



Environmental Statement Chapter 7. Marine Water Quality Assessment

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7.0 Marine Water Quality Assessment

7.1 Introduction

- 7.1.0.1 This Chapter provides an assessment of water quality in Swansea Bay and the potential impacts of the construction, operation and decommissioning of the Project on marine water quality. The review will make reference to the Water Framework Directive (EC 2000/60/EC) (WFD), the Bathing Water Directive (EC 76/160/EEC) (BWD), and the Shellfish Water Directive (EC 2006/113/EC) (SWD), which are the principal legislative drivers for water quality assessments in coastal waters around the UK. The review will also cover European Union (EU) regulations pertaining to bacterial sampling of shellfish flesh, which is a key water quality indicator.
- 7.1.0.2 Figure 7.1 provides a geographical overview of the Swansea Bay water body, highlighting the designated bathing and shellfish waters as well as significant local wastewater outfalls that are owned and operated by Dŵr Cymru Welsh Water (DCWW). These DCWW assets, along with diffuse inputs (e.g. urban and agricultural runoff) to local streams and rivers, are known to affect water quality in the Bay to varying degrees. There are also a number of other industrial and private discharges to the Bay and river waters which may also impact water quality.
- 7.1.0.3 The WFD was introduced by the European Union in 2000 as a means to ensure protection of water bodies in member states. The WFD is essentially an operational tool with which legislative bodies are able to set clearly-defined objectives relating to the protection, improvement and sustainable use of water bodies within their jurisdiction. The WFD groups surface and ground water bodies together into larger River Basin Districts (RBDs), each of which is the subject of a River Basin Management Plan (RBMP), administered by a local competent authority. The Swansea Bay water body lies within the Western Wales RBD, the Management Plan for which was set out by Environment Agency Wales (EAW), the predecessor of the Countryside Council for Wales, which itself became Natural Resources Wales (NRW).
- 7.1.0.4 In addition to the objectives proposed under the WFD, coastal water bodies may also be subject to water quality assessments at designated bathing and shellfish waters that lie within their boundaries. These assessments are carried out in accordance with the BWD, the SWD, and EC regulations pertaining to bacterial concentrations in the flesh of bivalve molluscs. These directives aim to ensure that coastal waters are clean enough to ensure safe use for leisure and aquaculture purposes.
- 7.1.0.5 Swansea Bay water body, as defined by the WFD, contains two designated bathing waters (BW) and three shellfish waters (SWs). One bathing water is located within the confines of Swansea Bay itself and one is to the east, at Aberavon. There are an additional four bathing waters which lie along the southern coast of the Gower Peninsula between Bracelet Bay and Caswell Bay which will be considered, although these beaches are likely to be too distant to be influenced by the Project in terms of water quality. Beyond this, there are a further three designated beaches extending as far as Rhossili Head. The shellfish waters cover Swansea Bay and adjacent expanses of sea extending to a point some 7km offshore.
- 7.1.0.6 The UK is presently in a transitional phase in terms of the management of its bathing waters, as the present legislation is due to be replaced in 2015 by the Revised Bathing

Water Directive (EC 2006/7/EC) (rBWD). The revised directive sets more stringent water quality standards than its predecessor, and places a greater emphasis on beach management and public information.

- 7.1.0.7 This Chapter of the ES sets out the legislation by which the environmental status of the Bay is assessed, and summarises the current status of the Bay in terms of key contributors and receptors. Section 7.2 introduces the key applicable elements of the legislation; Section 7.3 outlines the criteria based on the key applicable elements of the legislation used to assess water quality and to determine the significance of potential impacts; Section 7.4 provides a summary of the present and expected water quality in Swansea Bay; Section 7.5 outlines the general assessment process; Section 7.6 outlines the model applications undertaken; Section 7.7 presents the results of the assessment; and Section 7.8 provides a discussion and conclusions.
- 7.1.0.8 For the assessment of water quality, this chapter reports operation-phase effects prior to construction phase impacts. Whilst both have been assessed with equal rigour, this emphasises the focus upon long-term effects in relation to this parameter.
- 7.1.0.9 This chapter does not contain an assessment of the Project cumulatively with other developments since none are predicted to result in additional discharges to Swansea Bay.

Tidal Lagoon Swansea Bay plc

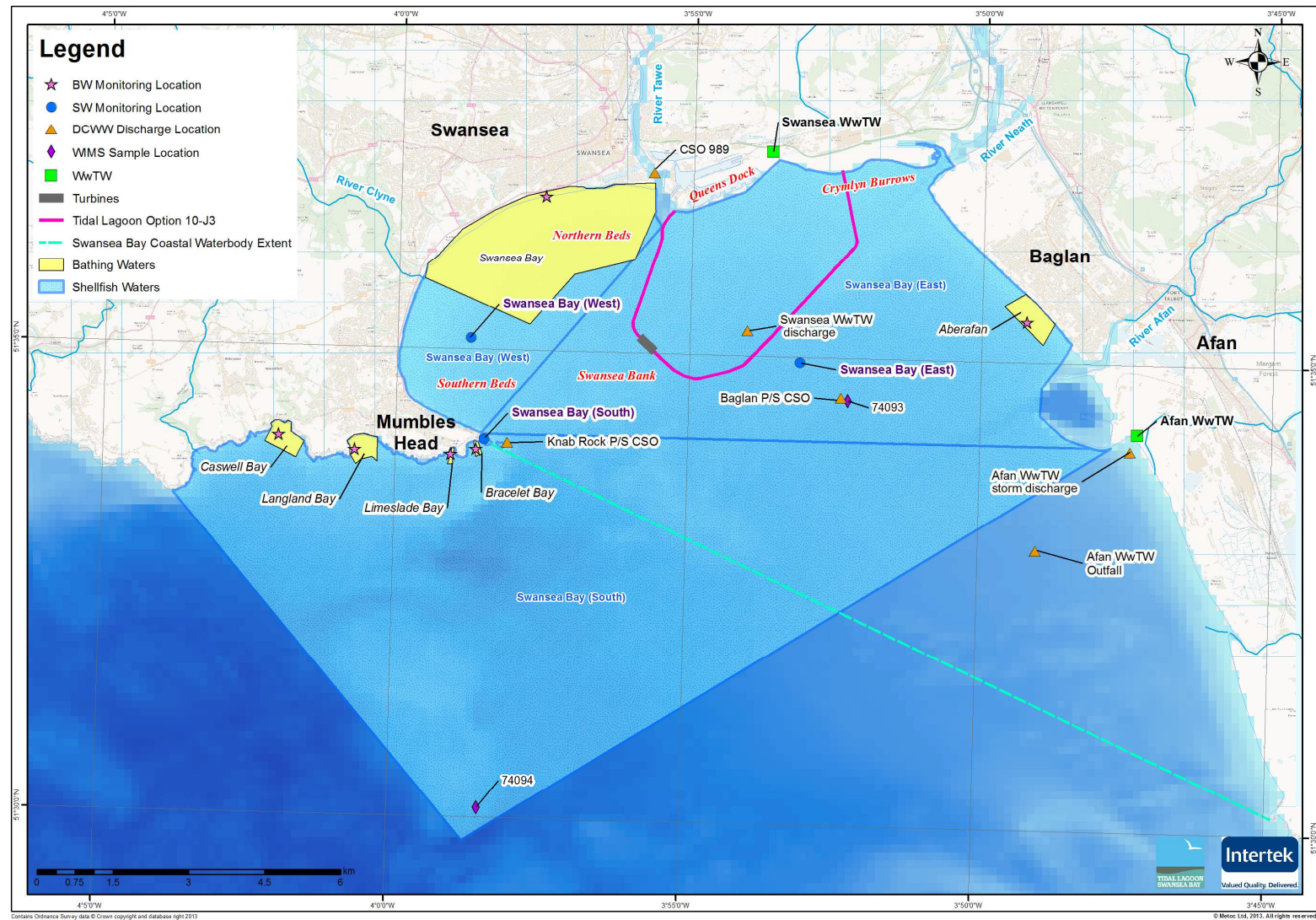


Figure 7.1 Swansea Bay – study area, water quality designations and key locations

7.2 Legislation, planning policy and guidance

7.2.1 Water Framework Directive

7.2.1.1 The WFD introduces a range of objectives relating to the protection, improvement and sustainable use of water bodies. It operates on a six year cycle, with objectives for the next six years set at the beginning of each cycle. The WFD came into effect in 2009: the performance of each water body in meeting the 2009 objectives will be assessed in 2015. The environmental objectives for surface waters such as the Swansea Bay water body are as follows:

- a) prevent deterioration in status for water bodies;
- b) aim to achieve good ecological and good surface water chemical status in water bodies by 2015;
- c) for water bodies that are designated as Artificial or Heavily Modified, aim to achieve good ecological potential by 2015;
- d) comply with objectives and standards for protected areas where relevant; and
- e) reduce pollution from priority substances and cease discharges, emissions and losses of priority hazardous substances.

7.2.1.2 The WFD stipulates that all waters should achieve Good status. Surface waters are assessed in terms of ecological and chemical health, and for a water body to achieve Good overall status it must achieve at least a Good rating in both categories. Ecological status is measured on a scale from High to Good to Moderate to Poor to Bad, while chemical status is simply recorded as Good or Fail. If a water body is currently at less than Good ecological status, the regulating authority must report how certain it is that the water body does not meet Good status. NRW defines certainty in relation to predicted outcomes and status as Very Certain, Quite Certain and Uncertain based on the criteria identified in Table 7.1 below.

Table 7.1 NRW Definition of certainty that a water body will not achieve Good Ecological status.

How certain NRW are that the water body is less than Good ecological status	Threshold
Very Certain	≥95% certain that the water body does not meet the objective of Good status
Quite Certain	≥75to <95% certain that the water body does not meet the objective of Good status
Uncertain	>50% to <75% certain that the water body does not meet the objective of Good status

7.2.1.3 The WFD stipulates that the ecological status of a water body should be classified according to the following elements:

- i. the condition of biological elements, for example fish;
- ii. concentrations of supporting physico-chemical elements, for example ammonia levels;
- iii. concentrations of specific pollutants, for example copper;
- iv. supporting conditions of morphology and hydrology; and
- v. for high status, largely undisturbed hydromorphology.

7.2.2 Bathing Water Directives

- 7.2.2.1 The legislative framework for water quality assessments at designated BWs is set out in the current Bathing Water Directive (cBWD, 1976), although this will be superseded in 2015 by the revised Bathing Water Directive (rBWD, 2006). The rBWD places more stringent controls on water quality than the cBWD, which has resulted in local authorities and water companies placing increasing emphasis on meeting the requirements of the revised directive rather than the current one. Since the new legislation will be in force when the Project development begins, the ES will assess the performance of bathing waters in terms of the rBWD. The cBWD will nonetheless be discussed in Sections 7.3 and 7.4 to provide some perspective on the historical performance of Swansea's bathing waters.
- 7.2.2.2 Although the cBWD and rBWD are different standards (see Section 7.3), it is useful to consider how to relate one to the other. The following comparisons have been taken from an Environment Agency Wales document on the rBWD (EAW 2012):
- a) rBWD Excellent – approximately twice as stringent as the cBWD Guideline standard
 - b) rBWD Good – similar to the cBWD Guideline standard
 - c) rBWD Sufficient – tighter than the cBWD Mandatory standard
 - d) rBWD Poor – normally non-compliant water
- 7.2.2.3 All bathing waters will be required to achieve at least the rBWD Sufficient class by the end of 2015.
- 7.2.2.4 The Poor class is effectively Failure under the existing BWD. Good is broadly equivalent to Guideline, and Excellent is a higher standard still. The Sufficient classification is a balance between a small increase in health risk from Good, and the delivery of a mechanism for a smoother transition from the cBWD to rBWD, without wholesale compliance failures.

7.2.3 Shellfish Waters Directive (SWD)

- 7.2.3.1 The EU Shellfish Waters Directive protects or improves shellfish waters in order to support shellfish life and growth. It sets out physical, chemical and microbiological water quality requirements that designated shellfish waters must either comply with (Mandatory Standard) or endeavour to meet (Guideline Standards). The directive will be repealed in 2013 by the EU Water Framework Directive (WFD). The WFD will provide at least the same level of protection to shellfish waters (which the WFD classifies as protected areas), meaning that the current water quality standards applied to shellfish waters will remain for the foreseeable future. Additional standards are likely to be added, but these have not yet been confirmed. For this ES the assessment of impacts on shellfish waters will be considered under the SWD.
- 7.2.3.2 The original SWD (79/923/EEC) was transposed into UK legislation, as a series of regulations, and directions in 1997 and was amended in 2006, following amendment of the directive (EU Shellfish Waters Directive, 2006/113/EEC, codified version (EU 2006/113/EC)).

7.2.3.3 Compliance with the SWD in itself will not ensure the protection of public health. This is the objective of the Food Hygiene Regulations (EC 852, 853, 854/2004), which took effect on 1 January 2006, and repealed the previous 1991 Shellfish Hygiene Directive (91/492/EEC).

7.2.4 EU Regulation No. 854/2004 for Products of Animal Origin

7.2.4.1 EU Regulation No. 854/2004 (the PAO Regulation) sets out specific rules for the organisation of official controls on products of animal origin intended for human consumption. Appendix II, Part A, Item 6 of the regulation states that if a competent authority decides to classify an area for production of live bivalve molluscs, it must:

- a) make an inventory of the sources of pollution of human or animal origin likely to be a source of contamination for the production area;
- b) examine the quantities of organic pollutants which are released during the different periods of the year, according to the seasonal variations of both human and animal populations in the catchment area, rainfall readings, waste-water treatment, etc;
- c) determine the characteristics of the circulation of pollutants by virtue of current patterns, bathymetry and the tidal cycle in the production area; and
- d) establish a sampling programme of bivalve molluscs in the production area which is based on the examination of established data, and with a number of samples, a geographical distribution of the sampling points and a sampling frequency which must ensure that the results of the analysis are as representative as possible for the area considered.

7.2.4.2 The PAO Regulation provides four classifications for bivalve mollusc production and relay beds, based on the level of *Escherichia coli* (E Coli) found in the flesh and intravalvular liquid of molluscs from the bed in question. Class A beds produce molluscs that are essentially fit for direct human consumption, while Classes B and C denote beds whose molluscs require varying degrees of relaying and purification before they may be put on the market. Class D or prohibited areas produce molluscs that must not be harvested or offered for human consumption. Section 7.3.5 contains further details on the assessment criteria.

7.3 Water quality assessment criteria

7.3.0.1 This section provides details of the criteria used to assess the potential impacts of the Project during the construction, operation and decommissioning phases. The criteria are set out under the following key headings based on the legislation governing water quality as described above:

- i. Water quality assessment under the WFD;
- ii. Water quality assessment under the Current BWD;
- iii. Water quality assessment under the Revised BWD;
- iv. Water quality assessment under the Shellfish Waters Directive; and
- v. Shellfish hygiene assessment under the Food Hygiene Regulations.

- 7.3.0.2 An impact will be considered to be **not significant** where the effect will not exceed the appropriate standards or guidance values; does not result in non compliance with the WFD and associated bathing waters and shellfish waters directive; or does not result in deterioration in WFD chemical or ecological status.

7.3.1 Water quality assessment under the WFD

- 7.3.1.1 Ecological status is measured on the scale High, Good, Moderate, Poor and Bad, where good status would typically represent a *slight variation from undisturbed natural conditions*. Chemical status is simply measured as Good or Fail.
- 7.3.1.2 Under the WFD, surface water bodies are characterised in terms of an ‘overall status’ which is the result of assessments of their chemical and ecological health. In 2009, at the beginning of the first six year assessment cycle, all water bodies were assigned a current and predicted (2015) status. In cases where both the current and predicted status were less than Good, justification for not achieving Good status was required.
- 7.3.1.3 The chemical and ecological components of a water body’s environmental health comprise a number of different elements, which are measured against specific standards proposed by the Water Framework UK Technical Advisory Group (UKTAG) and the European Union.
- 7.3.1.4 In order to arrive at a chemical and ecological classification for a water body a range of elements are measured: the poorest individual element is used as a basis for the classification, thereby ensuring a conservative characterisation of overall environmental health. Table 7.2 provides a breakdown of chemical and ecological status in terms of the various influential elements.

Table 7.2 Components of chemical and ecological status under the WFD

Overall status	Chemical status	Priority substances which present a significant risk to the water environment
	Ecological status	Physico-chemical elements, e.g. nutrients, pH, dissolved, oxygen, ammonia
		Biological elements, e.g. phytoplankton, macroalgae, fish, invertebrates
		Specific pollutants, e.g. metals and their compounds, organic compounds
		Hydromorphology, e.g. depth, width, flow, structure

- 7.3.1.5 This chapter examines the effects of the Project on concentrations of key water quality determinands designated as such by the WFD. These relate to key physio-chemical determinands (temperature, salinity, nutrients and dissolved oxygen) relevant to Ecological Status under WFD.
- 7.3.1.6 The effects of construction on the concentrations of a number of chemical pollutants are also assessed. The concentrations of these pollutants relate to Chemical Status under WFD (e.g. Priority Substances) and effects on Ecological Status. These determinands relate to contaminants identified in the sediments of Swansea Bay that may be mobilised during construction (Section 7.6.4).
- 7.3.1.7 The effects of the Project are considered in terms of potential changes in concentration of these determinands and the effects of these changes on WFD Class, measured against relevant standards set by UKTAG. Microbiological water quality, which also forms part of the WFD, is assessed separately under the relevant Bathing and Shellfish Water Directives.

7.3.1.8 The effects of the Project on biological and hydromorphological components of Ecological Status are considered elsewhere in the ES (e.g. Coastal Processes, Intertidal and Subtidal Benthic Ecology, Fish and Terrestrial Ecology), but may draw upon the results of the water quality assessment. A review of compliance of the Project with meeting WFD objectives is provided as a separate report accompanying the application for development consent.

7.3.1.9 Tables 7.3 to 7.5 below present the relevant UKTAG standards for coastal and transitional waters for temperature, nitrogen and dissolved oxygen.

Table 7.3 Temperature standards in riverine, transitional and coastal waters under the WFD.

Classification	Cold Water*	Warm Water
High	20	25
Good	23	28
Moderate	28	30
Poor	30	32

*Cold water standard relates to salmonid waters

Table 7.4 Nutrient standards in marine and transitional waters under the WFD.

Area	Salinity (psu)	Dissolved Inorganic Nitrogen (Winter mean)							
		High/Good Boundary		Good/Moderate Boundary		Moderate/Poor Boundary		Poor/Bad Boundary	
		µmol/l	µg/l	µmol/l	µg/l	µmol/l	µg/l	µmol/l	µg/l
Offshore	More than 34.5	10	140	15	210	-	-	-	-
Coastal	30 – 34.5	12	168	18	252	27	378	40.5	567
Transitional	Less than 30	20	280	30	420	45	630	67.5	945

Table 7.5 Dissolved oxygen standards in marine waters under the WFD.

Classification	Standard (5 percentile mg/l)	Description
High	5.6	Protect all life-stages of salmonid fish
Good	4.0 ~ 5.7	Resident salmonid fish
Moderate	2.4 ~ 4.0	Protects most life-stages of non-salmonid fish
Poor	1.6 ~ 2.4	Resident non-salmonid fish, poor survival of salmonid fish
Bad	1.6	No salmonid fish. Marginal survival of resident species.

7.3.1.10 UKTAG Environmental Quality Standards (EQS) relating to Priority Substances (specifically metals and tributyltin tin) are presented in Table 7.6.

Table 7.6 Environmental Quality Standards for Priority Substances under the WFD.

Priority Substance	EQS (ug/l)	Type	Source
Arsenic	25.0	Mean Annual Concentration (MAC)	UKTAG ¹
Copper	5.0 ^a	Mean Annual Concentration (MAC)	UKTAG ¹
Lead	25.0 ^a	Mean Annual Concentration (MAC)	UKTAG ¹
Cadmium	2.5	Mean Annual Concentration (MAC)	UKTAG ¹
Chromium	15.0	Mean Annual Concentration (MAC)	UKTAG ¹
Nickel	30.0	Mean Annual Concentration (MAC)	UKTAG ¹
Zinc (dissolved) ^b	40.0	Mean Annual Concentration (MAC)	UKTAG ¹
Mercury	0.3	Mean Annual Concentration (MAC)	UKTAG ¹
Tributyltin ^d	0.002	Maximum Concentration	RIVM ²
Phenanthrene ^c	6.7	Mean Annual Concentration (MAC)	SEPA ³
Fluoranthene ^c	1.0	Mean Annual Concentration (MAC)	SEPA ³
Pyrenec	0.1	Mean Annual Concentration (MAC)	SEPA ³
Benzo[a]anthracenec	0.4	Mean Annual Concentration (MAC)	RIVM ⁴
Chrysenec	0.007	Mean Annual Concentration (MAC)	SEPA ³
Benzo[b]fluoranthenec	0.1	Mean Annual Concentration (MAC)	SEPA ³
Benzo[a]pyrenec	0.1	Mean Annual Concentration (MAC)	UKTAG ¹

Notes

- These standards are annual averages.
- The standard for Zinc is for total zinc. Dissolved zinc has been included as it is the fraction which will stay in the water column over a longer period. Zinc partitioning to the sediment will be rapidly removed from the water column.
- These contaminants do not have formal EQS but different regulators have set environmental standards (see Table 7.6).
- The standard for Tributyltin is a maximum value.

Sources

- UK TAG: - Proposals for Environmental Quality Standards for Annex VIII Substances. January 2008. For determinands with no formal UKTAG EQS, standards are derived from those set by other European regulators.
- RIVM - E.M.J. Verbruggen | R. van Herwijnen. Environmental risk limits for chrysene. RIVM Letter Report 601357008/2011. (Dutch National Institute for Public Health and the Environment).
- Scottish Environment Protection Agency guidance SEPA. (2013). Environmental Standards for Discharges to Surface Waters. WAT-SG-53.
- RIVM - E.M.J. Verbruggen | R. van Herwijnen. Environmental risk limits for phenanthrene. RIVM Letter Report 601357007/2011. (Dutch National Institute for Public Health and the Environment).

7.3.2 Water quality assessment under the cBWD

- 7.3.2.1 There are two standards to be met for the cBWD: a statutory Mandatory standard (sometimes referred to as the Imperative (I) standard); and a more stringent Guideline (G) standard. Where a bathing water does not meet the Mandatory standard water quality is referred to as Poor.
- 7.3.2.2 When reporting bathing water sample results the NRW refer to the Mandatory standard as the Minimum (M) standard and the Guideline as the Higher (H) standard, failure to meet the Mandatory standard is classed as Fail (F).
- 7.3.2.3 There are also two Faecal Indicator Organisms (FIOs) which are used to indicate pollution by faecal matter, and by implication the potential health risk posed by such pollution. FIOs are considered to be more reliably present in wastewater (and other sources of faecal contaminants) than actual pathogenic organisms, which may be affected by disease levels in a given population. The two FIOs most commonly used are known as faecal coliforms (FC or fc) and faecal streptococci (FS or fs).

- 7.3.2.4 The cBWD requires that at least 20 samples are taken during a bathing season at a specific location, known as the Designated Sample Point (DSP). The Mandatory (Imperative) standard requires that at least 95% (i.e. 19 samples) must be below a fc threshold of 2000 fc/100ml. There is no Mandatory standard for faecal streptococci.
- 7.3.2.5 The cBWD Guideline standard requires that, of the 20 samples taken during a bathing season, at least 80% of samples must be below a faecal coliforms threshold of 100 fc/100ml, and at least 90% must be below a fs threshold of 100 fs/100ml. The standards set out in the cBWD are presented in Table 7.7.

Table 7.7 Water quality standards under the cBWD

For coastal waters and transitional waters				
Parameter		Poor quality	Good quality (Imperative or Mandatory Standard)	Excellent quality (Guideline Standard)
1	Faecal coliforms (cfu/100ml)	>2,000	2000 (*)	100 (**)
2	Faecal streptococci (cfu/100ml)	n/a	n/a	100 (***)
3	Total coliforms (cfu/100ml)	>10,000	10,000	500
(*) Must be achieved for 95% of samples (i.e. 19/20 samples)				
(**) Must be achieved for 80% of samples (i.e. 16/20 samples)				
(***) Must be achieved for 90% of samples (i.e. 18/20 samples)				

7.3.3 Water quality assessment under the rBWD

- 7.3.3.1 The rBWD has four levels of classes: Excellent; Good; Sufficient; and Poor. The classifications are assessed statistically using data collected during the current bathing season and the three preceding bathing seasons, making a four-year rolling assessment period providing approximately 80 samples (4 x 20 samples per year).
- 7.3.3.2 Percentile concentrations of the bathing water sample data are calculated based on a log-normal distribution of the data, and the calculated percentiles are then compared to the classification standards set out in Table 7.8 to establish the class of the bathing water.
- 7.3.3.3 The key aspect of these classifications is that they are assessed statistically over a four year bathing-season period, and the magnitude of bacteria concentrations are an important component of bathing water performance (unlike the cBWD).

Table 7.8 Water quality classifications under the rBWD

For coastal waters and transitional waters					
Parameter		Excellent quality	Good quality	Sufficient quality	Reference methods of analysis
1	Intestinal enterococci (cfu/100ml)	100 (*)	200 (*)	185 (**)	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100ml)	250 (*)	500 (*)	500 (**)	ISO 9308-3 or ISO 9308-1
(*) Based upon a 95-percentile evaluation, assuming a log normal distribution of the sample data.					
(**) Based upon a 90-percentile evaluation, assuming a log normal distribution of the sample data.					

7.3.4 Water quality assessment under the Shellfish Waters Directive

7.3.4.1 The SWD includes a Guideline standard for faecal coliforms in shellfish flesh of 300 per 100ml of flesh and intravalvular liquid in 75% of samples. The standard is not mandatory but provides a level which EC member states should endeavour to meet. In addition to the targets of the SWD, the UK Government has set a target for all commercial-harvested shellfish beds to achieve a classification of Category B under the Shellfish Hygiene Directive.

7.3.4.2 There is evidence that the microbiological quality of the water column will affect the microbiological quality of the flesh of shellfish, although the form of this relationship is uncertain. Based on work undertaken by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), a water quality standard for the protection of Category B status for shellfish flesh has been derived. This standard is generally implemented in Wales (by NRW) in one of two forms:

- A. where continuous and intermittent discharges affect shellfish waters a water quality standard of 1,500 faecal coliforms per 100ml for at least 97% of the time is applied; or
- B. for the consenting of continuous discharges affecting shellfish waters a geomean concentration standard is applied. This standard is derived on the same basis as the 97%ile standard and is expressed in two forms. A geomean concentration of 112 fc/100ml, generally rounded to 100 fc/100ml, or as a dilution standard expressed as a minimum 5.25 log reduction in faecal coliforms between crude sewage and a point within the designated shellfish water. The 5.25 log reduction ensures that for a crude influent, with a typical concentration of 2×10^7 fc/100ml, a concentration of approximately 112 fc/100ml is achieved in the shellfish water.

7.3.4.3 These standards are currently under review by CEFAS and a more stringent standard may be adopted in future.

7.3.5 Shellfish hygiene assessment under EC Regulation No. 854/2004

7.3.5.1 Under the PAO Regulations (EC 854/2004) competent authorities are required to carry out periodic monitoring of production and relaying areas to check:

- a) that there is no malpractice with regard to the origin, provenance and destination of live bivalve molluscs;
- b) the microbiological quality of live bivalve molluscs in relation to the production and relaying areas;
- c) for the presence of toxin-producing plankton in production and relaying waters and biotoxins in live bivalve molluscs; and
- d) for the presence of chemical contaminants in live bivalve molluscs.

7.3.5.2 The regulation states that the competent authority may classify an area as Class A (i.e. fit for the production of molluscs that are fit for direct human consumption), if the molluscs in that area meet health standards laid down in Annex III, Section VII, Chapter V of the Food Standards Regulations (EC 853/2004).

- 7.3.5.3 An area can be classified as Class B if molluscs collected from that area do not exceed the limits of a five-tube, three dilution Most Probable Number (MPN) test of 4600 E Coli per 100 g of flesh and intravalvular liquid. Such molluscs may be placed on the market for human consumption only after treatment in a purification centre or after relaying so as to meet the health standards laid out in the Food Standards Regulations.
- 7.3.5.4 An area can be classified as Class C if molluscs collected within its boundaries do not exceed 46,000 E Coli per 100g of flesh and intravalvular liquid. Such molluscs must be subjected to a long period (for at least 2 months) of purification or relaying before they may be deemed fit for human consumption according to the Food Standards Regulations.
- 7.3.5.5 A fourth class (Class D) is used where E Coli levels are greater than 46,000 per 100g of meat. In this case the bed is classed as Prohibited or Unclassified and molluscs must not be harvested from these areas for human consumption.

7.4 Baseline conditions

7.4.1 WFD objectives and performance

- 7.4.1.1 The WFD recognises that human activity has changed the hydrology and morphology (hydromorphology) of the water environment by providing certain functions or uses, e.g. for ports and harbours or to reduce the risk of flooding. Restoring the hydromorphology of such water bodies to good ecological status, as defined in the WFD, may have a significant impact on these uses. If this is the case, the WFD allows the designation of the water body as artificial or heavily modified. The NRW assess the ecological potential of heavily modified water bodies, such as Swansea Bay, by reference to a standardised list of pressures, impacts and mitigation measures within a water body. To reach Good Ecological Potential all of the reasonable mitigation measures to improve and protect the environment have to be in place and functioning. Some mitigation measures may already be in place, but one or more may be missing. If this is the case, the Heavily Modified Water Body will be at Moderate Ecological Potential. WFD mitigation measures may also result in a significantly adverse impact on socio-economic, heritage and/or conservation interests. In these cases the sustainable balance has already been reached and the water body is at Good Ecological Potential.
- 7.4.1.2 Under the terms of the WFD, Swansea Bay has been classified as a Heavily Modified Water Body, at risk from diffuse pollution (resulting from surface water run-off to rivers) and morphological alterations. However, the Bay is not considered to be presently at risk from point source pollution (i.e. from sewage, drainage and industrial outfalls).
- 7.4.1.3 Table 7.9 summaries the characteristics of the Swansea Bay water body, as defined by NRW (formerly EAW) under the WFD in 2009 and reiterated in the 2012 Water Body Action Plan (WAP), highlighting its long and short term objectives.

Table 7.9 Water body characteristics for Swansea Bay

Water Body Category and Map Code	Coastal – C21
Water Body ID and Name	GB641008260000, Swansea Bay
National Grid Reference	SS 70917 86276
Current Overall Potential	Bad
Status Objective (Overall)	Good by 2027
Status Objective(s)	Good Ecological Potential by 2027, Good Chemical Status by 2015
Justification if overall objective is not good status by 2015	Disproportionately expensive, technically infeasible
Protected Area Designation	Bathing Water Directive, Freshwater Fish Directive, Natura 2000 (Habitats and/or Birds Directive*), Shellfish Water Directive
Species of Special Scientific Interest (Non-N2K) related	No
Hydromorphological Designation	Heavily Modified
Reason for Designation	Coastal protection

*These Directives are not directly relevant to this element of water quality assessment. Ecological effects are assessed elsewhere in the ES, although the ecological considerations in terms of water quality are addressed below.

- 7.4.1.4 Table 7.10 summarises the Bay's ecological potential in terms of the biological elements, supporting elements and mitigation measures that were identified in the first cycle of the WFD. As Swansea Bay is classified as a Heavily Modified Water Body the table identifies the current ecological potential, a prediction of when the water body will meet good ecological potential (or justification where Good potential is not achievable) and the mitigation measures that have a defined ecological potential in terms of reducing hydromorphological impacts.
- 7.4.1.5 Chemical status is assessed in terms of priority substances that present a significant risk to the water environment. Table 7.11 summarises Swansea Bay's chemical potential, as determined in the first six year cycle of the WFD, published in 2009. The table shows that four elements were identified as posing potential risks to the aquatic environment in the bay, but that in all four cases the rating was recorded as High, ensuring a Good chemical status.
- 7.4.1.6 The relevant River Basin Management Plan also identifies a number of objectives for the protected areas within the Bay. Of relevance to the Project, these protected areas include: freshwater fish waters; shellfish waters; bathing waters; water dependent Special Areas of Conservation (SAC); and water dependent Special Protection Areas (SPAs).

Table 7.10 Ecological characteristics of the Swansea Bay water body

Ecological Potential			
Current status (and certainty that status is less than Good)		Bad (uncertain)	
Biological Elements			
Element	Current status (and certainty of less than Good)	Predicted status by 2015	Justification for not achieving Good status by 2015
Phytoplankton	Bad (Uncertain)	Bad	Disproportionately expensive
Supporting Elements			
Element	Current status (and certainty of less than Good)	Predicted status by 2015	Justification for not achieving Good status by 2015
Dissolved Inorganic Nitrogen	Moderate	Moderate	Disproportionately expensive
Dissolved Oxygen	High	High	n/a
Copper	High	High	n/a
Toluene	High	High	n/a
Ecological Potential Assessment			
Element	Current status (and certainty of less than Good)	Predicted status by 2015	Justification for not achieving Good status by 2015
Mitigation Measures Assessment	Moderate	Moderate	Technically infeasible
Mitigation Measures that have defined Ecological Potential			
Mitigation Measure			Status
Indirect / offsite mitigation (offsetting measures)			Not in place
Alter timing of dredging / disposal			Not in place
Reduce sediment re-suspension			Not in place
Reduce impact of dredging			Not in place
Prepare a dredging / disposal strategy			Not in place
Avoid the need to dredge (e.g. minimise under-keel clearance; use fluid mud navigation; flow manipulation or training works)			Not in place
Operational and structural changes to locks, sluices, weirs, beach control, etc			Not in place
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone			Not in place
Managed realignment of flood defence			Not in place
Bank rehabilitation / re-profiling			Not in place
Preserve and, where possible, restore historic aquatic habitats			Not in place
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution			Not in place
Remove obsolete structure			Not in place

Table 7.11 Chemical characteristics of the Swansea Bay water body

Chemical Status			
Current status (and certainty that status is less than Good)		Good	
Chemical Elements			
Element	Current status (and certainty of less than Good)	Predicted status by 2015	Justification for not achieving Good status by 2015
Benzene	High	High	n/a
Lead and its compounds	High	High	n/a
Mercury and its compounds	High	High	n/a
Nickel and its compounds	High	High	n/a

Salinity

- 7.4.1.7 Salinity in Swansea Bay is influenced by the mixing of seawater, from the Bristol Channel, with freshwater discharges from local rivers and streams. The salinity of the Bristol Channel water is also affected by the river discharges from the Severn and other rivers. Chapter 6: Coastal Processes, Sedimentation and Contamination describes the baseline salinity within Swansea Bay. Table 7.12 summarises the variation in salinity described in Chapter 6. In addition data from the NRW Water Information Management System (WIMS) at two sites in Swansea Bay (Figure 7.1) is presented. The two sites presented correspond to WIMS sample site 74093 (Inner Swansea Bay, approximately 2km south east of the Lagoon) and sample site 74094 (Outer Swansea Bay, approximately 6km south of Mumbles Head).
- 7.4.1.8 The effects of river discharges can clearly be seen in the range of salinities observed in Swansea Bay: seawater typically has a salinity of 35 psu. Lowest salinities are observed close to the coastline, particularly the river estuaries, and during winter conditions, when freshwater inputs are greatest. The offshore WIMS data tends to show a slightly higher mean and maximum salinity compared to the inshore sites, which are more influenced by local freshwater inputs.

Table 7.12 Measured salinity (psu) in Swansea Bay

Sampling Point	Mean (psu)	Max (psu)	Min (psu)
Aberavon Sands 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
WIMS - Inner Swansea Bay**	31.70	34.40	20.90
WIMS - Outer Swansea Bay**	32.40	35.00	23.20

(*Source: ABP Research (2000), samples Sept 1995 to May 2000)

(**Source NRW WIMS sample sites, samples 1992 to 2008.)

Temperature

- 7.4.1.9 Temperature of the Swansea Bay water body is determined by atmospheric heating and the mixing of river waters with those in the Bay. Temperature is lowest in winter and gradually increases in summer, to a maximum in September/October. As the Bay is a large mass of seawater, its temperature tends to lag air temperature and river temperature, i.e. higher in winter, lower in summer. Chapter 6: Coastal Processes, Sedimentation and Contamination describes the variations in baseline temperature within Swansea Bay. In summary, the mean sea temperature in Swansea Bay varies from around 8°C during winter to 13°C during summer (United Kingdom Digital Marine Atlas UKDMAP, 1998). Data from the NRW WIMS indicates an annual mean of approximately 13°C, with a seasonal temperature minimum of 3.5°C in winter and 20°C in summer, with a typical range of 8°C to 18°C. These temperatures are typical of UK coastal waters.

Nutrients

- 7.4.1.10 Nutrients (nitrogen and phosphorous) are required for primary production of phytoplankton (algae) in the aquatic environment. High nutrient concentrations can lead to high phytoplankton concentrations (eutrophication) which can have adverse impacts on the ecology of an aquatic system, and can lead to blooms of toxic algae. In saline waters nitrogen acts as the limiting nutrient to the growth of marine phytoplankton. Nitrogen concentrations have been classified as Moderate under the WFD ecological characterisation for Swansea Bay (Table 7.10). Similarly phytoplankton is identified as Bad, although this is Uncertain, and indicates that Swansea Bay is likely to be sensitive to nutrients and high algal productivity.
- 7.4.1.11 Specific nutrient data for Swansea Bay is limited, but there is data available from the NRW WIMS sample sites in Swansea Bay. These data are summarised in Table 7.13. Data is presented for nitrogen and phosphorous, nitrogen is the limiting nutrient in marine waters against which water quality is assessed under WFD.

Table 7.13 Measured nutrient concentrations in the Swansea Bay water column (NRW WIMS sample sites 1992 – 2008).

Sampling Point	Nitrogen (as DAIN) (ug/l)			Total Phosphorous (ug/l)		
	Mean	Max	Min	Mean	Max	Min
WIMS - Inner Swansea Bay	326.5	516.8	15.0	55.1	820.0	6.0
WIMS – Outer Swansea Bay	337.5	934.0	16.0	46.6	163.0	6.3

- 7.4.1.12 The sample data shows little difference in nutrient concentrations between the inner and outer offshore sites. Seasonal variability in nutrient concentrations usually occur with minimum (spring/summer) and maximum (winter) concentrations. During peak primary production in the spring and summer, available nutrients are used in the growth of phytoplankton. These are then released back into the water column as phytoplankton die back in winter. The average concentration of nitrogen would indicate Moderate class under WFD, and is consistent with the water body class for Swansea Bay (Table 7.10).
- 7.4.1.13 The low minimum values recorded would suggest high primary production in spring and summer, and would tend to concur with the estimated Bad class for phytoplankton in the water body (Table 7.10).

- 7.4.1.14 A recent report prepared by the Centre for Research into Environment and Health (CREH) in 2012 (CREH 2012) for NRW, provides an assessment of continuous loads¹ of nutrients from rivers and waste water treatment works (WWTWs) to Swansea Bay. The total mean annual nitrogen load is approximately 5000 kg/day, while the phosphorus load is approximately 200 kg/day. Some variation is seen seasonally, with highest loads during the winter months. The majority of the load, approximately 50% is from the Tawe, Neath and Afan rivers. The Swansea and Afan WWTWs contribute a further 40%, with the remaining 10% from the smaller rivers and streams draining to the bay.

Dissolved Oxygen (DO)

- 7.4.1.15 DO is required for respiration of marine organisms, and is a primary indicator of the ability of an aquatic system to support marine life. The amount of oxygen that can be dissolved in seawater is a function of temperature and salinity: high temperature and high salinity reduce the solubility of oxygen. For any given temperature and salinity there is a maximum dissolved oxygen concentration that can be achieved (saturation). Oxygen enters the water column through the surface air/water interface (re-aeration), and as a product of photosynthesis by marine phytoplankton. Oxygen is consumed through chemical reactions, e.g. oxidation of ammonia, and bio-chemical reactions, e.g. decay of organic material, represented by Biological Oxygen Demand (BOD). Oxygen is also consumed by respiration of marine organisms and by oxidation processes within the sediment. In coastal marine waters, DO concentrations are typically close to saturation, due to the large surface area, increased re-aeration from wind and waves, high mixing, and relatively low concentrations of chemical and biological sinks.
- 7.4.1.16 Table 7.14 provides a summary of DO concentration data from the NRW WIMS database for two locations in Swansea Bay.

Table 7.14 Measured dissolved oxygen concentrations in the Swansea Bay water column (NRW WIMS sample sites 1992 – 2008).

Sampling Point	Concentration (mg/l)			Saturation (%)		
	Mean	Max	Min	Mean	Max	Min
WIMS - Inner Swansea Bay	8.8	16.7	6.4	100.3	172.0	79.2
WIMS – Outer Swansea Bay	8.5	10.6	6.3	97.6	125.0	81.7

- 7.4.1.17 The data in Table 7.14 shows similar DO concentrations are found at both the inner and outer sites and indicates a high level of DO in Swansea Bay, confirming its current High class under WFD (Table 7.10).
- 7.4.1.18 The high levels of oxygen saturation indicate the water body is well aerated. The very high maximum values are indicative of high levels of primary production (high phytoplankton concentrations) during spring and summer months. Photosynthesis during daylight hours can lead to conditions of super-saturated DO in coastal areas. High DO concentrations are evidence of potentially high levels of phytoplankton in Swansea Bay during summer and spring and would support the WFD Bad (uncertain) status for phytoplankton (Table 7.10).

¹ For the purpose of this study a load is defined as the mass per time of a pollutant entering a river or coastal water. The load is determined by multiplying the pollutant flow (discharge rate) by the concentration of pollutant present.

Dissolved metals

- 7.4.1.19 Measured data for a number of metals in Swansea Bay are available for the two NRW WIMS sample locations. These provide an indication of background concentrations in Swansea Bay, and are presented in Table 7.15.

Table 7.15 Measured metal concentrations in the Swansea Bay water column (NRW WIMS surveys 1992 – 2008).

Metal	Concentration (ug/l)					
	Inner Swansea Bay			Outer Swansea Bay		
	Mean	Max	Min	Mean	Max	Min
Mercury	0.06	0.71	0.01	0.07	1.03	0.01
Cadmium	0.09	1.14	0.04	0.07	0.69	0.04
Zinc	7.99	58.6	1.16	6.08	45	0.92
Chromium	0.4	4.92	0.02	0.31	2.29	0.02
Nickel	0.96	3.77	0.32	0.66	3.69	0.12
Arsenic	1.41	6.7	1	1.35	3.7	1
Iron (unfiltered)	71	219	3	79.5	308	3
Iron	5.9	24	3	5	21	3
Boron	3292	4250	1790	3368	4370	1800
Vanadium	17.8	70	2	17.7	70	2
Copper	1.5	5.4	0.7	1.5	3.4	0.5

- 7.4.1.20 Little variation in concentrations is seen between the inner and outer sites. The sample results indicate metals concentrations are within current EQS values. Of these only copper, zinc and mercury have mean concentrations of more than 5% of the EQS in the water column.

7.4.2 Bathing water quality

- 7.4.2.1 The Swansea Bay water body, as defined by the WFD, comprises two designated bathing waters: one in the Bay itself and one at Aberafan Sands. For completeness a further four bathing waters on the Gower Peninsula, west of The Mumbles (Figure 7.1) have also been reviewed.
- 7.4.2.2 All six bathing waters are administered by NRW, in partnership with the relevant local authority and DCWW. Under the rBWD, NRW publishes a Bathing Water Profile for all bathing waters under its jurisdiction, outlining all major issues pertaining to water quality at the sites. This sub-section aims to summarise the key elements of the six relevant profiles.
- 7.4.2.3 Water quality in coastal waters is typically impacted by point source discharges from WWTWs and diffuse inputs from agricultural and urban runoff to rivers and streams. Discharges from private sewers and ground water may also have localised impacts on water quality. During periods of high rainfall, additional inputs from Combined Sewer Overflows (CSOs), which provide relief to the sewer network, may also occur. High rainfall will increase the flow from WWTWs and the diffuse pollutant loads to rivers and streams. Micro-organisms are subject to processes of decay in the natural environment, due to the effects of sunlight, salinity and predation. The hydrodynamics of the receiving water will also affect water quality: discharges in dynamic environments like the Bristol

Channel will be subject to high dispersion, leading to rapid dilution in the receiving water.

