DECC

SEVERN TIDAL POWER - SEA TOPIC PAPER

Hydraulics and Geomorphology

April 2010

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

In association with
Black & Veatch Limited
and
ABP Marine Environmental Research Limited

Prepared for
DECC
3 Whitehall Place
London
SW1A 2HD

ABBREVIATIONS

ABBREVIATIONS

The following abbreviations are used in this Topic Paper:

1D	1-Dimensional
2D	2-Dimensional (horizontal depth-averaged)
3D	3-Dimensional
ASMITA	Aggregated Scale Morphological Interaction between Tidal inlet and Adjacent coast
BGS	British Geological Survey
CCW	Countryside Council for Wales
CHaMP	Coastal Habitat Management Plan
SAC	Special Area of Conservation
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EU	European Union
HabMap	Habitat mapping for conservation and management of the Southern Irish Sea
HAT	Highest Astronomical Tide
Hs	Significant waveheight
IOS	Institute of Oceanographic Sciences
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
MW	Megawatt
NAO	North Atlantic Oscillation
ODPM	Office of the Deputy Prime Minister
PB	Parsons Brinkerhoff
POL	Proudman Oceanographic Laboratory
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SDC	Sustainable Development Commission
SEA	Strategic Environmental Assessment
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
STP	Severn Tidal Power
SWRDA	South West Regional Development Agency
TWh	Terrawatt hours
WAG	Welsh Assembly Government
UK	United Kingdom
UKCP09	UK Climate Projections, 2009

NON-TECHNICAL SUMMARY

NON-TECHNICAL SUMMARY

Introduction

A strategic environmental assessment (SEA) is being conducted as part of the Severn Tidal Power (STP) feasibility study, in accordance with the requirements of the EU SEA Directive and UK Regulations. The SEA comprises two phases: Phase 1, the scoping stage, has already been undertaken. This Hydraulics and Geomorphology topic paper forms part of the reporting arising from Phase 2, the main assessment of short-listed options.

Consultation

The following consultation activities have been undertaken:

- Scoping consultation in January 2009

- Technical Workshops held on:

  - Phase 1 — 10th September 2008
  - Phase 1 — 25th June 2008
  - Phase 2 — 11th March 2009
  - Phase 2 — 22nd September 2009

- Meeting with Government's Chief Scientific Advisors on 22nd July 2009
- Meeting with Government's Chief Scientific Advisors on 13th January, 2010
- Meeting with Government's Chief Scientific Advisors on 25th February 2010

Baseline Environment

Baseline information provides the basis for predicting and monitoring environmental effects, by describing the area that may be affected. Due to the long timescales associated with the construction and operation of alternative options, baseline information is considered over three time periods, to reflect the predicted changes in the area when considered without the development of a Severn Tidal Power project.

Baseline environment up to 2009
It is widely recognised that the Severn Estuary is a high-energy environment. It is a dynamic system that responds to the influence of tides and storms. The hydrodynamic character of the Severn Estuary is partly due to its form and partly due to its geographic setting. The form is determined from geological evolution, human intervention and interaction with present day physical processes which results in a funnel-shaped estuary and the largest coastal plain type estuary in the UK. The geographic setting provides a direct approach across the European continental shelf for ocean tides and Atlantic swell waves into the outer parts of the estuary. The net effect is an estuary with a hyper tidal range (>6m) and partial exposure to prevailing storms. The large tidal range is a defining feature of the estuary and is the feature that is being explored by the current Severn Tidal Power project for energy generation. The large tidal range acts over a wide shallow basin to expose large areas of intertidal at times of low water which provide an important feeding ground for birds. The large tidal range also draws a large volume of water in and out of the estuary on a semi diurnal cycle which produces strong currents and conditions that sustain high concentrations of suspended sediments.

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.

Future baseline during construction: 2014-2020
In the period 2014 to 2020 the future baseline is not considered to be markedly different from the present baseline and is anticipated to remain within the envelope of variability which is demonstrated by the manner in which the estuary responds to inter-annual variations in tides and prevailing storms.

