



Environmental Statement

Chapter 6. Coastal Processes, Sediment Transport and Contamination

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6.0 Coastal Processes, Sediment Transport and Contamination

6.1 Introduction

- 6.1.0.1 This chapter of the Environmental Statement (ES) discusses the potential effects of the proposed Swansea Bay Tidal Lagoon Project (the 'Project') on the physical marine environment, incorporating hydrodynamic processes (water levels, currents and waves) and the effect of these processes on the sediment regime. Within the sediment regime, consideration is also given to potential concerns related to sediment contamination. In addition, consideration is also given to the effects of potential changes in hydrodynamic and sedimentary processes on coastal and subtidal morphology. Where appropriate, the coastal processes study has been used to inform the assessment of associated EIA topics (including Intertidal and Benthic Subtidal Ecology (Chapter 8); Fish, Recreational and Commercial Fisheries (Chapter 9); Marine Mammals and Turtles (Chapter 10); Coastal Birds (Chapter 11); Terrestrial Ecology (Chapter 12) and Economy Tourism and Recreation (Chapter 22)). A summary of the effects on key receptors associated with each of these subjects can be found in Table 6.22 at the end of this chapter, whilst detailed discussion on the location, assessment of effects and mitigation for receptors can be found in the relevant chapter (as identified above) and supporting figures (Volume 2). The interrelationship between the various chapters of this ES is summarised in Chapter 24, Interrelationships.
- 6.1.0.2 The Environmental Impact Assessment (EIA) considers all the relevant phases of the Project from construction, to operation and decommissioning. For each of these phases the impact is assessed relative to a baseline defined as the environmental conditions which are likely to exist without the Project. The design life of the Project is likely to extend for several decades, and project design presently assumes an overall life expectancy of around 120 years. Such long-term timescales must recognise associated climate change effects.
- 6.1.0.3 It is appreciated that changes that might occur as a result of the Project may be localised or extend over a wider area, and that they may represent short-term effects during periods of construction or longer-lasting effects during the operational phase. Longer-term effects may also demonstrate changes in the distribution of local sediments and patterns of erosion and deposition which result in adjustments to some areas of the seabed.
- 6.1.0.4 The study area for the assessment has been established from initial high-level modelling of various lagoon options (ABPmer, 2012). This initial modelling provided a conservative assessment as to how the effect of a full impoundment might displace the incoming and outgoing tide and how it might interfere with the characteristic tidal resonance behaviour of the Bristol Channel and Severn Estuary. It is noted here that the Project does not harvest tidal energy directly from the main progressive tidal wave, rather its location is partially removed from the Bristol Channel in a side embayment, where the tidal head is in response to a standing wave. As a result, the extensive far-field changes in water levels shown to occur with a full tidal barrage option are not realised for this (smaller in relative terms) lagoon option sited in Swansea Bay. The EIA study area is therefore defined with near-field spatial scales being Swansea Bay, and the far-field extending from Worms Head to Nash Point and offshore to Scarweather Sands (within the Bristol Channel). Modelling tools have been designed to include both scales, but also extend to areas west of Lundy and east into the Severn Estuary so that boundary conditions for waves, tides and sediment transport can be properly defined.

- 6.1.0.5 In order to consider how the marine physical environment might be affected by the Project, it has been necessary first to establish the baseline conditions. Those impacts that are both associated with the Project and have the potential to affect coastal processes have then been identified, and their nature, extent and duration described. Their effects on coastal processes are then predicted, and the significance assessed.

6.2 Legislation, planning policy and guidance

- 6.2.0.1 The guidance provided within the National Policy Statement (NPS) for Renewable Energy Infrastructure (EN-3; DECC, 2011) provides the outline requirements for physical process assessments which underpin the EIA. Notwithstanding that it is not directly applicable to tidal range generating stations, the relevant provisions remain appropriate to the assessments undertaken in respect of the Project. In this respect, the NPS (paragraph 2.6.189) highlights the following issues:

- i. Water quality - disturbance of the seabed sediments or release of contaminants can result in indirect effects on habitats and biodiversity and fish stocks thus affecting the fishing industry;
- ii. Waves and tides - the presence of the turbines and other infrastructure (in this case the Lagoon structure and tidal turbines) can cause indirect effects on flood defences, marine ecology and biodiversity, marine archaeology and potentially, coastal recreation activities;
- iii. Scour effect - the presence of wind turbines and other infrastructure (as here) can result in a change in the water movements within the immediate vicinity of the infrastructure, resulting in scour (localised seabed erosion) around the structures. This can indirectly affect navigation channels for marine vessels and marine archaeology, which are considered in this ES;
- iv. Sediment transport - the resultant movement of sediments, such as sand and/ or mud across the seabed or in the water column, can indirectly affect navigation channels for marine vessels; and
- v. Suspended solids - the release of sediment during construction and decommissioning can cause indirect effects on marine ecology and biodiversity.

- 6.2.0.2 The NPS (paragraphs 2.6.190 to 2.6.194) also includes guidance on what matters are to be included in an applicant's assessment, these being summarised as follows:

- I. The Applicant should consult Natural Resources Wales (NRW) and Cefas on methods for assessment of impacts on physical processes (paragraph 2.6.192 of NPS EN-3);
- II. The assessment should consider all stages of development, i.e. the entire lifespan of the Project (paragraph 2.6.190 of NPS EN-3);
- III. Geotechnical investigations should form part of the assessment as this will enable the design of appropriate construction techniques to minimise any adverse effects (paragraph 2.6.193 of NPS EN-3); and
- IV. The assessment should include predictions of the physical effect from the construction and operation of the required infrastructure and include effects such as scouring (paragraph 2.6.194 of NPS EN-3).

- 6.2.0.3 Following the abolition of the Infrastructure Planning Commission (IPC), the application and examination process is now administered by the Planning Inspectorate (PINS), with the decision on the DCO being taken by the Secretary of State. NPS EN-3 highlights a

number of points relating to decisions upon an application and in relation to mitigation (paragraphs 2.6.195 to 2.6.197). These are summarised - with references to the IPC now being read as to the Secretary of State - below:

- 1) The direct effects on the physical environment can have indirect effects on a number of other receptors. Where indirect effects are predicted, the IPC should refer to relevant sections of this NPS and EN (or the Welsh equivalent - paragraph 2.6.195 of NPS EN-3);
- 2) The methods of construction, including use of materials should be such as to reasonably minimise the potential for impact on the physical environment (paragraph 2.6.196 of NPS EN-3); and
- 3) Mitigation measures which the IPC should expect the applicants to have considered include the burying of cables to a necessary depth and using scour protection techniques around offshore structures to prevent scour effects around them. Applicants should consult the statutory consultees on appropriate mitigation (paragraph 2.6.192 of NPS EN-3).

6.2.0.4 In addition to the NPS guidance, a number of other policy, guidance and regulation documents are also of relevance to the assessment of physical processes within the marine environment. These include:

- I. 'Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects' (Cefas, 2011); and
- II. 'Advice Note Seven: Environmental Impact Assessment, screening and scoping' (PINS, 2012a).

6.2.0.5 It should be noted here that although none of the cited extracts from the various guidance documents refer specifically to the assessment of potential long-term effects on coastal and subtidal morphology, such assessments have been carried out within this study.

6.3 Methodology

6.3.1 Baseline understanding and data gathering

6.3.1.1 The first stage of the assessment is the determination of the baseline through the analysis and interpretation of data and information collated from a variety of different sources. The evidence base for this study includes a programme of project specific surveys, pre-existing datasets, available literature and output from numerical modelling activities undertaken specifically as part of this study. The evidence base collated to help define the baseline environment has been informed through a general literature review of relevant studies and includes the following key information sources:

- i. TLSB geophysical and geotechnical surveys (Titan, 2012a; Atkins, 2013) – these surveys covered the area within and adjacent to the footprint of the Project;
- ii. TLSB metocean survey (Titan, 2012b) – the metocean survey collected data from two locations within the footprint of the Project between February and April, 2012;
- iii. TLSB benthic survey (Titan, 2013) – among other data, this study collected a number of seabed sediment samples across the Project footprint and over the wider Swansea Bay, in order to provide information on particle size distribution and contaminant levels;

- iv. Factual Report on Ground Investigations (Atkins 2013) undertaken by ESG Ltd of the Project footprint – this study collected data from a number of samples sites across the Project footprint which would be affected by the development. Samples were collected from the surface and at depth, in order to provide information on, among other things, particle size distribution and contaminant levels;
- v. Severn Tidal Power SEA (ABPmer, 2010) – this was prepared on behalf of the Department of Energy and Climate Change to study the effects of a number of marine renewable energy options within the Severn Estuary. It is noted that whilst useful information was gathered during this study (particularly in determining the baseline character of the Severn Estuary / Bristol Channel system), the SEA did not specifically carry out detailed assessments within Swansea Bay;
- vi. Bristol Channel Marine Aggregates: Resources and Constraints (Posford et al., 2000) – this study covered an assessment marine aggregate resources within the Bristol Channel region and provides information to help inform the characterisation of the baseline environment across the wider study area; and
- vii. Lavernock Point to St. Ann's Head Shoreline Management Plan SMP2 (Halcrow, 2012a) – this study contained a high-level desk review of coastal processes and shoreline characteristics, providing information to help inform the characterisation of the baseline environment across the wider study area.

6.3.2 Numerical modelling

- 6.3.2.1 To support this EIA a number of modelling studies have been completed to assess the hydrodynamic, wave, sedimentation, and plume impacts from the development and to inform the assessment of the potential for significant environmental impact.
- 6.3.2.2 A suite of DHI Mike21 hydrodynamic and wave models describe the study area and include a sediment transport module for both cohesive and non-cohesive sediments. This suite of models enables examination of changes in suspended sediment concentration (SSC), sediment transport pathways and associated sedimentation and erosion, over both the near-field (across the proposed development site) and far-field regions (the wider Swansea Bay and Bristol Channel area, including the adjacent coastline and covering the approach channels to the local ports). The numerical models employed in this study are an adaptation of existing models of the Approaches to the Bristol Channel and the Severn Estuary, used previously for the Severn Estuary Tidal Power Study and the Atlantic Array Offshore Windfarm EIA Study (ABPmer, 2010 and ABPmer 2013a, respectively). The extent of coverage of the numerical models is shown in Figures 6.1 to 6.2 (Volume 2).
- 6.3.2.3 The bathymetry for the models includes the 2012 Titan survey of the proposed lagoon site and additional surveys over the wider Swansea Bay and Bristol Channel region (from a variety of sources, including the UKHO, ABP and the Neath Estuary Working Group). The morphology of the intertidal areas within Swansea Bay was obtained from the Coastline Response Study (Bullen, 1993) and subsequently combined with the wider bathymetry. A more detailed description of the data sources and preparation of the bathymetric and topographic data utilised within the numerical modelling is provided in ABPmer, 2013b. Specific provision in the model grid has been made to provide detailed representation of the features of the bay (including the Swansea, Neath and Port Talbot Harbour and dredged channels) as well as to define the components of the Project and associated construction activity (such as dredging).

- 6.3.2.4 The offshore boundaries of the hydrodynamic model are driven by tidal constituents and the fluvial inputs within the model domain were included as constant average freshwater flow discharges.
- 6.3.2.5 Details of the data, boundary conditions and parameters used to run the models are provided in the model Calibration and Validation Report (ABPmer, 2013c). The most important physical processes represented by a range of field measurements have been used to calibrate and validate the model, optimise its performance and parameterise the processes. In addition, the results of the ground investigation surveys, the conceptual understanding of sediment transport processes and complimentary data on maintenance dredging tonnages have been further used to inform the modelling of cohesive and non-cohesive sediments.
- 6.3.2.6 The results of the calibration and validation exercise (ABPmer, 2013c) demonstrate that the numerical models have been successfully calibrated and validated against available up-to-date field measurements to provide a sufficiently accurate representation of the hydrodynamic and wave regimes within the study area. The calibration process involved the adjustment of various parameters within the numerical model (whilst ensuring any adjustment was scientifically realistic) until the respective model output reached an acceptable 'fit' with the comparative field measurements. In general, the model outputs from the calibration and validation exercises were in very good agreement with the observational data. Specifically:
- peak tidal flow speeds (flood and ebb), tidal flow directions and tidal asymmetry measured at the calibration sites are reproduced well by the model. In particular, the notable asymmetry in tidal flow, with distinct ebb dominance;
 - comparisons between predicted and measured water levels used to validate the model across the study area show very good agreement;
 - comparisons between predicted and modelled wave parameters (height, period and direction), used to validate the model across the study area show very good agreement; and
 - the modelled baseline distribution of sedimentation and erosion areas and the relative magnitudes between the different dredged channels agree well with the conceptual understanding and annual sedimentation rates as derived from the dredge data.
- 6.3.2.7 The model is therefore considered suitable for use in support of the present EIA studies.

Hydrodynamics

- 6.3.2.8 The changes caused by the proposed Project on the hydrodynamics of the study area, and particularly the Swansea Bay region, have been modelled for a representative mean spring-neap tidal cycle. The outputs from the model have been presented to show the maximum spatial extent of change and the time history variation throughout the tidal cycle at strategic locations for water levels, flow speeds and directions.

Waves

- 6.3.2.9 The Mike21 Spectral Wave module has also been used to determine the extent and magnitude of changes to waves in the vicinity of the Project and to identify any further changes to the wave climate across the wider study area. The wave module is a state-of-the-art third generation spectral wind-wave model, which has been applied to simulate

wave growth, decay and transformation due to diffraction, refraction, reflection and shoaling processes.

- 6.3.2.10 The effects of the proposed Project on waves across the study area have been investigated for a range of wave events and for two general wave directions, from the south west and south east. From the predominantly south-westerly direction, the 0.1, 1, 10 and 20 year return period waves have been assessed; whilst from the less dominant south-easterly direction, the 0.1 and 10 year return period waves have been assessed. These wave conditions were selected to give a range of extreme events from 'average' winter storms, through to less frequent but greater magnitude storms.
- 6.3.2.11 The wave conditions included in the assessment are shown in Table 6.1.

Table 6.1 Wave conditions assessed for EIA studies

General Wave Direction	Return Period (years)	Wave parameters		
		Hs (m)	Tp (s)	Mean Direction (°N)
South westerly	0.1	5.56	11.6	253
	1	6.33	13.6	261
	10	7.33	14.2	254
	20	7.45	14.3	250
South easterly	0.1	0.51	3.4	120
	10	1.36	4.9	120

- 6.3.2.12 The wave data is based on a long-term hindcast of wind and wave conditions across the study area (ABPmer, 2013d). These wave conditions were applied to re-create the equivalent extreme wave conditions, for the baseline scenario, at the Scarweather wave buoy site. These same conditions were then modelled with the Project in place in order to determine what the effects on the wave parameters would be across the study area.

Sediment

- 6.3.2.13 The sediment modules of Mike21 for cohesive (mud transport) and non-cohesive (sand transport) material have been used to establish the potential impact the Project might have on both the near-field and far-field sediment regime. The model has been validated against suspended sediment concentration (SSC) data from field measurements at the metocean survey locations within Swansea Bay (as shown in Figure 6.3, Volume 2), whilst sedimentation rates have been factored to validate against the annualised maintenance dredging data from the various approach channels in the local area (Swansea, Neath and Port Talbot). The dredging data referred to has been used to compare the outputs of the mud transport model against (since the material dredged from the approach channels is predominantly mud). In this way, the deposition volume across the study area, as predicted by the numerical modelling, is scaled such that the volume of material in the approach channels is representative of the volume derived from the annualised maintenance dredging data.
- 6.3.2.14 Model scenarios have been run over mean spring and neap tidal cycles to determine:
- 1) the impact of the Project on the distribution of SSC and accretion/ erosion patterns; and

- 2) the potential effect on the maintenance dredging commitment at the existing port infrastructure and to determine the future requirement within the proposed lagoon itself.

6.3.2.15 In addition, a simulation of the sediment disturbance (leading to sediment plume dispersal) that would likely occur during the construction phases of the Project has also been undertaken using the Mike21 Particle Tracking module. The aim of this assessment was to determine the potential effects on the water column and the potential for smothering of the seabed as a result of sediment plumes created by the processes of excavation for construction. This model simulation has been based on the following assumptions for the construction of the lagoon wall:

- i. a cutter suction dredger (CSD) will be used to dredge material and fill the Geotubes® simultaneously;
- ii. the confirmed filling rate for the Geotubes® is 5m³/s, of which 20% of the fill material is sediment, the remainder is water;
- iii. each Geotube® is 5m in diameter and 150m in length, meaning it will take approximately 50 minutes to fill a single Geotube®;
- iv. average losses of material to the water column during dredging and filling have been estimated for the project (based on assumed sediment information) at 10 kg/s from the dredging activity and 90 kg/s for the Geotube® filling;
- v. information obtained from the PSA results of the benthic sampling and the geotechnical investigation have been used to determine the general character of the dredged material. The relative proportion of material of different grain sizes, as considered in this part of the assessment, is provided in Tables 6.2 and 6.3 for construction activity to the east and west of the lagoon, respectively;
- vi. following the completion of each filling operation, placement of a new Geotube® will be undertaken and the barge will be repositioned – a process expected to take a total of approximately 60 minutes – following which, the filling process is repeated; and
- vii. once the Geotube® ‘pyramids’ are placed, the volume between is then filled with further dredged material – a continuous process that will necessarily take longer than the Geotube® filling since the fill volume is greater.

6.3.2.16 This ES has considered the use of Geotubes® seawall construction. In practice, construction may use a more traditional approach consisting of dredged gravel or imported quarry run, which will retain and secure the sediment cores of the seawalls in place of Geotubes®. In that sense, the Geotubes® technique represents the worst case for assessment purposes since it will require the most dredging and disturbance of fine material.

6.3.2.17 The construction process was replicated in the model at the above stated intervals throughout construction of a section of lagoon wall, at the eastern and western limits of the proposed lagoon extent.

Table 6.2 Particle size distribution of sediment assessed for construction activity to the east of the lagoon

Sediment size (µm)	Avg. % in surface samples	Release from dredging (kg/s)	Release from filling (kg/s)	Approx. settling velocity (m/s)
125 – 250	51.7	5.2	46.6	0.01
63 – 125	37.4	3.7	33.7	0.003
<63	6.8	1.1	9.7	<0.003

Table 6.3 Particle size distribution of sediment assessed for construction activity to the west of the lagoon

Sediment size (µm)	Avg. % in surface samples	Release from dredging (kg/s)	Release from filling (kg/s)	Approx. settling velocity (m/s)
125 – 250	25.1	8.0	72.0	0.01
63 – 125	4.5	1.4	12.9	0.003
<63	1.8	0.6	5.1	<0.003

6.3.2.18 In addition to the wall construction activity, the potential disposal of up to 500,000 m³ of dredged material from the turbine housing site (which is predicted to be unsuitable for further use in the construction process) has also been assessed in a similar manner. It is noted here that there is also a potential additional requirement for sediment disposal from dredging of the impounded area of the Lagoon (up to 300,000 m³) for boating purposes, although this is anticipated to be undertaken approximately 1 to 2 years after the dredging activity at the turbine housing site has been completed. As such, the assessment has not considered both disposal activities in-combination, since it is considered that any effects would not be sustained over this time period. The assessment of dredge disposal has been based on the following assumptions:

- I. dredged material will be placed into a 10,000 m³ capacity barge/ dredger and transported to the Swansea Outer Spoil Ground for disposal;
- II. it is considered that wave activity will act to reduce deposition and speed up the dispersal of material in suspension. Therefore the assessment has considered a scenario without wave conditions, as being representative of a realistic worst case;
- III. based on assumed timings, a round trip for disposal of a single load will be approximately 6 hours;
- IV. once at the disposal ground, the material is assumed to be released as a single load, with source terms input to the water column between the bottom of the barge/ dredger and the seabed;
- V. the disposal activity is assessed as being continuous throughout the model run period; thus, based on the estimated timings, a total of 25 loads are included, equating to approximately half of the total estimated volume of material potentially requiring disposal, over most of a spring-neap cycle (it is noted here that the assessment volume equates to approximately half of the total possible disposal volume although it is considered that the assessment has captured the maximum magnitude of effect); and
- VI. information obtained from the PSA results of the benthic sampling and the geotechnical investigation have been used to determine the general character of the

dredged material for subsequent disposal (of the 10,000m³ for each disposal cycle, the proportion of material of different grain sizes is given as: 125 – 250µm = 78%; 63 – 125µm = 14%; <63µm = 8%).

Presentation of results

- 6.3.2.19 Model results have been presented in two complimentary ways. First, spatial plots at a single point in time are used to represent the maximum extent and magnitude of impact of the Project on the study area, at any time within the modelled scenario. In addition, water level changes have been extracted at HW and LW to determine the effects of the Project on the extents of the intertidal area within Swansea Bay.
- 6.3.2.20 Secondly, temporal plots have been produced in the form of time series at a number of specific locations. These locations vary depending on the focus of the assessment (i.e. water levels, wave height, etc.), and have generally been selected to show, throughout a tidal cycle, the effects of the development phases on:
- specific seabed receptors;
 - water level, flow speed, wave height and sediment erosion/ accretion identified in the spatial plots in the areas of maximum predicted change; and
 - other topic receptors that may be affected by the effects on physical processes.
- 6.3.2.21 When considered together, these complimentary plots provide information to help quantify the changes occurring as a result of the Project both in space and time. Comparison of these changes against the baseline condition allows the impact significance to be assessed.

6.3.3 Assessment methods

- 6.3.3.1 The extent and nature of the coastal process impacts and their assessment are based on modelling studies and field measurements undertaken specifically for the Project, as well as appropriate data/ information from relevant technical studies and assessments. In addition, the assessment has been further informed through local knowledge and experience in undertaking these types of assessments.
- 6.3.3.2 The methodology for the assessment involves the application of ABPmer's established and standardised protocols which recognise the dynamic nature of marine systems and the interconnections between physical processes, habitats and species. The approach to the evaluation of effects has been developed with reference to a number of guidance documents and regulations, including the criteria listed in Annex III of the EC Environmental Assessment Directive (97/11/EC). The evaluation particularly draws on the assessment process developed by nature conservation agencies (e.g., Countryside Council for Wales (now Natural Resources Wales), Natural England, Scottish Natural Heritage etc.) to provide advice on operations within European marine sites and the Environmental Risk Assessment approach developed by ABP R&C (1997). This is based upon the Department of Environment's (DoE) guide to risk assessment for environmental protection (1995), and also draws upon the guidance provided in the Town and Country Planning (EIA) Regulations 2011.
- 6.3.3.3 This ES proceeds on the basis of the outline construction programme as discussed in Chapter 4, Section 4.5.2, which anticipates construction starting in 2015 and with the main construction lasting for about three years. The assessments contained in this

chapter are not materially sensitive to works commencing within the anticipated validity of the DCO, which is five years, or to an extension of (say) a further year-or-so.

Identification and estimation of change and exposure

- 6.3.3.4 Construction (including dredging and disposal) and operational phases of the Project have the potential to result in a range of changes in the environment. These changes, or impacts, may or may not affect a receiving environment (i.e. receptor).
- 6.3.3.5 Whether a receiving environment can be exposed to an impact or change depends on there being a route or pathway. The magnitude of the exposure and its ability to affect a receptor also depends on a range of other factors, such as its duration, frequency and spatial extent:
- duration - the length of time a change can be considered to operate over is described as being either a short or long-term period. 'Short-term' changes are more likely to occur as a result of activities during the construction phase (which are temporary in nature), whilst 'long-term' is more likely to be relevant to the operational period;
 - spatial extent - the spatial extent of a change is referred to using the terms 'immediate', 'near-field' and 'far-field';
 - frequency - the ability for a change to be repeated is described by the terms 'infrequent', 'frequent' or 'continuous'; and
 - sensitivity – the specific sensitivity or response characteristics of the receptor is defined by the terms 'none', 'low', 'moderate' or 'high'.
- 6.3.3.6 Many different methods may be used to determine the exposure to changes, and in some cases it is also desirable to take account of uncertainty. Within this assessment uncertainty has been expressed by presenting changes and exposures as ranges rather than single point values, wherever possible. Furthermore, a worst case approach makes this assessment conservative.
- 6.3.3.7 Table 6.4 sets out the basic criteria used to determine the magnitude of the impact of the Project on the coastal processes and receptors for the purposes of the impact assessment. Whilst these are basic criteria, not all changes can be neatly defined. To take account of this the assessment needs to be 'moderated' taking account the holistic understanding of the physical system to ensure consistency.

Table 6.4 Basic criteria for defining magnitude of impact

Magnitude	Definition
Large	Far-field spatial extent with scale of change greater than the natural variability with a continuous signal extending long-term.
Medium	Near-field spatial extent with scale of impact with the same order as the natural variability, frequently occurring in the long-term. OR Immediate spatial extent (the Project footprint) with scale of change greater than the natural variability, occurring frequently over a short timescale.
Small	Near-field spatial extent with scale of impact smaller than the natural variability, frequently occurring over a short/temporary timescale.
Negligible	Immediate spatial extent, with scale of impact smaller than the natural variability, occurring infrequently over a short/temporary timescale

- 6.3.3.8 Inevitably this process is subjective and some of the impacts that are identified will not neatly fall into these criteria. On this basis, expert judgement based on the overall system understanding is made to 'moderate' the assessment to ensure consistency for each issue at different locations.
- 6.3.3.9 The matrix in Table 6.5 is based on the Department of Environment's (DoE) approach to risk assessment (DoE, 1995) and is used as a means of generating an estimate of exposure. This matrix is a guide and does not always represent the true complexity of the change; therefore, some further qualification may be necessary. It is in this respect that the evaluation of the available numerical modelling studies has been used to assess the magnitude and extent of changes introduced by the Project.

Table 6.5 Table summarising how the exposure to change can be described by combining the magnitude of change and probability of occurrence

Probability of Occurrence	Magnitude of Change			
	Large	Medium	Small	Negligible
High	High	Medium	Low	Negligible
Medium	Medium	Medium/ Low	Low/ Negligible	Negligible
Low	Low	Low/ Negligible	Negligible	Negligible
Negligible	Negligible	Negligible	Negligible	Negligible

Sensitivity of receptor

- 6.3.3.10 An effect can only occur if a receiving environment (receptor) is exposed to a change to which it is sensitive. Hence, it is necessary to understand the sensitivity of receiving environments. Sensitivity can be described as the intolerance of a receiving environment readily to accept the levels of predicted change to which they are exposed.
- 6.3.3.11 The assessment of sensitivity, therefore, considers the adaptability of the environment to its former state following exposure to the impact. In this assessment, sensitivity is considered as the degree of perturbation a receiving environment can tolerate in response to the predicted changes to which they are exposed. It should be noted that physical processes may, in some cases, be more appropriately considered as an 'intermediary' rather than a receptor in their own right, and may, therefore, not have a relative sensitivity as defined above. This stage essentially provides a benchmark against which the changes and level of exposure can be compared. In some cases it may be applicable to compare the anticipated change or exposure against either baseline conditions or other relevant thresholds such as quality criteria (i.e. for water, light or noise).

Vulnerability

- 6.3.3.12 The vulnerability of a receiving environment is essentially the comparison of the anticipated exposure with the specific sensitivity or response characteristics. Where the exposure and sensitivity characteristics overlap then vulnerability exists and an effect may occur. Where an exposure or change occurs for which the receptor is not sensitive then no effect will occur. Table 6.6 sets out how the level of vulnerability is determined.

Table 6.6 Summary of how the level of vulnerability is estimated based on receptor sensitivity and exposure to change

Sensitivity of Receptor	Exposure to Change			
	High	Medium	Low	Negligible
High	High	High	Moderate	None
Moderate	High	Moderate	Low	None
Low	Moderate	Low	Low	None
None	None	None	None	None

6.3.3.13 In determining the vulnerability with respect to coastal processes, consideration is given to the known, past behaviour of Swansea Bay at the locations of change and how this is likely to have changed due to the parameter being assessed. This is a subjective assessment based on the understanding of the natural system and set criteria for determining vulnerability are not possible to establish.

6.3.3.14 The vulnerability is an expression of the risk associated with an impact. Whether this 'vulnerability state' or risk is significant or not is then considered.

Significance criteria

6.3.3.15 Estimating and categorising the significance of an effect involves a degree of subjectivity. A receiving environment may have a high or low vulnerability, but whether the potential effect is 'significant' may depend on other factors, such as its potential recoverability (temporary or permanent impact), its relative 'importance' (either to the ecosystem or in terms of statutory designations) or the scale of habitat/ population affected and its overall tolerability, either to the receiving environment itself or its users. For this assessment Table 6.7 provides basic definitions for determining the importance of the feature being assessed.

Table 6.7 Definition of receptor importance

Magnitude	Definition
High	Receptor designated and/ or of international importance. Likely to be rare with minimal potential for substitution or unable to tolerate change. May also be of high or very high socioeconomic importance.
Moderate	Receptor designated and/ or of national importance and/or some ability to tolerate change and recover in the medium term. Likely to be relatively rare. May also be of high socioeconomic importance.
Low	Receptor not designated but of local to regional importance and able to tolerate the effect to a large extent, with relatively rapid rate of recovery or not designated/ of local importance but not tolerant to change.
Negligible	Receptor only of local importance with a high tolerance to change.

6.3.3.16 Table 6.8 summarises the process of estimating an overall significance of effect based on vulnerability and importance of the interest feature.

Table 6.8 Summary of how the relative level of significance can be estimated based on vulnerability and importance

Importance of Receptor	Vulnerability of Feature to Impact			
	High	Moderate	Low	Negligible
High	Major	Moderate	Minor	Neutral
Moderate	Moderate	Moderate/ Minor	Minor/ Neutral	Neutral
Low	Minor	Neutral	Neutral	Neutral
None	Neutral	Neutral	Neutral	Neutral

- 6.3.3.17 The significance statement provides a summation of the evaluation process and considers both adverse and beneficial effects, which may be categorised as being neutral, minor, moderate or major.
- 6.3.3.18 In summary, therefore, effects can be beneficial or adverse and can be described as follows:
- neutral - insignificant change not having a discernable effect;
 - minor - effects that are discernable but tolerable;
 - moderate - effects that are of a local to regional nature, of medium to long-term duration and/ or where effects are anticipated to potentially be above accepted guidelines/standards. Where these changes are adverse they will usually require some impact reduction or mitigation measure where feasible; or
 - major - acute effect on a national or international scale, of long-term or permanent duration, and clearly above accepted guidelines or standards (or indeed against best practice policy, or even illegal in nature). Where these changes are adverse they will generally require extensive impact reduction or mitigation.
- 6.3.3.19 For the purposes of this assessment, effects are only considered to be significant if they are of major or moderate significance.

6.3.4 Assessment of long-term morphological change

- 6.3.4.1 The approach most commonly advocated to the prediction of long-term coastal morphological change relies on a combination of historical trend analysis (HTA) and expert geomorphological assessment (EGA) (Blott et al., 2006). The former approach frequently uses evidence from one or more of the following sources: historical maps and aerial photographs/remote sensing imagery; bathymetric charts (e.g. Admiralty); beach and bathymetric profile data; and LIDAR. The approach is based upon the assumption that future changes in the coastline will follow historical and contemporary trends. They take no account of changes in the processes driving coastal evolution such as sea level, storm and coastal developments. To account for these additional variables, it is necessary first to conceptualise and, if possible, to quantify the interactions between different geomorphological elements in a description of the coupled coastal system and then exercise expert judgment on how this conceptual model might respond to external changes in forcing and/or the anthropogenic factors.
- 6.3.4.2 Whitehouse et al., (2009) present a framework and conceptual model to predict long-term and large-scale geomorphological evolution. In their approach a conceptual model is used to describe a coupled coast and estuary system and EGA analyses are used to evaluate coastal change. Although this work has been further advanced in the iCOAST

project¹, it does not yet provide a tool for quantifying future changes in coastal geomorphology beyond that achievable by using a combination of the approaches identified above and as such it remains essentially an academic activity at the present time.

- 6.3.4.3 It is noted that EGA is an imprecise term covering assessment of top-down concepts, including background experience in the discipline of geomorphology and the use of HTA. Other geomorphological tools, knowledge and/or modelling of (mainly) physical processes are then used to establish an understanding of the underlying functioning of the system. This understanding is in turn used as the basis for predicting qualitatively, or more rarely quantitatively, the impacts of natural or anthropogenic change using the relevant geomorphological tools.
- 6.3.4.4 Building on the baseline conceptual understanding of sediment transport and morphodynamics in Swansea Bay, and evidence from numerical modelling, assessments of the potential impacts of the proposed Lagoon on sand and mud transport (and the sequent effects on coastal and subtidal morphology) are described in Section 6.5.2. Given that knowledge of the future climate forcing conditions and associated sediment responses is essentially unknown and unpredictable in anything other than broad terms, it is necessary to make the following assumptions: sediment supply from offshore locations is unchanged over time (i.e. out to 120 years); and climate change follows the medium emissions scenario set out in UKCP09 (and discussed further in Section 6.4.2).
- 6.3.4.5 Within the assessment all the likely impacts of the Lagoon that may affect baseline sediment and near-shore and coastal processes have been considered and as such some degree of control over the rate and magnitude of changes to coastal and subtidal morphology has been exerted. It is not considered possible to quantify precisely what the impacts will be. Rather, it is possible to provide a range of possible outcomes and associated probabilities.
- 6.3.4.6 In the assessment consideration is given to the potential effects over three temporal scales that relate to well-documented observations of changes to coastal and subtidal morphology at a range of locations worldwide. These are: (a) short-term changes occurring on a time scale of weeks to months up to years (e.g. morphological recovery of a beach following a severe storm); (b) medium-term changes occurring on a time scale of years to decades (e.g. the adjustment of the coastline following the artificial opening of a tidal inlet in a managed realignment scheme); and (c) long-term changes occurring on a time-scale of centuries or more.
- 6.3.4.7 In the context of the Project, short-term changes to the coastal and subtidal morphology will occur in response to changes brought about by the presence of the lagoon structures - the physical works. It is likely that these short term responses will occur on the time-scale of a few months, during which time it is considered likely (given the construction programme) that the area will also experience storms. During this time the coastal geomorphic system will experience a fairly rapid response to the re-distribution of wave and tidal energy in Swansea Bay resulting from the presence of the Lagoon. Given that identifiable cause-effect relationships between the Lagoon and morphological change can be established in the short-term, a view is offered on likely changes at spatial scales commensurate with the available data and model outputs. Section 6.5.2 offers an

¹ <http://www.icoasst.net/>

assessment of short-term changes to the coastal and subtidal morphology within Swansea Bay.

- 6.3.4.8 In the medium-term, it is anticipated that there will be a period of transition, during which the rate of change to the coastal and subtidal morphology will decrease as the sedimentary system seeks to establish a quasi-equilibrium state with the new hydrodynamic regime imposed by the Lagoon. The length of time this process will take will be governed by the magnitude and spatial extent of change attributable to the Lagoon in the wave and tidal energy distribution in Swansea Bay. In the medium-term, the new quasi-equilibrium state may fluctuate over the short-term (as it does now) in response to the prevailing short-term climatic drivers. The ability to resolve these changes at the same spatial resolution at that offered for short-term changes is restricted by the inherent non-linearity of the coastal system response. Changes are therefore considered with regard to broad regions of Swansea Bay. Section 6.5.2 offers an assessment of medium-term changes to the coastal and subtidal morphology within Swansea Bay.
- 6.3.4.9 The impacts of climate change on morphology would be expected to be evident in the long-term in response to changes in mean sea level and possibly to an increase in storminess. Changes in the coastal and subtidal morphology attributable to the Lagoon over this time-scale will be difficult to distinguish from the morphological changes resulting from as yet unknown changes in sea level and waves. By definition, long-term impacts will have regional-scale effects that probably greatly exceed those directly attributable to the Lagoon. Section 6.5.2 offers an assessment of long-term changes to the coastal and subtidal morphology within Swansea Bay.

6.3.5 Uncertainty

- 6.3.5.1 The ability of the numerical modelling used within the EIA studies conservatively to represent the effects of the Project on coastal processes, sediment transport and contamination in Swansea Bay is determined by a number of factors. Primarily, the models used must be capable of adequately describing the key physical processes across the near-field and far-field regions. The ultimate performance of the numerical models is controlled by the science underlying the model software, the expertise of model developers, the data used to develop the model and any assumptions made during the process. Additionally, for a model to be able to provide sufficiently robust results the input data must be of adequate quantity and quality to describe baseline and future conditions. Where uncertainty exists in the input data, or where assumptions have been used, then there is the potential for increased uncertainty in the model predictions of the possible effects of the Project.
- 6.3.5.2 In order to provide an assessment of uncertainty within the predicted effects from coastal processes assessment, consideration has been given to the assessment approach, the data used and any assumptions made. Uncertainty within each part of the assessment has then been estimated and described as high, moderate or low. Where possible, uncertainty is assessed based on quantitative metrics (e.g. statistical verification of model performance against measured data). Where this is not possible, a qualitative assessment is made based on parameters such as the availability and quality of data, expert knowledge and previous experience, and industry standards and best practice.
- 6.3.5.3 Where uncertainty is moderate or high, for instance due to availability of data or assumptions, and cannot be improved, additional steps have been undertaken to provide

additional confidence. These steps may include sensitivity testing, the use of conservative design information and assumptions, and the adoption of a 'realistic worst case' approach.