- 7.4.2.4 Water quality at a bathing water is determined by a number of factors, but is most affected by local hydrodynamics and proximity to specific sources: e.g. beaches close to urban areas are generally more affected by WWTW and CSO discharges, while those in rural areas are more influenced by diffuse sources.
- 7.4.2.5 Swansea Bay bathing water is influenced by multiple sources. In dry weather the water quality at the bathing water is generally Good (i.e. below cBWD Guideline concentrations), as the primary sources of background pollutants are low level diffuse inputs from rivers and streams and the discharge from the Swansea WWTW, which discharges some 3km offshore to the East of the bathing water. The WWTW has little impact on the bathing water, UV disinfection of the treated final effluent provides an additional 1.5 log of bacteria removal and the offshore location of the discharge minimises impacts on the bathing waters in Swansea Bay.
- 7.4.2.6 If higher concentrations of pollutants occur during dry weather, this is usually due to discharges from misconnections, i.e. foul household/industrial effluent entering the surface storm water drainage system and discharging to local rivers and streams. NRW and County and City of Swansea Council (CCSC) have stated that they are working to remove misconnections in a number of the streams discharging into Swansea Bay. DCWW have also stated that they are removing misconnections as part of their ongoing improvement works.
- 7.4.2.7 In wet weather, the water quality in Swansea Bay can be significantly reduced as a result of additional inputs from storm water discharges. These discharges include CSOs, storm-water drainage systems and increased diffuse loads from rivers and streams. Many of the rivers and streams flow through culverts and onto the Swansea Bay foreshore. Screened storm water is also discharged from the long sea outfall from Swansea WWTW into the Bay. However, ongoing assessments of water quality in Swansea Bay, carried out by Intertek on behalf of DCWW (Intertek 2012), have shown that during storm conditions the WWTW outfall contributes a relatively small proportion of FIOs at the Swansea DSP, when compared to local CSO and river discharges.
- 7.4.2.8 The Aberafan Sands bathing water is located between the River Neath and River Afan. The lower catchments of the two rivers are characterised by residential and light industrial use, while an area to the south east of the beach is used predominantly for heavy industry. During dry weather, the primary sources of low level background bacteria are the Swansea and Afan WWTWs and diffuse loads from the two rivers. Several emergency and storm overflows discharge to the Neath and Afan estuaries, offering flood protection for properties in Aberafan: discharge from these overflows may reduce water quality at bathing waters during heavy rainfall. Rainfall also increases the diffuse loads from the rivers which discharge into the two estuaries.
- 7.4.2.9 The beaches along the Gower Peninsula generally show Excellent water quality (as defined by rBWD) as they are typically remote from major pollutant sources, and there are only a few minor local pollutant sources. These beaches are not significantly affected by discharges to Swansea Bay.
- 7.4.2.10 Starting from around the headland at Mumbles and heading west are Bracelet and Limeslade Bays. There are no local streams or rivers discharging near these bathing

waters. The beaches are approximately 1.3km from the emergency and storm overflow at Knab Rock, (approximately 500m off Mumbles Head, see Figure 7.1). While the discharge plume can reach the beaches on an ebbing tide, high dispersion reduces the concentration of bacteria to very low levels.

- 7.4.2.11 Moving further west, Langland Bay has a relatively large catchment area that is characterised by urban and residential usage. The water quality at the bathing water can be affected by local private and public surface water drains during periods of heavy rainfall.
- 7.4.2.12 At Caswell Beach, a groundwater stream discharges to the sea, near to the bathing water DSP. This has the potential to affect local bathing water quality. Furthermore, groundwater from the Caswell Valley may discharge through a sink hole at the bottom of the car park before flowing onto the beach. Lastly, the small Bishopston Sewage Treatment Works discharges treated effluent offshore, about 500m to the West of the bathing water. However, none of these inputs is considered to have a significant effect on bathing water quality; as the bathing water samples show low levels of FIOs and the DSP achieves Guideline compliance under cBWD and Excellent class under rBWD.
- 7.4.2.13 Table 7.16 provides a summary of bathing water performance under the cBWD, from 1988 to 2013. This is based on routine data collected by NRW and its predecessors at the DSPs. Over the last 25 years, there have been significant improvements in sample water quality at all of the bathing waters. In the last ten years, the four Gower beaches have achieved Higher (Guideline) standard, apart for one isolated Minimum Imperative or Mandatory) standard at Limeslade Bay in 2009. Aberafan Sands met Higher (Guideline) standard (excluding 2006) until the two years from 2011 to 2012 where only Minimum (Imperative or Mandatory) standard was achieved. Swansea Bay's status is less certain, in the last ten years the Higher standard (Guideline) was only achieved in 2007 and 2013.

Table 7.16 Summary of Swansea Bay water quality under the cBWD

Bathing Water	Year																									
	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13
Aberafan	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	H	H	H	F	H	H	H	H	M	M	H
Swansea Bay	F	M	F	M	F	F	M	F	F	F	F	M	M	M	M	M	M	M	M	H	M	M	M	M	M	H
Bracelet Bay	M	M	M	M	M	M	M	M	M	M	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Limeslade Bay	M	F	M	M	M	M	F	M	M	F	M	H	M	M	H	H	H	H	H	H	H	M	H	H	H	H
Langland Bay	M	F	M	M	M	F	M	M	M	M	M	H	M	H	H	H	H	H	H	H	H	H	H	H	H	H
Caswell Bay	M	M	M	M	F	M	M	M	M	H	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H

H = Higher (Guideline Standard), M = Minimum (Imperative or Mandatory standard); F = Fail

- 7.4.2.14 While the majority of the beaches in, and around, Swansea Bay are expected to meet the minimum (Sufficient) standard under the rBWD, NRW has identified the Swansea Bay bathing water as being at risk of not meeting Sufficient standard under the rBWD by 2015.
- 7.4.2.15 Table 7.17 presents the bathing water sample data presented in Table 7.16, re-processed to assess water quality under the rBWD for the period 1996 to 2013. A similar pattern in bathing water quality is seen under the rBWD, with marked improvements at all beaches since 1996. Bathing water quality at Swansea Bay DSP improved over the period 2004 to 2007, but since then it has reduced in quality. The reduction in water quality is due to

multiple factors, but two potential causes have been identified (Intertek 2012). Firstly, an assessment of rainfall data, from a gauge at St Helens in Swansea, has shown a significant increase in summer rainfall over the period 2008 to 2012. Higher rainfall during these wetter summers will cause an increased in storm water discharges and diffuse runoff. Summer 2013 was drier than the preceding five years, which may have contributed to a return to the Higher (Guideline) standard shown in Table 7.16. Secondly a number of operational issues in the sewer network since 2007 have been identified by DCWW and NRW. These issues have since been resolved, but they would have led to more frequent storm discharges from a number of DCWW assets.

- 7.4.2.16 During 2004 to 2007 Sufficient standard would have been achieved, but in all other years the standard would have been Poor. Aberafan beach improved between 2004 and 2010, but the two wet summers (2011 and 2012) would have resulted in only Sufficient class being achieved. The relatively dry summer of 2013 produced improved water quality at both Aberafan and Swansea (as shown in the cBWD performance in Table 7.16), but this was not sufficient to lift rBWD class above the 2012 low.

Table 7.17 Summary of Swansea Bay water quality under the rBWD

Bathing Water	Year																	
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Aberafan	P	P	P	P	P	P	P	S	G	G	G	G	G	G	G	S	S	S
Swansea Bay	P	P	P	P	P	P	P	P	S	S	S	S	P	P	P	P	P	P
Bracelet Bay	P	P	P	P	S	E	E	E	E	E	E	E	E	E	E	E	E	E
Ilmeslade Bay	P	P	P	P	P	P	S	G	G	E	E	E	E	E	E	E	E	E
Langland Bay	P	P	P	P	S	S	E	E	E	E	E	E	E	E	E	E	E	E
Caswell Bay	G	G	G	G	G	E	E	E	E	E	E	E	E	E	E	E	E	E

E = Excellent, G = Good, S = Sufficient, P = Poor

- 7.4.2.17 The four Gower Peninsula beaches all performed well against the rBWD criteria over the last ten years. However, more detailed analysis of DSP sample data shows that these beaches have experienced a small reduction in quality over since 2007 caused by the wetter summers resulting in increased storm water discharges.
- 7.4.2.18 DCWW is currently undertaking improvement works under the UK AMP5 Asset Management Plan (AMP). AMP is an investment plan which is undertaken by all English and Welsh water companies on a five year cycle. The investment plan is based on needs and objectives identified by the water companies and regulators. The AMP is then agreed with OFWAT, on the basis of likely impacts on spend and average water bills. A key objective of the AMP5 plan for Swansea Bay is a reduction in the frequency and duration of storm spills from key CSOs in the local catchments, particularly Swansea. The need for improvement is identified in the Environment Agency PR09 National Environment Programme (NEP) for AMP 5 (Ref ID 5DC2032001, Swansea Bay Investigation, Driver rB3) which mandates investigations to identify which assets require improvement in order to allow the Swansea Bay bathing water to achieve a minimum Sufficient standard under the rBWD. Improvements identified were added to the AMP5 programme via Change Protocol), a procedure by which changes can be made to AMP during each five year cycle. These improvements are expected to lead to Sufficient standard at the Swansea Bay bathing water by 2015 or 2016, with a steady improvement in water quality over the intervening period as improvement schemes come on line.

- 7.4.2.19 As part of the rBWD CCSC will be required to implement a beach management plan for the Swansea Bay bathing water, this plan should include provision to advise bathers when water quality is Poor. In order to improve this advice CCSC is making use of a predictive, so-called, black box model developed by the University of Aberystwyth. This model has been developed under the EU-funded Smart Coasts initiative and is based on a series of relational algorithms determined from extensive field data surveys undertaken jointly by the University and CCSC during summer of 2011. The model allows hourly predictions of bathing water quality at the DSP, based on a series of environmental inputs, e.g. sunlight, wind, tide and river flow.
- 7.4.2.20 Comparison of the predicted water quality with a threshold value, based on risks of gastrointestinal disease in line with WHO guidance, allows CCSC to advise the public against bathing when FIO levels are predicted to be above the threshold. Under the provisions of the rBWD the black box model predictions also permits discounting of DSP water quality samples taken during periods when poor quality is predicted and confirmed by sampling.
- 7.4.2.21 During the bathing water season of 2013, the water quality in Swansea Bay met the Sufficient class, the standard required under the rBWD. This represents a significant improvement on previous years, and is due in part to the implementation of the black box model predictions and discounting scheme. The drier summer of 2013 will also have helped to improve bathing water quality.
- 7.4.2.22 The black box model is based on an analysis of field data from the Smart Coasts surveys. This data describes the environmental conditions (sunlight, wind, tide, rainfall, river flow), loads and receiving water bacteria concentrations recorded in summer 2011. A detailed analysis of the correlation between environmental conditions and water quality at the DSP was undertaken and a set of parameters has been determined from which bathing water quality can be predicted by a black box model. The data set used was sufficiently robust for a high level of confidence in the correlation to be achieved.
- 7.4.2.23 As the black box model uses a correlation approach it is not a fully predictive model, as it does not explicitly consider cause and effect (i.e. it does not attribute effects to sources), and cannot take account of changes in the catchment or receiving waters. Furthermore it is not possible to modify or re-verify the model should conditions change. Any changes in these conditions might affect the correlations on which the model is based, potentially reducing accuracy of predictions. The accuracy of the Smart Coast black box model predictions relies on the conditions monitored in the 2011 field study. In the event that these conditions change in the future, and the conditions relate to dynamic marine processes in any event, field surveys would need to be repeated to develop a new set of correlations.
- 7.4.2.24 Construction of the Lagoon will have some effect on the prevailing conditions of tidal circulation in Swansea Bay. Current and future changes to the sewerage network, which are not part of or in any way related to the Project, would also affect the FIO loads to Swansea Bay and FIO concentrations at the DSP. These factors may potentially render inaccurate/obsolete both the black box model and any predictions the model makes. Given the above, it is not possible to directly determine to what extent changes in sewerage infrastructure or the presence of the Lagoon would affect the accuracy of the black box model. However the following observations can be made:

- a. Present and ongoing sewer network improvements being undertaken by DCWW will have an impact on bacteria concentrations at the Swansea DSP. The black box model may be more sensitive to these changes than to the construction of the Lagoon, as these changes will reduce the frequency and volume of storm discharges to the Swansea Bay bathing water. These improvements will be implemented after construction of the black box model and include:
 - i. Operational efficiency of the Swansea WWTW, particularly at the Langdon Road pumping station. These improvements, completed in 2013, will reduce storm spills from CSO989 (via Port Tawe pumping station) which impacts the Swansea DSP. These changes may lead to the black box model predicting higher concentrations during storm events.
 - ii. Proposed AMP5 improvements to CSOs discharging to Swansea Bay will significantly reduce loads to the DSP during storms. This would potentially lead to the black box model predicting higher concentrations during these events.
- b. The predicted Lagoon impacts on water quality at the Swansea DSP are low, as the effects on tidal movement and dispersion to the west of the lagoon are relatively small. The effects of the lagoon on the black box model would, therefore, be expected to be small, but cannot be quantified. Effects from DCWW asset improvements are proportionately larger. Referring to Table 7.12, the AMP5 changes will reduce 90%ile IE concentrations by 20%, while the Lagoon will cause a further reduction of <1%. Therefore, the relatively small effects of the Lagoon at the DSP may not change the accuracy of the black box model as much as improvements in the Swansea sewerage network.

7.4.2.25 To update the black box model would require the Smart Coasts survey exercise to be repeated and a new model created. Any new model would be subject to the effects of further changes in the catchment, e.g. AMP6 improvements. It may be possible to collect sufficient data to determine if the Lagoon has had an effect on the model. However where an effect is observed it would not be possible to tell if this were due to the Lagoon or other factors, e.g. sewer network improvements. If an effect were observed new surveys would still be required and a new black box model would need to be created.

7.4.2.26 Further analysis of the Swansea Bay Coastal Model output may help to provide an indication of the likely effects of future changes in water quality on the black box model, e.g. by considering specific events or conditions and assessing changes in geomean and peak concentrations.

7.4.2.27 The Smart Coasts project team have stated that they are liaising with DCWW and its partners to facilitate exchange of data and model output to help all parties better understand the water quality processes in Swansea Bay. Smart Coasts' data has been used to provide additional, and more detailed, validation of DCWW's coastal models that have been used for this ES. The model improvements and re-validation are discussed in section 7.5.3, with further details provided in Appendix 7.1 and 7.2.

7.4.3 Shellfish water quality

7.4.3.1 Waters designated under the Shellfish Waters (Wales) Notice 2013, for Swansea Bay are shown in Figure 7.1, together with Shellfish Beds and NRW water sample locations. Further information on the locations of monitoring points can be found in the Cefas

(2011) study '*Sanitary Survey of Swansea Bay (Wales)*'. The study was undertaken by Cefas, on behalf of the Food Standards Agency, to demonstrate compliance with the requirements for classification of bivalve mollusc production areas in England and Wales under Regulation (EC) No. 854/2004.'

7.4.3.2 Shellfish water quality sampling. There are three designated shellfish waters monitoring points in the water body, Swansea Bay (East), Swansea Bay (West) and Swansea Bay (South) (Figure 7.1). All have been subject to bacteriological sampling under the SWD and WFD since 2008. Based on the results of these sampling campaigns, all have achieved a Guideline Fail/Imperative Pass status under the WFD.

7.4.3.3 Shellfish flesh sampling. Molluscs from five beds within Swansea Bay have been subject to flesh and intravalvular sampling since 1992: Southern Beds, Crymlyn Burrows, Swansea Bank, Northern Beds, and, since 2012, Queens Dock. However, only three of these sampling locations are currently monitored. Table 7.18 summarises the classifications that have been given to these beds since sampling began. The table shows that all the three currently monitored beds have consistently achieved Class B status in recent years. In certain cases Long-Term (LT) classification has been applied: this can only be applied to Class B water bodies, and is intended to highlight a water body's consistent achievement of Class B status in preceding years.

Table 7.18 Summary of bivalve mollusc bed classifications in Swansea Bay

Bed name/ year	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12
Southern Beds	B	B	C	B	B	B	B	B	B	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT	B-LT
Crymlyn Burrows	C	B	C	C	C	C	C	D/C	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c
Swansea Bank	B	B	C	n/c	n/c	B	B	D/C	D/C	D/C	B	D/C	B	B	B-LT	B-LT	B-LT
Northern Beds	B	C	n/c	B	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c
Queens Dock	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	n/c	B

B = Class B, C = Class C, D = Class D, LT = Long term classification applies
n/c = No classification

7.4.4 Summary of baseline conditions

7.4.4.1 Table 7.19 summarises the key water quality features which have been examined as part of the ES. Their current 2012/2013 status is provided and the anticipated baseline in 2016 (or status predicted in 2015 based on current AMP5 design studies), when the Lagoon would be present, has also been provided.

Table 7.19 Summary of present water quality baseline, and anticipated 2016 baseline

Feature	Current baseline (2012)	Anticipated future baseline (2016)
Beaches	cBWD / rBWD	rBWD
Aberafan Beach	Imperative / Sufficient	Good
Swansea Beach	Imperative / Poor	Sufficient / Poor
Bracelet Bay	Guideline / Excellent	Excellent
Limeslade Bay	Guideline / Excellent	Excellent
Langland Bay	Guideline / Excellent	Excellent
Caswell Bay	Guideline / Excellent	Excellent
Classified shellfish waters	Current	2015
Southern Beds	B - LT	B - LT
Swansea Bank	B - LT	B - LT
Crymlyn Burrows	n/c	n/c
Northern Beds	n/c	n/c
Mumbles	n/c	n/c
Queens Dock	B	B
WFD Biological and supporting element	Current	2015
Phytoplankton	Bad	Bad
Dissolved Inorganic Nitrogen	Moderate	Moderate
Dissolved Oxygen	High	High
Copper	High	High
Toluene	High	High
Chemical Elements	Current	2015
Benzene	High	High
Lead and its compounds	High	High
Mercury and its compounds	High	High
Nickel and its compounds	High	High

7.5 Assessment process

7.5.1 Overview

- 7.5.1.1 This section provides details of the approach taken for the water quality assessment. It describes the model used and the validation process. The model applications are then outlined including the sensitivity and microbial applications. The method used to assess the potential impacts for construction and decommissioning are outlined.
- 7.5.1.2 In addition, at the planning stage of the Project, it was considered that there may potentially be a need to secure an appropriate water quality within the Lagoon for water contact sports due to the presence of intermittent storm discharges. Optimisation options were examined and the method used for this process and the key findings are also presented in this section.
- 7.5.1.3 Finally, Table 7.23 presents a summary of the model applications used for the ES. The findings of the model applications are then presented in Section 7.6.

7.5.2 Approach

- 7.5.2.1 As the operational Project will not itself be the source of, or discharge, any significant pollutants it is not itself expected to generate a direct impact on water quality. However the Project will have an indirect effect on water quality in Swansea Bay, because placing a large obstruction, such as the Lagoon, into the Bay will modify the existing water movement, mixing and pollutant dispersion. The extent of the indirect effects is further investigated in Chapter 6: Coastal Processes, Sedimentation and Contamination. It is anticipated that the following potential changes may occur:
- a) the normal tidal circulation within the Bay will be changed because the large tidal gyre within the Bay will be interrupted. The Project could, potentially create two gyres, one to the east and one to the west of the Lagoon;
 - b) the area of circulation and mixing which will be occupied by the Lagoon will be changed, potentially reducing the mixing area of the Bay (mixing will still occur as there will be twice daily exchange of water within the Lagoon);
 - c) The Lagoon seawalls will limit the lateral dispersion of pollutants discharged from the Tawe and Neath estuaries. However, this may have a positive benefit in causing the plumes to move further out into the Bay, reducing their impacts on the local coastline; and
 - d) the water body of the Lagoon may be more quiescent and, as such, the existing mixing of the discharges in the Lagoon area may change. In addition the discharge of any "in-lagoon inputs" (i.e. discharges into the Bay via the Lagoon) into the Bay as a whole will change as this would be through the turbine array, which is situated offshore.
- 7.5.2.2 A reduction, or change, in circulation could limit mixing and dispersion and lead to short-circuiting of pollutant transport paths. This would be expected to lead to changes in bacteria concentrations at bathing beaches and shellfish waters, and a change in the distribution of other determinands, e.g. temperature, salinity, nutrients and dissolved oxygen with the potential formation of hot spots.
- 7.5.2.3 In order to assess the effects of the Project on water quality a series of numerical models are used. These models are applied to a Baseline (present) case and a Development (future) case with the Project in situ. Comparison of the output from the Baseline and Development models allows an assessment of changes in water quality to be made. Optimisation options are then incorporated in the model and tested to determine their relative effectiveness.
- 7.5.2.4 The proposed water quality assessment is based on established fine resolution numerical models and comprehensive input data sets. The models have been continually developed over a number of years to provide support to DCWW's investment programmes. The models have been further enhanced and improved using newly available data from the Smart Coasts project and bespoke data collected specifically for the Swansea Tidal Lagoon EIA (Titan 2012b). As such, it is considered that the models used in this assessment are as up-to-date as possible and include the latest available knowledge and data.
- 7.5.2.5 The use of established knowledge, tools and data ensures accurate modelling of the current state of drainage infrastructure in the local catchments and an understanding of

water quality in Swansea Bay. The models and input data developed during the AMP4 Swansea Water Quality Investigation undertaken in 2006 were verified (Hyder 2006), audited (Falconer and Lin 2006) and accepted by regional NRW water quality specialists, and signed off as fit for use in July 2006. The ongoing AMP5 Swansea Bay Investigations, which include further updates to the sewer network model and Swansea Bay Coastal Model (as outlined in this ES), have been undertaken in consultation with local and regional NRW officers. Model improvements and input data have been agreed in principal with NRW during this process and will be formally submitted for approval and scheme sign off during 2014.

7.5.3 Swansea Bay Coastal Model

- 7.5.3.1 The Swansea Bay Coastal Model has been used to represent the circulation (hydrodynamics) and pollutant transport (advection dispersion) in Swansea Bay. The model was originally constructed and validated in the early 1990s by Delft Hydraulics and Wallace Evans, using the Delft3D modelling system, one of the most accurate and robust software suites available for marine simulations, and used extensively for academic research and consultation throughout the world.
- 7.5.3.2 The model was constructed to support DCWW's investment programme, particularly the design of the Swansea and Afan WWTWs. The model domain extends from the tip of the Gower Peninsula to Porthcawl and some 15km to 20km offshore. The model includes Swansea Bay and the tidal (transitional) waters of the rivers Tawe, Neath and Afan.
- 7.5.3.3 The model is built on a curvilinear grid system with a varying resolution over the model domain: from approximately 50m in Swansea Bay to 200m at the offshore boundary. The curvilinear grid allows greater spatial resolution and computational accuracy to be achieved in areas of high spatial gradient, e.g. within shallow intertidal areas, channels, headlands etc. The original model underwent extensive validation against site specific surveys during the early to mid 1990s.
- 7.5.3.4 The original water quality model was constructed using the Delft3D software. While this software is capable of providing a 3-dimensional (3D) model, the Swansea Bay model was constructed using a 2-dimensional (2D) representation of Swansea Bay. The use of a 3D model for the assessment is not considered to provide any significant additional benefit to the study because:
- I. 3-Dimensional modelling is normally undertaken where there is significant variation in hydrodynamics and pollutant concentrations with depth. This phenomenon typically only occurs in areas of strong stratification (high vertical salinity or temperature gradients), or where significant variation in vertical velocity is observed (e.g. wind driven flow in low energy environments).
 - II. Swansea bay is a dynamic and well mixed coastal water. There is no evidence of significant stratification or variation in vertical velocity in Swansea Bay that would require a 3D model. This was the case during the original model construction and was confirmed during surveys undertaken for the 2006 AMP4 Bathing Water Investigations. Recent temperature and salinity surveys undertaken for the Project in May 2013 (Titan 2013) showed no significant variation in salinity with depth. Velocity data collected for the model re-verification (Section 7.6.1) also showed no significant variation with depth.

- III. Previous modelling of Swansea Bay, since 1990, has relied on a 2D model that was considered fit for purpose by NRW (see below). The addition of the lagoon is an extension to the previous model and would not be expected to cause any significant additional 3-dimensional effect in Swansea Bay.
- IV. A 3-dimensional model would not provide any significant benefit to the EIA or be likely to alter its conclusions, particularly in light of the well-recorded and modelled environment in Swansea Bay.

7.5.3.5 During 2005 and 2006 the model was extensively updated, re-calibrated and validated as part of DCWW's AMP4 investment programme, when the model was used to assess combined impacts of continuous and intermittent discharges on local bathing waters. During this time the model bathymetry was validated and updated against new surveys and additional hydrodynamic and dispersion validation was carried out against Acoustic Doppler Current Profiler (ADCP), drogue and dye surveys. Additional loading surveys, to measure bacteria concentrations in sewers, rivers, streams and coastal waters were also undertaken to support the model's application. The re-validated model (Hyder 2006) was audited by Professor Roger Falconer of Cardiff University (Falconer and Lin 2006) and accepted as fit for use by NRW (then EAW) in July 2006.

7.5.3.6 Since 2012, the model and supporting data have undergone further update and improvement in support of DCWW's AMP5 investment programme - this work continued through 2013. These updates have been undertaken with the support of both DCWW and TLSB, to ensure the revised model is fit for purpose for the TLSB ES and DCWW's future investment planning. Updates include:

- a. extension of the model into the non-tidal River Tawe to better represent the time of travel of all discharges from the Swansea catchment;
- b. model grid refinement in the Neath Estuary channel;
- c. revised bathymetric data to ensure consistency with the coastal process model (developed by ABPmer for the Coastal Process assessment of the ES) in the coastal area and to incorporate the extended River Tawe. River Tawe bathymetry is based on NRW Section 105 (Water Resources Act 1991) topographic surveys. The revised model domain, grid and bathymetry are presented in Figure 7.2.; and
- d. validation of revised model hydrodynamics against a comprehensive set of new water level and current speed data from 2011 (Smart Coasts) and 2012 (Titan Environmental Surveys Ltd.) surveys. Surveys were undertaken using established methods under current industry best practise, and include continuous (14 or more days) data sets at five tide gauge sites and seven current meter sites.

7.5.3.7 In addition to model updates, much of the supporting data underpinning the model and the application of the model has also been reviewed and updated, including:

- I. revised sewer network models that define WWTW and CSO discharges to the Bay. The model revisions reflect changes in the sewer network, the effects of recent changes in population, and DCWW asset improvements that are expected to come into effect by 2015. The sewer model applications also reflect recent increases in rainfall observed in the Swansea area between 2008 and 2012, and assume a similar pattern will remain in future, as a worst case scenario. The validated models were developed by DCWW as part of the AMP5 investment programme and include the major catchments of Swansea, Neath, Baglan and Afan; and

- II. extensive tracer, loading and bathing water quality data collected by CCSC and Aberystwyth University in 2011 under the Smart Coasts project. These new data sets provide additional data to support validation and model applications for bathing and shellfish water impacts. Data has been used to provide more accurate definition of sewer concentrations and river loads of FIOs.

7.5.3.8 Overall, the updates to the model and supporting data provide what should be considered the most up-to-date and extensively validated modelling systems available in the UK for coastal water quality applications. This provides a very robust platform for assessing water quality impacts with a high degree of confidence in the results.

7.5.4 Model updates and re-validation

7.5.4.1 The following site specific data and data collected from recent studies were used to update the existing version of the Swansea Bay numerical model:

- a) a new bathymetry based on the most up-to-date survey data available, including a bathymetric survey of the Project area undertaken by TLSB in 2011. The new bathymetry was provided by ABPmer who have undertaken the coastal process assessment. As such the water quality model is based on the same base data as the coastal process model; and
- b) Two ADCP current meter surveys undertaken by TLSB in 2011/2012, continuous water level (tide gauge) records at three sites (Mumbles, Swansea Dock and Port Talbot Dock) and five ADCP deployments undertaken as part of the Smart Coasts project in 2012 were used to validate the updated model.

7.5.4.2 More detailed information on the hydrodynamic model update and validation can be found in the hydrodynamic model validation report: 'Swansea Bay Tidal Lagoon Water Quality - Hydrodynamic Model Update and Validation Report'; P1609_RN3290_Rev0, (Intertek, August 2013) (Appendix 7.1, Volume 3).

7.5.4.3 The water quality model has also been validated against bacteria and tracer survey data from the 2011 / 2012 Smart Coasts project and NRW bathing water sample data. Further information can be found in the supporting report ('Swansea Bay Tidal Lagoon Marine Water Quality Assessment, Supporting Technical Information'; P1609_RN3391_Rev0, (Intertek, December 2013)) provided as Appendix 7.2, Volume 3.

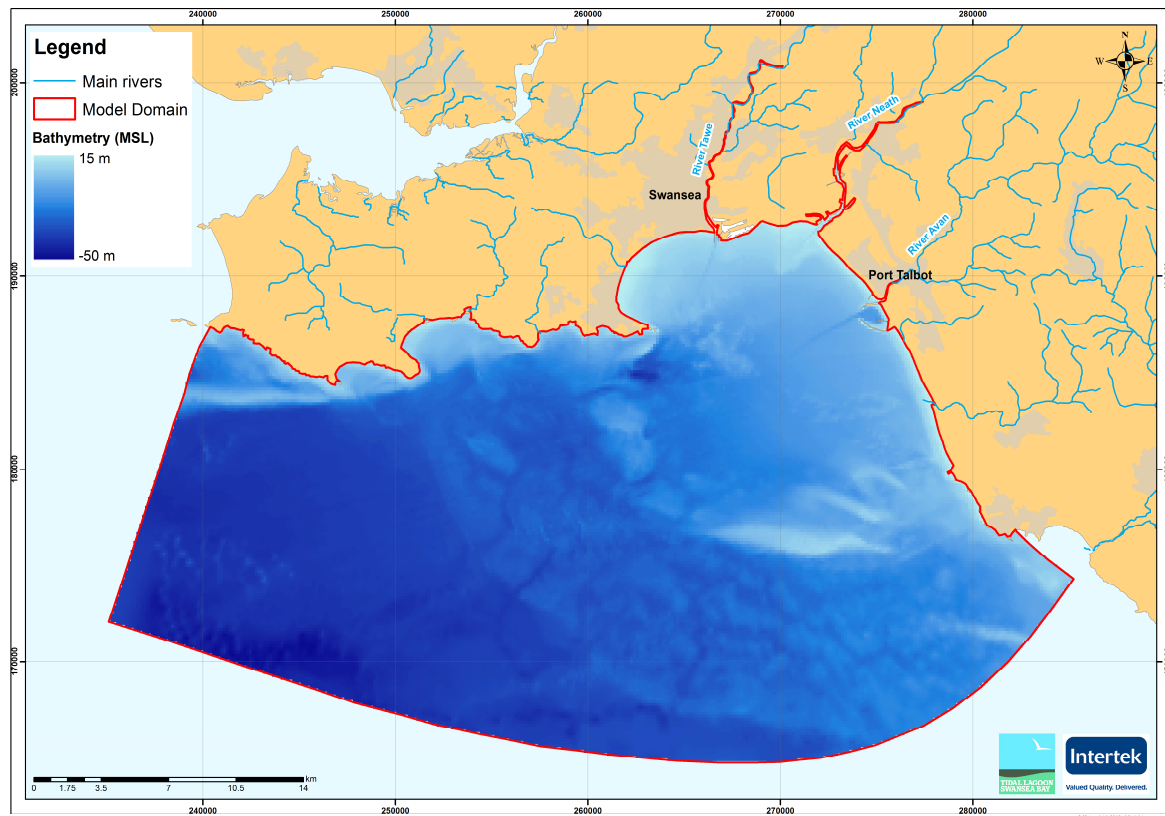
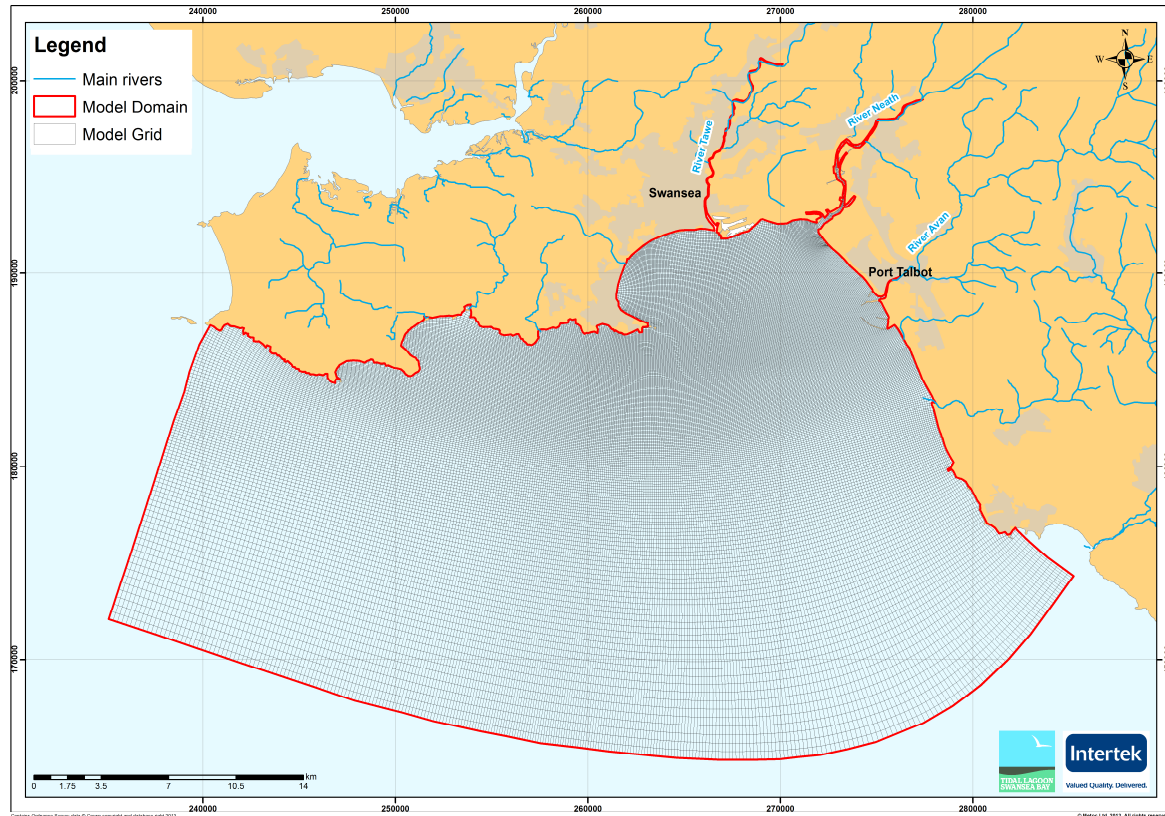


Figure 7.2 Swansea Bay Coastal Model - model grid and bathymetry

7.5.5 Model parameters

7.5.5.1 Key model parameters have been derived from the previous Swansea Bay modelling studies, and re-validated for this study where significant new data is available. Key parameters include:

- dispersion coefficients describe pollutant mixing in the receiving waters due to small scale (sub-grid) processes such as turbulence and Fickian diffusion². In the coastal model the dispersion process is calculated by an advection dispersion (AD) model. The model dispersion coefficient was calibrated against dye survey data during the update undertaken in 2006. The final calibrated and validated dispersion coefficient of $0.4\text{m}^2/\text{s}$ is adopted. During this study further validation of the advection dispersion was carried out against tracer studies undertaken as part of the Smart Coasts project (Appendix 7.2);
- bacteria decay rate, defined as the time required for 90% bacterial die off (T_{90}), is the most commonly used parameter for describing bacterial mortality. As part of the present study, the decay rates were re-validated using the latest available bathing water sample data. Bacteria decay rates (T_{90}) for E Coli and I Enterococci of 55 hours and 70 hours respectively were adopted. These are higher than typical values in coastal waters (20 hours and 40 hours) due to the high turbidity in Swansea Bay, and are consistent with values used in previous studies along the South Wales coast. (It should be noted that the decay rate represents a daily average, consistent with the precautionary approach adopted throughout the ES); and
- wind speed, direction and frequency are potentially important in pollutant transport in coastal waters, as wind can modify local hydrodynamics and pollutant dispersion. Wind conditions used in the previous 2006 bathing water study are adopted in this assessment. Representative wind conditions were determined using wind frequency data from Mumbles Head, a sub-set of wind speeds and directions were chosen to represent conditions that most affect pollutant dispersion in Swansea Bay. Table 7.20 provides a summary of the wind conditions used in the assessment. Wind frequencies given in the table are used to weight the impact of individual wind conditions in the STORM-IMPACT assessment (see Section 7.7.3).

Table 7.20 Summary of water quality baseline

Wind Condition	Wind Speed (°N)	Wind Direction (m/s)	Frequency
No wind*	-	-	16.21%
South-Easterly Moderate	120	5	12.49%
South-Easterly Strong	120	10	4.60%
South-Westerly Moderate	240	5	27.47%
South-Westerly Strong	240	10	21.97%
North-Westerly Moderate	300	5	17.26%

* representing wind speed below 2.5m/s from all directions.

² Fickian diffusion: Spreading of solutes from regions of high to regions of lower concentrations caused by a concentration gradient

7.5.6 Discharge sources – model inputs

- 7.5.6.1 The coastal model includes a representation of the significant discharge sources to Swansea Bay, these fall into a number of categories, described below.
- 7.5.6.2 Diffuse inputs, of pollutant wash-off from land to rivers, streams and the coastline. Diffuse loads contain a continuous (dry weather) component, which acts as a background (base) load. During wet weather higher run-off and wash-off increases pollutant concentrations and river flows leading to a significantly higher storm load. The largest diffuse source is generally as wash-off from upstream agricultural land. Localised urban runoff may also contribute, as direct wash-off and local separated drainage systems (not discharging to sewer). Pollutants may also come from misconnections, i.e. domestic foul discharges misconnected to separated drainage systems. In Swansea Bay, the primary diffuse loads are from the rivers Tawe, Neath, Afan and Clyne, with smaller loads from local streams along the Swansea frontage (e.g. Washinghouse Brook and Singleton Park Stream).
- 7.5.6.3 Inputs from Swansea and Afan WWTWs. The WWTWs provide secondary treatment of sewage collected from the Swansea, Neath, Baglan and Afan catchments. Swansea WWTW also provides additional UV disinfection of secondary treated effluent. The WWTWs discharge via long outfalls into Swansea Bay. During dry weather, the WWTWs produce a relatively continuous base load, which contributes to background pollutant levels. In wet weather, the WWTW treatment capacity may be exceeded, leading to an additional discharge of untreated (screened) storm effluent.
- 7.5.6.4 CSOs provide relief to the wastewater collection network during periods of high rainfall. CSOs typically discharge a mixture of foul domestic effluent and storm water runoff (e.g. from roads, roofs, hard standing etc.). During periods of rainfall, CSOs can discharge a significant load into rivers and the coastline. Much of DCWWs current investment programme is stated to be aimed at reducing discharges from significant CSOs in Swansea, through a combination of storm water storage and storm water separation under the SWEAR (Storm Water Eradication and Removal) initiative.
- 7.5.6.5 Separated drainage systems provide storm water drainage from roofs, roads and areas of hard standing in residential and industrial areas. Historically this water was discharged to local sewers, but more recent developments have separated drainage systems that discharge to local water courses or the coastline. The pollutant load from these systems tends to be small compared with other sources, as there is no domestic or industrial effluent in the discharge, with only small quantities of pollutants washed off of the drainage area.
- 7.5.6.6 Industrial effluent may be discharged directly from industrial sites to water courses or the coastline, where suitable permits are in place. Some industrial effluent may contain large quantities of nutrients or BOD (biological oxygen demand), but generally contains little bacteria. There are few significant industrial discharges in the Swansea Bay area, and smaller sites tend to discharge to sewers.
- 7.5.6.7 A review of discharge consents and data presented in the Smart Coasts project has identified the following significant discharges to Swansea Bay which were included in the model:

- I. all DCWW assets (WWTWs and CSOs) in the Swansea, Neath, Afan and Baglan catchments;
- II. diffuse river inputs from all major rivers and streams in the Swansea, Neath Afan and Baglan catchments;
- III. the Tata steel discharge at Port Talbot; and
- IV. small discharges have been excluded, i.e. where the discharge load is typically 100 to 1000 times smaller in comparison to significant sources.

7.5.6.8 Of the identified point sources approximately 175 discharges are represented in the EIA study. These discharge sources represent the significant pollutant sources to Swansea Bay and are summarised in Figure 7.3, together with model discharge locations and the locations of Smart Coast sample points. To maintain a manageable number of discharge locations, sources are grouped based on proximity. For smaller streams and tributaries all discharges are located at a common point close to the location of the river discharge in the model. This is a conservative approach as it excludes dilution of the discharge in the watercourse. Where a discharge is located between high water and low water a walking discharge is adopted. This allows the discharge location to move up or down the beach as the tide rises and falls, simulating the effect of discharge running over the beach. A total of 38 discharges are included in the model. The locations are shown in Figure 7.3. A full list of discharge sources can be found in Appendix 7. 2.

7.5.6.9 Discharges are defined as a time varying load of pollutant. The load is defined as flow multiplied by discharge concentration. Discharge concentrations are derived from directly measured concentrations where possible, as this takes account of local variations and the effects of dilution by storm water. Where direct measurements are not available, concentrations are derived from measurements in similar catchments, previous studies and best practice guidelines. A precautionary approach is adopted when defining concentrations.

7.5.6.10 FIO bacteria concentrations were derived from surveys undertaken by DCWW in 2005 and extended using loading surveys undertaken during the Smart Coasts project in 2011 (Figure 7.3). Sample data were used to establish average sewer concentrations and flow/concentration relationships for the main rivers and streams.

7.5.6.11 Other pollutant concentrations (e.g. nutrients) are derived from NRW river and coastal sample data, DCWW sample data and discharge consent information. Where sample data were not available a conservative estimate has been made from the literature and professional experience.

