Appendix 7.2

Supporting Technical Information Report

TIDAL LAGOON SWANSEA BAY LIMITED

TIDAL LAGOON SWANSEA BAY MARINE WATER QUALITY ASSESSMENT

SUPPORTING TECHNICAL INFORMATION

Report Reference. P1609_RN3391_Rev1

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LIST OF ABBREVIATIONS

ABPMer	ABP Marine Environmental Research Ltd
AD	Advection Dispersion
ADCP	Acoustic Doppler Current Profiler
BOD	Biological Oxygen Demand
cBWD	current Bathing Water Directive
CCSC	City and County of Swansea Council
cfu	Colony Forming Units
CREH	Centre for Research into Environmental Health
CSO	Combined Sewer Overflows
DAIN	Dissolved Available Inorganic Nitrogen
DAIP	Dissolved Available Inorganic Phosphorus
DO	Dissolved Oxygen
DSP	Designated Sampling Point
DCWW	Dŵr Cymru Welsh Water
EA	Environment Agency
EC	Escherichia Coli
EIA	Environmental Impact Assessment
FC	Faecal Coliforms
FEH	Flood Estimation Handbook
FIO	Faecal Indicator Organism
HD	Hydrodynamic
HW	High Water
Intertek	Intertek Energy & Water Consultancy Services
IE	Intestinal Enterococci
km	Kilometre
l/s	Litres per second
LSO	Long Sea Outfall
ml	Millilitre
NRW	Natural Resources Wales
PDM	Probability Distribution Model
psu	Practical Salinity Units
rBWD	revised Bathing Water Directive
SEPA	Scottish Environment Protection Agency
SW	Shellfish Water
SWEAR	Storm Water Eradication and Removal
TLSB	Tidal Lagoon Swansea Bay
T/S	Temperature and Salinity
UKTAG	United Kingdom Technical Advisory Group
UV	Ultra-Violet
WFD	Water Framework Directive
WIMS	Water Information Management System
WwTW	Wastewater Treatment Works

1 INTRODUCTION

1.0.0.1 This report provides a technical appendix to Chapter 7: Marine Water Quality Assessment of the Swansea Tidal Lagoon Environmental Impact Assessment (EIA). The appendix provides supporting technical information not presented in the EIA Chapter. This report covers seven main areas:

Section 2 A description of the Swansea Bay Coastal Model. This is largely a repeat of information provided in Section 7.5 of the EIA, but is reproduced here for context.

Section 3 A description of the model applications. This section expands on Section 7.6 of the EIA, and provides additional information on the model set-up and a more detailed description of Intertek Energy & Water Consultancy Services' (Intertek) STORM-IMPACT software.

Section 4 A description of the validation of the advection dispersion (AD) component of the coastal model. This information is not presented in the EIA.

Section 5 A description of the validation of the STORM-IMPACT model. This information is not presented in the EIA.

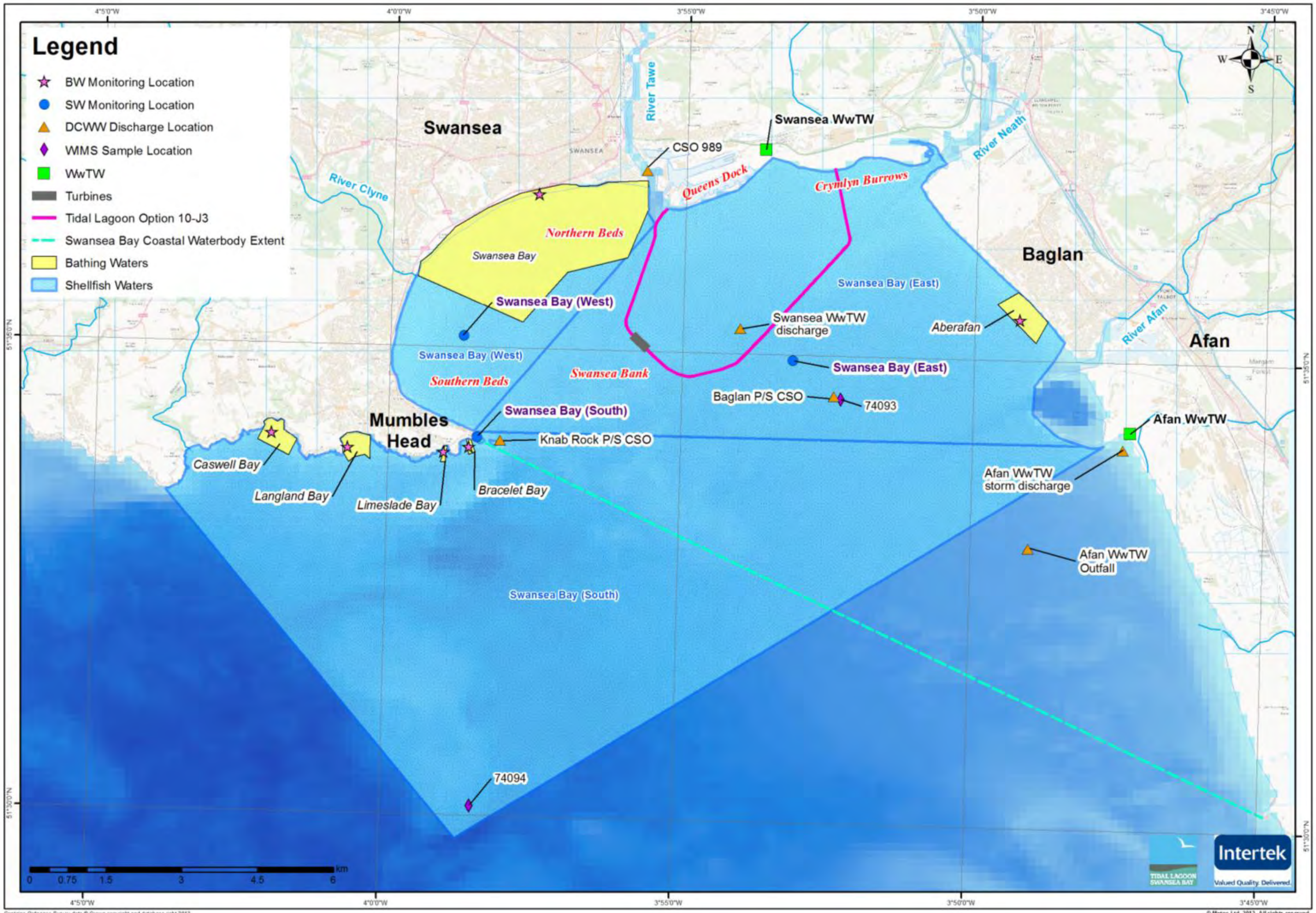
Section 6 A description of wind sensitivity applications. This section expands on the information provided in Section 7.7.2 of the EIA.

Section 7 A description of the input sources, flows and concentrations used in the microbiological sensitivity applications and STORM-IMPACT applications. This information is not presented in the EIA.

Section 8 A description of the input sources, flows and concentrations used in the model applications for Water Framework Directive parameters, e.g. temperature, salinity, nutrients and dissolved oxygen. This section expands on the information provided in Section 7.6 of the EIA.

1.0.0.2 Figure 7-1 from the EIA is reproduced here as Figure 1-1, and provides a geographical overview of the study area and key locations.

Figure 1-1: Geographical Overview of Swansea Bay



2 SWANSEA BAY COASTAL MODEL

2.0.0.1 The Swansea Bay Coastal model was originally constructed and validated in the early 1990's 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.

2.0.0.2 The model was constructed to support Dŵr Cymru Welsh Water's (DCWW) investment programme, particularly the design of the Swansea and Afan WwTWs. The model domain extends from the tip of the Gower Peninsular to Porthcawl and some 15 kilometres (km) to 20km offshore. The model is built on a curvilinear grid system with a varying resolution over the model domain: from approximately 50 metres (m) in Swansea Bay to 200 m 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-1990's.

2.0.0.3 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 applications. The re-validated model was audited by Professor Roger Falconer of Cardiff University and accepted as fit for use by Natural Resources Wales (NRW) (then EAW).

2.0.0.4 Since 2012, the model and supporting data have undergone further update and improvement in support of DCWW's AMP5 investment programme: this work has continued through 2013. These updates have been undertaken with the support of both DCWW and Tidal Lagoon Swansea Bay (TLSB), to ensure the revised model is fit for purpose for the TLSB EIA and DCWW 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 (being developed by ABP Marine Environmental Research Ltd (ABPmer) for the Lagoon EIA) in the coastal area and to incorporate the extended river Tawe. River Tawe bathymetry is based on NRW Section 105 topographic surveys; and

d) Validation of revised model hydrodynamics against new water level and current speed data from 2011 (Smart Coasts) and 2012 (Titan Environmental Surveys Ltd.[Ref 1]). These include continuous (14 or more days) data sets at five tide gauge sites and seven current meter sites.

2.0.0.5 The revised model domain, grid and bathymetry are presented in Figure 2-1. Full details of the model update and validation can be found in the Swansea Bay Hydrodynamic Model Update and Validation Report[Ref 2].