- 6.3.5.4 **Numerical modelling:** the Danish Hydraulic Institute's (DHI) Mike21FM software suite is an established code used internationally for both academic research and commercial consultancy. The model uses one of the most advanced numerical schemes of its type and has been extensively validated and peer reviewed over many years. The software is regularly updated by DHI and beta tested where appropriate. To effectively model the physical processes within the study area a two-dimensional horizontal (2DH) model was selected, using an unstructured finite element mesh linking far-field and near field in a single grid scheme. The Mike21FM software provides one of the best tools available for the study and is, therefore, considered to provide a low level of uncertainty and a high degree of confidence.
- 6.3.5.5 **Two-dimensional numerical scheme:** as discussed in Section 6.4, Swansea Bay is a highly dynamic and tidally well mixed marine environment. An assessment of the baseline environmental data has revealed little evidence of stratification or consistent differences in flow velocity and direction with depth that might otherwise suggest a three-dimensional (3D) model would be better suited to this assessment. As such, there is no evidence of depth dependent effects in Swansea Bay and, therefore, for the purpose of the EIA study a 2-dimensional model is considered appropriate and has a low level of associated uncertainty.
- 6.3.5.6 **Representation of lagoon structures and hydrodynamics:** the Project will alter the tidal flow patterns within Swansea Bay, due to the presence of the lagoon walls and the flow through the turbines. Wall structures can be well represented within the Mike21FM software. The software has been successfully used in many studies to represent similar walled and bunded structures, e.g. for ports, harbours, dams and flood defences. The representation of sluices, gates and other control structures is also well implemented in the software. In this case, the predicted changes in water levels and the discharges through the turbines and sluice gates were validated against the data output from a separate model of the Project turbine operation, used by the Project engineers to calculate energy generation. Due to the factors described above, it is considered that the numerical modelling software is able to model the effects of the operation of the Project on hydrodynamics, with a low level of associated uncertainty.
- 6.3.5.7 **Hydrodynamic model accuracy and resolution:** the Swansea Bay hydrodynamic model has been configured using the MIKE21-FM-HD module. This module is a 2D, depth-averaged model, which applies a flexible mesh (FM) element grid and is used to provide a description of tidal flows. The flexible mesh enables the far-field, near-field and structure scale processes to be accounted for in one model, with approximate mesh element dimensions ranging between 20m x 20m to 12,000m x 12,000m. The resolution of the mesh is high enough to accurately define the channels, structures and bathymetry of Swansea Bay. The model is based on an existing numerical model that has been previously used for other EIA studies within the Bristol Channel and the Severn Estuary. In addition to the improved resolution across the near-field and far-field regions adjacent to Swansea Bay, a revised and updated bathymetry has also been employed, based on best available data. While the bathymetry of the bay is subject to continual change the data used is considered a good representation of current conditions and fit for purpose. The detailed numerical model has been verified over a full spring-neap period, using a comprehensive hydrodynamic data set. Verification metrics meet, or exceed, guideline

values (see Appendix 6.1, Volume 3 for further information). No adjustment to model bathymetry, boundaries or calibration coefficients was required, and no significant assumptions were required in the model construction. The hydrodynamic model and input data are considered fit for purpose and the model has been shown to provide the required level of accuracy and, therefore, a low level of associated uncertainty.

- 6.3.5.8 **Wave model accuracy and resolution:** the Swansea Bay wave model has been undertaken using the MIKE21-FM-SW modelling software. This model applies a similar flexible mesh as the hydrodynamic model, and enables waves to be simulated from a variety of user specified directions, without altering the orientation of the grid. The detailed numerical wave model has been verified using a comprehensive wave data set. Verification metrics meet, or exceed, guideline values (see Appendix 6.1, Volume 3 for further information), and the wave model is considered fit for purpose. This provides a high level of confidence in the wave model and a low level of uncertainty.
- 6.3.5.9 **Supporting models accuracy and resolution:** in addition to the hydrodynamic and wave models, a series of supporting modules have been utilised to inform the coastal processes assessment. The modules are used to model the sediment plume during construction (using the Mike21FM Particle Tracking (PT) module) and to investigate the potential changes to mud and sand transport (using the Mike21FM Mud Transport (MT) and Sand Transport (ST) modules, respectively). Each of the supporting modules have been run using the outputs of the hydrodynamic (and wave in the case of MT and ST) modelling. In this way, the effects of the Project on the hydrodynamics and waves are included in the assessment of sediment transport effects. Sediment information obtained from the project benthic, geophysical and geotechnical surveys has been used to inform the sediment transport modelling. Where possible, these performance of these modules has been verified against measured data (in the case of the MT module, the known volumes of sedimentation within the Swansea and Port Talbot approach channels were used to ensure the numerical model was adequately predicting the baseline sedimentation conditions). Where verification has not been possible, the approach to assessment has used a conservative approach (for example, using sensitivity testing to investigate the effect on the model results of changes to particle fall velocity), and assessing the worst case scenario (as described below). This provides a high level of confidence in the supporting models and a low level of uncertainty.
- 6.3.5.10 **Baseline applications:** the baseline applications have been informed through the data collected (both by the project and from existing data sources) and the associated conceptual understanding of the Swansea Bay system. The conceptual understanding provides the basis of developing a hypothesis of tidal, wave and sediment transport behaviour, with the modelling subsequently used to validate the hypothesis and quantify the baseline conditions. Considering this, along with the description of the baseline model performance (provided above), the results of Baseline applications carry a low level of uncertainty. Verification or comparison with measured data provides a good fit and, therefore, it is considered that the baseline application is fit for purpose and a high level of confidence can be applied to the baseline assessment.
- 6.3.5.11 **Construction applications:** the construction applications are based on the current Project design and construction methodology, these are not expected to change significantly as the project develops. Input data is derived from the sediment particle size distribution as provided by the project benthic and geotechnical surveys at a representative number of sites and depths. Overall, a low level of uncertainty can be assigned to the model inputs. A conservative approach has been taken to representing the construction method within

the model applications, e.g. continuous discharges from dredging and filling activities using realistic worst case estimates of loads, sediment losses etc. While the modelling of construction activities entails a number of factors with varying levels of uncertainty, the use of a conservative approach is considered to provide a high level of confidence in the model predictions.

- 6.3.5.12 **Operation applications:** the operation applications are based on the current Project design and operation methodology, these are not expected to change significantly as the project develops. Input data is derived from the project description of the lagoon siting and the operating regime of both the turbines and the sluice gates. Overall, a low level of uncertainty can be assigned to the model inputs. While the modelling of operation activities entails a number of factors with varying levels of uncertainty, the use of a realistic worst case approach is considered to provide a high level of confidence in the model predictions.
- 6.3.5.13 **Assessment of medium- to long-term effects:** given that knowledge of future climate forcing conditions are unknown and unpredictable in anything other than broad terms, it is necessary to make a number of assumptions in any assessment of medium to long-term changes in the coastal and subtidal morphology. For example, this assessment of likely outcomes has assumed that sediment supply from offshore locations is unchanged over the lifetime of the Project (i.e. out to 120 years). It is also assumed that climate change effects follow the medium emissions scenario (as set out in UKCP09). Within the context of this conceptual understanding, an expert geomorphological assessment has been undertaken to describe and quantify, where information allows, the most likely impacts of the Project. The level of uncertainty within this approach is considered relatively high. As a result, the outcomes of the assessment are provided based on a range of possible outcomes and associated probabilities.
- 6.3.5.14 **Impacts assessment:** comparison of results from the Baseline and Lagoon model applications are used to determine and quantify the potential scale of changes in coastal processes, sediment transport and contamination resulting from the Project. Any uncertainties that may be present in the observational data or the models themselves, is to a large extent removed at the scenario testing stage as results will be comparable to the calibrated baseline. In this way, the net residual difference is effectively removed from the relative results of the scheme, when compared against the baseline scenario. This approach ensures that the assessment of the potential effects from the lagoon do not incorporate the net residual differences (uncertainties) from the calibration stage.
- 6.3.5.15 Overall, confidence in the coastal processes assessment for the Project is high, and the effects predicted are considered representative and robust.

6.4 Baseline conditions

- 6.4.0.1 The baseline is the reference point for determining changes to the physical environment which may be brought about by the Project. The baseline is defined here as the environmental conditions that are likely to occur over the same period as the Project lifecycle but without any development in place within the study area. Necessarily, long-term variability of the baseline over periods of up to 120 years, or more, draws on climate change related effects.
- 6.4.0.2 The completion of the following surveys provides the basis to enhance the initial conceptual understanding of the baseline:

- I. A metocean survey (Titan, 2012b) to measure currents, waves and turbidity at two locations within the bay over a period of 3 months between February and May, 2012;
- II. A geophysical survey (Titan, 2012a) to collect detailed swathe bathymetry, sidescan sonar, sub-bottom profiler and magnetometer data within the immediate vicinity of the Project;
- III. A geotechnical survey (Atkins, 2013) to investigate sediment characteristics at depth for specific locations within the Lagoon footprint where capital dredging is expected to occur; and
- IV. A subtidal benthic survey (Titan, 2013) to collect sediment samples for Particle size analysis (PSA) and sediment contamination analysis from both within the Lagoon footprint and across the bay.

6.4.1 Physical setting

6.4.1.1 Swansea Bay can be described as a shallow tidal embayment formed in the central region of the Bristol Channel through wave action and tidal inundation during the Holocene marine transgression (UU, 2003). The seaward limit of Swansea Bay is generally taken between two hard Carboniferous Limestone points; Mumbles Head in the west and Porthcawl Point in the east (Figure 6.3, Volume 2) (which is also the extent of the water body area defined in the Water Framework Directive (WFD)). Swansea Bay is also partially separated from the deeper waters along the Central Bristol Channel by the linear sandbank, Scarweather Sands. There are measureable differences in the hydrodynamic and sediment regime from the more exposed channel into the more sheltered bay; these differences demonstrate a process divide which is explored further in the following sections.

6.4.1.2 The intertidal sand and mudflats of Swansea Bay attract important overwintering and passage waders, particularly around Blackpill which is designated as a Site of Special Scientific Interest (SSSI). In addition Crymlyn Burrows SSSI adjacent to the Project is a dune system which supports a number of rare plant species. Further information regarding these designated areas is provided within Chapter 11: Coastal Birds and Chapter 12: Terrestrial Ecology.

6.4.2 Hydrodynamic regime

6.4.2.1 The general hydrodynamics of Swansea Bay is the result of the interaction between:

- i. The tidal dynamics of the Bristol Channel, which are in turn influenced by the bathymetry and coastal geology;
- ii. The wave climate;
- iii. Meteorological forcing effects, i.e. surges and wind; and
- iv. Local density current effects as a result of salinity and temperature fluctuations, more common nearer to the shoreline as a result of freshwater inputs in the bay, from discrete sources.

6.4.2.2 The following sections detail the components that combine to form the hydrodynamic regime of Swansea Bay.

Tidal dynamics

6.4.2.3 The tidal characteristics through the Bristol Channel are determined by a progressive tidal wave which increases in amplitude as the channel narrows into the Severn Estuary. As this progressive wave moves past the shallow side-embayment of Swansea Bay the tidal behaviour changes into a standing wave, exhibited by near coincident times of high water at both Swansea and Port Talbot.

6.4.2.4 Swansea Bay experiences a hyper-tidal range (i.e. greater than 6 m), with a mean spring tidal range of between 8.46m (Mumbles Head) and 8.60m (Port Talbot). In contrast, the mean neap tidal range within the bay is around 4m, still considerably greater than spring tidal ranges experienced in most locations elsewhere in the UK. Table 6.9 summarises key tidal levels across Swansea Bay for locations at Mumbles Head, Swansea and Port Talbot. Values are expressed in metres relative to Ordnance Datum Newlyn (mODN).

Table 6.9 Key tidal levels for Swansea Bay (from 2013 Admiralty Tide Tables)

Tidal Level		Mumbles Head (mODN)	Swansea (mODN)	Port Talbot (mODN)
Highest Astronomical Tide	HAT	5.51	5.50	5.60
Mean High Water Springs	MHWS	4.54	4.50	4.50
Mean High Water Neaps	MHWN	2.28	2.20	2.10
Mean Sea Level	MSL	0.22	0.20	0.21
Mean Low Water Neaps	MLWN	-1.75	-1.90	-1.70
Mean Low Water Springs	MLWS	-3.92	-4.00	-4.10
Lowest Astronomical Tide	LAT	-4.86	-5.00	-5.20
Mean Spring Range	MSR	8.46	8.50	8.60
Mean Neap Range	MNR	4.03	4.10	3.80

6.4.2.5 The variability of tidal currents across Swansea Bay demonstrates four main areas:

- Offshore, approximately beyond the 10 m below CD (-15 mODN) contour (see Figure 6.3 for location, Volume 2), dominated by rectilinear flows;
- Inshore west, from Mumbles Head to Swansea Docks, dominated by the Mumbles headland;
- Inshore middle, between Swansea Docks and Port Talbot – relatively calm area with flows moving in and out of the bay; and
- Inshore east, south from Port Talbot – shore aligned flows moving towards and from Porthcawl Point.

6.4.2.6 Figure 6.4 (Volume 2) illustrates the typical magnitude and orientation of ebb and flood tides for representative mean spring and neap tides. The strongest currents are in the offshore area. Here flows are typically rectilinear and are aligned to the axis of the Central Bristol Channel. Peak ebb currents tend to be greater than peak flood, indicating some asymmetry in the tide.

6.4.2.7 Tidal flows across the inshore area from Mumbles Head to Swansea Docks are typically weaker and exhibit a rotary pattern formed by the headland. Locally, flows past Mumbles Head are stronger, diverging across the bay on the flood tide and converging back into the channel on the ebb. The residual pattern in the tide is an anti-clockwise circulation in the lee of the headland.

- 6.4.2.8 For the inshore area between Swansea Docks and Port Talbot, which includes the River Neath, tidal flows are again generally weak and can be prone to wind driven effects. This area is also coincident with the major part of the Project and was the area recently targeted by the metocean survey. Figure 6.3 (Volume 2) shows the locations of Site 1 and 2 metocean deployments with each deployment capturing around three months of data from February to May 2012. Figure 6.5 (Volume 2) summarises data from these sites as a set of current roses, divided between periods of spring and neap tides.
- 6.4.2.9 Site 1 was located towards the shallow intertidal in a depth of around 1.4 m above CD (-3.6 mODN); i.e. within the breaker zone. The equipment was subject to periods of drying during low waters on spring tides and recorded generally low current speeds with a maximum rate of 0.42 m/s for the entire deployment period. Generally, the faster flows were shown to occur on the ebbing tide which had a typically variable direction to the west and south-west. This variability may be an indicator to local wind and wave influences in the shallow water.
- 6.4.2.10 In comparison, Site 2 is more central to the bay and in a depth of around 5 m below CD (-10 mODN). Flows here are slightly faster, reaching a maximum of 0.52 m/s. The orientation of these flows is also definite with a north-east (flood) to south-west (ebb) axis. The fastest flows occur on the ebb tide.
- 6.4.2.11 Numerical modelling undertaken by ABP R&C (1996a) to compare the effects of calm and storm conditions on tidal currents within the bay identified that during storm conditions (9.75 m spring tide, 15 m/s south easterly wind, 2 m wave height), tidal flow directions can be changed by up to 45° and flow speeds can be increased by up to around 0.1 m/s for parts of bay.
- 6.4.2.12 For the area identified as inshore east, there is a further flow divergence centred on Port Talbot. Flood flows from around Port Talbot are generally to the north-east whilst flows south of Port Talbot diverge towards the south-east to become aligned to the coast and towards Sker Point. On the ebb tide, tidal flows to the south of Port Talbot are reversed to a north-westerly direction.

Extreme water levels

- 6.4.2.13 At any instance in time, the water level along the Bristol Channel and within Swansea Bay is the summation of an astronomical tidal level and a non-tidal (surge) component. Surges are generally formed by strong winds and rapid changes in atmospheric pressure with an inverse relationship, with low atmospheric pressure raising the water surface (positive surge) and high atmospheric pressure depressing the water surface (negative surge). The surge component is generally much smaller in the summer than the winter. During winter periods deep atmospheric depressions and strong winds can have a significant effect on tidal levels. The phasing between tidal and non-tidal contribution to the water level is important, as a positive surge in conjunction with a high tidal level will result in an unusually high water level.
- 6.4.2.14 Estimated extreme water levels are published for sites around England and Wales by the Environment Agency Coastal Flood Boundary Conditions Study (EA, 2011). Data for Mumbles Head, Swansea Docks and Port Talbot is summarised in Table 6.10 for a range of return periods. These values have been derived for locations approximately 1 to 2 km from the shoreline (i.e. at the approximate outer limits of the lagoon) and values at the coast and those derived by other methods may differ slightly from these estimates. The table also includes local HAT at each coastal site for comparison purposes.

Table 6.10 Summary of extreme water levels with Swansea Bay

Return Period (year)	Mumbles Head (mODN)	Swansea Docks (mODN)	Port Talbot (mODN)
HAT	5.51	5.50	5.60
1	5.45	5.47	5.50
2	5.53	5.54	5.57
5	5.64	5.65	5.67
10	5.73	5.74	5.76
20	5.81	5.83	5.85
50	5.94	5.94	5.97
100	6.03	6.05	6.08
200	6.13	6.15	6.19
500	6.26	6.28	6.34
1000	6.37	6.39	6.47

Note: values relate to 2008 as a base year.

(Source: EA, 2011)

- 6.4.2.15 Analysis of water levels at the Mumbles Class A tide gauge located in Swansea Bay identified that the greatest positive surge event observed at this location for a 20 year period (between 1998 and 2008), was approximately 1.81 m on the 4th January 1998, whilst the greatest negative surge was around -0.90 m on the 13th February 2005 (NTSLF, 2013). The highest measured water level at the Mumbles gauge over this time period (i.e. the extreme water level) was 5.63 mODN, recorded on the 8th October 2006, which relates to a relative small positive surge of approximately 0.22 m on a very large spring tide; equivalent to 0.12 m greater than HAT.
- 6.4.2.16 ABPmer (ABPmer, 2005) undertook a detailed analysis of surge heights at the Mumbles tide gauge for a 15-year period from 1990 to 2004. The key result from this analysis was that extreme surge events do not tend to result in extreme water levels, with peak surges typically occurring a number of hours before or after HW. Had the 1.81 m positive surge actually coincided with a period of high astronomical tides (rather than around 3.5 hrs after HW), it would have resulted in a considerably greater extreme water level.
- 6.4.2.17 Should a positive surge occur during the flood tide, this may lead to an increased rate of tidal rise and a potential enhancement of flow speeds along the Bristol Channel and within Swansea Bay. Similarly, a negative surge event during an ebb tide may lead to an increased rate of tidal fall, once again resulting in a potential enhancement of flow speeds. Where these respective surge events occur at corresponding times of peak flow speeds, particularly during larger spring tides (when tidal flows are already relatively high), there is an increased potential for seabed scour and shoreline erosion.

Waves

- 6.4.2.18 There are obvious contrasts in the wave conditions between the Central Bristol Channel and within Swansea Bay associated with relative exposure, local sheltering and different water depths, but each wave environment remains dominated by the influence of long westerly fetches into the Atlantic and prevailing strong westerly winds. At each location the local wave environment is the product of longer period Atlantic swell seas and locally generated wind-seas. However, the two wave components generally align and form a unimodal sea-state.
- 6.4.2.19 Offshore, the best available wave information is provided by wave monitoring from WaveNet at a site seaward of Scarweather Sands (Cefas, 2013). Existing data spans an eight year period between 2005 to 2013 (ongoing) and represents a medium-term

record. Figure 6.6 (Volume 2) summarises the available data as a wave rose that clearly illustrates the influence of the long fetch and strongest winds from the west to south-west, which is the predominant wave direction. Of all waves recorded, approximately 49% are less than 1.0 m in height, with 85% of waves being less than 2.0 m. Typical wave periods are between 7 and 9 seconds; although long period swell waves with periods of up to 20 seconds have also been recorded. The largest storm event within the record had a wave height of 6.03 m. Figure 6.6 (Volume 2) also presents a wind rose for a location representing the approaches to Swansea Bay and is based on 19 years of hindcast data (ABPmer, 2013d). This information demonstrates the strongest and most frequent winds are from the west to south-west sectors.

- 6.4.2.20 The inshore wave climate within Swansea Bay is locally influenced by coastal sheltering, especially from Mumbles Head, as well as wave shoaling and refraction effects as waves move into the shallower water and begin to dissipate more energy onto the seabed. The headland sheltering effects tend to protect the western part of the bay from exposure to longer period swell seas, whereas around the eastern side of the bay (i.e. to the east of the River Neath), the westerly facing beaches remain exposed to the long period swells and are popular locations for surfers for this reason.
- 6.4.2.21 A specific metocean survey was undertaken to develop further evidence of wave behaviour across the inshore part of the bay. The same deployments (Site 1 and 2) which obtained water level and flow information also recorded wave information for the period February to May 2012 (Titan, 2012b). In contrast to WaveNet, the recent survey only represents a short-term period and must also be considered as seasonally biased. The available data is summarised as a set of wave roses (Figure 6.7, Volume 2) and includes the same sample of events from WaveNet to enable comparison between offshore and inshore waves. The two sets of inshore wave roses (Site 1 and Site 2) show a great deal of similarity to each other, noting that Site 1 was a much shallower location within the intertidal. In contrast to the offshore wave conditions, waves recorded at the metocean sites show clear evidence of sheltering from Mumbles Head to long period westerly waves, with the predominant wave direction orientated further to the south than seen at the Scarweather Buoy, with much reduced wave heights in the shallower water (as also shown in Figures 6.10 and 6.11 (Volume 2), which show a timeseries of significant wave height, measured during the metocean survey campaign).
- 6.4.2.22 It should be noted, however, that this data is to be used with care since the wind conditions at Mumbles Head during the period of measurement did not conform to the longer-term average conditions. This period was one of relatively low wind speeds with a lower incidence of winds from the westerly to south-westerly directions. The strongest winds during this period occurred in April 2012 from a north-easterly direction, i.e. against the predominant wave direction. As such, the metocean campaign did not capture any severe south-westerly wind and wave events. It is noted, however, that the longer-term measured dataset from Scarweather, and the modelled hindcast dataset (ABPmer, 2013d) both describe the dominant wave environment with largest waves approaching from the west to south-westerly directions.
- 6.4.2.23 The data (Figures 6.10 and 6.11, Volume 2) does however show, as might be expected, wave heights at Site 1 are typically lower than those at Site 2 (likely as a result of the more sheltered, shallower nature of Site 1, compared to Site 2). During the survey period the largest wave event at Site 1 had a significant wave height (H_s) of 1.7 m, an average zero crossing period (T_z) of 4.8s and a mean wave direction from 208°N. At Site

2, further offshore and in deeper water, the equivalent event resulted in a significant wave height of 1.87 m, Tz of 4.5s and a direction of 191°N.

- 6.4.2.24 The pattern of wave activity described here has a direct influence on wave-driven sediment transport processes. Waves in the Central Bristol Channel generally propagate in an east to north east direction and move through relatively deep water which limits their influence on the local seabed; here strong tidal currents dominate the sediment transport process. In contrast, as waves move into the shallow areas of Swansea Bay they interact more strongly with the seabed and dissipate more energy as they shoal and refract onto the shoreline. Currents in the bay are generally weaker than in the Central Bristol Channel and the wave driven sediment transport process is likely to become dominant, especially at times of storm events. The most likely wave driven sediment transport pathway is towards the westerly facing beaches such as Aberafan Sands, Margam Sands and Kenfig Sands, all of which have experienced substantial periods of dune formation in the past.

Fluvial inputs

- 6.4.2.25 Swansea Bay receives freshwater inputs from the following key rivers; Rivers Tawe, Neath, Afan, Kenfig, Ogmere and Clyne, as well as direct atmospheric sources and catchment runoff. The volume of freshwater entering the bay is also further increased by a number of effluent discharges. Table 6.11 shows the range and average discharge entering Swansea Bay from the three main rivers. Freshwater discharges from these sources into Swansea Bay may give rise to local reductions in salinity.

Table 6.11 Key river discharges into Swansea Bay

River Flow (m ³ /s)	River Tawe (at Ynystanglws)	River Neath (at Resolven)	River Afan (at Marcroft Weir)
	1957 - 2012	1962 - 2012	1978 - 2011
Q10	29.90	22.98	11.77
Mean	12.33	9.31	5.14
Q95	1.53	0.73	0.88
River Catchment Size (km ²)			
Area	227.7	190.9	87.8
Note: Q10 and Q95 relate to 10% and 95% exceedance			

(Source: CHE, 2013)

Temperature and salinity

- 6.4.2.26 The mean sea temperature in Swansea Bay varies from around 8°C during winter to 13°C during summer (UKDMAP, 1998), with temperatures nearer the bed being about 0.5°C cooler than at the surface.
- 6.4.2.27 Salinity measurements taken at a number of locations within Swansea Bay are summarised for the period 1995 to 2000 (ABP Research, 2000) in Table 6.12. Generally, salinity levels within the bay are consistent with marine conditions modified by freshwater inputs, which may give rise to occasional low density currents in the order of 0.01 to 0.02 m/s (Heathershaw and Hammond, 1979). This being said, whilst discharges from the rivers can lead to local reductions in salinity, they are unlikely to be sufficient to develop any permanent stratification. This is further evidenced by the results of a series of CTD profiles, collected during the benthic survey (as provided in Titan (2013), Appendix E). The results of this survey showed little or no variation in either temperature or salinity with depth, again providing evidence of the well-mixed nature of

the Bay. Furthermore, tidal residuals in the bay are more likely influenced by meteorological forcing, particularly during periods of storm surge activity, than density driven effects (ABP R&C, 1995).

- 6.4.2.28 Within the ES, the consideration of potential changes to temperature and salinity, as a result of the Project, are considered further in Chapter 7 (Marine Water Quality). Any findings of this assessment that potentially influence coastal processes have been considered in the relevant sections of this Chapter.

Table 6.12 Average, Maximum and Minimum Salinity (ppt) in Swansea Bay (Sep 1995 to May 2000)

Sampling Point	Average	Max Value	Min Value
Aberafan Beach at Slip	31.22	32.72	27.44
BSC Newsea Outfall: 100m Downtide	31.95	33.82	29.89
Afan Outfall: 100m Downtide	31.89	33.66	29.80
Swansea Bay downstream of Margam Outfall	32.98	32.98	32.98
BSC Newsea Outfall	1.56	3.38	0.80

(Source: ABP Research, 2000)

Climate change

- 6.4.2.29 The Project is capable of having a lifetime of over 120 years from construction, which is a timescale requiring consideration of influences that might be expected to occur as a result of climate change. Key climate change factors are taken here as changes that might occur to the baseline are related to mean sea level, river discharges, winds and waves. The primary source of climate change information is the UK Climate Change Impacts Programme (UKCIP) and the most recent predictions are from UKCP09 (Lowe et al, 2009). Climate change predictions are not exact but are based on a range of high, medium and low greenhouse gas emission scenarios using ensemble modelling techniques to help bound the level of uncertainty involved. A medium emissions scenario is considered here as the representative description for climate change and information is quoted in relation to the 50%ile and 95%ile likelihood of non-exceedance.

Sea level rise

- 6.4.2.30 The Swansea Bay region has experienced a number of historical changes in relative sea-levels. Appendix 20.2 of Chapter 20 (Cultural Heritage: Marine Archaeology) provides a description of the likely differences in sea-level over approximately the last 780,000 years. More recently, the general trend for the south west of the UK (as given at Newlyn, Cornwall between 1916 and 1996) is of an increase in relative mean sea-level at an average rate of 1.68 ± 0.12 mm per year (Woodworth, et al., 1999). A further analysis of the tide gauge data from Mumbles (PSMSL, 2014) over a shorter period (between 1990 and 2010) reveals a rate of 1.13 mm per year.
- 6.4.2.31 Future changes in relative sea level (RSL) are quoted as the net effect of geological adjustments in land levels and the projected absolute changes in mean sea level. Table 6.13 presents a summary of UKCP09 projections up to 2100 for the medium emissions scenario and for 50%ile and 95%ile likelihoods.

Table 6.13 Summary statistics of 21st Century relative sea-level rise within Swansea Bay

Year	RSL Rise Based On Medium Emissions 50%ile Scenario (m)	RSL Rise Based On Medium Emissions 95%ile Scenario (m)
2008	0.00	0.00
2020	0.04	0.06
2050	0.16	0.25
2100	0.42	0.64

(Source: Lowe *et al*, 2009)

- 6.4.2.32 A general increase in relative sea level may result in a number of effects, such as, displacing the high water mark towards the coast, enabling wave energy to move further towards the coast (exposing the shoreline to greater periods of wave and tidal energy) and increasing potential flood risk. The magnitude of this impact would vary depending upon the rate of predicted sea level rise and the timing relative to the 18.6 year Lunar Nodal Cycle variations, which may have a larger amplitude in the shorter term.

Rivers

- 6.4.2.33 River discharges and any change in land use across catchments in the future will be influenced primarily by changes in precipitation and winter snow melt (ABPmer, 2010b). Guidance issued by UKCP09 indicates that between 2009 and 2020, summer precipitation will decrease by around 5%, whilst winter precipitation will increase by approximately 10% (Lowe *et al*, 2009). No figures are provided for changes in peak river flow by UKCP09 guidance, however, previous Defra guidance (Defra, 2006) suggests that this will increase by 10% between 1990 and 2025. Whilst the Defra guidance is not based on an equivalent UKCP09 emissions scenario, the outcomes are generally seen as conservative (i.e. more associated with a high emissions scenario). Beyond 2020, the UKCP09 guidance states that peak summer and winter precipitation will vary as shown in Table 6.14. During this period, Defra guidance suggests that peak river flows will increase by 20% relative to 1990 levels.

Table 6.14 Future peak summer and winter precipitation changes

Epoch	Winter	Summer
2020 - 2050	+20%	-10%
2050 - 2080	+25%	-20%
2080 - 2140	+30%	-25%

Note: All values are relative to 2009 and that the values from 2080 to 2140 have been extrapolated.

(Source: Lowe *et al*, 2009)

- 6.4.2.34 As a consequence of the predicted changes in precipitation and river flow, there are likely to be sustained periods of higher river flow in winter and lower river flow in summer. Whilst this is not likely to have a major effect on the salinity regime within Swansea Bay as a whole, localised changes close to the river mouths may occur, particularly in the vicinity of the Neath and Swansea navigation channels.

Wind and wave climate

- 6.4.2.35 UKCP09 includes projections of the likely future wind and wave climate. Over the 21st Century, climate changes may influence the frequency and magnitude of storms as well as their direction. Along the Bristol Channel, and within Swansea Bay, mean winter and summer significant wave heights are projected to increase by up to approximately 0.3m

by 2100. This increase is relatively insignificant when compared with the interannual variability in present day (baseline) wave conditions where locally the biggest measured wave is over 6m. The projections also identify that local wind speeds are likely to reduce by 0 to 0.1 m/s. However, as the wave climate in Swansea Bay is dominated by the longer period westerly waves, this small predicted reduction in wind speed will likely have little impact on the local wave regime generated within the bay.

6.4.3 Sediment regime

6.4.3.1 The following sections detail the components of the physical environment that combine to define the sediment regime of Swansea Bay. These components include the material which is generally found on the seabed or in the water column, the location of contemporary sources of mobile sediment as well as the locations which generally receive sediment either temporarily (stores with a finite capacity) or more permanently (sinks). The sediment regime also includes the process linkages for each component (i.e. the hydrodynamic and wave processes) that can act as mechanisms for transport and provide the pathways for moving sediments.

Seabed sediments

6.4.3.2 The description of seabed sediments relate to the surface materials which may originate as geological exposures, lag deposits, relict deposits or contemporary deposits, and they may comprise either fine or coarse material. The coarser sediments are likely to be mobile less frequently than the finer material and tend to be subject to bedload transport rather than suspended transport. However, high energy conditions, such as periods of large tides and storms, may still be sufficient to suspend coarser sediment if only for short periods of time.

6.4.3.3 The distribution of seabed sediments varies considerably along the Bristol Channel. Across the Central Bristol Channel, seabed sediments are mainly coarse grained deposits of sands and gravels whilst further to the east much of the Inner Bristol Channel sea floor is swept bare of significant sediment accumulations by strong tidal currents (Defra 2006), and is an area generally described as a bedload parting zone, driven by opposing tidal asymmetry.

6.4.3.4 In contrast, the seabed sediments within Swansea Bay are generally much finer with westerly facing beaches characteristically wide and sandy and backed by extensive dunes. The British Geological Survey (BGS) seabed sediment and quaternary geology map (BGS, 1986) broadly identifies (at a 1:250,000 scale) the larger part of the bay to contain areas of muddy sand and sandy mud, although in the west of the bay these are described as gravelly sand (sediment classification after Folk, 1954). This BGS map data provides a high-level limited overview of the seabed sediment found across Swansea Bay.

6.4.3.5 In order to supplement this broad-scale data, a comprehensive sediment sampling campaign was undertaken as part of the subtidal benthic characterisation survey (Titan, 2013) for the Swansea Tidal Lagoon development. This survey included sampling and particle size analysis (PSA) of 59 sediment samples from across Swansea Bay, 27 of which were taken from within the proposed footprint of the Lagoon. Figure 6.8 (Volume 2) illustrates the sediment types observed according to the Folk sediment classification, whilst the spatial distribution of sediment fraction percentages (for gravel, sand and mud) is provided in Figure 6.9 (Volume 2) for PSA sample location inside and adjacent to the lagoon footprint. This survey data is further complimented by a recent geophysical

investigation (Titan, 2012a), which covers the proposed footprint of the Lagoon, situated between the Swansea Channel and the River Neath, and provides a local description of high-resolution bathymetry and interpretation of shallow sediments (Figure 6.8, Volume 2). The results of the PSA analysis are provided in Appendix 6.3, Volume 3, and are summarised below.

- 6.4.3.6 Evidence from the geophysical survey and the PSA analysis of surface samples identify that the seabed within the proposed footprint of the Lagoon is divisible into two distinct zones (east and west), separated by an irregular central strip, which represents an outcrop of hard sediments (interpreted as boulder clay). In the western part of the Lagoon footprint, the seabed sediments predominantly comprise sandy gravel and gravelly sand, often with a thin sand veneer. The geophysical survey further indicates that the gravel is particularly coarse at the shoreline to the east of the Swansea Dock entrance breakwaters. A preliminary geotechnical investigation for the Swansea Tidal Lagoon development (Atkins, 2013), which included a number of exploratory boreholes, vibrocores and cone penetration tests, indicates that the seabed sediments found across the western side of the lagoon footprint range in depth from around 0.25 to 0.8 m. Beneath these sediments are numerous layers of (medium) sandy sediments, with varying proportions of silt/ clay and gravel.
- 6.4.3.7 The eastern half of the Lagoon footprint predominantly consists of sands (smooth and featureless) and slightly gravelly sands. An increase in sediment reflectivity in a southerly direction along the eastern half of the geophysical survey area indicates an increase in gravel content or a reduction in thickness of the sandy veneer. The geophysical survey also suggests that these sediments are typically no greater than 0.5m in thickness; although thicker accumulations do occur, i.e. within the sand deposited against the River Neath training walls. The superficial sediments are then underlain by fine grained sediments (silty fine sands), which typically increase in coarseness to the south and west. The depth from the seabed to the base of this silty sand layer varies from a maximum of 21m immediately south of the shore at Crymlyn Burrows, to 0m against the flanks of the central boulder clay ridge; although the depths are typically more than 4m across the majority of the survey area. This layer then rests on an erosion surface cut into underlying materials interpreted as boulder clay (Titan, 2012a).
- 6.4.3.8 Within the western side of Swansea Bay, the PSA from the subtidal benthic survey identifies that seabed sediments predominantly consist of sand, with slightly gravelly sand found more in an offshore and easterly direction (i.e. towards the Mumbles and the Swansea Approach Channel). At the edge of the subtidal zone, a single sample comprising muddy sand was identified, which is likely to be more representative of the adjacent intertidal area. Along the Swansea Channel, the seabed sediments typically coarsen in a southerly (offshore) direction from muds within the upper half of the channel, to fine muddy sands (with low amplitude sand waves), and then medium to coarse sand and gravel (with elongated patches of exposed boulder clay caused by dredging activity) at the end of the channel and in the immediate approaches. The surficial muds found within the upper half of the approach channel are typically 0.5 to 1.0 m in thickness, underlain by fine muddy sands and sandy muds (Fugro, 1995a). This material conforms to that which requires to be dredged to maintain the navigation depths within the channel, and indicates a contemporary deposit.
- 6.4.3.9 Within the River Neath approach channel, sediment samples analysed as part of the Port Talbot Channel Deepening Mitigation Studies (ABP R&C, 1996b) identified that the surficial seabed sediments are predominantly medium sand, with slightly coarser

material (which included up to 20% gravel) found within the inner half of the channel. Samples taken adjacent to the channel consisted of finer sand.