Tidal Lagoon Swansea Bay plc

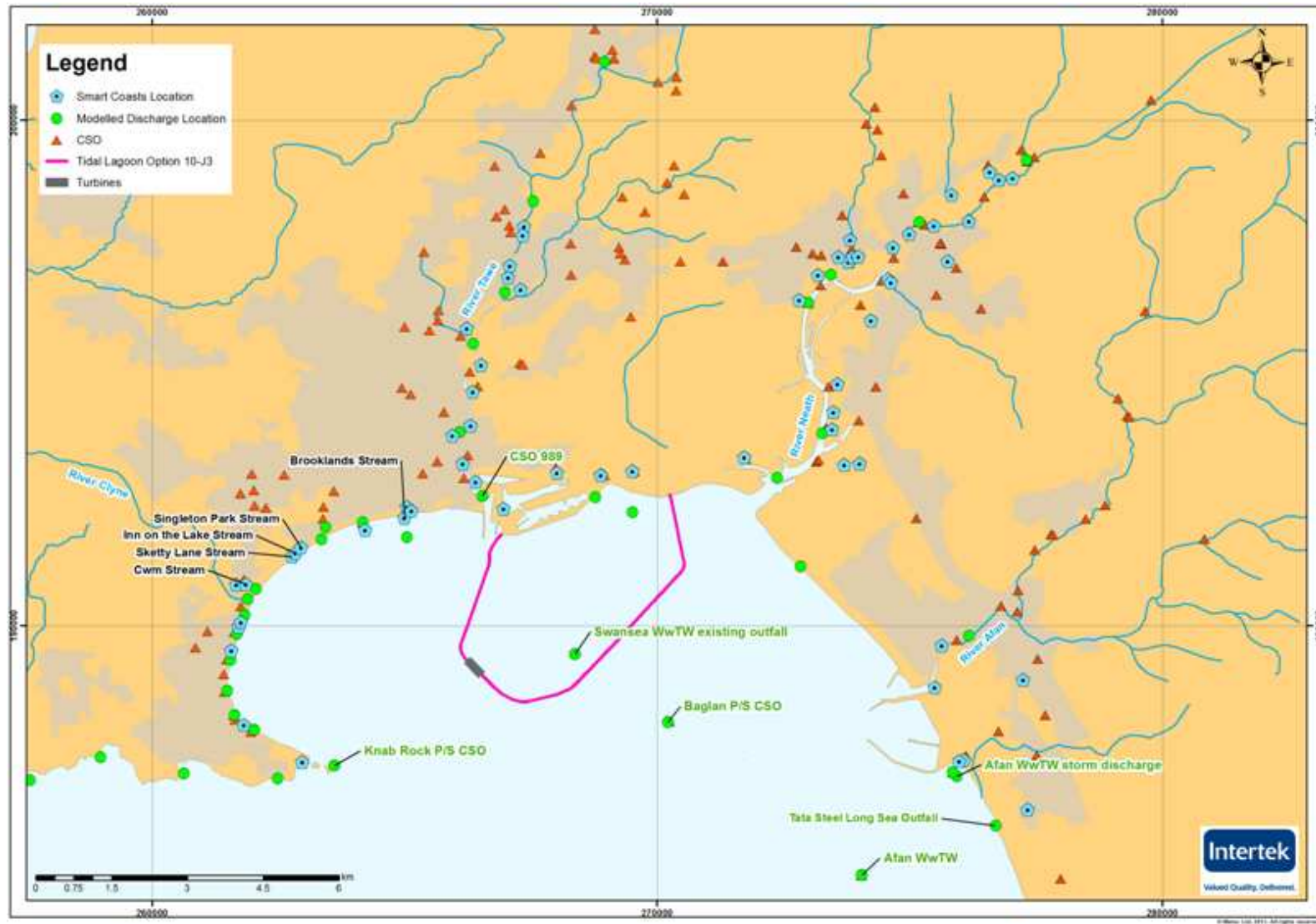


Figure 7.3 Discharge sources, model discharge locations and Smart Coasts sample sites

- 7.5.6.12 Measured discharge flows are seldom available in sufficient quantity for model applications. Flows are therefore derived from a number of sources, including:
- a. rivers Tawe, Neath, Afan flows were derived from NRW gauging station records;
 - b. smaller rivers and streams are generally not gauged. Flows were determined from a hydrological model, developed for AMP4/AMP5 studies. The hydrological model is driven by rainfall recorded at St. Helens in Swansea, and was previously validated against available flow gauging in the Clyne catchment, together with spot gauging in a number of the smaller streams. Additional verification of the model has been undertaken against data available from the Smart Coasts project from 2011;
 - c. sewer discharges, from WWTW and CSOs are derived from catchment network models developed by DCWW. Network models of the Swansea, Neath, Baglan and Afan sewerage catchments, initially developed during AMP4 (2006) and updated in AMP5 (2013), are used to predict CSO and WWTW flows from the catchments discharging to Swansea Bay. A 2015 baseline has been adopted commensurate with completion of AMP5 improvement schemes, implementation of the rBWD, and construction of the project from 2015; and
 - d. flows from industrial sources are determined from consent records or design information.
- 7.5.6.13 The current modelling uses sewage discharge flows based on projected increases in population up to 2021. This provides a conservative approach to the Baseline assessment, and includes a number of significant planned developments in Swansea, e.g. at SA2 and Llandarcy. Within the lifetime of the Project, population would be expected to increase further. An estimation of the effects of population growth beyond 2021 and over the lifetime of the Lagoon is difficult, as the rate of growth will depend on a number of extraneous factors that cannot be quantified. While a potential growth in population could be estimated, its effect on flow from the WWTW is much more difficult to predict.
- 7.5.6.14 During dry weather the WWTW discharge would be expected to increase in proportion to population growth, as the majority of the flow to the WWTW is from domestic sources.
- 7.5.6.15 During storm events the flow to the WWTW is increased due to storm runoff entering the sewer network. A significant increase in flow due to population growth would potentially reduce available capacity and cause an increase in the frequency and duration of storm spills from the sewer network and WWTW. Conversely, improvements in the sewer network would reduce storm water discharges and potentially free capacity within the network.
- 7.5.6.16 The type of development would also affect both dry weather and storm flows. Brown field development may increase dry weather flows, depending on the former use of the site. Green field development would increase dry weather flows. In both cases storm inputs would be expected to remain the same or reduce for brown field sites, as storm water would be separated at source.
- 7.5.6.17 The effects of population growth on discharges from the WWTW would therefore depend on a number of factors. Accurately assessing the likely changes in these over the lifetime of the Lagoon is not considered possible at this time. However, based on existing information the following broad assumptions can be made:

- a. Based on measured flows at Swansea WWTW the current dry weather flow to the WWTW is below the consented flow, suggesting dry weather capacity remains available at the WWTW for future population growth.
 - b. As a conservative estimate, a doubling of the population would be expected to approximately double the dry weather flow from the WWTW. By extrapolation, this would be expected to increase dry weather loads of FIOs and other contaminants by a similar factor, i.e. by two.
 - c. An increase in FIO loads from the WWTW would have relatively little impact in bathing water performance at the Swansea and Aberafan DSPs, as the WWTWs provide relatively small contributions of FIOs at these bathing waters. Furthermore these changes would occur regardless of presence of the Project.
 - d. Bathing water quality is more significantly affected by diffuse and storm discharges. These would be expected to improve over the lifetime of the Lagoon in response to improvements in sewerage infrastructure and river catchment management.
 - e. Microbiological water quality in the Lagoon would be reduced in dry weather in response to an increase in flow to the WWTW. However, the likely reduction would be relatively small, and could be offset by optimisation of existing treatment e.g. a small increase in the UV dose applied to treated discharges (see further below).
 - f. Changes in dry weather flow to the Lagoon would have relatively little effect on water quality under the rBWD, as the 90%ile and 95%ile FIO concentrations are more significantly affected by storm discharges. Over the lifetime of the Project storm discharges from the WWTW would be expected to reduce in response to improvements in the Swansea sewer network.
 - g. The presence of the Project would not change any obligation on DCWW to maintain or improve water quality in Swansea Bay under existing or future legislative drivers.
- 7.5.6.18 While the effects of future population growth cannot be accurately assessed, it is considered unlikely that changes in population beyond 2021 would significantly affect water quality in Swansea Bay and the Lagoon. Overall the situation would be expected to improve in response to current and future water quality drivers.
- 7.5.6.19 TLSB is currently consulting with DCWW regarding the design and impact of the Project on DCWW assets, in particular the WWTW at Swansea.

7.6 Model applications

7.6.0.1 The modelling approach varies depending on the determinands and scenarios considered. In each case the approach is designed to provide the best possible prediction of impacts based on the available data. All model applications use the validated Swansea Bay hydrodynamic (HD) and advection dispersion (AD) models as a basis. The integration of coastal model, supporting models and data sets is shown diagrammatically in Figure 7.4.

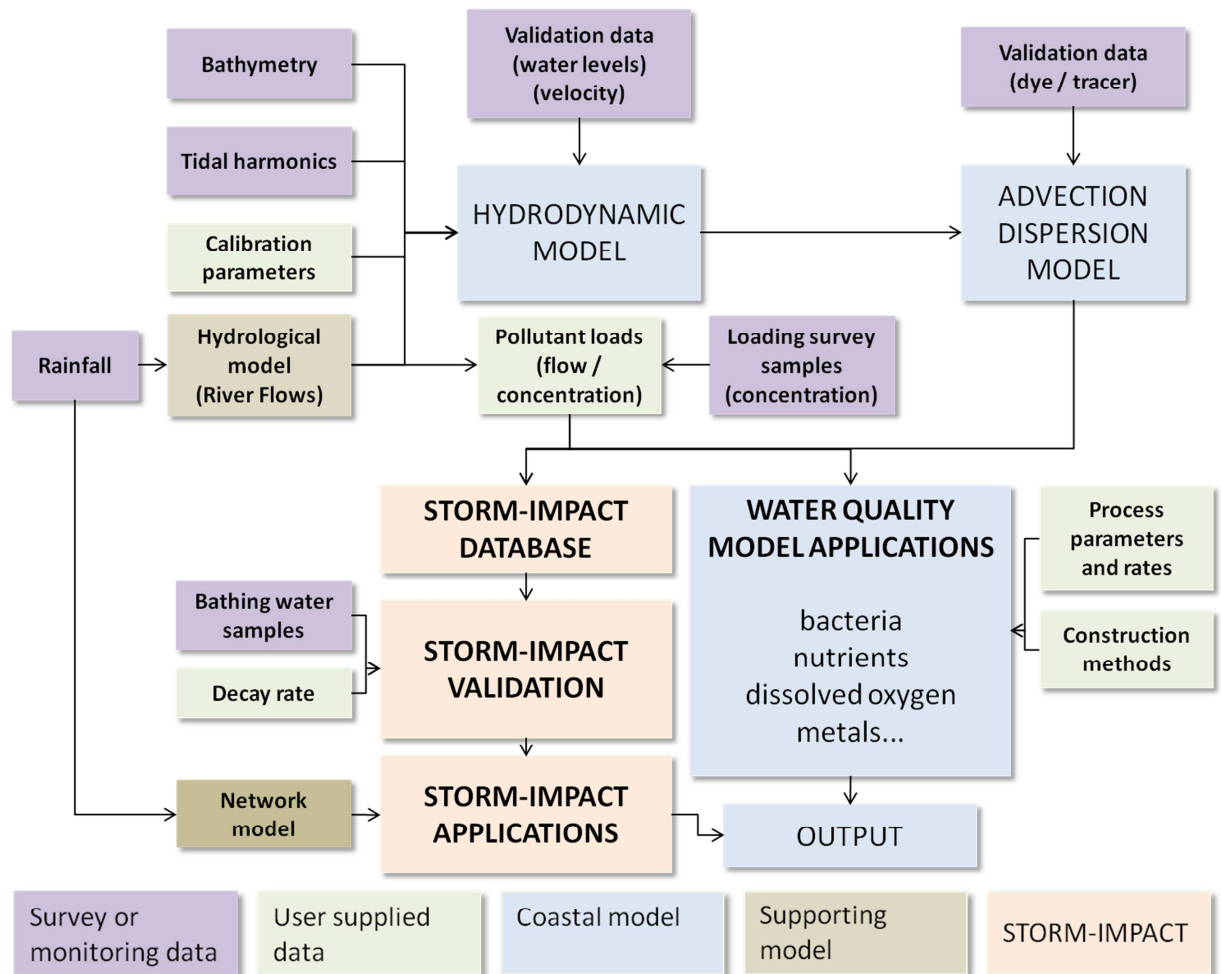


Figure 7.4 Schematic representation of model and data interfaces

7.6.0.2 Model applications have been undertaken as a series of iterative steps. These are shown schematically in Figure 7.5. At each step the type of application, the model inputs, scenarios, and environmental conditions assessed are optimised to maintain a manageable number of applications, while ensuring sufficient model output for an informed analysis and interpretation of the results to be made.

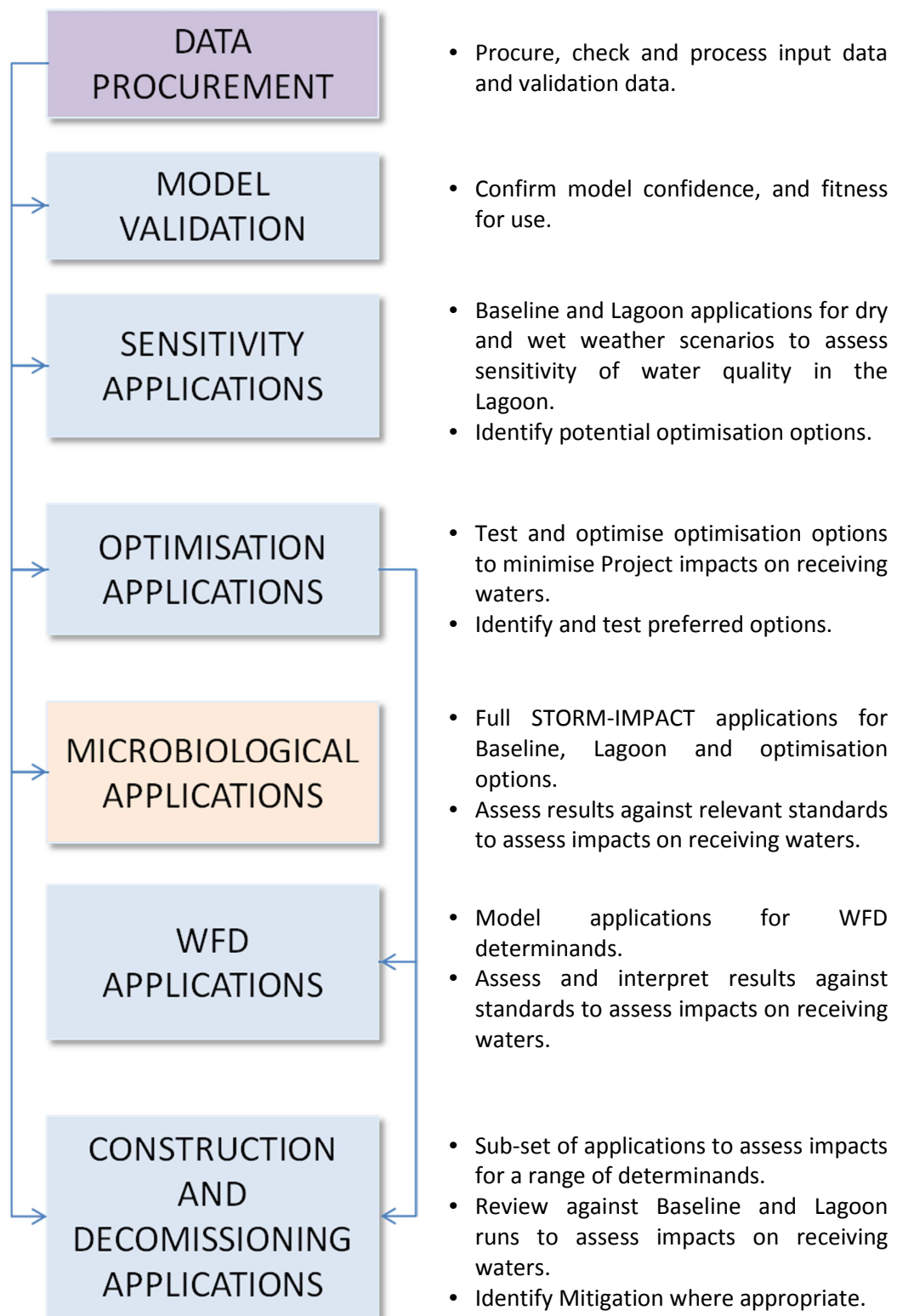


Figure 7.5 Schematic representation of model application process

7.6.1 Validation applications

- 7.6.1.1 Validation applications are used to demonstrate the accuracy and fitness for purpose of the models. Validation is based on a comparison of model output with observation.
- 7.6.1.2 The validation of the exiting hydrodynamic model for the Lagoon study is detailed separately in '*Swansea Bay Tidal Lagoon Water Quality - Hydrodynamic Model Update and Validation Report*'; P1609_RN3290_Rev0, August 2013 (Appendix 7.1, Volume 3).
- 7.6.1.3 The advection dispersion model was validated in 2006 against dye tracer surveys from 2005 and 2006. Further validation against Smart Coasts tracer studies has been undertaken for this chapter and is described in Appendix 7.2, Volume 3.
- 7.6.1.4 STORM-IMPACT model validation was undertaken against NRW routine monitoring data. Additional event based validation was also undertaken against Smart Coasts sample data. The validation of STORM-IMPACT against NRW DSP sample data for the period 2008 to 2011 and against specific event data from the 2011 Smart Coasts project is described in Appendix 7.2, Volume 3.
- 7.6.1.5 Results of the validation exercises confirmed that the models are capable of providing accurate predictions of hydrodynamics, dispersion and water quality. Confidence in the models is good and the models are considered fit for use for determining Baseline conditions and the impacts of the Project.

7.6.2 Sensitivity applications

- 7.6.2.1 Water quality applications use the coastal model to assess the dispersion of a specific pollutant under a specific condition of tide, wind and discharge, e.g. dry weather flow or wet weather flow. These applications provide an understanding of the behaviour of discharge plumes under specific conditions, and the sensitivity of plume dispersion to the presence of the Lagoon seawalls. These applications provide a means of assessing short term sensitivities during specific discharge events (e.g. storms). They can also be used to assess longer term sensitivity where changes in discharge or environmental conditions have a limited effect, e.g. in the case of conservative contaminants such as nutrients. To assess sensitivity to the presence of the Project, models are run for two conditions:
- i. **Baseline**, current discharges (see section 7.5.6) but with no lagoon; and
 - ii. **Lagoon**, the model is modified to include a representation of the Lagoon and re-run: all discharge conditions remaining the same as the Baseline.
- 7.6.2.2 Sensitivity applications were also undertaken to assess the effects of proposed dredging within the Project area on hydrodynamics and dispersion. The dredging is required to provide fill for the Geotubes® and Lagoon seawalls. No significant changes in hydrodynamics or dispersion were identified, i.e. these were not sensitive to dredging area or depth.
- 7.6.2.3 Model output from Baseline and Lagoon applications were compared to determine the potential sensitivity of water quality in Swansea Bay to the Project and to identify if mitigation is required. The Sensitivity Applications were run for the determinands listed below:

- I. **Microbiology.** Microbiological sensitivity was assessed by applying the model to a typical dry weather condition and a large storm event from 2011. Significant river, WWTW and CSO discharges were included;
- II. **Temperature and salinity (T/S).** Temperature and salinity in Swansea Bay are determined by atmospheric heating and the mixing of river waters with those in the Bay. As the Lagoon will not significantly affect these processes it is unlikely that any changes in temperature or salinity would occur post construction. The coastal model was applied to Baseline and Lagoon applications under typical winter and summer conditions. Winter conditions will produce greatest salinity differences and temperature differences: due to high river flow and maximum temperature difference between sea, rivers and atmosphere. Summer conditions will typically show lower variation due to more consistent river flows and lower differences between atmospheric, river and sea temperatures;
- III. **Nutrients (Nitrogen).** Nitrogen is the key nutrient in saline waters and will act as the main limiting nutrient to the growth of marine phytoplankton (algae). Model applications were undertaken to assess the sensitivity of the receiving waters to changes in nitrogen distribution during the operational phase of the Project. A winter condition, when algal production is at a minimum, was adopted using a conservative approach in which nitrogen losses were ignored. Nutrient loads were based on a recent NRW report prepared by the Centre for Research into Environment and Health (CREH) (2012). Continuous loads from rivers and WWTWs were inputted into the model. Storm discharges were excluded as these inputs are relatively small compared to continuous sources and have relatively little effect on the long-term average nutrient concentrations; and
- IV. **Dissolved Oxygen (DO).** Dissolved oxygen is required for respiration of marine organisms, and is a primary indicator of the ability of an aquatic system to support marine life. A conservative approach was adopted, with a summer condition modelled as a likely worst case scenario when higher sea temperatures and salinity reduces oxygen solubility. Dry weather and storm conditions were modelled. Separate runs including storm discharges were also undertaken to assess possible short term effects resulting from high load, particularly with respect to the larger river discharges.

7.6.2.4 The models were run for sufficient time for an equilibrium condition to establish and results output over a spring/neap tidal cycle. Discharge concentrations were determined from available sample records. Discharge flows were determined from available river and WWTW flow records and hydrological and network models. Further information on model inputs is provided in Appendix 7.2, Volume 3.

7.6.2.5 From these applications changes in plume behaviour and the distribution of pollutants in response to the presence of the Lagoon were determined. Results were also assessed against relevant standards, e.g. rBWD and SFW standards and WFD UKTAG standards where applicable.

7.6.3 Microbiological applications (STORM-IMPACT)

- 7.6.3.1 Compliance with bathing water and shellfish water standards is assessed on the basis of percentile concentrations determined from water quality samples. The use of percentile standards reflects the often highly variable nature of bacteria FIO concentrations in coastal waters. These concentrations vary in response to a number of factors:
- discharge conditions - during dry weather the primary sources of bacteria are continuous treated WWTW discharges and diffuse river inputs. These loads are typically low and lead to a background bacteria concentration in receiving waters. During periods of rainfall runoff and storm water discharges from multiple sources can add a significant additional load;
 - environmental conditions – river flow, tide and wind affect the dispersion of discharge plumes and bacteria in the receiving water;
 - phasing – storm events occur independently of tide conditions and under a wide range of wind conditions. The same event may give rise to very different impacts depending on whether it occurs at high water, low water, on a spring or neap tide, or under different wind speeds and directions; and
 - year-on-year variation – rainfall varies from year to year. Receiving water performance is generally worse in wet years due to more frequent and/or larger storm spills.
- 7.6.3.2 In order to predict the impacts of discharges on bathing and shellfish water performance, it is necessary to determine percentile concentrations from a large number of model applications representing dry and storm events over a wide range of environmental, phasing and rainfall conditions. Achieving this with a coastal model is impractical as a large number of model applications are required to produce a statistically significant set of conditions. However, without such an assessment accurate prediction of bathing water and shellfish water performance would not be possible. In order to provide robust predictions of bathing water performance Intertek have developed STORM-IMPACT.
- 7.6.3.3 STORM-IMPACT allows the full assessment of effluent impacts under a range of conditions (e.g. rainfall, phasing, tide and wind). All significant discharges can be accounted for and their relative contributions to the total impact can be assessed.
- 7.6.3.4 Rather than directly modelling the impact of discharges, the water quality model is used to generate impacts from a series of 'unit discharges'. A unit discharge is a discharge of fixed load (typically 1 m³/s with a concentration of 1x10⁶ cfu/100ml) for a discharge period of 1 hour. For each unit discharge the coastal model generates a 'unit impact' for a series of environmental conditions, designed to represent the typical distribution of tide, wind, and rainfall that occur. A unit impact is the impact resulting from an individual unit discharge predicted at a single location for a single environmental condition. For each discharge, between 100 and 200 unit impacts are produced. Further information on the theory and set-up of the STORM-IMPACT model is provided in Appendix 7.2, Volume 3.
- 7.6.3.5 The unit impacts are collated into a unit impact database which STORM-IMPACT then combines with the river catchment model (river discharge hydrographs) and the sewerage network model (WWTW and CSO discharge hydrographs) output. Each hydrograph is split into units, corresponding to the modelled unit discharges. The environmental impact of the hydrograph unit is calculated by factoring the unit impact

data from the water quality model, according to the hydrograph flow and the relevant bacteria concentration for the type of discharge.

7.6.3.6 The factored hourly impacts are then combined by superposition to give a total impact for the hydrograph. Combining the factored impact for each discharge then allows the total impact at any location to be calculated. This process is repeated for each environmental condition to give a database of thousands of permutations of impact at each location. To account for potential year-on-year variation STORM-IMPACT is generally applied to a number of bathing seasons, or years.

7.6.3.7 The marginal probabilities of the modelled environmental conditions are then used to determine the probability of the particular impacts occurring. By combining impacts and probabilities, a cumulative frequency distribution of bacteria concentrations can be derived for any given period. From these, key percentile concentrations can be derived from which compliance with relevant statistical standards can be evaluated.

7.6.3.8 STORM-IMPACT provides a number of significant advantages over conventional modelling techniques:

- I. by considering long period hydrograph data over a wide range of environmental conditions, impact predictions are detailed and robust;
- II. as each individual discharge is considered, the total impact and the impact of each source can be considered; and
- III. applications can be run quickly for any set of discharge hydrographs. Multiple scenarios and 'what ifs' can be tested in a highly accurate and efficient way.

7.6.3.9 The STORM-IMPACT has been used by Intertek on numerous sensitive water investigations and waste water scheme designs around the UK coast. These studies were undertaken in consultation with Environment Agency (EA) in England, NRW in Wales and the Scottish Environmental Protection Agency (SEPA) in Scotland. The results of the STORM-IMPACT studies have been used to inform the design, consenting and implementation of many UK sewerage improvement schemes over the last 15 years.

7.6.4 Construction impacts

7.6.4.1 The effects of construction are considered to be less than those of the operational Project, as the blocking effects on water movement in Swansea Bay will be proportionately lower until the seawall comprised in the Project is complete. Notwithstanding this the shape of the Lagoon may result in the formation of different flow patterns which may in turn affect the dispersion of pollutants.

7.6.4.2 The model applications for the Baseline and Lagoon scenarios represent the ends of the spectrum of impacts during the construction phase. Early in construction, impacts will be broadly similar to the baseline case, as the effects of the Lagoon seawalls will be relatively small. Towards the end of construction, impacts will be broadly similar to those for the completed Project, as the Lagoon seawalls will be largely in place. In between these periods, the partially completed Lagoon seawalls will have different effects on the tidal dynamics of Swansea Bay, when compared to the Baseline and Lagoon scenarios, these impacts have been considered as a special case and assessed using sensitivity runs for specific construction phases.

7.6.4.3 As discussed in Chapter 4, an outline construction programme has been developed which identifies the principal works that will be undertaken over each year of construction. The construction works can be broken down into the following progress at the end of each dredging season (April to October):

- a) season 1 - construction of 2.5km western Lagoon seawall and turbine cofferdam; and 2.3km eastern Lagoon seawall;
- b) season 2 – further construction of eastern Lagoon seawall leaving 2.9km gap; and
- c) season 3 – closure of gap. The Project becomes operational.

7.6.4.4 As the bathing season (May - Sept) is within the dredging/offshore construction season it is considered that modelling the changes in flow patterns from work completed within each season would provide a good understanding of potential effects in terms of water quality: i.e. completion of each stage represents the greatest hydrodynamic interaction with the lagoon walls. Two interim stages were modelled, as shown in Figures 7.6 and 7.7. The last step, season 3, is not modelled as this will take the Project to operational status as modelled by the completed Lagoon applications.

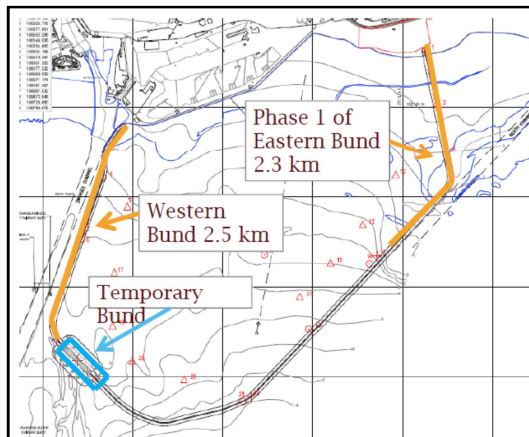


Figure 7.6 Phase 1 construction

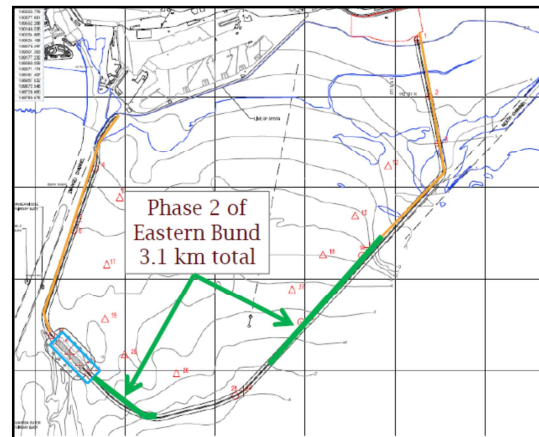


Figure 7.7 Phase 2 construction

7.6.4.5 In addition to hydrodynamic effects, the construction period may lead to specific additional impacts, principally those associated with sediment plumes created during dredging and construction operations. These have been assessed in relation to two specific cases, described below.

7.6.4.6 **Turbidity** - release of sediment will increase local turbidity and may temporarily reduce the rate of decay of bacteria where there is interaction of sediment plumes with river, WWTW and CSO plumes. Higher sediment concentrations in the water column would lead to a reduction in light penetration and bacteria mortality, due to reduced UV levels. Swansea Bay has naturally high suspended sediment concentrations, and a low bacteria decay rate. The temporary works to fill the Geotubes® may not significantly alter the baseline as the Geotubes® are designed to retain sediment and sediment losses to the receiving water will be low. Increases in T_{90} would only be expected where waste water discharge plumes interact with sediment plumes, principally in the areas around the Swansea WWTW discharge and the Neath and Tawe rivers.

- 7.6.4.7 Using the predicted change in suspended sediment concentrations during dredging, and comparing decay rates at a number of sites in the Bristol Channel, from a recent study by Kay *et al* (2005), estimates of the potential effects of increased turbidity on decay rates were made. The sediment transport modelling (Chapter 6) predicts a peak increase in suspended solids in the dredged plume of approximately 150 mg/l, compared to a baseline of between 50 and 100 mg/l. If an average increase in suspended solids of 100 mg/l is conservatively assumed then, based on the relationship between suspended solids concentrations and decay reported by Kay *et al* (2005), an increase in T_{90} of approximately 50% would occur.
- 7.6.4.8 Model sensitivity applications were repeated applying a 50% increase in T_{90} to the River Tawe, Swansea WWTW and River Neath discharge plumes. The baseline hydrodynamic scenario was used as a worst case scenario as:
- impacts will be most significant during the initial stages of construction when the dredging activity is closest to the Tawe and Neath rivers, and interactions between plumes will be greatest; and
 - during the initial stages of construction the Lagoon seawalls will least affect hydrodynamics, allowing greater plume dispersion and a larger area to be affected.
- 7.6.4.9 **Contaminant release** – pollutants may be released from sediments as they are disturbed by dredging, Geotube® filling and Lagoon seawall construction. These pollutants, which may be adsorbed to sediment or resident within sediment pore waters, typically include conservative³ substances such as heavy metals, polycyclic aromatic hydrocarbons (PAHs) and TBT. Offshore site investigation works undertaken in June and July 2013 have identified a number of potential contaminants in the sediment, typically in the finer muds and silts (Titan, 2012a, Titan 2013, Atkins, 2013). Of the 67 samples collected the majority of the samples (approximately 73.5%) were below CEFAS Action Level 1. The remaining samples had slightly elevated levels, above Action Level 1 but below Action Level 2 (approximately 26.5%) and none (0%) had values above Action Level 2.
- 7.6.4.10 CEFAS guidance states: *“In general, contaminant levels in dredged material below Action Level 1 are of no concern and are unlikely to influence the licensing decision. However, dredged material with contaminant levels above Action Level 2 is generally considered unsuitable for sea disposal. The latter situation most often applies only to a part of a proposed dredging area and so that area can be excluded from disposal at sea and disposed of by other routes e.g. landfill. Dredged material with contaminant levels between Action Levels 1 and 2 requires further consideration and testing before a decision can be made⁴”.*
- 7.6.4.11 While the contaminant levels are generally below CEFAS Action Level 1 and the amount of sediment released is expected to be small, the mobilisation of contaminants over the construction period could elevate pollutant levels in Swansea Bay. An estimate of the dilution required for released contaminants to reach the relevant EQS under the WFD was undertaken. Allowance was made for the relative solubility of contaminants in the discharge water. A literature review provided representative partition coefficients between sediment and saline water for each contaminant. The sources are listed in the

³ Conservative substances are those that are not readily lost (e.g. decay, react, oxidise) in the marine environment. Such substances may therefore accumulate over extended periods.

⁴ <http://www.cefas.defra.gov.uk/media/562541/cefas%20action%20levels.pdf>

tables. Table 7.21 presents the pollutants which have been considered in this assessment together with the partitioning coefficients between sediment and water which have been applied. The estimated required dilution was then compared with the likely available dilution to assess the potential area impacted during dredging and construction operations (Section 7.7.11). This exercise was undertaken for the measured maximum concentration (Table 7.21a) and the measured mean concentration (Table 7.21b).

- 7.6.4.12 Tables 7.21a and 7.21b indicate that in most cases a dilution of less than 10 times is required for metals released from sediment to reach the relevant EQS. In a dynamic environment like Swansea Bay, a tenfold dilution would be achieved within a few metres of the discharge. The organic compounds are present in very low concentrations and require dilutions of less than 1. The highlighted rows show those contaminants requiring more than 10 dilutions, i.e. arsenic, copper, lead, cadmium, nickel and zinc. Tributyltin also requires dilution greater than 10 dilutions, although this is conservatively based on the analytical detection limit as no samples showed concentrations above this level. The maximum required dilution is for copper (>900), with other contaminants requiring less than 300 dilutions.
- 7.6.4.13 It should be noted that the maximum required dilutions in Table 7.21a are based on the highest measured concentrations in the sediment core samples taken during the site investigation works. Elevated concentrations were observed in only 18 of the 67 samples taken. For example, the dilution for copper is based on a maximum concentration of 327.3 mg/kg, observed in a thin layer of fine surface sediment. The remainder of the core showed significantly lower concentrations (<30 mg/kg). The second highest copper concentration was 91.4 mg/kg, less than one third of the maximum. This was also a surface sample of fine sediment, as were the next two highest concentrations (81.7 mg/kg and 49.90 mg/kg). Only seven samples out of 67 had concentrations above the mean (Table 7.21b). A similar pattern is seen for other metals.
- 7.6.4.14 The use of the maximum concentrations and dilutions in Table 7.21a provides a conservative worst case scenario. It should also be noted that these concentrations occur in surface sediments. Surface sediments are likely to be subject to mobilisation under natural wave and current action, and may therefore contribute to existing metal concentrations in the water column.
- 7.6.4.15 The mean concentrations and dilutions provided in Table 7.21b provide a more realistic picture of sediment contaminations in the Offshore Works area. In most cases, 75% or more of the samples had measured concentrations less than the mean, i.e. high concentrations in a limited number of samples tended to skew the combined mean.
- 7.6.4.16 In the areas where dredging is proposed (see Chapter 4: Project Description) contaminant concentrations tended to be lower (CEFAS Action Level 1), typically at or below the average values shown in Table 7.21b.

Table 7.21a Contaminants, partition coefficients, EQS and required dilutions for max measured contaminant levels.

Contaminant	Sediment Phase		Soluble Phase			Dilution to Standard		Source For Partition Coeff
	Max Conc.		Partition Coefficient	Conc.	EQS	Dilution	Log	
	(mg/kg)	(ug/l)		(ug/l)	(ug/l)			
Arsenic	48.3	30188	4	7547	25 ^a	302	2.48	Allison / Wang ¹
Copper	327.3	204563	44	4649	5 ^a	930	2.97	Statoil PNEC ²
Lead	344.9	215563	79	2729	25 ^a	109	2.04	Statoil PNEC
Cadmium	3.5	2188	29	75	2.5 ^a	30	1.48	Statoil PNEC
Chromium	52.2	32625	1738	19	15 ^a	1.3	0.10	Statoil PNEC
Nickel	68	42500	5.1	8333	30 ^a	278	2.44	Allison/ Hatje ³
Zinc (dissolved) ^b	688.1	430063	69	6233	40 ^a	156	2.19	Statoil PNEC
Mercury	0.29	463	61601	0.0075	0.3 ^a	0.025	-1.60	Statoil PNEC
Phenanthrene ^c	0.74	69	57.2	1.20	6.7	0.18	-0.75	Inchem ⁴
Fluoranthene ^c	0.11	125	41687	0.0030	1.0	0.003	-2.52	Inchem
Pyrene ^c	0.2	106	43807	0.0024	0.1	0.024	-1.62	Inchem
Benzo[a]anthracene ^c	0.17	75	150000	0.0005	0.4	0.001	-2.90	Inchem
Chrysene ^c	0.12	69	309029.5	0.0002	0.007	0.032	-1.50	Inchem
Benzo[b]fluoranthene ^c	0.11	94	1202264	0.0001	0.1	0.001	-3.11	Inchem
Benzo[a]pyrene ^c	0.15	75	478947	0.0002	0.1	0.002	-2.81	Inchem
Tributyltin ^d	0.08	50	2200	0.023	0.002	11	1.06	Journal13 ⁵

Notes

Highlighted contaminants require >1 log dilution to achieve EQS.

For standards see Table 7.6

- These standards are annual averages.
- The standard for Zinc is for total zinc. Dissolved zinc has been included as it is the fraction which will stay in the water column over a longer period. Zinc partitioning to the sediment will be rapidly removed from the water column.
- These contaminants do not have formal EQS but different regulators have set environmental standards (see Table 7.6).
- The standard for Tributyltin is a maximum value.

Partition Coefficient Sources:

- Wang - Shaofeng Wang, Liying Xu, Zhixi Zhao, Shuying Wang, Yongfeng Jia 王, He Wang, Xin Wang. Arsenic retention and remobilisation in muddy sediments with high iron and sulphur contents from a heavily contaminated estuary in China. Chemical Geology 314-317 (2012) 57–65
- Statoil PNEC – <http://www.sintef.no/project/ERMS/dokumenter/PNEC%20determination.pdf>
- Hatje - V. Hatje, S.C. Apte, L.T. Hales, G.F. Birch. Dissolved trace metal distributions in Port Jackson estuary (Sydney Harbour), Australia. Marine Pollution Bulletin 46 (2003) 719–730
- Inchem <http://www.inchem.org/documents/ehc/ehc/ehc202.htm>
- Journal13 - S. Bangkedphol, H.E. Keenan, C. Davidson, A. Sakultantimetha, A. Songsasen. The partition behaviour of tributyltin and prediction of environmental fate, persistence and toxicity in aquatic environments. Chemosphere 77 (2009) 1326–1332. <http://pirun.ku.ac.th/~fsciass/PDF/journal%20PDF/journal13.pdf>

Table 7.21b Contaminants, partition coefficients, EQS and required dilutions for mean measured contaminant levels.

Contaminant	Sediment Phase		Soluble Phase			Dilution to Standard		Source for Partition Coeff.
	Mean Conc.		Partition Coefficient	Conc.	EQS	Dilution	Log	
	(mg/kg)	(ug/l)		(ug/l)	(ug/l)			
Arsenic	8.4	5274	4	1318	25	52.7	1.72	
Copper	22.1	13836	44	314	5	62.9	1.80	Statoil PNEC
Lead	22.9	14297	79	181	25	7.2	0.86	Statoil PNEC
Cadmium	0.4	227	29	8	2.5	3.1	0.49	Statoil PNEC
Chromium	16.8	10511	1738	6	15	0.4	-0.40	Statoil PNEC
Nickel	11.9	7451	5.1	1461	30	48.7	1.69	
Zinc (dissolved) ^b	41.6	40178	69	582	40	14.6	1.16	Statoil PNEC
Mercury	0.02	29	61601	0.0005	0.3	0.002	-2.52	Statoil PNEC
Phenanthrene	0.74	79	57.2	1.2	6.7	0.18	-1.70	RIVM
Fluoranthene	0.11	143	41687	0.003	1.0	0.003	-3.00	SEPA
Pyrene	0.2	121	43807	0.002	0.1	0.02	-1.52	SEPA
Benzo[a]anthracene	0.17	86	150000	0.0005	0.4	0.001	-3.00	SEPA
Chrysene	0.12	79	309029.5	0.0002	0.007	0.03	-1.52	RIVM
Benzo[b]fluoranthene	0.11	107	1202264	0.00008	0.1	0.001	-3.00	SEPA
Benzo[b]fluoranthene	0.11	86	1202264	0.0002	0.1	0.002	-2.70	SEPA
Benzo[a]pyrene	0.15	79	478947	1.2	0.1	0.18	-0.74	SEPA
Tributyltin	0.08	50	2200	0.02	0.002	11.4	1.06	Journal13

Notes – See Table 7.21a

- 7.6.4.17 **De-watering** - a potential further source of contaminant mobilisation from sediment will be from the de-watering of the turbine/sluice gate housing area during construction. This area will be isolated by a temporary cofferdam which will be pumped dry to allow construction. As the cofferdam is surrounded by the sea, the difference in hydrostatic pressure will cause water ingress into the dry area. This water will need to be discharged to sea to maintain the dry working area. The estimated discharge rate will be between 800 and 1600 l/s. The water will have travelled through the sediment, potentially mobilising soluble contaminants, which would then be discharged to the Bay during de-watering.
- 7.6.4.18 As the dewatering operations are likely to produce a continuous discharge over the construction period, potentially up to three years when the cofferdam is in use, a series of model applications were undertaken to simulate the dispersion of pollutants released during de-watering activities. Applications used a conservative tracer (assuming contaminants remain within the water column and are not lost to sediment absorption or other sink processes). It is also conservatively assumed that contaminants within the sediment are not limited, i.e. concentrations will not reduce significantly over the de-watering period.
- 7.6.4.19 Model tracer results were scaled to the concentration of specific contaminants identified in sediment samples, allowing for partitioning and background contaminant levels. Results are compared with relevant standards (e.g. UKTAG) to quantify potential impacts and likely effects on classification under the WFD. The results are presented in Section 7.7.10.

7.6.5 Decommissioning impacts

7.6.5.1 In terms of decommissioning, as identified in Chapter 4: Project Description, at this stage there are two potential options for the future. The two options include varying degrees of intervention and therefore potential impacts. Starting from minimal intervention the options being considered are:

- a) progressive updating of the facility so it is kept in use as an energy source as well as its ongoing leisure use; and
- b) turbines and sluice gates to be removed, and the tide allowed to flow through the resultant gaps in the housing structure.

7.6.5.2 An assessment of the potential effects from decommissioning under option b) have been undertaken by applying the bacteria (E Coli FIO) sensitivity runs to the Lagoon operation scenario with no turbines in place. Under this scenario, sea water flows freely between the Lagoon area and the sea through the area previously occupied by the turbines and sluices.

7.6.5.3 Results were compared with the Lagoon and Baseline cases to identify potential changes in plume behaviour and circulation following decommissioning. This provides an indication of how future water quality might change when the Project is decommissioned. However it should be noted, only relative changes can be assessed, since decommissioning is not expected to take place for some 120 years, the discharge sources and water quality in Swansea Bay would be expected to be significantly different to the present day.

7.6.6 Optimisation applications

7.6.6.1 In the design development of the Project, the location of the turbine housing structure was assessed and optimised, in terms of east, west or south facing, to minimise impacts on water quality, within practical engineering constraints (Chapter 3, Site Selection and Option Appraisal). Lagoon water quality is impacted by the presence of the Swansea WWTW discharge within the impounded area. Water quality is further modified by the flow of water into and out of the Lagoon on each generating cycle. This determines how effluent disperses within the Lagoon and how effectively the Lagoon is flushed. Flushing of the Lagoon determines the impacts of the water released from the Lagoon on the Swansea Bay water body. Optimisation options were assessed with respect to:

- i. reducing potentially adverse impacts of the Lagoon discharge on the waters of Swansea Bay; and
- ii. reducing the impacts of the WWTW discharge within the Lagoon to improve local water quality within the Lagoon impoundment.

7.6.6.2 The continuous treated discharge from the WWTW has been assessed as having relatively little impact on the water quality of either the Lagoon or Swansea Bay. Treatment reduces the concentration of pollutants to low levels, and subsequent dispersion and decay in the receiving waters reduces concentrations further. During wet weather the storm discharge from the WWTW can have a more significant impact, as the discharge rate is almost twice that of the maximum treated flow and the concentration of pollutants, particularly bacteria, in storm water is significantly higher. The concentration of bacteria FIOs in the storm discharge can be up to 1000 times greater than the treated effluent.

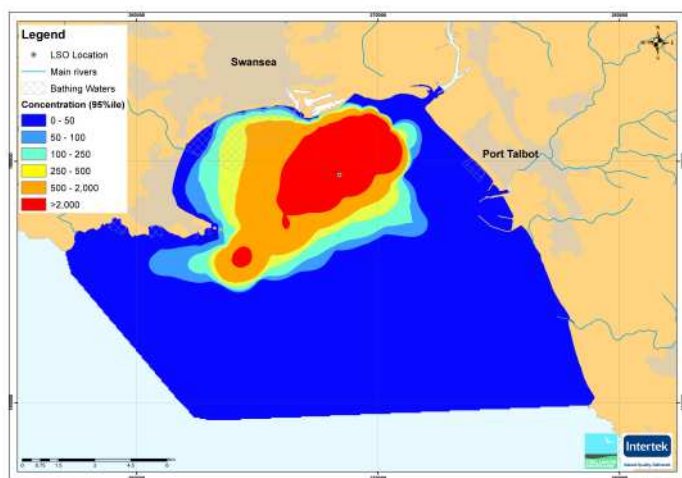
- 7.6.6.3 Options to address storm discharges from the WWTW are of relevance in circumstances where the water quality within the Lagoon is important. For instance, where water contact sports are proposed, the risk of storm discharge disrupting events would be lessened if design measures are used in developing the Project so that more certainty can be ascribed to the benefits from such measures.
- 7.6.6.4 Management options to take account of storm discharges can be used, such as closure of the Lagoon to swimmers in whole or in part, designation of advisory zones, etc. Three physical options which could be incorporated into or provided alongside the Project were originally considered to reduce the effects of storm discharges from the Swansea WWTW on the Lagoon and the wider Swansea Bay. The options are discussed in Chapter 3: Site Selection and Option Appraisal. The options were evaluated preliminarily on a number of factors including the engineering feasibility and estimated cost (which serves as a proxy for use of resources and difficulty of delivery), carbon footprint and construction timescale. From this analysis, two options were taken forward for detailed assessment and either may be adopted:
1. option 1 (storm water disinfection) addresses the discharge of storm water from the WWTW, by reducing the discharge concentration. This would improve water quality both within the Lagoon and within Swansea Bay. Depending upon the circumstances, further management resources may still be required; and
 2. option 2 (outfall extension) would completely remove the treated and storm discharges from the Lagoon, but requires consideration of potentially greater impacts on local bathing waters, when combined with the hydrodynamic effects of the Lagoon. Optimisation runs were therefore undertaken to determine a minimum outfall extension that would not lead to detrimental impacts on local bathing waters. A number of outfall locations were assessed along the existing line and to the east and west. The existing outfall line provided least impact, as moving east or west caused greater impacts along the Afan and Swansea shorelines.
- 7.6.6.5 Figure 7.8 represents the extent of the storm water discharge plume from the WWTW under a) Baseline conditions; b) with the Lagoon in place; c) with an outfall extension of 1.5km along the existing outfall line (Option 2); and d) with UV disinfection applied to the discharge at its current location (Option 1). The applications assume a continuous storm water discharge from the WWTW only, in order to specifically assess those impacts. This is a worst case scenario for comparative purposes: storm discharges occur for shorter periods than modelled, and would generally cause lower concentrations than shown. The figures present the 95%ile percentile concentration predicted at all locations within the model. The 95%ile concentration is used in preference to the peak or maximum concentration, as these can be misleading where high instantaneous (in the order of a few seconds) concentrations are predicted.
- 7.6.6.6 Comparison of the plots in Figure 7.8 a) (Baseline) and b) (with the Lagoon in place) indicates that the changes in hydrodynamics caused by the Lagoon would cause the storm discharge from the Swansea WWTW to affect a greater area along the Swansea seafront, at higher concentrations. The plume also moves further offshore, and further from the Afan beaches. The high concentration seen off Mumbles Head under the Baseline is reduced, but the plume moves slightly closer to the shoreline west of Mumbles. Water quality within the Lagoon is largely unchanged compared to the Baseline, with some improvement near the shoreline.