2.0.0.6 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:

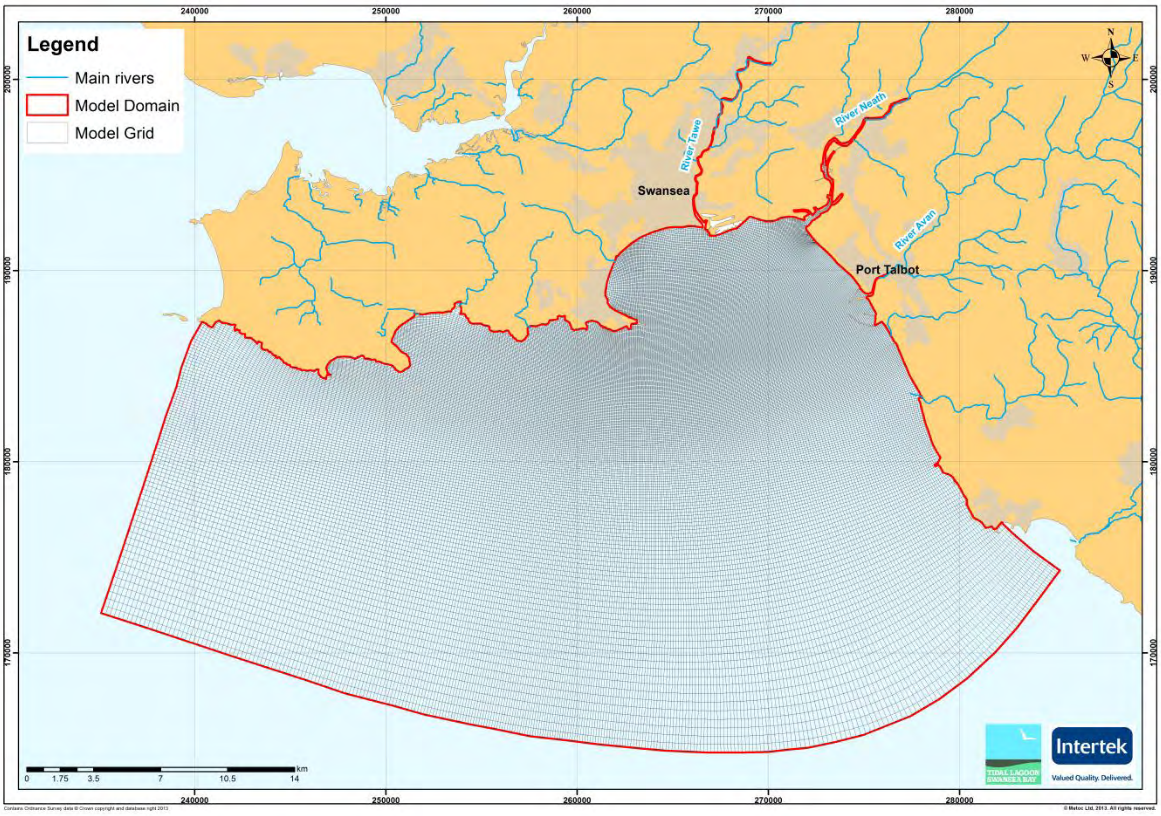
a) Revised sewer network models that define Wastewater Treatment Works (WwTW) and Combined Sewer Overflows (CSO) discharges to the bay. The model revisions reflect changes in the network and the effects of recent changes in population and improved asset performance expected to come in to effect from 2015. The sewer model applications also reflect recent increases in rainfall in the Swansea area, and assume a similar pattern will remain in future. The validated models were developed by DCWW as part of the AMP5 investment programme and include the catchments of Swansea, Neath, Baglan and Afan; and

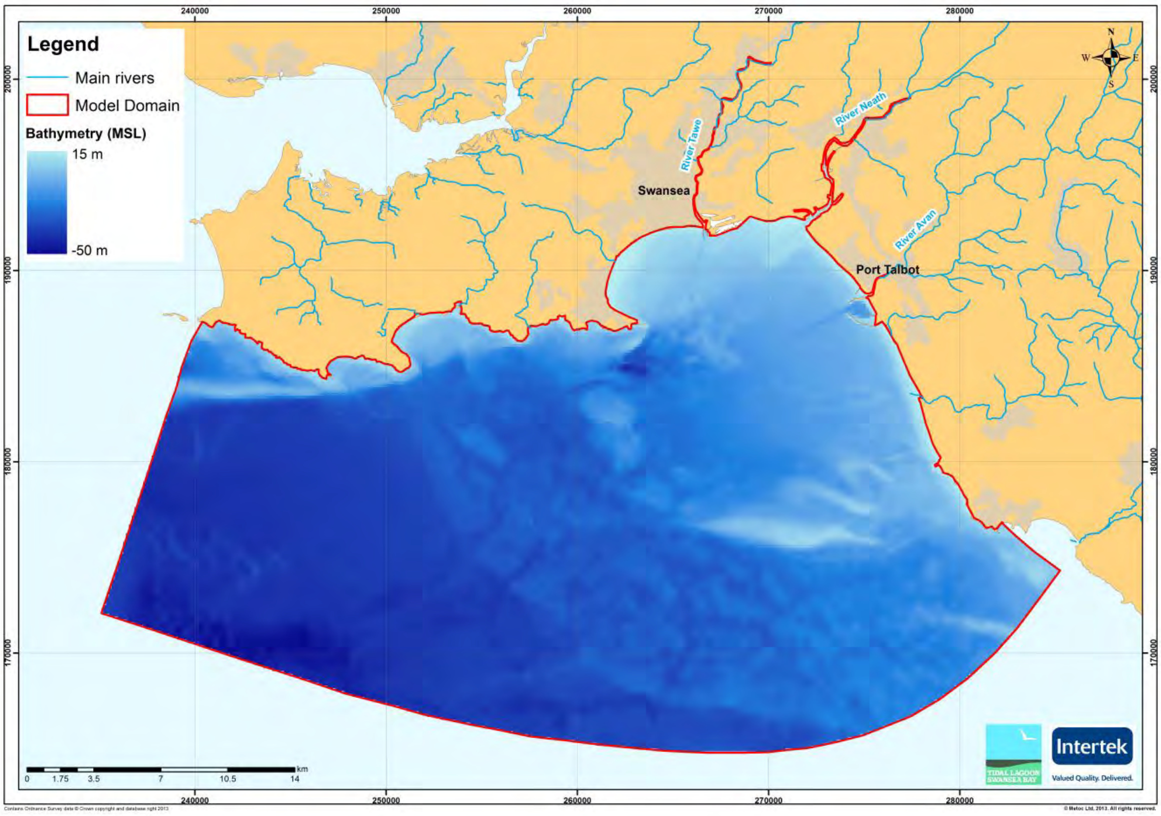
b) Extensive loading and bathing water quality data collected by City and County of Swansea Council (CCSC) and Aberystwyth University in 2011 under the EU-Interreg funded Smart Coasts project. These new data sets provide additional input and validation information to support model applications for bathing and shellfish water impacts. Data has been used to provide more accurate definition of sewer concentrations and river loads of faecal indicator organisms (FIO).

2.0.0.7 The updates to the model supporting data will be described in more detail in the following sections.

2.0.0.8 Overall, the updates to the model and supporting data provide one of 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.

Figure 2-1: Model domain, grid and bathymetry





2.1 MODEL PARAMETERS

2.1.1 Dispersion

2.1.1.1 Dispersion is a physical process that governs pollutant transport in the coastal waters. In the coastal model the dispersion process is calculated by the AD model. A dispersion coefficient is used to represent sub-grid dispersion processes. The dispersion coefficient was re-calibrated against dye survey data during the updates of the Swansea Bay Model in 2006. During this study, further validation of the AD model was carried out against tracer studies undertaken as part of the Smart Coasts Study (Section 5).

2.1.2 Decay rate

2.1.2.1 Bacteria decay rate (T_{90}), defined as the time required for 90% bacterial die off, is the most commonly used parameter for describing bacterial mortality.

2.1.2.2 As part of the present study, the decay rates were re-validated using the latest available bathing water sample data from NRW and the Smart Coasts study. Bacteria decay rates (T_{90}) for Escherichia Coli (EC) and IE in the order of 50 hours (EC) and 70 hours (IE) were found to provide best fit with bathing water sample data. These T_{90} values are higher than typical values in coastal waters (20 hours for EC and 40 hours for IE), and reflect the high turbidity found in Swansea Bay, but are consistent with values used in previous studies along the South Wales coast and the available literature. It should be noted that the decay rate represents an average; in order to maintain a precautionary, worst case approach variable (diurnal) decay rates have not been adopted.

2.1.2.3 Details of the validation of decay rates, primarily for use in the STORM-IMPACT model, can be found in Section 6.

2.1.3 Wind conditions

2.1.3.1 Wind is an important component of the overall impact assessment as wind speed, direction and frequency are potentially important in pollutant transport and impact on bathing and other receiving waters.

