DECC

SEVERN TIDAL POWER - SEA TOPIC PAPER

Marine Water Quality

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ABBREVIATIONS

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The following abbreviations are used in this Topic Report:

AONB	Areas of Outstanding Natural Beauty
BERR	Department for Business, Enterprise and Regulatory Reform
CCW	Countryside Council for Wales
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
Cd	Cadmium
CHaMP	Coastal Habitat Management Plan
cSAC	Candidate Special Area of Conservation
DBT	Dibutyltin
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DIN	Dissolved Inorganic Nitrogen
DOC	Dissolved Organic Carbon
EIA	Environmental Impact Assessment
EC	European Commission
EQS	Environmental Quality Standard
EU	European Union
G8	Group of 8 Nations
GIS	Geographical Information System
GW	Gigawatts
Hg	Mercury
HRA	Habitats Regulations Assessment
LNR	Local Nature Reserve
LOD	Limit of Detection
MBA	Marine Biological Association
MMO	Marine Management Organisation
MW	Megawatt
NERC	Natural Environment and Rural Communities Act
Ni	Nickel
NNR	National Nature Reserve
NPS	National Policy Statement
ODPM	Office of the Deputy Prime Minister
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PCB	Polychlorinated biphenyls
POC	Particulate Organic Carbon
PPG	Planning Policy Guidance
PPS	Planning Policy Statements
PSA	Public Service Agreement
PSU	Practical Salinity Units
PWS	Public Water Source
RBMP	River Basin Management Plan
	Special Area of Conservation
SDC	Sustainable Development Commission
SEA	Strategic Environmental Assessment
SFW	Shellfish Waters
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SPA	Special Protection Area
SPM	Suspended Particulate Matter

SSSI	Site of Special Scientific Interest
STP	Severn Tidal Power
SWRDA	South West Regional Development Agency
TAN	Technical Advice Note
TBT	Tributyltin
TON	Total Oxidised Nitrogen
TWh	Terrawatt hours
UKCIP	United Kingdom Climate Impacts Programme
UN	United Nations
WAG	Welsh Assembly Government
WFD	Water Framework Directive
WWTW	Waste Water Treatment Works
Zn	Zinc

NON TECHNICAL SUMMARY

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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 Marine Water Quality 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 in June and November 2009
- Direct consultation with Environment Agency water quality specialists

SEA Objectives
SEA Objectives have been developed to enable alternative options to be compared. Objectives may not necessarily be met in full by a given alternative option, but the degree to which they do would provide a way of identifying preferences when comparing effects of alternative options. The SEA Objectives for this topic are listed below:

- To avoid adverse effects on water quality in relation to water quality standards.
- To avoid adverse effects on designated marine wildlife sites of international and national importance due to changes in water quality.
- To avoid adverse effects on water quality which would affect human health, flora and fauna, recreation and other users.
- To avoid adverse effects on inherent water characteristics (temperature, salinity, pH) that could lead to adverse changes in water quality.
- To minimise risks of pollution incidents.

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. The baseline therefore also describes the estuary in a 'do-nothing' scenario.

Baseline environment up to 2009
The Severn Estuary is the UK's second largest estuary with a tidal range in excess of 12m. The resultant strong tidal currents fundamentally affect the physical, chemical and biological properties of the estuary. The Severn Estuary receives an average freshwater flow of approximately 25 million m^3/day of which around 1 million m^3/day comes from sewage and industrial discharges.

There are a wide range of direct discharges into the Severn Estuary including urban wastewater, industrial and power station discharges and a small number of discharges containing radioactive substances. Various diffuse inputs occur, principally from agriculture, but also to a lesser extent from shipping

The Severn Estuary is well mixed vertically as a result of the high tidal flows and shallow water depth. A characteristic feature of the estuary is a persistent north south salinity gradient, with the lowest salinities occurring along the Welsh Coast. The mean salinity distribution along the axis of the estuary appears to remain constant over time.

Elevated temperatures occur in the vicinity of large thermal discharges such as at Hinkley B power station. Data in Kirby (unpubl.) from the PISCES model indicates that average seawater temperatures have increased by more than 1°C in the last 25 years based on monitoring data at Hinkley. The data also show an absence of extreme low water temperatures in recent years, possibly due to milder winters.

The pH of water in the estuary increases from around 7 at its freshwater end to approximately 8 in the outer estuary. Locally, acidic discharges can result in local modifications to pH.

The Severn Estuary is naturally a highly turbid estuary due to its physical shape, tidal regime and flow rates and the availability of fine sediment for resuspension. The turbidity maximum lies between Watchet and Beachley. There is a sharp peak in suspended Particulate Matter (SPM) concentration between 4 km and 20km downstream from Lower Parting in the freshwater adjacent to the limit of saline intrusion. The English side of the estuary is perpetually more turbid than the Welsh side.