- 6.4.3.10 Between the River Neath and Port Talbot in the eastern side of Swansea Bay, fine and medium sands are found across Aberafan Sands (ABP R&C, 1996a). This is confirmed by the PSA analysis of the surface samples taken during the subtidal benthic survey (Titan, 2013), which also identifies that the shallow subtidal region is largely characterised by sand and slightly gravelly sand (Figure 6.8, Volume 2). The period between the two datasets tends to confirm that the material type remains consistent over time.
- 6.4.3.11 A geophysical and geotechnical survey of the Port Talbot approach channel (Fugro, 1995b) identified that a surficial layer of mud and muddy sand is present along the channel (with occasional pockets of clay). Within the channel this surficial layer varies in thickness from approximately 1.5 m thick at the seaward end of the channel to less than 0.5m below the seabed at approximately 1.5 km from the harbour entrance. This surficial layer is then underlain by medium sands, the base of which is found at 2 to 5 m below the seabed surface. It should be highlighted that this survey was undertaken prior to a capital deepening of 2.6 m along the approach channel which occurred in 1996, and therefore the base of the maintained channel is expected to be medium sands. It should be emphasised that the channel is still subject to sedimentation, in which material ranging from medium silt to medium sand is dredged from the channel; a greater proportion of sand is supplied to the channel during storm events. Outside of the approach channel (along its length), the subtidal benthic survey suggests that seabed sediments predominantly consist of slightly gravelly sands (Figure 6.8, Volume 2). To the south of Port Talbot, on the eastern foreshore of the bay, the seabed sediments across Margam and Kenfig Sands comprise a thin veneer of sand, which overlies hard deposits of peat and clay (Blackley, 1978).
- 6.4.3.12 Within the offshore central region of Swansea Bay, around the 10 m below CD bathymetric contour (shown in Figure 6.3, Volume 2), the seabed sediments are coarser than those typically found within the Bay, comprising predominantly sandy gravels and gravels (Figure 6.8, Volume 2). PSA of the samples show an array of mean grain diameters, which range from medium sands (~0.5 mm) to medium pebbles (~8.5 mm). Further offshore, the sediments on Scarweather Sands primarily comprise fine sands, typically ranging from 0.16 to 0.22 mm in diameter (Titan, 2013). In contrast, these sediments are finer than at Nash Bank, where grain sizes are typically 0.31 to 0.47 mm in diameter. Contours representing mean grain size and sorting on the bank tend to follow the bathymetric contours, with the well-sorted, finer-grained material present along the crestline. A longitudinal gradient is also evident across the bank, with finer-grained and better-sorted sediments on the western part of the bank (UU, 2003).

Suspended sediment concentrations

- 6.4.3.13 Along with sediments that are found on the seabed there are also sediments that are carried in suspension, either permanently or for short periods. Suspended sediments tend to be finer and can be carried over long distances by the tide and take a long time to fall out of suspension when conditions allow. They also have an exchange with the seabed through periods of deposition during calm events or erosion in response to higher energy events. Sources of suspended sediment may be local, or more remote from a specific area, and will also include contributions from rivers. Whilst reference is made here to suspended sediment concentrations (SSC) this term is interchangeable with the term suspended particulate matter (SPM) and the generic term turbidity, when

the measurements have been converted to mg/l by calibration against water/ sediment samples.

- 6.4.3.14 SSC are generally not uniform throughout the water depth, being typically lowest at the sea surface and increase with proximity towards the seabed, especially at times of sediment exchange with the seabed.
- 6.4.3.15 As part of the recent metocean survey (Titan, 2012b) two Optical Backscatter (OBS) devices were deployed at Site 1 and 2 for a three month period (February to May 2012), in order to be coincident with the collection of wave and tidal data. The OBS devices provide a single point measurement at an equivalent near-bed depth of less than 0.5 m above the seabed (mounting height on the deployment frame). The observations represent the amount of light attenuation at this point in the water column and are recorded in standard units of FTU (Formazin Turbidity Units). The conversion of FTU into equivalent sediment concentrations of mg/l was achieved from calibration to a limited set of water samples (eight at each location taken at times of deployment and recovery) (Titan, 2012b). The level of confidence in this conversion depends on the number of water samples as well as the range of conditions and concentrations they represent. The overall pattern of variance in concentration should still remain consistent with process variations (e.g. by tide and wave) even though the absolute accuracy of the conversion to SSC may be limited.
- 6.4.3.16 The variability in turbidity recorded at the metocean sites is presented in Figures 6.10 and 6.11 (Volume 2) for a one month period during the second deployment, and is illustrated alongside measured variations in water levels, depth averaged current speeds and significant wave heights. This period of time was chosen as it illustrates a reasonable variation in both astronomical (water levels) and meteorological (wave) conditions.
- 6.4.3.17 At Site 1, it can be clearly seen that turbidity values are considerably greater during spring tides than neaps. This increase is driven principally by the slightly higher flow speeds experienced over the spring tides, which would appear to be sufficient to remobilise fine sediments (mud) from the seabed. Increased wave activity over spring tides would appear to have little to no effect on peak turbidity measurements, however, greater turbulence (at the bed) associated with larger waves do result in turbidity increases around LW when depths across the intertidal are shallow (i.e. typically less than 2m). (It should be noted that due to the location of the site, the site regularly dries out over LW on spring tides.) In contrast, it can be seen that waves play a more dominant role on turbidity over neap tides, with spikes in turbidity being observed during periods of greater wave activity, such as on the 30th April 2012, when waves greater than 0.6m were recorded at the site (Figure 6.10, Volume 2).
- 6.4.3.18 In comparison, turbidity is typically greatest at Site 2 during peak current speeds, approximately 2 hours either side of LW over spring tides. Figure 6.11 (Volume 2) also identifies some clear differences in measured turbidity between two separate spring tidal cycles over the one month period, with considerably greater values between the 17th and 26th April 2012. These differences would appear to correspond with a prolonged period of larger wave conditions (with wave heights greater than 0.5 m) around the time of peak flows, thus increasing disturbance at the bed. The measurements also indicate that over this period, larger waves (recorded at 0.8 to 1.2 m) seem to have little effect on turbidity during neap tides. This is a result of the increased LW levels, compared with that of spring tides, thus allowing the waves to propagate closer inshore before any substantial interaction with the seabed takes place.

- 6.4.3.19 Based on the converted values, the mean near-bed SSC values were moderate to high at both sites, with a mean of 113 mg/l at Site 1 and 54 mg/l at Site 2. The generally higher concentrations at Site 1 are likely to be a function of the shallower environment within the surf zone, which tends to retain concentrations above 50mg/l. In comparison, concentrations at Site 2 tend to indicate lower concentrations during calmer periods, suggesting that some material may locally drop out of suspension.
- 6.4.3.20 Complementary descriptions of near-surface suspended sediment have been derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite database to provide a series of synoptic monthly/seasonal turbidity maps for UK surface waters (Dolphin et al, 2011). The satellite derived maps provide a useful overview of spatial and temporal patterns in suspended sediment concentrations at the regional scale, however, sources of uncertainty exist in the relationship between satellite-derived reflectance and in-situ SSC or turbidity data. The MODIS observations suggest that near-surface SSCs in Swansea Bay are in the order to 2 to 8mg/l in summer months, and 8 to 20 mg/l in winter months (see Figures 6.12 and 6.13, Volume 2). These values are comparable to the measured turbidity of the water samples collected during the metocean survey campaign (Titan, 2012b), which provided average surface SSCs of 14 mg/l and 9 mg/l at sites 1 and 2, respectively (with samples collected on two separate neap tides during February and May 2012). In contrast, summer and winter near-surface concentrations vary significantly along the Central Bristol Channel and into the Severn Estuary, increasing in an easterly direction towards the Severn; with the MODIS observations suggesting peak near-surface SSC values in the range of 40 to 48 mg/l and 70 to 78 mg/l in summer and winter months, respectively, in the approximate vicinity of Cardiff.

Sediment sources, stores and sinks

- 6.4.3.21 The sources and sinks for fine and coarse sediment which influence Swansea Bay are largely separate. The primary source of coarse sediment (sand and gravel) into Swansea Bay is from the Central Bristol Channel, largely through reworking of quaternary sediments in the offshore zone, whilst coastal cliff erosion may also provide some further contribution (Halcrow, 2012b). However, the expanses of the Bristol Channel that no longer have any permanent sediment cover (predominantly the Inner Bristol Channel, but also parts of the Central Bristol Channel) would suggest this source is now limited.
- 6.4.3.22 In contrast, the primary source of fine sediment (muds and silts) into the Bristol Channel and Severn Estuary is from the main river systems (principally the River Severn). Data compiled for the recent Severn Tidal Power SEA (PINS, 2012a) suggests that the River Severn may supply approximately 273,000 tonnes of sediment per year to the Bristol Channel, approximately 41% of the total input from the major river sources; although this value may range from 137,000 to 410,000 tonnes per year to take account of inter-annual variation.
- 6.4.3.23 Limited fine sediment is sourced from within the Bay itself, with Stoner (Stoner, 1977) reporting that approximately 260 tonnes/day (95,000 tonnes/year) of suspended sediment is discharged into the bay by the four main rivers; Tawe, Neath, Afan and Kenfig. Since this publication the Tawe barrage has been built in 1992, which is likely to have reduced the sediment input from this source. This volume of river sediment is a relatively small source, considering that Port Talbot requires annual maintenance dredging (for the period 2007 to 2012) of around 1.5 million wet tonnes on average, whilst Swansea requires on average a further 250,000 wet tonnes of dredging per annum (2010 to 2012). These larger volumes of sediment are considered to have been advected into the bay from remote sources such as the Inner Bristol Channel and Severn Estuary,

especially at times of spring tides, and strong south westerly winds. These dredgings are disposed of at the Swansea (Outer) spoil ground (see Figure 6.3 for location, Volume 2), which on average has received *circa* 2.6 million wet tonnes per annum between 1986 and 2010. This material therefore remains in the wider system for further mobilisation. Collins (Collins, 1983) estimated that the quantity of sediment in suspension at any time in the Bristol Channel is equivalent to 3 or 4 years of the annual river sediment supply. It should also be noted that following large storm events, sandy material is also dredged from the Port Talbot channel and disposed at the Swansea (Outer) spoil ground.

- 6.4.3.24 Muds and silts are largely transitory within Swansea Bay, in which sedimentation will occur across the shallower intertidal and subtidal areas during slack periods (i.e. at HW and LW), before being resuspended into the water column and further transported by the ambient tidal flow conditions. However, some of this sediment will remain on the seabed in low energy environments for a prolonged period of time and will become mixed with sand, thus giving rise to mixed sediments of muddy sand and sandy mud sediments found across areas of the bay (particularly along the western side, as identified through the Phase 1 habitat survey – see Chapter 8: Section 8.4). These types of deposits are typical of low tidal energy environments where the tidal currents are too weak to sort the sediments. Locally, sediment sinks for mud are mainly represented on the Crymlyn Burrow SSSI where there are small areas of intertidal mudflats, and the navigation channels to Port Talbot Harbour and Swansea Docks.
- 6.4.3.25 Major local stores for sand include the linear sandbank of Scarweather Sands and westerly facing beaches, both features have a capacity to store a large volume of sand with the excess likely to be moved through the sediment regime at times of peak energy, such as during storms. The Margam and Kenfig Burrows dune systems, which back these beaches (Margam and Kenfig Sands) are effectively sinks for sand, taking sand out of the sediment regime until periodic erosion of the dunes occurs. Analysis of historical maps has indicated slow retreat of the dune frontage over the last century, despite protection offered against wave action by the natural shingle toe. Leading up to the 1970's the dune field was relatively active, but since the implementation of dune management measures in the 1980s, most of the dunes have now stabilised. Beach profile analysis undertaken at Kenfig Burrows for the period 1998 to 2013 (Profile 228, Figure 6.14 (Volume 2)) indicates a slight landward movement of MHWS between 1998 and 2008, which has remained largely stable between 2008 and 2013, even showing signs of a small seaward movement of HAT over this same period. Further along the beach profile (i.e. 100 to 400m chainage), clear gains in elevation of approximately 0.1 to 0.4 m have been observed between 2008 and 2013, following losses previously seen between 2003 and 2008. This recent reversal from erosion to accretion would suggest that sand supply to this system has been relatively healthy over the past 5 years. Contrastingly, to the north of Port Talbot at Aberavon Sands (Profile 220, Figure 6.14 (Volume 2)), there has been an observed steepening of the beach between 2008 and 2013, whereby there has been an increase in upper beach levels between approximately 20 and 230 m, with a reduction further offshore. Overall however, there has been a general reduction in beach levels of approximately 0.5 m between 1998 and 2013.
- 6.4.3.26 Historically, as a consequence of shoreward sand transport enhanced by long-period south-westerly swell waves, sand has accumulated against the training walls and within the channel in the approaches to the River Neath. In order to maintain access for shipping prior to 2003, approximately 250,000 to 400,000 wet tonnes of sand have been dredged annually between the jetty at the BP chemical plant at Baglan and the Port of Neath's outer buoys. This sand was disposed at the licensed Swansea (Outer) spoil

ground. However, since 2003 vessel using the Port of Neath have been smaller and as a result it has only been necessary to undertake maintenance dredging to sections of the navigable channel up to the Monkstone light (last fixed illuminated post). Consequently, the amount of sand dredged has reduced to approximately 70,000 to 100,000 wet tonnes per annum and the sand is now discharged within the Port and used in the construction industry (pers. comm., Robert Minty, Neath Port Authority).

- 6.4.3.27 Volumetric analysis of topographic data undertaken by the Neath Estuary Group (NEG, 2011) from within the intertidal zones of the Crymlyn and Baglan/ Aberafan sides of the Neath, to the west and east side of the training walls respectively, identified considerable changes in volume (resulting from both erosion and accretion) over an 8 year period (between 2001 and 2009).
- 6.4.3.28 Between 2001 and 2004, erosion occurred in many areas to the west of the Neath Channel (i.e. across the Crymlyn intertidal area). Accretion in the form of an intertidal ridge/bank was also noted slightly landward of the centre of Crymlyn shore. In contrast, substantial accretion occurred within the central part of the Baglan intertidal zone, extending over 5 km east of the training walls, with further accretion also taking place along the eastern wall. Although such changes suggest the transfer of sediment from the Crymlyn to Baglan intertidal, this is thought unlikely to be a simple exchange owing to the presence of the training walls and channel which would tend to act as sediment transport barriers. However, overall a net loss of sediment of approximately 500,000 m³ was identified within the surveyed areas (i.e. the erosion seen across the Crymlyn intertidal far exceeded the accretion seen at Baglan). A reversal in these patterns was then seen between 2004 and 2006, with some erosion across the Baglan intertidal and Aberafan Sands beach. However, there were also significant sediment gains to the west of the training wall reflected by the development of the intertidal bank/ridge and building of dunes on the shoreline in the lee of this ridge. Following this period, the area to the east of the channel (i.e. across the Baglan intertidal and Aberafan beach) began to stabilise, and erosion or accretion was approximately in balance, before showing signs of overall accretion in 2009. In contrast, accretion continued to occur across the Crymlyn intertidal, with the further development of the intertidal ridge, and some erosion along the Crymlyn dunes (between 2006 and 2008). At this time a sand spit encroaching across the navigation channel was removed by dredging with the dredged material being deposited on the beach to the west.
- 6.4.3.29 Overall, the volumetric analysis undertaken by the Neath Estuary Group (NEG, 2011) for the period 2001 and 2009 identified that on the western side of the Neath Channel significant development of an intertidal ridge/bank had taken place towards the western part of Crymlyn, with elevation increases of up to 2 m, with some dune erosion near the navigation channel. To the eastern side of the Neath Channel net accretion occurred over the same time-scale, particularly within Baglan Bay and towards Aberafan Sands where accretion of 1.5 to 2.0 m was shown to have occurred. It should be noted, however, that due to the frequency of the surveys undertaken (i.e. 1 to 3 years), the results do not identify any seasonal patterns, but rather a general trend in both erosion and accretion across the intertidal areas adjacent to the Neath.
- 6.4.3.30 In order to manage sedimentation in the navigational access into the River Neath, the training walls were built to accelerate and straighten the river discharge and tidal exchanges with the objective of purge sediments imported into the channel on the flood tide. This has not been entirely effective at it has been necessary at times to dredge the channel to remove excess sediments. A comparison between monthly bathymetric

surveys along the channel for the period October 1991 to October 1996 (ABP R&C, 1996b) identified an overall trend of accretion of the order of 20,000 m³ per year. The data indicate that depths within the channel are generally shallowest in December and January, following high rates of accretion that result from storm activity in the winter months. This accumulation usually required dredging between January and March.

- 6.4.3.31 Using beach profile data provided by the Swansea and Carmarthen Bay Coastal Engineering Group (SCBCEG) for the period 1998 to 2013, it is possible to review medium- to long-term changes (i.e. annual to decadal) in beach/ intertidal morphology (elevation) across Swansea Bay. A comparison of beach profiles from along the Crymlyn Burrows frontage in front of the Swansea University Bay Campus (SUBC) Development (Profile 214, Figure 6.14 (Volume 2)) and approximately 750 m further to the east (Profile 215, Figure 6.14 (Volume 2)) identifies that there is a landward migration of an intertidal ridge/bank along the Crymlyn shore, which appears to have migrated circa 550 m over the 15-year period (as seen in Profile 215). As this feature approached the shore at this location, slowly driven in a non-linear fashion towards the shore by the prevailing wind and waves (Beckett Rankine, 2009), it lost both height and volume whilst the remainder of the beach was subject to healthy accretion. In contrast, whilst the landward migration of this intertidal ridge can also be identified at Profile 214, beach elevations at this location are considerably more variable with no distinct medium to long-term pattern, i.e. both erosion and accretion of the upper and lower intertidal can be seen over this 15-year period.
- 6.4.3.32 Within the western region of Swansea Bay (between Swansea Docks and Mumbles Head), the coastal frontage has been highly modified and is characterised by a series of seawalls, revetments and groynes, fronted by wide intertidal mud and sand flats. These intertidal flats are over a kilometre in width in the region of West Cross, although they narrow towards Mumbles Head and Swansea Docks. The upper beach along this frontage is generally narrow. However, it widens at Blackpill, where a small area of sand dunes is present and sand accumulates updrift of outfalls. The beach lies in front of an area of older dunes, which are now defended (Halcrow, 2012b). Analysis of the SCBCEG beach profile data for the period 1998 to 2013 at West Cross (Profile 205, Figure 6.14 (Volume 2)) and Lower Sketty (Profile 206, Figure 6.14 (Volume 2)) identifies a similar pattern of change over the 15-year period, with a general reduction in beach/ intertidal levels, and a slight landward movement of HAT and MHWS. These observed reductions are relatively consistent along the length (chainage) of the beach profiles, with changes in the region of approximately 0.3 to 0.5 m (i.e. losses of 0.02 to 0.03 m per annum). Similar patterns of change are also identified at other locations between Mumbles and West Cross, thus indicating general net erosion within this region of Swansea Bay.

Sediment transport and pathways

- 6.4.3.33 Sediment transport pathways are defined as the links between sediment sources, stores and sinks, which are driven by a combination of wave and tide action. The tidal pathways are determined by the balance between ebb and flood conditions and when there is some asymmetry between ebb and flood (in magnitude or duration) then a net pathway is often revealed. For waves, the pathway tends to be active in one direction for a particular wave condition and results in a stirring effect on the seabed. This effect is limited to shallower conditions where wave energy is dissipated on the seabed. At times when the wave stirring effect is sufficient to mobilise sediments it is the tidal currents that are likely to be responsible for moving the sediments away.

- 6.4.3.34 As detailed in Paragraph 6.4.2.1 onwards, there are important differences in the hydrodynamic regime between the wider Bristol Channel and Swansea Bay, which inherently results in a process divide. This divide is largely defined by the variation in predominant (net) bedload sediment transport pathways and the sediment distribution between the bay and the channel, a process divide which broadly follows the 20m contour (see Figure 6.15, Volume 2).
- 6.4.3.35 In general terms, the area south of the process divide (Central Bristol Channel) is deeper and has a seabed with areas of coarse sediments which tend to represent a highly worked seabed which has responded over time to strong tidal flows. These tidal flows are typically asymmetric exhibiting higher speeds during the ebb phase of the tide which gives rise to a bedload transport vector to the west (Figure 6.15, Volume 2); this asymmetry is more pronounced during spring tides. Where there are local arrangements of sediments as sandwave-type features then the cross-sectional profile of these features confirms an asymmetry which indicates the net westerly transport pathway (i.e. the steeper face is orientated toward the west). Since this net pathway would require sediment delivery from an easterly source, the limited presence of any sediment here would suggest that the contemporary source is effectively depleted (Halcrow, 2012b).
- 6.4.3.36 Along the northern margin of the Bristol Channel there is evidence of a flood transport pathway for sandy sediments, enhanced by long period westerly waves, which may move some material between beaches of the South Gower (local sediment stores). When this pathway reaches Swansea Bay the westerly waves help to push some of this material into the bay. A proportion of this material may reach the Neath Delta and some may be worked down the coast toward Sker Point where a local headland feature encourages a local pathway to take some material offshore to form a sequence of linked sandbanks; Kenfig Patches, Hugo Bank and the larger Scarweather Sands. Some of this material may still be moved further east and when it reaches Nash Point the strong tides of the Inner Bristol Channel push the material back to the west. Locally, the complex flows from this headland create a circulation of sediment that forms the local store of Nash Sands.
- 6.4.3.37 The Bristol Channel is exposed to long period swell originating from the North Atlantic as well as locally generated wind-waves. As swell waves, in particular, move into shallow water, some of their high energy is dissipated onto the seabed. The point at which the waves begin to influence sediment transport depends on the total water depth, the amplitude and period of the wave and the local seabed conditions. The influence from swell is relatively confined to directions between west to south west, as detailed in Paragraph 6.4.2.18 onwards. This direction band is important to the overall net balance of sediment transport as it can work against the influence of the ebb tide and enhance the flood tide, particularly during storm events. It is during these events that large volumes of sand can be transported in the subtidal (offshore) region of the bay from west to east (Figure 6.15, Volume 2). Such events can often result in large scale sedimentation in Port Talbot Outer Harbour and approach channel; for example, a single storm in 1974 produced the same level of siltation as the equivalent annual maintenance dredging (ABP R&C, 1996a). Within the shallow subtidal and intertidal regions of the bay, net sand transport to the east of Swansea Docks is predominantly towards the Neath (driven by a combination of waves and tides). In contrast, sand is aperiodically supplied to the western region of the bay (to the west of Swansea Docks) under large south easterly storm events, but also in suspension from east to west across the bay during large spring tides (i.e. from the Neath) when there is sufficient seabed disturbance from waves approaching from the south west.

- 6.4.3.38 In contrast to sand transport pathways, the transport of muds and silts around Swansea Bay is largely driven by the ambient tidal flow and wind conditions, rather than waves; although wave disturbance will both minimise sedimentation and influence local circulation (particularly during storm events).

Morphology

- 6.4.3.39 The term morphology is applied here to describe the changing form of the seabed and seabed features over time. Some areas may show a high degree of change at the scale of spring and neap tides or summer and winter wave conditions, other areas may respond and demonstrate change over longer timescales, such as annual and decadal trends and certain areas may show minimal change and can be considered stable over a historical timescale. The interaction between local coastal processes and sediment supply determine the scales of change in seabed morphology. The primary evidence for changes in morphology is the survey data of seabed depths and beach levels. Both the accuracy and detail of this data has improved markedly over time.
- 6.4.3.40 Traditionally, the subtidal has been charted for navigation. Shallow areas which are known to change at a high rate have tended to be the areas most surveyed in order to make sure the navigation charts remain up to date. Areas that have not been resurveyed often tend to represent more stable areas of the seabed. For example, across the rocky areas of the Central Bristol Channel there are expected to be no changes, whereby these areas can be reliably informed by relatively older charts.
- 6.4.3.41 A consideration of navigation charts from 1949 to the present date suggests the subtidal region across the bay has remained largely unchanged. The scale of any change is likely to be less than the accuracy of such charts; hence the evidence suggests stability at a decadal level.
- 6.4.3.42 Locally, there are features within and adjacent to Swansea Bay that demonstrate higher rates of change in their morphology. These include the sandbank features and intertidal areas, including the Neath Delta. Anthropogenic change has also been introduced where local dredging occurs to ensure navigable depths into local ports and harbours are maintained, with associated repositioning of the removed sediments onto designated disposal sites.

6.4.4 Contamination of sediments

- 6.4.4.1 Swansea Bay has a long industrial past and, as such, even though some areas have been re-worked (e.g. through channel maintenance dredging), there is potential for sediments in the area to be contaminated (e.g. with heavy metals and man-made substances such as TBT and PCBs). Existing sediment quality data from within the bay has been collated primarily from the Swansea and Port Talbot approach channels and docks. A review of this information, surveyed between 1995 and 2002, suggests a general decline in contamination levels within these parts of the bay. Across the wider Swansea Bay region, and specifically within the footprint of the proposed Lagoon, there is a general paucity of historic sediment quality data.
- 6.4.4.2 For the Project, it is anticipated that a total of up to 8.1 million m³ of material (predominantly sands and gravels) will be dredged. Of this total volume, up to 7.3 million m³ is anticipated to be used for construction fill, whilst up to 800,000 m³ of mud/ silt may require disposal at the licensed Swansea Bay (Outer) deposit ground (LU130). This is considered a worst case disposal volume and is comprised of 500,000 m³

of material from the turbine and sluice gate housing and a further 300,000 m³ of material from the boating area inside the lagoon. As discussed in Chapter 4: Section 4.3.1, if the turbine/sluice gate housing is micro-sited to the southeast the volume of silts and clays for the disposal from this site would be significantly reduced to approximately 360,000 m³. It is further noted that the construction programme is such that the material from the turbine and sluice gate housing will be dredged during construction year 1, whilst the material for disposal from the boating area is most likely to be dredged during construction year 3. It is proposed that all sediment for use in construction will be obtained from an area of approximately 2.5 km² within the Lagoon, requiring dredging to an average depth of 2 m, whilst further excavation down to -14.5mCD (Chart Datum), approximately 9 to 10m below existing bed level will also be required around the turbine housing area.

- 6.4.4.3 To characterise this material from a chemical perspective, a comprehensive sediment contamination analysis of surface samples from the benthic survey (Titan, 2012a) and both surface and sub-surface samples from the geophysical/ geotechnical investigations (Titan, 2013; Atkins, 2013) was undertaken specifically for the Swansea Tidal Lagoon development. In total, 21 stations were sampled from within the proposed Lagoon footprint, with a further nine stations (surface samples only) across other areas of Swansea Bay; the locations of which are provided in Figure 6.16 (Volume 2). From within the proposed Lagoon footprint, six surface samples were analysed from the benthic survey, whilst numerous samples were extracted at nine vibrocore stations (with samples taken at approximately 1 m intervals with depth, to a depth no greater than 5.5 m) and from six borehole stations (with varying sample depths, to a maximum of 14.5 m). An additional borehole sample and an additional vibrocore sample were also collected during the survey. Both were analysed for particle size distributions but neither were analysed for contaminants. The results of the contamination analysis are provided in Appendix 6.3, Volume 3, and are summarised below.
- 6.4.4.4 Results from this analysis indicate that surficial sediment contaminant levels within the proposed Lagoon footprint, that are likely to be dredged, are similar to those seen across the wider Swansea Bay, with slightly elevated levels (i.e. above Cefas Action Level 1²) of some heavy metals (e.g. Chromium, Copper, Nickel and Zinc). Both surficial and at-depth concentrations of organic contaminants (i.e. TBT and DBT) are predominantly below Cefas action levels, with some localised increases in DBT along the eastern side of the Lagoon, albeit only slightly above Action Level 1. Polyaromatic Hydrocarbons (PAHs) are also generally below Cefas action levels, although some individual hydrocarbons were found to exceed Action Level 1 in near-surface samples (i.e. less than 1.5 m depth), and mostly within the southern extents of the Lagoon (to the rear of the turbine array). With respect to Polychlorinated Biphenyls (PCBs), concentrations across the proposed Lagoon footprint have been conservatively analysed as being higher than Action Level 1; due to uncertainty resulting from the limits of detection associated with the analysis.
- 6.4.4.5 In summary, no analysed sample exceeds Cefas Action Level 2 for any specific contaminant. Furthermore, there is clear evidence of lessening contamination levels with depth, suggesting that the deeper sediments found across the bay have not been subject to historic anthropogenic activities. As a result, the sediments that will be dredged and then subsequent used/ disposed in the construction of the Lagoon are not considered to

² A description of Cefas Action Levels with respect to dredge material assessments is provided at <http://www.cefas.defra.gov.uk/media/562541/cefas%20action%20levels.pdf>

be contaminated with respect to using/ disposing the sediments within the marine environment.

6.5 Assessment of impacts

6.5.0.1 This section is structured in accordance with the Project lifecycle, which recognises the following key periods:

- I. **Construction period:** the changes that might be expected to occur to the physical environment along the timeline of construction and considered in relation to primary stages of construction. As the construction involves a number of component phases which will impact upon the environment in their own right for significant periods of time, each phase is assessed separately;
- II. **Operational period:** the changes that might be expected as a result of the physical presence of the lagoon, its operation and maintenance; and
- III. **Decommissioning period:** the changes that might be expected to occur as a consequence of modifying the development or placing the development in a non-operating state, including the adjustment of the baseline.

6.5.0.2 For each period of the Project lifecycle the potential impacts of the Project on coastal processes and the sedimentary regime within Swansea Bay are considered. The coastal process features can be grouped simply into four principal receptors, namely:

- i. sea bed;
- ii. coastal hydrodynamics (water levels, flow speeds and directions along with waves);
- iii. water column (suspended sediments); and
- iv. sediment regime, leading to changes in morphology.

6.5.0.3 It should be noted that these receptors are both important with respect to ascertaining the environmental impact of the Project in their own right, but also as pathways to change for other receptors, e.g. ecological, nature conservation, recreation and navigation. It is therefore entirely possible that a change may not be significant from a coastal process perspective, but may have a greater significance of effect on other categories of receptors, which are assessed in other chapters.

6.5.0.4 For each component of the development phases, the impact on the principal receptor will first be assessed for extent and magnitude of change that will occur and the significance of effect determined. Consideration will then be given to specific matters that were identified through scoping and the Preliminary Environmental Information Report (TLSB, 2013), with respect to the coastal processes and sedimentary regime. Where the change in processes are effectively a pathway to potential impact on other topic receptors, a cross-reference to other sections is provided where that concern will be assessed.

6.5.0.5 The specific matters identified which have a coastal process component include:

1. Disturbance of contaminated sediments during the construction phase leading to raised sediment loads and potential dispersal of contaminants (e.g. heavy metals);
2. Changes in the wave climate and tidal circulations in the vicinity of the approach channels to the ports of Swansea and Port Talbot, but also to the River Neath.

Particularly, the impact that such changes may have on dredging requirements and navigation;

3. The potential effect of changes in the wave climate on recreational use of local beaches (e.g. surfers);
4. Changes in local flows in the vicinity of the turbines and the risk of scouring of the local seabed (including the potential release of contaminated sediments) during operation;
5. Assessment of potential sediment accumulation within the Lagoon during operation and the requirements for potential maintenance dredging and disposal;
6. Changes in littoral drift patterns that might alter the feed of sediments to Crymlyn Burrows SSSI sand dunes, Baglan Dunes, Aberafan Sands and Margam Burrows dune system, the beaches of Swansea Bay (i.e. Blackpill) or other similar areas in the near-field (Mumbles Head to Port Talbot);
7. Changes in erosion and deposition patterns in the immediate vicinity of the Project which may affect the local and wider intertidal areas of Swansea Bay, including localised areas of muddy sands, clay and peat between Mumbles and Swansea;
8. The potential changes to far-field littoral drift at Margam Sands, Kenfig SAC and other local beaches; and
9. Potential changes to the offshore sandbanks as a result of changes to the hydrodynamic regime (tides and waves).

6.5.1 Construction

6.5.1.1 As previously detailed and illustrated within Chapter 4: Project Description, the construction period of the project is split into three main phases, spanning a period of *circa* 3 years, with additional works and finishes extending the completion of the main works comprised in the Project programme to approximately 39 months. Construction works undertaken within these main phases that are important to this assessment are identified below:

- i. Phase 1:
 - i. Seawall – Western Arm;
 - ii. Seawall – Eastern Arm (Phase 1); and
 - iii. Temporary bund wall around the construction area for the turbine/ sluice gate structure.
- ii. Phase 2:
 - I. Construction of the turbine and sluice gate structure;
 - II. Installation of the turbines and sluice gates; and
 - III. Seawall – Eastern Arm (Phase 2).
- iii. Phase 3:
 - i. Removal of temporary bund wall around the turbine/ sluice gate structure;
 - ii. Seawall – Eastern Arm (Closure); and
 - iii. Wet commissioning of the turbines and sluice gates.

6.5.1.2 The individual components of each phase of construction have the capacity to affect the coastal process receptors directly and indirectly during construction of the Project, for temporary and permanent periods, at a number of different locations within Swansea Bay. There may be instances when the impacts will not affect every receptor, and in some cases, the impacts (particularly during construction) may interact. The construction activities associated with the Project will have both short and longer-term effects on the identified receptors, with the operational impacts predominantly relating to the permanent direct and indirect changes to both the morphology and the physical processes that have the potential to cause longer-term change.

6.5.1.3 The approach to the construction phase assessment draws upon approaches developed for the Severn Tidal Power Study (ABPmer, 2010c), thus largely considering the potential effects resulting from each phase of the construction (based nominally on an annual time step) on a qualitative basis. The assessment will, therefore, give reference to the conceptual understanding of the coastal processes across the study area.

Phase 1

6.5.1.4 During Phase 1 of the construction, capital dredging will be initially required to prepare the foundation of the permanent western arm of the seawall. The western arm will start adjacent to the Port of Swansea and progress seawards alongside the River Tawe navigation channel towards the location of the proposed turbine and sluice gate structure. The seawall will be built sequentially, starting with layers of geotextile casing (Geotubes®) either extent of the seawall footprint. It is considered that the construction activity with the use of Geotubes® represents the worst case scenario with respect of potential effects on SSC (as a result of the maximum amount of dredging and filling activity, with the conventional seawall construction potentially using less). As such, specific assessment of the construction method that does not use Geotubes® (as considered for the landward extent for the eastern wall) is not specifically assessed. These Geotubes® will be hydraulically filled by a purpose modified vessel with sediments provided by a Cutter Suction Dredger (CSD) from capital dredging taking place within the Lagoon footprint (as described in Chapter 4). Once two rows of Geotubes® have been laid, the void between them will be filled with sand and gravel. It is expected that dredge material for this section of the seawall will be predominantly extracted from the western side of the Lagoon to a depth of 2m below the existing seabed surface. The seabed sediments in this area have been identified as predominantly comprising sandy gravel and gravelly sand, intermittently covered by a thin sand veneer.

6.5.1.5 Additional dredge material will be sourced from within the construction area for the turbine and sluice gate structure. At this location, up to 10 m depth of material would need to be dredged from the seabed. Geotechnical investigations undertaken for the Project (Atkins, 2013) suggest that approximately 1.2 million m³ of this sediment will be suitable for construction, predominantly sand and gravels (with varying proportions of silt/ clay fractions). About 500,000 m³ of the capital dredging for the turbine/ sluice gate foundations will comprise silts and clays that would be disposed at the Swansea (Outer) licensed deposit ground (LU130) using a trailing suction hopper dredger (TSHD). Suitable material from this location may also be used in the construction of a temporary bund around the turbine and sluice gate construction area. It should be noted that if the turbine house is micro-sited to the southeast the volume of silts and clays for the disposal would be significantly reduced or negated.