2.1.3.2 Wind conditions used in the previous 2006 bathing water study are adopted in this assessment. Representative wind conditions were determined using sensitivity analysis based on wind frequency data from Mumbles Head. A sub-set of wind speeds and directions were determined that represent wind conditions with greatest influence on pollutant dispersion in Swansea Bay.

2.1.3.3 Table 2-1 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 4.4).

Table 2-1: List of wind conditions used in model applications

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

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

2.2 DISCHARGE SOURCES

2.2.1 Source terms

2.2.1.1 In order for the coastal model to provide accurate and robust predictions of water quality it is essential that all of the significant discharges to Swansea Bay are included in the model. These discharges fall into a number of categories:

a) **Diffuse inputs:** typically direct runoff, to rivers and the coastline, of pollutants washed from the land when it rains. The largest source is generally nutrient and faecal indicator runoff from upstream agricultural land. Localised urban runoff may also contribute to rivers from direct wash-off and local storm water drainage systems. Loads from misconnections (i.e. domestic foul discharges connected to land drains in error) are also a significant source of diffuse loads in a number of small streams in Swansea. 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). Inputs from WwTWs and CSOs located higher in the river catchments may also be considered as a component within the diffuse load.

b) **WwTW inputs:** in Swansea Bay there are two WwTWs at Swansea and Afan. Both WwTWs provide secondary treatment of effluent; Swansea WwTW also provides further Ultra-violet (UV) disinfection of secondary treated effluent. The WwTWs discharge via long outfalls to Swansea Bay. These outfalls may also discharge untreated storm effluent during rainfall events.

c) **CSOs** provide relief to the sewer network during periods of high rainfall. These typically discharge a mixture of foul domestic effluent and storm water runoff (e.g. roads, roofs, hard standing etc.). During periods of rainfall CSOs can discharge a significant load to rivers and coastline. Much of DCWW's current investment programme is aimed at reducing discharges from significant CSOs in Swansea, through a combination of storm water storage and storm water separation under the Storm Water Eradication and Removal (SWEAR) initiative.

d) **Storm water run-off:** from separated drainage systems. These systems provide local drainage from roofs, roads and areas of hard standing and typically discharge direct to local water courses. As there is no domestic effluent in the discharge the concentrations of pollutants, particularly FIOs, tend to be low, compared with other sources.

e) **Industrial effluent:** may be discharged directly from industrial sites to water courses, where suitable permits are in place. Some industrial effluent may contain large quantities of nutrients or biological oxygen demand (BOD), but generally contains little bacteria. There are few significant industrial discharges in the Swansea Bay area; smaller sites tend to discharge to sewer.

2.2.1.2 All discharges are considered as two components, a continuous background load during dry weather conditions and an additional storm load during rainfall events. Storm water discharges do not generally have a continuous load, as they only operate during rainfall.

2.2.1.3 In order to adequately represent the various discharge sources within the model, a review of discharge consents and available asset data held by DCWW was undertaken. Reference was also made to the discharges monitored in the recent Smart Coasts study. From this information, the significant discharges to Swansea Bay were identified. These included:

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; and

iii) The Tata steel discharge at Port Talbot;

2.2.1.4 Other smaller discharges have been excluded, as these are relatively small compared to the other source; typically the discharge from these sources are 100 to 1000 times smaller than the significant discharges.

2.2.1.5 The discharge sources used in the model applications are summarised in Figure 2-2. A total of approximately 175 discharge sources are used in the study. The locations of the discharge from each asset were then entered in to the coastal model. To maintain a manageable number of discharge locations assets were grouped based on proximity of discharge location. For smaller streams and tributaries all discharges were 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; although such dispersion is generally low along the short reaches of stream considered. A total of 38 discharges are included in the model; locations are shown in Figure 2-2.

2.2.1.6 Where a discharge is located between high water (HW) and low, a walking discharge is adopted in the model. This allows the discharge location to move up or down the beach as the tide moves in and out, simulating the effect of discharge running over the beach.

2.2.1.7 A full list of discharge sources, their modelled discharge locations and loads is provided in Section 7.

2.2.2 Definition of discharge load

2.2.2.1 Discharge sources are defined as a time varying load of pollutant. The load is made up of flow multiplied by discharge concentration.

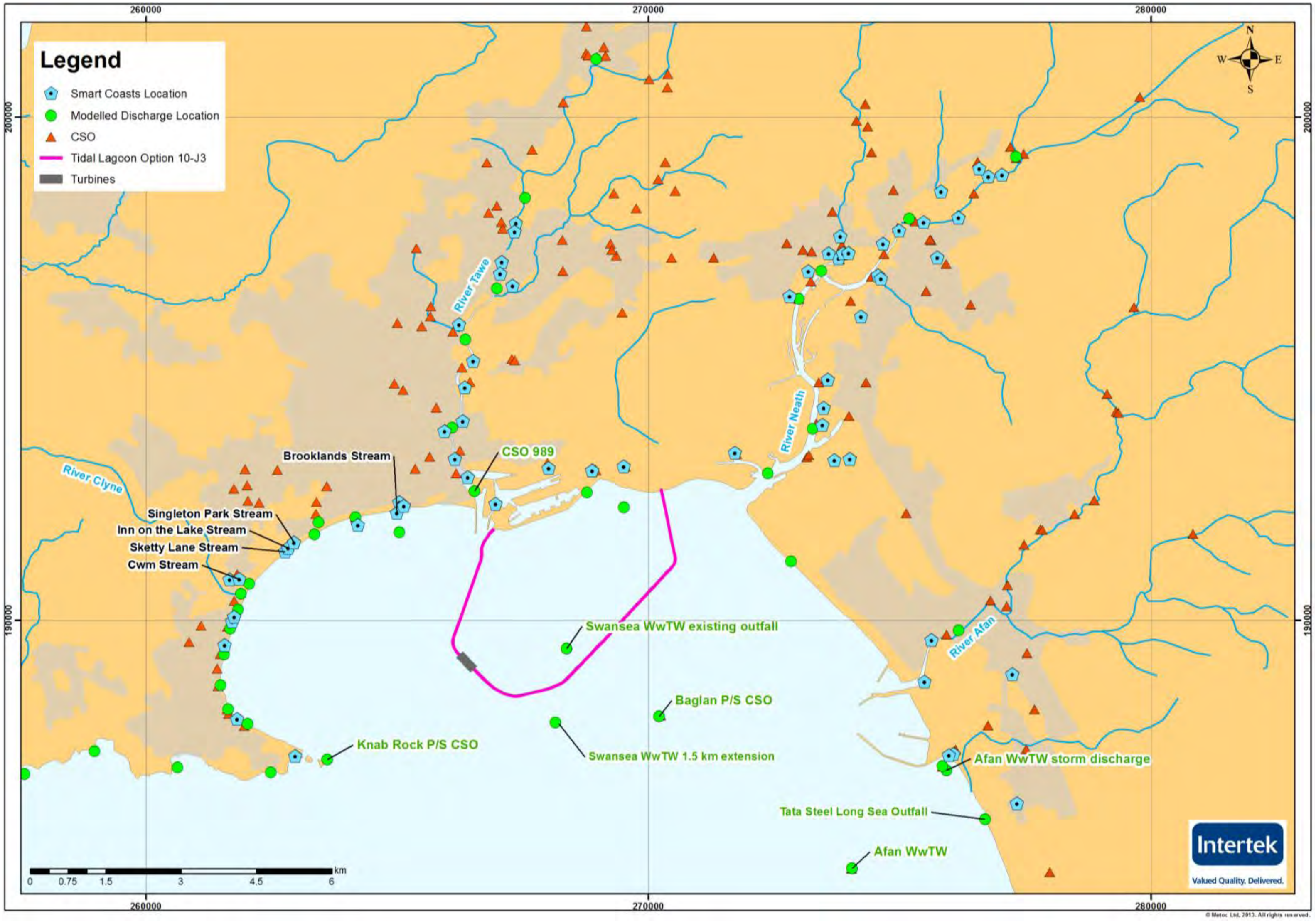
2.2.2.2 Discharge concentrations are derived from a number of sources. Directly measured concentrations are preferred, as these take account of local variations and the effects of dilution, e.g. by storm water. The Smart Coasts study provided sewer and river FIO samples at a number of locations in the catchments (Figure 2-2). A description of the discharge concentrations applied in the model is provided in Section 7.

2.2.2.3 Where direct measurement is not available, concentrations are derived from measurements in similar catchments, literature, or industry best practice guidelines. A number of comprehensive sources for discharge concentrations are available in the absence of measured data. Where concentration data is not available a precautionary approach is adopted.

2.2.2.4 Measured discharge flows are seldom available in sufficient quantity for model applications. Flows are therefore derived from a number of sources, which include:

a) River flows for larger rivers (Tawe, Neath, Afan) are derived from NRW gauging station records;
b) Smaller rivers and streams are generally not gauged; flows in these are estimated using hydrological models and available rainfall records. Where possible, these models are validated against available data. For very small catchments, flows are derived by adjusting measured or modelled flows from neighbouring catchments with similar characteristics, typically by factoring based on catchment area;
c) Sewer discharges, from WwTW and CSOs, are derived from catchment network models developed for sewer network investigations;
d) Flows from industrial sources are determined from consent records or design information,
e) Supporting hydrological and network models.