Future baseline during operation 2020-2140, decommissioning and longer-term trends
The period 2020 to 2140 represents a timescale where the effects of climate change have the potential to influence the functioning of the estuary. It is widely recognised that climate change will lead to increases in mean sea level and storminess (winds and waves), and alter patterns of river flows (drier summers and wetter winters). These changing conditions are likely to lead to changes in the future baseline whereby the amount of intertidal is reduced through coastal squeeze.

Key Environmental Issues and Problems
The main environmental issues are related to managing coastal squeeze and sediments within the estuary.

There are also several areas of uncertainty associated with defining the present baseline which relate to both gaps in primary data and apparent contradictions in present scientific understanding. Key gaps occur in relation to defining the form and composition of the estuary that are only revealed when trying to blend together a variety of data from a variety of sources; here there are strengths in contemporary foreshore mapping but weaknesses in older subtidal surveys where the focus has previously only been required to aid navigation. Further, the majority of measurements tend to have been focussed in the main body of the estuary whereas above The Shoots the amount of available data is markedly reduced. Seaward, there also remains an absence of primary evidence over sediment exchanges with the Bristol Channel resulting in competing hypothesis as to whether the system should be regarded as open or closed or other.

Evaluation of Plan Alternatives

Assessment Methodology
The SEA Directive specifies the criteria that should be taken into account when determining the likely significant effects of the plan and thus these criteria have been adopted throughout the assessment process of this SEA. This topic paper therefore considers the characteristics of the effects and the areas likely to be affected.

This topic has been delivered from a comprehensive work plan that was widely circulated and given general support from the Government's Chief Scientific Advisors. This work plan responds to Phase 1 Scoping, the direct requirements for the Hydraulics and Geomorphology topic and the related requirements from other SEA topic areas wishing to understand how the key features of the estuary might change as a consequence of each of the short-listed options.

The technical assessments undertaken during the Hydraulics and Geomorphology studies aimed to improve the baseline understanding of physical processes within the Severn Estuary and to develop an evidence base for identifying short and long-term changes to the estuary wide regime as a consequence of the alternative options. An integrated set of desk based studies and state of the art numerical modelling tools have been used to predict high level patterns of key physical change.

The Hydraulics and Geomorphology studies were structured into a series of discrete (but interlinked) work packages termed 'Geo' Tasks. Of these, Tasks 1 and 14 aimed to inform the engineering feasibility studies and provide a high level overview of construction related issues respectively. Tasks

2 to 5 and 9 aimed to enhance the understanding of existing physical processes in the estuary (including a review of analogues) and to identify baseline trends, which provide an indication of how the estuary might evolve in the short and long-term.

The remaining Geo Tasks applied 2 Dimensional numerical models to determine how the alternative options would affect the hydrodynamic and morphological regime. Specifically, the effects on water levels, flows and waves were assessed using hydrodynamic models and the outputs from these studies were used to inform modelling of the suspended sediments and sand transport. Finally, the morphological evolution of the estuary was assessed using intertidal profile and estuary wide behavioural models.

Alternative Options

There are five shortlisted alternative options that are being assessed within Phase 2 of the SEA for their likely significant effects. These alternative options and key parameters associated with the alternative options are:

Alternative	Location	Length (approx)	Operating mode	Turbine type	No. turbines (capacity)	Annual energy output*	Caissons	Locks
B3: Brean Down to Lavernock Point Barrage	Lavernock Point to Brean Down	16km	Ebb only	Bulb-Kapeller	216 (40MW)	15.1 to 17.0 TWh/year	129	3
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

* Before inclusion of measures to prevent or reduce environmental effects

Assessment of Likely Significant Effects on the Environment

Alternative Option B3: Brean Down to Lavernock Point Barrage

The B3 barrage is predicted to reduce tide range by more than 50% over much of the impounded area as a result of the low water levels moving up to around the existing mean water level and a smaller lowering of high water levels. Immediately upstream from the barrage, the spring tidal range is predicted to decrease to 5.2m compared to 11m under baseline conditions. In the mode of operation assessed, spring tide low waters are predicted to occur at a higher level than neap tide low waters. The ebb only operational mode of the barrage means that high water levels are held behind the barrage to create a sufficient head for turbining. This creates a high water stand and extended ebb period, which distorts the baseline tidal curve. This effect is evident as far downstream as Ilfracombe. In the far-field, increases in high water levels in the range of 0.2m to 0.3m are predicted away from the Severn Estuary, in Cardigan Bay and around the Llyn peninsular.