Tidal Lagoon Swansea Bay plc

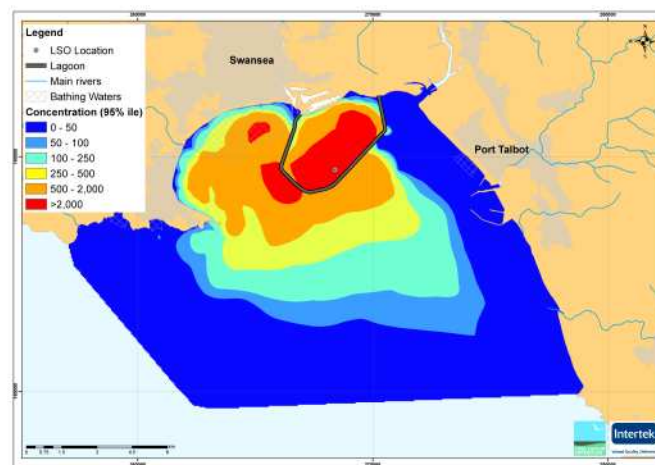
- 7.6.6.7 Extending the outfall (Figure 7.8 c) reduces impacts along the Swansea coastline, with a reduction over the Baseline, and off Mumbles. However the plume moves further offshore and closer to the Afan coastline. Water quality within the Lagoon is significantly improved, although some dilute storm water is drawn back into the Lagoon on the flood tide generation, its concentration is low.

Tidal Lagoon Swansea Bay plc

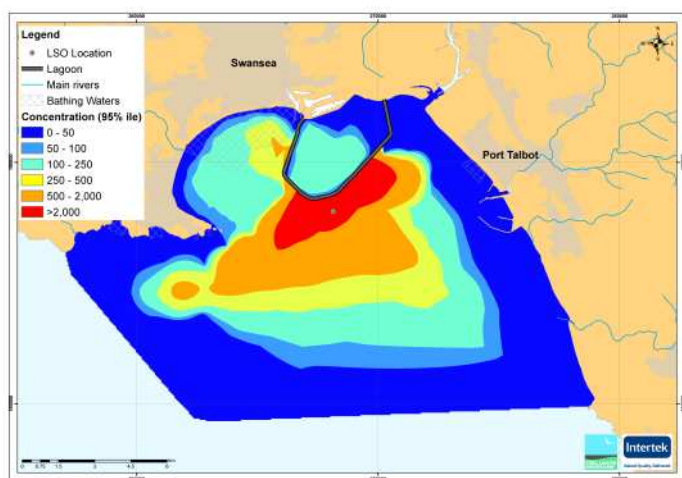
95%ile E Coli concentration:
Continuous storm discharge
Spring tide
No wind



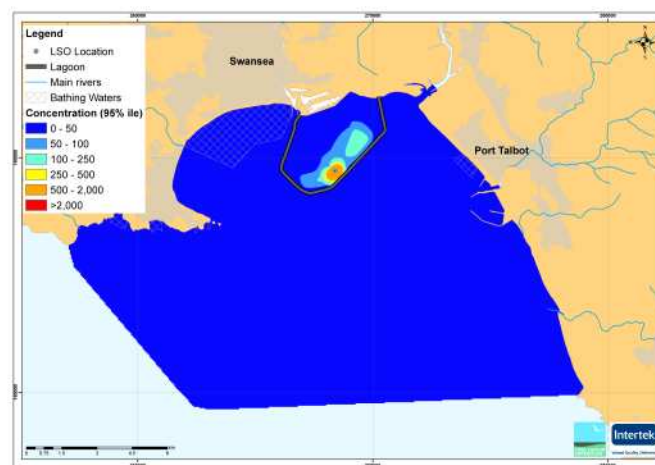
a) Baseline



b) Lagoon



c) Outfall Extension (1.5km)



d) UV Disinfection

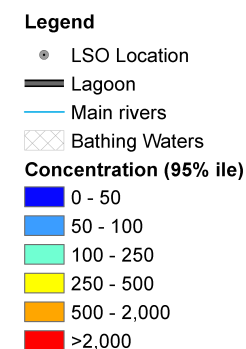


Figure 7.8 Comparison of Swansea WWTW impact optimisation options (E Coli /100ml)

- 7.6.6.8 Applying UV disinfection to the storm discharge at the current outfall location (Figure 7.8 d) significantly reduces the concentration of the discharge, resulting in minimal impact of the Swansea WWTW storm discharge on Swansea Bay and improved water quality within the Lagoon.
- 7.6.6.9 It is proposed to establish a Water Quality Strategy for the Lagoon, as part of an Operation Environmental Management Plan (OEMP). This would be developed in consultation with DCWW to ensure that the Lagoon operations team are advised of any issues at the Swansea WWTW that might impact Lagoon water quality. Provision will be made within the Water Quality Strategy for appropriate action to be taken should operational issues at the WWTW occur. This plan would include provision for advisory notices, advisory zones for bathing or water contact sports, and - in extreme cases - prohibition of water activities within the Lagoon. Specific events would include:
- i. Reduction in treated water quality due to plant failure at the WWTW. In this case the action taken would depend on the nature of the event and the likely effect on water quality. As a worst case untreated effluent may be discharged to the Lagoon with impact similar to those presented in Figure 7.8b. In the case of outfall extension impacts on the Lagoon would be low (Figure 7.8c).
 - ii. Failure of the UV disinfection plant, or disruption of flow to the UV plant, would result in storm effluent being discharged without treatment. During this period the impacts on the Lagoon would be as those for the baseline lagoon case, i.e. without optimisation / mitigation. It is proposed that in the event of failure of the UV plant water sports would be prohibited within the impoundment until repairs are affected and water quality has returned to normal. Normal water quality would be defined by an appropriate elapsed time (e.g. 48 hours) possibly supported by water quality sampling in key areas of water based activity.
 - iii. In the event of the outfall becoming blocked the most likely scenario is that influent to the WWTW would be discharged from the upstream pumping station emergency overflows. This situation is no different to that which would occur under current conditions, and would lead to untreated discharges from CSO989 on the River Tawe and the pumping station at Baldwins Crescent. The Baldwins Crescent emergency overflow discharges directly to the foreshore within the Lagoon impoundment. The risk of outfall blockage is more likely under the extended outfall scenario, where the outfall would pass under the lagoon wall. Measures to mitigate such risks, including provision of a second outfall pipe under the Lagoon wall and a relief plate on the shoreward side of the outfall pipe, have been considered as part of the design process. Blockage under the UV treatment option is considered less likely, as there are multiple outfall diffusers and the flow through these provides a self cleansing effect preventing sediment accumulation. In the event of the outfall becoming blocked water sports would be prohibited until the blockage is removed and water quality returned to normal conditions.
- 7.6.6.10 The optimisation options proposed are based on engineering solutions that can be applied within the development envelope. It is recognised that reducing the storm effluent reaching the WWTW also provides an effective means of reducing storm discharges. However, this relies on DCWW implementing infrastructure improvements within the larger Swansea catchment and is not within the control of TLSB. Implementation of storm water reduction schemes would also not be possible within the construction period for the lagoon.

- 7.6.6.11 DCWW is currently implementing a range of infrastructure improvements under AMP5, which should reduce local storm spills to the Swansea Bay bathing water and should lead to a reduction in storm spill volumes from the Swansea WWTW. Storm water reduction measures proposed by DCWW in AMP5 are accounted for in the 2015 Baseline assessment.
- 7.6.6.12 Improvements under future AMP programmes would be expected to deliver further reductions in storm flows to the WWTW. However the nature of any further storm water reduction is not currently known and will depend on future investment programmes and any future changes in directives and legislation.
- 7.6.6.13 It is however reasonable to assume that over the lifetime of the Lagoon the amount of storm water reaching the WWTW will be reduced leading to improvements in water quality in the Lagoon. The Baseline condition modelled is therefore considered a worst case in terms of future changes in storm flows.
- 7.6.6.14 Baseline and Lagoon sensitivity runs were repeated for the two options that could be provided as part of the Project, to assess the relative effects of each option on plume behaviour and pollutant distribution in Swansea Bay. The additional optimisation sensitivity runs undertaken are presented in Table 7.22 below.

Table 7.22 Summary of additional sensitivity runs undertaken for optimisation options

	Option		Comment
	Disinfection	Outfall Extension	
Microbiology (E Coli)	✓	✓	Affected by all options
Salinity	✗	✗	No significant effect from options
Nutrients	✗	✓	Only significantly affected by outfall extension.
DO	✗	✗	No significant effect from options

✓ - Run

✗ - Not Run - where an option would have little effect on a specific determinand, i.e. small change in load or not affected by option, these runs were excluded, e.g. UV disinfection would have no effect on DO and nutrient concentrations, temperature / salinity changes would be insignificant.

7.6.7 Summary of model applications

- 7.6.7.1 Table 7.23 provides a summary of all the application runs undertaken for the EIA. The results of these applications are presented in Section 7.7.

Table 7.23 Summary of model applications

Application	Determinands	Driver	Inputs / Sources	Scenarios	Conditions		Assumptions / Notes
Sensitivity Microbiology	E Coli	rBWD SFD	Significant continuous and storm loads of bacteria.	Baseline Lagoon Optimisation (All Options) Construction Decommissioning	Discharge Tide Wind Season	Background Storm event Spring Calm, SW, SE Summer	A real large storm event. Discharge loads from existing models and data sets. WWTWs, rivers and significant storm inputs. Mean spring tidal conditions and a range of winds. Applications for E Coli FIO, decay rate of 50 hours.
Sensitivity Temperature /Salinity (T/S)	Temperature Salinity	WFD	Continuous loads of freshwater and temperature from rivers	Baseline Lagoon	Discharge Tide Wind Season	Background Storm event Spring / Neap cycle Calm Winter / Summer	Winter case: high river flow river T/S 4°C / 0 psu sea T/S 7°C / 31 psu air T 5°C Summer Case: mean river flow river T/S 15°C / 0 psu sea T/S 15°C / 31 psu air T 15°C Thermal discharge from the Baglan Bay power station to the Neath Estuary (1 m ³ /s at 0 psu and 5°C above ambient temperature).
Sensitivity Nutrients	Nitrogen	WFD	Continuous loads of nutrients from rivers and WWTWs	Baseline Lagoon Optimisation (Option 2 only)	Discharge Tide Wind Season	Background Spring / Neap cycle Calm Winter	Conservative winter conditions. Nitrogen losses, e.g. the take up of nitrogen by algae and losses to the atmosphere ignored. Nitrogen concentrations determined from NRW study by CREH (2012). Open water boundary from NRW WEMS sample data, two stations outside Swansea Bay.
Sensitivity DO	Dissolved Oxygen (DO)	WFD	Continuous loads of BOD and ammonia from rivers and WWTWs. Storm load from WWTW.	Baseline Lagoon	Discharge Tide Wind Season	Background Storm event Spring / Neap cycle Calm Summer	Conservative summer conditions, lowest solubility: i.e. High temp (15°C) and salinity (34psu). No wind – minimum re-aeration. Algal photosynthesis and respiration excluded. Discharge concentrations from available NRW and DCWW sample records and literature. Additional run including storm discharges from Swansea WWTW to assess potential for short term DO sags in Lagoon.

Tidal Lagoon Swansea Bay plc

Table 7.23 Summary of model applications cont.

Application	Determinands	Driver	Inputs / Sources	Scenarios	Conditions	Assumptions / Notes
Microbiology BW / SFW	E Coli I Enterococci	rBWD SFD	All significant continuous and storm loads of bacteria.	Baseline Lagoon Optimisation Options) (All	Discharge Background (all) Storm (all) Tide Spring / Neap Wind Calm, SW, SE Season BW – Summer SFW – All year	BWs - All sources over 4 bathing seasons. SFWs All sources over 1 year. Background and storm. Seven wind conditions. All tide / storm discharge phase combinations.
Sediment Contaminants	Metals TBT	WFD	Release of contaminants from sediment during dredging and de-watering activities	Construction	Discharge Dredged sediments De-watering Tide Continuous 5 month Wind Calm Season Summer	Conservative tracer modelled over duration of dredging period. Lagoon seawall added through application. Continuous average dredging rates / volumes. Minimum dilutions of tracer determined at all locations. Comparison with discharge concentrations

Notes:

Optimisation options for Swansea WWTW Discharge: Option 1 = UV disinfection, Option 2 = outfall extension

Background – normal continuous inputs under dry weather conditions, represented as average loads from rivers, streams and WWTWs

Storm – additional intermittent loads from storm discharges during rainfall events, e.g. diffuse run-off, land drainage and CSO discharges

Wind: Calm < 5m/s, SE = South Easterly Wind 5 m/s, SW = South Westerly Wind 5m/s

rBWD = Revised Bathing Water Directive: SFD = Shellfish Directive(s): BW = bathing water: SFW = shellfish water

7.6.8 Accuracy, Assumptions and Uncertainty

- 7.6.8.1 The ability of the Swansea Bay Coastal Model to accurately predict the effects of the Project on water quality in Swansea Bay is determined by a number of factors. Firstly the model must be capable of describing the key physical and physio-chemical process in Swansea Bay. These are influenced 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. Secondly, for an accurate model to provide accurate results the input data must be of sufficient quantity and quality to describe baseline and future conditions. Where there is uncertainty, and / or there are assumptions inherent in the input data, uncertainty in model predictions of the impacts of the Project will increase.
- 7.6.8.2 An assessment of uncertainty in the assessment of the impacts of the Project has been undertaken. This assessment is summarised below. The assessment considers the key components of the model and data and the accuracy and assumptions inherent in each. A level of uncertainty for each component has then been identified. Uncertainty is described as high, moderate or low. Where possible, uncertainty is assessed based on quantitative metrics, e.g. model verification. Where this is not possible, a qualitative assessment is made based on parameters such as the availability and quality of data, the consultants knowledge and previous experience, and industry standards and best practice.
- 7.6.8.3 Where uncertainty is moderate or high, due to e.g. availability of data or assumptions, and cannot be improved, additional steps are taken to provide additional confidence. These steps may include sensitivity testing, the use of conservative data and assumptions, and the adoption of a precautionary (worst case) approach.
- 7.6.8.4 **Numerical model:** the Delft3D software is an established code used internationally for both academic research and commercial consultancy. The software 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 Delft Hydraulics and beta tested where appropriate. The Delft3D 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.
- 7.6.8.5 **Two-dimensional numerical scheme:** as discussed previously Swansea Bay is a highly dynamic and well mixed marine environment. There is no evidence of stratification or other depth dependent effects in Swansea Bay. For the purpose of the EIA study a 2-dimensional model is considered appropriate and has a low level of associated uncertainty.
- 7.6.8.6 **Representation of lagoon structures and hydrodynamics:** the Project will alter the tidal flow 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 Delft3D 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 well implemented in the software. However, in this case a more straightforward approach has been undertaken by representing the turbines as discharge flows derived from a more detailed and advanced model of Lagoon turbine operation. By not explicitly defining control structures within the model a potential area of assumption and uncertainty is removed. The expert

assessor team has extensive experience of the application of models to impoundments and structures. The model numerical scheme is sufficiently accurate and robust to accurately model the effects of tidal lagoons on hydrodynamics, with a low level of associated uncertainty.

- 7.6.8.7 Swansea Bay Water Quality Model:** the Swansea Bay Water Quality model has been constructed, based on accepted industry best practice and guidelines. The model has been built and verified by experts in the field of coastal numerical modelling, and with extensive experience of working in Swansea Bay. The long history of the model for use in water quality assessments in Swansea Bay provides added confidence in a model that has been through three distinct phases of development and verification. All these model phases were conducted in consultation with NRW (and its predecessor organisations), to ensure the model was fit for purpose. The Swansea Bay Water Quality model provides a robust and accurate means of predicting water quality in Swansea Bay, with a low level of associated uncertainty.
- 7.6.8.8 Hydrodynamic model accuracy and resolution:** the Swansea Bay Water Quality model is constructed on a fine (50m) curvilinear mesh, providing sufficiently high resolution to accurately define the channels, structures and bathymetry of Swansea Bay. The model has been extended and modified to include greater definition in the river Tawe and Neath estuary. 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 revised model has been verified using a comprehensive hydrodynamic dataset. Verification metrics meet, or exceed, industry guidelines (Appendix 7.1, Volume 3). No adjustment to model bathymetry, boundaries or calibration coefficients was required, and no significant assumptions were required in the model. 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.
- 7.6.8.9 Dispersion model accuracy and resolution:** the Swansea Bay Water Quality model was previously calibrated and validated for dispersion using accepted dye tracing techniques (Hyder (2006)). The model was audited (Falconer and Lin (2006)) and accepted as fit for purpose by NRW. The updated model has been further verified using tracer studies undertaken during the 2011/2012 Smart Coasts study (See Appendix 7.2, Volume 3). The level of fit achieved is good, with no significant assumptions or changes to calibration coefficients required. This provides a high level of confidence in the model and a low level of uncertainty.
- 7.6.8.10 Supporting models and input data:** pollutant loads are described for all significant sources entering Swansea Bay. Discharge flow from point and diffuse sources are derived from hydrological models (supported by gauged flow records for larger rivers) and sewer network models. Hydrological models have been constructed using best available data and verified against gauged flow records. The Swansea Bay and Afan / Baglan network models were constructed using industry best practise and have been further updated and re-verified during DCWW's ongoing investigation works. Network and river models are driven by a common set of rainfall data, recorded at St Helens in Swansea. A period of 'wetter' summers (2008-2011) has been used to provide a precautionary, worst case, basis for the study. Pollutant concentrations are based on historical data and data sets collected during the 2011 Smart Coast surveys. This data set is believed to be one of the most comprehensive data sets currently available in the UK.

Where concentration data is not available a conservative approach has been taken to describing input loads. The uncertainty in the microbiological input data is, therefore considered low.

- 7.6.8.11 **Microbiological water quality model accuracy:** the performance of the microbiological model is a function of the accuracy of the underlying numerical model, the calibration of process parameters (e.g. decay rate) and the quality and quantity of the input data describing the pollutant loads to the receiving water. The model construction and verification is based on an approach that has been developed and continuously improved by Intertek over more than 15 years, and in consultation with UK regulators (SEPA, EA, NRW). Intertek have constructed models of the majority of the UK coastline, providing an extensive level of knowledge, expertise and experience in the construction and verification of microbiological water quality models. The microbiological component of the water quality model has been verified against Smart Coasts and NRW DSP sample data and shows a good level of performance (See Appendix 7.2, Volume 3). In general the model over-predicts FIO concentrations at the DSPs and is considered conservative in this regard. Decay rates employed are consistent with other UK studies and are conservative compared to current guidance. Confidence in the microbiological model is considered high, with a low level of associated uncertainty.
- 7.6.8.12 **WFD water quality model accuracy:** model applications have been undertaken for a range of determinands including temperature, salinity, nitrogen and DO. To provide accurate predictions these models applications are required to model physio-chemical processes, including the decay of organic material and uptake of nutrients by phytoplankton. The complexity of these processes requires a significant quantity of input and verification data, which was not available for the Project EIA study. Since a lack of data can lead to uncertainty in model predictions, a precautionary approach has been adopted for these model applications. This approach provides a higher level of confidence, in that it will tend to generate conservative predictions. Pollutant loads have been defined using measured data where available, where data is not available a conservative load is used based on Intertek's experience from previous projects. Process parameters are derived from literature and previous studies, and conservative values are again assumed. Some sink processes, e.g. uptake of nutrients by phytoplankton, are omitted to provide a conservative assessment. Worst case environmental conditions are generally used, or are applied in addition to a normal case. Where survey data is available this has been used to check the output from the model and determine an approximate level of uncertainty, and where appropriate model results are modified to account for uncertainty. While the availability of data may limit model predictions for these determinands to moderate uncertainty, this has been accounted for by applying a conservative approach to derive a high level of confidence in model predictions.
- 7.6.8.13 **Baseline applications:** given the above discussion, the results of Baseline applications carry a low level of uncertainty, as verification or comparison with measured data provides a good fit and, therefore, a high level of confidence in the model predictions.
- 7.6.8.14 **Construction applications:** the construction applications use a modified version of the Baseline model, in which there is high confidence. 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 previous studies and data on sediment and sediment contaminants collected specifically for the Project at a representative number of sites and depths. The effects of increased suspended

sediment concentrations on bacteria decay are derived from evidence from studies in Swansea Bay and output from the coastal process model (Chapter 6). Contaminant discharges from sediment are based on best available information on construction activities, contaminant concentrations and partition coefficients. Overall a low level of uncertainty can be assigned to the model inputs. A precautionary approach has been taken to representing the construction method within the model applications, e.g. continuous discharges from dredging and dewatering activities with conservative estimates of loads, sediment loss etc. Model applications consider average and worst case conditions. The modelling approach adopted for sediment contaminants has been simplified, to an assessment of tracer dispersion with no sink terms applied, to provide a more conservative and transparent methodology. 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.

- 7.6.8.15 **Lagoon and optimisation applications:** the inputs for these options are derived from the Baseline. The Lagoon is included within the model, and is represented using best available information on location and turbine flows. The only input variables changed are the location of the outfall, for the outfall extension option, and a reduction in FIO concentration for the UV option. The reduction in FIO concentrations for the UV option is based on data from existing similar plant used by DCWW. Uncertainty in the results of these applications is similar to those for the Baseline case, and is considered low.
- 7.6.8.16 **Impacts assessment:** comparison of results from the Baseline and Lagoon model applications are used to determine potential changes in water quality and the impacts of the Project. Impacts are assessed against established water quality metrics and standards. Where there is uncertainty in the absolute predictions of the model, a relative assessment is adopted. Relative changes are then assessed against available data to quantify the level of uncertainty in the impact of the Project. A conservative, precautionary approach is adopted throughout.
- 7.6.8.17 Given the above, the ability of Swansea Bay Water Quality model to deliver accurate and robust predictions of baseline and future hydrodynamics and dispersion is considered High, and is supported by good model verification. The corresponding level of uncertainty is low. While additional data and further fine tuning of the model could potentially improve confidence in the model, such improvements would be relatively small, and unlikely to affect the predicted impacts and outcomes of the study.
- 7.6.8.18 Uncertainty in the microbiological water quality model and its predictions is considered low, due to the well defined input data and good model verification.
- 7.6.8.19 There is greater uncertainty in the WFD water quality model applications, due to fewer available data for model set-up and verification. A precautionary approach has therefore been taken to provide an increased level of confidence in the model and predicted impacts.
- 7.6.8.20 Overall, confidence in the Swansea Bay Water Quality model is high, and the impacts predicted are considered accurate and robust.

7.7 Assessment outputs for construction, operation and decommissioning

7.7.1 Introduction

7.7.1.1 The results of the various water quality applications summarised in Table 7.23 are presented in this section. For efficiency, and to minimise repetition, results are presented and compared for all model scenarios at the same time. Some scenarios may be omitted, as they are not applicable to some determinands.

7.7.1.2 Results will first be presented for Baseline, Lagoon operation and optimisation options. Results will then be presented for construction and finally for decommissioning to allow Baseline and Lagoon results to more fully inform the assessment of these impacts.

7.7.1.3 Results for microbiology applications will be presented first, as these are used to gain a more detailed understanding of dispersion processes within the bay, which are then applied to interpretation of the WFD applications.

7.7.2 Microbiological sensitivity applications

7.7.2.1 Microbiological sensitivity applications (see Section 7.6.2) provide an initial indication of the effects of the Lagoon on pollutant transport in Swansea Bay, and how this varies between dry and wet conditions. These results will then be combined with the results from the detailed STORM-IMPACT modelling to assess the effects of the Lagoon on key water quality drivers, i.e. bathing waters and shellfish waters.

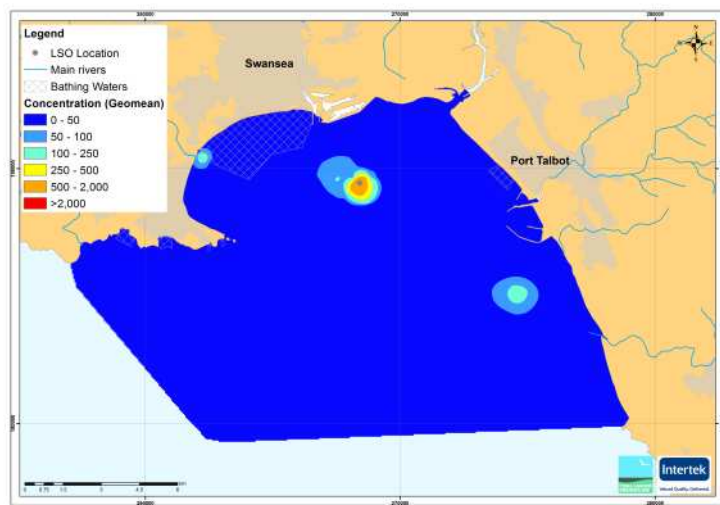
7.7.2.2 Figure 7.9 presents summary results of the sensitivity applications. Results are presented for two cases, representing the likely range of concentrations that would be experienced during the bathing season, i.e.:

- a) the **dry weather** concentration, typical of FIO bacteria (E Coli) concentrations under the effects of continuous dry weather discharges, this represents the normal background condition; and
- b) the **storm concentration** provides an indication the high FIO bacteria (E Coli) concentrations that would be expected in response to a large rainfall event.

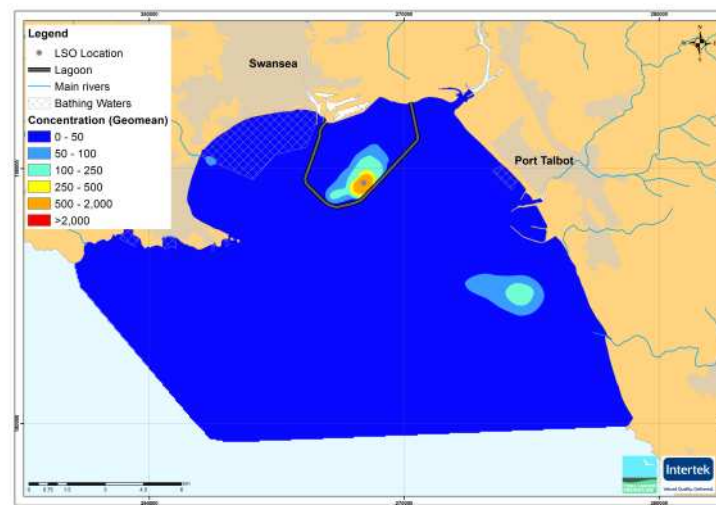
7.7.2.3 For the dry weather case plots are presented for a geomean (average) concentration and a 95%ile (peak) concentration. For the storm case only a 95%ile concentration is presented to identify a worst case concentration during a storm event. The geomean has little relevance for a storm event, as concentrations will vary rapidly in response to the timing of the various storm discharges. It should be noted that the plots are not an instantaneous concentration, but a composite representing geomean or 95%ile concentration in each model cell during the entire dry or wet period modelled. This provides an assessment of the maximum extend of impacts under the at the specified scenario and level (geomean or 95%ile)

7.7.2.4 Figure 7.9a shows average dry weather (geomean) concentrations under the Baseline condition. In general E Coli concentrations are less than 50 cfu/100ml throughout the Bay. Higher concentrations are observed close to the main bacteria sources, i.e. the Swansea and Afan WWTW discharges. Elevated concentrations are also seen around the mouth of the River Clyne: the river discharges directly on to the beach at high water and experiences relatively little dilution in the shallow intertidal waters around the discharge point.

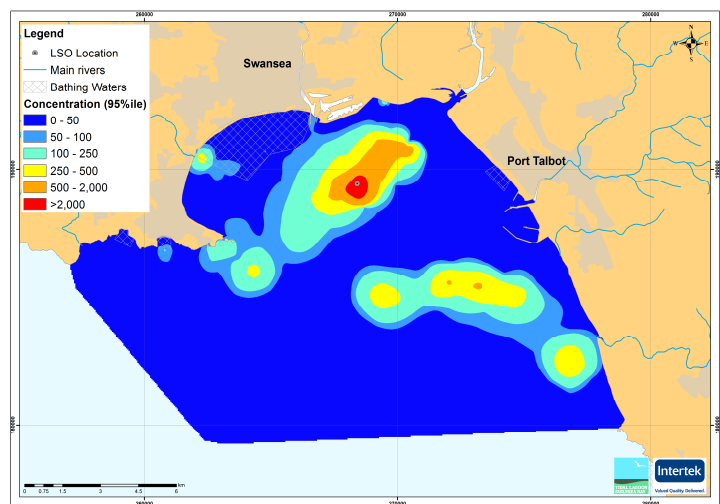
Tidal Lagoon Swansea Bay plc



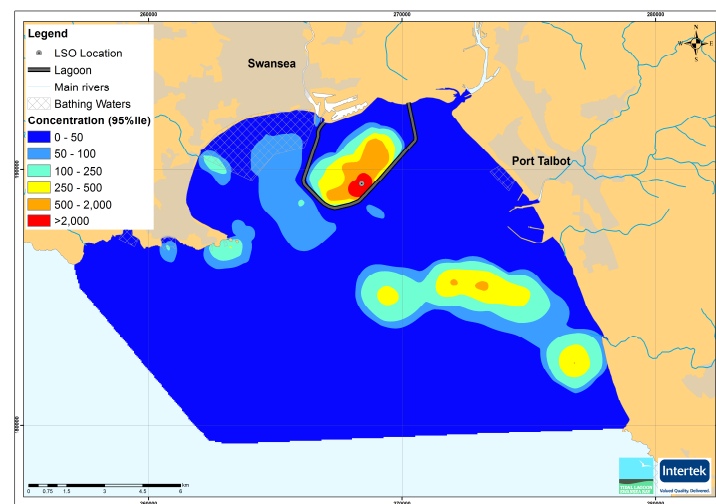
a) Baseline dry weather geomean



b) Lagoon dry weather geomean



c) Baseline dry weather 95%ile



d) Lagoon dry weather 95%ile

E Coli /100ml
Background loads
Spring tide
No wind

Legend

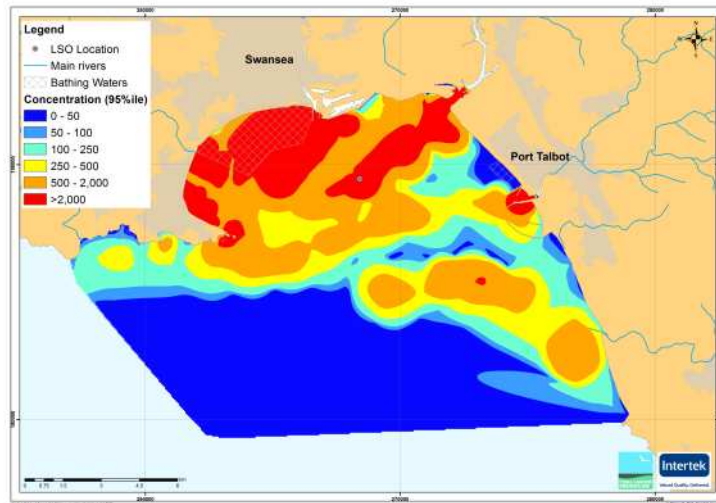
- LSO Location
- Lagoon
- Main rivers
- Bathing Waters
- Concentration (Geomean)
 - 0 - 50
 - 50 - 100
 - 100 - 250
 - 250 - 500
 - 500 - 2,000
 - >2,000

Legend

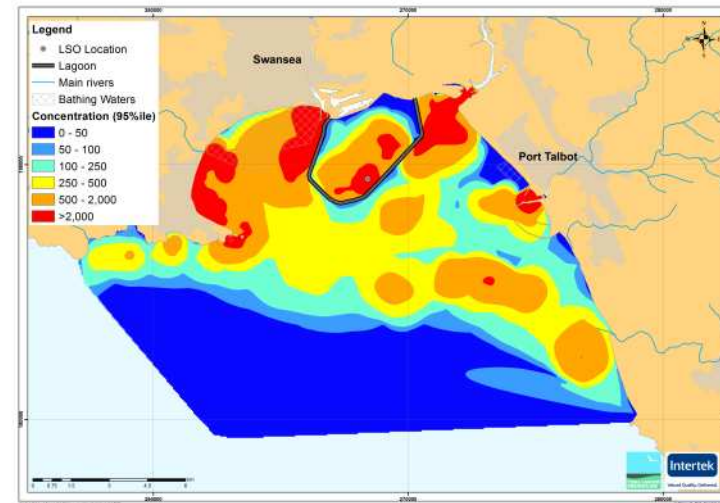
- LSO Location
- Lagoon
- Main rivers
- Bathing Waters
- Concentration (95% ile)
 - 0 - 50
 - 50 - 100
 - 100 - 250
 - 250 - 500
 - 500 - 2,000
 - >2,000

Figure 7.9 Comparison of Baseline and lagoon operation impacts on microbiological water quality (E Coli / 100ml)

Tidal Lagoon Swansea Bay plc



e) Baseline wet weather 95%ile



f) Lagoon wet weather 95%ile

E Coli /100ml

Background loads

Spring tide

No wind

Legend

● LSO Location

— Lagoon

— Main rivers

⊞ Bathing Waters

Concentration (95% ile)

0 - 50

50 - 100

100 - 250

250 - 500

500 - 2,000

>2,000

Figure 7.9 Continued. Comparison of Baseline and lagoon operation impacts on microbiological water quality (E Coli / 100ml)

- 7.7.2.5 Figure 7.9c shows the 95%ile concentrations under a dry weather condition, indicating the maximum likely extent of the discharge plumes in dry weather, i.e. during spring tides. Concentrations are approximately five times higher than the geomean value and the plumes from the WWTW can be seen to extend over a larger area. The bathing waters at Swansea and Aberafan are not significantly impacted by the treated WWTW plumes from Swansea and Afan, or the discharges from the major rivers. However an impact from the river Clyne can be seen at the Swansea bathing water.
- 7.7.2.6 With the Lagoon in place (Figure 7.9b) the geomean distribution of bacteria is largely unchanged, although the area of high concentration at the Swansea WWTW outfall is now contained within the Lagoon impoundment. Under the 95%ile condition (Figure 7.9d) the effect of the Lagoon in containing the Swansea WWTW discharge can clearly be seen. This has the effect of reducing FIO concentrations in Swansea Bay. Within the lagoon the WWTW discharge plume is confined to a reduced area, leading to an increase in local concentrations.
- 7.7.2.7 Figure 7.9c and 7.9d show the 95%ile concentrations predicted over the storm event. During this time the high discharge loads from multiple sources can lead to high concentrations, which are typically sustained for short periods of less than 24 hours.
- 7.7.2.8 Under the Baseline case (Figure 7.9c) highest concentrations are seen along the Swansea foreshore, in response to local CSO discharges and increased inputs from local rivers and streams. As these discharges occur between high and low water, the discharge plumes become attached to the shoreline, limiting dispersion. The impacts of the plume from the Tawe can be seen extending some distance into the Bay, along a line from the Tawe to Mumbles Head.
- 7.7.2.9 The Swansea WWTW discharge plume and the Neath Estuary plume merge along a line of high concentration extending from the Neath Estuary to Mumbles Head. The area between the Tawe and Neath Estuaries also shows high concentrations as a result of interaction between the two river plumes.
- 7.7.2.10 Further high concentrations can be seen at the mouth of the River Afan, around Port Talbot Docks, and around the discharges from the Baglan pumping station long sea outfall and Afan WWTW long sea outfall (LSO). The plume from Baglan outfall merges with the Swansea WWTW and Neath plumes along its northern edge, while the Afan WWTW outfall remains largely separated from other discharge plumes.
- 7.7.2.11 A further plume can be seen around the Knab Rock (Mumbles) storm outfall. This plume merges with local CSO plumes along the Swansea shoreline and with the Swansea WWTW and Baglan outfall plumes, along a line south of Mumbles Head and extending north east towards Afan.
- 7.7.2.12 Construction of the Lagoon (Figure 7.9d) can be seen to have a number of effects on plume behaviour within Swansea Bay. These are:
- I. the Swansea WWTW plume is effectively trapped within the Lagoon during the flood tide, slightly reducing its impact on the outer Bay, i.e. from the outfall location towards the Neath Estuary and offshore towards Mumbles Head. As the plume is released during ebb generation it has dispersed within the Lagoon and has less impact on the area of the Bay to the west of the Lagoon;

- II. the discharges from the Tawe and Neath become attached to the Lagoon seawall. This limits lateral dispersion along the Swansea and Afan coastlines, and causes the plumes to be transported further offshore, reducing the concentrations in the central Bay area. The plume from the Tawe has slightly less impact along the Swansea frontage between the Tawe and Clyne rivers, although concentrations around Blackpill are slightly increased as a result of reduced tidal flows in this area;
- III. an increase in current speeds between the turbines and Mumbles Head causes an increase in dispersion in this area, which helps to disperse the discharge from the Tawe, Neath and Lagoon. In response, the area of impact in the southern Bay area (south of a line from Mumbles Head to Port Talbot) moves offshore and there is a small increase in concentration in the waters offshore of the Gower; and
- IV. Changes in hydrodynamics to the south east of the Lagoon cause a small increase in concentration between the Baglan and Afan LSOs.

- 7.7.2.13 Model sensitivity results for the same discharge scenarios under south-easterly and south-westerly winds were also undertaken (see Appendix 7.2, Volume 3). These show that a south-easterly wind causes a residual movement of water to the north west, which tends to cause greater concentrations along the Swansea and Afan shorelines, as seaward dispersion of discharge plumes is reduced. The Tawe discharge has a much greater impact along the Swansea coastline. The presence of the Lagoon has little effect on plume dispersion in these areas. The south-westerly wind causes plume movement towards the Afan shoreline. Concentrations between the Tawe and Neath estuaries are increased as the Tawe plume moves further east. The change in trajectory of the Tawe plume reduces impacts along the Swansea shoreline, but impacts at Afan are increased over the Baseline, as the Neath and Afan river plumes move shoreward. With the Lagoon in place, the impacts along the Swansea seafront are slightly reduced, probably due to higher flow velocities and increasing offshore dispersion which would lead to slightly elevated concentrations towards the Lagoon.
- 7.7.2.14 Results from the sensitivity applications suggest that the presence of the Lagoon will serve to alter the distribution of bacteria FIOs within Swansea Bay, particularly those from sources close to the Lagoon, e.g. Tawe and Neath rivers and Swansea WWTW. The area impacted also moves slightly offshore in the central and southern Bay, and slightly west along the Gower. However, the changes in FIO distributions are small and the impacts of the Lagoon are low.
- 7.7.2.15 Figures 7.10 and 7.11 compare model results for the Baseline and Lagoon scenarios with the two optimisation options under dry and wet conditions with no wind.
- 7.7.2.16 Under a dry weather condition (Figure 7.10) the optimisation option of UV disinfection has no net effect, as this would only operate in storm conditions. Outfall extension (Figure 7.10d) removes the WWTW discharge from the Lagoon area and into deeper water further offshore, where dispersion is increased and therefore the plume cannot be seen in the figure. The effects of outfall extension can be more clearly seen for the 95%ile condition (Figure 7.10e to g). In Figure 7.10h the WWTW discharge plume can clearly be seen to be displaced offshore and to merge with the plume from the Afan WWTW. Impacts within Swansea Bay are reduced compared to the Baseline, although the reduction when compared to the Lagoon with UV disinfection is smaller. Within the Lagoon concentrations are significantly reduced. While outfall extension would reduce concentrations in Swansea Bay, the increase in concentrations in the offshore waters could have implications for shellfish quality.

- 7.7.2.17 In wet weather, the effect of UV treatment (Figure 7.11c) reduces the bacteria FIO load by up to 500 times. Concentrations in the Lagoon are significantly reduced and lower concentrations can be seen between the Lagoon and Mumbles Head. Elsewhere changes are relatively small.
- 7.7.2.18 The outfall extension (Figure 7.11d) reduces FIO concentrations in the Lagoon to very low levels. FIO concentrations around the new discharge location increase, and the plume merges with the plumes from the river Neath and Baglan outfall. This can be seen in a clear area of increased concentration to the south of the lagoon, along a line passing through the extended outfall discharge location south-west from the Neath Estuary. Concentrations also increase in the offshore area south of Swansea Bay as the outfall extension displaces the discharge plume into this area. In the western part of Swansea Bay FIO concentrations are similar to the Lagoon and UV disinfection scenarios, with an overall improvement over the Baseline scenario.
- 7.7.2.19 Overall, both optimisation options improve water quality within the Lagoon during storm events. UV disinfection provides small improvements which are also predicted in the local offshore area between the Lagoon, Mumbles Head and the Neath Estuary. An outfall extension provides the greatest improvement in Lagoon water quality, but increases concentrations of bacteria FIOs in the local area outside the Lagoon. Dispersion between the extended discharge location and the Lagoon ensures that only a small proportion of the diluted discharge is drawn back into the Lagoon, leading to concentrations of below 50 EC/100ml within the Lagoon. The optimisation options have relatively little effect along the Swansea and Afan shorelines, as the WWTW storm discharge is a relatively small contributor to FIO concentrations in these areas during storm events.