Figure 2-2: Discharge sources, model discharge locations and Smart Coasts sample locations



2.2.3 Hydrological model

2.2.3.1 Flows from un-gauged rivers and streams are estimated from a hydrological model developed for DCWW AMP4 / AMP5 studies. The hydrological model was originally developed and validated against available flow gauging in the Clyne catchment, and is driven by rainfall recorded at St Helens in Swansea. This model was then used to estimate flows in other small local streams around Swansea Bay. Additional checks of the model were undertaken against a number of spot gauging records and gauged data collected during the Smart Coasts study.

2.2.3.2 The hydrology model is based on the 'Revitalised FSR/ Flood Estimate Handbook (FEH) Rainfall-Runoff Method[Ref 3] that has been extensively documented in the Flood Estimation Handbook Supplementary Report No. 1, Revitalisation of the FSR/FEH rainfall-runoff method, and Dissemination of the revitalised FSR/FEH rainfall-runoff method. The revitalised FSR/FEH rainfall-runoff method was developed to replace the rainfall-runoff method provided in the FEH, following criticism of the existing methodology. This model has been developed to improve the way that observed flood events are simulated.

2.2.3.3 The key improvements are:

a) a new baseflow model. This model provides an improved approach to the separation of total runoff into baseflow and direct runoff

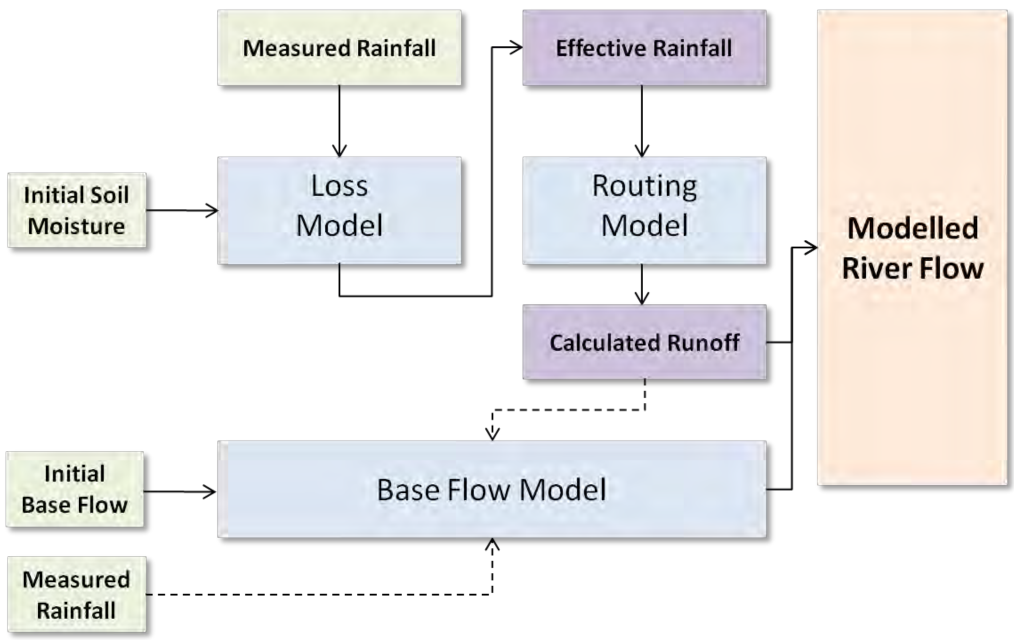
b) a loss model based on a uniform probability distribution model (PDM)

c) a unit hydrograph approach with a more flexible hydrograph shape

d) a better methodology for calculating antecedent soil moisture conditions

2.2.3.4 The overall basis for the model is represented in Figure 2-3.

Figure 2-3: Schematic representation of the hydrological model



2.2.4 Sewer network models

2.2.4.1 WwTW and CSO discharges have been derived from DCWW network models of the Swansea, Neath, Baglan and Afan sewerage catchments. These models were initially developed and validated during AMP3 and AMP4. They have subsequently been updated and re-validated for sewer network improvement works in AMP5.

2.2.4.2 For the purpose of this study, DCWW was requested to run the network models for a range of scenarios. This work was undertaken by DCWW's network consultant's Grontmij during summer 2013. The latest versions of the models were used. For the Swansea catchment this includes re-validation against surveys undertaken in the Clyne, Singleton Park and Mumbles areas in 2012 and 2013. All models were run using the same rainfall time series data as the hydrological models to ensure consistency in the phasing of storm events between river and network discharges. Two scenarios were requested.

a) **Historical baseline**, covering the period 2008 to 2011 and representing current conditions. This output was used for validation of the coastal and STORM-IMPACT models (see Sections 4 and 5) against bathing water monitoring data collected by NRW routine monitoring and during the 2011 Smart Coasts surveys.

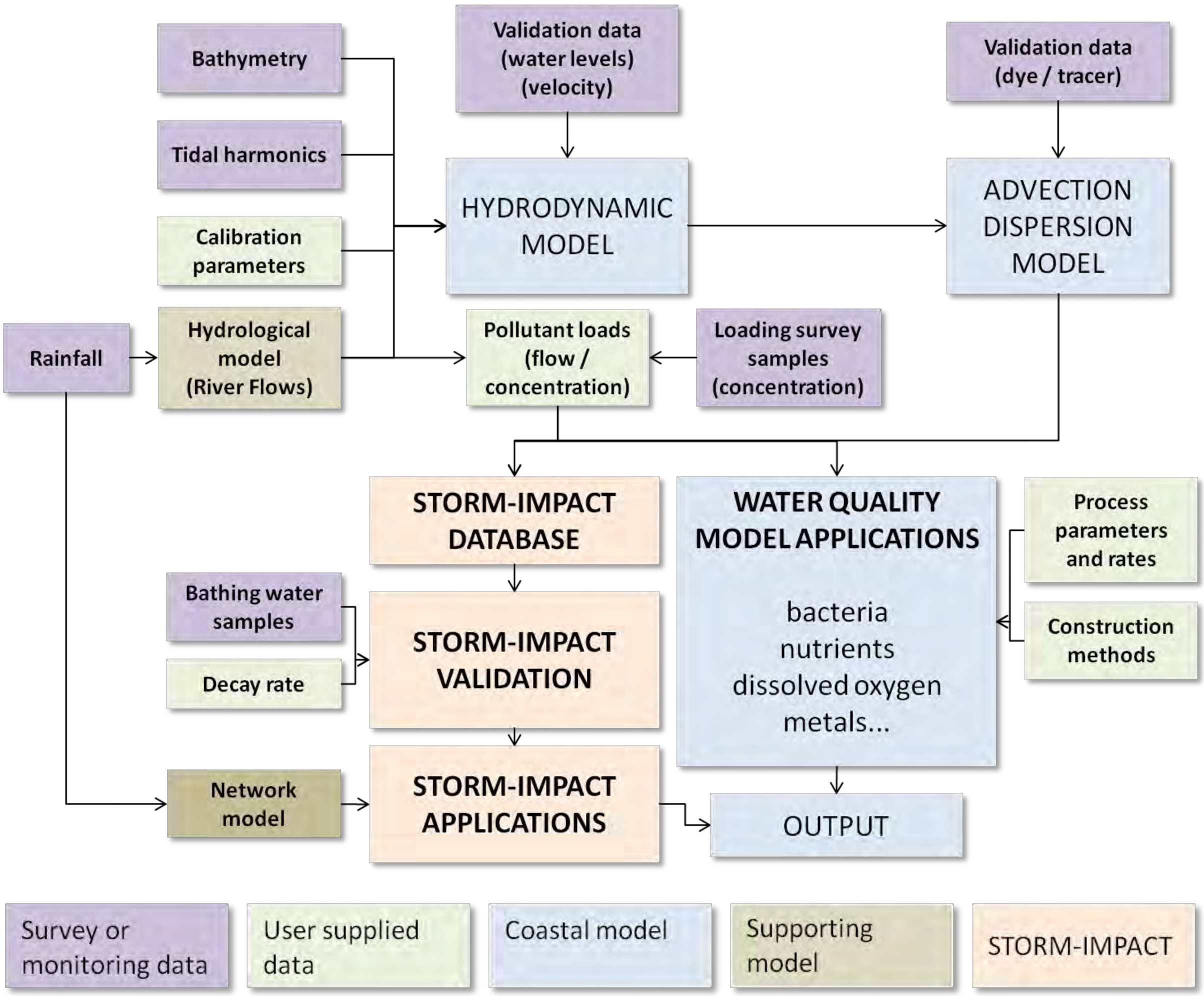
The 2008 to 2011 period was also chosen as it represents the recent period where bathing water performance at Swansea and Aberafan bathing waters has deteriorated. This deterioration is in part due to a series of wet summers, with higher than average rainfall. It therefore provides a worst case condition for subsequent impact assessments as it is assumed that recent trends in higher summer rainfall will continue.

b) **Baseline**, covers the expected sewer network conditions at the time of the proposed Lagoon construction and commissioning, i.e. between 2015 and 2018. This model includes the proposed AMP5 improvements that are due for completion in 2015 to 2016.