The spring tidal prism is predicted to decrease by up to 57% within the impounded area. Outside the impoundment, a 40% reduction in the volume of water flowing through the Bristol Channel is predicted. The B3 barrage is also predicted to reduce peak flow speeds by 20–40% throughout much of the estuary and Bristol Channel, with a 40-60% reduction predicted along the main channels between the barrage and the River Usk, and between the barrage and Avonmouth. In the vicinity of the turbines local flow speeds are predicted to increase.

The B3 barrage will modify the existing wave climate primarily by reducing fetch lengths for westerly and south westerly waves at high water and increasing the fetch length for locally generated waves at low water as a result of the raised water levels. Reductions in wave height of up to 20% are predicted at high water whilst increases of a similar magnitude are predicted at low water for a variety of directional sectors. Increases in wave height are predicted close to the structure as a result of reflections.

Peak suspended sediment concentrations are predicted to decrease by a factor of between 2 and 3 both within the impounded area and downstream. This is predicted to be associated with permanent deposition of up to of 9.4Mtonnes of fine sediment, of which 8.2 Mtonnes would be upstream of the barrage. The reduced variability in deposited mass from spring to neap tides would be 3Mtonnes for B3 compared to 5.4Mtonnes under existing conditions. Rapid accumulations of up to 2m sediment are predicted in the channels upstream from the Old Severn Bridge. A longer term trend of further reduction in suspended sediment concentrations is predicted.

After the B3 barrage becomes operational, more than 50% of the existing intertidal area within the SAC is predicted to be lost as a result of the raising of the low water levels. During the operational lifetime of the barrage both erosion and deposition is predicted at different locations over the intertidal area. The intertidal profile model predicts initial losses of 36-63% of intertidal width depending upon location. After 120 years of morphological response involving erosion of four profiles and accretion on three profiles upstream of the impoundment, the range of final losses of intertidal width is predicted to be 39-66%.

Net sediment fluxes are predicted to decrease over much of the study area as a result of a widespread reduction in tidal energy. The spatial scale of this effect has implications for sediment movement around the linear sandbanks in the Bristol Channel seawards of the B3 barrage.

This scheme could potentially alter the existing sediment regime of the Severn Estuary, dependant on the availability of marine sediment sources. The reduction in concentrations within the tidal basin leads to an increased demand for sediment to move up-estuary from seawards of the structure. If this demand is not matched by supply (as is postulated based upon today's understanding of the sediment budget) then the preferred results from the long-term morphology modelling would lie between the results of two different model runs using different assumptions on sediment supply. These model runs predict 1.3-3.1m erosion over the Mid Severn flats and 0.3-1.4m accretion over the Outer Severn channel elements.

Alternative Option B4: Shoots Barrage
The B4 barrage is predicted to reduce the tidal range by 50% immediately upstream of the barrage and by 30% at Sharpness as a result of the low water levels moving up to around the existing mean water level and a smaller lowering of high water levels. Outside the impounded area, the tidal range was predicted to increase marginally as far downstream as Minehead.

The spring tidal prism is predicted to decrease by up to 45% within the impounded area and by up to 10% in the vicinity of Lavernock Point. The B4 barrage is also predicted to reduce peak flow speeds by up to 80% immediately upstream from the structure with more widespread reductions of 20%-40% within the impounded area. Reductions of 10% – 40% were predicted seawards of the barrier as far as Cardiff. In the vicinity of the turbines local flow speeds are predicted to increase.

The B4 barrage would modify the existing wave climate primarily by reducing fetch lengths for westerly and south westerly waves at high water and increasing the fetch length for locally generated waves at low water as a result of the raised water levels. Localised reductions in wave height in excess of 20% were predicted at high water with increases of a similar magnitude predicted at low water for south westerly waves within the impounded area. Increases in wave height are predicted close to the structure as a result of reflections.

Peak suspended sediment concentrations are predicted to decrease by more than 50% both within the impounded area and downstream as far as Cardiff. This will result in the permanent deposition of up to 2.1Mtonnes of fine sediment in the main estuarine channels within 14 days of operations commencing. Accumulations of up to 1m sediment are predicted in the channels upstream from the Old Severn Bridge.