The Severn Estuary and Bristol Channel provide one of the highest UK inputs of nitrogen and phosphorus to the marine environment, reflecting the estuary's size, the location of human settlements and the intensity of agricultural land use. Concentrations of dissolved inorganic nitrogen are reported to have doubled over the past 20 to 25 years. Peak dissolved Nitrate concentrations are common in the turbid, low salinity region.

Dissolved oxygen saturation in the Severn Estuary is relatively constant and near full saturation (greater than 95%) beyond 80km downstream of the tidal limit. Dissolved oxygen levels of less than 90% saturation have been observed up-estuary of this location. This was found to coincide with elevated SPM concentrations and may be related to increased oxygen demand from sediment resuspension and phytoplankton activity.

The distributions of dissolved metals generally reflect the magnitude of the riverine input relative to the inputs from wastewater and industrial discharges and aerial inputs. Sediment contamination by trace metals was shown to be relatively uniform around the estuary and Bristol Channel. This reflects the strong tidal mixing and fluid mud transport which disperse contaminants from their source. Elevated concentrations of Ni, Cd, Hg and Zn were found at the mouth of the Severn Estuary and were attributed to increased run-off with proximity to industrial areas.

Sediment concentrations of metals, PAHs and PCBs in the EA data sets of 2004 and 2005 were relatively homogeneous throughout much of the system, presumably as a result of the highly turbid nature of the Severn Estuary (Langston and Millward, 2008). In the 1978 MBA sediment metal data set there was a slight but significant decrease downstream for Hg, Ni, Pb and Zn. For the later EA data, the trend was only significant for Cd in 2005. In contrast to metals, there was a slight but significant increase in PAH concentrations in sediments in a downstream direction, with evidence of a hotspot for PAHs in sediments near Cardiff. The majority of pesticide values were below detection limits and assessment of trends was therefore impossible. It seems unlikely that these residues pose a significant threat to the environment.

Under the existing Bathing Waters Directive, most bathing waters in the study area have been regularly complying with the more stringent guideline standards of the Directive. In 2007, only one bathing water failed the mandatory standard. In comparison, it is predicted that 7 bathing waters would fail the minimum standards under the revised Bathing Water Directive.

For 2007/08, the Food Standards Agency has classified Swansea Bay South as Class B (Long-Term) for the harvesting of *Mytilus spp.* None of the other shellfish waters in the study area were classified for harvesting purposes.

Future baseline during construction: 2014-2020
No appreciable changes to the marine water quality receptors are predicted during the construction phase. Current baseline trends are expected to be maintained throughout this period.

Future baseline during operation 2020-2140, decommissioning and longer term trends
The main drivers for change with respect to the marine water quality receptors are climate change and legislation such as the Water Framework Directive. Specifically, ambient water temperatures are predicted to rise by almost 4°C by 2140, whilst the past trend of ocean acidification as a result of CO2 absorption by the sea is predicted to continue. The effects of climate change are also expected to affect the variability of salinity, particularly in the upper parts of the estuary as freshwater flows are affected by increased precipitation, less snow melting and more frequent droughts.

The adoption of environmental legislation such as the WFD would lead to tighter controls on contaminants and pathogens, which contribute to the chemical and biological status of the water body. Overall, it is expected that the water quality of the Severn Estuary and its tributaries would improve over the next 120 years.

Key Environmental Issues and Problems

- Change initial dilution and dispersion characteristics around outfalls and discharges resulting in local changes in the concentrations of contaminants and pathogens in the water column;
- Modify the salinity regime resulting in changes in the behaviour of contaminants;
- Increase the potential for salinity (density driven) stratification resulting in changes in the behaviour of contaminants and biological availability and influencing dissolved oxygen concentrations and nutrient cycling;
- Modify flushing characteristics in the main estuary and tributary estuaries resulting in changes in residence times of contaminants and pathogens;
- Modify suspended sediment concentrations, sediment transport patterns and processes with consequences for dissolved oxygen concentrations and the transport, fate and behaviour of sediment-associated contaminants;
- Changes in flushing time and light attenuation may affect primary productivity and thus may alter nutrient cycling within and export from the main estuary and tributary estuaries;
- Changes in physical processes and nutrient cycling may alter carbon cycling within the main estuary and tributary estuaries and export from the Severn Estuary.
- Changing sediment properties and dynamics may affect the potential for colonization and sediment water interchanges.
- Changing the physical processes of the estuary may affect land drainage processes, particularly with respect to reed beds and groundwater flows.

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 of the area likely to be affected.