2.3 MODEL APPLICATIONS

2.3.0.1 The types of model applications used vary depending on the determinands and scenarios considered. Applications are designed to provide the best possible prediction of impacts based on the available input data. All model applications use the validated hydrodynamic (HD) and AD models as a basis. The integration of coastal model, supporting models and data sets are shown diagrammatically in Figure 2-4.

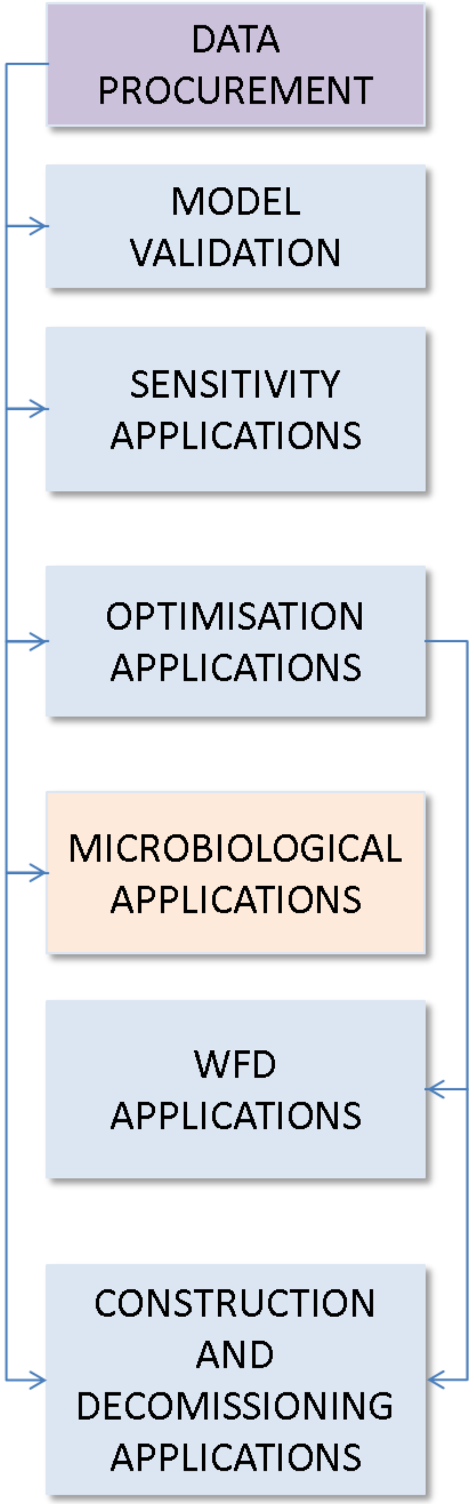
Figure 2-4: Schematic representation of model and data interfaces



2.3.0.2 Model applications have been undertaken as a series of iterative steps. These are shown schematically in Figure 2-4. At each step, the type of application, the model inputs, scenarios, and environmental conditions assessed is optimised to maintain a manageable number of applications while ensuring sufficient model output for an informed analysis and interpretation of the results to be undertaken.

2.3.0.3 The models and applications shown in Figures 2-4 and 2-5 are described further in Section 3.

Figure 2-5: Schematic representation of model steps



- Procure, check and process input data and validation data.

- Confirm model confidence, and fitness for use.

- Baseline and Lagoon applications for typical dry and wet weather scenarios to assess sensitivities of water quality to Lagoon.
- Identify potential optimisation options.

- Test and optimise optimisation options to minimise Lagoon impacts on receiving waters.
- Identify and test preferred options.

- Full STORM-IMPACT applications for baseline, Lagoon and optimisation options.
- Assess results against relevant standards to assess impacts on receiving waters.

- Model applications for relevant Water Framework Directive (WFD) determinands.
- Assess and interpret results against relevant standards to assess impacts on receiving waters.

- Sub-set of applications to assess impacts for a range of determinands.
- Review against full Lagoon runs to assess impacts on receiving waters.
- Identify mitigation where appropriate.

3 MODEL APPLICATIONS

3.0.0.1 The following section provides a summary of the model applications undertaken, in terms of the model set-up and inputs and any modifications made to the model to represent the various scenarios that have been considered. Further details on the specific applications of the model and interpretation of model output are provided in the EIA Chapter 7 Marine Water Quality Assessment.

3.1 VALIDATION APPLICATIONS

3.1.0.1 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 observations. Calibration parameters are adjusted until best fit between model and observation is achieved.

3.1.0.2 The validation of the existing hydrodynamic model for the Lagoon study is detailed separately[Ref 2].

3.1.0.3 The AD model was validated in 2006 against dye tracer surveys in 2005 and 2006. Further validation against Smart Coast's tracer studies has been undertaken under this study and is described in Section 4.

3.1.0.4 STORM-IMPACT model validation has been undertaken against NRW routine monitoring data and Smart Coasts sample data and is described separately in Section 6.

3.2 SENSITIVITY APPLICATIONS

3.2.0.1 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 a discharge plume(s) under these conditions, and the sensitivity of plume dispersion to the presence of the Lagoon structure. These applications provide a means of assessing short term sensitivities during specific discharge events (e.g. storms). The models can also be used to assess longer term impacts for conservative contaminants, where short term changes in discharge rates or environmental conditions have a more limited effect.

3.2.0.2 To assess sensitivity to the presence of the Lagoon, models are run for two conditions:

a) **Baseline**, i.e. current discharge but with no Lagoon.

b) **Lagoon** in place, i.e. the model is modified to include a physical representation of the Lagoon and the discharge through the turbines. The turbine discharge is based on information provided by TLSB and is set up in the model as an internal flow boundary controlling flow to and from the Lagoon. For Lagoon applications, the Lagoon model is run with all discharge conditions remaining as for the Baseline, except for optimisation options where the discharge concentration or location of the Swansea WwTW is modified (see Section 3.4).

3.2.0.3 Sensitivity applications were also undertaken to assess the effects of proposed dredging within the Lagoon area on hydrodynamics and dispersion. The dredging is required to provide fill for the Geotubes® and Lagoon walls. A number of dredging locations and depths scenarios were tested. No significant changes in hydrodynamics or dispersion within the Lagoon were identified, i.e. hydrodynamics and dispersion were not significantly sensitive to dredging area or depth.

3.2.0.4 Sensitivity applications were run for:

a) Microbiology
b) Temperature and salinity (T/S)
c) Nutrients (Nitrogen)
d) Dissolved Oxygen (DO)

3.2.1 Sensitivity – Microbiology

3.2.1.1 Microbiological sensitivity was assessed by applying the model to a typical dry weather condition and a storm event. A large storm event from 2011 was chosen, with discharge loads determined from existing models and data sets. Discharges included WwTWs, rivers and significant storm inputs (e.g. CSOs). Model applications were undertaken for mean tidal conditions and a range of wind conditions. Applications were undertaken for an E Coli FIO, with a decay rate of 50 hours applied.

3.2.1.2 A summary of the sensitivity applications undertaken is provided in Table 3-2 at the end of this section. Further details of the model set-up and inputs for each application are provided in Section 8.

3.2.2 Sensitivity – WFD determinands

3.2.2.1 Applications were undertaken to assess the sensitivity of a range of other physio-chemical determinands to the effects of the Project. These additional determinands are typically conservative, i.e. not subject to significant decay or loss, or are subject to other physical or chemical processes.

3.2.2.2 Models were set up using a precautionary approach in terms of the selection of environmental conditions, input parameters and process coefficients. 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 Section 8.

3.2.2.3 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. revised Bathing Water Directive (rBWD) and shellfish water standards and Water Framework Directive (WFD) UK Technical Advisory Group (UKTAG) standards where applicable. Details of these directives and standard are provided in Section 7.2 of the EIA.

3.2.2.4 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.

3.2.2.5 A summary of the sensitivity applications undertaken is provided in Table 3-2. Details of the model set-up and inputs for each application is provided in Section 8.

3.3 MICROBIOLOGICAL MODEL (STORM-IMPACT)

3.3.0.1 Bathing water and shellfish water standards are determined from percentile concentrations of bacteria FIOs from long term monitoring data. 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:

a) **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 generally low levels of bacteria in receiving waters. During periods of rainfall, diffuse runoff and storm water discharges (e.g. CSOs) can add a significant additional load from multiple sources to the receiving water.

b) **Environmental conditions –** river flow, tide and wind affect the dispersion of discharge plumes and bacteria in the receiving water.

c) **Phasing** – storm conditions generally occur independently of tide conditions and under a wide range of wind conditions. The same storm event may give significantly different impacts depending on whether the discharge occurs at high water (HW), low water (LW), on a spring or neap tide, or under different wind speeds and directions.

d) **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.