Tidal Lagoon Swansea Bay plc

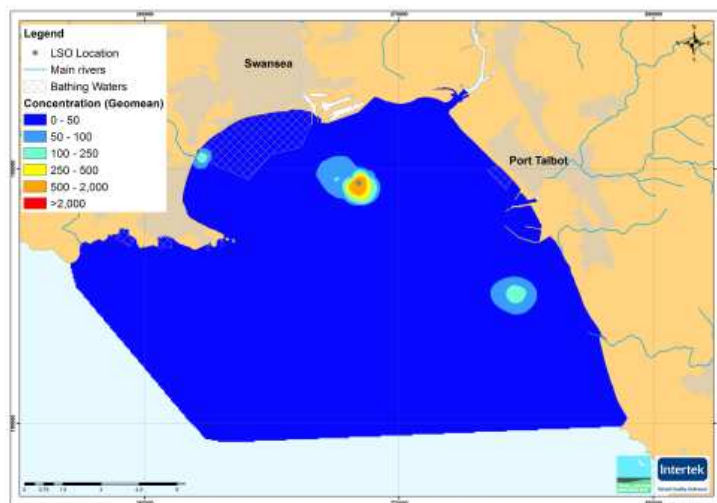
E Coli /100ml
Background loads
Spring tide
No wind

Legend

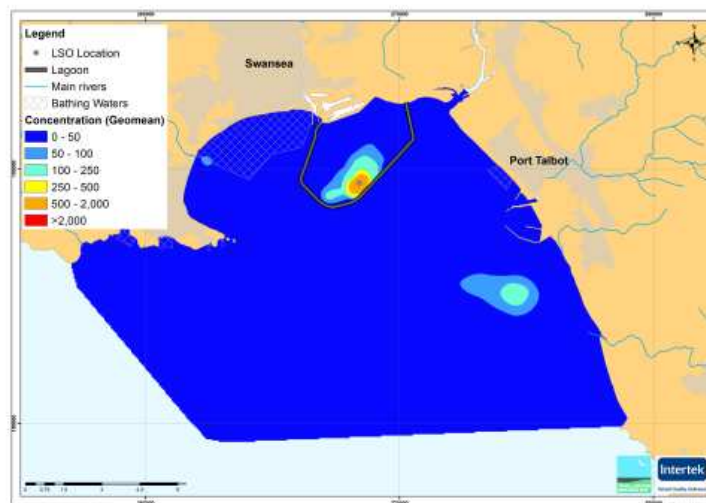
- LSO Location
- Lagoon
- Main rivers
- ▨ Bathing Waters

Concentration (Geomean)

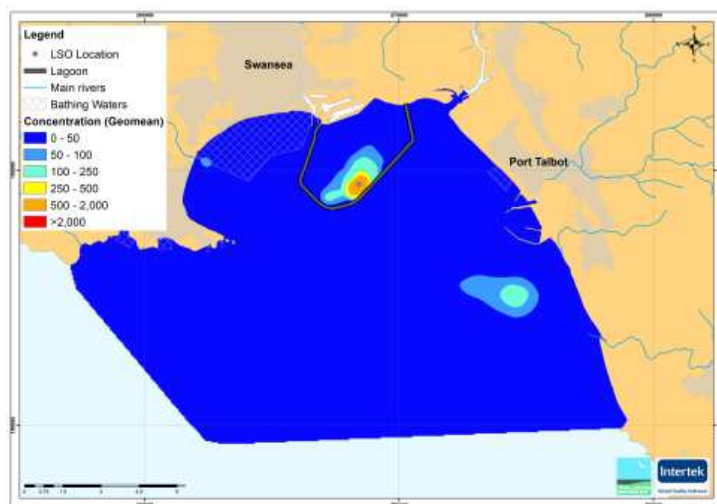
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000



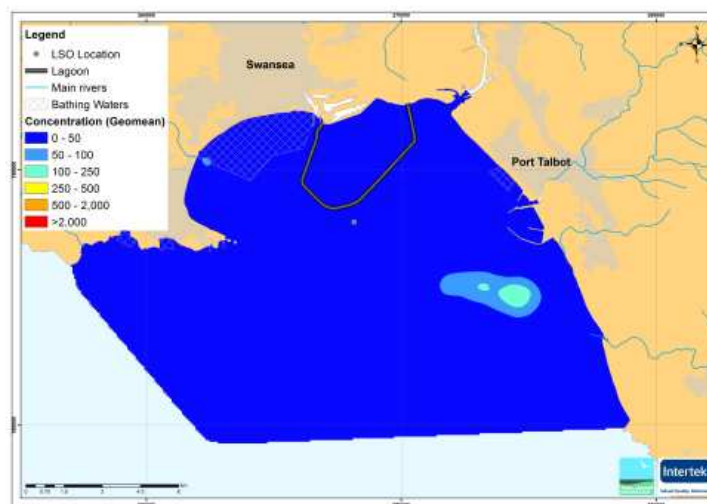
a) Baseline Geomean



b) Lagoon Geomean



c) UV disinfection Geomean



d) Outfall extension Geomean

Figure 7.10 Comparison of effects of enhancement options on microbiological water quality, dry weather (E Coli / 100ml)

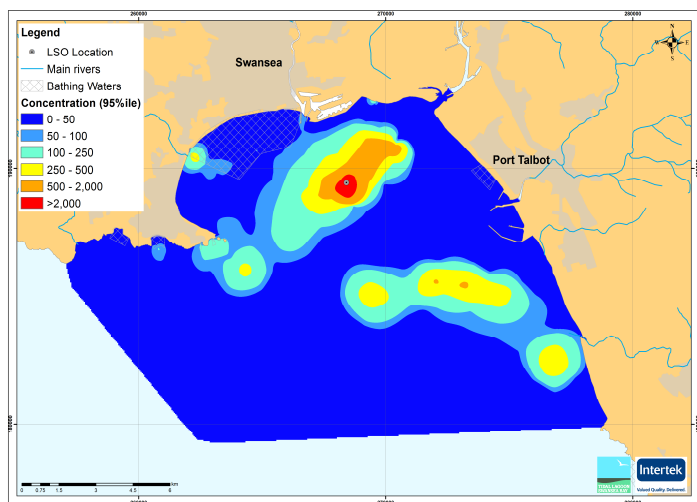
Tidal Lagoon Swansea Bay plc

E Coli /100ml
Background loads
Spring tide
No wind
Legend

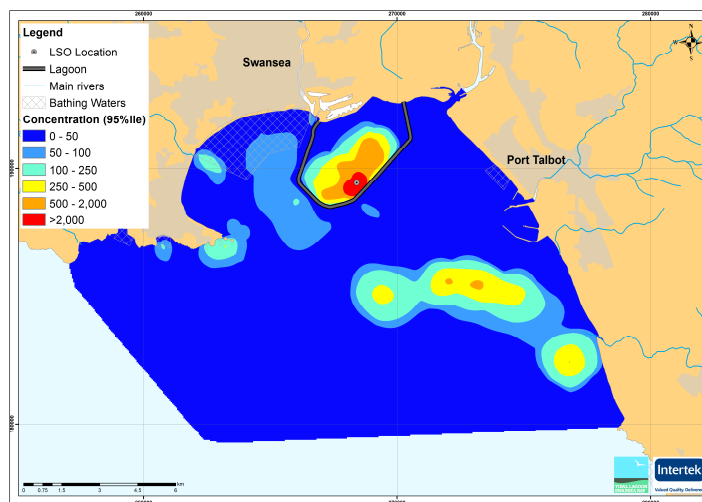
- LSO Location
- Lagoon
- Main rivers
- Bathing Waters

Concentration (95%ile)

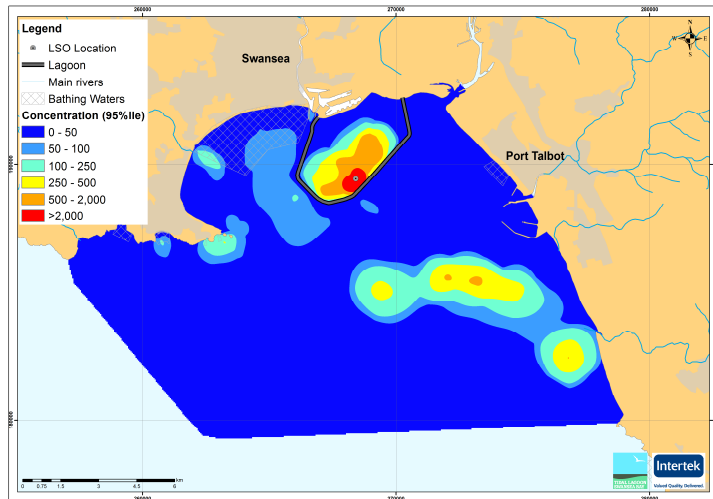
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000



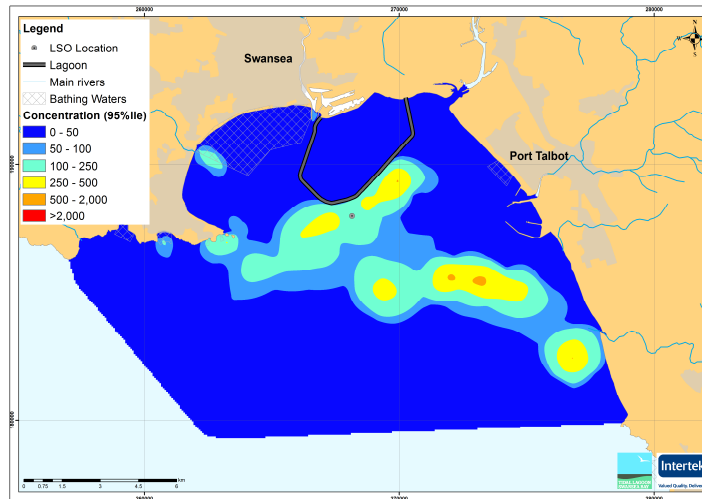
e) Baseline 95%ile



f) Lagoon 95%ile



g) UV disinfection 95%ile



h) Outfall extension 95%ile

Figure 7.10 Continued. Comparison of effects of enhancement options on microbiological water quality, dry weather (E Coli / 100ml)

Tidal Lagoon Swansea Bay plc

E Coli /100ml

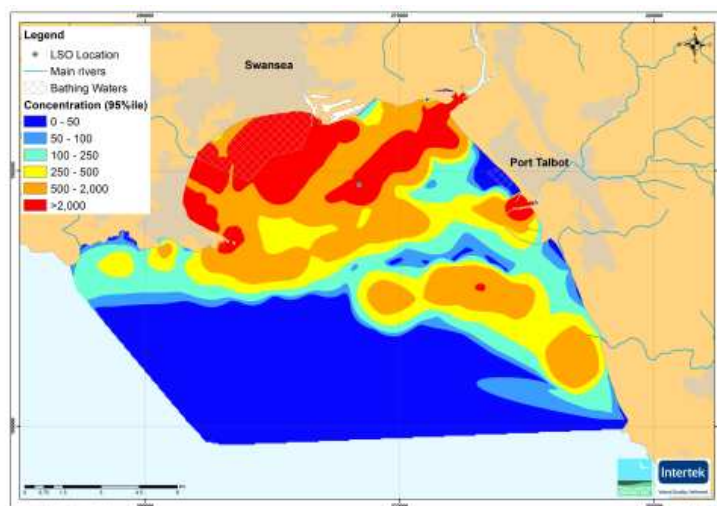
Storm event

Spring tide

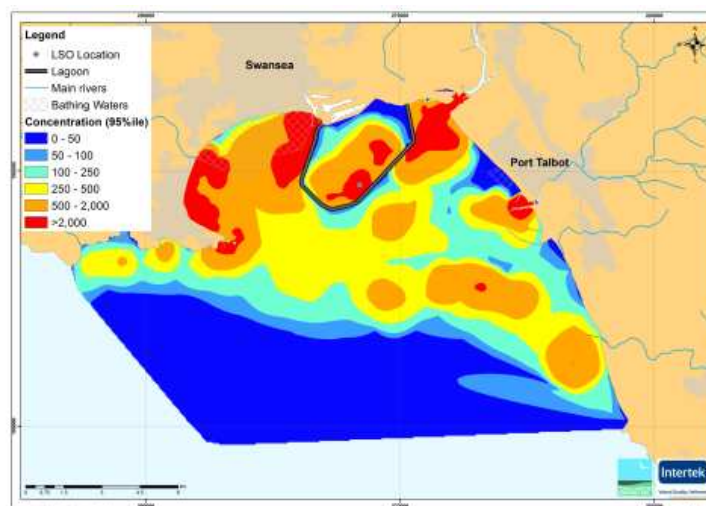
No wind

Legend

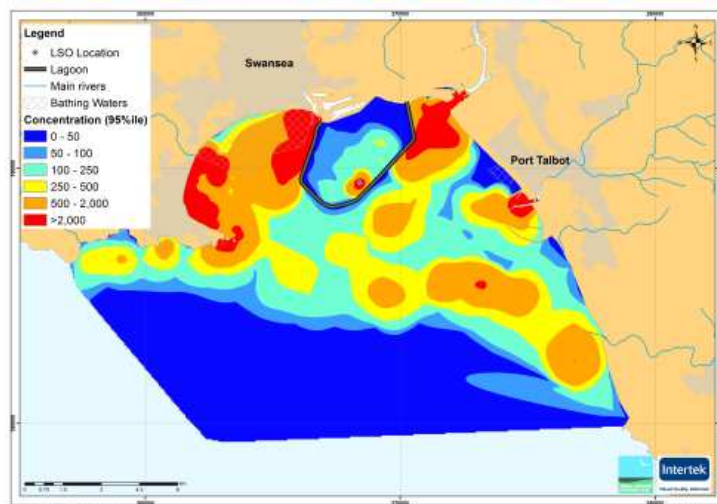
- LSO Location
- ▬ Lagoon
- Main rivers
- ▨ Bathing Waters
- Concentration (95%ile)**
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000



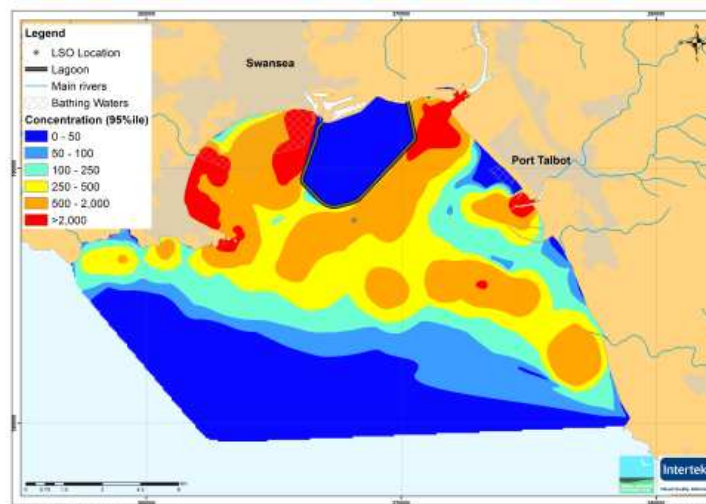
a) Baseline 95%ile



b) Lagoon 95%ile



c) UV disinfection 95%ile



d) Outfall extension 95%ile

Figure 7.11 Comparison of effects of enhancement options on microbiological water quality, wet weather 95%ile (E Coli / 100ml)

7.7.3 STORM-IMPACT applications – bathing waters

- 7.7.3.1 The sensitivity applications presented in Section 7.7.2 provide a good indication of the effects of the lagoon on plume behaviour and microbiological water quality in Swansea Bay. However, these applications only consider impacts from background loads and a single storm event under a limited set of tide and wind conditions. STORM-IMPACT provides a means of assessing impacts from all storms under a wider range of tide and wind conditions.
- 7.7.3.2 STORM-IMPACT was run for Baseline, Lagoon and optimisation scenarios to predict bacteria FIO concentrations at the two designated bathing waters: Swansea Bay and Aberafan. Runs were undertaken using a worst case four bathing season period from 2008 to 2011 for E Coli and I Enterococci FIOs.
- 7.7.3.3 Results are presented in Figures 7.12 and 7.13 as concentrations of EC and IE at the 90%ile and 95%ile levels which are used for assessing bathing water class under the rBWD. Concentration values in figures a) and b) have been removed, as final designs for AMP5 bathing water improvements have not yet been agreed between DCWW and NRW and model predictions of bathing water class are therefore subject to change. However, the results can be used to assess the relative effects of the Lagoon on FIO concentrations at the DSPs, from which impacts from the Lagoon can be estimated. Plots c) and d) present the percentage difference between the current condition and the 2015 Baseline (first bars) and between the 2015 Baseline and each of the Lagoon and optimisation options (subsequent bars). The 2015 baseline is the predicted bacterial condition when the present AMP5 improvements are complete in 2015.
- 7.7.3.4 Comparison of the current and 2015 Baseline cases predict that the proposed DCWW improvements will reduce FIO concentrations at the Swansea Bay DSP by between 20% and 40%. Analysis of the detailed STORM-IMPACT results shows that once infrastructure improvements are implemented, the major sources of FIOs are likely to be from local streams (e.g. River Clyne and Singleton Park Stream) and from the River Tawe.
- 7.7.3.5 At Aberafan DSP the largest contributors are the rivers Neath, Afan and Tawe. CSO discharges to the River Tawe, particularly from CSO989 at the mouth of the Tawe, can also impact Aberafan under some wind conditions. At Aberafan DSP proposed improvements in the sewerage catchments produce an improvement of approximately 20%, mainly as a result of reduced spill frequency at CSO989.
- 7.7.3.6 Introduction of the Lagoon produces relatively little change from the 2015 Baseline condition at Swansea DSP. A small improvement is predicted, primarily as a result of the River Tawe discharge becoming attached to the Lagoon seawall (Figure 7.9c and d).
- 7.7.3.7 More significant (20%) improvements are seen at Aberafan DSP, where the Lagoon blocks the impacts from the Tawe River and associated CSO discharges. The effects of the Neath River discharge are also slightly reduced, as the plume becomes attached to the Lagoon seawall.
- 7.7.3.8 Optimisation options considered in this chapter have only a small additional effect, as the Swansea WWTW storm discharge has very little impact at either bathing water. Extending the outfall produces a smaller improvement than UV treatment, as the storm load remains within Swansea Bay where it continues to contribute to FIO concentrations.

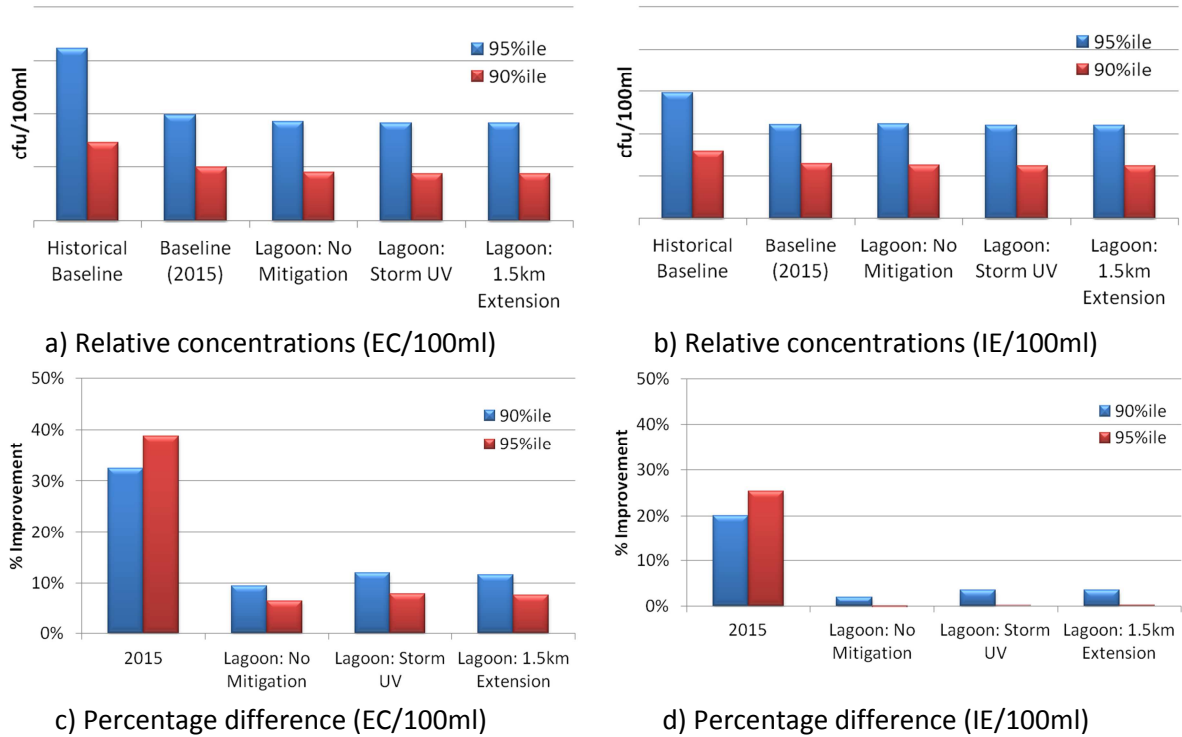


Figure 7.12 Predicted changes in 90%ile and 95%ile FIO concentrations at Swansea Bay DSP

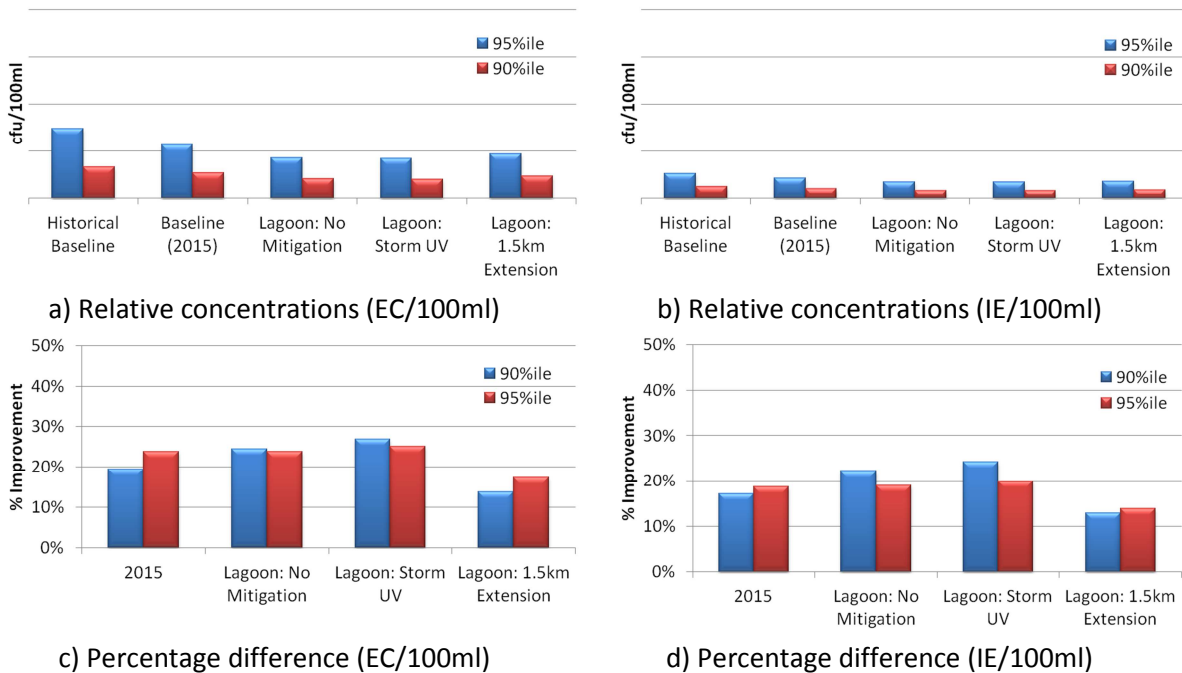


Figure 7.13 Predicted changes in 90%ile and 95%ile FIO concentrations at Aberafan Sands DSP

7.7.3.9 Impacts at Gower bathing beaches were also assessed using results for a number of locations offshore of the bathing waters at Bracelet Bay, Langland Bay, Limeslade Bay and Caswell Bay. Local discharges to these bathing waters are excluded from the assessment, and so the model results provide an indication of the relative effects of the Lagoon on Swansea Bay discharges compared to current conditions. The results indicate that the presence of the Lagoon would not cause deterioration in bathing water class at these sites, and that the combined effects of proposed DCWW improvements and the Lagoon would potentially lead to a small net improvement in bathing water quality. Optimisation options have relatively little effect on bathing water quality along the Gower coast.

7.7.4 **STORM-IMPACT applications – Lagoon waters**

7.7.4.1 The assessment of water quality within the Lagoon impoundment is based on water quality standards under the revised Bathing Waters Directive, as a recognised means of assessing risk to bathers and other water users. In common with the rBWD the assessment considers the 90%ile and 95%ile FIO concentrations over a wide range of tide and wind conditions, and under a range of discharge conditions from low flow to storm flows. While bathing water standards are generally applied to a single location (the bathing water DSP) the assessment presented here considers water quality over the entire impoundment area. This permits those areas within the Lagoon at greatest risk of poor water quality to be identified, and allows the potential to identify advisory zones for bathing activities.

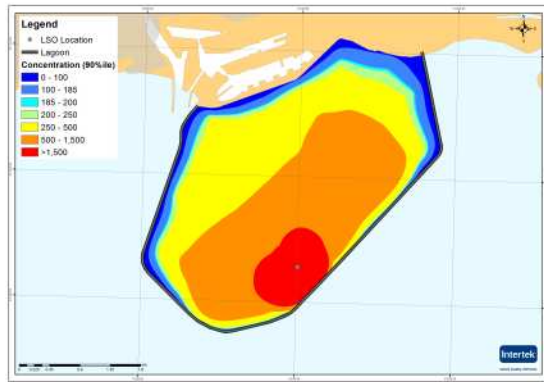
7.7.4.2 Figure 7.14 presents predicted contours of 90%ile and 95%ile E Coli concentrations over the 2008 to 2011 bathing seasons. Figure 7.15 presents results for I Enterococci. For clarity, results are presented for the Lagoon only.

7.7.4.3 For E Coli, with the Lagoon in place, and no optimisation (Figure 7.14a), the Sufficient rBWD class would be achieved over much of the Lagoon area (yellow and blue contours). Good class would be limited to the shoreline area (yellow and blue contours in Figure 7.14d). The majority of the Lagoon would not therefore be suitable for bathing activities during or after storm events. However parts of the Lagoon, along the shoreline and away from the WWTW discharge, could be used for such activities during dry weather. Figure 7.9b indicates that geomean FIO concentrations in dry weather would be below 100 EC/100ml over much of the lagoon. Figure 7.9f indicates that 95%ile concentrations could exceed 250 EC/100ml in this area during dry weather, although this is a likely worst case condition as the results represent a spring tide when the extent of the WWTW discharge plume would be at a maximum, particularly around high water.

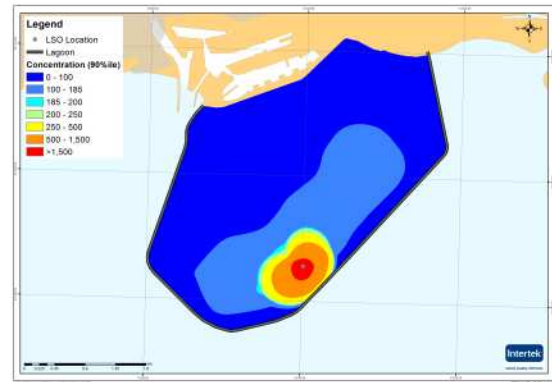
7.7.4.4 Optimisation options will have greater impact within the Lagoon, where the Swansea WWTW discharge is contained over the flood tide. UV treatment improves the overall water quality within the Lagoon and increases the area available for bathing by reducing the impacts of the storm discharge, although it would have no effect during dry weather periods. Figure 7.14b (UV disinfection) indicates that Sufficient class would be achieved throughout the lagoon, except for an area, of approximately 500m radius, around the discharge (orange and red contours). Figure 7.14e (UV disinfection) indicates that Good class would be achieved over a similar area and Excellent class (blue contour) could be achieved over a significant proportion of the lagoon: particularly in the intertidal area and close to the shoreline, where the majority of bathing activity would be expected.

Tidal Lagoon Swansea Bay plc

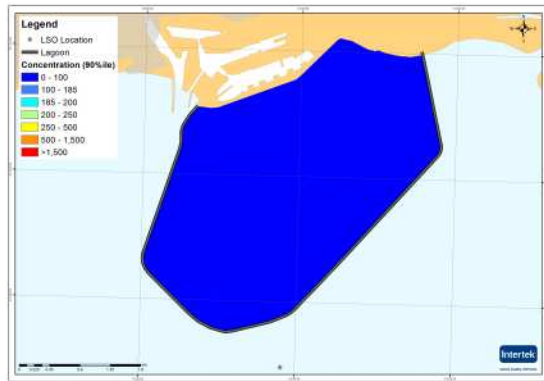
- 7.7.4.5 Outfall extension (Figure 7.14c and 7.14f) would deliver Excellent class throughout the Lagoon. While a small proportion of the discharge from the extended outfall is drawn back into the Lagoon, this effluent is well mixed with Swansea Bay water. When this is mixed with the Lagoon water, it produces 95%ile concentrations of less than 50 EC/100ml within the Lagoon.
- 7.7.4.6 A similar pattern is seen for I Enterococci. With the Lagoon in place, and no optimisation (Figure 7.15a), the Sufficient rBWD class would be achieved over much of the Lagoon area (pale blue contour, and below). Good class would be limited to the shoreline area (blue contour in Figure 7.15d). UV treatment provides Sufficient class throughout the Lagoon except for a small area around the discharge (Figure 7.15b (UV disinfection)). Good class (cyan contour Figure 7.15e (UV disinfection)) would be achieved over a similar area. Excellent class (blue contour) could be achieved over a significant proportion of the Lagoon, particularly in the intertidal and shallow areas close to the shoreline for UV disinfection. Outfall extension (Figure 7.15c and 7.15f) would deliver Excellent class throughout the Lagoon.



a) Lagoon – no optimisation (90%ile EC/100ml)

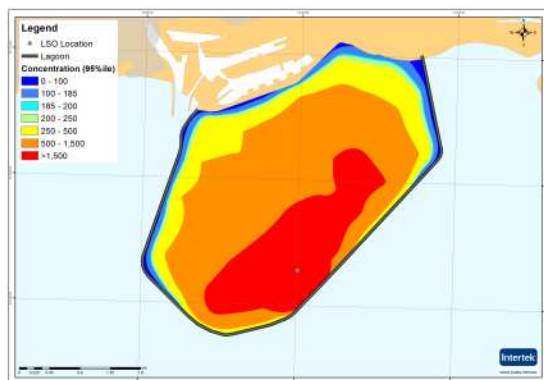
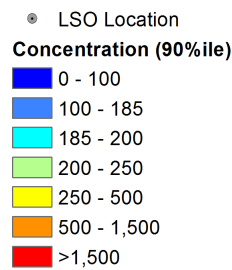


b) Lagoon – UV disinfection (90%ile EC/100ml)

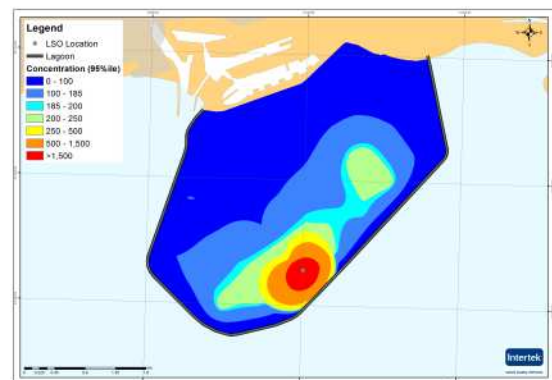


c) Lagoon – outfall extension (90%ile EC/100ml)

90%ile E Coli /100ml
Bathing Season (2008-2011)
Legend

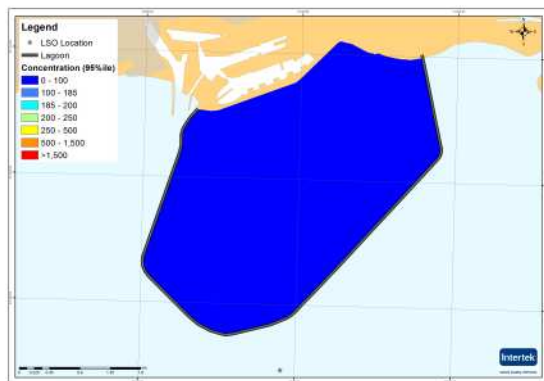
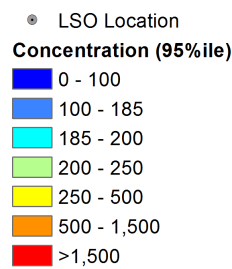


d) Lagoon – no optimisation (95%ile EC/100ml)



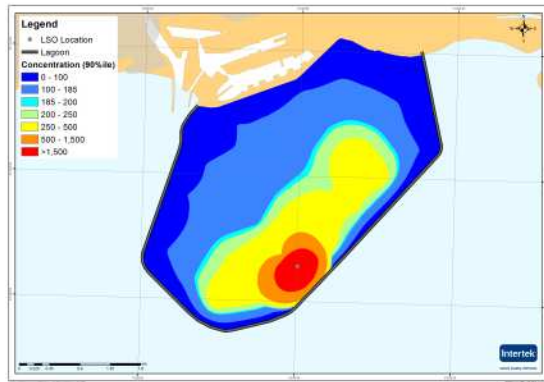
e) Lagoon – UV disinfection (95%ile EC/100ml)

95%ile E Coli /100ml
Bathing Season (2008-2011)
Legend

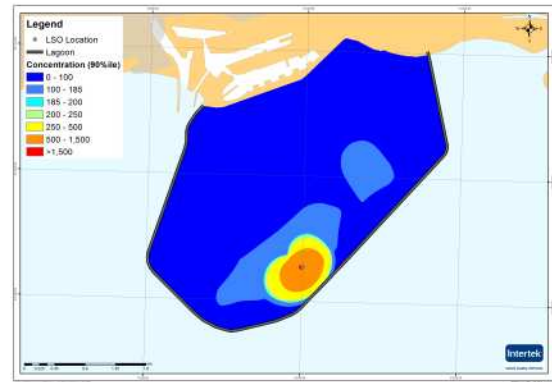


f) Lagoon – outfall extension (95%ile EC/100ml)

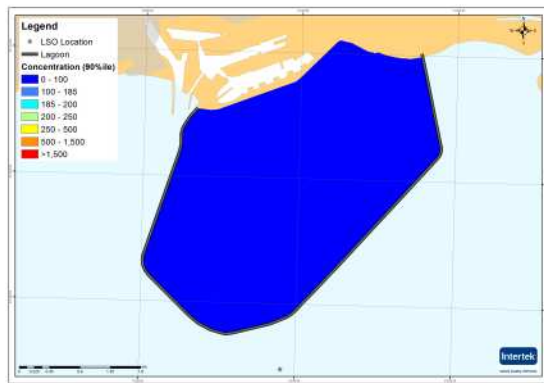
Figure 7.14 Predicted Lagoon impoundment 90%ile and 95%ile E Coli concentrations



a) Lagoon – no optimisation (90%ile IE/100ml)

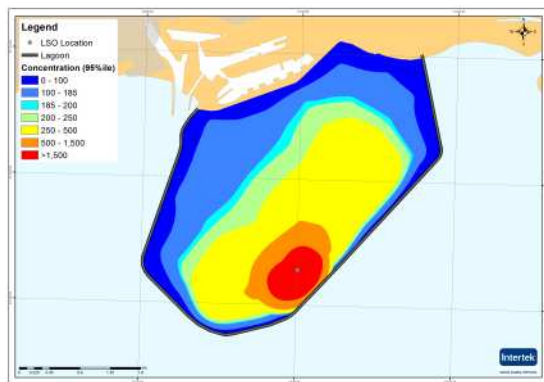
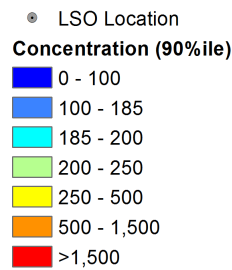


b) Lagoon – UV disinfection (90%ile IE/100ml)

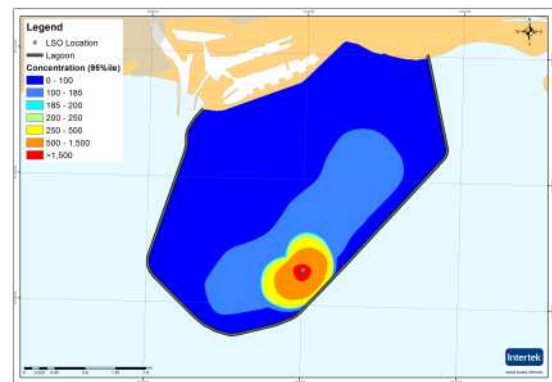


c) Lagoon – outfall extension (90%ile IE/100ml)

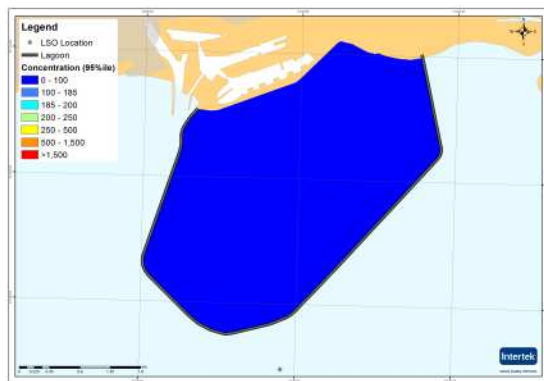
90%ile I Enterococci /100ml
Bathing Season (2008-2011)
Legend



d) Lagoon – no optimisation (95%ile IE/100ml)



e) Lagoon – UV disinfection (95%ile IE/100ml)



f) Lagoon – outfall extension (95%ile IE/100ml)

90%ile I Enterococci /100ml
Bathing Season (2008-2011)
Legend

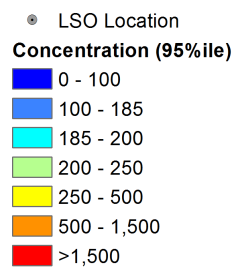


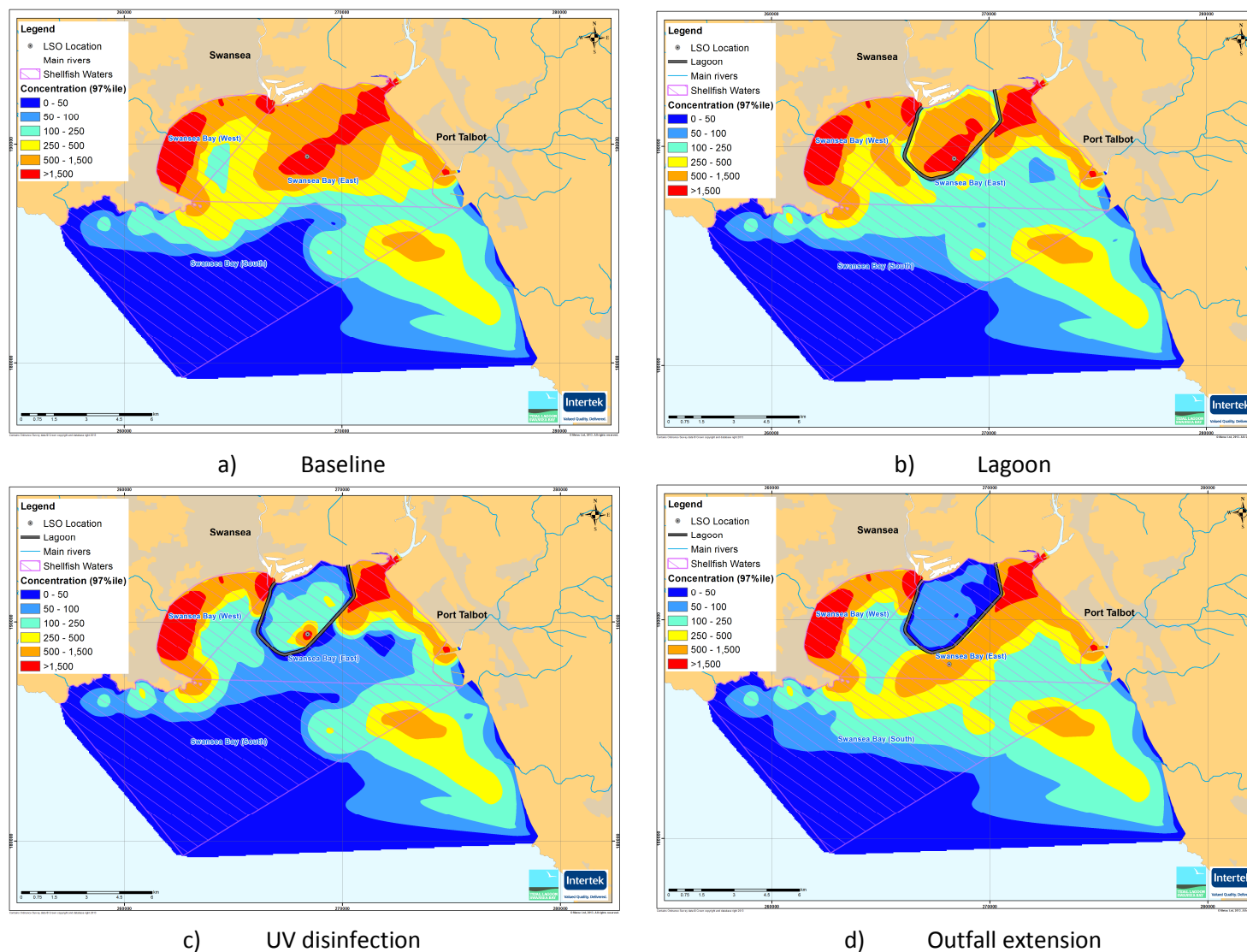
Figure 7.15 Predicted Lagoon impoundment 90%ile and 95%ile I Enterococci concentrations

- 7.7.4.7 As part of the Project it is proposed to implement an Operation Environmental Management Plan (OEMP). A key part of the plan would be a water quality management plan developed in consultation with DCWW, NRW and CCSC. The extent of the plan would depend on the optimisation option adopted, but would be expected to include:
- i. Further analysis of existing model output in consultation with CCSC. This would include a health risk assessment based on *E. coli* inside and outside the Lagoon, which would be used to refine the management plan.
 - ii. Establishment of an advisory zone around the outfall location, if the outfall remains within the Lagoon. The extent of the proposed Zone is a 500m radius from the outfall position. However this would be reviewed in consultation with CCSC and NRW.
 - iii. Establishment of bathing and swimming areas. These would be located in parts of the Lagoon least impacted by the WWTW discharge, to minimise effects on bathing and swimming activities.
 - iv. Proposed construction of a Lagoon-specific Water Quality Model to allow real time prediction of Lagoon water quality. The model would be based on output from the existing model supported by additional monitoring data. The model would be driven by WWTW discharge flow and environmental conditions, e.g. tide and wind. The model would then be operated in a similar way to the current CCSC black box model to predict water quality in real time and advise water users accordingly.
 - v. Establishment of advisory notices to inform Lagoon users of Lagoon water quality and allow them to make informed decisions. Notices would be based on model output and advise users of predicted water conditions at various locations within the impoundment. Under extreme conditions, bathing and other water activities may be prohibited.
 - vi. Proposed short term monitoring of Lagoon water quality. During the early stages of Lagoon operation FIO monitoring will be undertaken at a number of locations within the Lagoon and under a variety of discharge and environmental conditions. Sample results would be used to confirm model predictions and assist in further development and refinement of the management plan.
 - vii. Thereafter long-term FIO monitoring is proposed on a similar basis to current DSP monitoring programmes. A suitable monitoring location will be established based on modelling, short-term monitoring results and an assessment of Lagoon use.
 - viii. Development of a liaison plan by which DCWW can advise the Lagoon operators of any issues at the WWTW. Appropriate action can then be taken to advise Lagoon users of any potential reduction in water quality.
 - ix. Ongoing liaison with DCWW, NRW and CCSC to identify any long-term changes in the discharge from the WWTW and allow action to be undertaken where appropriate.

7.7.5 STORM-IMPACT applications – shellfish waters

- 7.7.5.1 STORM-IMPACT has been used to assess potential changes in shellfish water quality as a result of the Lagoon. Under current guidance a 97%ile concentration of 1500 EC/100ml in the receiving water is considered a reasonable indicator that shellfish will achieve Class B. The assessment is based on the annual 97%ile concentrations determined by STORM-IMPACT under Baseline and Lagoon scenarios. Figure 7.16 presents contours of the annual 97%ile concentrations predicted by STORM-IMPACT at approximately 300 locations within the designated Swansea Bay shellfish areas (see Figure 7.1).
- 7.7.5.2 Under Baseline conditions (Figure 7.16a) there are several areas that fail to meet the 1500 EC/100ml guideline (red contoured areas). These areas are located along the Swansea seafront, in the mouth of the Tawe Estuary and along a line extending south west from the Neath channel. These areas correspond with the plumes from the rivers and WWTW that carry high load under storm conditions. Between these areas water quality is improved by dispersion of the plumes. Only the offshore area in the Swansea Bay South shellfish water shows generally low 97%ile concentrations of E Coli.
- 7.7.5.3 The presence of the Lagoon (Figure 7.16b) has relatively little effect on the overall distribution of E Coli at the 97%ile. The high concentration seen along the line from the Neath Estuary is largely confined within the Lagoon, as the Swansea WWTW storm discharge is trapped in the impoundment during flood tides. Concentrations to the west of the Lagoon, along the Tawe channel, increase as the Tawe plume attaches to the Lagoon seawall and the WWTW discharge is effectively diverted to the Lagoon turbine discharge. South of the Lagoon, a net increase in concentration is seen in the Swansea Bay South shellfish area, again largely in response to changes in the Tawe plume and the effective discharge location of the Swansea WWTW.
- 7.7.5.4 Optimisation options lead to a general improvement in water quality, as the storm discharge from Swansea WWTW is removed or relocated. UV disinfection (Figure 7.16c) reduces E Coli concentrations within and around the Lagoon. Outfall extension has less effect, as the storm load is displaced rather than being removed. This causes a rise in E Coli concentrations south of the Lagoon, with the discharge plume from the extended outfall extending further into the Swansea Bay South shellfish area. However, improvements over the Baseline condition are seen within and around the Lagoon, particularly along the Tawe and Neath channels.

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Annual 97%ile E Coli /100ml

Legend

- LSO Location
 - Main rivers
- Concentration (97%ile)**
- 0 - 50
 - 50 - 100
 - 100 - 250
 - 250 - 500
 - 500 - 1,500
 - >1,500

Figure 7.16 Comparison of effects of optimisation options on predicted annual 97%ile microbiological water quality (E Coli / 100ml)

- 7.7.5.5 Results were also extracted from STORM-IMPACT at a number of locations within the shellfish areas. These locations correspond to existing water quality monitoring locations at Swansea Bay (East, West and South) and the shellfish beds that are currently sampled achieve Class B (Figure 7.1). As the Swansea Queens Dock bed (also Class B) is not included in the model, an additional sample point in the mouth of the Tawe, from where water to top up the dock level is abstracted, has been included.
- 7.7.5.6 Predicted annual 97%ile and geomean concentrations are presented in Table 7.24 and Table 7.25. The geomean concentration is included as a guideline concentration of 100 EC/100ml for shellfish waters is normally applied to assessing the impact of continuous discharges from WWTW (Section 7.3.5) and provides a useful indicator of general background water quality.