After the B4 barrage becomes operational, around 30% of the existing intertidal width is predicted to be lost as a result of the upwards movement of the low water levels.

Net sediment fluxes are predicted to decrease within the impounded areas as a result of a reduction in tidal energy. Relatively minor reductions in sediment flux are predicted across much of the study area downstream from the structure. The sediment movement around the linear sandbanks in the Bristol Channel is not predicted to be affected by the B4 barrage.

During the 120 year operational lifetime of the B4 barrage a total of almost $200Mm^3$ is predicted to accumulate in the estuarine channels immediately upstream of the structure. This is likely to result in bed level changes of up to 7m in this location.

Alternative Option B5: Beachley Barrage

The B5 barrage is predicted to reduce the existing tidal range by more than 50% over the entire impounded area as a result of the low water levels moving up to around the existing mean water level and a smaller lowering of high water levels. Downstream from the barrage, the spring tidal range is predicted to increase slightly compared to baseline conditions.

The spring tidal prism is predicted to decrease by up to 43% within the impounded area and by up to 17% through The Shoots. The B5 barrage is also predicted to reduce peak flow speeds by 20% both within the impounded area and downstream as far as Avonmouth. In the vicinity of the turbines local current speeds are predicted to increase.

The B5 barrage would modify the existing wave climate primarily by reducing fetch lengths for westerly and south westerly waves at high water and increasing the fetch length for locally generated waves at low water as a result of the raised water levels Localised reductions in wave height in excess of 20% were predicted at high water with increases of a similar magnitude predicted at low water for south westerly waves within the impounded area. Increases in wave height are predicted close to the structure as a result of reflections. Outside the impounded area, only very minor modifications to the wave climate are predicted.

Peak suspended sediment concentrations are predicted to decrease by more than 50% both within the impounded area and up to 10km downstream. This will result in the permanent deposition of up to 1.5Mtonnes of fine sediment in the estuarine channels within fourteen days of operations commencing. Accumulations of up to 2.5m sediment are predicted in the channels upstream from the Old Severn Bridge.

During the 120 year operational lifetime of the B5 barrage 43% of the existing intertidal area within the impounded area is predicted to be lost. Much of this will occur as soon as the barrage becomes operational as a result of the raised low water levels.

Net sediment fluxes are predicted to marginally decrease within the impounded areas as a result of a reduction in tidal energy. Relatively minor reductions in sediment flux are predicted across much of the study area downstream from the structure. The sediment transport around the linear sandbanks in the Bristol Channel is not predicted to be affected by the B5 barrage.

During the 120 year operational lifetime of the B5 barrage a total of almost 150Mm^3 is predicted to accumulate in the estuarine channels immediately upstream of the structure. This would be likely to result in bed level changes of up to 3 m in this location.

Alternative Option L2: Welsh Grounds Lagoon

Upon closure of the lagoon, the mean spring tidal range inside the impoundment would be reduced by approximately 6.3m due to the mean low water moving up. Outside the lagoon, the spring tidal range is predicted to decrease by between 0.1 and 0.2m between Cardiff and Sharpness. Conversely, the spring tidal range at Minehead is predicted to increase as a result of high water levels rising by around 0.1m

The spring tidal prism is predicted to decrease by 10% downstream from the structure and increase by around 7% upstream. The L2 lagoon is also predicted to reduce peak flow speeds by 20 – 40% within the impounded area and by around 10%-20% elsewhere in the estuary. However, flow speeds in the vicinity of the turbines are predicted to increase.

Both increases and decreases in wave height in excess of 20% in localised areas are predicted within the impounded area at low and high water respectively. Outside the impounded area, reductions in wave height of 10%-20% are predicted with increases in wave height predicted close to the structure as a result of reflections.

Peak suspended sediment concentrations within the lagoon are predicted to decrease by a factor of 3 on spring tides and a factor of 2 on neaps. Adjacent to and downstream from the lagoon, suspended sediment concentrations are reduced in the Bristol Deep channel and also around the mouth of the Usk on spring tides. On neap tides, reductions in suspended sediments are predicted for all areas downstream from L2. The L2 lagoon is predicted to experience immediate deposition of around 0.2m sediment within the impounded area, with more quiescent areas of the lagoon gaining up to 0.9m sediment within the first fourteen days of operation. Sediment is also predicted to accumulate within Newport Deep.