6.5.1.6 It is envisaged that approximately 2,960 m³ of sediment will be dredged by the CSD over a period of *circa* 50 minutes to fill a single Geotube® within the lagoon seawall. Each tube

will have a diameter of around 5 m and a length of 150 m. Downtimes of around 1 hour are expected between successive Geotube® filling associated with the repositioning of the dredging/ fill plant. Subsequent layers of Geotubes® will be added to build up the seawall to the required height, with the void between filled with dredged sediment. It is estimated that this void (for a 150 m length of wall) would take approximately 8.5 hours to fill based on similar dredging rates for the Geotubes®. Based upon these rates of dredging and filling, it is expected that a 150 m length of seawall would take approximately 30.5 hours to complete. Following on behind the installation of the Geotubes® will be the stone and rock placing operations. The gap between the two operations will be kept to a minimum to ensure unprotected sections of the seawall are minimised. The Geotubes® will be covered with a geotextile to protect them from damage during stone placing, which will then be covered by a small sized rock under layer, with a larger sized rock protection layer placed on the seaward side of the seawall; the depth of rock will be dependent on location.

6.5.1.7 Following completion of dredging and construction works to the western lagoon seawall, a distance of approximately 2.5 km, works to the eastern seawall adjacent to the new SUBC will begin. The first phase of this eastern arm construction will extend outwards from the shoreline towards the Neath Channel, a distance of approximately 2.3 km. The dredge material for this section of the seawall will be largely extracted from the eastern side of the Lagoon to a depth of 2m below the existing seabed surface. In this area, the seabed sediments are predominantly characterised by sands (smooth and featureless) and slightly gravelly sands to a depth typically no greater than 0.5m. These surficial sediments are then underlain by fine sediments (silty fine sands), which typically increase in coarseness to the south and west (Titan, 2012a).

6.5.1.8 The programme timescale for Phase 1 assumes that the capital dredging and construction works associated with these stages of the seawall will generally be undertaken between April to October (7 months) such that there is less potential chance of delay due to bad weather. Whilst it is considered that a high level of efficiency will be maintained, this timescale does take weather and mechanical delays into consideration.

Impact Identification

6.5.1.9 The environmental impacts of the proposed Phase 1 dredging and construction works include:

- i. sediment dispersion arising from the dredge plant disturbing sediments into the tidal flows, and through the infilling of both the Geotubes® and the seawall voids, thus creating a plume which will impact upon the water column and estuary bed;
- ii. sediment dispersion arising from the disposal of capital dredge material at the licensed Swansea (Outer) deposit ground, causing the potential for increased SSC and smothering of the seabed;
- iii. the direct removal (loss) or physical modification to the existing seabed within the Project footprint, primarily the bathymetry and bed characteristics;
- iv. modification to both near and far-field hydrodynamics (e.g. water levels, flow speeds and waves) as a result of construction works and capital dredge disposal; and
- v. direct and indirect changes to the sediment (morphological) regime due to erosion/ accretion from the presence of the new infrastructure, driven by changes to sediment transport within Swansea Bay.

- 6.5.1.10 Each of these issues is considered in more detail below.

Sediment dispersion (water column and seabed)

Capital dredging and seawall construction

- 6.5.1.11 During the construction of the western and eastern (Phase 1) lagoon seawalls, sediment dispersion will occur from: sediment disturbance at the seabed by the CSD; sediment loss during the filling of the Geotubes®; and, sediment disturbed to the water column from the hydraulic infill of the void between the Geotubes®. As these activities will occur simultaneously, the resulting sediment dispersion and their impacts on the water column and seabed will be jointly assessed. An assessment of the potential effect, particularly in relation to increased SSC as a result of the dredge disturbance plume and subsequent sedimentation. To inform this assessment the numerical model has simulated these dredging and filling (construction) operations for a representative location along both the western and eastern seawall (for a single 150 m section of seawall), for a spring-neap tidal cycle; thus taking into account a range of tidal conditions that would be experienced within Swansea Bay. Further information on the modelling undertaken is provided within the methodology section of this chapter (Section 6.3.2).
- 6.5.1.12 In addition to these permanent structures, sediment dispersion will also arise from the dredging and subsequent construction requirements associated with the temporary bund around the turbine/ sluice gate construction area. At the present time, there are two options for the construction method of this temporary bund, and this may vary from a sediment bund to a sheet piled cofferdam wall (see Chapter 4 for further details). As such, the potential effects of these works are discussed on a qualitative basis.

Western seawall construction

- 6.5.1.13 With respect to the western seawall model scenario, the distribution of sediment dispersion from the dredging and filling processes are shown in a spatial context for the maximum increase in depth-averaged SSC at any location and time during the model run (Figure 6.17, Volume 2). The model results indicate that the sediment plume disperses predominantly in a southerly direction through Swansea Bay and around Mumbles Head (into the rectilinear tidal flows found within the Bristol Channel), and to a lesser extent, in a south-easterly direction towards the centre of Swansea Bay. In the case of the plume that passes around Mumbles Head, the modelling shows that this dispersion extends westwards to approximately Caswell Bay, a distance of approximately 4 km. The maximum SSCs at this extent are less than 10 mg/l above background concentrations and comparable to surface concentrations observed by the MODIS satellite at this location (Figures 6.12 and 6.13, Volume 2), where the depth-averaged and near-bed background SSC will be considerably higher. At and beyond this extent the plume effects will not be distinguishable from background SSC. It is important to note that the sediment plume does not extend into the Carmarthen Bay and Estuaries SAC found to the west of Oxwich Bay, nor does it pass within 500 m of the coastline beyond Mumbles Head. The modelling also shows that increased SSC only exceeds 60 mg/l within Swansea Bay along an approximate 500 to 1,500 m track extending from the dredge/ fill location towards Mumbles Head, and also towards the Swansea shoreline. This compares with results from the recent metocean survey which indicated that that mean background near-bed SSCs are in the vicinity of 113 mg/l and 54 mg/l across the intertidal and shallow subtidal areas of Swansea Bay, respectively (Titan, 2012b), with peak concentrations in the order of 460 to 570 mg/l.

- 6.5.1.14 A number of time series plots (Figure 6.18, Volume 2) provide further context to the spatial change. At the dredge/ fill location (W2, Figure 6.17, Volume 2), where increases in SSC are greatest, peak depth-averaged concentrations reach around 160 mg/l (above background). This peak occurred for a period of less than 5 minutes around the time of HW slack. More typically throughout the tide, however, peak increases in SSC at this location are around 20 mg/l above background during the dredging and construction works. Following completion of these works, i.e. cessation of sediment losses to the water column, increases in SSC at this location dropped below 1 mg/l after a period of less than 48 hours. Adjacent to Mumbles Head, within the main plume track, peak increases in SSC reached around 70 mg/l above background and occurred immediately either side of LW slack (W4, Figure 6.18, Volume 2). At this location, increases in SSC are observed for a prolonged period of time over the spring-neap cycle, although concentrations are shown to decrease to background levels. No increases in SSC as a result of dredging and construction works on the western seawall were found at Blackpill, Crymlyn Burrows, within the Neath Channel (nor River itself) or across Baglan and Aberafan Sands.
- 6.5.1.15 In addition to SSC, Figure 6.19 (Volume 2) identifies the maximum amount of sedimentation experienced during the representative western seawall works at any location and time during the model run. The results show that only within the immediate vicinity of the works will sedimentation exceed 1 mm, with changes elsewhere across the bay being indiscernible from natural background variations. At the dredge/ infill location itself (W2), Figure 6.20 (Volume 2) identifies that sedimentation will continue to take place over the period of the works to a maximum value of approximately 24 mm. This deposit is not remobilised on subsequent tides, but remains on the seabed throughout the modelled spring-neap tidal cycle. Realistically, however, most sediments settling within the dredging area will be re-dredged.
- 6.5.1.16 It should also be noted that these predicted changes in SSC and sedimentation as a result of the dredging and construction works will vary slightly depending on the location of the works along the western seawall. The location of the representative scenario is considered 'worst case' with respect to potential sedimentation within the entrance to Swansea Docks (and along the inner section of the navigation channel), but also along the Swansea shoreline. Furthermore, the placement of rock armour over the Geotubes® may lead to some seabed disturbance, although sediment dispersion arising from this would be very small and localised in comparison to the dredging and sediment filling works.
- 6.5.1.17 Following the completed construction of any individual 150 m section of seawall, the purpose modified vessel used to fill the Geotubes® will require repositioning for any new section of seawall; estimated to be in the order of 2 to 3 hours. Once repositioned, the dredger and vessel will begin construction on the new section of wall, with sediment dispersion patterns (with respect to concentration and distribution) likely to be very similar to those seen for the previous section of wall. Due to the nature of the filling procedure, i.e. only one Geotube® to be filled any single time, there will be no aggregation effect because there is still only a single input source into the water column. An aggregation effect, in this instance, would only occur if construction of two sections of the seawalls was to occur simultaneously. As such, it is considered that further assessment of aggregation effects is not required.

Eastern seawall construction

- 6.5.1.18 The distribution of sediment dispersion for the eastern seawall model scenario is shown for the maximum increase in depth-averaged SSC at any location and time during the model run in Figure 6.22 (Volume 2). The results indicate that the sediment plume extends predominantly along a north-east to south-west axis into the River Neath and towards the Mumbles, with further dispersion into the centre of Swansea Bay and along the Bristol Channel towards Caswell Bay (as is the case in the western scenario). Increases in SSC above 100 mg/l are identified within the Neath Channel, across Baglan Bay, along the Crymlyn Burrows frontage and within the shallow subtidal region to the east of the Swansea Channel (i.e. largely within the footprint of the proposed Lagoon). A number of time series plots (Figure 6.23, Volume 2) provide further context to the spatial change. At the dredge/ fill location, peak depth-averaged concentrations reach around 700 mg/l (above background), with concentrations dropping to less than 50 mg/l following a period of *circa* 24 hours upon cessation of the works. Over the spring-neap cycle, the increased SSCs return to background levels. At the entrance to the Neath, peak concentrations reach around 115 mg/l during the works, falling rapidly to background concentrations in around 5 days following cessation of activities. In contrast, at Location E6 (Figure 6.23, Volume 2), towards the end of the plume adjacent to Caswell Bay, there is an observed increase in SSCs to a peak of around 10 mg/l approximately 3 days after works ceased (caused by delays in sediment transport to the area), followed by a rapid reduction over subsequent tides to background concentrations over a period of a further 5 days.
- 6.5.1.19 A spatial plot showing the maximum amount of sedimentation experienced during the representative eastern seawall works at any location and time during the model run is provided in Figure 6.24 (Volume 2). The results show that sedimentation in excess of 1 mm is attained in the immediate vicinity of the works, but also along the Crymlyn Burrows frontage and towards the end of the Neath Channel. Figure 6.25 (Volume 2) identifies that whilst sedimentation at the dredge/ construction location reaches approximately 4.1 mm during the works, these sediments are rapidly eroded over a single tide following cessation of the works. Elsewhere across Swansea Bay and beyond Mumbles Head (i.e. westerly towards Caswell Bay), maximum sedimentation rates are below 1 mm and therefore likely to be indiscernible from natural background variations. The resulting sedimentation at the end of the modelled spring-neap tidal cycle is provided in Figure 6.26 (Volume 2).

Impact

- 6.5.1.20 The magnitude of sediment dispersion is considered to be small on the scale of Swansea Bay but is considered to be medium in close proximity to the dredge and fill works. As the effect is almost certain to occur, the probability of occurrence is considered high. As a result, the exposure to change is medium local to the works and low at the bay scale. The sediment being disturbed during the proposed works is common to the bay area, in which increases in SSC resulting from natural changes between tidal and wave events can be greater than those resulting from the works (across Swansea Bay in general), therefore, the sensitivity of the seabed and water column is considered to be low. The vulnerability to sedimentary disturbance from the works is therefore assessed as low. The modelling indicates that the maximum extent of the changes has a potential to impact upon the SSSI at Crymlyn Burrows, and therefore the receptor importance in this area is considered moderate, whilst the wider Swansea Bay is assessed as low. On this basis the significance of the impact is considered **minor adverse / neutral** in the area of Crymlyn Burrows and **neutral** for the wider bay.

- 6.5.1.21 Additionally, the proposed capital dredging and construction works have the potential to remobilise contaminants that may be trapped within the sediments. Based upon the sediment contaminant analysis results discussed in Section 6.4.4, where no analysed sediment sample across the Lagoon footprint exceeded Cefas Action Level 2 for any specific contaminant, the risk of contamination through these proposed works to other areas of Swansea Bay (or the Bristol Channel) are therefore not considered significant.

Temporary bund construction around turbine/ sluice gate construction area

- 6.5.1.22 With respect to the dredging and subsequent construction of the temporary bund around the turbine/ sluice gate construction area, the impact of the works on sediment dispersion will vary depending on the chosen construction method.
- 6.5.1.23 In the instance that only dredging works were to take place at this location, with the sediment pumped to another location (i.e. to be used within the western and eastern seawalls), sediment dispersion will be considerably less than a combined dredge and construction scenario. For instance, sediment loss rates into the water column for dredging disturbance alone are expected to be around 9 times lower than that for the construction fill process. Taking this into account, along with the position of the turbine/ sluice gate construction area with relevance to local hydrodynamic processes, it is expected that a plume of a similar spatial extent to the western scenario will be created within the bay. Due to the smaller sediment loss rates, however, the magnitude of increased SSC will be considerably reduced, with peak depth-averaged concentrations at the dredge location likely to be in the region of 20 to 30 mg/l, with a 10 mg/l plume likely to extend to the Mumbles (rather than further westwards into Bristol Channel). In contrast, if the construction of the temporary bund included the requirement for Geotube® filling or the development of a sediment mound, sediment dispersion will considerably increase similar to those seen in the western and eastern seawall model scenarios. In such an instance, the sediment dispersion is likely to once again follow a similar spatial extent to that of the western scenario but also with a slightly further easterly extent into the centre of the bay and a likely reduction towards the River Tawe.

Impact

- 6.5.1.24 The assessment of effects for the temporary bund construction indicates that sediment dispersion will be over a similar extent to the construction and Geotube® fill for the western seawall arm, but at a lower/ higher rate depending on the construction method. Assuming the worst case method of construction was chosen with respect to potential sediment dispersion, i.e. a sediment mound, the construction of the temporary bund will be similar to that for construction of the western/ eastern arms, i.e. **neutral** on a bay scale, but **minor adverse / neutral** local to the source of disturbance.

Dredge disposal

- 6.5.1.25 Without micro-siting of the turbine/ sluice gate structure, approximately 500,000 m³ of silt and clay sediments dredged would be required to be disposed at the Swansea (Outer) licensed deposit ground (LU130); see Figure 6.3 (Volume 2) for location. It is estimated, based upon the characteristics of this sediment, that this would be equivalent to 650,000 to 900,000 wet tonnes *in situ*. In contrast, the deposit ground has received on average approximately 2.6 million wet tonnes of fine sediments (both mud and sand) per annum between 1986 and 2010, with a peak volume of 9.1 million tonnes (maintenance and capital) received in 1996. Historic capital dredgings to the deposit ground, particularly from Port Talbot, have included similar types of sediments to those proposed. As such, the proposed disposal relates to approximately 25 - 35% of the average annual disposal

volumes at the deposit ground, and no more than 10% of the maximum annual volume received at this ground over the 24 year period. Over this period, little or no accumulation of material at the seabed has occurred indicating the deposit ground is dispersive for this type of material.

- 6.5.1.26 Numerical modelling has been undertaken for the disposal of this sediment at the licensed deposit ground over a spring-neap cycle. The model assumes that 10,000 m³ *in situ* of dredged sediment is disposed approximately every 6 hours over the spring tides (at varying locations across the deposit ground), which accounts for around half of the total volume of sediment expected to be disposed as a result of the Project. Initial release of this dredged sediment occurs at LW on a spring tide, allowing for maximum transport up-estuary on the subsequent flood tide, i.e. towards the Kenfig SAC. Further detail of the modelling approach is provided in Section 6.3.2. Modelling of the total sediment volume to be disposed is not considered necessary, as any substantial aggregation effect that may arise from the proposed disposal works would be constrained predominantly to or in the immediate vicinity of the deposit ground itself (i.e. relative close to the disposal source). Within the disposal ground, the seabed is already conditioned to extensive disposal activities that have taken place historically.
- 6.5.1.27 A spatial plot of maximum ‘worst case’ depth-averaged SSC (above background) at any point in time as a result of the proposed disposal activities is provided in Figure 6.27 (Volume 2), which also identifies the maximum extent of any plume that may arise from the disposal. The pattern of sediment dispersion from the deposit ground is clearly shown to be controlled by the rectilinear flows found within the Central Bristol Channel, which are predominantly along a west-east axis, before turning along a south-east to north-west axis in closer proximity to the eastern shoreline (i.e. south of Port Talbot). The total extent of sediment dispersion from the deposit ground is *circa* 12 km to the west and up to approximately 20 km to the east (just beyond Porthcawl), with this variation being driven by the characteristic asymmetry in the tide within the Bristol Channel; whereby a prolonged flood tide allows for fine sediment fractions to be transported (at lower velocities) a greater distance than the shorter ebb tide. Due to these tidal characteristics of the Central Bristol Channel, there is a very limited exchange of suspended sediments from the deposit ground to Swansea Bay, with increases in SSC constrained to the deeper central region of the bay.
- 6.5.1.28 Whilst Figure 6.27 (Volume 2) identifies maximum changes to SSC as a result of the disposal operations, it should be emphasised that these maximum concentrations are only experienced for a very short period of time. Temporal changes in SSC as a result of the disposal operations are illustrated in a number of timeseries plots (Figure 6.28, Volume 2) extracted at various locations within the sediment plume extent; the locations of which are shown in Figure 6.27 (Volume 2).
- 6.5.1.29 At Location 1, situated within the centre of the deposit ground, peak SSC can reach around 3,500 mg/l over the disposal period (Figure 6.28, Volume 2). This peak occurs immediately following a disposal in the near vicinity, whereby a dense sediment plume passes through this location and occurs for less than 5 minutes (minimum resolution of the model outputs); although this peak is more likely to occur over a period of less than 1 minute. More generally, however, increases in SSC tend to occur in ‘pulses’ over the flood and ebb tide, as sediment suspended in the water column passes back and forth across the deposit ground under the rectilinear flow conditions, being enhanced by further dredger disposals. Similar patterns of increased concentrations are found outside the deposit ground, although it can take approximately 5 tidal cycles before the disposed

sediments initially reach the furthest extents of the plume under the residual flood (easterly) sediment transport (i.e. Location 8, Figure 6.28, Volume 2). Furthermore, there is evidence of some sediment aggregation within the plume, as sediments released during successive disposals interact to a degree (see Location 5 as an example, Figure 6.28, Volume 2). In contrast, tidal flows within the Inner Bristol Channel are insufficient to keep these sediments in suspension over LW and HW slack, therefore resulting in sedimentation. Over these slack periods, increases in SSC (above background) are typically less than 10 mg/l throughout the plume extent. Figure 6.29 (Volume 2) illustrates maximum 'worst case' sedimentation that may occur across the extent of the sediment plume at any given time over the modelled spring-neap cycle. Temporal changes over the spring-neap tidal cycle are illustrated through timeseries plots at the same representative locations provided for SSC (Figure 6.30, Volume 2). The spatial plots identify that maximum sedimentation across the plume extent is predominantly below 10 mm, with localised peaks of up to *circa* 40 mm along the main west-east axis aligned section of plume; principally within the deposit ground under and in close vicinity to the dredger. These depths are representative of about half of the volume of material dredged, therefore, it is possible that the maxima could be double these depths in reality.

- 6.5.1.30 It is through these timeseries plots that the process of sedimentation during slack periods is clearly identifiable, although sedimentation is determined by whether sediments (provided through the disposal activities) are present in the water column at these times at any given location. On the subsequent flood/ ebb tide when flow speeds are sufficient, these sediments are once again re-suspended into the water column and undergo further dispersion. With time, these dispersed sediments migrate further away from the source (i.e. the deposit site) towards the outer extent of the predicted plume, with maximum concentrations decreasing with distance. Following the cessation of the disposal operations, peak SSC increases within the deposit ground (Location 1, Figure 6.28, Volume 2) fall to less than 100 mg/l by the end of the spring-neap cycle with this pattern expected to continue until concentrations will be indistinguishable from natural background variations. Whilst this process will be very similar across the rest of the plume extent, it will take longer further eastwards due to the initial delay in sediment dispersion in this direction, with background concentrations likely to be returned to following a subsequent spring-neap tidal cycle. Figure 6.31 (Volume 2) shows sedimentation over the final slack period (LW) of the modelled spring-neap tidal cycle, which clearly illustrates how these disposed sediments are dispersed with time.

Impact

- 6.5.1.31 Sediment dispersion from the Swansea (Outer) licensed deposit ground (LU130) will be largely constrained to the Inner Bristol Channel, although extending towards the shoreline between Kenfig Burrows and Porthcawl. Temporary short duration peaks in SSC may reach *circa* 3,500 mg/l in relatively close proximity to the deposit ground for short periods of time (minutes). General increases in SSC, however, are typically below 500 mg/l, falling rapidly to less than 10 mg/l over slack periods (LW and HW) when sedimentation occurs. In close proximity to the shoreline (i.e. within 100 m of MHWS), maximum increases in SSC at any given time are predominantly below 10 mg/l. Following cessation of the capital dredge disposal activities associated with the Project, all increases in SSC will revert to background levels in less than two spring-neap tidal cycles.
- 6.5.1.32 The magnitude of the disposal impact is considered to be medium due to the extent of coverage of the plume within the Inner Bristol Channel (and offshore areas of Swansea

Bay), with the probability of occurrence as high. The exposure is therefore considered to be medium. As the deposit ground has been extensively used historically, receiving much greater volumes of sediment than that proposed for the Project, the sensitivity of the deposit ground and seabed in the area of the plume is considered to be low. This gives rise to a low level of vulnerability both immediately adjacent to the site, and further afield to the extents of plume dispersion. The vast majority of the extent of plume dispersion covers areas which are not environmentally designated and have been impacted from similar disposal events over a considerable time period without significant effect. Whilst sediment dispersion from the disposal activities extends towards the Kenfig SAC, predicted changes in SSC are in the order of background variation (and relatively short lived), and will have no impact on the designated features of the Kenfig SAC (i.e. the sand dunes) as no sedimentation has been predicted to occur. As such, the overall receptor importance for the total plume extent is considered to be low. Therefore, the level of potential significance is considered as **neutral** for the extent of the disposal plume.

Modification to the existing seabed

Capital dredging and seawall construction

- 6.5.1.33 During Phase 1 of the construction period, capital dredging up to a depth of 2m will be required within both the western and eastern sections of the Lagoon in order to provide material for lagoon seawall construction. As such, the removal of this material will potentially change the character of the seabed sediments at these locations, which may have an impact on species composition; which is assessed separately in Chapter 8: Intertidal and Subtidal Benthic Ecology.
- 6.5.1.34 As described previously, the seabed sediments found within the dredge footprint to the western side of the Lagoon predominantly comprise sandy gravel and gravelly sand, intermittently covered by a thin sand veneer. Following the completion of the proposed capital dredging works at this location, the seabed is expected to still predominantly comprise slightly gravelly to gravelly medium sands, albeit with increased clay fractions. Approximately mid-way along the western seawall arm, a pocket of silty clay sediments with thin partings of fine sand may be encountered at the base of the dredged area. Along the eastern side of the Lagoon, seabed sediments predominantly comprise sands and slightly gravelly sands. On completion of the proposed capital dredging for the eastern seawall, the seabed sediments are expected to comprise slightly gravelly to gravelly medium sands, with rare lenses of clay and shell fragments. Whilst changes in seabed character are likely to be more pronounced within the footprint of the temporary bund structure, resulting from greater dredge depths, these changes will be short-term (i.e. the seabed will be constructed upon).
- 6.5.1.35 In addition to seabed character changes, a total loss in seabed will arise from the construction of the lagoon seawalls, i.e. the seabed will be situated underneath the seawalls and will no longer be subject to physical processes. It has been estimated that during the construction of the western and eastern (Phase 1) seawalls, approximately 20.5 and 21.7 ha of intertidal and subtidal seabed will be lost, respectively. These losses are based on the total footprints of the seawalls. Furthermore, during the construction of the temporary seawall around the turbine/ sluice gate structure, there may be a potential loss in subtidal seabed of up to 20.3 ha (worst case); this includes both the footprint of the temporary bund and the enclosed area. Note there will be a gain of habitat on the walls of the new structures which will offset this loss to some degree. Although not included in this assessment further details can be found in Chapter 4. Table

4.4a and 4.4b and the assessment in terms of habitats is provided in Chapter 8: Intertidal and subtidal benthic ecology.

Impact

- 6.5.1.36 Whilst some changes in the character of the seabed (in terms of sediment composition and distribution) are expected as a result of the proposed capital dredging works, these changes are relatively small in magnitude, with sediments remaining very similar to those presently found on the seabed. As such, there will be no significant impact to the character of the seabed within the capital dredge pockets along the western and eastern sides of the Lagoon.
- 6.5.1.37 More importantly, however, are the expected seabed losses that will result from the construction of the seawalls. Based upon the loss values provided above, it is predicted that approximately 0.85% and 0.21% of intertidal and subtidal seabed will be lost within Swansea Bay, respectively; with Swansea Bay defined as extending between Mumbles Head in the west and Porthcawl Point in the east. Furthermore, an additional 0.2% of subtidal seabed (worst case) will be lost during the construction of the temporary bund around the turbine/ sluice gate construction area within the bay; although this loss will lessen with the removal of the temporary bund during Phase 3 of the construction works. Based upon these estimated changes, the maximum magnitude of change is considered small; i.e. immediate spatial extent (within the Project footprint) with scale of change greater than natural variability. The probability of occurrence for this change is high, and therefore the exposure to change is assessed as low. The sensitivity of the seabed affected is considered to be low, giving rise to a low vulnerability to such change. As these modifications to the existing seabed will be occurring outside of any designated areas, the receptor importance is considered low due to the limited potential socio-economic importance of the seabed within Swansea Bay. As such, the overall level of potential significance is considered **neutral**.

Dredge disposal

- 6.5.1.38 The Swansea (Outer) deposit ground is generally characterised by sandy muds, however, the site has received a range of material through its operational life which may have led to short-term local changes in seabed sediment characteristics. Given the similarity of the proposed dredgings to sediments regularly received by the deposit ground and its dispersive nature, in which the capital dredgings from the Project are likely to be dispersed into the water column (i.e. over a couple tides), there will be no significant impact to the character of the seabed.

Changes to the coastal hydrodynamics

Capital dredging and seawall construction

- 6.5.1.39 The initial construction of the western seawall will essentially divide the existing inshore bay-scale hydrodynamic conditions into two smaller coastal cells, principally impacting upon tidal flows, and to a lesser extent waves. The impact of the western seawall will increase during the construction phase, as its extent into Swansea Bay increases. Taking into consideration the location and full extent of the western seawall, it is expected that any change in the tidal currents resulting from its construction will largely be limited to the region between Mumbles Head and the Neath Channel (inshore of the 10m below CD contour).
- 6.5.1.40 As detailed previously within the baseline section (Section 6.4.2), tidal currents in the western region of the bay (i.e. between Mumbles Head and Swansea Docks) are greatly

influenced by the headland. The flood tidal flows passing close to Mumbles Head initially diverge away from the rectilinear flows found further offshore to fill the western side of the bay, i.e. orientating around Mumbles Head and towards the western shoreline. As the tide rises, an anticlockwise eddy is generated in the lee of the headland. Within the eastern side of the bay, i.e. between Swansea Docks and the Neath Channel, the baseline flood tidal flows are orientated more generally to the north and north-east. On the ebb tide, there is once again a clear distinction between the tidal conditions found across the western and eastern sides of Swansea Bay. Within the western region of the bay, ebb tidal currents are generally orientated south to south-south-east until approximately HW + 3 hours, when the tidal flows rotate anticlockwise (to approximately south-east) in order to pass around Mumbles Head. In contrast, tidal flows within the inshore eastern region of the bay (between Swansea and the Neath Channel) are largely orientated south-west throughout most the ebb tide.

6.5.1.41 The characteristics of the baseline flood and ebb tidal currents within Swansea Bay lead to a clear tidal residual pattern (see Figure 6.40, Volume 2), which includes:

- i. an anticlockwise circulation eddy to the west of Swansea Channel, extending from the shoreline to the 10m below CD contour;
- ii. shoreline parallel residuals across the Swansea Bay intertidal areas in a westerly direction between Mumbles Head and Port Talbot; and
- iii. north-east tidal residuals in the eastern region of the bay, between 0m CD and the 10m below CD contour, orientated towards Aberafan Sands and Port Talbot.

6.5.1.42 Following construction of the western seawall, local changes in flow directions (and potentially current velocities) are expected throughout a tidal cycle. During a flood tide, the seawall is expected to restrict the easterly extent of the anticlockwise eddy presently found in the lee of Mumbles Head, with tidal currents immediately to the west of the seawall (i.e. within 250m) expected to become orientated more parallel to the structure towards the River Tawe. The presence of the seawall will also prevent tidal flows along the shoreline between the western and eastern sides of the bay. To the east of the western seawall, changes in flood tide flow directions are expected to occur immediately adjacent to the structure, with flows being aligned parallel to the seawall. Within the shallow areas (less than 2m below CD) between Swansea and Crymlyn Burrows (i.e. within the footprint of the Lagoon), the western arm of the Lagoon is likely to result in a small anticlockwise eddy being generated at the root of the seawall. It should also be highlighted that changes in the bathymetry through dredging may also have a small and localised impact on flow speeds and directions along the eastern side of the western seawall, predominantly leading to reduction in flow speeds and an increased potential for sedimentation. These changes are, however, expected to be negligible compared to any changes caused by the structure itself.

6.5.1.43 In contrast, during an ebb tide the presence of the western seawall will hinder the south-westerly movement of tidal flows from the eastern side of the bay, particularly at higher states of the tide (between HW and HW + 3 hrs). As a result, these flows will be aligned more southerly (anticlockwise) towards the offshore region. Beyond this time, it is expected that the structure will have a minimal impact on tidal flows within the eastern region of the bay. Owing to the ebb tide characteristics within the western part of the bay, no considerable changes in flow directions are expected as the western arm is located near the divide in tidal characteristics within the bay.

- 6.5.1.44 These changes in flow direction are likely to have a small impact on current velocities within Swansea Bay over a tidal cycle, with a likely reduction in mean velocities within the western region of the bay. It is unlikely that there will be any increase in peak current velocities, except potentially around the head of the structure, which would be a temporary effect. Changes in flow speeds have been investigated further for the operational phase of the impact assessment using results from the numerical modelling and are discussed in Section 6.5.2.4.
- 6.5.1.45 Importantly, when changes in flow directions are considered with respect to residual tidal currents (discussed previously in Section 6.4.2.7), the construction of the western seawall in Swansea Bay is expected to:
- i. reduce the anticlockwise residuals in the western part of the bay near Swansea, particularly across the intertidal between Singleton Park and the entrance to the River Tawe;
 - ii. remove the shoreline parallel westerly tidal current residual across the landfall location of the western seawall, which would typically extend into the western section of the bay; and
 - iii. realign the tidal residuals immediately along the western side of the seawall to a more northerly direction, and to a south-westerly direction (rather than a north-westerly direction) along the eastern side of the seawall.
- 6.5.1.46 In addition to the predicted changes in tidal currents, the presence of the western seawall will also have an impact on waves within Swansea Bay. The orientation and extent of the western arm will provide shelter from waves approaching from the south-east, particularly along the Swansea shoreline between Singleton Park and the entrance to the River Tawe, but also in the immediate lee of the structure. Under south-west wave conditions, the seawall will also cause diffraction of waves around its end, thus reducing wave activity in its lee and towards the shore to the east.
- 6.5.1.47 Following completion of the western seawall, Phase 1 of the construction programme also includes the initial construction of the eastern seawall. The presence of this additional structure will not further impact upon hydrodynamic conditions within the western region of Swansea Bay (to the west of the western arm). Within the eastern region of the bay, however, the additional structure will have a further 'combined' impact on tidal flows. These changes principally relate to the ebb tide, in which flows at the mouth of the Neath are expected to be hindered from passing in both a west and south-westerly direction during initial stages of the ebb tide (approximately between HW and HW + 3 hours), thus turning more southerly (anticlockwise). This change will contribute to a reduction in residual tidal currents in a westerly direction along the intertidal fronting Crymlyn Burrows, but will also potentially lead to a net tidal residual in a southerly direction along the eastern side on the seawall. The initial construction of the eastern seawall will also provide a limited amount of wave protection to the Crymlyn Burrow frontage between the structure and the entrance to the River Neath to waves approaching from the south-west (i.e. the predominant wave direction). Residual tidal currents are shown in Figure 6.41 (Volume 2).
- 6.5.1.48 Furthermore, the construction of the temporary bund around the turbine/ sluice gate construction area will not substantially alter the expected hydrodynamic changes resulting from the construction of the western seawall, albeit with some localised variations in current direction and velocity towards the southern end of the structure.

Impact

- 6.5.1.49 The proposed capital dredging and construction works during Phase 1 of the construction programme will cause a change to the coastal hydrodynamics within Swansea Bay, specifically changes to flow direction and velocities, but also waves. Most of these changes are expected to occur within the western region of the bay, where the anticlockwise tidal residuals will be hindered by the construction of the western seawall, with reductions in flow velocities along the upper intertidal area expected. Further changes in flow direction and velocities will occur in close proximity to the structures, in which flows will largely become trained parallel to them at certain stages of the tide, with the potential for localised flow accelerations. The presence of the western and eastern seawall structures will also prevent westerly tidal residuals across the bay, specifically along the intertidal, between the Neath and the western Bay. With respect to waves, the western seawall is expected to provide additional shelter to the Swansea frontage from south-east wave conditions, whilst the initial section of the eastern seawall will provide some limited protection to the Crymlyn Burrow frontage from waves approaching from the south-west. Neither structure will impact upon wave conditions at Aberafan Sands, which are of recreational importance to local surfers.
- 6.5.1.50 Overall, the impacts on the coastal hydrodynamics remain confined to Swansea Bay, but these changes are not considered within the natural variability of the system. However, as these impacts are likely to change during both the construction and operation phases, the magnitude of this impact is, therefore, assessed as medium. As these impacts are almost certain to occur, the probability of occurrence is considered as being high, with exposure to change assessed as being medium. For the most part, the bay is likely to be tolerable to such changes (particularly within the subtidal regions), however these changes are likely to have a more pronounced effect across the expansive intertidal areas within the bay. Within the subtidal and undesignated intertidal areas, the sensitivity of the receptor is assessed as low, therefore resulting in a low vulnerability assessment. For the most part, the undesignated subtidal region of the bay will adapt to the hydrodynamic changes, therefore the receptor importance is considered to be low. As such, the relative level of significance is assessed as **neutral**. Contrastingly, whilst the sensitivity of the receptor within the nationally designated intertidal areas at Blackpill and Crymlyn Burrows are also considered as being low, resulting in a low vulnerability assessment, the importance of the receptor across these designated areas of intertidal are assessed as being moderate. Whilst changes in the coastal hydrodynamics experienced at both locations are inherently different, the overall level of potential significance is assessed as **minor adverse / neutral**.

Dredge disposal

- 6.5.1.51 The Swansea (Outer) deposit ground area was surveyed by the Admiralty in 1966 and then again between 1988 and 1993. Using the limited information shown on Admiralty Chart 1161, the average depth across the disposal area was found to decrease by approximately 0.5 m. During the period between the two surveys, approximately 70 million m³ of material was deposited in the area, thus the depth change only accounts for about 4% of the material disposed, therefore indicating that the ground has a long-term dispersive nature.
- 6.5.1.52 Taking account of the limited bathymetric change that has occurred historically following significant disposal volumes, the dispersive nature of the tidal flows at this location mean that disposal of the proposed capital dredge sediments (predominantly silts and muds) will have no significant impact on bathymetry levels in the long term. Temporarily,

however, accumulations will occur due to the dredger disposal, before they are eroded by the natural flows. As such, there will be no significant impact to hydrodynamic or sediment patterns local to the deposit ground, therefore the significance assessment is **neutral**.

Changes to the sediment (morphological) regime

Capital dredging and seawall construction

- 6.5.1.53 Taking into consideration the changes to the hydrodynamic conditions that are likely to result from the first phase of the capital dredging and construction works (assessed previously and relating to the western seawall), it is expected that there will be some associated changes to the sediment regime, and hence morphology, within Swansea Bay.