This topic has also used the following specific assessment methods.

- 1D numerical modelling of salinity, flushing and key tributaries
- 2D numerical modelling of dilution, dispersion, pathogens and thermal plumes
- 3D numerical modelling to identify changes in stratification
- Desk based assessments of temperature, pH, nutrients and light penetration, dissolved oxygen and contaminants.

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	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	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

Assessment of Likely Significant Effects on the Environment

Alternative Option B3: Brean Down to Lavernock Point Barrage (also known as Cardiff to Weston)

Once operational, the B3 barrage would induce considerable changes to the hydrodynamic and sedimentary regime, which would affect the marine water quality receptors as follows:

The **flushing** capacity of the estuary would be reduced, with flushing times increasing by up to 20% within the impounded area.

In response to changes to the tidal regime and increased low water volume within the impounded area, the B3 barrage is predicted to increase the tidally averaged **salinity** distribution, but reduce the amplitude of change over a tidal cycle for all flow conditions as a result of increases in minimum salinity values. As the salinity distribution remains within the existing envelope of change, the estuary would not fail current legislative guidelines and as such the predicted effects of the B3 barrage on salinity are deemed **not significant.**

Maximum (summer) **temperatures** would be largely unaffected by the barrage and no detectable changes (>1°C) are expected either within the impounded area or downstream from the structure. Similarly, minimum (winter) temperatures are shown to increase by less than 0.2°C for all locations, which is considered below detectable levels. Given that increases in water temperature of 3.8°C over 120 years are predicted in response to climate change, the effect of the barrage is considered **not significant**.

Thermal plume dispersion from major power stations is predicted to decrease both upstream and downstream of the barrage with the largest changes occurring in the impounded areas. For the most part, the reduced dispersion would not result in temperature increases in the vicinity of the outfalls as initial dilution is predicted to increase compared to the baseline. Where changes are predicted to occur, these were below detectable levels (>1°C). Therefore, threshold levels under the WFD and Shellfish Waters Directive would not be exceeded and the effect of B3 on temperature is **not significant.**

The predicted changes to the hydrodynamic regime (including flushing times) and the resultant effects on temperature and salinity would not have any effect on the existing **pH** distribution within the estuary. Furthermore, despite slightly reduced dispersion characteristics at Aberthaw, the improved initial dilution of the outflow means that pH values in the vicinity of the power station would not be affected by the B3 barrage. Consequently, the magnitude of this effect is deemed to be **not significant**.

The potential effects of the B3 barrage on **suspended sediment** concentrations were investigated in the Hydraulics and Geomorphology Topic. Numerical simulations of mud transport predict that seaward of the Second Severn Crossing, suspended sediment concentrations on both spring and neap tides would reduce by a factor of between 2 and 3. The results obtained using the data derived method indicate that under B3, the suspended sediment concentrations would reduce by up to a factor of 10 and that neap tide concentrations will may drop as low as 10mg/l compared to baseline values. If suspended sediment concentrations were to drop this low, the turbidity of the estuary would be considerably reduced in certain locations. Consequently the effect of the B3 barrage on suspended sediment concentrations is considered to be **significant**.

A 3D numerical model has been used to determine whether the alternative options would result in the estuary becoming **stratified** at any point in the tidal cycle. The results of this assessment show that the estuary would remain well mixed and this effect is considered **not significant**.

The distribution of nutrients within the estuary reflects simple dilution and based on the predicted changes to salinity, nutrient concentrations may be largely unaffected by the operation of the barrage. The key implications of changes to nutrient behaviour in the Severn Estuary are the potential for increased primary productivity and enhanced risk of eutrophication. With the B3 barrage concentrations of suspended sediments on spring tides would generally preclude phytoplankton blooms but on neap tides enhanced algal growth might occur for limited periods. There are sufficient nutrients in the estuary to support primary productivity and therefore it is concluded that the B3 barrage could increase the potential risk of eutrophication within the estuary although light conditions would continue to limit primary productivity during much of the tidal cycle. The effect of the B3 barrage on nutrients is therefore **significant.**

Overall, **dissolved oxygen** levels in the estuary would be likely to change little, or show a slight increase due to reduced turbidity and increased primary production. This effect is therefore **not significant.**

The extent of the effluent plume and **pathogen** concentrations is predicted to be considerably reduced at all impounded WWTWs under B3 due to increased mortality caused by lower suspended sediment concentrations and improved initial dilution. In all cases there is not expected to be an increase in pathogen concentrations either in the vicinity of bathing beaches or the shellfish waters in Swansea Bay and as such the relevant Marine Water Quality standards will not be exceeded. Hence the effect of B3 on pathogens is **not significant**.