Table 7.24 Comparison of STORM-IMPACT predictions of annual 97%ile E Coli concentrations at shellfish monitoring sites in Swansea Bay.

Locations (see Figure 7.1)	EC Concentration (97%ile, cfu/100ml)			
	Baseline (2015)	Lagoon No Optimisation	Lagoon Storm UV	Lagoon 1.5km Extension
Swansea Bay (East)	264	185	71	385
Swansea Bay (South)	687	558	491	504
Swansea Bay (West)	3149	3295	3270	3279
Swansea Bank	342	287	93	106
Northern Beds	813	982	692	743
Tawe Mouth (adjacent to Queens Dock)	10135	10490	10488	10489

Table 7.25 Comparison of STORM-IMPACT predictions of annual geomean E Coli concentrations at shellfish monitoring sites in Swansea Bay.

Locations (see Figure 7.1)	EC Concentration (97%ile, cfu/100ml)			
	Baseline (2015)	Lagoon No Optimisation	Lagoon Storm UV	Lagoon 1.5km Extension
Swansea Bay (East)	8	14	4	31
Swansea Bay (South)	10	18	9	8
Swansea Bay (West)	21	40	20	17
Swansea Bank	10	13	5	5
Northern Beds	14	33	13	12
Tawe Mouth (adjacent to Queens Dock)	51	58	57	58

- 7.7.5.7 From Table 7.24 and Table 7.25 it can be seen that under baseline conditions the majority of sites are within the 1500 EC/100ml 97%ile and the 100 EC/100ml geomean guidelines. The Swansea Bay West and Tawe sites do not meet the 97%ile guideline, due to the high storm loads from the Tawe.
- 7.7.5.8 The effects of the Lagoon depend upon the sampling point location; concentrations are slightly higher at some sites, and slightly lower at others. Differences are typically small, in the order of 5% to 15%. UV disinfection generally reduces predicted concentrations at

the selected sites, while outfall extension leads to an increase or no net change. This is because the UV option reduces the storm load from the WWTW, while outfall extension redistributes the load.

- 7.7.5.9 The area of least change is in the mouth of the Tawe. Following construction of the Lagoon an increase in the 97%ile and geomean concentrations is observed, which is largely unaffected by optimisation options. The main source of bacteria at the mouth of the Tawe is the diffuse pollutants and CSO loads in the river, which are not related to the Project. Construction of the Lagoon reduces dispersion at the mouth of the river, as the plume becomes attached to the Lagoon seawall and dispersion to the west is reduced and to the east is prevented.
- 7.7.5.10 The area at the mouth of the Tawe provides water for the Queens Dock, which is a designated shellfish bed. Changes in water quality at the mouth of the Tawe could influence water quality in the dock and shellfish quality. The increase in concentration is due to the seawalls of the Lagoon restricting easterly dispersion of the Tawe River plume, when compared to the baseline.
- 7.7.5.11 However, the changes in the lower Tawe are relatively small, and would be limited in upstream extent due to the presence of the tidal barrage. The geomean increases by around 7 EC/100ml, but remains below the 100 EC/100ml guideline. The 97%ile increases by 355 EC/100ml, or 3.5%, and remains significantly above the 1500 EC/100ml guideline. Given that the higher concentrations under present storm event conditions do not appear to affect shellfish quality adversely, a small increase in 97%ile concentration in the Tawe would not be expected to adversely impact the water quality of the dock.
- 7.7.5.12 As part of the Lagoon development it is proposed to include mariculture, including shellfish beds, within the Lagoon impoundment. The feasibility of shellfish beds within the Lagoon will depend upon the water quality in the Lagoon and the proposed purpose of the shellfish produced, e.g. for human consumption or for repopulating local shellfish stocks.
- 7.7.5.13 Without optimisation measures it is unlikely that a viable commercial shellfishery could be established. Comparison of Figure 7.16a and 7.16b shows that at the 97%ile concentration water quality would be similar to Baseline conditions. The Lagoon occupies part of the current Crymlyn shellfish water, which is no longer classified, but previously only achieved a classification of class C (Table 7.18). Shellfish from the Lagoon would therefore need to be relayed before they could be used for human consumption, although this may not preclude the use of the Lagoon for restocking Swansea Bay with native species, e.g. oyster.
- 7.7.5.14 Optimisation options would permit some areas of the Lagoon to be used for commercial shellfish beds, as the options would provide an improvement in water quality within the lagoon area when compared to Baseline conditions. From Figure 7.16d it can be seen that outfall extension would provide 97%ile concentrations below the present guideline geomean water quality standard of 100 fc/100ml (Section 7.3.5). This would suggest the potential for shellfish production throughout the lagoon impoundment, with shellfish achieving Class B. However, it should be noted that water quality modelling or measurement only provides an indication of the quality of shellfish, shellfish quality can only be determined from direct analysis of shellfish flesh.

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- 7.7.5.15 UV disinfection would reduce the peak (97%ile) FIO concentrations in the impoundment to below the guideline (1500 fc/100ml) standard over much of the lagoon area (Figure 7.16c). However it is unlikely that the geomean standard could be achieved within a radius of 750 m of the WWTW outfall (Figure 7.10c). The northern and eastern parts of the Lagoon impoundment, close to the Lagoon walls and shoreline would potentially provide sites for shellfish beds from a water quality perspective. However these areas are largely intertidal or close to the turbines, which may restrict the available area for production. As stated above the current guideline concentrations only provide a guide to likely shellfish flesh quality. Actual quality may be dictated by other factors such as species and the frequency and duration of exposure to high FIO concentrations. Given these considerations it is considered unlikely that shellfish grown in the Lagoon would consistently achieve Class B and would most likely be limited to Class C. Shellfish from the Lagoon would therefore need to be relayed before they could be used for human consumption, although use of shellfish from the lagoon for restocking may still be viable.
- 7.7.5.16 As discussed in Section 7.7.3 an emergency at the WWTW, blockage of the outfall or failure of the UV disinfection plant, would cause water quality within the Lagoon to be reduced due to discharges of untreated effluent. The level of reduction would not be expected to be significantly different to that which might occur under similar conditions at present. However, where applicable, the proposed Water Quality Strategy would include provision for potential impacts on mariculture within the Lagoon. These would depend on the end use of any shellfish cultivated within the Lagoon. As a minimum shellfish collection or harvesting would be halted until water quality in the Lagoon had returned to normal for a sufficient period.

7.7.6 Summary of impacts for microbiological determinands

- 7.7.6.1 By combining the results of the sensitivity applications and STORM-IMPACT applications for bacteria FIOs it can be seen that:
1. background (dry weather) FIO concentrations in Swansea Bay are typically below 50 cfu/100ml;
 2. during rainfall storm water discharges from land drainage, the sewer network and from rivers and streams can increase background FIO concentrations by a factor of 100 or more;
 3. current and proposed infrastructure improvements planned by DCWW are expected to lead to a 20%-40% improvement in bathing water quality at Swansea by the time that the Project becomes operational;
 4. the presence of the Lagoon changes the hydrodynamics of the central area of Swansea Bay. The Tawe and Neath river plumes become attached to the Lagoon seawalls and exchange with offshore waters, between the turbines and Mumbles Head, is increased. These factors modify local dispersion and reduce FIO concentrations along the Swansea shoreline, with a consequent improvement in water quality, particularly at the Swansea and Aberafan DSPs;
 5. during wet weather the extended trajectory of the river plumes, combined with changes in currents between the turbines and Mumbles Head causes an increase in FIO concentrations in the offshore area, particularly in the region immediately south of Swansea Bay, i.e. south of a line from Mumbles Head to Port Talbot;

6. changes in flow around Mumbles Head lead to a slight increases in predicted FIO concentrations along the Gower coast. However, this would not be expected to affect bathing water quality along the Gower coast;
7. trapping of the Swansea WWTW discharge in the Lagoon improves water quality in the area to the east and west of the Lagoon, but has little overall effect on water quality at bathing waters;
8. within the Lagoon, water quality is broadly similar to Baseline conditions, with some improvement under south westerly wind conditions. Parts of the Lagoon would meet rBWD Sufficient class, but large areas would be unsuitable for bathing activities during storm events;
9. during dry weather FIO concentrations would be low enough to meet the Good or Excellent thresholds of the rBWD, except within a radius of approximately 750m of the discharge, where higher concentrations would occur;
10. optimisation options help reduce the impact of the storm water discharge from the outfall on the receiving waters of the Lagoon and Swansea Bay;
11. UV disinfection would reduce the storm load from the WWTW, leading to improved water quality in Swansea Bay and Good or Excellent rBWD class over most of the Lagoon;
12. outfall extension would provide Excellent rBWD class in the whole of the Lagoon, but would cause an increase in FIO concentrations in the southern part of Swansea Bay, as the discharge is displaced to the south;
13. overall, the presence of the Lagoon is not expected to have a detrimental impact on the bathing waters or shellfish waters within Swansea Bay; and
14. with optimisation measures in place, the impact of the Lagoon would be potentially beneficial to microbiological water quality in Swansea Bay, although improvements would generally be small.

7.7.7 WFD sensitivity applications

- 7.7.7.1 This section presents a summary of the results of the WFD sensitivity applications undertaken to assess the impacts of the Lagoon on distribution of temperature, salinity, nutrients (nitrogen) and dissolved oxygen in Swansea Bay. Results are presented for Baseline and Lagoon scenarios to allow a comparative assessment of changes in water quality following commissioning of the Project.
- 7.7.7.2 Results are also compared with relevant WFD UKTAG standards to provide a context for assessing existing water quality and the effects of the Lagoon. However, it should be noted that as the model applications have been developed to provide relative assessments of change using a conservative precautionary approach, the model predictions cannot provide a full assessment against WFD class, particularly around class boundaries.
- 7.7.7.3 Tables 7.3 to 7.5 (Section 7.3.2) present the relevant UKTAG standards for coastal and transitional waters for temperature, nitrogen and dissolved oxygen.
- 7.7.7.4 It is noted that under the provisions of the WFD it is necessary to ensure a development does not "*exclude or compromise the achievement of the objectives of the Directive in other bodies of water within the same river basin district*". The model includes Swansea Bay and the tidal (transitional) waters of the rivers Tawe, Neath and Afan, and therefore

allows an assessment of the impacts on both Swansea Bay and the adjacent transitional waters. Impacts on the water quality of upstream fresh water bodies are not considered, as the effects of the Project would not be able to propagate into these waters, as they are separated by the physical obstruction of weirs at the tidal limits. The Tawe Barrage presents a partial obstruction to tidal ingress, but may be overtopped during Spring tides. Nevertheless, for assessment purposes, the transitional water is assumed to extend upstream of the Tawe Barrage to the historical tidal limit, where further upstream propagation is prevented by the weir at Trewyddfa.

7.7.7.5 Temperature: The Lagoon will affect water temperature in two ways. Heat generated by the turbines could cause local increases in water temperature. The effects of the Lagoon structure on hydrodynamics may lead to areas of higher or lower temperature, particularly where the dispersion of thermal plumes (e.g. the Baglan Bay power station discharge) is affected.

7.7.7.6 Within the turbine housing, heat loss from the generators will be discharged into the water via a heat exchange jacket on the draft tube liner (see picture in Figure 7.17). The mean heat loss is conservatively estimated as approximately 40 GJoules per tidal cycle. Assuming an average flow discharge of $1 \times 10^8 \text{ m}^3$ across the turbines per tidal cycle, and a specific heat capacity for water of approximately $4.2 \times 10^6 \text{ J/m}^3 \text{ }^\circ\text{C}$, this gives a potential rise in temperature of less than 1 ten thousandth of a degree, which is not considered significant.

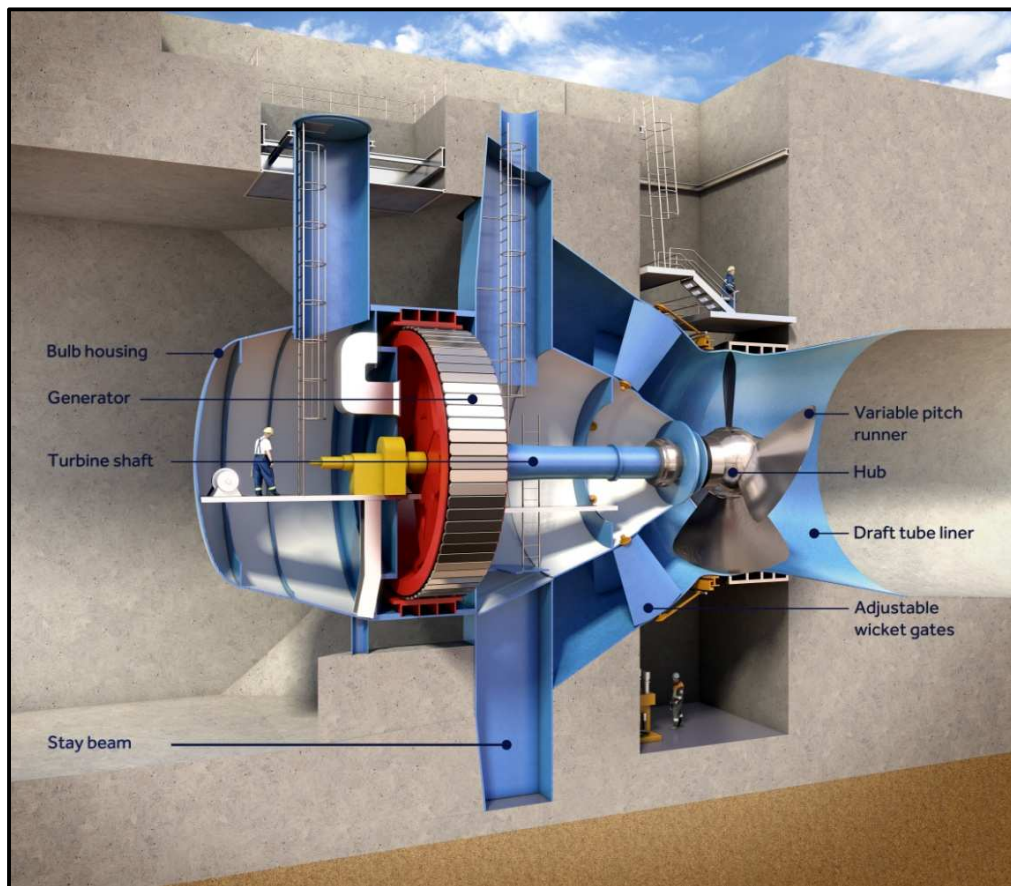
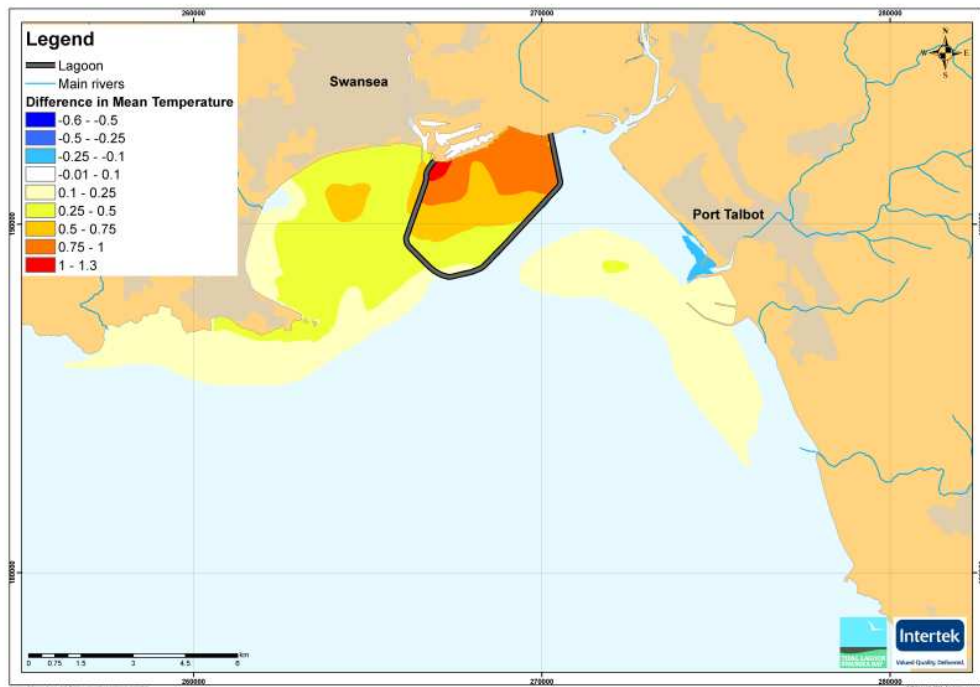


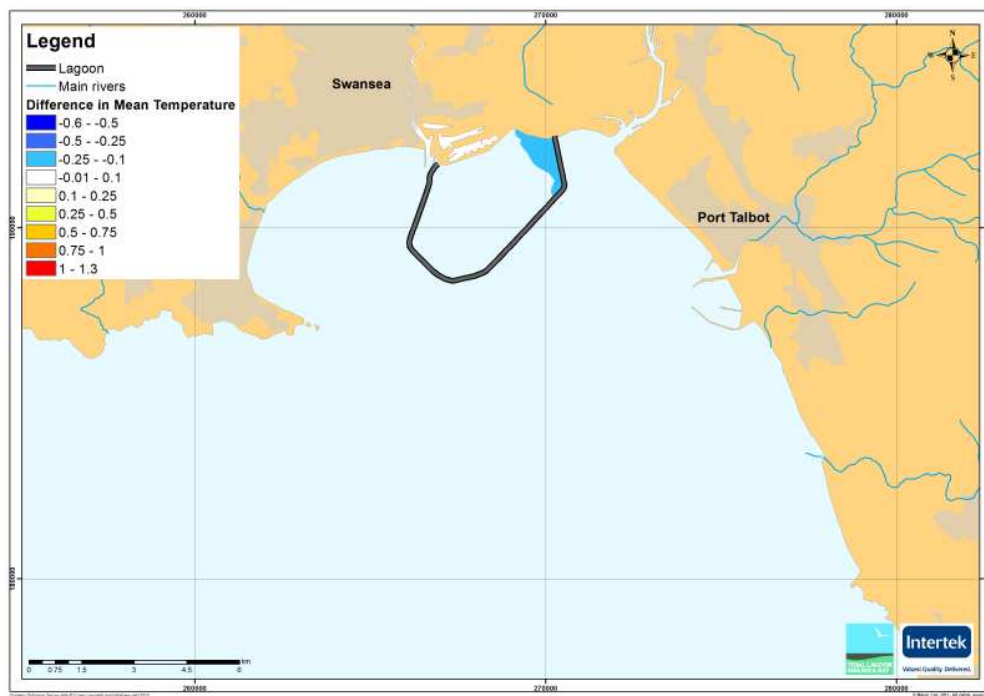
Figure 7.17 Illustrative cross section of a bi-directional bulb fixed speed turbine

- 7.7.7.7 Figures 7.18a to 7.18d present results of the sensitivity applications to assess the effects of the Lagoon seawalls on temperature in Swansea Bay. Results are presented for two cases, which represent the likely range of temperatures that would be experienced over a typical year:
- winter:** the difference between the mean temperature in each model cell of the Baseline and Lagoon cases. This provides an indication of the relative effects of the Lagoon on the mean temperature over three months of river and wastewater discharge conditions; and
 - summer:** the difference between the mean and the maximum temperatures in each model cell of the Baseline and Lagoon cases. This provides an indication of the relative effects of the Lagoon on mean and maximum temperatures, under conditions of continuous dry weather discharges.
- 7.7.7.8 Figures 7.18a and 7.18b show the difference in mean temperature between Baseline and Lagoon cases for the winter and summer, respectively. Summer temperatures (Figure 7.18b) are largely unaffected by the presence of the Lagoon, as difference between river and sea water temperatures is reduced compared to the winter condition.
- 7.7.7.9 In winter (Figure 7.18a), the Lagoon causes a marginal increase in temperature in response to two main drivers. Firstly, the lower temperature water from the River Tawe becomes attached to the Lagoon seawall and is partially prevented from dispersing into the western part of the Bay. At the same time the flow into the Lagoon on the flood tide causes warmer water from offshore to enter the Lagoon and the western side of Swansea Bay. A temperature increase of between 0.1°C and 0.75°C is predicted.
- 7.7.7.10 The warmer offshore water also causes temperature within the Lagoon to increase by 0.5°C to 1°C in winter. The water held in the Lagoon is subject to less cooling from river waters. When discharged, this warmer Lagoon water is predicted to contribute to a temperature increase of 0.25°C along the Gower coast and toward the Afan coast.
- 7.7.7.11 Temperature changes around the Neath Estuary are low, with a small temperature decrease of less than 0.1°C. The plume from the Neath is prevented from moving west by the Lagoon, and so the cooler river water is therefore displaced along the Afan coast. This causes a slight temperature decrease along the Afan coastline and Lagoon seawall, with a maximum difference of <0.25°C at the mouth of the River Afan.
- 7.7.7.12 Figures 7.19a and 7.19b show the maximum summer temperature over the model period for Baseline and Lagoon cases. Figures 7.19c and 7.19d present these same maximum plots focussed to show detail around Baglan Bay power station. These model predictions show that a maximum temperature of around 15.5 °C for both the Baseline and Lagoon cases. The detailed plots around Baglan Bay power station (Figures 7.19 and 7.19d) indicate that the presence of the Lagoon is not predicted to impact thermal dispersion around the power station.

The effects of the Lagoon on temperature in Swansea Bay are low, typically less than 0.5°C in winter. Temperature in the Lagoon may increase by 1°C relative to Baseline temperature. However, no temperature hot spots, which might affect shellfish waters or form a barrier to fish migration, for example, are predicted. Overall, these changes are not considered significant, as they are within normally expected year-on-year variability.



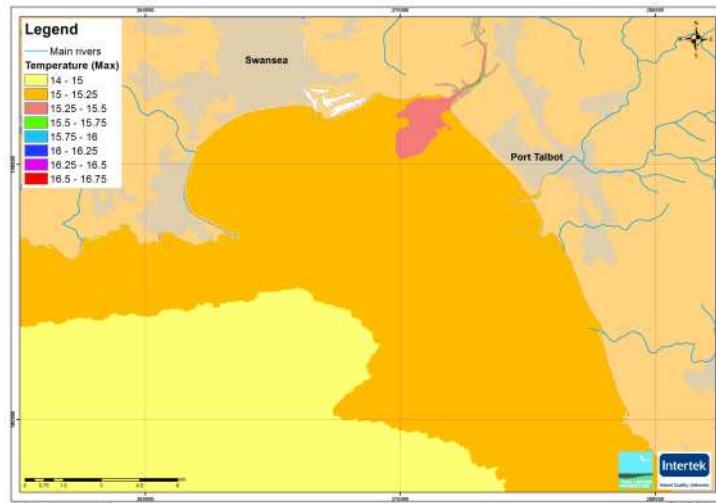
a) Winter average



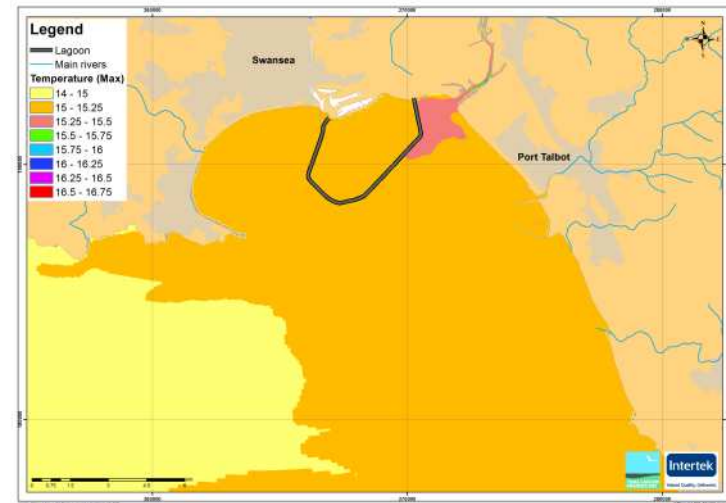
b) Summer average

Figure 7.18 Difference in Baseline and Lagoon operation temperatures (°C).

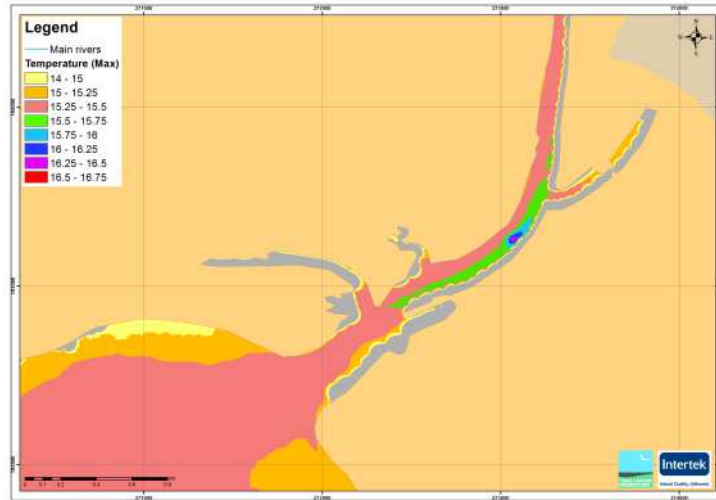
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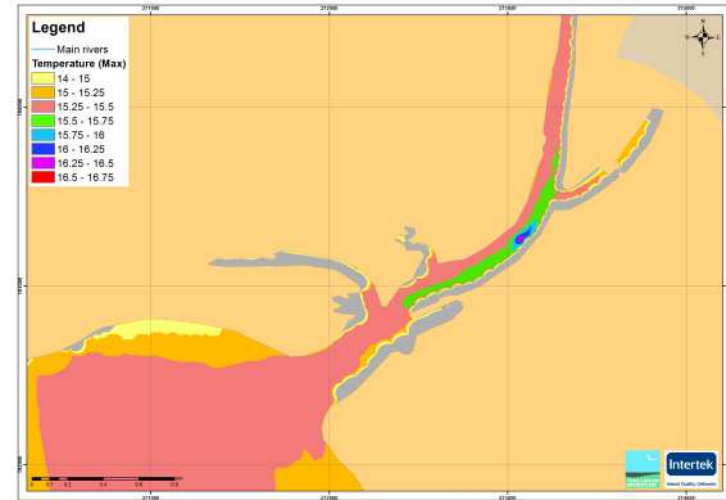
a) Baseline



b) Lagoon



c) Baseline – Neath Estuary detail



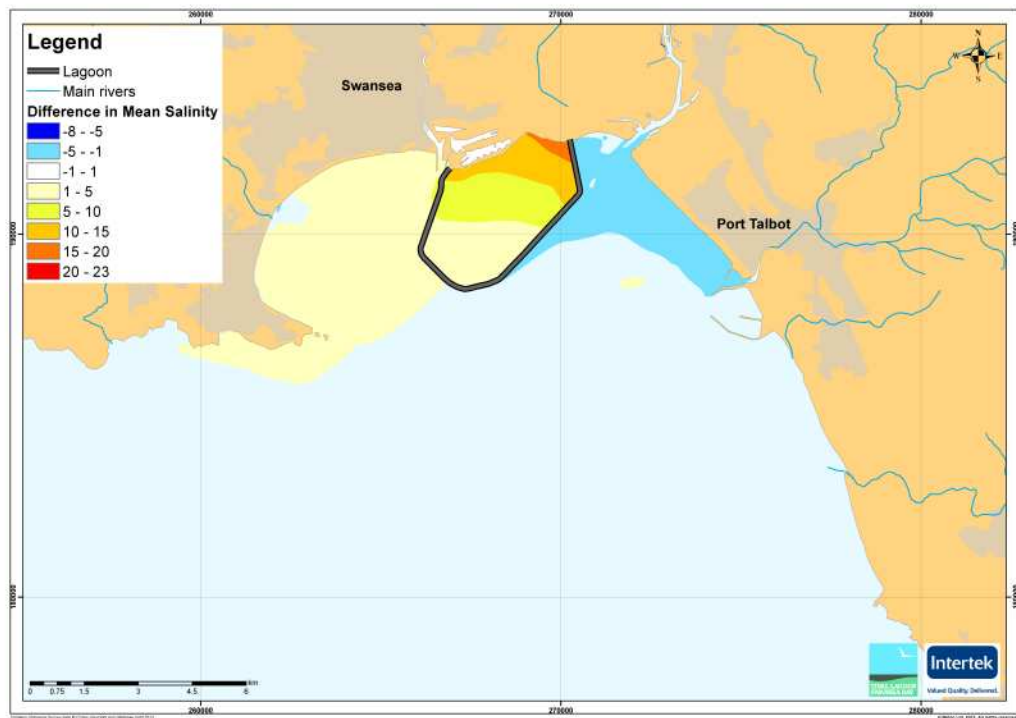
d) Lagoon – Neath Estuary detail

Figure 7.19 Comparison of Baseline and Lagoon operation on maximum summer temperature (°C).

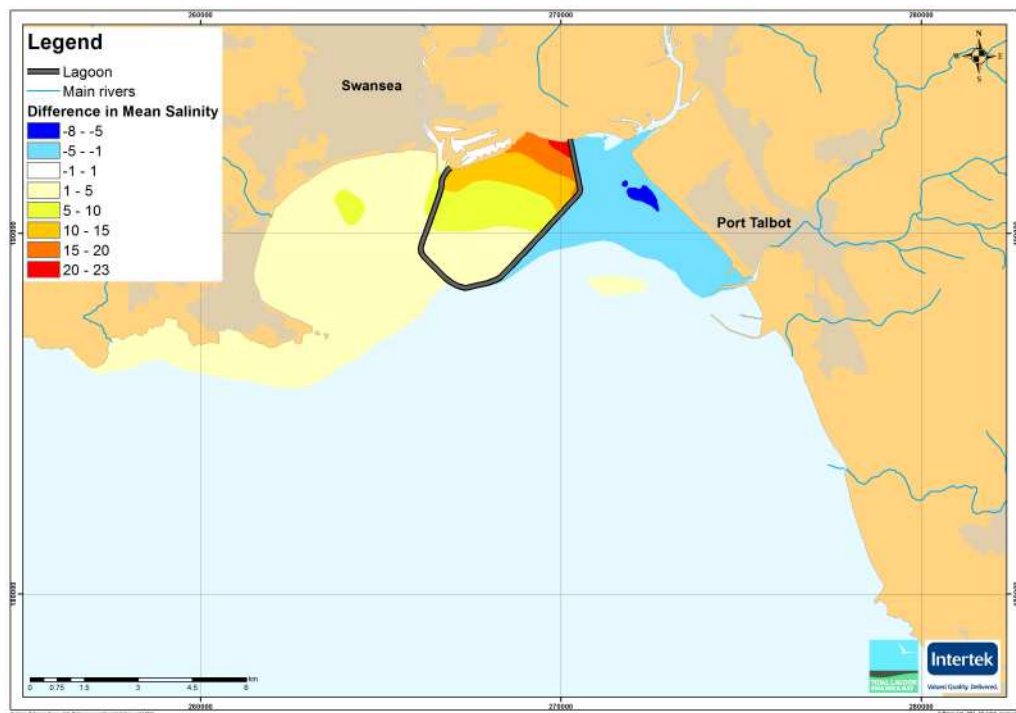
- 7.7.7.13 Salinity:** Figures 7.20a and 7.20b present results of the salinity sensitivity applications under the summer and winter cases, as applied for temperature. The plots show the difference in mean salinity between the Baseline and Lagoon case.
- 7.7.7.14** Results show a similar pattern for both the summer and winter scenarios. In the western Bay, between the Swansea shoreline and a line between Mumbles Head and the Lagoon turbine and sluice gate housing structure, a net increase in mean salinity is predicted. This is due to two main factors: firstly, the Tawe River plume becomes attached to the Lagoon seawall, partially drawing it away from the western part of Swansea Bay; secondly, the flow of offshore waters through the turbines and into the Lagoon, draws higher salinity water into the western part of Swansea Bay. The subsequent release of Lagoon water also helps elevate salinity in the western part of the Bay. With the relative change in the mass of river and offshore waters entering the western part of the Bay, the mean salinity along the Swansea shoreline is increased by 1 psu to 5 psu.
- 7.7.7.15** On the eastern side of the Lagoon, a reduction in salinity is seen. The west Lagoon wall blocks the easterly movement of water from the River Tawe and western part of Swansea Bay on the flood tide. Conversely, on the ebb tide the east Lagoon wall prevents the westerly flow of the Neath Estuary discharge and displaces the Neath plume to the south. These effects combine leading to a 1 psu to 5 psu decrease in salinity around the mouth of the Neath Estuary and along the Afan shoreline.
- 7.7.7.16** Salinity within the Lagoon is increased by the largest amount, as the area is cut off from the low salinity discharges from the Neath and Tawe estuaries. The Lagoon is filled by more saline offshore water passing through the turbines. Increases in average salinity of up to 20 psu are predicted in winter. In summer, an increase of up to 23 psu is predicted in the north east corner of the Lagoon. The greatest change is restricted to the shallow areas most influenced by the river discharges. The level of change decreases offshore to between 1 psu and 5 psu.
- 7.7.7.17** These effects can be seen more clearly in Figure 7.21, which shows salinity during the high water (HW) and low water (LW) periods in the winter under high river flow conditions, when freshwater inputs are greatest. Figure 7.21a (Baseline LW) shows the LW period, when river discharges lower local salinity along the shoreline. The river discharges from the Tawe and Clyne lower salinities to between 15 psu and 20 psu in the western bay. Salinity increases in the offshore direction reaching 25 psu in the central Bay and over 30 psu further offshore, i.e. outside of Swansea Bay. At HW (Figure 7.21b Baseline HW) the influx of offshore water increases salinity in the Bay to over 25 psu, reducing the area of low salinity (<20 psu) to a narrower strip along the shoreline.
- 7.7.7.18** At low water (Figure 7.21c) the salinity along the Swansea shoreline is slightly reduced with the Lagoon in place, to around 10 psu. This occurs as the Tawe discharge is displaced by the Lagoon at LW. At HW (Figure 7.21d (with Lagoon)) the increased intrusion of saline offshore water can clearly be seen in the western Bay. Minimum salinity is increased from 15 psu to 20 psu along the shoreline.
- 7.7.7.19** In the Lagoon, the salinity remains relatively stable, at 25 psu to 30 psu, compared with a Baseline of 15 psu to 30 psu. The greatest variation is seen in the shallower water.
- 7.7.7.20** Overall, the Lagoon would cause a change in salinity of between 1 psu and 5 psu over the shallower areas of the Bay, with slightly greater change in the shallowest areas. These changes are mainly due to changes in minimum salinity as the river plumes are displaced

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and offshore water enters the western Bay. The changes in mean salinity should be seen within the context of the naturally high variability of salinity in the bay, particularly in the very dynamic intertidal and near shore area where the rivers most strongly influence salinity. Given the naturally high variability in salinity within the Bay it is considered that the predicted change is within the natural variation and should therefore have no effect.

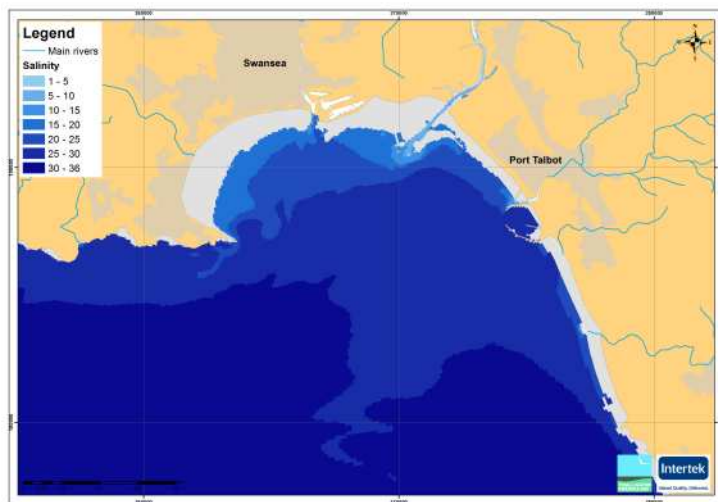


a) Winter

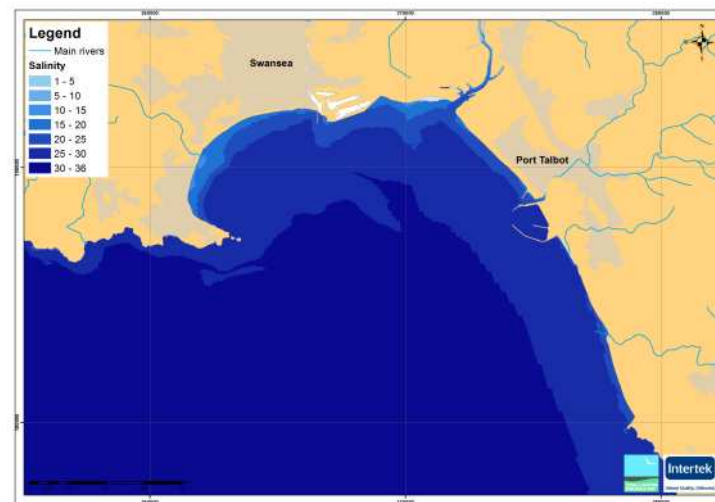


b) Summer

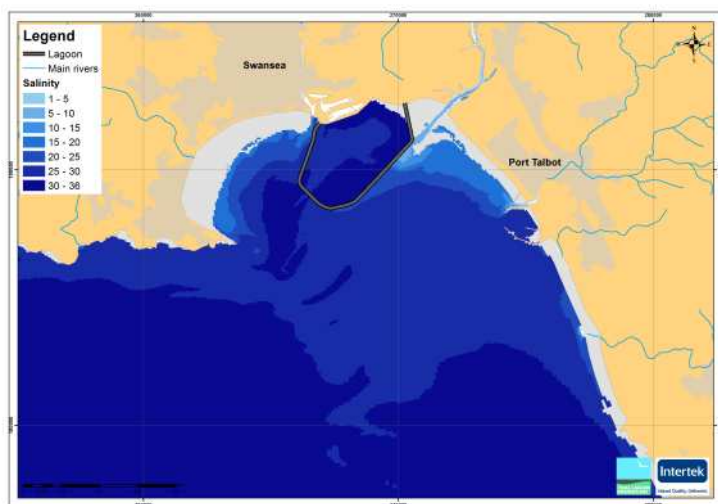
Figure 7.20 Difference in mean salinity between Baseline and Lagoon (psu).



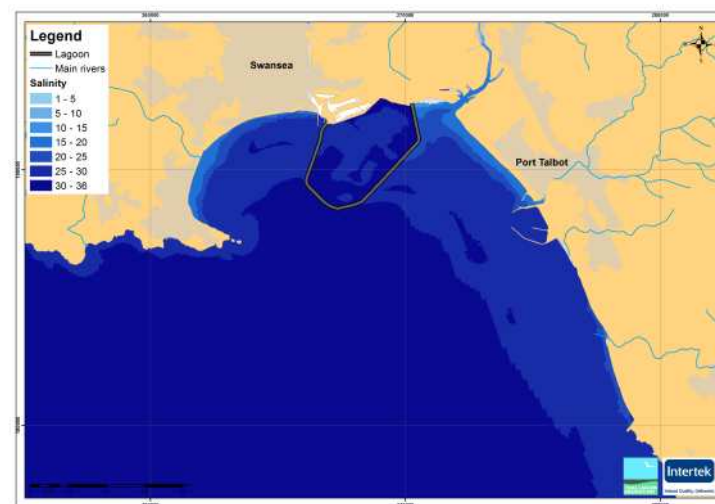
a) Baseline – winter LW spring tide



b) Baseline – winter HW spring tide



c) Lagoon – winter LW spring tide



d) Lagoon – winter HW spring tide

Figure 7.21 Comparison of Baseline and Lagoon on winter salinity (psu).

- 7.7.7.21 **Nutrients:** Figure 7.22 presents results of the nutrient (nitrogen) sensitivity applications. In order to be consistent with UKTAG standards, results are presented for the mean concentration of soluble nitrogen (DAIN) during the winter for a) Baseline conditions, b) with the Lagoon in place and c) with the Lagoon in place and the Swansea WWTW outfall extended by 1.5km. Figure 7.23 presents the difference in average nitrogen concentrations between the Baseline and the Lagoon scenarios presented in Figure 7.22.
- 7.7.7.22 Results are compared with UKTAG standards (Table 7.4) to provide an indication of current class and potential changes following construction of the Lagoon. However, it should be noted that the UKTAG classes are dependent upon salinity, particularly in transitional waters, and the boundary between classes is difficult to define in areas with a large salinity variability. Furthermore, the model results for nitrogen can only provide an indication of relative changes as:
- the model takes a conservative approach to modelling of nitrogen, with no sink terms applied;
 - the model inputs are based on a limited dataset; and
 - there is currently insufficient data with which to verify the model for nitrogen.
- 7.7.7.23 The model results therefore provide a means of assessing relative changes after the Lagoon has been constructed, but cannot provide results sufficient to fully determine changes in class against the WFD.
- 7.7.7.24 From Figure 7.22a, it can be seen that under the Baseline scenario, concentrations of DAIN in Swansea Bay are predicted to be greater than 250 µg/l, indicating Moderate WFD class in the Swansea Bay water body. In the offshore area outside the Bay WFD water body concentrations are below 250 µg/l, i.e. potentially Good class. This is consistent with the observed WIMS sample data (mean, Table 7.13) and the present Moderate classification for the Swansea Bay WFD water body (Table 7.10).
- 7.7.7.25 In the transitional waters of the Neath and Tawe Rivers concentrations are predicted in excess of 500 µg/l, again indicating Moderate class, with possible risk of Poor class under UKTAG where concentrations exceed 750 mg/l. The lower class in the transitional waters and the Bay is due to the nutrient loads from the main rivers, particularly the rivers Tawe, Neath and Afan. This can clearly be seen in Figure 7.22a as there are high concentrations (> 750 µg/l) in parts of the estuaries and high concentrations (>500 µg/l) extending into the shallow waters around the estuary mouths and along the Swansea shoreline. Concentrations along the shoreline in excess of 500 µg/l indicate possible Poor class in inshore waters.
- 7.7.7.26 With the Lagoon in place (Figure 7.22b and 7.23a) the nutrient concentrations along the Swansea shoreline are reduced by up to 300 µg/l. This is in response to the Tawe River plume attaching to the Lagoon seawall, which would partially divert the plume from the coastline, and also to offshore waters drawn into the Lagoon on the flood tide. The offshore waters contain less nitrogen and therefore partly dilute the concentrations in the western part of Swansea Bay.
- 7.7.7.27 In the mouth of the Tawe, the discharge is prevented from moving east along the coastline, which leads to a local increase in nitrogen concentrations of up to 300 µg/l along the navigational channel and into the mouth of the Tawe Estuary.