- 6.5.1.54 Following the construction of the permanent western and eastern (Phase 1) seawalls and the temporary bund around the turbine/ sluice gate structure, predicted changes to both flow speeds and directions within the western region of Swansea Bay is likely to result in the increased potential for sedimentation of fine sediments, principally muds. Increased rates of sedimentation are likely to be experienced predominantly along the Swansea Channel, i.e. immediately to the west of the western seawall, and within the shallow subtidal areas adjacent to the Blackpill SSSI (but not within the designated intertidal itself). Immediately to the east of the western seawall, it is likely that a small anticlockwise eddy will be formed at the landfall (root) of the seawall, which in combination with localised changes in flow speeds and directions associated with the capital dredge pocket, may also result in the increased potential for sedimentation of muds in this area. In contrast, potential increases in sediment mobility (erosion) are expected around the heads (offshore end) of the seawall structures, where flow speed increases are expected to occur.

- 6.5.1.55 Under the predominant SW wave conditions within Swansea Bay, the western seawall and temporary bund are expected to provide some shelter to the shoreline immediately to the east, thereby reducing the potential for littoral drift (of sand) in an easterly direction towards Crymlyn Burrows. More importantly, however, the presence of the eastern seawall is expected to greatly reduce the wave conditions more normally experienced within the entrance to the Neath (particularly to the north end of the channel), which may lead to an increased potential for sand accumulation in this area. Under SE wave conditions, shelter will be provided to the west of Swansea Docks by the presence of the western seawall and temporary bund, thereby reducing any potential disturbance of seabed sediments across the intertidal and beaches under storm conditions.

- 6.5.1.56 Furthermore, the overall presence of these structures within Swansea Bay will likely hinder any potential transport of sand (in suspension) from east to west across the bay, i.e. from the Neath towards Blackpill, under storm conditions (with large waves approaching from the SW). It is during these storm conditions when wave disturbance may infrequently be sufficient to re-suspend sandy sediments within the entrance to the Neath, which may then be subject to westerly sediment transport across the bay under large spring tide ebb flows between *circa* HW and HW + 3 hours. Any such transport is unlikely to occur under more 'normal' tide and wave conditions. Changes to the potential aperiodic transport of sand into the western side of the bay (from the offshore region) under extreme SE wave conditions are not expected (see paragraph 6.4.3.37). Overall, the potential net loss of infrequent sand supply to the western region of the bay may

slightly increase the potential for beach erosion between West Cross and Singleton Park in the long-term.

Impact

- 6.5.1.57 The proposed capital dredging and construction works during Phase 1 of the construction programme will likely have an impact on the sediment (morphological) regime within Swansea Bay. The greatest changes are expected to occur within the western region of the bay, with the potential for increased accumulation of fine (muddy) sediments within the shallow subtidal areas adjacent to the Blackpill SSSI and a potential reduction in the infrequent supply of sandy sediments (under storm conditions) from the Neath. This potential reduction in sand supply may possibly lead to a small long-term net erosion (over the operation period) of the sandy beaches within the western region of the bay. Other potential changes will occur to the north of the Neath Channel, along the Crymlyn Burrows frontage, where increased sand accretion is likely to occur due to the increased shelter (reducing the erosion potential) provided by the eastern seawall to SW wave conditions.
- 6.5.1.58 Whilst the impacts on the sediment regime are confined to Swansea Bay, these changes are not considered within the natural variability of the system. The magnitude of effect on the sediment regime increases from negligible in the Inner Bristol Channel, to low in the subtidal areas of the bay and medium across the intertidal; especially in the area immediately either side of the root of the western and eastern seawalls. As these predicted changes are almost certain to occur, the probability of occurrence is considered as being high. Therefore, the exposure to change ranges from negligible offshore, through to medium at the shoreline in the vicinity of the seawall works. For the most part, the subtidal regions of the bay are likely to be tolerable to such changes, therefore, the sensitivity of the morphological regime is considered low, and the vulnerability of the subtidal bay area is assessed as low. Receptor importance across the undesignated subtidal areas is considered to be low. As such, the level of significance within the subtidal areas of Swansea Bay is assessed as **neutral**.
- 6.5.1.59 Across the intertidal areas of the bay, however, changes in the sediment regime are likely to have a more pronounced effect. This is particularly evident within the entrances to the Neath, i.e. along the Crymlyn Burrows frontage, where enhanced sand accretion is expected to occur. The sensitivity of the receiving environment within this area with respect to sand accretion is considered low, as historically there have been significant changes in sand accretion/ erosion across the Crymlyn Burrows frontage, Baglan intertidal and Aberafan Sands. Due to the nationally designated SSSI at Crymlyn Burrows, the receptor level of importance in this local area is considered to be moderate. Therefore, the overall impact significance is assessed as **minor adverse / neutral**. It should be highlighted, however, that the potential for increased sand supply to the Crymlyn Burrows might also be considered a beneficial impact, as this additional sand may 'feed' the dune system.
- 6.5.1.60 As mentioned previously, a potential reduction in sand supply to the western region of Swansea Bay may lead to a small, long-term net erosion of the sandy beaches within the upper extents of the intertidal, i.e. in a narrow band fronting the existing coastal defences. The sensitivity of the receptor in this specific area is assessed as moderate, therefore resulting in a moderate vulnerability assessment. As these beaches are situated within the nationally designated Blackpill SSSI, the receptor importance is defined as moderate. As a result, the level of potential significance is assessed as **moderate/ minor adverse**. Elsewhere across the Blackpill SSSI, i.e. across the lower

sandy mud/ muddy sand intertidal, the likelihood of change as a result of the Project is much less and the sensitivity of the receptor is considered low, as is the vulnerability at this location. Based on this outcome, and the receptor importance still remaining moderate, the overall impact significance across the wider Blackpill SSSI (away from the upper sandy beaches) is generally considered to be **minor adverse / neutral**.

Phase 2

- 6.5.1.61 During Phase 2 of the construction, capital dredging and seawall construction works will continue on the eastern arm; a distance of approximately 3.1 km. The same capital dredging and construction process as described for will be followed, with the seawall built sequentially using layers of Geotubes® (in two rows), with the void between them filled with sand and gravel. It is expected that dredge material for this section of the seawall will be predominantly extracted from the eastern and southern sides of the Lagoon to a depth of 2m below the existing seabed surface. The Geotubes® will then be covered with a geotextile and a small sized rock under layer. A larger sized rock layer will then be placed on the seaward side of the seawall, with the depth of this layer varying with location to provide wave protection.
- 6.5.1.62 In addition to the construction works on the eastern arm, operations will also begin on the construction of the turbine and sluice gate structure within the cofferdam. Initially, water trapped within the temporary bund enclosure will be pumped out. The water will be pumped directly into the sea, possibly through silt traps if the seabed is disturbed during the final stages of the emptying operation. Once the enclosure has been emptied, construction of the turbine and sluice structure will begin. This work will take place within the temporary bund structure and will have no direct interaction with the marine environment. Following the completion of the structure, the turbines and sluice gates will be installed (also inside the temporary bund).
- 6.5.1.63 The programme timescale for Phase 2 assumes that the capital dredging and construction works associated with the continuation of the eastern seawall will take around 3 months (within the period roughly between April and October). Whilst it is considered that a high level of efficiency will be maintained, this timescale does take weather and mechanical delays into consideration.

Impact identification

- 6.5.1.64 The environmental impacts of the proposed Phase 2 dredging and construction works include:
- i. sediment dispersion arising from the dredge plant disturbing sediments into the tidal flows and through the infilling of both the Geotubes® and the seawall voids, thus creating a plume which will impact the water column and estuary bed;
 - ii. sediment dispersion arising from the pumping of water from the temporary bund enclosure, potentially causing an increase in SSC;
 - iii. the direct removal (loss) or physical modification to the existing seabed, primarily the bathymetry and bed characteristics;
 - iv. modification to both near and far-field hydrodynamics (e.g. water levels, flow speeds and waves) as a result of construction works; and

- v. direct and indirect changes to the sediment (morphological) regime due to erosion/accretion from the presence of the new infrastructure, driven by changes to sediment transport within Swansea Bay.

Sediment dispersion (water column and seabed)

Capital dredging and seawall construction

- 6.5.1.65 As previously detailed for Phase 1, during the continued construction of the permanent eastern (Phase 2) seawalls, sediment dispersion will occur from: sediment disturbance at the seabed by the CSD, sediment loss during the filling of the Geotubes® and sediment disturbed to the water column from the hydraulic infill of the void between the Geotubes®. As these activities will occur simultaneously, the resulting sediment dispersion and their impacts on the water column and seabed is jointly assessed. Whilst numerical modelling has not been specifically used to simulate dredging and construction operations along these sections of the eastern seawalls, modelling results from other representative locations (i.e. for the eastern seawall section constructed during Phase 1) is used to inform the potential extent and magnitude of sediment dispersion and sedimentation that may arise from these works.
- 6.5.1.66 Phase 2 of the of the eastern seawall construction works is split into two sections, the first section (east) stretches in a south-westerly direction from the end of the previous eastern seawall (Phase 1) works, whilst the second section (west) extends in a south-easterly direction from the temporary bund surrounding the turbine/ sluice gate construction area. Due to a slight variation in the hydrodynamic processes (i.e. tidal flows and waves) experienced along each of these sections of the eastern seawall, the potential distribution of sediment dispersion (and any potential sedimentation) is discussed separately for each.
- 6.5.1.67 For the east section of the seawall construction works, it is envisaged that the distribution of sediment dispersion will be of a similar pattern to those modelled for Phase 1 of the eastern seawall; see Figure 6.22 (Volume 2) for maximum increases in SSC. A sediment plume will predominantly extend along a north-east to south-west axis between the River Neath and the Mumbles, with further dispersion into the centre of Swansea Bay. At the dredge/ fill location, peak depth-averaged concentrations are expected to be in the region of 300 to 400 mg/l (above background) for brief periods of time (minutes), with concentrations dropping to less than 50 mg/l over a period of around 24 hours following cessation of the works. SSCs are expected to return to background concentrations over a spring-neap tidal cycle. Peak increases in SSC within the Neath approach channel and along the Crymlyn Burrows frontage (to the east of the Lagoon structure) are expected to be reduced compared to baseline conditions, in the order of 50 to 100 mg/l (above background). Following cessation of the dredging and construction (sediment filling) works, however, SSC will return to background levels within approximately 5 days. A greater proportion of the dispersed sediment is also likely to pass into the Lagoon due to changes in hydrodynamic processes in the immediate vicinity of the existing eastern seawall (Phase 1). In a south-westerly direction away from the dredge/ construction operations, peak increases in depth-averaged SSC may reach 40 mg/l above background in the vicinity of the Mumbles, decreasing to less than 10 mg/l in the region of Caswell Bay. This is considered the maximum distance in which the sediment plume could realistically be recorded against background concentrations.
- 6.5.1.68 It is expected that a similar magnitude and spatial distribution of maximum sedimentation seen for the representative Phase 1 eastern seawall works, shown in

Figure 6.24 (Volume 2), is also likely to occur for the east section of the Phase 2 eastern seawall works. The results show that sedimentation in excess of 1 mm is attained in the immediate vicinity of the works, but also along the Crymlyn Burrows frontage and towards the end of the Neath Channel. As detailed above, due to the presence of Phase 1 of the eastern seawall, potential increases in SSC within the north-east corner of the lagoon may subsequently lead to increased sedimentation within this area. For Phase 1, maximum sedimentation at the dredge/ construction location reached 4 mm during the works, although these sediments are rapidly eroded over a single tide (following cessation of the works). Elsewhere across Swansea Bay and beyond Mumbles Head (i.e. westerly towards Caswell Bay), maximum sedimentation rates are less than 1 mm and, therefore, insignificant.

- 6.5.1.69 For the west section of the seawall construction works, the pattern of sediment dispersion will be more akin to the western seawall construction (Phase 1). However, clear differences are envisaged. First, dredge and construction works will take place at a greater distance from the shoreline (in deeper water), where sediment dispersion may be subject to increased circulatory patterns within the western region of the bay. Secondly, there is a potential for increased sediment dispersion to the eastern side of the bay over the flood tide, possibly to the extent of the Neath Channel; although to a considerably lesser extent than is seen for the eastern seawall (Phase 1) representative model scenario. As a result of this increased spread of sediment dispersion across Swansea Bay, peak SSC concentrations at the dredge/ fill location will be less than those seen for the east section of the seawall works, possibly in the order of 200 to 300 mg/l (above background). Elsewhere within Swansea Bay, peak increases in SSC are likely to be in the order of 20 to 60 mg/l, with possible localised increases in the region of 100 mg/l within the Swansea Channel and in the immediate vicinity of the works (i.e. within 200 m). These concentrations, however, would rapidly fall to background levels following cessation of the dredge/ fill activities. Furthermore, increases in SSC are likely to be indiscernible from natural background variations outside of Swansea Bay beyond Caswell Bay.
- 6.5.1.70 During the proposed works, it is expected that maximum sedimentation will be greatest within the immediate vicinity of the dredging/ infill operations with values expected to be in the order of 10 to 30 mm, whilst also possibly exceeding 1 mm within sections of the Swansea Channel. Elsewhere within the extents of the sediment dispersion plume, maximum sedimentation will be less than 1 mm for any representative single section of Phase 2 seawall (150 m in length), and therefore expected to be indistinguishable from natural conditions.

Impact

- 6.5.1.71 Taking into consideration the available numerical modelling outputs from Phase 1, it is assessed that the maximum magnitude of change on the water column and seabed is small compared against the background SSC in the context of Swansea Bay as a whole, but medium in close proximity to the works. These effects are not cumulative with Phase 1. Furthermore, these changes are relatively short-lived with increases in SSC dissipating to background concentrations within a spring-neap tidal cycle on cessation of the works. Changes outside Swansea Bay are unlikely to be distinguished from the natural variability. The probability of occurrence of these changes are considered high, as numerous dredging and sediment filling events will be required to complete Phase 2 of the eastern seawall. However, this will cease on completion of the works. The exposure to change is therefore classified as medium at worst close to the dredging/ fill operations, but low with respect to the wider bay. The coastal process receptors within

Swansea Bay will be largely tolerant to such changes in the sediment regime, and so the sensitivity of the receptors is classified as low, giving rise to a low vulnerability. The modelling indicates that the maximum extent of the changes has a potential to impact upon the SSSI at Crymlyn Burrows, and therefore the receptor importance in this area is considered moderate, whilst the wider Swansea Bay is assessed as low. On this basis, the significance of the impact is considered **minor adverse / neutral** in the area of Crymlyn Burrows and **neutral** for the wider bay.

- 6.5.1.72 As detailed previously for Phase 1, the proposed capital dredging and construction works have the potential to remobilise contaminants that may be trapped within the sediments. Taking into consideration the sediment contaminant analysis results discussed in Section 6.4.4, where sediment samples did not exceed Cefas Action Level 2 for any specific contaminant, the risk of contamination through these proposed works to other areas of Swansea Bay (or the Bristol Channel) are therefore not considered significant for the Phase 2 works, similarly to Phase 1.

Dewatering of the turbine/ sluice gate construction area

- 6.5.1.73 During the construction of the temporary bund around the turbine/ sluice gate structure in Phase 1, the closure of the bund would have been started at low tide to leave the minimum amount of water trapped in the enclosure. This volume of water, estimated to be in the region of 1,000,000 m³, has to be pumped out towards the start of Phase 2 before construction on the turbine/ sluice gate structure can begin. Whilst this volume of water would have been laden with (suspended) sediment prior to the closure of the temporary bund, these sediments will settle to the bed relatively quickly without disturbance provided by tides and waves. As such, little to no sediment will initially be provided to Swansea Bay when this water is pumped from the enclosure. However, during the final stages of this emptying operation there may be increased disturbance of seabed sediments, which could result in their suspension. As such, these sediments (entrained within the water column) may be pumped into Swansea Bay from the enclosure, leading to sediment dispersion. Sediment dispersion arising from this operation will be significantly less (with respect to both magnitude and extent) than that assessed for the construction of the temporary bund, with any dispersion likely to be fairly local to the outfall pipe (i.e. within a few hundred metres) at concentrations detectable against the natural variability in background concentrations.

Impact

- 6.5.1.74 All increases in SSC within the water column as a result of the dewatering operation, predominantly in the final stages, will quickly revert to background levels following completion of the pumping. Importantly, it has also been indicated in Chapter 4, that silt traps may be used (if needed) during the final stages of the pumping operation should seabed sediments become disturbed. This will limit any potential sediment dispersion. As such, the magnitude of impact is considered to be at worst small, with the probability of occurrence as low. The exposure is therefore considered to be negligible. As any increase in SSC would be short-lived, and most probably within the levels of natural variability, the sensitivity of the receptor is considered to be low. This gives rise to no vulnerability. The significance of the dewatering of the temporary bund is therefore **neutral**.

Modification to the existing seabed

Capital dredging and seawall construction

- 6.5.1.75 During Phase 2 of the construction period, it is expected that material will be predominantly extracted from the eastern and southern sides of the Lagoon, to a depth of 2m below the existing seabed, for the continued construction of the permanent eastern seawall. The material types to be dredged are the same as for the Phase 1 works, therefore the modifications to the seabed character will also be the same as assessed for Phase 1.
- 6.5.1.76 In addition to seabed character changes, a total loss in seabed will arise from the continued construction of the eastern seawall. It has been estimated that during Phase 2 of its construction, approximately 27.2 ha of subtidal seabed will be lost, whilst no further loss in intertidal seabed will take place; all intertidal loss occurs during Phase 1 of seawall construction works only.

Impact

- 6.5.1.77 As described previously for Phase 1, whilst some changes in the character of the seabed (in terms of sediment composition and distribution) are expected as a result of the proposed capital dredging works, these changes are small, with sediments remaining similar to those presently found on the seabed. As such, there will be no significant impact to the character of the seabed within the capital dredge pockets along the eastern and southern sides of the Lagoon.
- 6.5.1.78 Based upon the loss values provided above, it is predicted that approximately 0.26% of subtidal seabed will be lost within Swansea Bay as a result of the continued construction of the permanent eastern seawall. In total, approximately 48.9 ha of subtidal seabed (equivalent to approximately 0.47% of the bay) will be lost through the construction of the permanent seawalls during construction Phases 1 and 2, whilst there will be no additional loss in intertidal seabed. Taking these estimated losses into consideration, the maximum magnitude of change is assessed as small/ medium. The probability of occurrence for this change is high, and therefore the exposure to change is, at worst, medium. The sensitivity of the seabed affected is low giving rise to a low vulnerability to such change, predominantly as a result of the scale. As previously identified through the impact assessment in Phase 1, these modifications to the existing seabed will be occurring outside of any designated areas, therefore, the receptor importance is considered low due to the potential socio-economic importance of the seabed within Swansea Bay. As such, the overall level of potential significance is conservatively assessed as **neutral**, i.e. the overall impact significance is not increased with Phase 2 over the seabed effects from Phase 1.

Changes to the coastal hydrodynamics

Capital dredging and seawall construction

- 6.5.1.79 During the construction period, the most significant changes to coastal hydrodynamics within Swansea Bay will result from the initial construction works during Phase 1, which have been described and assessed previously (Paragraph 6.5.1.39 onwards). The continued construction of the permanent eastern seawall during Phase 2 is unlikely to have any further substantial impacts to the western region of the bay, nor in the vicinity of the Neath Channel. However, noticeable changes are expected to occur within the

footprint of the Lagoon and in the vicinity of the gap remaining between the west and east sections of the eastern seawall.

- 6.5.1.80 As the proposed construction works progress over Phase 2, the gap remaining in the eastern seawall will reduce to approximately 1.5 km; with this final section of the seawall to be completed during Phase 3. As this gap narrows, water volume exchange between the bay and Lagoon will become increasingly more constrained, which will inherently lead to changes in flow speeds and direction through the gap and within the Lagoon itself. Over the flood tide, tidal flows passing into the Lagoon will be slightly accelerated through the gap, with the potential for a large clockwise circulatory gyre to be generated within the eastern side of the lagoon; likely resulting in much reduced (average) flow speeds within the footprint of the Lagoon compared to baseline conditions. Over the ebb tide, accelerations through the gap are once again expected to occur, with these increases anticipated to continue to some extent within the bay. In turn, these increased flows will likely modify the ebb flows adjacent to the gap, potentially orientating them in a slightly more southerly direction.
- 6.5.1.81 Phase 2 of the construction works will also provide additional shelter to the shoreline within the footprint of the Lagoon from both SW and SE wave conditions, albeit with increased wave diffraction expected to occur around the ends of the seawalls within the Lagoon. Outside the Lagoon, there is potential for increased wave heights within the bay immediately adjacent to the SW section of the seawalls as a result of wave reflection. In the western region of the bay, this could marginally increase significant wave heights between Mumbles Head and possibly West Cross from SW waves. Similarly, SE waves would be reflected causing some increases in wave height on the eastern side local to the seawall.

Impact

- 6.5.1.82 Overall, changes to the coastal hydrodynamics resulting from Phase 2 of the construction works are considerably less than those identified during Phase 1, and remain confined to Swansea Bay. The combined magnitude of changes associated with both phases of the construction works are considered as medium, and not within the natural variability of the system. The probability of these changes occurring is considered as being high, therefore, exposure to change is assessed as being, at worst, medium. Whilst the bay may largely be tolerant of such changes (particularly within the subtidal regions), these changes are likely to have a more pronounced effect across the expansive intertidal areas within the bay. As such, within the subtidal and undesignated intertidal areas, the sensitivity of the receptor is assessed as low, therefore resulting in a low vulnerability assessment. For the most part, these undesignated regions of the bay (particularly the subtidal) will adapt to the hydrodynamic changes, therefore the receptor importance is considered to be low. As such, the relative level of significance is assessed as **neutral**. Contrastingly, whilst the sensitivity of the receptor within the nationally designated intertidal areas at Blackpill and Crymlyn Burrows are also considered as being low, resulting in a low vulnerability assessment, the importance of the receptor across these designated areas of intertidal are assessed as being moderate; although the characteristics of the hydrodynamic changes are completely different at the two locations. Whilst changes in the coastal hydrodynamics experienced at both locations are inherently different, the overall level of potential significance is assessed as **minor adverse / neutral** at both locations.

Changes to the sediment (morphological) regime

Capital dredging and seawall construction

- 6.5.1.83 The potential combined changes to the coastal hydrodynamics resulting from both Phase 1 and 2 of the capital dredging and construction works will inherently have an impact of the sediment (morphological) regime with Swansea Bay. The initial construction works during Phase 1 are expected to result in the greatest changes, whereas the subsequent Phase 2 works are expected to further enhance these changes and change the overall distribution as a cumulative effect.
- 6.5.1.84 In the western region of the bay, predicted increases in wave heights resulting from wave reflection along the seawalls (under SW wave conditions) are likely to increase sediment disturbance across the intertidal between Mumbles Head and West Cross. Whilst under 'normal' wave conditions this is unlikely to have any significant morphological impact, under more extreme wave events (i.e. 1 in 1 year or greater) or during a prolonged stormy period over spring tides, this disturbance may potentially lead to increased erosion of the seabed sediments in this area, being greatest in closest proximity to the western seawall. Whilst similar wave reflection processes are experienced in the eastern region of the bay under SE wave conditions, these waves are typically much smaller and of a short period. As such, any increase in wave heights, and the associated impact upon morphology, is expected to be considerably less.
- 6.5.1.85 The greatest changes to the sediment regime as a result of Phase 2 of the construction works are expected to occur within the footprint of the Lagoon itself. Whilst flow speeds are likely to be accelerated through the gap in the seawalls on the flood tide, with the potential to remobilise and transport sand fractions into the Lagoon, flow speeds across the Lagoon in general are envisaged to reduce. As such, suspended sediments entrained within the water column are more likely to settle to the seabed within the scheme over HW, particularly towards the north of the Lagoon. Ebbing flow speeds are unlikely to be sufficient to remobilise a large proportion of this sediment. This change will lead to increased sedimentation rates within the Lagoon, particularly that of mud, further exacerbated by reduced wave disturbance of the seabed; caused by the increased shelter afforded to the Lagoon by the extensions to the eastern seawall.

Impact

- 6.5.1.86 Whilst the combined impacts of the Phase 1 and 2 construction works on the sediment (morphological) regime are confined to Swansea Bay, these changes are not considered within the natural variability of the system. The magnitude of change on the sediment regime increases from low in the subtidal areas of the bay to medium across the intertidal. As these changes will almost certainly occur as a result of the Project, the probability of occurrence is considered as being high. This gives rise to a low change in exposure within the subtidal region of the bay, increasing to medium exposure across the intertidal (particularly in close proximity to the works). For the most part, the undesignated subtidal (and the intertidal between the western and eastern seawalls) region of the bay are likely to be tolerable to periods of accretion and erosion, therefore the sensitivity of the morphological regime is considered low. Receptor importance across these undesignated areas is also considered low, therefore the overall level of impact significance is assessed as **neutral**.
- 6.5.1.87 Contrastingly, as previously assessed during Phase 1 of the construction period (see Section 6.5.1.53, onwards), the overall impact significance within the intertidal to the east of the Lagoon (within the entrances to the Neath) is assessed as **minor adverse /**

neutral, particularly within the designated Crymlyn Burrows SSSI. Within the western region of the bay, in the long term, a potential reduction in the net sand supply (aperiodically from the eastern side of the bay) to the beaches situated to the rear of the Blackpill SSSI results in a level of potential significance assessed as **moderate/ minor adverse**. However, across the lower intertidal, although still within the Blackpill SSSI (but away from the sandy beaches), the overall impact significance is generally considered to be **minor adverse / neutral**.

Phase 3

6.5.1.88 During Phase 3 of the construction, once the turbine and sluice gate structure and installation is complete, the temporary bund wall will be removed. The removal method depends on the option chosen, which are described further in Chapter 4. Based upon the descriptions of each option, Option 2, as presented below, is considered worst case with respect to potential impacts on coastal process receptors, particularly sediment dispersion to the water column and morphological change. A summary of this option is provided below:

- i. **Option 2:** The sediment with Geotubes® and rock armour would initially require the stone rock armour above water moved by land plant to a position where it can be used for the eastern seawall. The Geotubes® would then be split and emptied. Once the enclosure is flooded, the remaining sediment would again be removed by the CSD and placed into the eastern seawall.

6.5.1.89 Following the removal of the temporary bund wall, the final section of the permanent seawall will be completed. This section of seawall is approximately 1.5 km in length and joins the west and east sections of the eastern seawall arm (completed during Phase 2). The same capital dredging and construction process described previously for Phases 1 and 2 will be followed. It is expected that dredge material for this section of the seawall will be extracted predominantly from material re-dredged following the removal of the temporary bund wall around the turbine/ sluice gate structure, but possibly also from the southern side of the Lagoon to a depth of 2m below the existing seabed surface.

6.5.1.90 On completion of the seawall, a 'wet' commissioning will be undertaken. This procedure requires a head of water (hydrostatic head) within the lagoon, in which the water volume is then drained predominantly through the sluice gates, but also through each turbine (in turn) to commission them. The impact of this procedure on coastal process receptors has not been reported here, as the full operational procedure (i.e. the combined impact of all the turbines together) will be reported within the operational period assessment.

6.5.1.91 The programme timescale for Phase 3 assumes that the removal of the temporary bund and the capital dredging and construction works associated with the completion (closure) of the eastern seawall will take around 3 months. Whilst it is considered that a high level of efficiency will be maintained, this timescale does take weather and mechanical delays into consideration.

Impact identification

6.5.1.92 The environmental impacts of the proposed Phase 3 dredging and construction works include:

- i. sediment dispersion arising from the splitting and emptying of the Geotubes® during the removal of the temporary bund;

- ii. sediment dispersion arising from the dredge plant disturbing sediments into the tidal flows and through the infilling of both the Geotubes® and the seawall voids, thus creating a plume which will impact the water column and estuary bed;
- iii. the direct removal (loss) or physical modification to the existing seabed, primarily the bathymetry and bed characteristics;
- iv. modification to both near and far-field hydrodynamics (e.g. water levels, flow speeds and waves) as a result of construction works; and
- v. direct and indirect changes to the sediment (morphological) regime due to erosion/accretion from the presence of the new infrastructure, driven by changes to sediment transport within Swansea Bay.

Sediment dispersion (water column and seabed)

Removal of the temporary seawall bund around the turbine/ sluice gate structure

- 6.5.1.93 As described previously, in order to remove the temporary seawall bund under the Option 2 scenario, the rock armour placed over the temporary bund to provide wave protection would initially have to be removed. Once removed, the temporary seawall bund would comprise a large sediment mound (previously created through the pumping of sediments onto the seabed), fronted by a row of Geotubes® (3 Geotubes® in height) along its seaward side. When these Geotubes® are split, and subsequently emptied, sand and gravel sediments will be made available for sediment transport under the characteristic hydrodynamic regime within this region of Swansea Bay. Similarly, the rear sediment mound will now also be subject to sediment dispersion through tide and wave action, as the significant protection previously provided by the rock armour and Geotubes® has now been removed. Given the nature of the hydrodynamic processes occurring in the vicinity of the temporary bund, some sand will likely be transported towards the western region of the bay (driven by the anti-clockwise residual currents). Dispersion is also likely to occur offshore towards Mumbles Head and easterly towards the centre of Swansea Bay; although much of this transport is likely to be near-bed, rather than suspended.
- 6.5.1.94 Dispersion of finer sediments (muds) is likely to be limited, as a large proportion of these sediments would have been lost to the water column during the initial dredging and construction of the temporary bund. As such, the extent of the resulting sediment plume is envisaged to be smaller, with SSC increases (above background) also expected to be considerably less than seen in the representative western and eastern seawall scenarios modelled for Phase 1 of construction. Furthermore, increases in SSC are expected return to background levels over a single spring-neap tidal cycle. Realistically, a large proportion of the coarser sediments (sand and gravel) is unlikely to be transported away from the temporary bund structure in the short-term, and will therefore be available for re-dredging.

Impact

- 6.5.1.95 Overall, the magnitude of impact is considered to be small, with the probability of occurrence expected to be high. The exposure to change is therefore considered to be low. As any increase in SSC would be short-lived, and most probably within the levels of natural variability, the sensitivity of the receptor is also considered to be low. This gives rise to a low level of vulnerability. On the basis that the material is unlikely to be transported to the SSSI areas (e.g. Blackpill), the impact significance is considered to be **neutral**.

Capital dredging and seawall construction

- 6.5.1.96 Should the dredging and construction works on the remaining section of the eastern seawall start on its western side (i.e. closest to the turbine/ sluice gate structure), it is very likely that a large proportion of fine sediment dispersed during the works may initially be transported into the Lagoon over the flood tide. Once in the Lagoon, this sediment will rapidly settle over HW slack, and will be difficult to remobilise under the weakened tidal flow conditions found across the majority of the Lagoon. In such an instance, sedimentation rates within the Lagoon would be expected to be greater than rates found outside of the Lagoon. On the ebb tide, however, sediment dispersion will largely occur in a south-west direction towards the Mumbles, with some dispersion into the Central Bristol Channel likely, as seen during other phases of the construction works.
- 6.5.1.97 In contrast, should the dredging and disposal works begin on the eastern side of this wall section, it is envisaged that the distribution of sediment dispersion will be largely towards the Neath and the central bay area, with some exchange to the western region of Swansea Bay. Taking into consideration the representative scenarios modelled for Phase 1 of the construction works, peak depth-averaged SSC are not expected to exceed *circa* 300 to 400 mg/l in close proximity to the works. Furthermore, increases in SSC across the bay are unlikely to be distinguishable from background variability after a period of approximately 5 days following cessation of the dredging and construction works. Maximum sedimentation as a result of the activities is unlikely to exceed 1 mm across the majority of the plume extent. Localised increases will occur in close proximity to the dredge and construction works and within areas of reduced energy.

Impact

- 6.5.1.98 Taking into consideration the available numerical modelling outputs from Phase 1 of the construction works, it is assessed that the maximum magnitude of change that sediment dispersion arising from Phase 3 of the construction has on the water column and seabed is small compared against the background SSC in the context of Swansea Bay as a whole, but medium in close proximity to the dredging/ construction works. As detailed previously for Phases 1 and 2, expected changes to SSC are relatively short lived, with increases dissipating to background concentrations within a spring-neap tidal cycle on cessation of the works. The probability of occurrence of these changes are considered high, as numerous dredging and sediment filling events will be required to complete the seawall during Phase 3. As a result, the exposure to change is classified as low across the wider bay area, but medium in close proximity to the works. The coastal process receptors within Swansea Bay will be largely tolerant to such changes in the sediment regime, and so the sensitivity of the receptors is classified as low, giving rise to a low vulnerability across the bay. The vulnerability to sedimentary disturbance from the works is therefore assessed as low. The modelling indicates that the maximum extent of the changes has a potential to impact upon the SSSI at Crymlyn Burrows, and therefore the receptor importance in this area is considered moderate, whilst the wider Swansea Bay is assessed as low. On this basis the significance of the impact is considered **minor adverse / neutral** in the area of Crymlyn Burrows and **neutral** for the wider bay
- 6.5.1.99 Furthermore, based upon the sediment contamination analysis results presented in Section 6.4.4, the risk of contamination resulting from these proposed works is considered insignificant.

Modification to the existing seabed

Removal of the temporary seawall bund around the turbine/ sluice gate structure

- 6.5.1.100 During the removal of the temporary seawall bund, there is potential for slight smothering of the seabed in the immediate vicinity (i.e. within tens of metres) of the bund with sand and gravel. This smothering will occur when the Geotubes® are split/ emptied, and the sediment mound is subject to some movement under the hydrodynamic regime. Any smothering which may occur will be temporary, with capital dredging and construction works to begin rapidly on the remaining section of the permanent seawall, which will recycle the material from the temporary bund.
- 6.5.1.101 As a worst case, it was previously assessed that the footprint of the temporary bund and the enclosed construction area would result in approximately 20.3 ha of subtidal seabed loss. Following the removal of the temporary bund, much of this seabed will be restored, apart from approximately 3.28 ha of seabed associated with the construction of the turbine/ sluice gate housing and sections of the bed covered with scour protection mattresses.

Impact

- 6.5.1.102 It is predicted that approximately 0.03% of subtidal seabed will be lost within Swansea Bay as a result of the construction of the turbine/ sluice gate housing and sections of the bed covered with scour protection mattresses. In total, approximately 68.48 ha of subtidal seabed (equivalent to approximately 0.66% of the bay) will be permanently lost through the construction of the permanent seawalls, turbine/ sluice gates housing and scour protection up to this point in the construction programme; i.e. the final section of the permanent eastern seawall is not included. Taking these estimated losses into consideration, the maximum magnitude of change is still assessed as small/ medium, whilst the probability of occurrence for change is high as the area will be removed. Therefore, the exposure to change is considered at worst to be medium. As previously identified, these modifications to the existing seabed will occur outside of any national designated areas, therefore both receptor sensitivity and receptor importance are considered to be low. As such, the overall level of potential significance for losses in subtidal seabed is still assessed as **neutral**.

Capital dredging and seawall construction

- 6.5.1.103 During construction of the final section of permanent eastern seawall, sediments will be predominantly sourced from the temporary bund. These sediments will largely comprise sands and gravels, which had been previously dredged from within the turbine/ sluice gate structure dredge pocket. Following the removal of these sediments, the characteristics of the existing seabed (prior to the construction of the temporary bund) will be largely restored.
- 6.5.1.104 It has been estimated that the final section of the eastern seawall to be constructed during Phase 3 will result in *circa* 16.3 ha of subtidal seabed loss. As discussed previously, there will be no further loss in intertidal seabed, which occurs during Phase 1 of seawall construction works only.

Impact

- 6.5.1.105 During the final stage of construction for the eastern seawall, approximately 0.16% of subtidal seabed within Swansea Bay will be lost. In total, it is estimated that the

aggregate effect of all permanent construction works will result in approximately 68.48 ha (0.66%) and 20.5 ha (0.85%) of subtidal and intertidal seabed loss, respectively. Taking these total estimated losses into consideration for all stages of the construction programme, the maximum magnitude of change is still considered as medium. The probability of occurrence for change is assessed as high, and therefore the exposure to change has been determined as medium. Modifications (losses) to the existing seabed will occur outside of any designated areas, receptor importance is considered low to take account of the potential socio-economic importance of the seabed and the larger area permanently removed within Swansea Bay. As such, the level of potential significance for permanent seabed losses is assessed as **neutral**, whereby the overall impact significance is not assessed to have considerably increased for Phase 3, compared to the combined effects of Phases 1 and 2.