Given the predicted changes to the hydrodynamic and sedimentary regime the concentration of sediment associated **contaminants** in the estuary is likely to decrease. Contaminant levels within bed sediments may increase in certain locations as a result of widespread deposition of suspended sediments. Overall, it is it is unlikely that current legislative standards for contaminants would be exceeded under B3 and the effect is therefore **not significant**.

Alternative Option B4: Shoots Barrage

The potentially significant effects associated with the B4 barrage are:

Once operational, the B4 barrage would induce considerable changes to the hydrodynamic and sedimentary regime, which would affect the marine water quality receptors as follows:

The **flushing** capacity of the estuary would be reduced, with flushing times increasing by up to 50% within the impounded area.

In response to changes to the tidal regime and increased low water volume within the impounded area, the B4 barrage is predicted to increase the tidally averaged **salinity** distribution, but reduce the amplitude of change over a tidal cycle for all flow conditions as a result of increases in minimum salinity values. As the salinity distribution remains within the existing envelope of change, the estuary would not fail current legislative guidelines and as such the predicted effects of the B4 barrage on salinity are deemed **not significant.**

Maximum (summer) **temperatures** would be largely unaffected by the barrage and no detectable changes (>1^{o}C) are expected either within the impounded area or downstream from the structure. Similarly, minimum (winter) temperatures are shown to increase by less than 0.1^{o}C for all locations, which is considered below detectable levels. Given that increases in water temperature of 3.8^{o}C over 120 years are predicted in response to climate change, the effect of the barrage is considered **not significant**.

Thermal plume thermal plume dispersion will decrease within the impounded area. No detectable changes are predicted downstream of the structure. Assuming that a detectible change is >1^{o}C then neither the postulated changes to ambient temperature or the thermal discharges would affect water temperatures in the Severn Estuary or its tributaries. Therefore, threshold levels under the WFD and Shellfish Waters Directive would not be exceeded and the effect of B4 on temperature is **not significant.**

The predicted changes to the hydrodynamic regime (including flushing times) and the resultant effects on temperature and salinity would not have any effect on the existing **pH** distribution within the estuary. Furthermore, despite slightly reduced dispersion characteristics at Aberthaw, the improved initial dilution of the outflow means that pH values in the vicinity of the power station would not be affected by the B4 barrage. Consequently, the magnitude of this effect is deemed to be **not significant**.

The potential effects of the B4 barrage on **suspended sediment** concentrations were investigated in the Hydraulics and Geomorphology Topic. Numerical simulations of mud transport predict that within the impounded area, suspended sediment concentrations on both spring and neap tides would reduce by more than half. Downstream from the barrage, suspended sediment concentrations were predicted to be affected as far as Cardiff. Consequently the effect of the B4 barrage on suspended sediment concentrations is considered to be **significant**.

A 3D numerical model has been used to determine whether the alternative options would result in the estuary becoming **stratified** at any point in the tidal cycle. The results of this assessment show that the estuary would remain well mixed and this effect is considered **not significant**.

The distribution of nutrients within the estuary reflects simple dilution and based on the predicted changes to salinity, nutrient concentrations may be largely unaffected by the operation of the barrage. The key implications of changes to nutrient behaviour in the Severn Estuary are the potential for increased primary productivity and enhanced risk of eutrophication. While some increased phytoplankton productivity may occur as a result of changes in SSC upstream of the barrage, the levels of change mean that strong light limitation would continue to prevent full utilisation of available nutrients. Some reduction in nutrient concentrations compared to baseline may be observed during spring/summer months but nutrient concentrations would generally be expected to remain high. The effect of the B4 barrage on nutrients is therefore **not significant.**

Overall, **dissolved oxygen** levels in the estuary would be likely to change little, or show a slight increase due to reduced turbidity and increased primary production. This effect is therefore **not significant.**

The extent of the effluent plume and **pathogen** concentrations is predicted to be considerably reduced at Avonmouth WWTW and marginally reduced at all others under B4 due to increased mortality caused by lower suspended sediment concentrations and improved initial dilution. In all cases there is not expected to be an increase in pathogen concentrations either in the vicinity of bathing beaches or the shellfish waters in Swansea Bay and as such the relevant Marine Water Quality standards will not be exceeded. Hence the effect of B4 on pathogens is **not significant**.

Given the predicted changes to the hydrodynamic and sedimentary regime the concentration of dissolved and sediment associated **contaminants** in the estuary is likely to decrease slightly. Contaminant levels within bed sediments may increase in certain locations as a result of widespread deposition of suspended sediments. Overall, it is it is unlikely that current legislative standards for contaminants would be exceeded under B4 and the effect is therefore **not significant**.