3.3.0.2 In order to fully predict the impacts of discharges on bathing and shellfish water performance, it is necessary to assess a large number of dry and storm events over a wide range of environmental, phasing and rainfall conditions. Achieving this with a coastal model is generally impracticable given the large number of model applications required to cover a statistically significant set of discharge and environmental conditions. However, without such an assessment, accurate prediction of bathing water performance would not be possible. In order to provide robust predictions of bathing water performance, Intertek has developed STORM-IMPACT.

3.3.0.3 STORM-IMPACT is a process for the evaluation of the impact of continuous and intermittent discharges on sensitive receivers. It 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. From these results, STORM-IMPACT can be used to assess performance against environmental standards and to provide environmental design optimisation (e.g. storm water storage requirements).

3.3.0.4 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 release of a nominal flow (1 m^3/s) with a nominal bacterial concentration (1 x 10^6 colony forming units (cfu)/100 millilitres (ml)) for a nominal period of time (1 hour). For each unit discharge, the coastal model generates a 'unit impact' at a number of specific locations, typically a bathing water or shellfish water. Unit impacts are generated for a series of environmental conditions, designed to represent the typical distribution of tide and wind. For each discharge location between 100 and 200 unit impacts are produced; for Swansea Bay 144 unit impacts (2 tides x 12 hours x 6 winds) were produced for each discharge. There are approximately 40 discharges, giving a total of 5,760 unit impacts.

3.3.0.5 The water quality impacts of all the unit discharges are collated to generate a unit impact database. STORM-IMPACT then combines output from the unit impact database, the river catchment models (river discharge hydrographs) and the sewerage network model (WwTW and CSO discharge hydrographs). Each hydrograph is split into hourly 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 bacterial concentration for the type of discharge. An example is provided here for clarity:

To determine the actual impact from a primary treatment WwTW for a particular hour of discharge, the impact from the nominal 'unit' model run for that hour is factored by the actual flow (from the network hydrograph) for that hour, and the bacterial concentration for primary treated effluent.

Modelled discharge

Unit Flow	= 1 m^3/s
Unit Concentration	= 1 x 10^6 FC/100ml

Actual discharge

Hydrograph flow (for hour in question)	= 0.33 m^3/s
Primary treated effluent concentration	= 1 x 10^7 FC/100ml

Modelled unit impact (at one particular timestep)

From unit impact database	= 150 FC/100ml

Actual (scaled) impact

Impact to be used	= 150 x 0.33 x (1 x 10^7 / 1 x 10^6)

3.3.0.6 For each monitoring location, the factored hourly impacts are combined by superposition to give the impact for each source hydrograph and the total impact from all source hydrographs. This process is repeated for each environmental condition to give a database of thousands of permutations of impact at each location.

3.3.0.7 The marginal probabilities of the modelled environmental conditions are then used to determine the probability of the particular impacts occurring. For instance, impacts from a spill starting at HW on a spring tide under calm conditions have a probability of occurrence equal to the product of the marginal probabilities of each variable, for example spring tide = 50%; HW = 8.33% (1 in 12 hours); and calm winds = 2.4% gives 0.5 x 0.0833 x 0.024 = 0.1%.

3.3.0.8 By combining impacts and probabilities, a cumulative frequency distribution of bacteria concentrations can be derived for any given period, from which key percentile concentrations can be derived. From these, compliance with relevant statistical standards can be predicted and evaluated.

3.3.0.9 To account for potential year-on-year variation, STORM-IMPACT is generally applied to a number of bathing seasons, or years.

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

a) By considering long period hydrograph data over a wide range of environmental conditions, impact predictions are far more detailed and robust than can be otherwise achieved.
b) As each individual discharge is considered, both total impact and the impact of each contributing discharge can be considered.
c) Once the unit impact database is created from the coastal model, output applications can be run very quickly for any set of discharge hydrographs. Multiple scenarios and 'what ifs' can be tested in a highly accurate and efficient way.

3.3.0.11 The STORM-IMPACT technique has been used successfully on numerous studies around the UK coast. It has previously been accepted by both the Environment Agency (EA) in England, NRW in Wales and Scottish Environment Protection Agency (SEPA) in Scotland, for use in sensitive waters investigations and wastewater scheme design.

3.3.0.12 During STORM-IMPACT model set-up, a validation process is undertaken. STORM-IMPACT is applied to a number of years or bathing seasons of hydrographs. Results are then compared with bacteria monitoring data from the receiving water, specific surveys, NRW DSP or shellfish water sample data, or a combination of these.

3.4 OPTIMISATION APPLICATIONS

3.4.0.1 During the early stages of the project the location of the turbine structure was assessed and optimised to minimise impacts on water quality, within practical engineering constraints. While this served to minimise impacts on water quality within Swansea Bay, it did not significantly affect water quality within the Lagoon, as this is largely determined by the presence of the Swansea WwTW discharge within the impounded area and the generating cycle, which determines the flow of water into and from the Lagoon.

3.4.0.2 Lagoon water quality is dictated by the presence of the Swansea WwTW discharge within the impounded area. Water quality is further modified by the flow of water into and from the Lagoon on each generating cycle, which determines how effluent disperses within the lagoon and how effectively the lagoon is flushed. Flushing of the lagoon determines the impacts of the impounded water released from the lagoon on Swansea Bay. During the sensitivity applications, a number of potential impacts from the Lagoon were identified. A series of model applications were therefore undertaken to assess the effects of potential optimisation options.

3.4.0.3 The optimisation models were set up to reflect the proposed optimisation options (see Chapter 3 of the EIA).

a) **For Option 1** (storm water disinfection by UV treatment) the discharge concentration of storm water from Swansea WwTW was modified to reflect typical efficacy of UV treatment. In this case, a 2.5 log reduction in storm water FIO concentrations was assumed, based on monitoring data from storm water UV treatment systems operated by DCWW at three sites in South Wales.

b) **For Option 2** (Swansea WwTW outfall extension) a series of optimisation runs were 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, both along the existing line and to the east and west. Optimum performance was achieved with a 1.5 km outfall extension along the existing outfall alignment. Model applications were re-run with the outfall extension in place to provide inputs to sensitivity applications and the STORM-IMPACT database.

3.5 Construction Impacts Applications

3.5.0.1 An outline construction programme has been identified which 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):

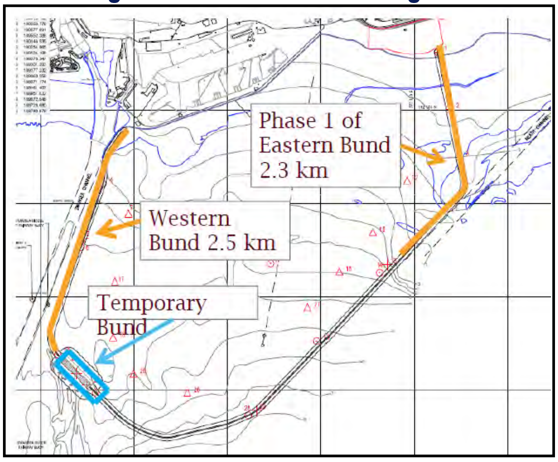
i) Season 1 - Construction of 2.5km western arm and turbine cofferdam; and 2.3km eastern arm;

ii) Season 2 – further construction of eastern arm leaving 2.9km gap; and

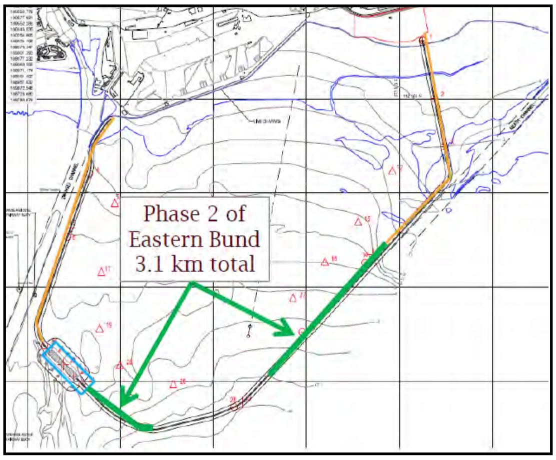
iii) Season 3 – closure of gap and Lagoon becomes operational

3.5.0.2 As the bathing season (May – September) is within the dredging/offshore construction season, it is assumed that modelling the changes in flow patterns from work completed within each season will provide a good understanding of potential effects on water quality. The difference between the stages being inferred based on professional judgement. Two interim stages were modelled, as shown in Figure 3-1, by adding the sections of Lagoon wall completed at the end of each construction stage and re-running the model. The last step, Season 3, is not modelled as this will take the Lagoon to operational status as modelled by the completed Lagoon applications. The construction models were then applied to the relevant sensitivity scenarios to assess potential impacts.