Changes to the coastal hydrodynamics

Capital dredging and seawall construction

- 6.5.1.106 During Phase 3 of the construction period, no significant changes to coastal hydrodynamics within Swansea Bay are predicted beyond those already identified and assessed within construction Phases 1 and 2. On completion of the final section of the permanent eastern seawall, however, there may be a short period of no tidal exchange between the Lagoon basin and Swansea Bay. During this period, tidal flows will not be observed passing into and out of the Lagoon, but flows will rather be orientated along the seawalls over respective flood and ebb tides. This process will continue until 'wet' commissioning of the turbines commences, shortly followed by full operation of the Lagoon. No further assessment of changes to the coastal hydrodynamics is required and the impact remains as for Phase 2.

Changes to the sediment (morphological) regime

Capital dredging and seawall construction

- 6.5.1.107 As was the case for changes to coastal hydrodynamics, during Phase 3 of the construction period, no significant changes to the sediment (morphological) regime within Swansea Bay are predicted beyond those already identified and assessed within Phases 1 and 2. However, it should be highlighted that on the completion of the construction works, sediment transport between the bay and the Lagoon will cease until at least 'wet' commissioning of the turbines is undertaken. No further assessment of changes to the sediment (morphological) regime is therefore required.

6.5.2 Operation

- 6.5.2.1 For the purpose of this assessment, the effects of both the tidal lagoon structure and the operational procedures of the turbines and sluice gates for tidal power generation have been combined, in order to provide an overall assessment of the impacts that the Project will have on the coastal processes operating within Swansea Bay.
- 6.5.2.2 With respect to the operational phase of the Project, the main impacts that could give rise to effects on the receptors are as follows:
- i. direct changes to hydrodynamic processes within Swansea Bay from the ongoing presence of the Lagoon infrastructure combined with the effects of the operation of the turbines and sluice gates;

- ii. direct and indirect changes to the sediment (morphological) regime within Swansea Bay due to erosion/ accretion from the ongoing presence of the Lagoon infrastructure, combined with the operation of the turbines and sluice gates; and
- iii. the requirement for future maintenance dredging within the Lagoon and potential changes to existing channels (Swansea, Port Talbot and Neath), and the subsequent disposal of this sediment at the licensed Swansea Bay (Outer) deposit ground (LU130), in order to maintain sufficient depths for tidal power generation and recreational activities (i.e. water sports).

6.5.2.3 It should be emphasised, that for the most part changes in both the hydrodynamic and sediment (morphological) regime within the Swansea Bay area as a whole are driven by the presence of the Lagoon structure, discussed and assessed previously during the construction period. However, these effects will be modified by the operation of the Lagoon, particularly from the discharge through the turbines and sluice gates. The numerical modelling undertaken for the operation period of the Project identifies the overall changes within the bay from the existing baseline, not the change between the operation and construction periods. Those changes more specific to the operation procedure, i.e. those controlled by the impounding of water within the Lagoon and the accelerated flows that will occur through the turbines and sluice gates (on both the flood and ebb tide) are highlighted in the following description of effects and the impact assessment.

Changes to the coastal hydrodynamics

Flow speeds and directions

6.5.2.4 During the operational period of the Project, local changes in flow speeds and directions will be experienced throughout the tidal cycle, with variations in these changes dependent upon the size of the tide. Spatial changes to depth-averaged mean flow speeds, in both absolute and relative terms, respectively, are provided in Figures 6.33 and 6.34 (Volume 2) for spring tides; the baseline depth-averaged mean flows speeds are provided in Figure 6.32 (Volume 2) for comparative purposes. In addition to these spatial plots, changes to flow speed and direction are also provided at key locations using time-series plots (Figures 6.35 to 6.39, Volume 2), the locations of which are shown in Figure 6.33 (Volume 2). The results from the numerical modelling indicate that changes are largely restricted to Swansea Bay, with limited changes extending both westwards and offshore beyond the Mumbles and the 10 m CD contour.

6.5.2.5 Inside the Lagoon, increases in flow speeds are principally controlled by 'jetting' flows through the turbines on both the flood and ebb tide, generated by a hydrostatic head difference during power generation, but also through sluice gate opening activities. A time series plot extracted at Location L1 (Figure 6.35 a, Volume 2) illustrates that during the flood tide, flow speeds rapidly accelerate from around 0.03 m/s (generated by residual circulatory flows within the Lagoon) to *circa* 1.1 m/s approximately 3 hours after LW (outside the Lagoon) for a mean spring tide. This rapid increase in flow speed results from the turbine gates opening at a pre-determined head difference (approximately 4.2 m), thus allowing the Lagoon to fill with water and for flood tide power generation to begin. Outside these jetting flows, particularly towards the back of the Lagoon, flow speeds are greatly reduced over the flood tide in comparison to the baseline scenario. This is illustrated in the time-series plots for Location L4 (Figure 6.36 a, Volume 2) and Location L7 (Figure 6.37a, Volume 2). These reductions are caused by the blockage of natural flows within Swansea Bay over the rising flood tide at these locations by the

structure, but also through the creation of low-energy circulatory gyres either side of the jetting flows within the Lagoon.

- 6.5.2.6 Over the flood tide, the head difference across the turbine structure lessens (i.e. the difference in water levels between the inside and outside of the Lagoon decreases), leading to a slight reduction in flow speeds with time. This pattern continues until the head difference reduces to a pre-determined level of 2 m, at which time the sluice gates are opened, allowing the Lagoon to fill at an increased rate towards HW. This process results in a sudden acceleration of flow speeds in the near vicinity of the turbine/ sluice gate structure, with peak flow speeds of up to 1.3 m/s at Location L1 (Figure 6.35 a, Volume 2).
- 6.5.2.7 Once HW is achieved within the Lagoon, both the turbine and sluice gates are closed in order to impound water within the basin, thus allowing a head difference to be generated as water levels outside the Lagoon fall over the ebb tide; flow speeds across the Lagoon rapidly decrease to less than 0.15 m/s. On reaching the pre-determined head differences of 5.2 m (inside to outside), the turbine gates are opened, allowing flows to pass for ebb tide power generation. This process results in an acceleration of flows within the Lagoon, with greatest flows in close proximity to the structure (i.e. Location L1, Figure 6.35 a, Volume 2), followed by a continued rise in flow speeds with time as depths across the basin shallow. Over this draining period, flow directions across the Lagoon are typically aligned towards the turbine structure (i.e. south-west), whilst baseline flow directions would be rotating further towards the south as Swansea Bay drains over the ebb tide (see Figure 6.35 b, Volume 2). As was the case during the flood tide, ebb tide flow speeds towards the back of the Lagoon are once again slower than those seen in the baseline scenario.
- 6.5.2.8 The spatial plots identify that within the Lagoon there are areas where flow speeds will be both significantly increased and reduced compared to the baseline conditions. The greatest changes in mean flow speeds (over spring tides) occur in close proximity to the turbine/ sluice gate structure (Figure 6.33, Volume 2). Results from the numerical modelling suggest that these increases in mean flow speeds will decrease with distance from the sluice gates, with changes in the region of 0.1 to 0.5 m/s to an extent of 1.1 km along an axis aligned south-west to north-east, and small increases no greater than 0.01 m/s identified beyond 2.3 km. In relative terms, these increases represent changes in mean flows speeds over spring tides of more than 100% in comparison to baseline flows in relatively close proximity to the turbine/ sluice gate structure (i.e. within approximately 225 m), with increases of around 5 to 20% at an extent of around 2.3 km; see Figure 6.34 (Volume 2) for relative changes.
- 6.5.2.9 In contrast, the spatial plots also identify that reductions in tidal mean flow speeds within the Lagoon can reach up to 0.5 m/s in the southern and eastern corners, although the majority of the changes are in the order of 0.01 to 0.05 m/s (Figure 6.33, Volume 2). These changes represent, in relative terms, decreases in mean flow speeds typically less than 40%, with reductions of up to 80% at the far eastern side of the Lagoon (Figure 6.34, Volume 2).
- 6.5.2.10 Outside the Lagoon, results from the numerical modelling suggest increases in tidally averaged mean (spring tide) flow speeds in the region of 0.1 to 0.5 m/s along an axis aligned in a south-west direction extending *circa* 1.4 km from the turbines, with increases no greater than 0.01 m/s identified beyond 2.4 km (see Figure 6.33, Volume 2). In relative terms, these increases represent changes in mean flow speeds of more than 100% (over spring tides) in comparison to baseline flows in relatively close proximity to

the turbines (i.e. within 600 m). At an extent of approximately 2.4 km, the increases vary between 5 and 20% (Figure 6.34, Volume 2). Large increases in flow speeds within this region are controlled by 'jetting' flows from the turbines (over the ebb tide) but also through sluicing activities, as was the case inside the Lagoon. A time-series plot extracted at Location O5 (Figure 6.38, Volume 2) illustrates absolute changes in both flow speed and direction experienced within these strong flows (compared with the baseline scenario) as a result of the Lagoon operation over spring tides. A rapid increase in flow speeds can be seen approximately 3 hours after HW on the ebb tide when the turbine gates are opened (at a pre-determined head difference of 5.2 m), allowing the initiation of ebb power generation. Peak flows at this location over this period are approximately 1.7 m/s for a mean spring tide, increasing up to 1.9 m/s for larger tides. In contrast, peak ebb baseline flows at the same location are around 0.45 m/s. Just after LW outside the lagoon, ebb flows are further accelerated when the sluice gates are also opened to allow further draining of the Lagoon before filling on the subsequent flood tide, with peak flow speeds of up to 3 m/s for a period spanning about 15 minutes. At times of peak ebb flow through the turbine/ sluice gates, these predicted increases might have an impact on navigation along the outer Swansea Channel, which is considered separately in Chapter 14 (Navigation). Further away from the turbine/ sluice gate structure at Location O3 (*circa* 1.4 km), but still within the jetting flows, peak ebb flows over a mean spring tide are around 1.1 m/s compared to a baseline of around 0.7 m/s (Figure 6.39, Volume 2).

- 6.5.2.11 Changes in flow speeds and direction are identified within other regions of the bay, particularly along the southern and eastern corners of the seawall (Figure 6.33, Volume 2), whilst reductions in mean flow speeds are identified within the western region of Swansea Bay. These changes are predominantly caused by the presence of the Lagoon structure within the bay itself, rather than as a result of the operational procedure of the Project. It is also worth noting that changes in flow speeds in the vicinity of the Neath and Port Talbot approach channels are considered insignificant, and therefore no adverse impact on navigation is expected due to hydrodynamic effects.
- 6.5.2.12 In addition to the numerical modelling outputs discussed above, tidal residual plots were extracted for the baseline and Lagoon scenarios, respectively, and are illustrated in Figures 6.40 and 6.41 (Volume 2). A comparison of these plots identifies important predicted changes to the residual tidal flow patterns (speed and direction) within Swansea Bay following the construction of the Lagoon and its subsequent operation. It is these changes to the residual currents within the bay that are likely to have a significant impact on the sediment (morphological) regime, particularly with respect to fine suspended sediments (mud). The main changes that can be identified, some of which were conceptually determined during the assessment for the various phases of the construction period, are as follows:
- i. the anticlockwise residuals within the western part of the bay are noticeably reduced, particularly along the Swansea shoreline (immediately to the west of the Lagoon structure). Within the central section of this region residual flows are orientated more to the north/ north-west compared to the baseline. Whilst these changes are principally controlled by the presence of the Lagoon structure, the accelerated flows from the Lagoon over the ebb tide (clearly identified as residuals), generate a clockwise circulating eddy to the north of the flow jet, further exacerbating flow changes from the Lagoon infrastructure alone.
 - ii. the presence of the Lagoon structure within the bay removes the westerly tidal residual from the Neath to the western part of the bay (shoreline parallel).

Furthermore, tidal flows become largely aligned with the Lagoon seawalls, particularly along its eastern and southern extents; and

- iii. tidal flows in and out of the Lagoon (over the flood and ebb tide) result in a distinct clockwise circulatory residual pattern, largely controlled by the shape of the Lagoon and the ability for a gyre to be created within the southern corner of the Lagoon. Importantly, however, the residual patterns further illustrate the reduced flow speeds at the back of the Lagoon, which will likely lead to increased sedimentation rates.

Impact

- 6.5.2.13 Overall, the operation of the Project will inherently have an impact on flow speeds and directions within Swansea Bay, although these are predominantly constrained to within the Lagoon and in the near-field across the western region of the bay (principally controlled by the jetting flows exiting the lagoon over the ebb tide). The assessment of effects for the operation of the Project has indicated three main areas where change will occur:
- i. between the western breakwater seawall and the Swansea shoreline;
 - ii. inside the Lagoon; and
 - iii. within the area of 'jetting' flow from power generation, particularly on the ebb tide.
- 6.5.2.14 These three areas are assessed for significance of impact separately.
- 6.5.2.15 For the western section of Swansea Bay the changes are predominantly the result of the Lagoon construction (rather than operation), whereby the impact significance was assessed (for coastal hydrodynamics) as **minor adverse / neutral** across the intertidal in the vicinity of Blackpill SSSI. The hydrodynamic effects from the operation of the Lagoon have little cumulative effect in this area, therefore the impact significant on flow speeds and directions will not change, therefore remaining the same as above. Similarly, no additional changes are predicted to the east of the bay beyond construction, i.e. in the entrance to the Neath, and therefore the impact significance also remains as **minor adverse / neutral**.
- 6.5.2.16 Within the Lagoon, the modelling has shown that the flow speeds and directions will be substantially changed compared to the baseline during the operational period, with large areas of both increased and decreased flows, which will continue for the life of the Project. The magnitude of these changes is considered to be medium on the basis that the charges are confined. The changes will definitely occur, giving a high probability of occurrence, and thus an exposure which is at least medium in scale. The seawalls around the Lagoon will protect the area from winds and waves, the changes of which will exceed the natural variability and will be distinctly different. Whilst the site has been reasonably tolerant of changes, it is considered that the flow speeds and directions will be so different that a moderate to high sensitivity should be assessed. On this basis, the vulnerability of the Lagoon area is considered moderate/ high. The seawall will effectively isolate the Lagoon from the Crymlyn Burrows SSSI. Therefore, the receptor importance is considered to be low with respect to the hydrodynamics. As a result the relative level of significance for the Lagoon area is **minor adverse**.
- 6.5.2.17 The effects description has identified an area of substantially higher flows 'jetting' from the turbines and sluices in a south-west direction towards Mumbles Head. For the

operation period, both flow speeds and directions will be changed above those created by the Lagoon infrastructure as this location. The increase in flow speeds and directional change are large but are confined to a relatively small area of the bay, therefore the magnitude of the impact in the areas of jetting flows is considered to be medium. As the changes are almost certain to occur, the exposure to change can also be assessed as medium. This section of the bay is considered to be tolerant to such flow changes, and therefore has a low sensitivity to hydrodynamic change in their own right, resulting in a low vulnerability. The area of impact is away from any designated sites and therefore has low receptor importance. Overall, the impact of the jetting flows with respect to hydrodynamic impact is therefore **neutral**.

Water levels

- 6.5.2.18 Results from the numerical modelling identify that operation of the proposed Lagoon will cause some marginal changes to water levels within Swansea Bay (outside of the Lagoon), but more significantly within the Lagoon itself. These changes will be discussed with respect to spring tides, considered worst case, as the effects during neap tides are significantly less (and therefore not presented). Changes to water levels, specifically at high and low water, may have an impact on habitats both inside and outside of the Lagoon; although these ecological impacts will be assessed separately in Chapter 8: Intertidal and Subtidal Benthic Ecology.
- 6.5.2.19 Outside of the Lagoon, it is predicted that the maximum change in the MHWS tidal level will be an approximate 0.01 to 0.02 m reduction within the western side of the bay, specifically adjacent to Swansea and in the lee of the Mumbles (Figure 6.42, Volume 2). More noticeably, however, are predicted changes to MLWS outside of the Lagoon, where increases of up to 0.04m are observed largely across the subtidal region of the western bay (see Figure 6.43, Volume 2) and an increase of approximately 0.01m along the edge of the intertidal. It is estimated that these changes to water levels outside of the Lagoon will equate to a loss of 2.88 ha of intertidal within the western part of the bay, although there will be an equivalent gain in subtidal.
- 6.5.2.20 Further assessment of potential effects when including consideration of surge and sea-level rise effects has also been undertaken. The numerical models were re-run first to include a 1.5m surge on top of the MHWS level, and secondly to include sea-level rise based on the medium emissions scenario (95%) prediction for 2100 (as provided in Table 6.13). The results of both these assessments resulted in similar changes predicted in the western part of the bay, outside of the lagoon. Here HW levels were predicted to reduce by between 0.01 and 0.02m, whilst LW levels were predicted to reduce by up to 0.04m in the sub-tidal region and by approximately 0.01m at the lower limit of the intertidal.
- 6.5.2.21 The most substantial changes in water levels over a tidal cycle are constrained to within the Lagoon itself. The operational procedure required for dual-tide power generation requires the creation of a hydrostatic head (water level difference) between the Lagoon and Swansea Bay on both the flood and ebb tide. This process results in a phasing difference between the tidal levels inside and outside the lagoon, as illustrated in Figure 6.35 (Volume 2). Of more importance, however, are the changes caused by the operational procedure on both high and low water levels within the Lagoon. Results from the numerical modelling predict that the maximum change for a tidal level of MHWS (outside the Lagoon) will be a reduction of around 0.6 m towards the front of the Lagoon (in close proximity to the turbine/ sluice gate structure), lessening to around 0.4 to 0.5 m at the back of the Lagoon against the shoreline (Figure 6.42, Volume 2). Changes in MLWS are just as pronounced within the Lagoon, being just over 1.0 m higher in close

proximity to the turbine/ sluice gate structure, with this increase reducing towards the back of the Lagoon to about 0.5 m (Figure 6.43, Volume 2). Based on these changes, it is estimated that approximately 62 ha of intertidal will be lost within the Lagoon, although there will be a similar gain in subtidal.

Impact

- 6.5.2.22 During the operation period of the Project, it has been predicted that around 64.88 ha of intertidal will be lost as a result of changes in water levels both inside and outside of the Lagoon. These changes represent a total loss of approximately 2.68 % of the intertidal present within Swansea Bay (2,424 ha), although this will lead to an equivalent gain in subtidal. Taking these predicted changes into consideration, the magnitude of impact with respect to water levels alone is assessed as small outside the Lagoon, where changes are restricted to the near-field and the scale of impact is smaller than the natural variability, whilst inside the Lagoon the magnitude of impact is considered medium. As the probability of occurrence is considered high, based upon the proposed operational procedure, the exposure to change is considered low outside the Lagoon and medium within the Lagoon. Due to the large tidal ranges experienced in Swansea Bay, with a spring range of approximately 8.5m (Swansea), the system is accustomed to significant changes in water levels over any given tidal cycle. As such, the sensitivity of the hydrodynamic receptor is considered low, meaning that the level of vulnerability both inside and outside the Lagoon is assessed as Low. Changes in water levels are expected only to occur within the Lagoon itself or across the western part of the bay (away from any nationally designated features), therefore, receptor importance is considered low. Based upon this outcome, the overall level of potential significance impact is assessed as **neutral**.
- 6.5.2.23 It should be noted that these changes in water levels are likely to affect the area and timing of intertidal exposure within the Lagoon. The assessment of which will be considered in Chapter 8: Intertidal and Subtidal Benthic Ecology.

Waves

- 6.5.2.24 Following the construction of the Project, Figures 6.44 to 6.49 (Volume 2) show the potential spatial change in modelled wave height, period and direction for a range of extreme wave events within Swansea Bay from the predominant SW direction and also from the SE. As described in Section 6.3.2, the model assumes a still water level of 4.35 m above MSL (equivalent to approximately MHWS), over which the waves are propagated.
- 6.5.2.25 Importantly, the wave conditions will generally be considerably greater than changes seen under more frequent 'normal' conditions. The model also assumes that waves will not pass through the turbines or sluice gates into the Lagoon. Furthermore, flows through the turbines/sluice gates may have an impact on wave conditions local to outside of the Lagoon. Typically over the ebb tide when flows from the Lagoon are in opposition to the predominant wave direction, local wave heights may be increased and the seastate will become more turbulent.
- 6.5.2.26 Figure 6.44 (Volume 2) identifies that for a 10 in 1 year wave event arriving from the SW (the predominant wave direction into Swansea Bay), the presence of the Lagoon structure leads to an increase in wave height of up to 0.22 m along the south-western side of the Lagoon. These increases are predominantly the result of wave reflection against the seawall and 'run up' along the structure. In order for the modelling to estimate wave reflection along the Lagoon structure, the seawalls in the modelling are assumed to have a reflection coefficient of 0.3. Due to this reflective coefficient, some

energy is lost from the conversion of the incident (arriving SW wave) to the reflected wave, known as partial reflection, whereby the combination of the incident and partial reflected wave results in a larger wave. This process will occur at this location for all SW wave conditions. However, the increase in wave height is controlled by the initial height of the incident wave; i.e. the larger the incident wave, the greater the increase in wave height (in absolute terms). The modelling also indicates that wave heights will be increased along the outer 2.5 km of the Swansea Channel by approximately 0.08 to 0.15m (compared to a baseline of for a 10 in 1 year event), although under more normal conditions, this increase is likely to be considerably less.

- 6.5.2.27 Increases in wave height are also shown to occur across the intertidal within the western region of the Bay between Mumbles Head and West Cross, where the reflected waves are refracted across the shallow foreshore. Present day (baseline) wave conditions within this area under SW conditions are relatively small, as this stretch of shoreline is protected from direct waves by the Mumbles. For a 1 in 20 year wave event, the model predicts that wave heights will generally be increased within this area by around 0.1 to 0.2 m, with a peak increase at the shoreline fronting Oystermouth. Increases in wave height in this region of the bay have the potential to increase sediment mobility rates (and hence erosion) through additional seabed disturbance and a change to the rate of any littoral drift. Anti-clockwise changes in wave direction (i.e. westward rotation) can also be seen within the western region of the bay as a result of these reflection processes, with a maximum change of approximately 15 to 20 degrees across the intertidal; with an associated small reduction in peak wave period.
- 6.5.2.28 Further assessment of the predicted effects of increased wave heights under prevailing south-westerly conditions along the Mumbles frontage has been undertaken, in order to determine any potential change in flood risk. Along the Mumbles frontage, the biggest waves occur during prevailing south-easterly conditions, since the Mumbles headland offers a degree of protection for the predominant south-westerly waves. Due to the orientation of the lagoon walls in relation to the angle of wave approach, predicted increases in wave height along the Mumbles frontage only occur under prevailing south-westerly conditions. Under these conditions, the predicted increase in wave height due to reflection off the lagoon wall is such that wave heights at Mumbles are still lower than the extreme heights (at equivalent return periods) of waves approaching from the south-east. As such, the presence of the lagoon is not considered to result in the biggest waves experienced along the Mumbles frontage being any higher than is presently the case. This topic is covered further in Chapter 17 (Hydrology and Flood Risk).
- 6.5.2.29 In contrast to the east of the Lagoon, decreases in significant wave height of up to 0.5 m are predicted immediately in the lee of the Lagoon across the intertidal fronting Crymlyn Burrows (north side of the Neath Channel) for a 1 in 10 year event; particularly in the vicinity of the Monkstone Light. This change decreases to less than 0.2m at a distance of approximately 1.3 km from the structure, i.e. within the entrance of the Neath Channel, as the sheltering effect diminishes radially. Reductions in wave height elsewhere in Swansea Bay are considerably less in both magnitude and extent. Predicted changes at the entrance to the River Tawe are localised and result from a sheltering effect provided by the western side of the Lagoon structure. Reductions are also seen, to a lesser degree, within the central section of the western bay, extending from the Mumbles to the northern shoreline in the vicinity of Singleton Park.
- 6.5.2.30 Elsewhere in Swansea Bay, e.g. along Aberafan Sands or in the vicinity of Port Talbot, no changes in wave height have been predicted under the dominant SW wave conditions.

- 6.5.2.31 More detail of predicted changes in wave height and period at specific locations within Swansea Bay is provided in Tables 6.15 and 6.16 for a range of extreme events from the predominant SW direction. The locations of the observation points are shown in Figure 6.44 (Volume 2). Both the modelled baseline and absolute changes under these events are provided for each location.

Table 6.15 Baseline wave heights (H_s) and predicted change under varying SW extreme wave events as a result of the Project

Observation Point	Wave Height (m)							
	10 in 1 Year		1 in 1 Year		1 in 10 Year		1 in 20 Year	
	Height	Change	Height	Change	Height	Change	Height	Change
1	1.04	-0.08	1.07	-0.12	1.28	-0.12	1.43	-0.12
2	2.22	0.08	2.36	0.10	2.89	0.12	3.44	0.11
3	2.65	-2.28	2.78	-2.07	3.30	-2.72	3.81	-3.20
4	2.12	-1.13	2.19	-1.02	2.45	-1.36	2.63	-1.12
5	0.75	-0.45	0.80	-0.48	0.85	-0.49	0.97	-0.45
6	2.65	-0.18	2.78	-0.20	2.96	-0.16	3.04	-0.15
7	0.49	0.07	0.57	0.05	0.57	0.09	0.59	0.11
8	0.58	0.11	0.62	0.10	0.66	0.15	0.68	0.17
9	3.84	0.15	3.71	0.22	4.38	0.23	4.80	0.19
10	2.82	0.22	2.68	0.28	3.40	0.30	3.88	0.26

Table 6.16 Absolute and percentage differences for wave periods (T_z) under varying SW extreme wave events as a result of the Project

Observation Point	Wave Period Difference							
	10 in 1 Year		1 in 1 Year		1 in 10 Year		1 in 20 Year	
	s	%	s	%	s	%	S	%
1	-0.46	-4.8	-0.40	-3.2	-0.44	-3.6	-0.41	-3.9
2	0.11	1.5	0.15	1.5	0.13	1.3	0.11	1.3
3	-5.66	-78.6	-7.23	-81.5	-7.86	-82.7	-7.14	-81.1
4	-4.86	-66.6	-6.37	-72.5	-7.25	-75.0	-6.05	-67.6
5	0.13	1.5	0.54	5.2	0.17	1.5	0.03	0.3
6	0.21	2.8	0.34	3.8	0.22	2.1	0.01	0.1
7	-0.85	-8.2	-0.61	-4.7	-0.75	-5.9	-1.20	-10.0
8	-1.20	-11.6	-1.09	-8.6	-1.11	-8.9	-1.30	-11.0
9	0.17	2.4	0.28	3.2	0.22	2.4	0.19	2.2
10	0.18	2.5	0.31	3.6	0.22	2.3	0.15	1.7

- 6.5.2.32 Further assessment has also been undertaken to investigate the potential effects on wave events when including a consideration of the effects of surge and future sea-level rise. The assessment has shown that when including a surge level of 1.5m on top of the MHWS level, the predicted increase in wave height observed at observation point 8 (along the Mumbles frontage), with an increase of 0.19m (compared to 0.17m for the case without surge). The results when a consideration of sea-level rise is included on the MHWS level (based on the medium emissions, 95% prediction, as provided in Table 6.15), provide a similar level of increase. At observation point 8 the predicted increase under sea-level rise conditions is 0.18m (compared to 0.17m for the case without sea-level rise).
- 6.5.2.33 In addition to the modelling undertaken for the SW conditions, consideration has also been given to representative extreme wave conditions approaching from the SE (10 in 1

and 1 in 10 year), whereby wave processes within Swansea Bay will be considerably different.

- 6.5.2.34 Figure 6.48 (Volume 2) identifies that for a 10 in 1 year wave event arriving from the SE, no increases in wave height (above 0.05 m) are expected to occur within Swansea Bay. Under more extreme conditions, however, the presence of the Lagoon will potentially lead to an increase in wave heights along its south-eastern side as a result of wave reflection processes. Increases in this area are expected to be in the region of 0.05 m under an extreme 1 in 10 year wave condition (Figure 6.49, Volume 2). Furthermore, under this extreme condition, similar wave height increases have also been predicted immediately to the north of Port Talbot around the entrance to the River Afan. These increases in wave height are also associated with a change in wave direction and period, controlled by the reflection processes, in which waves are rotated in a more easterly direction in an area extending from the Lagoon to Port Talbot. Changes in wave period, however, are confined predominantly to Port Talbot Harbour and the entrance to the River Afan, with increases in the region of 1.0 to 4.0 seconds. It must once again be highlighted, however, that wave reflection coefficients used within the model are conservative, and therefore the modelled waves are likely to be exaggerated (particularly at this distance from the Lagoon structure).
- 6.5.2.35 Contrastingly, substantial sheltering is predicted to occur to the west of the Lagoon under the SE wave conditions, with the greatest wave height reduction of *circa* 0.2 to 0.5 m (for a 10 in 1 year event) found along the inner section of the Swansea Channel (Figure 6.48, Volume 2); with this change increasing to approximately 0.5 to 1.2 m for a 1 in 10 year extreme wave event (Figure 6.49, Volume 2). The protection afforded to this region of the bay decreases with distance away from the Lagoon towards Lower Sketty. Additionally, a localised area of wave height reduction has also been predicted to the east of the Lagoon, in the near corner fronting Crymlyn Burrows.
- 6.5.2.36 More detail of predicted changes in wave height and period at specific locations within Swansea Bay is provided in Table 6.17 for both 10 in 1 and 1 in 10 year extreme SE wave conditions. Both the modelled absolute and percentage changes under these events are provided for each location.

Table 6.17 Absolute and percentage differences for wave heights (H_s) and periods (T_z) for a 10 in 1 year and 1 in 10 year SE extreme wave event as a result of the Project

Observation Point	Wave Height (m)				Wave Period Difference			
	10 in 1 Year		1 in 10 Year		10 in 1 Year		1 in 10 Year	
	Height	Change	Height	Change	s	%	s	%
1	0.67	-0.03	1.56	-0.05	-0.02	-0.68	0.08	2.14
2	0.67	-0.03	1.62	-0.07	0.07	2.58	0.16	4.39
3	0.65	-0.45	1.57	-1.15	-1.39	-54.10	-2.05	-56.91
4	0.53	-0.35	1.11	-0.76	-1.10	-50.40	-1.76	-55.51
5	0.39	-0.04	0.69	-0.10	-0.16	-6.83	-0.19	-5.07
6	0.52	-0.01	1.16	-0.01	-0.02	-0.89	-0.01	-0.24
7	0.63	-0.17	1.41	-0.42	-0.35	-13.84	-0.05	-1.56
8	0.64	-0.48	1.48	-1.15	-1.36	-54.58	-0.92	-26.18
9	0.62	0.02	1.47	0.04	0.08	3.21	0.09	2.68
10	0.10	0.01	0.22	0.05	1.87	210.71	2.22	126.11

Impact

- 6.5.2.37 The wave modelling has shown that under a range of extreme wave conditions, the construction and operation of the Lagoon will have an impact on the wave climate within Swansea Bay, which will be dependent upon the wave condition, i.e. its magnitude and direction. It has also been identified that any change to the wave climate will be principally constrained to the bay itself, with the potential for some small localised changes just beyond the Mumbles under SW wave conditions, resulting from reflection from the structures.
- 6.5.2.38 Taking the available modelling outputs into consideration, it is assessed that the magnitude of change to the wave climate is small, with the scale of impact smaller than the natural variability for the majority of the bay area. However, localised areas exist where substantial focussing or sheltering occur. These areas are considered separately. The probability of changes to the wave climate (occurrence), at the bay scale, associated with the presence of the Lagoon in Swansea Bay is considered high, although these changes will typically be associated with more 'normal' wave conditions. As such, the overall exposure of change is classified as low. The sensitivity of waves to change is also considered low due to the dynamic wave climate experienced within Swansea Bay, with large swell waves frequently propagating along the Inner Bristol Channel and into the bay. As such, receptor vulnerability is assessed as low. Waves, in themselves, are not a receptor (rather than a process affecting a receptor) of importance, and therefore importance is considered negligible across the wider subtidal region of Swansea Bay. As such, the overall level of potential significance is largely assessed as **neutral** within the subtidal region of Swansea Bay, but also across areas of intertidal where no change in the wave regime is predicted during either SE or SW wave events.
- 6.5.2.39 The modelling has identified four localised areas where the magnitude of wave effects are generally greater than for the wider area, either as a result of wave reflection or sheltering effects:
- i. Reflection effects (increased wave heights) at the SW corner of the Lagoon structure;
 - ii. Reflection effects (increased wave heights) transferring to the Swansea shoreline in the lee of the Mumbles;
 - iii. Sheltering of SE waves (wave height reductions) near the entrance to the River Tawe and the inner sections of the Swansea Channel; and
 - iv. Sheltering of SW waves (wave height reductions) along the frontage of Crymlyn Burrows.
- 6.5.2.40 These are in addition to the reduction in wave energy that will occur at the shoreline within the lagoon.
- 6.5.2.41 Within these areas, the scale of the change can be considered to range from small through to large, however, the small spatial extent of each area tends to reduce the magnitude of impact from moderate to negligible. It is very likely that the changes will occur giving a high probability of occurrence, therefore the worst case exposure is considered to be minimal. All the locations, with the exception of in the lee of the Mumbles are considered to have a low sensitivity as they are already susceptible and experience such conditions from extreme events. At the Swansea foreshore, behind Mumbles Head, the area will now be susceptible to reflected waves (which it was not before), initially propagating from the SW, therefore the receptor sensitivity in this area

is considered moderate. However, the exposure in this area would be slightly lower than the other areas. The vulnerability of all areas is therefore considered to be low. Crymlyn Burrows is a designated SSSI, and therefore has moderate receptor importance, whereas the other locations would be considered low. The overall level of impact significance is, at worst, **minor adverse** for these specific areas. A similar assessment results when considering the wave impacts on the shoreline within the Lagoon. It is also worth noting that the reduced wave heights predicted along the Crymlyn Burrows frontage could be considered beneficial in terms of encouraging deposition of sediment in this area.

- 6.5.2.42 Taking into consideration a number of specific concerns identified through the project scoping phase (see Section 6.5.0.5), it is further assessed that changes in the wave climate as a result of the Lagoon operation will have no significant impact on vessels manoeuvring navigation channels to the ports of Swansea, Port Talbot and the Neath. Although change will occur in the overall wave / hydrodynamic environment, which will be different to that which currently exists, it is considered that the degree of change will not be sufficient enough that it would impede navigation. Furthermore, the numerical modelling has identified that changes in the wave climate will not have an adverse impact on the recreational use of local beaches, i.e. surfing at Aberafan Sands (noting also that there is not predicted to be any significant changes to the morphology of this section of coastline, as discussed further in the following section).

Changes to the morphology

- 6.5.2.43 The operation (and construction) of the Lagoon has the potential to change sediment transport processes within Swansea Bay, which in turn has implications for local accretion and erosion (including scour) within the Lagoon, in close proximity to the Lagoon structure and across the bay in general.
- 6.5.2.44 In the short-term (i.e. weeks to months) following the construction of the Lagoon, rapid changes to the sediment (morphological) regime are to be expected as the processes within the bay (the 'system') respond to the presence of the Lagoon. It should be emphasised, however, that these rapid short-term changes will likely be localised and will largely take place in stages during the construction phase of the Lagoon (i.e. when the substantial seawalls are built), but will also continue into the operation phase as the system responds to the managed tidal exchange through the turbines and sluice gates.
- 6.5.2.45 Following this period of rapid change, the system is expected to undergo a period of transition in the medium-term (i.e. years to decades) in which changes to the sediment (morphological) regime will slow towards a new morphological equilibrium, albeit with more noticeable changes expected to occur during times of considerable variation in the physical forcing factors (e.g. during winter storms etc.).
- 6.5.2.46 Once a state of dynamic morphological equilibrium is reached, any future long-term changes spanning the lifetime of the Project (i.e. out to 120 years), are expected to oscillate around this equilibrium like those presently seen naturally within Swansea Bay (with respect to the current morphological equilibrium state). That being said, the predicted influence of climate change on water levels, the wind/ wave climate (storms) and freshwater discharge within the Bay (see Section 6.4.2.29) are expected to accelerate in the second half of the 21st century (and beyond), thus potentially having a significant impact upon the sediment (morphological) regime which may in turn hinder the system from maintaining a morphological equilibrium state in the future; a scenario which would also have arisen without the construction of the Project.

- 6.5.2.47 In order to investigate potential short-term changes to the sediment (morphological) regime within Swansea Bay, numerical modelling of both cohesive (mud) and non-cohesive (sand) sediments has been undertaken, whilst changes in the medium to long-term as a result of the Project will be identified separately through an expert geomorphological assessment (as detailed in Section 6.3.4).