Alternative Option B5: Beachley Barrage

Once operational, the B5 barrage would induce considerable changes to the hydrodynamic and sedimentary regime, which would affect the marine water quality receptors as follows:

The **flushing** capacity of the estuary would be reduced, with flushing times increasing by up to 20% within the impounded area.

In response to changes to the tidal regime and increased low water volume within the impounded area, the B5 barrage is predicted to increase the tidally averaged **salinity** distribution, but reduce the amplitude of change over a tidal cycle for all flow conditions as a result of increases in minimum salinity values. As the salinity distribution remains within the existing envelope of change, the estuary would not fail current legislative guidelines and as such the predicted effects of the B5 barrage on salinity are deemed **not significant.**

Maximum (summer) **temperatures** would be largely unaffected by the barrage and no detectable changes (>1°C) are expected either within the impounded area or downstream from the structure. Similarly, minimum (winter) temperatures are shown to increase by less than 0.1°C for all locations, which is considered below detectable levels. Given that increases in water temperature of 3.8°C over

120 years are predicted in response to climate change, the effect of the barrage is considered **not significant**.

Thermal plume thermal plume dispersion will decrease within the impounded area. No detectable changes are predicted downstream of the structure. Assuming that a detectible change is >1°C then neither the postulated changes to ambient temperature or the thermal discharges would affect water temperatures in the Severn Estuary or its tributaries. Therefore, threshold levels under the WFD and Shellfish Waters Directive would not be exceeded and the effect of B5 on temperature is **not significant.**

The predicted changes to the hydrodynamic regime (including flushing times) and the resultant effects on temperature and salinity would not have any effect on the existing **pH** distribution within the estuary. Furthermore, despite slightly reduced dispersion characteristics at Aberthaw, the improved initial dilution of the outflow means that pH values in the vicinity of the power station would not be affected by the B5 barrage. Consequently, the magnitude of this effect is deemed to be **not significant**.

The potential effects of the B5 barrage on **suspended sediment** concentrations were investigated in the Hydraulics and Geomorphology Topic. Numerical simulations of mud transport predict that within the impounded area, suspended sediment concentrations on both spring and neap tides would reduce by more than half. Downstream from the barrage reductions in suspended sediment concentration of up to 50% were predicted within 10km of the structure. Consequently the effect of the B5 barrage on suspended sediment concentrations is considered to be **significant**.

A 3D numerical model has been used to determine whether the alternative options would result in the estuary becoming **stratified** at any point in the tidal cycle. The results of this assessment show that the estuary would remain well mixed and this effect is considered **not significant**.

The distribution of nutrients within the estuary reflects simple dilution and based on the predicted changes to salinity, nutrient concentrations may be largely unaffected by the operation of the barrage. The key implications of changes to nutrient behaviour in the Severn Estuary are the potential for increased primary productivity and enhanced risk of eutrophication. While some increased phytoplankton productivity may occur as a result of changes in SSC upstream of the barrage, the levels of change mean that strong light limitation would continue to prevent full utilisation of available nutrients. Some reduction in nutrient concentrations compared to baseline may be observed during spring/summer months but nutrient concentrations would generally be expected to remain high. The effect of the B5 barrage on nutrients is therefore **not significant.**

Overall, **dissolved oxygen** levels in the estuary would be likely to change little, or show a slight increase due to reduced turbidity and increased primary production. This effect is therefore **not significant.**

The extent of the effluent plume and **pathogen** concentrations from Avonmouth WWTW would be highly restricted in the upstream direction by the presence of the structure, which limits passage of the pathogens. For the other WWTWs the extent of the effluent plume and enterococci concentrations would be marginally reduced compared to baseline conditions. This is due to increased mortality caused by lower suspended sediment concentrations and improved initial dilution. In all cases there is not expected to be an increase in pathogen concentrations either in the vicinity of bathing beaches or the shellfish waters in Swansea Bay and as such the relevant Marine Water Quality standards will not be exceeded. Hence the effect of B5 on pathogens is **not significant**.

Given the predicted changes to the hydrodynamic and sedimentary regime the concentration of dissolved and sediment associated **contaminants** in the estuary is likely to decrease slightly. Contaminant levels within bed sediments may increase in certain locations as a result of widespread deposition of suspended sediments. Overall, it is it is unlikely that current legislative standards for contaminants would be exceeded under B5 and the effect is therefore **not significant**.

Alternative Option L2: Welsh Grounds Lagoon

Once operational, the L2 lagoon would induce considerable changes to the hydrodynamic and sedimentary regime, which would affect the marine water quality receptors as follows:

With the L2 scheme some 50% of the tidal volume of the lagoon is exchanged per tide on both springs and neaps. The L2 lagoon is not predicted to affect the **flushing capacity** of the estuary as a whole.