Figure 3-1: Construction stages modelled



a) Season 1 Construction



b) Season 2 Construction

3.5.1 Contaminant Release from Construction Activities

3.5.1.1 During construction, sediment and water will be dredged from the seabed (e.g. by suction dredger) and pumped into the Geotubes®. As the Geotubes are porous, excess water will be discharged from the Geotubes® during the pumping process and subsequent settling of the tubes on the seabed.

3.5.1.2 The rate of water discharge through the Geotubes® was determined from the expected rate of dredging and the proportion of water and sediment in the dredged volume. Table 3-1 provides a summary of the estimated dredging and construction rates used in the model applications. The mobilisation rate of contaminants from the seabed was based on an estimated worst case loss of 22 kg/s of fine sediment during dredging. Continuous dredging is assumed throughout the dredging period. Losses are assumed at the location of dredging and at the location of wall construction. A constant average rate of Lagoon wall construction is assumed based on anticipated construction rate. The discharge point in the model is periodically moved to reflect changes in construction location.

Table 3-1: Estimated dredging and construction rates applied to model.

Dredging Rate – sediment seawater mix:	5	m^3/s
Solids:	25%	
Solids dredging rate::	1.25	m^3/s
Entrained water Rate:	3.75	m^3/s
Geotube dewatering rate (=entrained water rate)	3.75	m^3/s
GeotubeLength (approx)	200	m
GeotubeVolume (when full)	15.5	$m^3/s/m$
GeotubeRate of fill per metre length	12.4	s/m
Geotube fill time	2480	s
Total time Phase 1 and 2 construction period	10	months
Total Lagoon wall construction length	9.5	km
Construction Rate (average)	1000	m/month
Construction Rate (average)	30	m/day
Construction Rate per 200m section (average)	7	days

3.5.1.3 A further source of contaminant mobilisation from sediment will be from the de-watering of the turbine area during construction. This area will be isolated by a cofferdam or bund wall and pumped dry to allow construction. As the surrounding area is submerged 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, at an estimated rate of between 800 litres per second (l/s) and 1600 l/s; 1600 l/s is assumed for model applications for conservatism. The water will have travelled through the sediment, potentially mobilising soluble contaminants, which would be discharged to the bay during de-watering.

3.5.1.4 To minimise the number of lengthy model runs for contaminant releases during construction the model was run with a single conservative (non-decaying) tracer. The tracer was given a nominal concentration (1 mg/l) based on available sample data, and continuous discharge flow based on the activity considered (wall construction or dewatering). It is conservatively assumed that contaminants within the sediment are not limited, i.e. concentrations will not reduce significantly over the construction or dewatering period. It is also conservatively assumed that no contaminants are lost to absorption to sediment in the water column and subsequent settlement on the seabed.

3.5.1.5 Tracer results were then used to determine a dilution in the receiving water at each cell in the model. By applying the dilution at a given location to the discharge concentration of each determinand, the concentration of specific determinands can be calculated. The derivation of contaminant concentrations from disturbed sediment is described in Section 7.6.4 of the EIA.

3.5.2 Turbidity Effects

3.5.2.1 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. It should be noted that 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 background situation as sediment losses to the receiving water will be low, as the Geotubes® are designed to retain sediment.

3.5.2.2 While it is not possible to directly relate increased turbidity to reduced decay rate (increased T_{90}), a recent study by Kay *et al*[Ref4] in the Bristol Channel provides a basis for estimating potential effects of increased turbidity. The study shows decay rates increase from upstream (Beachley) to downstream (Langland Bay). However, the relative effects of turbidity, which increases in the upstream direction, and salinity, which decreases in the upstream direction, cannot easily be distinguished. By comparing the observed turbidity and decay rates at Minehead, Weston-Super-Mare, Porthcawl and Langland Bay and the results of the dredged plume modelling undertaken in support of the EIA it is possible to estimate the potential effects of increased turbidity on decay rates in Swansea Bay.

3.5.2.3 Measurements taken during the 2012 survey campaign (Titan Environmental Surveys Ltd.[Ref 1]) show suspended solids concentrations in Swansea Bay vary from 10 mg/l to 15 mg/l at the surface to 50 mg/l to 100 mg/l at depth. Samples taken by Kay *et al* at Porthcawl and Langland Bay gave similar results, i.e. suspended solids concentrations of between 75 mg/l and 300 mg/l. The sediment transport modelling undertaken in support of the EIA (see Chapter 6 Coastal Processes, Sedimentation and Contamination) predicts an increase in peak suspended solids in the dredged plume formed during construction of around 150 mg/l. This is approximately one to three times the background concentration. If an average increase in suspended solids in the dredged plumes is conservatively assumed as 100 mg/l, based on the relationship between suspended solids and decay rate determined by Kay *et al,* this equates to an increase in T_{90} of approximately 50%.

3.5.2.4 Significant increases in suspended sediment concentrations would be limited to the dredged plumes. Decay rates would only be increased where the dredged plumes interact with discharge plumes from the various sources in Swansea Bay. Given the location of the Lagoon, the most significant interactions would be expected between the dredged plumes and the discharge plumes from the Swansea WwTW, River Tawe and River Neath. These interactions would vary depending on the stage of Lagoon construction, e.g. Tawe discharges would interact with the dredged plume during construction of the west wall.

3.5.2.5 To assess the effects of increased turbidity, sensitivity model applications were repeated to simulate a 50% increase in decay rate in the plumes from the Tawe, Neath and Swansea WwTW. A precautionary approach was adopted in which it is assumed that plume interactions are simultaneous and occur throughout the construction period; this is unlikely to occur as the Lagoon walls will be constructed in sequence with the sediment source continually moving. A baseline hydrodynamic condition is assumed as a worst case, 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.

3.6 DECOMMISSIONING APPLICATIONS

3.6.0.1 The primary mode of decommissioning would involve the removal of the turbines and sluice gates to allow flow through the resultant gaps in the impoundment structure. A model representing the Lagoon post-decommissioning was constructed by removing a section of the lagoon wall corresponding to the turbine house and removing the internal flow boundary that controls flow into and from the Lagoon. Under this condition, sea water flows freely between the Lagoon impoundment and the sea through the area previously occupied by the turbines and sluices. Relevant model applications were then repeated with this revised model.

3.7 DESIGN ITERATION APPLICATIONS

3.7.0.1 The Lagoon model was also modified to allow an assessment of possible variations to the Lagoon design. 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. A modified model was constructed to represent the combined effects of:

a) Micro-sting of turbine house further offshore, i.e. moving of the turbine structure approximately 400m along the south wall of the Lagoon: and.
b) selection of variable speed turbines instead of fixed speed turbines to allow pumping at end of the tidal cycle which would reduce intertidal losses

3.7.0.2 The model was modified by moving the internal flow boundary representing the turbines to a location to the south. The flow boundary was then modified to reflect the potential changes in discharge flow with variable speed turbines, i.e. flows were increased by 10%. Relevant model applications were then repeated with this revised model.

3.8 SUMMARY

3.8.0.1 Table 3-2 provides a summary of all the application runs undertaken.

Table 3-2: Summary of model applications

Application	Determinands	Driver	Inputs / Sources	Scenarios / Model	Conditions	Assumptions / Notes
Sensitivity Microbiology	E Coli	rBWD SFD	Significant continuous and storm loads of bacteria.	Baseline Lagoon Optimisation (All Options) Construction Decommissioning Design Iteration	Discharge Background Storm event Tide Spring Wind Calm, SW, SE Season 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 Background Storm event Tide Spring / Neap cycle Wind Calm Season Winter / Summer	Winter case: high river flow river T/S 4°C / 0 practical salinity units (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 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 Background Tide Spring / Neap cycle Wind Calm Season 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 Centre for Research into Environmental Health (CREH) (2012). Open water boundary from NRW WEMS sample data, two stations outside Swansea Bay.

Application	Determinands	Driver	Inputs / Sources	Scenarios / Model	Conditions	Assumptions / Notes
Sensitivity DO	Dissolved Oxygen (DO)	WFD	Continuous loads of BOD and ammonia from rivers and WwTWs. Storm load from WwTW.	Baseline Lagoon	Discharge Background Storm event Tide Spring / Neap cycle Wind Calm Season 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.
Microbiology BW / SFW	E Coli I Enterococci	rBWD SFD	All significant continuous and storm loads of bacteria.	Baseline Lagoon Optimisation (All Options)	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 wall added through application. Continuous average dredging rates / volumes Minimum dilutions of tracer determined at all locations Comparison with discharge concentrations

Notes:
Scenarios are represented by the relevant model, i.e. the model, or input files are modified to reflect a change from the Baseline condition.
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

4 ADVECTION DISPERSION MODEL VALIDATION

4.0.0.1 Model dispersion coefficient, which describes the mixing process in the Swansea Bay was calibrated during the last major model update in 2006, by theoretical analysis of dye patches and model calibration against dye surveys.

4.0.0.2 For the EIA, the revised (2013) model was re-validated against microbial tracer survey data collected under the Smart Coasts Swansea Bay Study, to provide further confidence that the mixing process in the Swansea Bay is well described in the model.