Short-term change

- 6.5.2.48 Analysis of the impacts of the Project on mud transport was undertaken for representative mean spring and neap tides under a 10 in 1 year SW wave event. The greatest changes with respect to accretion and erosion were seen during the spring tidal conditions (worst case); although variations in sediment transport will arise from differing conditions. In order to assist with the validation of the numerical model, the results from the baseline scenario were compared to measured changes (sedimentation rates) in both the Swansea and Port Talbot approach channels. The results from the baseline scenario were then appropriately scaled in order to meet similar levels of change at these locations. This scaling factor was then also applied to the Lagoon (scheme) scenario. Figure 6.50 (Volume 2) shows the predicted accretion and erosion pattern of muds shown by the modelling to occur across Swansea Bay as a result of the Project over a period of 24 hours, during a Spring tide, i.e. after completion of two spring tidal cycles. In calculating changes in bed thickness, the model assumes a sediment density of approximately $1,300 \text{ kg/m}^3$ in situ at the bed. It should be noted that under differing sediment densities, the thickness of the deposited material may vary. However, the pattern of distribution will remain the same.
- 6.5.2.49 Results from the mud model clearly show that deposition occurs across the western side of the bay, predominantly within the shallow subtidal areas adjacent to the Blackpill SSSI, with accretion during the assessed storm event predicted to be in the range of 0.3 to 0.75 mm over the two tides. Higher rates of accretion are also predicted to occur within the Swansea Approach Channel, principally along the central section, which spans a distance of *circa* 2 km. Accretion rates in this location, and under the assessed storm event, are expected to be in the order of 0.5 to 1.25 mm over a 24 hour period. In general, accretionary trends identified across the western side of the bay following the construction and subsequent operation of the Lagoon are driven by the overall reduction in flow speeds resulting from the wave-current interaction (both peak and mean), whereby fine sediments (mud) are less likely to be remobilised following settling than is the case within the baseline scenario.
- 6.5.2.50 Across other areas of Swansea Bay, accretion can also be seen along sections of the Lagoon seawalls, typically where tidal energy has been reduced (compared to the baseline) from the scheme being in place. Small increases in sedimentation are also identified within sections of the Port Talbot Channel under the assessed storm event, with rates in the order of 0.3 to 0.5 mm over the 24 hour period. The potential impact of this change on the existing maintenance dredge regime will be considered in the subsequent section, as will that for the Swansea Channel. No change in mud distribution, either through erosion or accretion, has been identified within the Neath Channel, which corresponds with the sandy nature of this particular area.
- 6.5.2.51 In contrast, both erosion and accretion of mud has been predicted within the Lagoon. Erosion may initially occur in relatively close proximity to the turbine/ sluice gate structure (i.e. within 2 km of the turbine/ sluice gate housing), where muddy sediments will be subject to mobilisation under the jetting flows passing through the turbines/ sluice gates on both flood and ebb generation phases. Beyond any initial (limited)

erosion, however, these accelerated flow speeds will predominantly act in keeping sediments in suspension within this area, remobilising any sediments that may settle during slack periods. Elsewhere in the Lagoon, i.e. towards the back, sedimentation is expected to be relatively high, as mud fractions will drop out of suspension during HW slack. Flow speeds in these areas are insufficient to remobilise these sediments completely, resulting in accretion rates of up to 1.25 mm under the assessed storm event, and over the modelled 24 hour period. It is expected that this level of sedimentation within the Lagoon is likely to require long-term maintenance dredging in order to maintain sufficient depths for efficient (and cost-effective) energy generation. The potential requirement for maintenance dredging within the Lagoon will be assessed separately in a subsequent section.

- 6.5.2.52 The results of an assessment of effects of the Project on temperature and salinity are described in Chapter 7 (Marine Water Quality). The predicted effects were a slight increase in salinity inside the lagoon as a result of a reduced freshwater input, with little overall change outside the lagoon. Large changes in the physic-chemical properties of the bay could result in changes to fine sediment dispersal (as a result of increased potential for flocculation, for example). The effects predicted in the assessment are not considered to be great enough to have a resultant impact on transport and deposition of fine material.
- 6.5.2.53 Analysis of the impacts of the Project on sand transport was undertaken for a representative mean spring and wave condition (10 in 1 year event from the SW). Results from the modelling identified that for the baseline condition (without the Lagoon), sand transport is predominantly found within the eastern and offshore regions of Swansea Bay. Potential sand transport is generally towards the River Neath on the flood tide, predominantly along the Aberafan Sands shoreline (from Port Talbot) but also from directly offshore (i.e. across the centre of the Bay), whilst ebb transport is directed more towards the offshore area. However, while it was not identified in the representative mean spring and wave condition, more extreme wave events from the SW (e.g. 1 in 1 year), could potentially provide a westerly sand transport pathway between the Neath and the western region of Swansea Bay. This pathway exists on the ebb tide between approximately HW and HW + 3 hours, when complex interactions between the tidal flows, waves and seabed potentially drive sand along the shoreline to the west and around the Swansea breakwaters. Model results under these extreme conditions identify that the transport will continue to and beyond Blackpill, thus acting as a potential (but infrequent) sediment supply of sand.
- 6.5.2.54 The overall impact of the Lagoon on sand transport within Swansea Bay has been previously assessed for the construction period and this will not be further affected. However, the main impacts are summarised below for reference:
- i. the potential reduction in littoral drift in an easterly direction towards Crymlyn Burrows resulting from shelter provided to wave approaching from the SW;
 - ii. a predicted reduction in wave energy at the entrance to the Neath (particularly to the north of the channel) may lead to the increased potential for sand accumulation; and
 - iii. the potential transport of sand (in suspension) from the east to west across the bay, i.e. from the Neath to Blackpill, under storm conditions will be stopped.
- 6.5.2.55 In addition to these changes, the operation of the Lagoon will also have additional impacts on sand transport within Swansea Bay, although to a lesser degree. For example,

due to the increased flow speeds that will be experienced through the turbines/ sluice gates, it is estimated that there will be sufficient energy to erode (to an extent) some sand and gravel sediments from the seabed up to approximately 400 m from the structure both inside and outside the Lagoon. This erosion is expected to be relatively short lived due to the higher density of the gravelly sands and sandy gravels found at the seabed within this area of the bay. Furthermore, as sand will remain mobilised for a greater longer under the accelerated flow conditions, increased sand transport will also be seen both in the vicinity of, and through, the turbines/sluice gates. As a result, a proportion of sand may additionally pass into the Lagoon over the flood tide which will contribute to its potentially infilling by mud. However, it is expected that any loss in tidal volume within the Lagoon as a result of sand transport would be significantly less than that predicted by the cohesive (mud) model.

Medium and long-term change

- 6.5.2.56 Taking into consideration the predicted short-term changes likely to arise from the construction and operation of the Lagoon (as identified through the numerical modelling), along with a historical analysis of the existing sediment (morphological) regime within Swansea Bay (see Section 6.4.3), it is expected that any future medium to long-term changes will vary considerably across the bay. These changes will be discussed separately for the following primary areas:
- i. across the western region of the bay, between Mumbles Head and the western arm of the Lagoon;
 - ii. inside the Lagoon; and
 - iii. across the eastern region of the bay, particularly along the Crymlyn Burrows frontage and in the vicinity of the Neath.
- 6.5.2.57 It should be emphasised that the subsequent medium and long-term assessments assume no change in the existing sediment supply from offshore locations (i.e. sand from the Bristol Channel), nor do they include any additional works that may take place within Swansea Bay over the lifetime of the Project.
- 6.5.2.58 An analysis of historical beach profile data within the western region of the bay for the period 1998 to 2013 (see Section 6.4.3), along with available aerial photographs and maps, reveal that the beaches and intertidal foreshore have experienced general net erosion of around 0.3 to 0.5 m over the past 15-years. Consequently, any present mechanisms for delivering sediments to these areas are insufficient for maintaining beach/ intertidal levels in the medium to long-term.
- 6.5.2.59 It is considered that the completed Project will modify and redefine the existing residual circulation within the western region of Swansea Bay by effectively splitting the bay into two smaller embayment cells whereby the Lagoon structure essentially becomes a headland, thus restricting exchanges between either sides of the Lagoon. As a result, the western region of the bay is expected to experience an increased 'trapping' potential of sediments (predominantly mud) in the future compared to existing conditions, particularly across the shallow subtidal areas adjacent to the Blackpill SSSI and within the Swansea Approach Channel. Increased sedimentation across the intertidal (although to a much lesser extent) is also to be expected. Following the immediate operation of the Lagoon, short-term modelling has predicted mud accretion rates in the range of 0.3 to 0.75 mm/day and 0.5 to 1.25 mm/day within the shallow subtidal areas and Swansea

Approach Channel, respectively. These sedimentation rates will reduce rapidly with time (i.e. over the initial few weeks).

- 6.5.2.60 With respect to sand transport, the construction and operation of the lagoon will impede an infrequent supply pathway that potentially exists from east to west across the bay (i.e. from the Neath to Blackpill) under extreme storm conditions. Nevertheless, the dominant (direct) sand transport pathways to this region of the bay from the Bristol Channel under strong SE and SW wave and wind conditions will be unhindered. The reduction in tidal currents within this region of the bay following the construction and operation of the Lagoon may in fact reduce the re-suspension and ebb transport of sand out of the bay once it has accumulated. Thus, although there is a potential for a very small reduction in sand supply to this region of the bay (from the east), a net positive increase in sand volume in the medium to long-term could potentially occur. Therefore, over time, as the western region of the bay develops towards a new morphological equilibrium state, a general net pattern of accretion in both mud and sand is expected to continue (compared to the present day situation). However, although some short-term stability may be achieved it is unlikely that these rates will be sufficient to completely offset the erosion trend identified in the historic beach profiles.
- 6.5.2.61 Within the lagoon itself, results from the numerical modelling have predicted erosion in close proximity to the turbine/ sluice gate structure, whilst relatively high rates of accretion are predicted to take place towards the back of the Lagoon. The erosion identified is expected to last no longer than a few days (over spring tides) as the jet-like flow passing through the turbines and sluice gates scours the weakly consolidated sediment from the seabed. Much of this scoured material will then be transported and deposited further inside the Lagoon during the flood tide. With respect to accretion with the Lagoon, relatively high accretion rates (albeit slightly less than those predicted in the short-term) will be expected to occur in the medium to long-term as the Lagoon acts as an effective sediment sink, particularly for mud.
- 6.5.2.62 Over time, sediment which has been deposited in the Lagoon and which is unable to be re-mobilised (eroded) over subsequent tides will be subject to consolidation, i.e. the density of the sediment will increase as it becomes overlaid with fresher sediments. Whilst this depositional processes will be ongoing, the rates of deposition will generally reduce with time as the tidal exchange into the Lagoon (and hence the available sediment volume within the water column) reduces due to increased bed levels. Eventually, the Lagoon will require dredging in order to maintain a cost-effective tidal exchange volume (with respect to power generation). Due to the increased tidal exchange created by the removal of sediment from the Lagoon, there will be a marked increase in sedimentation. This will have characteristics similar to those observed immediately after the Lagoon operation phase begins. It should also be highlighted that deposition within the Lagoon is expected to be considerably higher in the winter than the summer due to increased background SSC found within Swansea Bay; a function of enhanced sediment disturbance/ re-mobilisation under increased wave and wind activity within the bay and the potential increased in sediment supply from fluvial sources. In essence, due to the long-term requirement for the Lagoon to be dredged, it will never reach a morphological equilibrium state.
- 6.5.2.63 Across the eastern region of Swansea Bay, specifically along the Crymlyn Burrows frontage and in the vicinity of the Neath, it is considered that the Lagoon structure will not impede the primary sediment transport pathway to these areas from the offshore environment (i.e. the Bristol Channel). However, the presence of the structures

comprised in the Project will reduce wave energy (and subsequently littoral drift) immediately to the east of the structure due to the sheltering effect created from predominant SW wave conditions, which may therefore lead to increased potential for accumulation (particularly along the eastern arm of the seawall). It is considered likely that any such accumulation will begin in the short-term and continue into the medium to long-term, up to a finite capacity governed by the tidal conditions and the morphology of the region. As sand transport into these areas is driven by the action of long-period SW waves, these processes are more likely to occur over medium-term time-scales (rather than short-term); with greatest sand transport expected to occur over the winter months. Any potential increase in sand accumulation as a result of the Project would further strengthen net accretionary patterns identified over the past 15-years (described previously in Section 6.4.3), although erosion has also been identified across the Crymlyn and Baglan/ Aberafan intertidal at times over this period.

Impact

- 6.5.2.64 Assessment of the short-term numerical modelling and the medium to longer-term geomorphological assessment has predicted that the Lagoon will have an impact on sediment transport, and hence coastal and subtidal morphology, within Swansea Bay during its operation period (i.e. over its 120 year lifetime). Due to the variation in potential changes across the bay, and the subsequent impact that may arise from these, impact significance will be assessed separately for the following areas:
- i. across the western region of the bay, between Mumbles Head and the western arm of the Lagoon (extending across the expansive intertidal areas);
 - ii. inside the Lagoon;
 - iii. within the area of 'jetting' flow through the turbines/ sluice gates, particularly over the ebb tide; and
 - iv. across the remainder of the bay, particularly to the east between Crymlyn Burrows and Port Talbot.
- 6.5.2.65 Within the western region of the bay, changes to the coastal hydrodynamics have the potential to increase sedimentation rates of mud across the shallow subtidal adjacent to the Blackpill SSSI, but also within the Swansea Channel. The results also identify the potential for reduced sand transport to this region (from the east of the bay) during large storm events, which may have contributed (infrequently) to the beaches. However, the increased trapping potential of the western region of the bay following the construction of the Lagoon is likely to retain sand more efficiently from the dominant transport pathways. The magnitude of these changes is considered to be medium, on the basis that these changes are within the near-field and within the same order of natural variability. As these changes are expected to occur, the probability of occurrence is considered high, thus leading to a medium exposure to change. The sensitivity of the sediment regime to change is considered, at worst, moderate as sediment transport within this region of the bay is subject to considerable natural variability under differing tide and wave conditions. On this basis, the vulnerability of the receptor is conservatively assessed as moderate. Receptor importance is considered as low on the scale of the total western region of Swansea Bay, therefore the overall level of significance is **neutral**.
- 6.5.2.66 Within the small localised areas of the Blackpill SSSI and within the Swansea Channel, receptor importance can be considered as moderate, therefore for these specific areas, the potential level of significance is considered **moderate / minor adverse** (as a result of the potential reduction in intermittent sand supply at Blackpill on the upper reaches of

the beach and the predicted increased mud deposition within the Swansea Channel). For these areas, consideration has been given to potential monitoring activity in order to identify the potential changes to level and substrate.

- 6.5.2.67 For the area within the Lagoon, results from the modelling have indicated that there is potential for considerable change to both sediment transport and morphology during the operation period. Sediments (predominantly mud) will pass through the turbines/ sluice gates on the flood tide, and will rapidly settle out of the water column within areas of lower energy across the Lagoon (i.e. towards the back). Increased sediment mobility will also occur within the Lagoon close to the turbine/ sluice gate structure, which may lead to the initial erosion of seabed sediments over a few days (during spring tides). The magnitude of these changes is considered to be medium on the basis that they are confined within the Lagoon. The changes predicted are expected to occur, giving rise to a high probability of occurrence and, therefore, a medium exposure to change. Whilst sediment transport and changes to morphology occur across the footprint of the Lagoon under baseline conditions, the short-term numerical modelling identifies that changes within the Lagoon will be greater than natural variability, and therefore the sensitivity is considered moderate to high. On this basis, the vulnerability of the Lagoon area is also considered moderate/ high. As the seawalls effectively isolate the Lagoon from nationally designated sites within the bay, particularly the immediately adjacent Crymlyn Burrows SSSI, the receptor importance is considered low with respect to the sediment (morphological) regime. The relative level of significance is, therefore, assessed conservatively as **minor adverse**.
- 6.5.2.68 Immediately adjacent to the turbines/sluice gates outside of the Lagoon, an area of substantially higher 'jetting' flows is expected during the operation period. These flows will potentially increase sediment transport to and from the Lagoon over both flood and ebb tides, respectively, but may also increase the erosion potential of the seabed sediments in this area. Modelling indicates that any erosion that does occur is likely to extend no further than 400 m from the turbine/sluice gate structure and be temporary in nature, with a morphological equilibrium state being reached relatively quickly (i.e. following a number of large spring tides), as depths increase against increasing density of the seabed. Taking these predicted changes into consideration, the magnitude of any change is therefore assessed to be medium. Whilst these changes are predicted to occur, erosion may be limited by the nature of the seabed sediments (i.e. sandy gravels and gravelly sands) which are then underlain by more consolidated material, therefore probability of occurrence is assessed to be medium. As such, exposure to change is therefore assessed as being medium/ low. This area of Swansea Bay is relatively tolerant to changes in coastal processes, however, the predicted changes in the sediment (morphological) regime is still greater than natural variability and therefore receptor sensitivity is conservatively considered to be moderate. On this basis, the level of vulnerability is, in the worst case, taken to be moderate. As the area of impact is away from any designated sites, the receptor importance is defined as low, with the overall level of significance therefore assessed as **neutral**.
- 6.5.2.69 Changes in the morphological regime have also been identified along the eastern side of the bay, predominantly between the Crymlyn Burrows shoreline and Port Talbot (including the navigation channel), during the operational period of the Lagoon. These changes principally relate to the potential for increased sedimentation (of sand) across the intertidal fronting Crymlyn Burrows, but also the potential for increased sedimentation (of muds) within the Port Talbot Channel. Changes to the morphology of the section of coastline between the Neath and Port Talbot (i.e. along the coastline and

offshore of the Aberafan Sands) are not predicted. Where changes are predicted to occur, the magnitude of these changes is considered to be small/ medium, on the basis that they are largely within the order of natural variability. As these changes are expected to occur, the probability of occurrence is considered high, thus leading to a medium exposure to change (as a worst case). Within these regions of the bay, both sediment transport and changes to morphology under baseline conditions can be substantial, therefore, the sensitivity of the receptor is considered to be low. On this basis, receptor vulnerability is assessed as low. In the area of the Crymlyn Burrows SSSI, receptor importance is considered to be moderate, due to the potential impact to the nationally designated area. Overall, the level of significance is assessed as **minor adverse / neutral**.

- 6.5.2.70 The Port Talbot channel, whilst not designated, has socio-economic importance and is therefore also considered to be moderate for receptor importance. The wider bay areas, however, where change is predicted, have a low receptor importance. On this basis, the significance for the localised areas of Port Talbot channel is assessed as **minor adverse / neutral**, but the impact for most of the bay is considered to be **neutral** with respect to sediment transport and morphological effects.

Maintenance dredging

Potential dredge commitment

- 6.5.2.71 Using the results from the sediment modelling, it is possible to ascertain the approximate likely impacts that the Project will have on sediment transport and sedimentation (accretion/ erosion), and more specifically, how these changes compare to sediment volumes presently dredged from within the Swansea and Port Talbot approach channels. No change has been predicted within the Neath Channel (outside of natural variability). Furthermore, the potential dredge commitment for the Lagoon can also be estimated, which assumes that there will be a requirement to maintain depths for power generation purposes.
- 6.5.2.72 As described previously in Section 6.4.3.23, Port Talbot requires annual maintenance dredging of approximately 1.5 million wet tonnes on average, whilst average annual maintenance dredging within the Swansea Channel is around 250,000 wet tonnes. These amounts are equivalent to a volume of around 1,154,000 m³ and 192,300 m³, respectively, at an assumed sediment density of 1,300 kg/m³.
- 6.5.2.73 Taking into account the predicted results from the cohesive (mud) sediment model (as the sediments that deposit in these channels are predominantly mud), the change in sediment volume (between the baseline and Lagoon scenarios) was extracted over the length of both approach channels (and within the Port Talbot Outer Harbour). These values were then scaled up to a period of one year, to provide an estimated annual increase in sediment volume within these areas. A number of assumptions are associated with this calculation method, which include:
- i. accretion within the channels occurs at a continuous rate over the annual period, i.e. the channels would need to be dredged frequently (to the modelled depths) for these maximum rates to occur;
 - ii. further variations in tidal and wave conditions, outside of those assessed, are not considered, whereby accretion rates may increase/ decrease to those predicted at any given time; and
 - iii. further consolidation of the deposited sediment, over time, will not occur.

- 6.5.2.74 Based upon the calculation method provided above, the estimated potential increase in annual sediment volume that may require additional dredging is provided in Table 6.18 for both Swansea and Port Talbot. In effect, the Project is predicted to potentially increase average annual maintenance dredge volumes by 20 to 34% along the Swansea Channel, and by 1.2 to 2.0% at Port Talbot (along the approach channel and within the Outer Harbour - although it is considered that this predicted change in deposition will be generally indistinguishable from the natural variation in annual dredge volumes). The ranges of potential annual sedimentation provided within Table 6.18 have been calculated based upon measured summer/ winter sedimentation variability within the channels. As shown in Figures 6.50 to 6.52 (Volume 2), the majority of the increased Swansea dredging would need to be undertaken within the inshore half of the channel, whilst increases within the Port Talbot approach channel is predominantly within patches along its length. It should be emphasised, however, that these predicted potential changes to maintenance dredging are based upon average annual dredging rates, therefore these changes will be considerably less during years when the existing maintenance dredging requirements within the channels is considerably greater.

Table 6.18 Predicted annual change in sedimentation volumes within the Swansea and Port Talbot approach channels, and the potential impact on maintenance dredging

Location	Existing Annual Volume Dredged (m ³)	Potential Increase in Annual Sediment Volume (m ³) (% increase above existing average dredge volume)		
		Minimum	Mean	Maximum
Swansea – Approach Channel	192,300	39,000 (20%)	52,000 (27%)	65,000 (34%)
Port Talbot – Approach Channel & Outer Harbour	1,154,000	13,500 (1.2%)	18,000 (1.6%)	22,500 (2.0%)

- 6.5.2.75 Within the Lagoon, mud will settle out over slack periods when there is no water exchange between the Lagoon and Swansea Bay. However, during power generation a proportion of this sediment will be resuspended and transported away from the turbine/ sluice structure under strong flow conditions; potentially exiting the Lagoon over the ebb tide. Across the majority of the Lagoon, away from the turbine/ sluice gate structure (i.e. towards the back), long-term sedimentation is to be expected; increases in this sedimentation (above baseline levels) are estimated to cover approximately one-third of the Lagoon. These areas of sedimentation are expected to coincide with the sedimentation distribution patterns illustrated in Figure 6.50 (Volume 2). It is also expected that some sand will also accumulate within the Lagoon, although this will be considerably less than that predicted for mud.
- 6.5.2.76 Based upon the same annual interpretation method undertaken for the Swansea and Port Talbot channels, it is estimated that accretion within the Lagoon will likely represent an annual volume of between 570,000 to 920,000 m³. It is expected that a large quantity of this sediment would need to be maintenance dredged, likely over a number of campaigns (dependent upon the chosen dredge methodology), in order for the Lagoon to maintain its power generation effectiveness. It is anticipated that maintenance dredging within the Lagoon will not need to start until 10 to 15 years after the completion of construction and then be performed approximately every two years. However, the need to do so will be monitored and, based on this monitoring, a dredging

strategy will be developed and a licence for disposal will be discussed and agreed with MLT.

Maintenance dredge disposal

- 6.5.2.77 It is proposed that any sediment dredged from within the Lagoon (predominantly mud) will be disposed at the Swansea (Outer) licensed deposit ground (LU130), as described previously in Section 6.5.1.25. The deposit ground is highly dispersive for maintenance dredge sediment and for the period 1986 to 2010 received on average approximately 2.6 million wet tonnes per annum of fine sediments (both mud and sand). The new requirement for the Lagoon dredge volume would, therefore, represent an increase of between 29% and 47% of the average sediment volume received at the deposit ground. It should be noted, however, that the deposit ground has received significantly greater volumes of sediment in the past, with approximately 9.1 million wet tonnes disposed in 1996 alone, the majority of which was quickly dispersed with little change occurring to the seabed of the deposit ground.
- 6.5.2.78 Based upon the numerical modelling undertaken for sediment disposal during the construction period (see Sections 6.5.1.25 to 6.5.1.32), dispersion of maintenance dredge sediments will be controlled by the rectilinear flows found within the Central Bristol Channel. The total extent of sediment dispersion from the deposit ground is predicted to be *circa* 12 km to the west and up to approximately 20 km to the east (just beyond Porthcawl), with this variation being driven by the characteristic asymmetry in the tide within the Bristol Channel. Due to these tidal characteristics of the Central Bristol Channel, there is a very limited exchange of suspended sediments from the deposit ground to Swansea Bay, with increases in SSC constrained to the deeper central region of the bay. Following the cessation of the disposal activities, increases in SSC (above background) anywhere along the extent of the sediment plume will be indistinguishable from natural background variations within 1 to 2 weeks.
- 6.5.2.79 Furthermore, it should be emphasised that the disposal of the maintenance dredge sediments will not be cumulative to the disposal activities during the construction period of the Project, where increases in SSC at the deposit ground would have long returned to background concentrations.

Impact

- 6.5.2.80 The magnitude of the proposed disposal impact is considered to be medium due to the extent of coverage of the plume, whilst the probability of occurrence is high (on the assumption that regular maintenance dredging will be undertaken). On this basis, the exposure to change is therefore considered to be medium. As the deposit ground has been extensively used historically, the sensitivity of the deposit ground and seabed in the area of the plume is considered to be low. This gives rise to a low level of vulnerability both immediately adjacent to the deposit ground, and further afield to the extents of plume dispersion. Receptor importance within the Inner Bristol Channel and outer Swansea Bay is considered low. As discussed previously for the capital dredge disposal, whilst sediment dispersion from the disposal activities extends towards the Kenfig SAC, predicted changes in SSC are in the order of background variation (and relatively short lived), and will have no impact on the designated features of the Kenfig SAC (i.e. the sand dunes) as no sedimentation has been predicted to occur. As such, the overall level of potential significance within the Inner Bristol Channel and outer Swansea Bay is assessed as **neutral**.

6.5.3 Decommissioning

6.5.3.1 During decommissioning, after 120 years, two options have been proposed:

- i. replace, upgrade and extend life of power generating station; and
- ii. removal of the turbines and sluice gates from the caissons to leave the openings, through which the natural tide will flow.

6.5.3.2 It should be noted here that full removal of the lagoon is not currently being considered by TLSB (see Chapter 4), although the potential for removal has been considered in Chapter 3: Site Selection and Option Appraisal. As a result, complete removal has not been assessed in this Chapter as a decommissioning option.

6.5.3.3 Following the decommissioning of the turbines and sluice gates, the water levels will no longer be managed and the natural tide will propagate into the Lagoon. The entrance will still have a restriction but flows will reduce compared to the operation period. The flow environment either side of the turbine/ sluice gate structure will become more benign and high water levels are likely to rise back closer to natural levels, although some lowering and time lag is still likely within the Lagoon from outside. It is probable that sedimentation will increase inside if it is not removed by dredging. If this was the case in the long-term, bed levels will increase and extensive intertidal mudflat and saltmarsh are likely to occur. Decommissioning could therefore in time likely result in a change in habitat within the Lagoon to that of mudflat/ saltmarsh.

6.5.3.4 The decommissioning as currently proposed will therefore cause considerable change to the physical environment that will develop during the operation of the Lagoon for power generation. Whilst this is likely to be a significant change to the environment, in 120 years' time such changes (to the future baseline environment) may be seen as beneficial and not adverse.

Impact

6.5.3.5 The potential effects of decommissioning through removal of the turbines and sluice gates are considered to be those resulting directly from the removal activity. Due to the likely scale of such undertakings, it is further considered that any effects will be less than those identified during the construction phase, and their associated potential significance will be similarly lower.

6.6 In-combination/ cumulative assessment

6.6.0.1 The development of the Project will take place alongside other plans, projects and activities within Swansea Bay and further afield. Some of these will have the potential to result in additional or modified impacts on the same coastal process receptors as those identified from the Tidal Lagoon, thus resulting in a cumulative and/or in-combination impact. Consideration is given to plans, projects or activities where spatiotemporal overlap of the impacts is likely to occur. Additionally, consideration is given to impacts associated with other plans, projects and activities that do not directly overlap but which may indirectly result in a cumulative/ in-combination impact.

6.6.0.2 A number of plans/ projects have been identified through consultation, which are potentially relevant to the Project in terms of cumulative and in-combination effects (although not necessarily to coastal process receptors). These schemes/ projects are listed in Table 6.19 below and an initial screening has been undertaken to identify those

which have potential interaction with the Project, with respect to coastal process receptors, and have been considered further in the cumulative and in-combination assessment.

Table 6.19 Screening of in-combination/ cumulative plans, projects and activities

Project and Location	Current Status	Preliminary Screening
Swansea Bay University Campus, adjacent to Crymlyn Burrows.	Construction Feb 2013 – Sept 2015.	Potential positive effects in terms of flood risk by lagoon encompassing the shoreline. Works associated with the campus are onshore and therefore there will be no cumulative/ in-combination impacts of coastal process receptors.
St Modwens land development - east of Swansea Docks, to west of Neath Estuary.	Remediation of land, and potential future developments – no details available.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Mumbles pier, foreshore and coastal strip redevelopment.	Due to be revamped by the end of 2013.	Construction will be completed prior to initiation of Project construction works. Any potential changes to the coastal process receptors will be insignificant and highly localised to the development works. There will be no cumulative/ in-combination impacts on coastal process receptors.
Construction of new RNLI Lifeboat Station, Mumbles.	Expected completion 2014.	Construction of the new RNLI Lifeboat Station will be completed prior to the Project construction works. Royal Haskoning (2010) determined that there will be no impact on local hydrodynamics and sediment transport during the construction of the scheme, whilst long-term impacts during operation are anticipated to be of negligible significance. Therefore, no cumulative/ in-combination impacts on coastal process receptors are expected.
SA1 development, Swansea.	Development currently taking place. Completion date unknown.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Construction of the southern access road to Coed Darcy Urban Village, crossing nearby Crymlyn Bog.	Yet to commence.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Swansea Boulevard project – work between Princess Way and The Strand, and the River Tawe bridges and The Strand.	Phase to be complete in November 2013. Phase 2 to start 2014.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Wind turbine- on Welsh water site on Fabian Way.	Application – Unsuccessful 25/10/2013	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.

Project and Location	Current Status	Preliminary Screening
Five wind turbines – at Mynydd Marchywel between Rhos and Cilfrew Neath	Submitted Jan 2012. Consultation finished Jan 2013. Still in planning.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Sixteen wind turbines- at Mynydd Y Gwair, Swansea.	Approved – unknown construction timetable.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Five wind turbines- on land at Mynydd Brombil Farm, Margam Port Talbot.	Submitted June 2012, still in planning. Consultation finishes April 2013.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Atlantic Array Wind Farm – off North Devon Coast approx 35km distant.	DCO application submitted but withdrawn in November 2013.	Not considered.
Seventy six turbine Pen y Cymoedd windfarm near Neath.	Planning approved – construction 2014	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Llynfi Afan Renewable Energy Park -fifteen turbine windfarm – on land 500m southwest of Cynnonville Port Talbot	Planning permission refused. Application was allowed on appeal 27/08/2013	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Mynydd y Betws- fifteen turbine windfarm located on land to the east of Ammanford in Carmarthenshire	Granted planning consent 2009. Started operating April 2013.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Mynydd y Gwrhyd- windfarm in the Upper Amman and Swansea valleys	Approved on appeal 07/05/2009	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Newlands Farm, single wind turbine- Margam	Application submitted January 2013	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Kenfig Industrial Estate single wind turbine	Application submitted. Expected decision by Feb 2014	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Port Talbot Harbour Redevelopment.	Potential future activities/development. Status unknown.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Upgrading of the existing coastal defence of Aberafan West Promenade, Sandfields, Port Talbot.	Completed August 2013.	Any change in the hydrodynamic and sediment regime caused by the upgrading of the existing defence works will be extremely localised, and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.

Project and Location	Current Status	Preliminary Screening
Porthcawl regeneration scheme includes Porthcawl Marina project and 19 th century lighthouse restoration.	Approved by BCBC - timescale unknown.	During both the construction and operation phase of the Project, sediments will be dispersed from the Swansea (Outer) licensed disposal ground from both capital and maintenance dredging activities towards Porthcawl. As such, there is a potential for cumulative/ in-combination impacts with the proposed marina project works, should dredging/ disposal activities occur at the same time. This has been assessed further in Sections 6.6.1 and 6.6.2.
Tata Steel works – Internal Power generation enhancement for Port Talbot steel works- installation of two new boilers and two new turbines housed in new power station building	Application expected to be submitted 2014	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors
Underground coal gasification under Swansea Bay.	License potentially to be extended.	Underground works. No information currently available and not within the foreseeable future. No cumulative/ in-combination impacts on coastal process receptors anticipated.
Underground coal gasification under Llanelli	Conditional Licence issued	Underground works. No cumulative/ in-combination impacts on coastal process receptors.
Maintenance (navigational) dredging along the Swansea (Tawe), Neath and Port Talbot Channels.	On-going	During the construction phases of the Project, there is potential for interaction between sediment plumes arising from the capital dredging and construction works (i.e. the infilling of the Geotubes®) with on-going maintenance dredging within the Swansea (Tawe), Neath and Port Talbot approach channels. There may also be the potential for sediment plume interaction at the Swansea (Outer) licensed disposal ground during the construction and operation periods of the Project with disposals by the Ports of Swansea and Port Talbot. Therefore, there is a potential for cumulative/ in-combination impacts should dredging/ disposal activities occur at the same time. This has been assessed further in Section 6.6.1.

Project and Location	Current Status	Preliminary Screening
Marina dredging - Monkstone cruising and sailing club and Swansea Marina.	On-going maintenance as required.	During the construction phase of the Project there is potential for interaction between sediment plumes arising from the dredging/ construction activities and plumes created though maintenance dredging of the marinas, should the activities occur at the same time. As such, there is a potential for cumulative/ in-combination impacts . This has been assessed further in Section 6.6.1.
Mumbles Oyster project: Plan to put 10,000 oysters on seabed off village of Oystermouth	Permission granted September 2013.	There will be no interaction between the sediment plumes arising from the Project construction and the oyster harvesting licence at Mumbles Ground and therefore there will be no cumulative/in-combination impact on this receptor.
Severn Barrage	Not within foreseeable future.	Not considered. See note in Chapter 2.
Swansea Barrage	Operational	The barrage is currently operational and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Cardiff Barrage	Operational	The barrage is currently operational and located more than 50 km away from the Project and, therefore, considerably beyond the extent of changes caused by the proposed Project. As such, there will be no cumulative/ in-combination impacts on coastal process receptors.
Baglan Power station	Operational	Onshore with no cooling water discharge into the marine environment, therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Prenergy Biomass Power Station – 350MW wood chip fuelled thermal generating station – Port Talbot	Granted condition approval by BERR on the 20 November 2007. While large scale construction has not been begun, a lawful start of development has occurred and as such the planning permission remains extant.	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.
Abernedd Power Station was granted conditional approval by DECC on the 23 February 2011 for construction of a 870MW gas fired combined cycle gas turbine power plant	No lawful start has yet been made to this development	Onshore works and therefore there will be no cumulative/ in-combination impacts on coastal process receptors.

Project and Location	Current Status	Preliminary Screening
Aggregate Dredging at the Nobel Banks site	On-going	This aggregate licence area is located approximately 35 km from the Project, where any resulting sediment plume (within the Inner Bristol Channel) is unlikely to interact with the disposal plumes at the Swansea (Outer) licensed disposal ground. As such, there will be no cumulative/ in-combination impacts on coastal process receptors.
The Swansea Bay (Thomas Shellfish Limited) Mussel Fishery Order	Ongoing.	There will be no interaction between the sediment plumes arising from the Project construction and the Swansea Bay Mussel Fishery Order.
Ro-Ro Ferry	Currently not operational	Not considered. Ferry not anticipated to recommence in the foreseeable future.
Rhiannon Offshore Windfarm	Pre-application phase	Screened out due to distance from project.
Burbo Bank Offshore Windfarm extension	Existing and extension sought 2013	Screened out due to distance from project.
Tidal Energy Ltd Deltastream Installation Ramsey Sound	Consent secured. Installation 2014	Screened out due to distance from project.
Seagen Skerries Tidal Stream Array	Consent secured. Installation 2014.	Screened out due to distance from project.
Tidal Stream Energy Demonstration Array St David's Head, Pembrokeshire	Construction is planned to commence in 2017.	Screened out due to distance from project.

6.6.0.3 Taking into consideration the full list of the plans, projects and activities provided in Table 6.19, only the following are considered likely to have potential cumulative and/or in-combination impacts coastal process receptors within Swansea Bay or the Inner Bristol Channel:

- i. Porthcawl regeneration scheme, specifically the Porthcawl Marina project;
- ii. Maintenance (navigational) dredging along the Swansea (Tawe), Neath and Port Talbot Channels; and
- iii. Maintenance dredging by the Monkstone cruising and sailing club and Swansea Marina

6.6.1 Construction

6.6.1.1 The key cumulative and/ or in-combination impacts as a result of the potential interaction between the Project and other plans, projects and activities during the construction phases of the Lagoon are the cumulative changes to sediment dispersion.