In response to changes to the tidal regime and increased low water volume within the impounded area, the L2 lagoon is predicted to increase the tidally averaged **salinity** distribution, but reduce the amplitude of change over a tidal cycle for all flow conditions as a result of increases in minimum salinity values. As the salinity distribution remains within the existing envelope of change, the estuary would not fail current legislative guidelines and as such the predicted effects of the L2 lagoon on salinity are deemed **not significant.**

Maximum (summer) **temperatures** would be largely unaffected by the lagoon and no detectable changes (>1^{o}C) are expected either within the impounded area or downstream from the structure. Similarly, minimum (winter) temperatures are shown to increase by less than 0.1^{o}C for all locations, which is considered below detectable levels. Given that increases in water temperature of 3.8^{o}C over 120 years are predicted in response to climate change, the effect of the lagoon is considered **not significant**.

Thermal plume thermal plume dispersion will decrease within the impounded area. No detectable changes are predicted downstream of the structure. Assuming that a detectible change is >1^{o}C then neither the postulated changes to ambient temperature or the thermal discharges would affect water temperatures in the Severn Estuary or its tributaries. Therefore, threshold levels under the WFD and Shellfish Waters Directive would not be exceeded and the effect of L2 on temperature is **not significant.**

The predicted changes to the hydrodynamic regime (including flushing times) and the resultant effects on temperature and salinity would not have any effect on the existing **pH** distribution either within the impounded area of elsewhere in the estuary. The acidic discharge from the power station at Aberthaw would not be affected by the L2 lagoon. Consequently, the magnitude of this effect is deemed to be **not significant**.

The potential effects of the L2 lagoon on **suspended sediment** concentrations were investigated in the Hydraulics and Geomorphology Topic. Numerical simulations of mud transport predict that suspended sediment concentrations within the area impounded by L2 would reduce by a factor of 3 on spring times and by 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. On spring tides, slight increases in suspended sediments are predicted to occur between the headlands at Sand Point and Brean Down compared to ambient concentrations. Upstream from the lagoon, suspended sediments concentrations are not affected on either spring or neap tides. Consequently the effect of the L2 lagoon on suspended sediment concentrations is considered to be **significant**.

A 3D numerical model has been used to determine whether the alternative options would result in the estuary becoming **stratified** at any point in the tidal cycle. The results of this assessment show that the L2 lagoon would not cause stratification to occur within the main estuary. As a result of the changes to the hydrodynamic and sedimentary regime within the impounded area, the lagoon may experience some degree of stratification. This is considered unlikely given the extent of water exchange per tidal cycle but the issue warrants further study. For the purposes of the SEA this effect is considered **not significant**.

The distribution of **nutrients** within the estuary reflects simple dilution and based on the predicted changes to salinity, nutrient concentrations may be largely unaffected by the operation of the lagoon. The key implications of changes to nutrient behaviour in the Severn Estuary are the potential for increased primary productivity and enhanced risk of eutrophication. Within the lagoon, concentrations of suspended sediment would be expected to limit algal blooms on spring tides but on neap tides concentrations would be sufficiently low for blooms to occur. However as the entire volume of the lagoon would be exchanged daily this means that even if algal growth occurred within the lagoon, this would not lead to bloom formation because of the high level of flushing. The effect of the L2 lagoon on nutrients is therefore **not significant.**

Overall, **dissolved oxygen** levels in the estuary would be likely to change little, or show a slight increase due to reduced turbidity and increased primary production. This effect is therefore **not significant.**

The extent of the effluent plume and **pathogen** concentrations from Avonmouth WWTW is restricted in the cross-estuary direction by the presence of the structure. Plume extents from Nash WWTW and to a lesser extent Cardiff WWTW are strongly restricted in an upstream direction. Effluent plumes from the remaining WWTWs were not noticeably affected by the presence or operation of the lagoon. In all cases there is not expected to be an increase in pathogen concentrations either in the vicinity of bathing beaches or the shellfish waters in Swansea Bay and as such the relevant Marine Water Quality standards will not be exceeded. Hence the effect of L2 on pathogens is **not significant**.

Given the predicted changes to the hydrodynamic and sedimentary regime the concentration of dissolved and sediment associated **contaminants** in the estuary is likely to decrease slightly. Contaminant levels within bed sediments may increase in certain locations as a result of widespread deposition of suspended sediments. Overall, it is it is unlikely that current legislative standards for contaminants would be exceeded under L2 and the effect is therefore **not significant**.

Alternative Option L3d: Bridgwater Bay Lagoon

Once operational, the L3d lagoon would induce considerable changes to the hydrodynamic and sedimentary regime, which would affect the marine water quality receptors as follows:

With the L3d scheme some 80% of the tidal volume of the lagoon is exchanged per tide during springs and 60% during neaps.