Estuary wide, approximately 25% existing intertidal is predicted to be lost as a result of raised low water levels. Inside the lagoon, average initial losses of 55% existing intertidal are predicted. During the operational lifetime of the scheme, both profiles are predicted to accrete with additional accretion predicted in areas outside the lagoon.

The L2 lagoon was predicted to cause a reduction in sediment fluxes in the Bristol Channel and Inner Bristol Channel. The predicted fluxes were greatly increased in the regions around the turbines and sluices for the lagoon and upstream of the lagoon in the Severn Estuary. The predicted decrease in flow speeds as a result of the reduction in tidal range means that tidal energies and sediment transport will be reduced in places but the spatial extent of these changes will be local to the lagoon.

Rapid accretion was predicted to occur within the lagoon impoundment. Over the 120 year period, almost 300Mm^3 sediment is predicted to be deposited inside the lagoon. This could result in an increase in bed level of up to 3.4m.

Alternative Option L3d: Bridgwater Bay Lagoon

The L3d lagoon is different to the other schemes in that it is proposed to generate power on both the ebb and flood tide cycles with this scheme. The proposed mode of operation is predicted to reduce the tidal range by up between 0.3m and 0.9m over most of the estuary. Inside the lagoon both the mean spring and mean neap tidal range would be reduced by approximately 1.9m.

The spring tidal prism is predicted to reduce by 1% between Cardiff and Brean Down and by 4% in the Bristol Channel. Through the Shoots and further upstream, increases of around 2% are predicted. These changes are considered negligible. For the L3 lagoon, peak current speeds were predicted to almost double at certain locations within the lagoon as a result of the rapid filling and draining time associated with the flood/ebb generation mode. Little effect was predicted over the rest of the estuary except for a predicted 40% - 80% reduction in peak flow speeds in the lee of the lagoon wall at Hinkley Point. This reflects the blockage to the flow by the lagoon bund.

For westerly waves at high water, waves are predicted to increase locally by up to 10% in the vicinity of the structure possibly due to reflections. Waves inside the structure will decrease by more than 20%. At low water both increases and decreases in wave height are predicted within the impounded area.

During neap tides, there is predicted to be a reduction in suspended sediment concentrations both upstream and downstream from the lagoon. During spring tides, suspended sediment concentrations are predicted to be lower than ambient levels outside the lagoon, in the vicinity of Weston Bay and inside the lagoon over much of the impounded area. Deposition of 0.5 – 1m is predicted to occur within the lagoon (primarily between the two turbine sections) and in the vicinity of Hinkley Point. Up to 2m deposition is also predicted to occur adjacent to the coast at the western end of the lagoon. The total mass permanently deposited is predicted to be 1.1 Mtonnes of which 0.9 Mtonnes will accumulate within the impounded area.

Estuary wide, a total of 7% of the intertidal area is predicted to be lost as a result of raised low water levels. Inside the impoundment, an initial loss of 11% intertidal area is predicted upon commencement of operation. Over the 120 year operational lifetime of the lagoon, a total of 21% existing intertidal is predicted to be lost from inside the lagoon.

Sediment fluxes in the Inner Bristol Channel were predicted to increase, particularly in the vicinity of the turbine blocks. Elsewhere in the estuary the net sediment flux is predicted to remain similar to baseline conditions. Within the impoundment, sediment fluxes were predicted to remain similar to baseline conditions or to increase slightly. Large changes in flows and associated sediment transport were predicted in the vicinity of the turbines both inside and outside of the lagoon.

The ebb/flood operation of the lagoon reduces the potential for large scale sediment deposition within the impounded area. Over the 120 year operating period up to 43Mm^3 of sediment are predicted to accumulate. The rate of accumulation is greatest during the first 5 years of operation and declines rapidly after year 20. Deposition was also predicted in the channel elements with the exception of the Inner Severn Channel.

Assumptions, Limitations and Uncertainty

The key assumption within the assessment of effects is the instantaneous superposition of the scheme into the estuary, which does not account for any gradual changes to the estuary regime in response to changes in the hydrodynamic and sediment over the construction period.