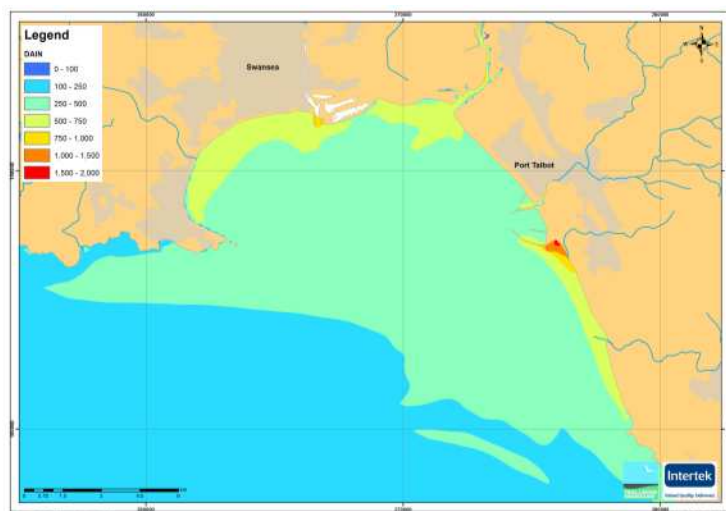
- 7.7.7.28 The presence of the Lagoon wall blocks westerly transport of waters from the River Neath. This causes a change in the distribution of nutrient concentrations in the shallow area of sand banks between the Lagoon and the Afan coastline and the lower Neath Estuary. In the shallow area, concentration increases of between 100 µg/l and 300 µg/l are predicted. This is largely a redistribution of nutrients caused by the Lagoon seawalls and is balanced by an equivalent decrease in nutrient concentrations within the Lagoon (Figure 7.23a). In the Neath Estuary, an increase in nutrient concentrations of between 10 µg/l and 100 µg/l is predicted.
- 7.7.7.29 The predicted increase in nitrogen concentrations around the Tawe and Neath estuaries is considered conservative, due to the precautionary approach taken in the modelling. The nitrogen loads are conservatively estimated, nitrogen sinks (e.g. atmospheric losses and uptake by plants and algae) are not included and the river discharges are based on mean flows, and do not account for potential flushing during high river flow conditions. The effects of conservatism in the model will be most apparent in and around the river estuaries, as these are close to the main nitrogen sources from the rivers.
- 7.7.7.30 An analysis of available nutrient sample data in the Tawe and Neath estuaries, derived from the NRW WIMS database, was undertaken and compared with model results. The data covers a period from 1990 to 2005. Data from the Tawe Estuary indicates relatively high mean annual nitrogen concentrations of 300 µg/l to 600 µg/l (Moderate class for transitional water under WFD). These concentrations are broadly consistent with model predictions (Figure 7.22), although indicate the model may overestimate nitrogen concentrations by a factor of two. Data from the Neath Estuary indicates mean annual concentrations of approximately 250 µg/l (Good class), and suggests the model may overestimate nitrogen concentrations by a factor of two to four. Given the conservatism in the model the increase in nitrogen concentrations around the estuaries will be similarly conservative.
- 7.7.7.31 While an increase in nutrient concentrations of between 10 µg/l to 300 µg/l is predicted in the transitional waters in and around the Neath and Tawe estuaries (Figure 7.23) this is considered an overestimate. In relative terms, comparing Figure 7.22 and 7.23, the predicted increase in concentrations is typically between 5% and 20% of the predicted Baseline concentration, applying this figure to the measured annual average concentration suggests an increase of 15 µg/l to 120 µg/l in the Tawe transitional waters and 10 µg/l to 50 µg/l around the Neath. Similarly, scaling the predicted increase in nitrogen concentrations by the estimated conservatism in the model (two to four times) the increase presented in Figure 7.23, would be between 10 µg/l and 100 µg/l in the Tawe area and between 10 µg/l and 75 µg/l around the Neath. This lower level of increase would not be expected to affect the WFD class of these waters.
- 7.7.7.32 Over the rest of the Bay, the Afan Estuary and the waters to the south, the redistribution of nitrogen caused by the Lagoon leads to a predicted reduction (positive benefit) in nitrogen concentrations of up to 100 µg/l. Actual reductions would be expected to be slightly lower given the conservatism in the model, although comparison with offshore WIMS sample data suggests the conservatism in the model reduces with distance offshore.
- 7.7.7.33 Figures 7.22c and 7.23b indicate that extending the WWTW outfall causes further changes in offshore nitrogen concentrations. Moving the discharge displaces the nitrogen load from the WWTW into deeper, more dynamic waters, with greater available

Tidal Lagoon Swansea Bay plc

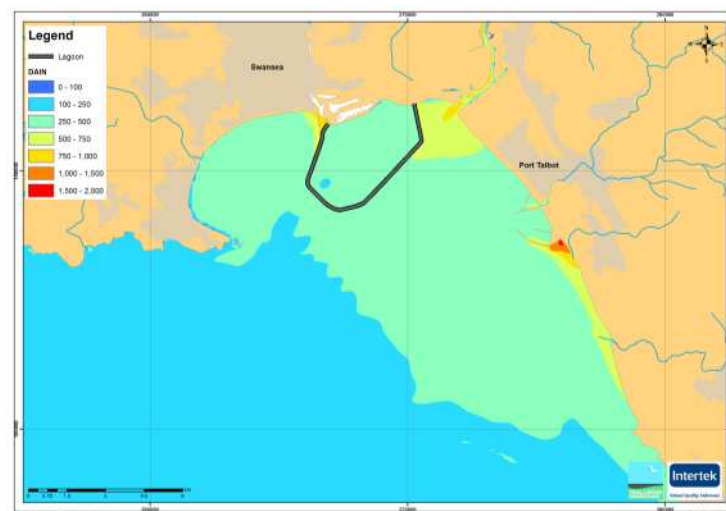
dispersion. This has the effect of reducing nitrogen concentrations in the Lagoon and in the area between the Lagoon and Mumbles Head. However, as the load from the WWTW is relatively small, compared to river loads, the reduction in nitrogen concentrations is small.

- 7.7.7.34 Overall, the Lagoon serves to reduce nitrogen concentrations within Swansea Bay, by modifying the trajectories of the river plumes and generating additional mixing with offshore waters. The net change is a general reduction of nitrogen concentrations in Swansea Bay. This reduction is partly offset by localised increases in nitrogen concentrations ($<100 \mu\text{g/l}$) in the transitional waters around the Tawe and Neath estuaries. This change is due to the river plumes being constrained at the estuary mouth as the lagoon wall restricts lateral dispersion. Mitigation of this local effect is, therefore, not possible without moving the lagoon walls further away from the estuaries. The slight increase in nitrogen concentration around the estuaries is also balanced by the improvement in nitrogen concentrations over the rest of Swansea Bay.
- 7.7.7.35 Given the potential conservatism in the model, the effects of the Lagoon on nitrogen concentrations in Swansea Bay are relatively small. These changes would not be expected to affect future WFD class in the Swansea Bay water body, and are considered unlikely to affect the WFD class in the transitional water bodies of the Tawe Estuary, Neath Estuary or Afan Estuary.
- 7.7.7.36 Given existing nitrogen concentrations, changes caused by the Lagoon would not be expected to significantly alter the distributions of phytoplankton in the Bay, or lead to significant changes in primary production. Due to the net reduction in nitrogen concentrations in the Lagoon and its high rate of flushing, the risk of algal blooms in the Lagoon is considered very low.

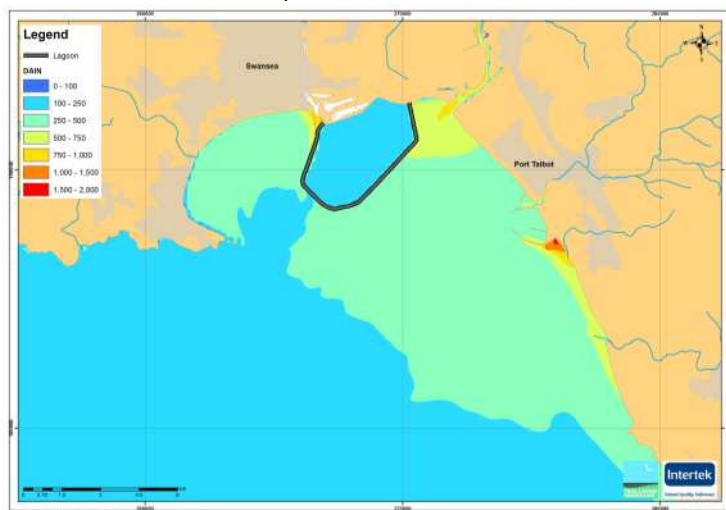
Tidal Lagoon Swansea Bay plc



a) Baseline



b) Lagoon, no optimisation



c) Lagoon, 1.5km outfall extension

Winter average DAIN (µg/l)
Continuous background loads.

Legend

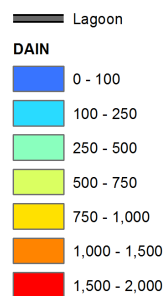
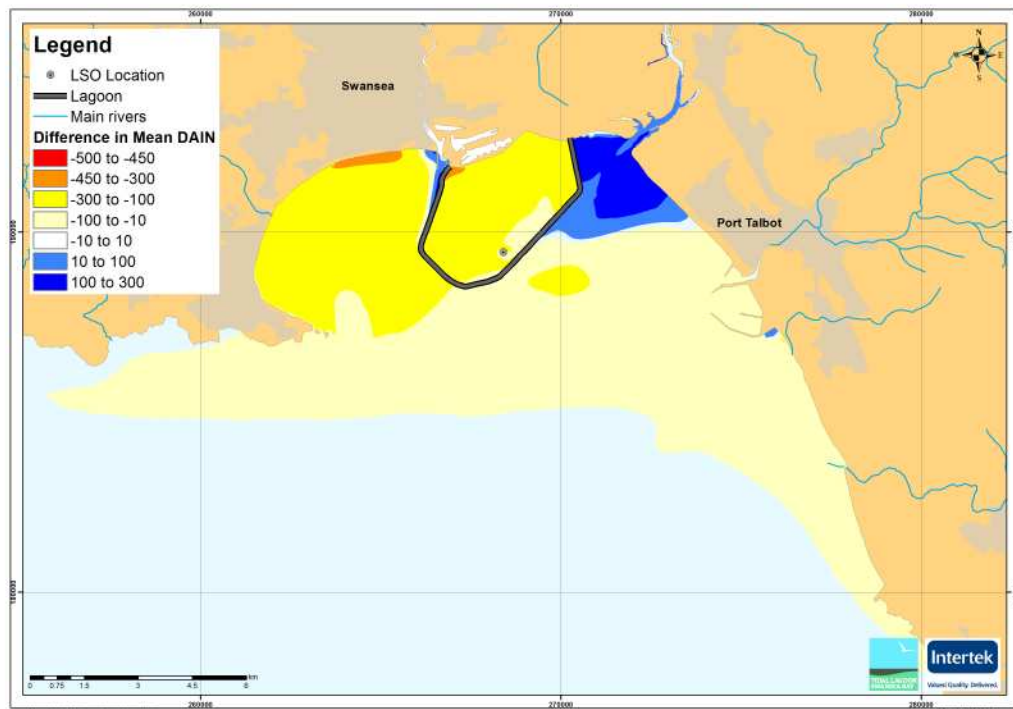
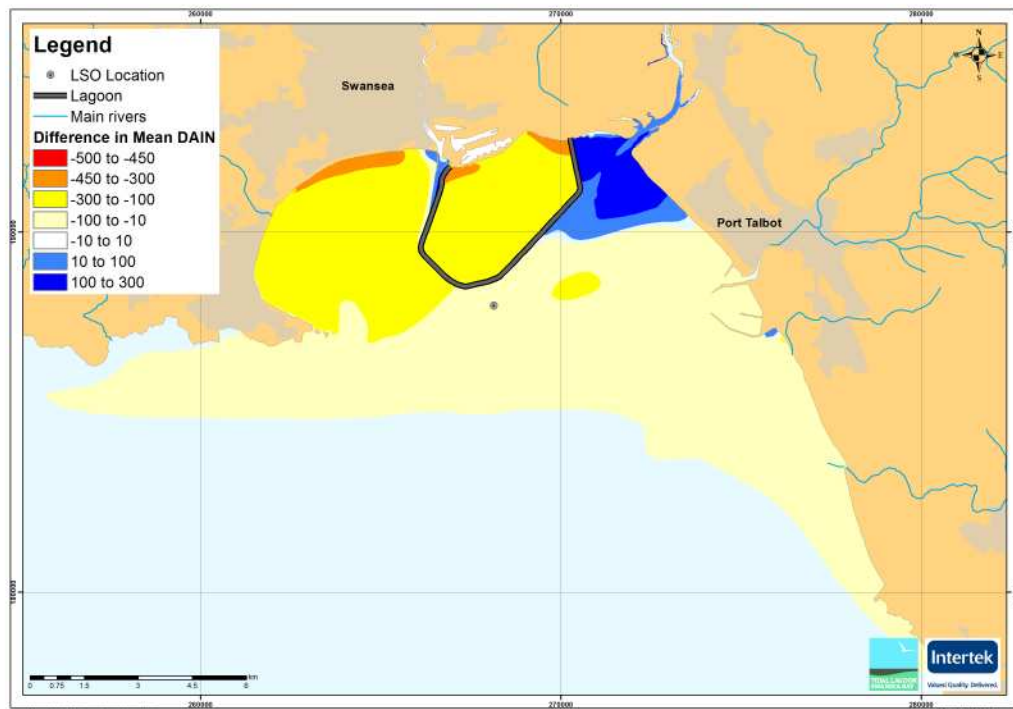


Figure 7.22 Comparison of Baseline and Lagoon on nitrogen concentrations (µg/l).



a) Lagoon, no optimisation minus baseline

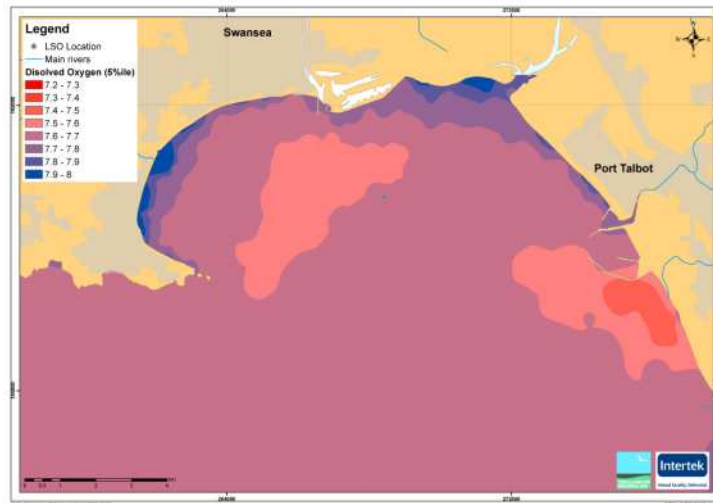


b) Lagoon, 1.5 km extension minus baseline

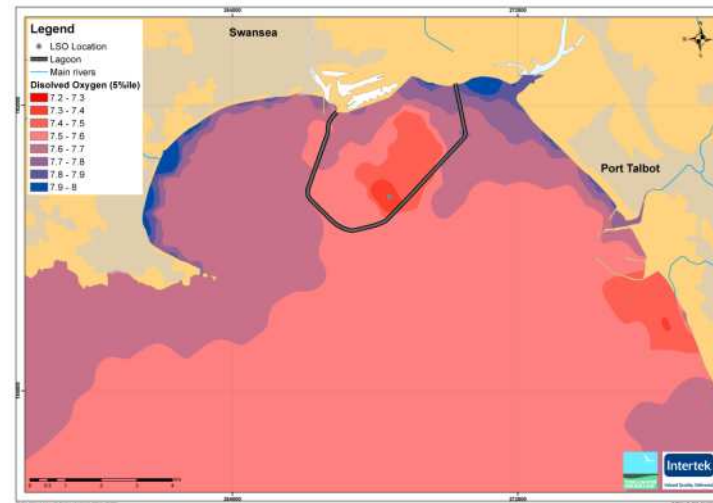
Figure 7.23 Difference in Baseline and Lagoon concentrations of nitrogen ($\mu\text{g/l}$).

- 7.7.7.37 Dissolved Oxygen (DO):** Dissolved oxygen applications were undertaken for a summer condition under dry weather and for a winter condition under storm loading conditions. Summer conditions present a worst case when DO solubility is lowest, DO sinks (e.g. BOD and ammonia) are highest, and reaction rates fastest. The storm loading condition demonstrates the response of Swansea Bay to high BOD and ammonia loads from rivers and intermittent discharges. Results are presented as minimum (5%ile) concentrations, consistent with WFD UKTAG standards.
- 7.7.7.38** Results for the dry weather case are presented in Figure 7.24a (Baseline) and Figure 7.24b (Lagoon): a neap tide with no wind is presented as a worst case condition. Under the Baseline (Figure 7.24a), DO concentrations throughout Swansea Bay are in excess of 7.4 mg/l. Lowest concentrations are seen south of Port Talbot Docks, probably in response to local river and WWTW discharges. However, it should be noted these low concentrations are not of concern, as DO in the entire Bay is close to saturation and well in excess of the WFD High class (Table 7.5; High class 5.6mg/l, 5%ile).
- 7.7.7.39** With the Lagoon in place (Figure 7.24b), DO concentrations are slightly increased (0.1 mg/l) in the west of the Bay due to changes in the trajectory of the River Tawe plume and greater mixing with offshore waters. In the east of the Bay, DO concentrations are reduced by around 0.1 mg/l, in response to changes in the trajectory of the River Neath plume. However, these changes are very small (<2%) and would not adversely impact water quality as DO concentrations remain high.
- 7.7.7.40** Within the Lagoon a drop of approximately 0.5 mg/l in DO concentration is predicted, in response to reduced dispersion and re-aeration in the quieter waters of the Lagoon. Again, this is a small change and unlikely to adversely affect water quality in the Lagoon. Extending the outfall beyond the Lagoon seawalls would mitigate this small impact, and would not be expected to reduce DO concentrations in Swansea Bay.
- 7.7.7.41** Under storm conditions (Figure 7.24c), DO concentrations for the Baseline scenario, remain similar to background conditions over most of the Bay. However, in shallow waters close to the Swansea LSO and Afan discharges, reductions in DO are predicted in response to higher loads of BOD and ammonia from storm water inputs. This can be most clearly seen as a reduction in DO concentrations at the mouths of the rivers, where diffuse and CSO loads of BOD and ammonia cause a reduction in DO to a minimum of approximately 4.5 mg/l. These discharges do not impact the wider Bay area as there is sufficient DO to assimilate storm water inputs.
- 7.7.7.42** With the Lagoon in place (Figure 7.24d), local changes in DO concentrations can be seen in the areas around the Neath and Tawe river mouths and around the Afan discharge. However, these changes are very small and unlikely to affect water quality. Within the Lagoon a reduction in DO is predicted in response to storm water discharge from the Swansea LSO. The reduction in DO is small and would not adversely affect water quality within the Lagoon.
- 7.7.7.43** For all scenarios modelled, DO levels within the Bay and Lagoon are well above the WFD High class boundary of 5.6 mg/l (Table 7.5).

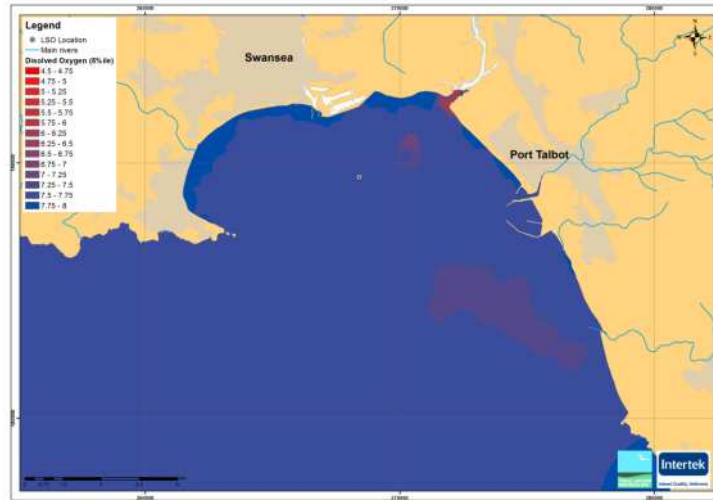
Tidal Lagoon Swansea Bay plc



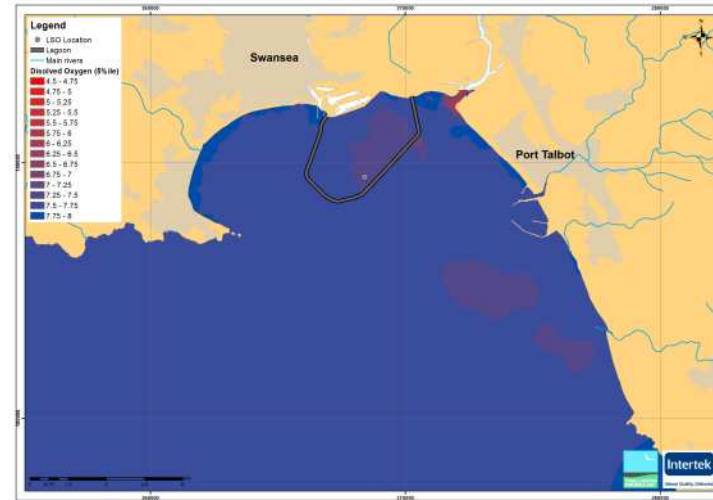
a) Baseline summer 5 %ile



b) Lagoon summer 5 %ile



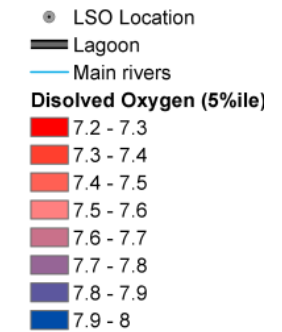
c) Baseline wet weather 5%ile



d) Lagoon wet weather 5%ile

5%ile DO (mg/l)
Background load.

Summer
Legend



5%ile DO (mg/l)
Storm event.

Summer

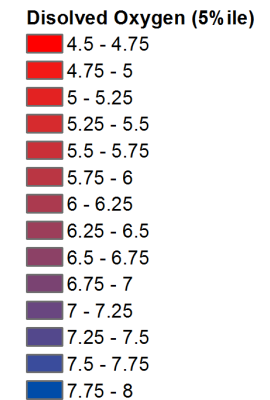


Figure 7.24 Comparison of Baseline and Lagoon impacts on dissolved oxygen concentrations

7.7.8 Summary of water quality impacts for WFD determinands

7.7.8.1 The results of the WFD sensitivity applications demonstrate the effects of the Lagoon on circulation and water quality within Swansea Bay:

- a. the Lagoon causes changes in hydrodynamics and circulation in the previously open water affected by the Lagoon. The physical structure of the Lagoon limits the dispersion of the Tawe plume in an easterly direction and the Neath plume in a westerly direction, and limits the interaction of these two water masses;
- b. each river plume becomes attached to the Lagoon seawalls causing greater seaward movement and further limiting lateral dispersion, to the south in the case of the Neath and west in the case of the Tawe;
- c. flow into the Lagoon through the turbines causes a change in velocities of current between Mumbles Head and the area where the Lagoon will be sited. This tends to draw offshore water into this area and into the western side of Swansea Bay. The greater intrusion of this water mass and the change in the trajectory of the Tawe plume, leads to greater mixing between the two water bodies. Greater mixing of the Neath plume with the offshore waters south east of the Lagoon also occurs, providing some potential improvement in water quality in these waters;
- d. these changes are most clearly seen in the distribution of salinity in the intertidal and shallow areas along the Swansea and Afan coastline. Salinity range is reduced by 1 psu to 5 psu. This change occurs as the river plumes from the Tawe and Neath are displaced by the Lagoon seawalls and the turbine flows induce greater mixing with offshore waters. The salinity range in the area occupied by the Lagoon reduces from 15 psu to 5 psu, as the salinity becomes more stable at 25 psu to 30 psu. Given the naturally high variability in salinity within the Bay it is considered that the predicted change in salinity is within the natural variation and should therefore have no effect;
- e. changes in temperature are much smaller, as the temperature difference between the river and Bay water masses are much smaller: atmospheric temperature exchange also reduces temperature differences. Maximum temperature variations are in the order of 1°C. Overall, these changes are not considered significant, as they are within normally expected year-on-year variability. The Lagoon is not predicted to impact the thermal plume from the Baglan Bay power station;
- f. nutrient distributions in Swansea Bay are predicted to show a general reduction in concentration in offshore waters. There will be a small localised increase in the coastal areas around the Tawe and Neath estuaries, but reductions across the majority of Swansea Bay;
- g. a small increase in nitrogen concentrations is predicted in the transitional waters of the Neath and Tawe rivers. UKTAG classifications in transitional waters are very salinity dependant and the model results for nitrogen can only provide an indication of relative changes, as there is currently insufficient monitoring data to accurately define absolute nitrogen concentrations in Swansea Bay. Increases in nitrogen concentrations in the transitional waters of the Tawe and Neath could reduce current class under WFD, if present levels are close to the Moderate/Poor class boundary. However, these changes are very localised and unlikely to affect overall water body class in the transitional waters;

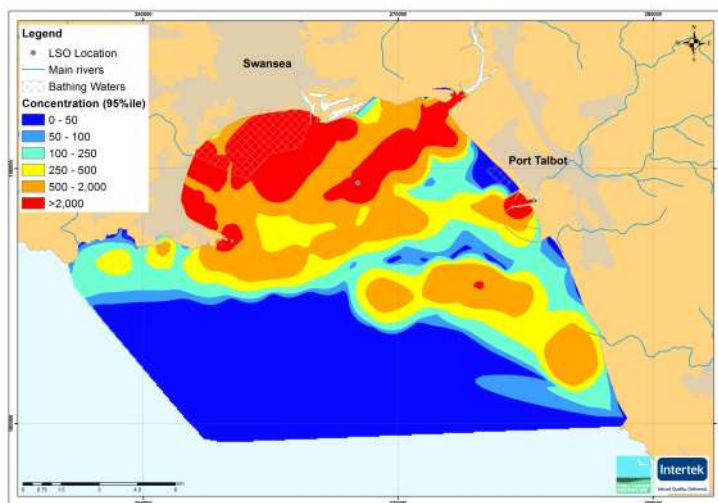
- h. the change in nitrogen concentrations is positive over the majority of Swansea Bay, but insufficient to raise the current Moderate class. Localised increase in nitrogen in the transitional waters would not be expected to reduce WFD class or impact primary production. The formation of algal blooms in the Lagoon would not be expected to occur;
- i. dissolved oxygen concentrations are largely unaffected by the Lagoon. Small changes are predicted, but these would not adversely affect water quality or the WFD class, which remains High; and
- j. overall the impacts of the Lagoon would not be expected to adversely affect water quality within Swansea Bay. WFD class for the determinands considered would not be affected.

7.7.9 Construction sensitivity applications - microbiology

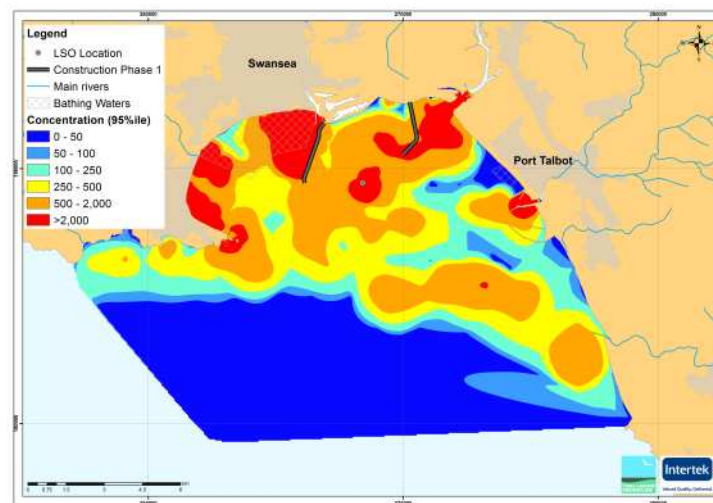
- 7.7.9.1 Figure 7.25 shows the 95%ile E Coli concentrations during the storm event used for previous sensitivity applications (section 7.7.2). Plots are presented for Baseline, Lagoon and partially completed Lagoon seawalls during phase 1 and 2 of construction (i.e. with completion of western seawall and partial completion of eastern seawall).
- 7.7.9.2 Comparison of Figure 7.25a (Baseline) and 7.25b (partial construction) shows how the partially constructed Lagoon seawalls cause a change in the trajectory of the plumes from the River Tawe and River Neath. The Tawe plume attaches to the western Lagoon seawall, reducing the lateral extent of the plume and reducing E Coli concentration along the Swansea shoreline. The Neath plume also attaches to the eastern Lagoon seawall.
- 7.7.9.3 Changes also occur in the current direction in the central Bay area, as the Lagoon seawalls deflect the normal south-west/north-east tidal flow further to the south. This causes the discharge from the Swansea WWTW to be partially diverted into the Lagoon area and deflected further south in the offshore area: leading to improved water quality in the area between the Lagoon and Mumbles Head. The trajectory of the Afan WWTW plume and the Baglan pumping station LSO plume are also slightly modified.
- 7.7.9.4 As the seawalls are extended further (Figure 7.25c) these effects become more pronounced, although the Swansea WWTW discharge is now more confined to the Lagoon area. Once construction is complete, the flow of the WWTW discharge through the turbines causes some further modification, with a slight increase in bacteria concentrations along the Swansea shoreline, although impacts are reduced compared to the Baseline condition.
- 7.7.9.5 The construction phase represents a transition from the Baseline to the Lagoon (Figure 7.25d). During the construction phase, the changes in plume behaviour and water quality are similar to those for the operational Lagoon, and in some cases slightly improved.

Tidal Lagoon Swansea Bay plc

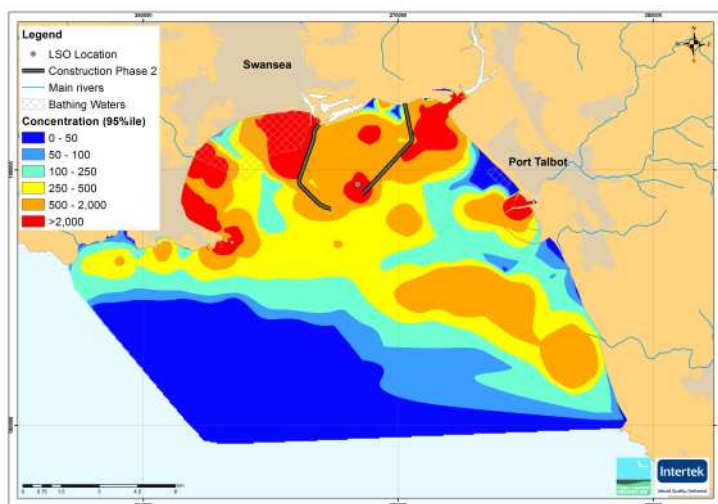
E Coli /100ml
Storm event
Spring tide
No wind



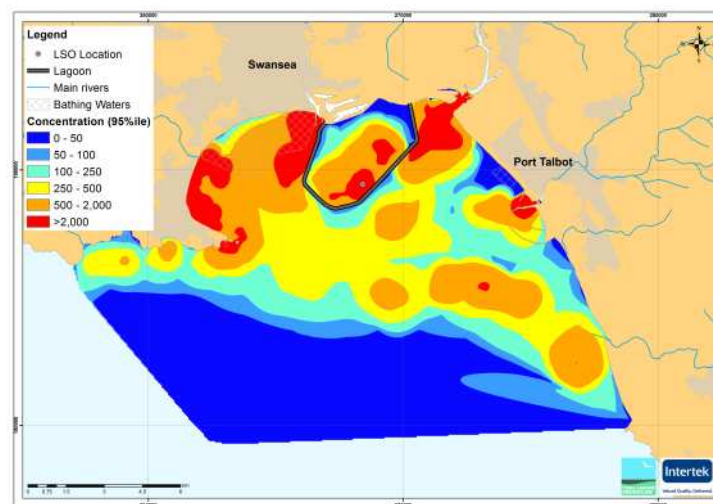
a) Baseline - wet weather 95%ile



b) Phase 1 construction - wet weather 95%ile



c) Phase 2 construction - wet weather 95%ile



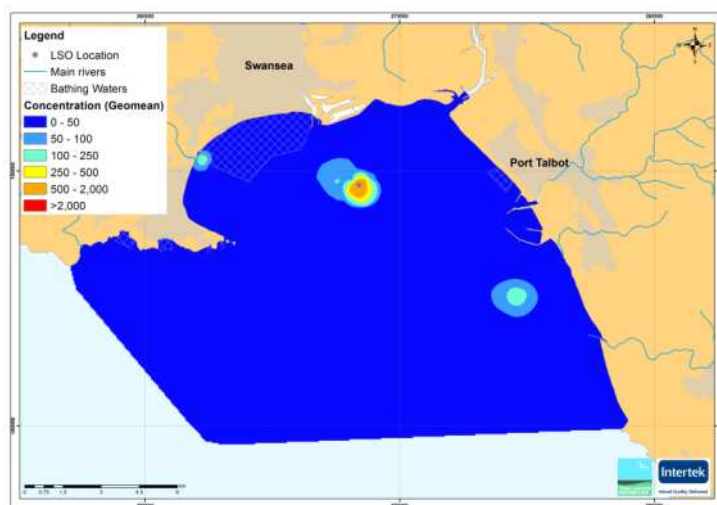
d) Lagoon - wet weather 95%ile

Legend
● LSO Location
— Lagoon
— Main rivers
⊞ Bathing Waters
Concentration (95%ile)
0 - 50
50 - 100
100 - 250
250 - 500
500 - 2,000
>2,000

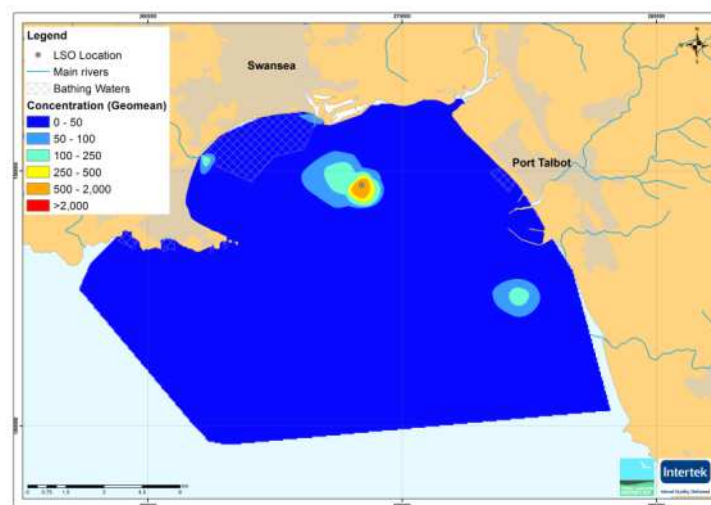
Figure 7.25 Comparison of Baseline and Lagoon construction impacts on Microbiological Water Quality (E Coli/100ml).

- 7.7.9.6 Construction of the Lagoon walls will cause an increase in turbidity around construction areas during the construction period (March to October), leading to a potential decrease in FIO decay rates. Figure 7.26 compares the difference in E Coli concentrations with a normal decay rate and a 50% decrease in decay rate in the plumes from river Tawe, river Neath and Swansea WWTW. Results are presented under the Baseline scenario for the background condition (geomean) and the storm condition (95%ile) during spring tides with no wind. This is considered a representative worst case condition when sediment plumes from construction would extend over the widest possible area.
- 7.7.9.7 Under dry conditions (Figure 7.26a and b), the results show a very small increase in the area of the wastewater plume from Swansea LSO with concentrations above 100 EC/100ml close to the outfall. These changes would not be expected to affect water quality in shellfish or bathing waters significantly.
- 7.7.9.8 In storm conditions (Figure 7.26c and d), a small area of Swansea Bay north east of the mouth of the River Clyne shows an increase in the 95 %ile concentration to above 2000 EC/100ml. This would suggest a potential reduction in water quality during the construction period under storm conditions. However, it should be noted that the model takes a conservative approach, assuming dredged plumes are present at all times and that these interact fully with the Tawe, Neath and WWTW plumes. In reality reductions in turbidity would be limited spatially and temporally as:
- plume interaction would vary depending on the stage of construction, the state of the tide and when and where intermittent discharges and dredging occur;
 - plume interactions would be localised and short-term, the probability of these events occurring coincidentally for extended periods over the entire construction area is low;
 - areas of reduced decay rate would be localised, moving as discrete patches, and would not affect decay over the whole bay;
 - once released sediment will begin to settle, reducing local turbidity over time and distance from the construction area,
 - local areas of high turbidity would reduce toward background levels over a period of a few days once dredging stops or construction location is moved.
- 7.7.9.9 Based on the plume trajectories shown in Figure 7.25, the effects of plume interaction on bathing water quality would also be expected to reduce during the construction period. As the seawalls are extended their effect on hydrodynamics and dispersion become more pronounced. Changes to the trajectory of the WWTW discharge plume and attachment of the river plumes to the Lagoon walls would serve to isolate the interaction of these plumes with the dredged plumes, carrying the plumes away from the shoreline and reducing potential impacts on the inshore waters.
- 7.7.9.10 Given these factors, the effects of increased turbidity on bacteria decay during Lagoon construction would not be expected to significantly affect bathing water class at Swansea Bay, Aberafan or along the Gower coast. Similarly the effects on shellfish water quality would also be localised and short-term and would not be expected to affect present shellfish quality or class during the construction period. Outside of the construction period (October to February) no impact on shellfish waters would be expected. Once each construction phase is completed, suspended sediment levels would return to normal (present) within a short period, probably in the order of a few days.

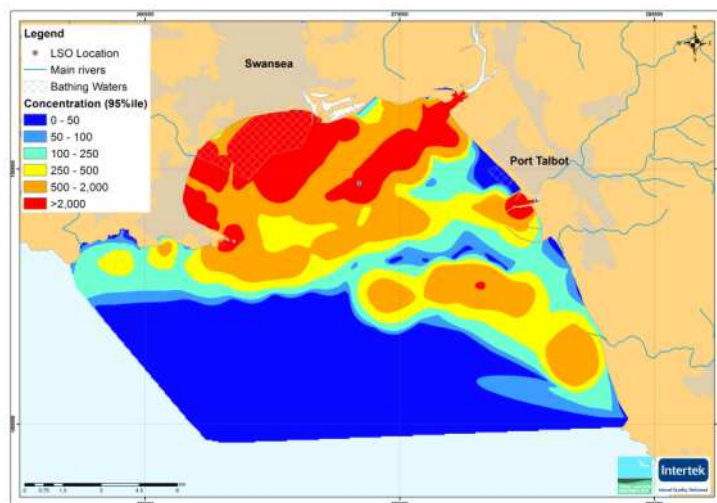
Tidal Lagoon Swansea Bay plc



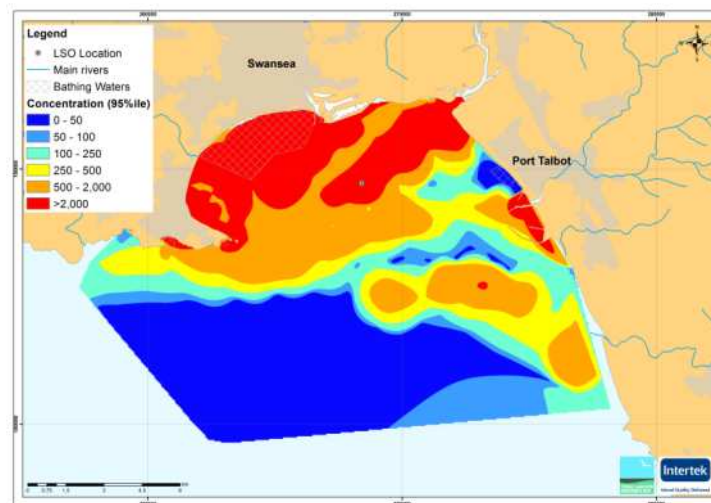
a) Baseline normal decay rate dry weather geomean



b) Baseline 50% increase decay rate - dry weather geomean



c) Baseline normal decay rate wet weather 95%ile



d) Baseline 50% increase decay rate wet weather 95%ile

E Coli /100ml
Background loads
Spring tide
No wind

Legend

- LSO Location
- Lagoon
- Main rivers
- ⊞ Bathing Waters

Concentration (Geomean)

- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000

E Coli /100ml
Storm loads
Spring tide
No wind

Legend

- LSO Location
- Lagoon
- Main rivers
- ⊞ Bathing Waters

Concentration (95%ile)

- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000

Figure 7.26 Comparison of Baseline and increased decay rates on microbiological water quality (E Coli/100ml)

7.7.10 Construction sensitivity applications – WFD determinands

- 7.7.10.1 The results presented in Section 7.7.9 (Figure 7.25) indicate that the effects of construction on pollutant dispersion are similar to those for the Lagoon, with small changes in plume behaviour occurring over the construction period. Combining these findings with the results presented in Section 7.7.7 would suggest that effects of construction on the dispersion of other pollutants would be similar, i.e. a transitional stage between Baseline and Lagoon, with relatively little difference when compared to the operational Lagoon.

7.7.11 Construction sensitivity applications – sediment contaminants

- 7.7.11.1 This section focuses on the impact of the potential release of sediment contaminants during the construction phase. The release of these contaminants will occur:

- during the construction of Lagoon seawalls and the temporary cofferdam to enable the construction of the turbine and sluice gate housing structure; and
- during de-watering of the construction area within the temporary cofferdam.

- 7.7.11.2 The contaminants selected for the analysis are those which have been calculated to require in excess of 10 (log scale 1) dilutions (see Table 7.21), and are shown in Table 7.26a and Table 7.26b. Table 7.26a gives the dilution required for contaminants released at the maximum concentrations, Table 7.26b provides dilution at the mean concentration.

Table 7.26a Contaminants and Environmental Quality Standards and dilutions – maximum contaminant concentration.

Contaminant	EQS (ug/l)	Dilution to Standard	Log Dilution to Standard	Comments
Arsenic	25	302	2.48	Annual average standard
Copper	5	930	2.97	Annual average standard
Lead	25	109	2.04	Annual average standard
Cadmium	2.5	30	1.48	Annual average standard
Nickel	30	278	2.44	Annual average standard
Zinc (dissolved)	40	156	2.19	Annual average standard
Tributyltin	0.002	11.4	1.06	Maximum standard

Table 7.26b Contaminants and Environmental Quality Standards and dilutions – mean contaminant concentration.

Contaminant	EQS (ug/l)	Dilution to Standard	Log Dilution to Standard	Comments
Arsenic	25	52.7	1.72	Annual average standard
Copper	5	62.9	1.8	Annual average standard
Nickel	30	48.7	1.69	Annual average standard
Zinc (dissolved)	40	14.6	1.16	Annual average standard
Tributyltin	0.002	11.4	1.06	Maximum standard

- 7.7.11.3 Background concentrations of some of these metals have been measured in the water column in outer Swansea Bay by NRW during the WIMS surveys of 1992 to 2008. In this period, around 80 samples were analysed for seven of the eight metals considered in the

sediment analysis carried out as part of this Project (Section 7.6.4). Table 7.15 (Section 7.4.1) provides a statistical overview of these results. The mean background concentrations have been incorporated in the dilution assessment to calculate the distance from the construction activity (seawall construction or cofferdam de-watering) at which each contaminant is predicted to meet its EQS (see Table 7.27).

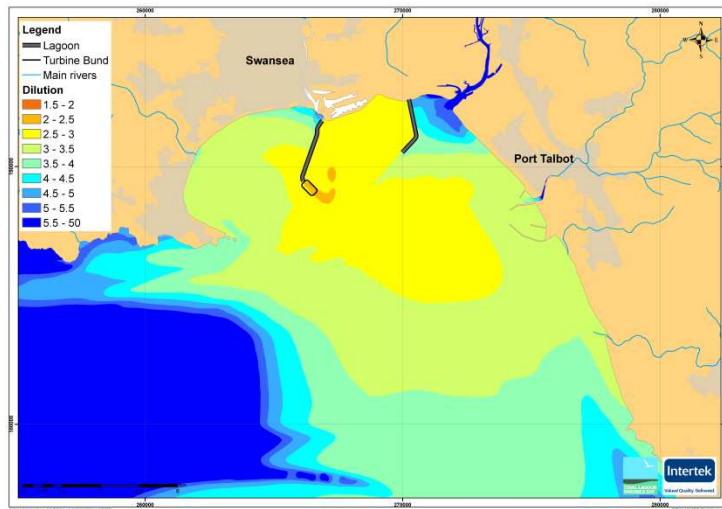
De-watering

- 7.7.11.4 Contaminant release during de-watering potentially presents the more significant impact, as the discharge is from a point source and would be sustained throughout the construction period, possibly up to 3 years. To assess these effects, dilution of a conservative tracer has been modelled, until an equilibrium condition is achieved. The concentration of tracer at all locations over the model simulation period was then extracted from the model output and divided by the initial discharge concentration to determine a dilution. This approach allows the dilution of the tracer to be compared to the number of dilutions required to achieve the environmental standard.
- 7.7.11.5 In order to simulate contaminant release for de-watering four scenarios have been modelled:
- Construction Phase 1 (year 1) Lagoon seawall and temporary cofferdam, de-watering to both sides of the construction area;
 - Construction Phase 1 (year 1) Lagoon seawall and temporary cofferdam, de-watering to the offshore side of the construction area only;
 - Construction Phase 2 (year 2) Lagoon seawall and temporary cofferdam, de-watering to both sides of the construction area; and
 - Construction Phase 2 (year 2) Lagoon seawall and temporary cofferdam, de-watering to the offshore side of the construction area only.
- 7.7.11.6 Figure 7.27 shows the average predicted dilution for de-watering during Phase 1 and Phase 2 of the construction. The plume from the de-watering exercise would potentially influence the whole of the Bay and the transitional waters of the Tawe, Neath and Afan rivers. However, it should be emphasised that given the available dilution (3 to 4 log, 1,000 to 10,000 times) this would be at very low concentrations.
- 7.7.11.7 Figure 7.27 indicates rapid dilution to 2 log (100 times) within a very short distance of the discharge (100m or less). For the majority of sediments (i.e. those with measured contaminant concentrations at or below the mean and below CEFAS Action Level 1) this would bring contaminants to within the EQS level and close to background concentrations. To dilute contaminants in sediments with higher concentrations (i.e. the few sites with concentrations above the mean and between CEFAS Action Level 1 and 2), would require a further 0.5 to 1 log reduction. A further 0.5 log reduction is achieved within a distance of 750m or so. A 3 log (1000 times) dilution (i.e. for sediments with concentrations close to the measured maximum) requires a relatively large area, with a plume extending over the full area of the Lagoon, east towards the Afan coastline and offshore to the edge of Swansea Bay (as defined by the WFD water body). This area is reduced in Phase 2 as the hydrodynamic effects of the Lagoon increase dispersion in the local area. It should be noted that this assessment assumes all contaminants within the sediment are available to be mobilised, and that the reservoir of contaminants in the sediment is unlimited.