In response to changes to the tidal regime and increased low water volume within the impounded area, the L3d lagoon is predicted to increase the tidally averaged **salinity** distribution, but reduce the amplitude of change over a tidal cycle for all flow conditions as a result of increases in minimum salinity values. Predicted changes to salinity both inside and outside the impoundment are less than 1PSU. As the salinity distribution remains within the existing envelope of change, the estuary would not fail current legislative guidelines and as such the predicted effects of the L3d lagoon on salinity are deemed **not significant.**

Maximum (summer) **temperatures** would be largely unaffected by the lagoon and no detectable changes (>1^{o}C) are expected either within the impounded area or downstream from the structure. Similarly, minimum (winter) temperatures are shown to increase by less than 0.1^{o}C for all locations, which is considered below detectable levels. Given that increases in water temperature of 3.8^{o}C over 120 years are predicted in response to climate change, the effect of the lagoon is considered **not significant**.

The L3d lagoon was predicted to have little effect on the thermal plumes from Aberthaw and Oldbury power stations. However significant effects are predicted for the thermal plume from Hinkley, which will require further detailed study to ensure that the discharge consents from Hinkley Point are not compromised. The effect of L3d on the Hinkley thermal plume is **significant.**

The predicted changes to the hydrodynamic regime (including flushing times) and the resultant effects on temperature and salinity would not have any effect on the existing **pH** distribution either within the impounded area of elsewhere in the estuary. The acidic discharge from the power station at Aberthaw would not be affected by the L3d lagoon. Consequently, the magnitude of this effect is deemed to be **not significant**.

The potential effects of the L3d lagoon on **suspended sediment** concentrations were investigated in the Hydraulics and Geomorphology Topic. Numerical simulations of mud transport predict that during neap tides, there would 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 outside the lagoon, in the vicinity of Weston Bay and inside the lagoon over much of the impounded area. However, concentrations in excess of 2000mg/l are predicted to occur in an area adjacent to the coast to the west of the mouth of the Parrett.

Within Bristol Deep, suspended sediment concentrations would be reduced during the flood tide, yet at Flat Holm, concentrations would remain close to ambient levels, or even increase. This suggests that the lagoon acts to redistribute the incoming sediments, rather than acting as a sink for sediment entering on the flood tide. Consequently the effect of the L3D lagoon on suspended sediment concentrations is considered to be **not significant**.

A 3D numerical model has been used to determine whether the alternative options would result in the estuary becoming **stratified** at any point in the tidal cycle. The results of this assessment show that the area impounded by the L3d lagoon is unlikely to experience stratification as a result of changes to the hydrodynamic regime, salinity or suspended sediments. This is mainly due to the preferred flood/ebb generation mode. Therefore this effect is considered **not significant**.

The distribution of **nutrients** within the estuary reflects simple dilution and based on the predicted changes to salinity, nutrient concentrations may be largely unaffected by the operation of the lagoon. The key implications of changes to nutrient behaviour in the Severn Estuary are the potential for increased primary productivity and enhanced risk of eutrophication. Within the lagoon, concentrations of suspended sediment would be expected to limit algal blooms on spring tides but on neap tides concentrations would be sufficiently low for blooms to occur. However as the entire volume of the lagoon would be exchanged daily this means that even if algal growth occurred within the lagoon, this would not lead to bloom formation because of the high level of flushing. The effect of the L3d lagoon on nutrients is therefore **not significant.**

Overall, **dissolved oxygen** levels in the estuary would be likely to change little, or show a slight increase due to reduced turbidity and increased primary production. This effect is therefore **not significant.**

The extent of the effluent plume from West Huntspill WWTW, which is within the impounded area would be considerably reduced due to the increased mean water level inside the lagoon which reduces the influence of bed topography on flow patterns. Conversely, the extent of the plume from the Weston-Super-Mare WWTW would be increased by the presence of the structure. Although the concentration of pathogens within the plume is not predicted to increase, the plume would now predicted to extend across Weston Bay in the vicinity of the bathing beaches. This may result in non compliance with the Bathing Waters Directive. No other plumes are predicted to be affected by L3d. The effect of the L3d lagoon on pathogens is therefore **significant.**

Given the predicted changes to the hydrodynamic and sedimentary regime the concentration of dissolved and sediment associated **contaminants** in the estuary is likely to decrease slightly. Contaminant levels within bed sediments may increase in certain locations as a result of widespread deposition of suspended sediments. Overall, it is it is unlikely that current legislative standards for contaminants would be exceeded under L3d and the effect is therefore **not significant**.