Considerable attention has been given to identifying and understanding the sources of uncertainty within the Hydraulics and Geomorphology topic. In general terms, levels of uncertainty can be identified in each of the following:

- Source data and information (e.g. due to data coverage, accuracy, significance of any gaps)
- Methods of analysis (e.g. due to levels of assumptions and simplifications required in the approaches that have been adopted and the ability to demonstrate tools which are "fit-for-purpose")
- Interpretation of outputs

These uncertainties are further compounded by the requirement to address an estuarine system which is inherently complex in its nature.

The numerical models used to perform the Hydraulics and Geomorphology assessments for the SEA are subject to different levels of uncertainties. In all cases the performance of the models depends on the quality of the input data and boundary conditions. There are some data gaps and limitations which affect the reliability of predictions, though these are not considered critical for this strategic assessment.

Changes in water levels, currents and energy generation can be modelled with reasonably high levels of certainty particularly as good calibration against baseline parameters has been achieved.

Greater uncertainty is attached to the numerical modelling of the sediment regime. Suspended sediments in the Severn Estuary behave in a very complex way and it is difficult to model all the key processes. The preferred approach was to model the dominant processes as simply as possible. The model calibration tends to show greater dispersal of sediment than observed in nature, but key erosion and deposition behaviour is reasonably reproduced temporally and spatially.

The highest degree of uncertainty relates to the prediction of long-term morphological response to the alternative options since we have no means of accurately predicting the baseline morphology 120 years from now. However, the modelling does predict clear trends, averaged over large areas of the estuary.

A number of other limitations have been identified including:

- A lack of up to date bathymetric data for the upper reaches of the estuary;
- No intertidal profiles have been considered upstream from B5; and
- A lack of measured suspended sediment data for areas upstream from the B5 barrage.

Measures to prevent, reduce and as fully as possible offset any significant adverse effects

The measures identified to prevent or reduce likely significant adverse effects identified within this topic are described below.

Measures to prevent or reduce the effects of the alternative options have been considered throughout the Engineering study and the SEA. Within the Optimisation phase, the following measures were considered:

- Alternative scheme alignment
- Alternative operating modes
- Variations in sluice and turbine numbers

With the exception of changes to the wave climate, the majority of effects on the Hydraulics and Geomorphology receptors arise as a consequence of the changes in water levels. Consequently measures to prevent or reduce the effects of the alternatives should primarily focus on this receptor. Potential mechanisms for reducing these effects (in addition to those described above) are listed below:

- Mechanical pumping of water through the structure to increase water levels;
- Sluicing after generation in one way ebb mode;
- Non – generation times including timing of turbine start up and shut down;
- Management of freshwater and seawater levels (pumping); and
- Alter type, size, and position of turbines and or sluices.

Other measures for preventing or reducing effects, which are relevant to the Hydraulics and Geomorphology Topic include:

- Alteration of structure design to moderate wave reflections;
- Inclusion of scour protection at the detailed design phase; and
- Creation of intertidal area within the designated site through placement if suitable material.

Additional measure not discussed but previously identified by other Topics, which may have an effect on the Hydraulics and Geomorphology receptors include:

A number of measures proposed by other topics have the potential to affect tidal range in the estuary, and to a lesser extent flow speeds. These are listed below.

- Management of operating regime to reduce effects on water levels such as ebb/flood generation;
- Management of operating regime to reduce the effects on water levels such as sluicing;
- Operational management of water levels through turbine management;
- Increasing the permeability of the barrage or lagoon by operating fewer turbines during lower efficiency periods;
- Inclusion of fish passage management options within or near the barrage or lagoon; and
- Freshwater and seawater level management (pumping).

For the most part, the proposed measures will affect the tidal range in the estuary by either raising high water levels or lowering low water levels (or both). Any increase in tidal range is also likely to increase flow speeds. However, it is not feasible for any measure proposed to completely remove the effects of the alternative options on water levels and whilst the magnitude of effect for the Hydraulics and Geomorphology receptors might be reduced, the proposed measures will neither improve, nor further enhance the net effect on the hydrodynamic regime.

A further group of measures proposed by other topics has the potential to affect the sedimentary and morphological receptors. These are listed below.