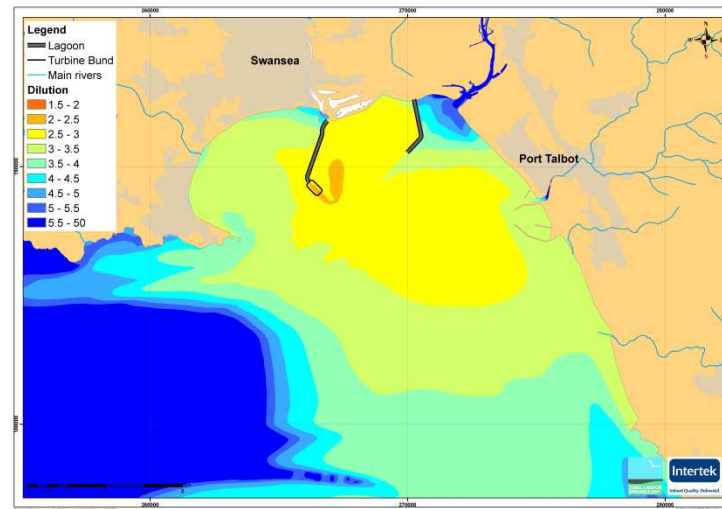
Tidal Lagoon Swansea Bay plc



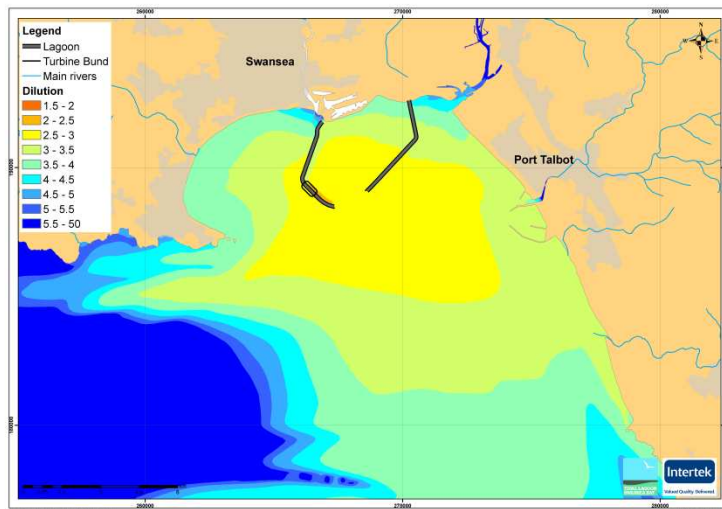
Log₁₀ dilution
Equilibrium mean
Log₁₀ dilution
Astronomical tides



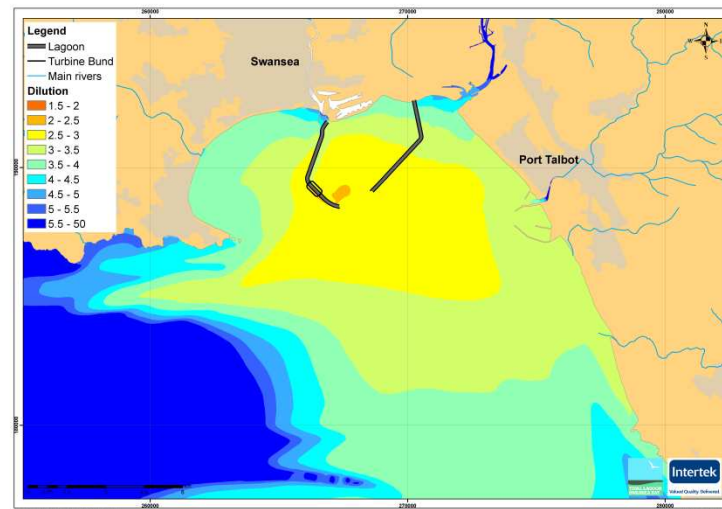
a) Year 1 discharge both sides



b) Year 1 discharge offshore



c) Year 2 discharge both sides



d) Year 2 discharge offshore

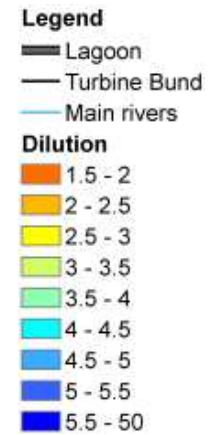


Figure 7.27 Average dilution (as Log₁₀) of contaminants from de-watering

- 7.7.11.8 Discharge location makes small differences to the dilution and distribution of contaminants. Dispersion is improved in Phase 1 by discharging on both sides of the construction area (Figure 7.27a and c), effectively spreading the load. During Phase 2 discharging to the seaward side of the structure would make use of changes in current velocities to improve dispersion, and avoid discharging to the more sheltered Lagoon side.
- 7.7.11.9 The distance from the discharge point over which each parameter is predicted to exceed its environmental standard is presented in Table 7.27, Figures for both with and without background concentrations are presented and assume average concentrations of contaminants in the sediment, as these are more representative of sediment quality over the site. For tributyltin, a conservative approach has been taken, as it has been assessed at the detection limit, which is likely to be considerably in excess of its actual concentration. Even at this maximum possible concentration, tributyltin would only require around 10 dilutions to achieve its EQS.

Table 7.27 Contaminants, Partition Coefficients, Environmental Quality Standards and dilutions for average contaminant concentrations.

Contaminant	EQS (ug/l)	Dilution to Standard	Log Dilution to Standard	Dilution to Standard*	Log Dilution to Standard*	Exceedence Distance (m)	
						Year 1	Year 2
Arsenic	25	52.7	1.72	54.6	1.74	< 80	< 80
Copper	5	62.9	1.80	82.4	1.92	~100	~100
Nickel	30	48.7	1.69	50.0	1.70	<80	<80
Zinc (dissolved)	40	14.6	1.16	15.6	1.19	<80	<80

* including background concentration

Seawall construction (dredging and Geotube® filling)

- 7.7.11.10 The results obtained for de-watering can provide an indication of the impacts of contaminants from construction activities (dredging/Geotube® filling). The average discharge rate during construction would be similar to that from de-watering. However, as the discharge location will move as construction progresses, the formation of large plumes with high concentrations would not be expected to occur (see Chapter 6: Coastal Process Sedimentation and Contamination for further information on dredging plumes). The distribution of contaminants would be expected to be similar to those presented in Figure 7.27, and the local dilution of contaminants would be of the same order of magnitude to those presented in Table 7.27.
- 7.7.11.11 Referring to Table 7.26b, the majority of sediment contaminants would require 10 to 100 dilutions to meet the EQS. This would typically be achieved within 100m of the dredging or tube filling location.
- 7.7.11.12 Where dredged sediments contain higher levels of contaminants, i.e. between CEFAS Action Level 1 and 2, a dilution of approximately 10 to 300 times would be required in most cases (Table 7.26a). This suggests EQS levels would be achieved within 100m to

1000m of the construction location. A number of sediment samples contain higher levels of contaminants and would required dilution of up to 1000 times.

- 7.7.11.13 However, as discussed in Section 7.6.4, the high contaminant concentrations shown in Table 7.26a occur in very few of the sediment samples, and are typically isolated to small patches of fine surface sediment. High contaminant concentrations occurred in only 4 out of the 67 samples. The highest copper concentration was 327.3mg/l, upon which the maximum dilution required is based, the second highest value was less than a third of this at 91.4mg/l (Titan 2012a, Titan 2013, Atkins 2013) and would require proportionately less dilution (300 dilutions as opposed to 930 dilutions). Furthermore, model applications are a conservative worst case, as they assume continuous release at high concentrations and do not account for any re-adsorption of contaminants to particles and consequent losses to sedimentation.
- 7.7.11.14 In the areas where dredging is proposed (see Chapter 4: Project Description) contaminant concentrations are lower (CEFAS Action Level 1), typically at or below the average values quoted in Table 7.26b and 7.27. Contaminants from these sediments would be diluted rapidly and achieve EQS levels within approximately 100m of the discharge point. Further dispersion would be expected to reduce these concentrations to background levels within relatively short distances - 500m or so.
- 7.7.11.15 The results presented in Figure 7.27 and Table 7.27 indicate that the effects of the release of contaminants from sediment during de-watering and construction will be low, as the majority of samples collected (73.5%) had contaminant levels below CEFAS Action Level 1. Sediments with slightly elevated levels, between Action Level 1 and 2 could still be used, as the contaminant concentrations released to the water column would be relatively low and would disperse to EQS levels within a reasonably limited area of the Bay. It should be noted that no samples had contaminants levels above Action Level 2. Notwithstanding this, as per CEFAS guidance, dredged material with contaminant levels above Action Level 2 is generally considered unsuitable for sea disposal.
- 7.7.11.16 Some further loss of water from the Geotubes® may occur after filling, as the Lagoon seawalls settle. However discharge rates would be expected to be small, as the majority of water loss will occur during the construction phase.
- 7.7.11.17 The overall impact of construction on metals and other contaminants released from sediment is predicted to be minimal. While local concentrations of pollutants would increase, these would be localised, typically within 100m of the de-watering or construction activities, and would not be expected to cause any long-term exceedence of EQS concentrations and WFD class in Swansea Bay.

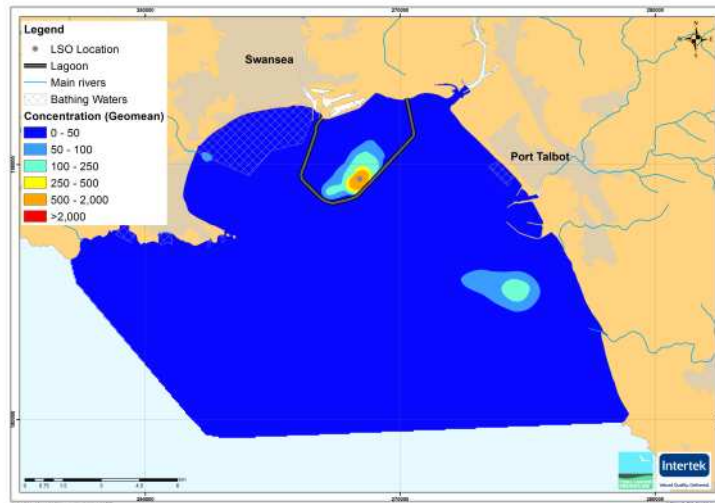
7.7.12 Decommissioning impacts

- 7.7.12.1 Decommissioning impacts investigations were carried out by applying the bacteria (E Coli FIO) sensitivity runs to the Lagoon operation case with no turbines in place. Figure 7.28 shows comparisons between the Lagoon Decommissioning and Baseline cases to identify potential changes in plume behaviour and how future water quality might change when the Lagoon is decommissioned. The Lagoon scenario with no optimisation has been assumed as a worst case condition.
- 7.7.12.2 Under dry conditions (Figure 7.28a and 7.28b), the wastewater discharges from the Swansea LSO is still largely contained within the Lagoon and dispersed to more offshore

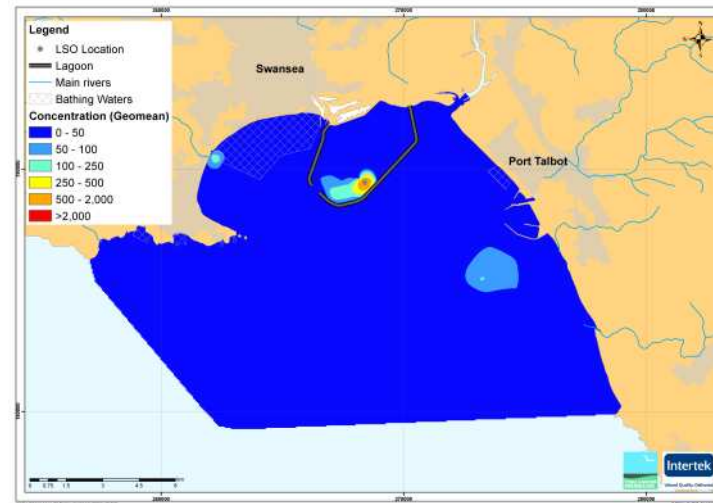
waters. Concentrations in the rest of Swansea Bay remain largely as in the Baseline case with some subtle changes resulting from small changes in circulation. For example the Afan WWTW plume becomes more dispersed, while the Clyne plume is slightly less dispersed.

- 7.7.12.3 In wet weather conditions (Figure 7.28c and 7.28d), impacts along the Swansea coastline are increased post-decommissioning. The western part of Swansea Bay shows a predicted increase in the 95 %ile concentration to above 2000 EC/100ml. This is in response to changes resulting from the removal of the turbines:
- a change in the phasing of the discharge from the Lagoon. Current operational planning means that the Swansea WWTW discharge is held in the Lagoon until approximately 2.5 hours after high water, and is then released as a strong jet flow during the generation period. This maintains the plume in the offshore waters, where dispersion is maximised before the flood tide brings the plume back into the Bay;
 - the reduced discharge velocity lessens the jet flow seen during operation, and the discharge forms a more concentrated, slower moving, plume;
 - the effects of the Lagoon on the Tawe River plume are also reduced as the earlier release of flow from the Lagoon serves to push the Tawe plume back into the Bay; and
 - a reduction in flow velocity to and from the Lagoon reduces the amount of offshore water that is brought into the western part of Swansea Bay. The dilution of effluent from the Lagoon and local river and CSO sources along the Swansea coastline is therefore reduced.
- 7.7.12.4 Greater plume excursion from the WWTW and River Tawe into Swansea Bay and reduced dilution with offshore water give rise to a greater impact along the shoreline.
- 7.7.12.5 Along the Afan coast a change in E Coli concentrations is also seen. In much of the area concentration is slightly reduced. However at the Aberafan DSP concentration is increased. This appears to be due to be a change in circulation along the Afan coast, in response to the removal of the turbines. This causes a northerly shift in the plume from the River Afan, also apparent as a northerly movement of the plume from the River Neath.
- 7.7.12.6 The model predictions suggest that changes in circulation and pollutant dispersion would occur after decommissioning of the Lagoon. These changes could have a detrimental impact on Swansea Bay when compared to the operation of the Project, with a reduction in microbiological water quality along the Swansea and Afan shorelines. While decommissioning would lead to a change in flow patterns and distribution of contaminants in Swansea Bay, large scale changes would not be expected to occur.
- 7.7.12.7 The magnitude of any change post-decommissioning is difficult to determine, as the pollutant loads at this time may be significantly different to present conditions. An assessment of impacts would, therefore, need to be undertaken nearer to the time of decommissioning. The proposed optimisation options would serve to reduce the impacts of decommissioning by reducing the Swansea WWTW discharge load (UV disinfection) or moving the discharge away from the Lagoon (outfall extension).

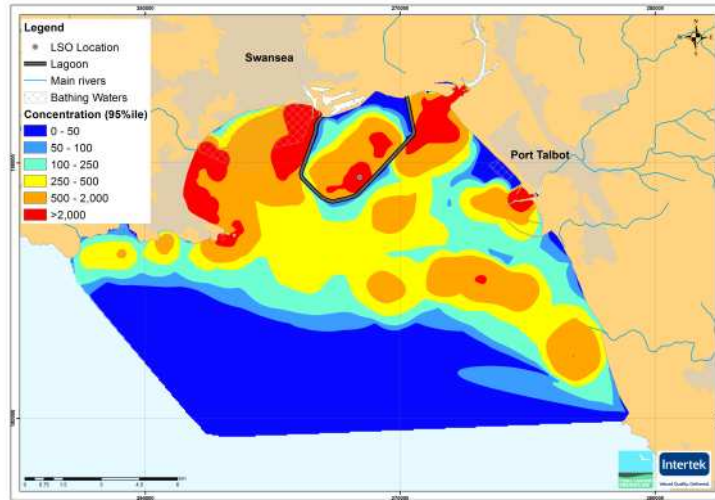
Tidal Lagoon Swansea Bay plc



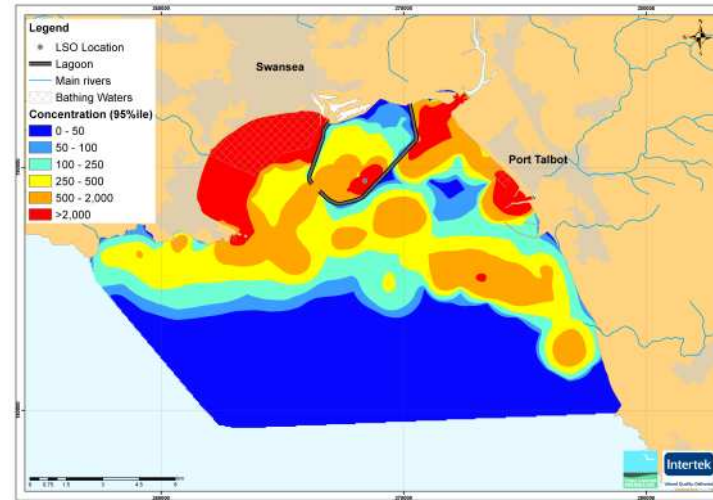
a) Operating Lagoon – dry weather geomean



b) Decommissioned Lagoon - Dry Weather Geomean



c) Operating Lagoon - wet weather 95%ile



d) Decommissioned Lagoon - wet weather 95%ile

E Coli /100ml

Background loads

Spring tide

No wind

Legend

- LSO Location
- Lagoon
- Main rivers
- ⊞ Bathing Waters
- Concentration (Geomean)**
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000

E Coli /100ml

Storm event

Spring tide

No wind

Legend

- LSO Location
- Lagoon
- Main rivers
- ⊞ Bathing Waters
- Concentration (95%ile)**
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000

Figure 7.28 Comparison of operational Lagoon and decommissioned Lagoon impacts on microbiological water quality (E Coli/100ml).

7.7.13 Design iterations impacts

- 7.7.13.1 As with all engineering projects, further ongoing refinement of the design will continue prior to construction. In the case of the Project and its offshore elements this will primarily be focussed on detailed analysis of the results of Ground Investigation and further development of turbine options.
- 7.7.13.2 Where consideration of further design is relevant to the assessment of water quality, it has been assumed that the scheme assessed above represents a worst case effect. This applies in respect of, for example, location of the turbine structure within the limits provided in the DCO application and turbine type.
- 7.7.13.3 As discussed in Table 4.1 (Chapter 4, Project Description), micro-siting of the turbine and sluice gate housing structure further offshore would mean that water quality may be affected. This would be through a potential improvement in water quality during construction, as less sediment material would need to be disposed of and water quality during operation of the Project would also be expected to improve as a result of the turbines being moved further offshore.
- 7.7.13.4 Selection of variable speed turbines instead of fixed speed turbines would allow pumping at end of tidal cycle which would reduce intertidal losses. Higher flows would also have potential improvements in terms of water quality, as increases in discharge flow would improve mixing with offshore waters.
- 7.7.13.5 To test these hypotheses a sensitivity run was undertaken with turbines moved further offshore (in a south easterly direction – see Chapter 4: Project Description) and flows increase by 10% to simulate pumped flows and changes in discharge during the generation cycle. The results are presented in Figure 7.29 and compared with the Lagoon operation applications previously presented. Figures 7.29a and 7.29b compare model results for a dry weather geomean concentration. These show a small change in plume distribution with the turbines moved and higher flow (Figure 7.29b) and a slight reduction in bacteria concentrations within the Lagoon.
- 7.7.13.6 Under storm conditions (Figure 7.29c and Figure 7.29d) there is a small change in bacteria concentrations in the western part of Swansea Bay. Between the mouth of the Tawe and the River Clyne, a slight increase in concentration is seen as the plume extends further west. A slight reduction in bacteria concentration is seen near the turbine housing. This is due to a change in the quantity of offshore water entering this part of the Bay after the turbines are moved to the south east. However, the change is small and would not be expected to significantly affect the predicted improvements in bathing water quality at Swansea Bay DSP with the Lagoon in place. Little change is seen in the eastern side of the Bay and along the Afan coast. Changes to shellfish water quality are not considered significant when compared to the Baseline or Lagoon case.
- 7.7.13.7 Water quality within the Lagoon would also change, as higher inflows and the increased tidal range in the Lagoon would cause greater advection of the plume toward the shoreline. The greater advection would increase the area impacted by the plume, but would also causes a reduction in the pollutant concentration within the plume. The area of the Lagoon achieving rBWD Sufficient class would be reduced by this greater plume movement. The proposed UV treatment option would reduce storm water load from the Swansea WWTW and would be expected to partly offset any reduction in water quality during storm events. However UV treatment would not affect the dry weather condition when a reduction in water quality would be expected in parts of the Lagoon (Figure 7.29a

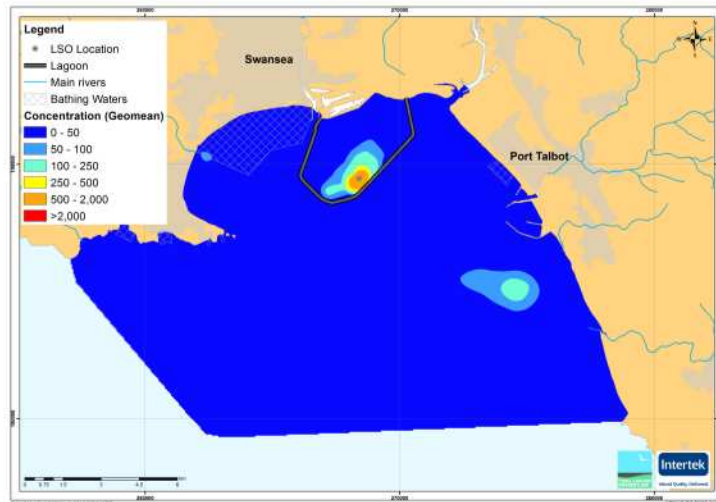
Tidal Lagoon Swansea Bay plc

and 7.29b). Lagoon water quality under the outfall extension option would not be significantly affected by changes in turbine siting or flows.

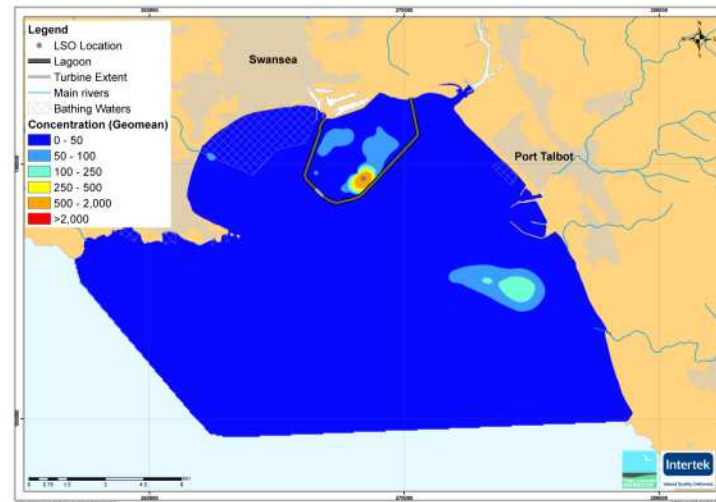
7.7.13.8 Given the relatively small changes in predicted plume distribution with the change to turbine location and flows, the effects on other (WFD) water quality determinands (temperature, salinity, nitrogen, and DO) would also be expected to be small. The increased flow through the turbines would potentially increase mixing with offshore waters, leading to further reductions in nutrient concentrations.

7.7.13.9 The results present in this section consider the impacts of micro-siting the turbine/sluice gate housing structure and turbine pumping options. If only one of these options is constructed, the degree of change revealed by the sensitivity analysis would be expected to be lower than the combined effect.

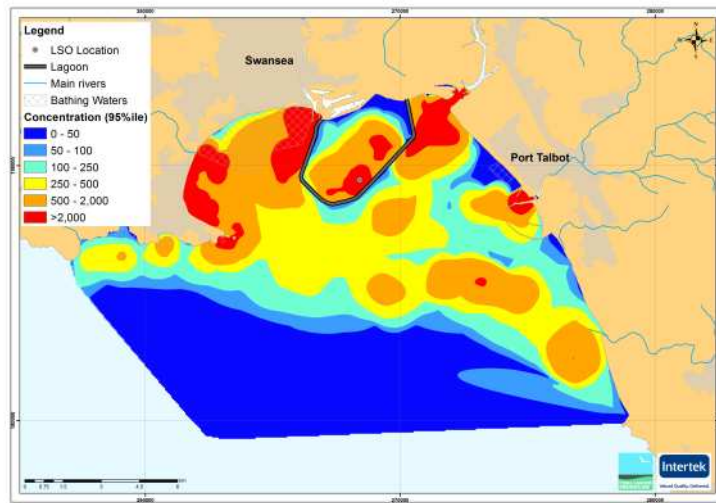
Tidal Lagoon Swansea Bay plc



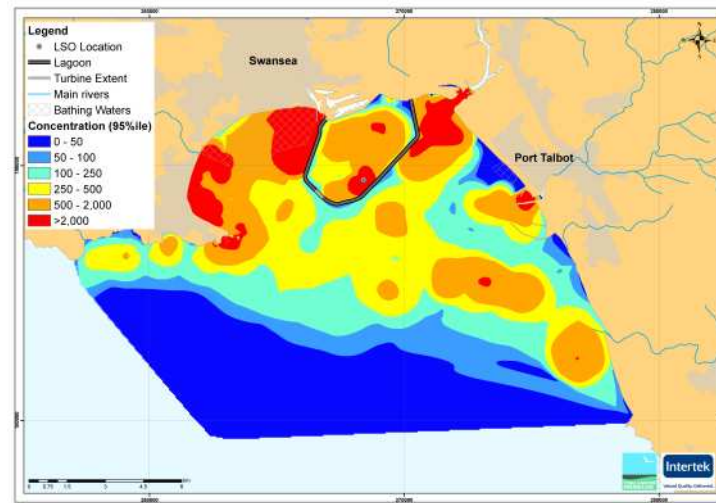
a) Operational Lagoon – dry weather geomean



b) Modified Lagoon - Dry Weather Geomean



c) Operational Lagoon - wet weather 95%ile



d) Modified Lagoon - wet weather 95%ile

E Coli /100ml

Background loads

Spring tide

No wind

Legend

● LSO Location

— Lagoon

— Main rivers

⊞ Bathing Waters

Concentration (Geomean)

0 - 50

50 - 100

100 - 250

250 - 500

500 - 2,000

>2,000

E Coli /100ml

Storm event

Spring tide

No wind

Legend

● LSO Location

— Lagoon

— Main rivers

⊞ Bathing Waters

Concentration (95%ile)

0 - 50

50 - 100

100 - 250

250 - 500

500 - 2,000

>2,000

Figure 7.29 Comparison of the operational Lagoon with turbines relocated and additional discharge on microbiological water quality (E Coli/100ml).

7.8 Conclusions

- 7.8.0.1 An assessment of the potential changes in water quality following construction of the Project in Swansea Bay has been undertaken. The assessment considers relative changes against a Baseline (2015) case and the impacts of these changes on existing water quality, measured against relevant microbiological and chemical standards under the WFD.
- 7.8.0.2 The assessment is based on interpretation of output from the established Swansea Bay Coastal Model. The model has been updated and re-verified against recent survey data, including specific surveys undertaken by TLSB and the Smart Coasts project undertaken by CCSC and Aberystwyth University. Revalidation includes hydrodynamics (current and water level surveys), dispersion (tracer studies) and bacteria decay rates (beach sampling surveys).
- 7.8.0.3 The Smart Coasts data has also allowed a more detailed description of microbiological concentrations from sewers, rivers and streams. The latest DCWW sewerage network models provide detailed predictions of WWTW and CSO discharges. Concentrations of other pollutants have been determined from NRW and DCWW sample records and recent studies of nutrient loads to Swansea Bay.
- 7.8.0.4 The model validation results show a good agreement with survey data and the model is considered fit for use for the Project ES. Combined with the comprehensive input data sets and a precautionary approach to the model applications and assessment of results, this provides a high level of confidence in the model results.
- 7.8.0.5 The following sections provide a summary of the model results, impacts assessment and conclusions. Table 7.28 at the end of the Section provides a summary of the Baseline water quality and the predicted impacts of the Project, in terms of predicted performance against water quality standards under the relevant directives. An indication of the level of confidence in the predicted impacts is also provided.

7.8.1 Effects of the Lagoon on mixing and dispersion

- 7.8.1.1 Models have been applied to a range of determinands and environmental scenarios to provide a broad understanding of water quality impacts. Applications have been undertaken for a Baseline (2015) case, the Lagoon operation and potential optimisation measures. Applications have also been undertaken to assess impacts during the construction and decommissioning phases. The presence of the Lagoon in Swansea Bay would lead to changes in tidal circulation and exchange of water between the Bay and the offshore waters of the Bristol Channel. A number of key changes were determined:
- I. the discharge from the Swansea WWTW becomes trapped in the Lagoon during the flood tide and for part of the ebb tide. During this time the effluent mixes with the Lagoon waters forming a mass of effluent and Lagoon water. Part of this mass is then released from the Lagoon during ebb generation, while part remains within the Lagoon. The high discharge flow and velocity of the release leads to a jet flow, rapidly dispersing the effluent released from the Lagoon into the outer part of Swansea Bay;

- II. the timing of the Lagoon discharge causes only little of the discharge from the Tawe River to enter the Lagoon, as the Tawe plume is transported back into Swansea Bay by the time flood generation begins;
- III. the high flow through the turbines increases tidal velocities between the Lagoon and Mumbles Head. This change in hydrodynamics, although relatively small, is sufficient to lead to changes in plume trajectories and dispersion along the Swansea shoreline, particularly between Blackpill and Mumbles Head. Most significantly it gives rise to greater exchange of offshore water with the water in the western part of Swansea Bay, helping to disperse pollutants in this area;
- IV. the Lagoon blocks tidal water movement between the Tawe and Neath Rivers. This limits the lateral dispersion of the river discharge plumes, i.e. east from the Tawe and west from the Neath;
- V. the river plumes become attached to the Lagoon seawalls. This leads to a further reduction in lateral dispersion;
- VI. in the case of the Tawe, the plume trajectory becomes confined to a much narrower part of the Bay adjacent to the Lagoon seawall. This, combined with greater mixing with offshore water, reduces the area affected by the plume; and
- VII. The effects of the Lagoon on the River Neath discharge are less than the effects on the River Tawe discharge. Attachment of the river plume to the Lagoon seawall has relatively little effect on the trajectory of the plume. Slight offshore movement occurs, and blocking of the flow to the west causes some trapping of the plume in the river. Some small deflection of offshore water south along the Afan coastline is also apparent.

7.8.1.2 The effects of these changes on water quality are generally positive. Changes in the trajectory of the Tawe River plume, and increased exchange of water in the western Bay, causes a small improvement in water quality in this area with the Lagoon in place.

7.8.2 Microbiological impacts

7.8.2.1 The effects of the Lagoon can be seen as a small improvement in predicted microbiological water quality at the Swansea Bay and Aberafan DSPs. These improvements are mainly the result of changes to the Tawe River discharge plume trajectory, and the Lagoon preventing the Tawe plume from reaching the Afan coastline. Additional mixing with offshore waters also helps reduce impacts along the Swansea coastline.

7.8.2.2 Changes in shellfish water quality would also be expected to be small, with potential improvement in some areas. The magnitude of these changes would not be expected to affect shellfish flesh quality or class. The shellfishery in the Queens Dock would not be expected to be impacted by the Lagoon. Although there is a slight deterioration in water quality in the Tawe, at the entrance to the dock, this change is not considered large enough to materially affect water quality in the Queens Dock.

7.8.2.3 Microbiological water quality in the Lagoon would be slightly improved over Baseline conditions, and parts of the shoreline within the Lagoon would be expected to meet Sufficient class under the rBWD. Two optimisation options have been considered to improve water quality in the Lagoon: implementation of UV treatment of storm water discharge from the Swansea WWTW and/or extending the outfall outside the lagoon.

- 7.8.2.4 Extending the existing outfall would place it outside the Lagoon, where impacts would be very low. However the discharge would be displaced, causing a reduction in water quality in some areas of Swansea Bay. To provide a viable solution, i.e. maintaining existing standards of water quality, the outfall would have to be extended by around 1.5km. Extending the outfall would bring potential benefits to all areas of water quality, as it would move the discharge further out into the Bay and into an area of higher dispersion. Extending the outfall would require the outfall pipe to pass through the Lagoon seawall, with potential risks to the integrity of the pipe and Lagoon. The additional outfall length may present hydraulic issues at the WWTW, possibly requiring pumping of the discharge. While these engineering challenges can be overcome, the costs and risks may be significant.
- 7.8.2.5 Implementation of UV disinfection of storm discharges at the Swansea WWTW presents the most cost effective solution. A UV plant is likely to be able to be installed within the existing WWTW site. UV treatment removes a large part of the storm load from the WWTW discharge. The UV plant should be able to treat all storm flows, except under extreme conditions or in the case of plant failure. UV treatment also provides flexibility; it can be up- or down-scaled in response to changes in the catchment. As future catchment improvements reduce storm flows to the WWTW, the UV treatment would need less frequent operation. UV would only remove microbiological pollutants.
- 7.8.2.6 It should be noted that while these options improve water quality in the Lagoon they have a limited effect on water quality in Swansea Bay and almost no effect on water quality at the Swansea and Aberafan DSPs. Given the potential positive effects of the Project on microbiological water quality at DSPs, the optimisation options offer no significant additional benefit, other than within the Lagoon.
- 7.8.3 WFD impacts**
- 7.8.3.1 The changes in circulation and plume behaviour brought about by the Lagoon are predicted to have an impact on other water quality determinands. In general the impacts are small and do not present a significant risk of changes to the WFD class in the Swansea Bay water body. Indeed, in some cases impacts may be positive.
- 7.8.3.2 Temperature and salinity may change in Swansea Bay. The magnitude of any change would be seasonally variable, with greatest change in winter. In winter, temperature and salinity increase slightly in the western part of the Bay as the Tawe discharge is displaced and warmer offshore water is brought in by the operation of the turbines. Conversely, on the eastern side of the Bay, a slight decrease in temperature and salinity may occur as the Neath plume is displaced. Within the Lagoon temperature and salinity would be raised compared to present, with much less variability, as Lagoon water is drawn from the more homogeneous offshore waters. Maximum temperature would not be expected to be raised by the Lagoon, and the Lagoon is not predicted to affect the dispersion of Baglan Bay power station discharge to the tidal River Neath.
- 7.8.3.3 Nutrient concentrations would be likely to fall slightly as mixing between the water in Swansea Bay with offshore water (i.e. beyond a line from Mumbles Head to Port Talbot) is increased. This would bring about slightly more efficient flushing of nutrient rich river water from the Bay. While nutrient concentrations in the Bay would be expected to fall, changes in flow and dispersion at the mouths of the Tawe and Neath estuaries would cause a local increase in nitrogen concentrations in these areas. Based on the available

data and the conservatism of the model predictions, the increase in nitrogen concentrations during Lagoon operation would be relatively small and would not be expected to cause a change in the WFD class of the Tawe, Neath or Afan transitional water bodies. A change in class could occur if the water body were currently close to class boundary over a significant proportion of its area. However available data suggests that this is unlikely to be the case.

7.8.3.4 Changes in nitrogen concentrations during operation of the Lagoon would not be expected to have an adverse effect on primary production.

7.8.3.5 The Lagoon has very little effect on DO levels in Swansea Bay. DO levels in the Lagoon may fall slightly, as the water mass becomes less dynamic and pollutants from the Swansea WWTW discharge are trapped in the Lagoon over the flood tide. However the predicted reduction in DO is small (<5%) and the DO levels remain well in excess of the threshold for High class. Changes in the Lagoon would not compromise existing water body WFD class or lead to adverse impacts on marine life.

7.8.4 Construction impacts

7.8.4.1 During construction the hydrodynamics of the Bay will change gradually as the Lagoon is constructed. The effects of the Lagoon seawalls on the discharge plumes from the Tawe and Neath rivers will increase as the Lagoon seawalls lengthen. In general, these effects will be positive and similar to those seen for the operational Lagoon. Changes in current flow patterns in the central area of the Bay will also cause a deflection of the plume from the WWTW. In general this deflection will be offshore, reducing the impacts of the discharge on coastal waters, until final closure of the Lagoon. At this point the discharge from the Swansea WWTW on the western Bay will increase slightly, but would be less than under Baseline conditions.

7.8.4.2 Disturbance of sediment during construction could lead to local reductions in bacteria decay rates where dredging plumes and discharge plumes from the Swansea WWTW and the Tawe and Neath rivers interact. Model applications suggest the increased turbidity could lead to a deterioration in microbiological water quality at Swansea DSP. However this would only be significant when sustained plume interaction occurred under storm conditions. Such an event is considered unlikely, as construction would be limited to a small area. These effects would also be offset by changes in the plume trajectories as construction progresses. While decay may increase this would be offset as discharge plumes would be less likely to impact the coastline. Overall the effects of local increases in turbidity during construction would not be expected to adversely affect bathing water class or shellfish class.

7.8.4.3 The effects of construction on other determinands, e.g. temperature, salinity, nutrients and DO are assessed as being insignificant, with the distribution of these determinands varying between the Baseline and operational Lagoon scenarios.

7.8.4.4 Contaminants released from sediment during construction and dewatering operations would lead to local increases in the concentration of these pollutants. Most contaminants within the sediment are below CEFAS Action Level 1 (73.5%), and are not considered likely to cause significant impact. Contaminant levels in some areas are between Action Level 1 and 2 (26.5%). Action Level 1 and 2 could still be used, as the contaminant concentrations released to the water column would still be relatively low

and would disperse to EQS levels within a reasonably limited area of the Bay. It should be noted that no samples had contaminants levels above Action Level 2.

7.8.4.5 Analysis of contaminant concentrations and an assessment of available dilution suggest that in most cases contaminants released during construction would reach UKTAG EQS standards within 100m of the release point. Contaminants released from sediment with higher concentrations would achieve EQS levels within 100m to 1000m. However, this is a worst case scenario, as sediment with high contaminant concentrations is restricted to very localised patches of fine surface sediment and the dilutions are based on a continuous release at high concentration. These sediments would generally be avoided, as they are unsuitable for construction purposes. Where these sediments used the duration of any release of contaminants would be relatively short. The dilutions derived from average contaminant levels are considered more representative of the construction area.

7.8.4.6 Overall, the potential impacts of construction on water quality are considered small. Some local and short term increase in pollutant concentrations would be expected, but these would not be likely to significantly impact water quality or lead to a reduction in the present WFD class.

7.8.5 Decommissioning impacts

7.8.5.1 Model sensitivity applications show that the removal of the turbines and sluice gates would change local plume behaviour and dispersion in Swansea Bay. The timing of flow into and from the Lagoon would be changed, as would the nature of the plume, changing from a jet-like behaviour towards a lower momentum behaviour. This would cause greater impact of the Swansea WWTW plume on local bathing waters at Swansea and Aberafan. These impacts could be mitigated by reducing the load from the Swansea WWTW storm discharge, e.g. UV treatment or outfall extension. However, it should be noted that the water quality in Swansea Bay by the time of decommissioning (over 100 years) is likely to have changed significantly. An assessment of impacts would, therefore, be required closer to the time of decommissioning.

7.8.6 Design iterations

7.8.6.1 Changes in the location of the turbines and a 10% increase in generating flow have been assessed using model sensitivity applications. Under these conditions water quality within the Lagoon is slightly reduced, as higher inflows and the increased tidal range in the Lagoon cause greater advection of the plume toward the shoreline. This would reduce the area of the shoreline within the Lagoon achieving rBWD Sufficient status. The implementation of optimisation options to reduce storm water load from the Swansea WWTW, would partly reduce this effect during storm conditions.

7.8.6.2 Within Swansea Bay changes to the turbine sluice gate housing location and flow have relatively little effect. A change in the quantity of offshore water entering the western part of the Bay leads to a small increase in bacteria concentrations in this area, as the WWTW discharge plume extends further west. This is accompanied by a slight reduction in the concentration near the turbines. The change is small and would not be expected to significantly affect the predicted improvements in bathing water quality at Swansea Bay DSP with the Lagoon in place. Little change is seen in the eastern side of the Bay and along the Afan coast. Changes to shellfish water quality are not considered significant when compared to the Baseline or Lagoon case.

- 7.8.6.3 Changes to just the turbine sluice gate housing location, or the generating flow would be expected to have a lower level of impact to those of their combined effects.

7.8.7 Smart Coasts model

- 7.8.7.1 As part of the rBWD CCSC will be required to implement a beach management plan for the Swansea Bay bathing water, this plan should include provision to advise bathers when water quality is Poor. In order to improve this advice CCSC is making use of a predictive black box model developed by the University of Aberystwyth under the EU-funded Smart Coasts project. The model allows hourly predictions of bathing water quality at the DSP, based on a series of environmental inputs, e.g. sunlight, wind, tide and river flow. Under the provisions of the rBWD the black box model predictions also permits discounting of DSP water quality samples taken during periods when poor quality is predicted and confirmed by sampling.
- 7.8.7.2 During the bathing water season of 2013, the water quality in Swansea Bay met the Sufficient class, the standard required under the rBWD. This represents a significant improvement on previous years, and is due in part to the implementation of the black box model predictions and discounting scheme.
- 7.8.7.3 Following completion of the Project it is possible that the hydrodynamics of Swansea Bay will be changed and predictions from the black box model may be rendered inaccurate. As such, it may well be necessary to adapt the model.
- 7.8.7.4 TLSB proposes that following completion of construction of the Project will make provision either to update or replace the model with a version that contains the Project as built. This is subject to it being necessary and appropriate to do so.

Table 7.28 Summary of water quality Baseline and Project impacts

Feature	Baseline		Project				Confidence in Baseline and Predicted Impacts
	2012	2015	Construction	Lagoon	Optimisation Option 1	Optimisation Option 2	
Beaches	cBWD / rBWD	Predicted rBWD					
Aberafan Beach	I / Sufficient	Good	Good	Good ²	Good ²	Good ²	High
Swansea Beach	I / Poor	Sufficient / Poor ¹	Sufficient / Poor	Sufficient / Poor ²	Sufficient / Poor ²	Sufficient / Poor ²	High
Bracelet Bay	G / Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	High
Limeslade Bay	G / Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	High
Langland Bay	G / Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	High
Caswell Bay	G / Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	High
Lagoon*	I / Sufficient	I / Sufficient	Sufficient	Sufficient ³	Sufficient ³	Excellent ³	High
Classified shellfish waters	Current	Predicted					
Southern Beds	B - LT	B - LT	B - LT	B - LT	B - LT	B - LT	High
Swansea Bank	B - LT	B - LT	B - LT	B - LT	B - LT	B - LT	High
Crymlyn Burrows	n/c	n/c	n/c	n/c	n/c	n/c	High
Northern Beds	n/c	n/c	n/c	n/c	n/c	n/c	High
Mumbles	n/c	n/c	n/c	n/c	n/c	n/c	High
Queens Dock	B	B	B	B	B	B	High
WFD Biological and supporting element	Current	Predicted					
Phytoplankton	Bad	Bad	Bad	Bad	Bad	Bad	Moderate to High
Dissolved Inorganic Nitrogen	Moderate	Moderate	Moderate ⁴	Moderate ⁴	Moderate ⁴	Moderate ⁴	Moderate to High
Dissolved Oxygen	High	High	High	High	High	High	High
Copper	High	High	High ⁵	High	High	High	High
Toluene	High	High	High	High	High	High	High
Chemical Elements	Current	Predicted					
Benzene	High	High	High	High	High	High	High
Lead and its compounds	High	High	High ⁵	High	High	High	High
Mercury and its compounds	High	High	High ⁵	High	High	High	High
Nickel and its compounds	High	High	High ⁵	High	High	High	High

* Or equivalent location prior to Project

1 Borderline Sufficient / Poor class. Risk of Poor class in wet years.

2 Some slight improvement in quality predicted, but not sufficient to change class.

3 Predicted minimum standard over those areas of the Lagoon impoundment proposed for bathing and swimming activities.

4 Large areas are expected to improve. Some reduction in quality is predicted in the Neath and estuaries and adjacent coastal waters. However this should not to impact WFD class.

5 Local short term reductions in water quality and class from construction and dewatering activities are predicted.

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