Assumptions, Limitations and Uncertainty

The assessment of effects assumes instantaneous superposition of the scheme into the estuary and does not account for any gradual introduction over a construction period of 4 - 6 years.

Uncertainty has been introduced to the Marine Water Quality assessment though the following means:

- 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 (e.g. due to the level of experience in the practitioner)

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

Some of the tools and source information for the Marine Water Quality assessments were developed or produced by the Hydraulics and Geomorphology Topic. Considerable attention has been given to identifying and understanding the sources of uncertainty within the Hydraulics and Geomorphology topic but it is important to recognise within Marine Water Quality that some of the source data has higher levels of uncertainty than others.

In particular, the main area of uncertainty within the Hydraulics and Geomorphology assessments which has a bearing on a number of the Marine Water Quality receptors is suspended sediments. The difference between observed and predicted values makes it difficult to determine the true extent to which the alternative options would affect suspended sediment concentrations. This adds considerable uncertainty to the Marine Water Quality Assessments of pathogen mortality light penetration and eutrophication potential, contaminants and dissolved oxygen. Efforts have been made to reduce the levels of uncertainty by considering both measured and modelled data in the modelling studies.

The conclusions drawn from this assessment are limited by the uncertainties associated with the modelling (these are described in the various annexes) and the quality of the input data used.

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

Relatively few significant marine water quality effects have been predicted during the assessment. Where significant effects may occur, these primarily arise from the major changes to the estuary hydrodynamic regime and there is little that can be done to mitigate marine water quality effects. During construction, it is assumed that, as a matter of good practice, standard measures to minimise effects would be taken, for example:

- careful timing of construction activities to minimise risks during sensitive periods for specific receptors;
- pollution prevention controls to minimise accidental spillages;
- management of dredging and piling activities to limit resuspension of sediments.

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.

The main predicted marine water quality effects relate to:

- Risk of eutrophication within the estuary upstream of option B3 as a result in increases in light penetration in response to the reduction in suspended sediment concentrations. This may cause failure of WFD objectives;

- Risk of failure of bathing waters standards at Weston-Super-Mare for option L3;

- Risk of failure of national policy on thermal plumes for possible Hinkley 'C' power station for option L3.

To offset eutrophication risk it would be feasible to implement additional controls on diffuse sources of nitrogen within the Severn catchment, for example by extending NVZ controls, or through additional levels of treatment for municipal wastewater (tertiary treatment at all outfalls). The costs associated with such offsetting measures could be very high. Implementation of such measures could affect agricultural yields and result in addition waste sludge generation from WWTW as well as increased energy costs.

Effects in relation to Weston-Super-Mare bathing beach could be offset through relocation of the outfall or UV treatment at the WWTW. Effects in relation to a possible Hinkley 'C' power station could be offset through relocation/redesign of the outfall. These measures should not give rise to any specific effects on other receptors within the Severn Estuary.

Assessment against SEA Objectives

This topic paper includes a full assessment of how each alternative option performs against each SEA Objective over the course of its entire life-cycle.

In summary:

- Alternative B3 is predicted to show minor negative performance against SEA objectives 1 and 2;
- Alternative L3d is predicted to show minor negative performance against SEA objectives 1, 3, 4 and 5.

- The remaining alternatives are predicted to comply with all SEA objectives

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 potentially significant effects predicted for the B3 barrage and L3 lagoon have the potential to both reduce the water body status under the WFD and Bathing Waters Directive respectively. The L3 lagoon is also likely to have an adverse effect on the consented thermal discharge from Hinkley Point power station

None of the other alternatives are predicted to compromise any of the relevant marine water quality legislation.

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.

The predicted changes in the hydrodynamic regime of the estuary necessarily introduce uncertainty into predictions of future marine water quality. This would necessarily require the development and implementation of a detailed, intensive and long-term monitoring programme to assess actual changes relative to predictions. This programme would need to include extensive long-term monitoring of changes in water column primary productivity to assess changes in eutrohpication risks, particularly for option B3. Given the sensitivity of the estuary to changes in eutrohpication risk, significant eutrophication monitoring programmes may also be required for the other options, even though the predicted changes for these options are very minor. Additional studies would be required to assess changes in dilution and dispersion of effluent for major discharges to validate model predictions and ensure that discharges continue to comply with consent requirements.

In addition to specific monitoring of predicted significant effects, it would also be necessary to undertake broader monitoring of changes in marine water quality, for example, changes in salinity regime and nutrient distributions as well as long-term monitoring of contaminant concentrations and distribution to assess changes in biogeochemical cycling of contaminants. Table 5.1 below summarises a high level framework for monitoring, which can be applied to all of the Severn Tidal Power Alternative options under consideration.