- Maintenance dredging to prevent accumulation of sediments upstream of barrages;
- Maintenance dredging to reduce loss of live storage capacity;
- Disposal of dredge material;
- Erosion protection measures to manage erosion of intertidal; and
- Topographic modification within the estuary to reduce losses of intertidal.

The extent to which maintenance dredging would affect the sedimentary/morphological regime is entirely dependent on the location of the dredge, the quantity of material removed and the frequency of the operation.

Similarly, the effects of disposing of dredged material are dependent on whether this occurs within the Severn Estuary or elsewhere. If material is lost from the system, this will have implications for the sediment budget.

The effect of erosion protection measures to limit the long-term loss of intertidal area is highly uncertain as no details as to the nature of these measures is currently available. Overall, the implementation of this measure would affect the predictions of long-term intertidal evolution.

In order to consider the effects of topographic modification on estuarine morphology, a better understanding of the nature and proposed location is required. This measure could only be taken forward if it were proven to be sustainable in the long-term and would not therefore create additional pressure on the form and function of the estuary.

Further detailed study is required to determine the extent to which these measures would affect the Hydraulics and Geomorphology receptors.

Offsetting measures within this SEA are measures to as fully as possible offset any significant adverse effects on the environment. These measures therefore make good for loss or damage to an environmental receptor, without directly reducing that loss/damage. In this SEA 'compensation', a subset of offsetting is only used in relation to those measures needed under the Habitats Directive.

No specific offsetting measures have been identified for the Hydraulics and Geomorphology Topic. The following measures have been identified elsewhere in the SEA, which may have an effect on the Hydraulics and Geomorphology receptors:

- New habitat creation through managed realignment; and
- Regulated tidal exchange to maintain or create estuarine habitats.

Comparison of Alternatives

This topic paper includes a comparison of alternative options over the course of the entire life-cycle.

In summary:

All three barrages and the L2 lagoon produce a similar pattern of tidal range reduction within the impounded areas, which is most likely due to the preferred mode of operation (ebb only). Alternatives B4 and B5 show the greatest proportional reductions in tidal range but the B3 barrage affects water levels over a much greater area as a result of the size and location of the barrage. Additionally, B3 is the only alternative to induce far-field effects on water level. The two lagoon options produce much smaller effects on the tidal range in the estuary as a whole. The ebb/flood Bridgwater Bay lagoon has a much smaller effect on water level. The three barrage options are also shown to distort the baseline tidal curve, creating a high water stand and longer ebb period. The two lagoon options do not alter the shape of the tidal curve anywhere outside the impounded areas.

The three barrage options and L2 reduce the spring tidal prism by at least 40% within the impounded areas. The most striking change is perhaps the predicted reduction of water flowing through the Bristol Channel as a result of B3.

Peak flow speeds are predicted to be reduced for all alternatives within the impounded areas, except in the vicinity of the turbines, where increased speeds are predicted. B3 produces the most widespread effects as this is both the largest scheme and creates the largest impounded area.

All the alternative options are predicted to affect the wave climate. The B3 barrage produces the largest effect as this alternative reduces fetch lengths to a greater extent than the others and raises low water levels over a much larger area. All alternatives were found to cause increases in wave heights in the area adjacent to the structures as a result of reflections.

In all cases, suspended sediment concentrations are predicted to decrease. The L3d lagoon produces the smallest changes compared to the baseline, whilst the L2 lagoon causes relatively minor reductions in concentrations in the main estuary but significantly reduces the suspended sediment concentration inside the impoundment. The B4 and B5 barrages both reduce suspended sediment concentrations by more than 50% within the impounded areas. However the B4 barrage affects suspended sediment concentrations over a much larger distance downstream from the structure than B5. The B3 barrage causes the greatest reduction in suspended sediment concentrations and also produces the most widespread effects.

All alternatives are predicted to cause rapid deposition (within a neap – spring – neap tidal cycle) of muddy material as a result of the reduced flow speeds. The B3 barrage is predicted to cause the most widespread deposition and the L3d lagoon the least. The largest volumes of sediment deposition are predicted upstream from the B5 barrage whilst the B4 and L2 alternatives produce similar amounts of deposition within the impounded areas.