Sediment dispersion (water column and seabed)

Capital dredging and seawall construction

6.6.1.2 During the proposed capital dredging and seawall construction works associated with the Project, increases in SSC (above background) are predicted to occur across Swansea Bay,

and potentially within the Inner Bristol Channel towards Caswell Bay. The distribution and magnitude of these increases will vary depending on the extent and timing of the dredging/ construction works (e.g. western or eastern seawall construction), with highest concentrations typically found immediately adjacent to the works. Results from the numerical modelling undertaken for the western and eastern seawall construction (see Section 6.5.1.11 onwards) identifies that increases in SSC are temporary during the proposed works, with elevations generally dissipating to background concentrations within a spring-neap tidal cycle on cessation of these activities. Outside of Swansea Bay, changes in SSC as a result of the dredging/ construction works are unlikely to be distinguishable from natural variations in background concentrations.

- 6.6.1.3 In addition to the proposed dredge/ construction works associated with the Project, ongoing maintenance dredging will also be undertaken along the Swansea (Tawe), Neath and Port Talbot approach channels, as well as within the Port Talbot Outer Harbour and by the Monkstone cruising and sailing club and Swansea Marina. These ongoing activities will further lead to both temporal and spatial increases in SSC (above background) within Swansea Bay and potentially slightly further afield within the Inner Bristol Channel. Whilst these activities will more than likely occur at differing times throughout the year, there is potential for a cumulative/ in-combination effect with each other, but also with the sediment plumes arising from the Project.

Impact

- 6.6.1.4 The magnitude of effect associated with the potential interaction of the sediment plumes arising from the Project and ongoing maintenance dredging is considered to be medium, whereby increases in SSC (above background) within Swansea Bay will be temporary and similar to cumulative effects that already take place with ongoing maintenance dredging activities and previous capital dredging works (such as the deepening of the Port Talbot Approach Channel in 1996). The probability of the sediment plumes associated with the Project overlapping with ongoing maintenance dredging activities in Swansea Bay (and within the Inner Bristol Channel) is considered to be medium to high, due to the relatively long periods of dredging/ construction works that are expected to take place over the 3 construction phases. Exposure to change is consequently assessed as medium. As detailed previously in Section 6.5.1.19, increases in SSC resulting from natural changes between tidal and wave events (across Swansea Bay in general) can be greater than those predicted from the proposed works. As a result, the potential cumulative effects with respect to the sensitivity of the seabed and water column are considered to be low. The vulnerability to sediment dispersion from the potential cumulative/ in-combination of the proposed works and the ongoing maintenance dredging is therefore assessed as low. The vulnerability to sedimentary disturbance from the works is therefore assessed as low. The modelling indicates that the maximum extent of the changes has a potential to impact upon the SSSI at Crymlyn Burrows, and therefore the receptor importance in this area is considered moderate, whilst the wider Swansea Bay is assessed as low. On this basis the significance of the impact is considered **minor adverse / neutral** in the area of Crymlyn Burrows and **neutral** for the wider bay

Dredge disposal

- 6.6.1.5 During Phase 1 of the Project construction period, it is estimated that approximately 500,000 m³ of silt and clay sediments (equivalent to *circa* 650,000 to 900,000 wet tonnes *in situ*) may require disposal at the Swansea (Outer) licensed deposit ground. Results from the numerical modelling identified that dispersion of these sediments will be

controlled by the tidal flows within the Inner Bristol Channel, with a total extent of approximately 12 km to the west and up to around 20 km to the east (just beyond Porthcawl), with this variation being driven by the characteristic asymmetry in the tide within the Bristol Channel (see Section 6.5.1.27). Due to these tidal characteristics of the Central Bristol Channel, there is a very limited exchange of suspended sediments from the deposit ground to Swansea Bay, with increases in SSC constrained to the deeper central region of the bay. Temporary, short duration peaks in SSC are predicted to reach *circa* 3,500 mg/l in relatively close proximity to the deposit ground for short periods of time (minutes), however, increases in SSC are typically below 500 mg/l, falling rapidly to less than 10 mg/l over slack periods (LW and HW). In close proximity to the shoreline (i.e. within 100 m of MHWS), maximum increases in SSC at any given time are predominantly below 10 mg/l. Following cessation of the capital dredge disposal activities associated with the Project, all increases in SSC will revert to background levels in less than two spring-neap tidal cycles (see Section 6.5.1.30).

- 6.6.1.6 Disposal of dredged arisings at the Swansea (Outer) deposit ground could occur from the Project as well as from the maintenance dredging of the port approach channels and marinas at the same time, thus leading to a cumulative impact. Between 1986 and 2010, on average approximately 2.6 million wet tonnes of fine sediments (mud and sand) has been received by the deposit ground per annum, primarily from maintenance dredging undertaken by the Ports of Swansea, Neath and Port Talbot; although sand from the Neath has not be deposited at the ground since 2003. As detailed in Section 6.5.1.25, the capital dredge disposal for the Project would relate to approximately 25 - 35% of the average annual disposal volumes at the deposit ground. Sediment dispersion from these disposal activities will be of a similar pattern and magnitude to those modelled for the Project, with the potential for enhanced peak SSC increases (and temporary sedimentation rates) should maintenance dredge disposals occur at the same time as the proposed capital dredge disposal for the Project. On the basis that these activities were to coincide, maximum increases in SSC in close proximity to the shoreline (i.e. within 100m of MHWS in the area of Kenfig Sands) are still expected to be predominantly below 20 mg/l (above background concentrations), and therefore within natural variability.
- 6.6.1.7 Furthermore, cumulative sediment dispersion effects from ongoing disposal activities would already likely to have been experienced historically at the deposit ground, with such changes to both the water column and seabed along the extent of the predicted plume therefore considered within the variability of the system. This is emphasised by the considerably larger disposal volume to the deposit ground in 1996, whereby approximately 9.1 million tonnes of maintenance and capital dredged sediments was received; primarily from capital works associated with the deepening of the Port Talbot Approach Channel.

Impact

- 6.6.1.8 The magnitude of the potential cumulative impact associated with the proposed capital disposal for the Project and on-going maintenance dredging disposal activities is considered to be medium due to the extent of coverage of the plume within the Inner Bristol Channel, whilst the probability of occurrence is considered low to medium due to the relative short time period predicted for the capital disposal works. The exposure is therefore considered, at worst, to be medium. As the deposit ground has been extensively used historically, receiving much greater volumes of sediment than that proposed for the Project and with previous cumulative effects likely, the sensitivity of the deposit ground and seabed in the area of the plume is considered to be low. This gives

rise to a low level of vulnerability both immediately adjacent to the deposit ground, and further afield to the extents of plume dispersion. As detailed previously in Section 6.5.1.32, the vast majority of the extent of plume dispersion covers areas which are not environmentally designated and have been impacted from similar disposal events over a considerable time period without significant impact. The overall receptor importance for the plume extent is therefore considered to be low. Whilst sediment dispersion from the disposal activities extends towards the Kenfig SAC, predicted changes in SSC are in the order of background variation (and relatively short lived), and will have no impact on the designated features of the Kenfig SAC (i.e. the sand dunes) as no sedimentation has been predicted to occur. As such, the overall receptor importance for the total plume extent is considered to be low. Therefore, the level of potential significance is considered as **neutral** for the extent of the disposal plume.

6.6.2 Operation

6.6.2.1 The key cumulative and/ or in-combination impacts as a result of the potential interaction between the Project and other plans, projects and activities during the operation period of the Lagoon are:

- i. the cumulative changes to sediment dispersion at the Swansea (Outer) deposit ground and along the subsequent plume extent due to the potential requirement for future maintenance dredging within the Lagoon.

Sediment dispersion (water column and seabed)

6.6.2.2 During the operational period of the Lagoon, there is potential for a cumulative impact to sediment dispersion at the Swansea (Outer) deposit ground and along the extent of the subsequent plume. These potential cumulative changes arise from the long-term disposal of maintenance dredge sediments (primarily mud) from within the Lagoon and those sediments disposed from on-going maintenance dredging activities at Swansea and Port Talbot. In addition to these cumulative changes originating from the deposit ground itself, the proposed construction works for the Porthcawl Marina project may also lead to further sediment dispersion in proximity to the plume at its eastern extent, although any increases in SSC (above background levels) are expected to be relatively small, with any interaction with the deposit ground plume likely to be highly localised.

Impact

6.6.2.3 Similarly to the potential cumulative impact associated with the proposed capital disposal for the Project and on-going maintenance dredging disposal activities during the construction period, the magnitude of impact is considered to be medium. The overall probability of occurrence is considered to be high, as maintenance dredge/ disposal campaigns for the Lagoon are expected to occur for periods/ campaigns on an annual basis over the expected 120 year lifetime of the Project. As such, the exposure to change is considered to be medium. As the deposit ground has been extensively used historically, receiving much greater volumes of sediment than that proposed for the Project and with previous cumulative effects likely, the sensitivity of the deposit ground and seabed in the area of the plume is considered to be low. This gives rise to a low level of vulnerability both immediately adjacent to the deposit ground, and further afield to the extents of plume dispersion. Whilst sediment dispersion from the disposal activities extends towards the Kenfig SAC, predicted changes in SSC are in the order of background variation (and relatively short lived), and will have no impact on the designated features of the Kenfig SAC (i.e. the sand dunes) as no sedimentation has been predicted to occur.

As such, the overall receptor importance for the total plume extent is considered to be low. Therefore, the level of potential significance is considered as **neutral** for the extent of the disposal plume.

6.7 Mitigation and monitoring

6.7.0.1 To confirm the assessment and provide assurance, it is proposed that a programme of general verification monitoring will be undertaken to assess (where appropriate) the longer-term impacts of the construction and operation of the Project on the coastal process receptors. Specifically, this monitoring should include:

- i. beach profile monitoring to the west of the Lagoon extending into the Blackpill SSSI and to the east in front of Crymlyn Burrows; and
- ii. monitoring of changes in sedimentation within the navigation channel to Swansea Docks to determine the amount of additional sedimentation that would lead to increased maintenance dredging taking account of the existing natural variability.

6.7.0.2 A monitoring programme will be agreed with NRW prior to the construction of the Project and will become part of an agreed Adaptive Environmental Monitoring Plan (AEMP) which will form part of the Operation Environmental Management Plan (OEMP) this will inform measures such as maintenance dredging for channels, etc. The results from any monitoring will be used to determine whether any additional mitigation measures (in accordance with the OEMP) are required in a process of adaptive management.

6.8 Conclusion

6.8.0.1 The chapter has identified that a number of potential impacts to coastal process receptors within Swansea Bay (and further afield in the Inner Bristol Channel), arising from the Project, could occur. Tables 6.20 and 6.21 summarise the significant impacts from the construction and operation works/ activities associated with the Project on the individual receptors, based on the findings presented in Sections 6.5.1 to 6.5.2. In addition Table 6.22 provides a summary of overall predicted effect, by receptor.

6.8.0.2 No mitigation measures have been identified that will reduce the potential impacts of the Project, and therefore an OEMP has been recommended in order to monitor potential changes. This data will be used to determine an appropriate adaptive management approach, to be agreed with NRW.

Table 6.20 Summary of significant impacts for construction activities

Project Stage	Phase	Receptor	Activity	Impact Significance
Construction	Phase 1	Water Column (suspended sediments)	Capital Dredging and Seawall Construction	Minor adverse / neutral in the area of Crymlyn Burrows. Neutral across the rest of Swansea Bay.
			Temporary Bund Construction around Turbine/ Sluice Gate Construction Area	Minor adverse / neutral local to the source of the disturbance. Neutral across the rest of Swansea Bay.
			Capital Dredge Disposal	Neutral for Swansea Bay and Kenfig SAC
		Seabed	Capital Dredging and Seawall Construction	Neutral
			Capital Dredge Disposal	No significant impact to character of seabed
		Coastal Hydrodynamics	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral across the designated Blackpill and Crymlyn Burrows SSSI.
			Capital Dredge Disposal	Neutral
		Sediment (morphological) Regime	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral at the entrance to the Neath, including the Crymlyn Burrows SSSI. Minor adverse / neutral across the wider Blackpill SSSI, whilst moderate/ minor adverse across the upper sandy beaches (narrow band fronting the existing coastal defences) situated within the Blackpill SSSI caused by a potential reduction in infrequent net sand supply (transport) aperiodically from the eastern side of the bay (i.e. from the Neath).
	Phase 2	Water Column (suspended sediments)	Capital Dredging and Seawall Construction	Minor adverse / neutral in the area of Crymlyn Burrows. Neutral across the rest of Swansea Bay.
			Dewatering of the Turbine/ Sluice Gate Construction Area	Neutral
		Seabed	Capital Dredging and Seawall Construction	Neutral
		Coastal Hydrodynamics	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral across the designated Blackpill and Crymlyn Burrows SSSI.
		Sediment (morphological) Regime	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral at the entrance to the Neath, including the Crymlyn Burrows SSSI. Minor adverse / neutral across the wider Blackpill SSSI, whilst moderate/ minor adverse across the sandy beaches situated within the Blackpill SSSI caused by a potential reduction (in the long term) in net sand supply (transport) aperiodically from the eastern side of the bay (i.e. from the Neath).

Project Stage	Phase	Receptor	Activity	Impact Significance
	Phase 3	Water Column (suspended sediments)	Removal of the Temporary Seawall Bund around the Turbine/ Sluice Gate Structure	Neutral
			Capital Dredging and Seawall Construction	Minor adverse / neutral in the area of Crymlyn Burrows. Neutral across the rest of Swansea Bay.
		Seabed	Removal of the Temporary Seawall Bund around the Turbine/ Sluice Gate Structure	Neutral
			Capital Dredging and Seawall Construction	Neutral
		Coastal Hydrodynamics	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral across the designated Blackpill and Crymlyn Burrows SSSI.
		Sediment (morphological) Regime	Capital Dredging and Seawall Construction	Neutral across the undesignated subtidal/ intertidal regions of the bay. Minor adverse / neutral at the entrance to the Neath, including the Crymlyn Burrows SSSI. Minor adverse / neutral across the wider Blackpill SSSI, whilst moderate/ minor adverse across the sandy beaches situated within the Blackpill SSSI in the long term caused by a potential reduction in net sand supply (transport) aperiodically from the eastern side of the bay (i.e. from the Neath).

Table 6.21 Summary of significant impacts for Lagoon operation

Project Stage	Receptor	Parameter	Impact Significance	
Operation	Coastal Hydrodynamics	Flow Speeds and Directions	Minor adverse / neutral across the intertidal in the vicinity of both the Blackpill and Crymlyn Burrows SSSIs. Minor adverse within the Lagoon itself, and neutral within the 'jetting' flows from the turbines/ sluice gates within the subtidal outside of the Lagoon.	
		Water Levels	Neutral	
		Waves	Largely neutral within the subtidal region of Swansea Bay. Minor adverse in areas where wave reflection (from the seawalls) increase wave heights, e.g. across the intertidal in the western region of the bay, or where sheltering is provided by the Lagoon structure. A reduction in wave heights along the Crymlyn Burrows frontage, however, could be considered as beneficial.	
	Sediment (morphological) Regime	-	Predominantly neutral within the western region (subtidal and intertidal) of Swansea Bay, with localised moderate/ minor adverse impacts across the sandy beaches in the Blackpill SSSI (where there may be a potential reduction in sand supply) and within the Swansea Channel (due to possible high rates of sedimentation). Within the Lagoon, impact significant is assessed as minor adverse , whilst immediately outside within the 'jetting' flows significance is neutral . Changes to the east of the Lagoon, i.e. at the entrance to the Neath and along the Crymlyn Burrows frontage, are considered minor adverse / neutral , as are changes within the Port Talbot Channel. Elsewhere across the wider bay, impact significance is assessed as neutral .	
	Water Column (suspended sediments)	Maintenance Dredge Disposal (from within the Lagoon)	Neutral	

Table 6.22 Summary of overall predicted effects on receptors

Receptor	Summary of Overall Effect
Kenfig SAC	Construction – some short-term increase to suspended sediment concentration due to sediment disposal at spoil ground, but no predicted deposition across the intertidal or shallow sub-tidal. Overall, no significant effect from construction phase. Operation – no predicted changes to hydrodynamics. No predicted changes to wave characteristics. Subsequently, no predicted changes to sediment transport processes. Overall, no significant effect predicted from operation phase.
Carmarthen Bay and Estuaries SAC, SPA and Burry Inlet SPA and Ramsar	Construction – no predicted effects from construction phase. Operation – no predicted effects from operation phase.
Blackpill SSSI	Construction – no predicted increases to SSC or sediment deposition during construction phase. Operation – general slight reduction in mean flow speeds over the western part of the bay as a result of the constriction of the bay between Mumbles headland and the outer extent of the lagoon wall. Predicted changes to HW and LW levels are predominantly constrained to the parts of the bay outside of the Blackpill SSSI. Reflection of SW waves off of the outer lagoon wall result in a small predicted increase in significant wave height to the southern part of the SSSI (behind Mumbles), along with an associated small reduction in wave period. The assessment of potential changes to mud transport shows no predicted increased deposition of mud material within the Blackpill SSSI, with any changes predicted to occur in the subtidal part of the bay. The potential intermittent transport of sand material from the eastern part of the bay to the western part of the bay (including the Blackpill SSSI) will be blocked by the lagoon, leaving direct transport from offshore during SW and SE storms as the primary source of sand to the western part of the bay. Analysis of the SCBCEG annual beach profiles for this region shows an initial reduction in beach and intertidal levels between 1998 and 2005, but a more stable elevation between 2005 and 2013. A slight general seaward movement of HAT and MHWS indicates a general trend for slight accretion since 2005. As a result of this, and the reduction in intermittent sand transport, it is considered that this slight accretion is likely to reduce following construction of the lagoon, leading to a more stable profile in the future.
Swansea designated beach	Operation – the potential intermittent transport of sand material from the eastern part of the bay to the western part of the bay (including the Blackpill SSSI) will be blocked by the lagoon, leaving direct transport from offshore during SW and SE storms as the primary source of sand to the western part of the bay. Analysis of the SCBCEG annual beach profiles for this region shows an initial reduction in beach and intertidal levels between 1998 and 2005, but a more stable elevation between 2005 and 2013. A slight general seaward movement of HAT and MHWS indicates a general trend for slight accretion since 2005. As a result of this, and the reduction in intermittent sand transport, it is considered that this slight accretion is likely to reduce following construction of the lagoon, leading to a more stable profile in the future.
Wider bay Swansea sandy beach areas and effect on lower shore	Construction – no predicted significant increases to SSC or sediment deposition during construction phase. Operation – general slight reduction in mean flow speeds over the western part of the bay as a result of the constriction of the bay between Mumbles headland and the outer extent of the lagoon wall. Predicted changes to HW and LW levels are predominantly constrained to the upper and lower parts of the bay (around the entrance to the Tawe and behind Mumbles). Reflection of SW waves off of the outer lagoon wall result in a small predicted increase in significant wave height to the southern part of the western bay (behind

	Mumbles). The assessment of potential changes to mud transport during smaller (10 in 1 year) storm conditions shows no predicted increased deposition of mud material across the intertidal part of the western bay, with any changes predicted to occur in the subtidal part of the bay. Where potential increased mud deposition is predicted, it should be noted that the system will reach an equilibrium condition whereby the increased deposition will result in shallower depths, such that the flows over the bed will be increased to the point that further deposition will be less likely. Additionally, calmer periods (which have less potential to mobilise sediment from the bed) and larger storm events (which have the potential to increase erosion), have been shown to result in lower levels of deposition, and over a reduced spatial extent. The potential intermittent transport of sand material from the eastern part of the bay to the western part of the bay (during larger storm events) will be blocked by the lagoon, leaving direct transport from offshore during SW and SE storms as the primary source of sand to the western part of the bay. Analysis of the SCBCEG annual beach profiles for this region show an initial reduction in beach and intertidal levels between 1998 and 2005, but a more stable elevation between 2005 and 2013. A slight general seaward movement of HAT and MHWS indicates a general trend for slight accretion since 2005. As a result of this, and the reduction in intermittent sand transport, it is considered that this slight accretion is likely to reduce following construction of the lagoon, leading to a more stable profile in the future.
Wider Swansea Bay offshore	Due to reflection of SW waves off of the lagoon wall, significant wave heights between the lagoon and Mumbles headland are predicted to increase during SW storms. During these conditions, vessels approach from around Mumbles headland may encounter waves with heights increased by approximately 30cm (depending on storm conditions), with the increases predicted to be greatest in closest proximity to the lagoon wall. Refraction of SW waves around Mumbles headland is still predicted to occur with the lagoon in place. Under these (SW) storm conditions, the lagoon will not act to shelter the western part of the bay from SW winds. It is therefore considered likely that windsurfing activity in the western part of the bay is unlikely to be affected by the lagoon. Conversely, for winds coming from the SE, the western part of the bay is likely to be sheltered by the lagoon (which will also offer shelter from longer fetch waves approach from the Inner Bristol Channel. If windsurfing activity currently takes place in the western part of the bay under these (SE) conditions, it is considered likely that this will be affected in the lee of the lagoon. Increased deposition during sediment disposal is predicted to be primarily constrained to the area surrounding the spoil ground. Predicted effects on hydrodynamics, waves and sediment transport processes during the operation phase are predicted to be primarily constrained to the Swansea Bay region. As a result, no significant effects predicted for the offshore region (outside of Swansea Bay), including Mixon Shoal.
SUBC beach within the lagoon	Predicted changes to mud deposition within the lagoon (during smaller (10 in 1 year) storm conditions) during the operation phase, shows the upper intertidal region fronting the SUBC development is likely to be less accretionary for muds, when compared to the baseline scenario. The middle intertidal shows no significant change to the baseline case, whilst the lower intertidal regions show a potential for increased mud deposition during the operation phase. As with the wider bay region, it is noted here that the system will reach an equilibrium condition whereby the increased deposition will result in shallower depths, such that the flows over the bed will be increased to the point that further deposition will be less likely. Additionally, calmer periods (which have less potential to mobilise sediment from the bed) and larger storm events (which have the potential to increase erosion), have been shown to result in lower levels of deposition, and over a reduced spatial extent.

Sediment inside lagoon – boating	Predicted changes to mud deposition within the lagoon during the operation phase, shows the upper intertidal region within the lagoon is likely to be less accretionary for muds, when compared to the baseline scenario. The middle intertidal shows no significant change to the baseline case, whilst the lower intertidal regions show a potential for increased mud deposition during the operation phase. Across the subtidal, regions that are influenced by the increased flow speeds through the turbines are considered likely to scour under the flood generation phase, until an equilibrium condition is reached (likely as a result of the more dense, less erodible, sub-bottom material), at which point further scouring is considered unlikely. In addition, as with the wider bay region, it is noted here that the system will reach an equilibrium condition whereby the increased deposition will result in shallower depths, such that the flows over the bed will be increased to the point that further deposition will be less likely. Additionally, calmer periods (which have less potential to mobilise sediment from the bed) and larger storm events (which have the potential to increase erosion), have been shown to result in lower levels of deposition, and over a reduced spatial extent.
Crymlyn Burrows SSSI	As a result of the reduction in mean flow speeds and the sheltering by the lagoon from the predominant SW waves, it is predicted that sand will accrete in the region fronting Crymlyn Burrows, against the eastern arm of the lagoon wall. The amount and extent of deposition is largely dependent on the prevailing SW storm conditions, with more severe storms potentially carrying more sand into this part of the bay, therefore increasing the potential accretion. It is considered likely that any such accumulation will begin in the short-term and continue into the medium to long-term, up to a finite capacity governed by the tidal conditions and the morphology of the region. As sand transport into these areas is driven by the action of long-period SW waves, these processes are more likely to occur over medium-term time-scales (rather than short-term); with greatest sand transport expected to occur over the winter months. Any potential increase in sand accumulation as a result of the Project would further strengthen net accretionary patterns identified over the past 15-years.
Baglan Burrows	Construction – some short-term increases to SSC predicted from construction activity to the eastern part of the bay. No associated predicted increases in deposition of material from construction activity. Overall, no significant effect predicted from construction phase. Operation – small and localised predicted reduction in mean current speed. No significant changes in wave climate predicted. No predicted changes to sediment transport processes. Subsequently, it is considered that the morphology of the Baglan Burrows region will not be significantly changed. Overall, no significant effect predicted from operation phase.
Aberafan Sands	Construction – overall, no significant effect predicted from construction phase. Operation – small and localised predicted reduction in mean current speed. No significant changes in wave climate predicted. No predicted changes to sediment transport processes. Subsequently, it is considered that the morphology of the Aberafan Sands region will not be significantly changed, nor is it predicted that there will be any significant changes to the wave climate (including the surfing waves). Overall, no significant effect predicted from operation phase.
Tawe channel	Construction – some localised predicted increases to SSC and sediment deposition as a result of construction activity in the western part of the bay. Operation – predicted effects on Tawe approach channel can generally be split into two regions: 1. Outer part of approach channel (offshore of the present lagoon extent) – predicted increases to current flow during ebb generation phase; small predicted increase in significant wave height as a result of reflection of SW waves off of the lagoon wall. As a result, it is considered unlikely that increased sediment deposition will occur in this part of the channel. 2. Inner part of approach channel (adjacent to the western arm of the lagoon wall) – predicted decrease in mean flow speed; predicted decrease in significant wave height from SW and SE waves as a result of sheltering from the lagoon. As a result, it is considered that

	increased sediment deposition (predominantly muds) is likely within this part of the approach channel. Maximum deposition within the channel of approximately 1.5mm is predicted over a 24 hour period during a 10 in 1 year storm event (i.e. this level of deposition might be expected to occur 10 times over an annual period). Calmer periods (which have less potential to mobilise sediment from the bed) and larger storm events (which have the potential to increase erosion), have been shown to result in lower levels of deposition, and over a reduced spatial extent.
Neath Channel	As a result of the reduction in mean flow speeds and the sheltering by the lagoon from the predominant SW waves, it is predicted that sand will accrete in the region fronting Crymlyn Burrows, against the eastern arm of the lagoon wall. The amount and extent of deposition is largely dependent on the prevailing SW storm conditions, with more severe storms potentially carrying more sand into this part of the bay, therefore increasing the potential accretion. Where the volume of material is great enough, it is considered possible that some of the accreted sand may build-up against the lagoon wall and 'fall-into' the Neath approach channel. No change in mud distribution, either through erosion or accretion, has been identified within the Neath Channel.
Port Talbot channel	Construction – some predicted increases in deposition within the outer parts of the approach channel as a result of disposal activity at the spoil ground. Overall, deposits are expected to be dispersed over time, following cessation of disposal activity. Any material that remains within the channel is considered likely to be indiscernible when compared to the natural variability of the system. Operation – some predicted increases in mud deposition within the inner and outer parts of the approach channel as a result of changes to mud transport pathways. Overall, it is considered that additional material deposited within the channel is likely to be indiscernible when compared to the natural variability of the system.
Monkstone Marina	Construction – predicted short-term increase in SSC expected to be constrained to the outer Neath. No predicted increases as far upstream as Monkstone Marina in SSC or subsequent deposition. Overall, no significant effect predicted from construction phase. Operation – no predicted increase in suspended sediment concentration within the Neath, either through increased SSC of waters entering from the bay or from any changes to the fluvial flushing of the river.
Offshore disposal ground	Potential deposit volumes remain within the envelope of historic variation in annual deposits from approach channel dredging. Overall, no significant effect predicted from potential deposit activity.

6.9 References

- ABPmer, 2005. Scarweather Sands Offshore Windfarm: Metocean Design Variables. ABP Marine Environmental Research, Research Report R.1206.
- ABPmer, 2010. Severn Tidal Power – SEA Topic Paper: Hydraulics and Geomorphology. Annex Geo 4: Improve baseline understanding of suspended sediment regime (river inputs). ABP Marine Environmental Research, Research Report R.1705.
- ABPmer, 2010b. Severn Tidal Power – SEA Topic Paper: Water Quality. Technical Annex 2: Salinity. ABP Marine Environmental Research, Research Report R.1713.
- ABPmer, 2010c. Port Talbot Proposed Channel Deepening: Environmental Appraisal. ABP Marine Environmental Research, Research Report R.1730.
- ABPmer, 2010c. Severn Tidal Power – SEA Topic Paper: Hydraulics and Geomorphology. Annex Geo 14: Construction related issues. ABP Marine Environmental Research, Research Report R.1710.
- ABPmer, 2012. Swansea Bay Tidal Lagoon: Feasibility Modelling. ABP Marine Environmental Research, Research Report R.1956TN.
- ABPmer, 2013a. Atlantic Array Offshore Windfarm: Environmental Statement – Physical Processes. ABP Marine Environmental Research Ltd., prepared for RWE Innogy. May 2013.
- ABPmer, 2013b. Swansea Bay Tidal Lagoon: Bathymetry Data Preparation. ABP Marine Environmental Research, Research Report R.2111TN.
- ABPmer, 2013c. Swansea Bay Tidal Lagoon: Model Setup, Calibration and Validation ABP Marine Environmental Research, Research Report R.2108TN.
- ABPmer, 2013d. Tidal Lagoon Swansea Bay: Extreme Wave Heights and Joint Probability Analysis. ABP Marine Environmental Research, Research Report R.2151TN.
- ABP R&C, 1996a. Port Talbot Channel Deepening: Effect of Storm Conditions on Dredging and Disposal Sediment Plumes. ABP Research & Consultancy Ltd, Research Report R.574
- ABP R&C, 1996b. Port Talbot Channel Deepening Mitigation Studies for Neath Harbour Commissioners. ABP Research & Consultancy Ltd, Research Report R.583.
- ABP R&C, 2000. Port Talbot and Tidal Harbour: Environmental Appraisal – Proposed Expansion of Jetty and Berthing Facilities. ABP Research & Consultancy Ltd, Research Report R.884.
- Atkins, 2013. Swansea Bay Tidal Lagoon: Factual Report on Ground Investigation. Atkins Limited, Report A3076-13.
- Beckett Rankine, 2009. The Bay Science and Innovation Campus: Wave Overtopping Report. 38pp.
- BGS, 1986. Bristol Channel: Sea Bed Sediments & Quaternary Map. Sheet 51N 04W, Scale 1:250,000. British Geological Survey.
- Blackley, M.W.L., 1978. Swansea Bay (SKER) Project – Topic Report 3. Geophysical Interpretation and Sediment Characteristics of the Offshore and Foreshore Areas. Institute of Oceanographic Sciences (IOS). Report No 60. 49p
- Blott, J. S., Pye, K., van der Wal, D. & Neal, A., 2006. Long-term morphological change and its causes in the Mersey Estuary, NW England. *Geomorphology*, 81, 185–206.

- Cefas, 2011. Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. ME5403, Cefas, 98pp.
- Cefas, 2013. Scarweather Wavenet Buoy data downloaded from Cefas data archive: <http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet/data-archive.aspx>
- Centre for Hydrology and Ecology (CHE), 2013. Website last accessed on: 5th June 2013. <http://www.ceh.ac.uk/data/nrfa/>
- Collins, M.B., 1983. Supply, distribution and transport of suspended sediment in a macrotidal environment, Bristol Channel, U.K. Canadian Journal of Fisheries and Aquatic Sciences, 40, Supplement 1, pp. 44-59.
- Defra, 2006. Flood and Coastal Defence Appraisal Guidance, FCDPAG3 Economic Appraisal, Supplementary Note to Operations Authorities – Climate Change Impacts, October 2006.
- DECC (2011) National Policy Statement for Renewable Energy Infrastructure (EN-3), London, The Stationery Office Dolphin, T.J., Silva, T.A.M. and Rees, J.M., 2011. Natural Variability of Turbidity in the Regional Environmental Assessment (REA) Areas. MEPF-MALSF Project 09-P114. Cefas, Lowestoft, 41p.
- EGS, 2013. Swansea Bay Tidal Lagoon: Factual Report on Ground Investigation. August 2013.
- Environment Agency, 2011. Coastal Flood Boundary Conditions for UK Mainland and Islands. Project: SC060064/TR2: Design Sea Levels. Environment Agency, Almondsbury, 142p.
- Folk, R L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology 62 (4), 344-359.
- Fugro, 1995a. Marine Geotechnical and Geophysical Site Investigation Report: Swansea Channel and Ferryport Wales. Fugro Limited, Report No. 55090-2.
- Fugro, 1995b. Marine Geotechnical and Geophysical Site Investigation Report: Port Talbot Tidal Harbour Wales. Fugro Limited, Report No. 55090-1.
- Halcrow, 2012a. Lavernock Point to St Ann's Head Shoreline Management Plan (SMP2) – January 2012. <http://www.southwalescoast.org/>
- Halcrow, 2012b. Lavernock Point to St Ann's Head Shoreline Management Plan (SMP2) – Appendix C: Baseline Processes Understanding. January 2012. <http://www.southwalescoast.org/content.asp?id=58>
- Heathershaw, A.D. and Hammond, F.D.C., 1979. Offshore Sediment Movement and its Relation to Observed Tidal Current and Wave Data. Swansea Bay (SKER) Project, Topic Report: 6. IOS Report No. 93.
- Lowe, J., Howard, T., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., and Bradley, S., 2009. UK Climate Projections Science Report: Marine and coastal projections. Met Office Hadley Centre, Exeter, 99p.
- National Tide and Sea Level Facility (NTSLF), 2013. Website last accessed on: 2nd June 2013. <http://www.ntsfl.org/data/uk-network-real-time>
- Neath Estuary Group, 2011. Neath Estuary Report 2011. 19pp.

Parsons Brinckerhoff Ltd, 2010. Severn Tidal Power – SEA Topic Paper. Hydraulics and Geomorphology Annex 9. Geo 6: Investigate Changes to Hydraulics for Short-Listed Options (water levels and flows) – Part B. April 2010. 122pp.

Posford Duvivier & ABP Research, 2000. Bristol Channel Marine Aggregates: Resources and Constraints Research Project, Final Report, August 2000. Posford Duvivier and ABP Research Ltd, for The National Assembly for Wales, Department of Environment, Transport & Regions and The Crown Estate.

PSMSL, 2014. Permanent Service for Mean Sea Level. Website last accessed on 24 January, 2014. <http://www.psmsl.org/data/obtaining/>

Pye, K. and Blott, S.J., 2009. Coastal processes and shoreline behaviour of estuary dominated systems in Swansea Bay and Carmarthen Bay. 15th May 2009. Annex A1 of the Lavernock Point to St Ann's Head Shoreline Management Plan (SMP2). 58pp.

The Planning Inspectorate, 2012a. Advice Note Seven: Environmental Impact Assessment, screening and scoping. 9pp.

Titan, 2012a. Swansea Tidal Lagoon Geophysical Investigation: Final Report. Titan Environmental Surveys Ltd, Report CS0330.

Titan, 2012b. Swansea Bay Tidal Lagoon – Current/Wave Monitoring: Final Overview Report. Titan Environmental Surveys Ltd, Report CS0343.

Titan, 2013. Swansea Lagoon Benthic Data Report: Draft Report V2. Titan Environmental Surveys Ltd, Report CS0399.

TLSB, 2012. Proposed Tidal Lagoon Development in Swansea Bay, South Wales, Environmental Impact Assessment Scoping Report. Tidal Lagoon Swansea Bay Ltd., October 2012.

TLSB, 2013. Preliminary Environmental Information Report. Tidal Lagoon Swansea Bay Ltd., 2013.

Stoner, J.H., 1977. A report on the first year of a programme to monitor inputs to Swansea Bay 1973/74. Welsh National Water Development Authority Report, No 55 TW 77/2, 24p.

UKDMAP, 1998. United Kingdom Digital Marine Atlas, Third Edition, July 1998.

United Utilities, 2003. Scarweather Sands Offshore Wind Farm. Environmental Statement. Volume 1. 638p.

Welsh Government, 2013. Scoping Opinion under the Marine Works (Environmental Impact Assessment) Regulations 2007. Ref SC/12/09. 25th March 2013. pp36.

Whitehouse, R., Balson, P., Beech, N., Brampton, A., Blott, S., Burningham, H., Cooper, N., French, J., Guthrie, G., Hanson, S., Nicholls, R., Pearson, S., Pye, K., Rossington, K., Sutherland, J. & Walkden, M., 2009. Characterisation and prediction of large-scale, long-term change of coastal geomorphological behaviours: Final science report. Defra/EA FCERM Science Report: SC060074/SR1

Woodworth, P.L., Tsimplis, M.N., Flather, R.A., and Shennan, I., 1999. A review of trends observed in British Isles mean sea level data measured by tide gauges. *Geophys. J. Int.*, (1999) 136, 651-670.