With the exception of the L3d lagoon, all alternative options were predicted to reduce net sediment fluxes. The largest effects (both in terms of magnitude and spatial extent) were predicted for the B3 barrage. The B5 barrage showed the smallest changes relative to baseline conditions. The L2 lagoon was predicted to cause a reduction in sediment fluxes downstream from the structure and an increase in the vicinity of Avonmouth and further upstream. The L3 lagoon produced widespread increases in sediment flux although the magnitude of change was relatively small. In all cases increases in sediment flux were predicted in the vicinity of the turbines.

The changes in flow speeds and the resultant effects on net sediment flux is also reflected in the predicted changes to bed shear stress with the B3 barrage producing the largest and most widespread effects.

The three barrage alternatives and the L2 lagoon are predicted to cause an immediate loss of intertidal area as a result of the raised low water levels within the impounded area. The L3d lagoon was predicted to have a lesser effect on intertidal area as a function of the ebb/flood mode of operation. Being the largest scheme and impounding the largest area, the greatest area losses are predicted for the B3 barrage. The B5 barrage was predicted to have the smallest effect on intertidal area although it is important to note that no profiles were considered upstream of the structure. For some locations accretion of the intertidal profile (compared to the baseline) was predicted for the B4 barrage and L2 lagoon during the operational lifetime of the scheme.

For all the alternative options, a general trend of deposition within the estuarine channels and erosion of the intertidal flats is predicted over the 120 year operational period. The exceptions to this are the L2 lagoon which appears to cause erosion of the Outer Severn Channel element and the B5 barrage which produces accretion of the intertidal flats outside the impoundment. The greatest rates of change occur during the first 5 years for the B3 barrage, L2 and L3d lagoons and during the first 10-20 years for the B4 and B5 barrages. The B3 barrage results in the most widespread changes but the deposition predicted within the areas impounded by B4, B5 and L2 is of a much greater magnitude.

In summary, the B3 barrage results in the most widespread effects on the Hydraulics and Geomorphology receptors and in general, the magnitude of change is also greatest for this alternative. However, the smaller barrages and L2 lagoon are shown to produce larger changes to the sedimentary and morphological regime, albeit over much smaller areas. The L3d lagoon generally causes the least changes to the Hydraulics and Geomorphology receptors.

Plan Implementation

Legislation and policy compliance

This paper contains a review of legislation and policy that is specifically relevant to this topic. An assessment has been made as to whether each alternative option would be compliant with existing relevant legislation and policy.

The two pieces of legislation and policy that are relevant to the Hydraulics and Geomorphology Topic are:

- The Habitats Regulations;
- Shoreline Management Plan 2 (not yet finalised)

Consideration of compliance with the Habitats Regulations and The Shoreline Management Plan (SMP2) is considered in a separate Habitats Regulations Assessment and in the Flood Risk Topic of the SEA respectively.

Monitoring of significant environmental effects

The SEA Directive requires that monitoring measures are described within the environmental reporting. The monitoring proposals contained within this paper are applicable to all of the alternative options under consideration.

To reduce these levels of uncertainty, it is recommended that further studies are carried out during the next phase of development.

Data and Monitoring Requirements

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

1. Wave data should be collected in the Severn Estuary

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. It is recommended that a survey of the Upper River Severn be commissioned, to tie in with the recent Gloucester Harbour Trustees survey. An understanding of which areas of the seabed 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. The survey should extend to the tidal limit where this is possible;

4. It is recommended that flow and water level and sediment load data be monitored 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 for the foreseeable future and at estuary wide scale.

Requirements for further studies

The following suggestions have been made as a result of the modelling assessments summarised in this report:

1. It is recommended that the offshore northern boundary of the flow model be extended to at least the Mull of Kintyre, and that far-field effects predicted by POL 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 B3.

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

3. It is recommended that the next assessment focuses 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 is recommended.

5. The use of 3D sediment modelling is recommended 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, is recommended.

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 turbine blocks should be re-evaluated if this scheme is taken forward for further assessment.

10. If B3 is taken forward it is recommended that the ASMITA boundary be extended seawards.

11. It is recommended that measures to seek to minimise the predicted accretion immediately upstream of B4 and B5 be further investigated (e.g. layout and modes of operation for sluice and turbine blocks, and/or any capital or maintenance dredging plans).

12. It is recommended that the management of sediment, and the predicted ongoing deposition, be considered.