4.0.0.3 During the Smart Coasts study a number of tracer surveys were undertaken. These were designed to investigate hydrodynamic connectivity between potential microbial sources and bathing waters in the Swansea Bay. Three microbial tracer surveys were carried out in the study, with four different microbial tracers (*Bacillus atrophaeus,* Coliphage MS2, *Enterobacter cloacae phage*, and *Serratia marcescens phage*) released at different locations in each survey. Locations were chosen to represent four key discharges to Swansea Bay.

4.0.0.4 In all surveys, samples were collected at the DSP for the designated bathing waters, together with a number of additional sites representing non-designated bathing waters. Samples were collected at approximately hourly intervals for more than 48 hours. Injection of the tracers was phased to take place when tidal streams were most likely to carry the tracers towards the bathing waters. Table 4-1 provides a summary of the three microbial tracer surveys.

Table 4-1: Summary of Smart Coast tracer surveys (2011)

Survey	Tracers	Release Locations	Release Time (GMT)	Dose (cfu/ pfu)
1	*Bacillus atrophaeus*	Knab Rock	05/12/2011 08:18	$2.80x10^{14}$
	Serratia marcescens phage	River Clyne	05/12/2011 02:59	$5.00x10^{16}$
	Enterobacter cloacae phage	Brynmill Culvert	05/12/2011 02:46	$4.85x10^{16}$
	Coliphage MS2	River Tawe (Fish Pass)	05/12/2011 03:17	$6.00x10^{17}$
2	*Enterobacter cloacae* phage	River Tawe (Fish Pass)	11/03/2012 10:14	$2.00x10^{16}$
	Coliphage MS2	River Neath	11/03/2012 10:14	$3.25x10^{17}$
	Serratia marcescens phage	River Afan	11/03/2012 10:17	$2.25x10^{16}$
	Bacillus atrophaeus	Afan WwTW Outfall	11/03/2012 10:10	$1.75x10^{14}$
3	*Serratia marcescens* phage	River Clyne	20/05/2012 08:07	$1.55x10^{16}$
	Enterobacter cloacae phage	River Neath	20/05/2012 08:06	$1.25x10^{16}$
	Coliphage MS2	Swansea WwTW	20/05/2012 06:04	$4.20x10^{17}$
	Bacillus atrophaeus	Baglan SPS Outfall	20/05/2012 08:00	$1.25x10^{15}$

4.0.0.5 FIO concentration data at Swansea Bay bathing water were also collected under the Swansea Bay Study of the Smart Coasts project, for presumptive faecal coliforms (FC), confirmed *E. Coli* and presumptive/confirmed intestinal enterococci (IE). This bathing water data provided an additional dataset for STORM-IMPACT validation. Validation of STORM-IMPACT against the Smart Coast data is presented separately in Section 6.

4.0.0.6 The updated model was set-up and run, to simulate the advection and dispersion conditions during the period of the release, i.e. tide, wind and release time.

4.1 SURVEY 1

4.1.0.1 Comparison of model and survey results at Swansea Bay DSP for a number of release locations are presented in Figures 4-1 to 4-4. In general, the model results agree well with the tracer data, with the connectivity of the tracer with the bathing water being well predicted. In most cases the model predictions of tracer concentration are higher than measured; this is likely due to a non-uniform (patchy) distribution of the tracer in the water column and the loss of tracer, e.g. to the sediment. The model assumes uniform distribution and no tracer losses.

4.1.1 Knab Rock release

4.1.1.1 Both model predictions and survey data (Figure 4-1) indicate that it took three tidal cycles for the released tracer reaching at Swansea DSP.

4.1.2 Brynmill Culvert (Singleton Park) release

4.1.2.1 Both model predictions and survey data (Figure 4-2) indicate a strong connectivity between Singleton Park Stream and Swansea DSP. The time when the released tracer reached the Swansea DSP and the initial impact concentration were well predicted by the model.

4.1.3 River Tawe (Fish Pass) release

4.1.3.1 Model results (Figure 4-3) show little connectivity during the survey period. Sample results suggest some connectivity as low concentrations were observed in some samples. However, these are most likely random concentrations due to background Coliphage MS2, rather than from the tracer release; samples taken at Tawe Fish Pass before the release show traces of Coliphage MS2.

Figure 4-1: Modelled and measure tracer concentrations measured at Swansea DSP Survey 1, Knab Rock release

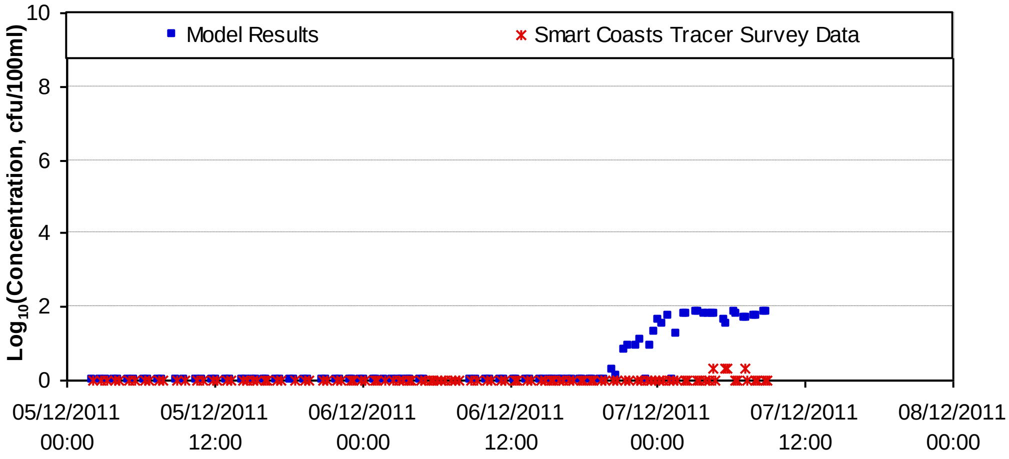


Figure 4-2: Modelled and measure tracer concentrations measured at Swansea DSP Survey 1, Singleton Park Stream release

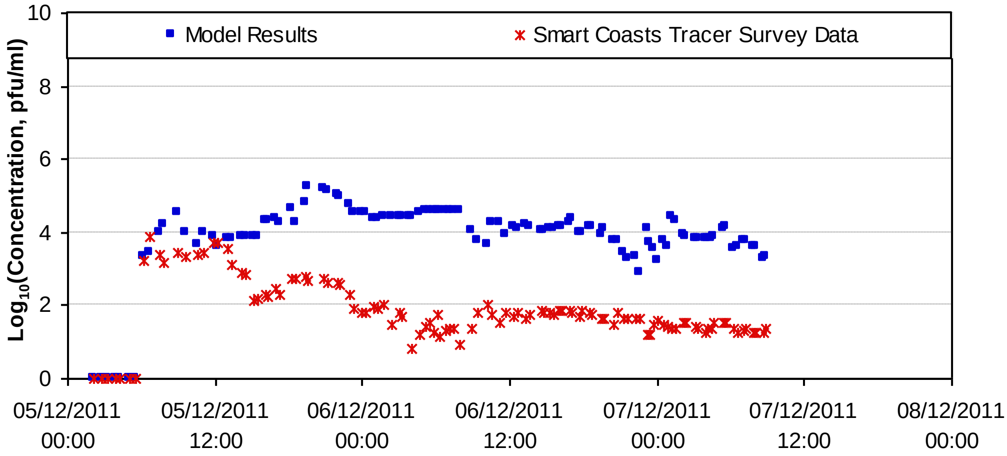
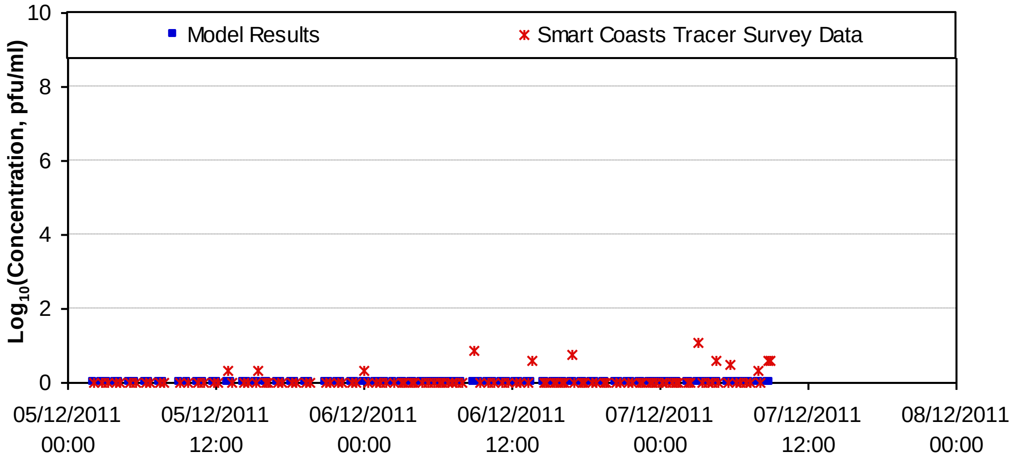


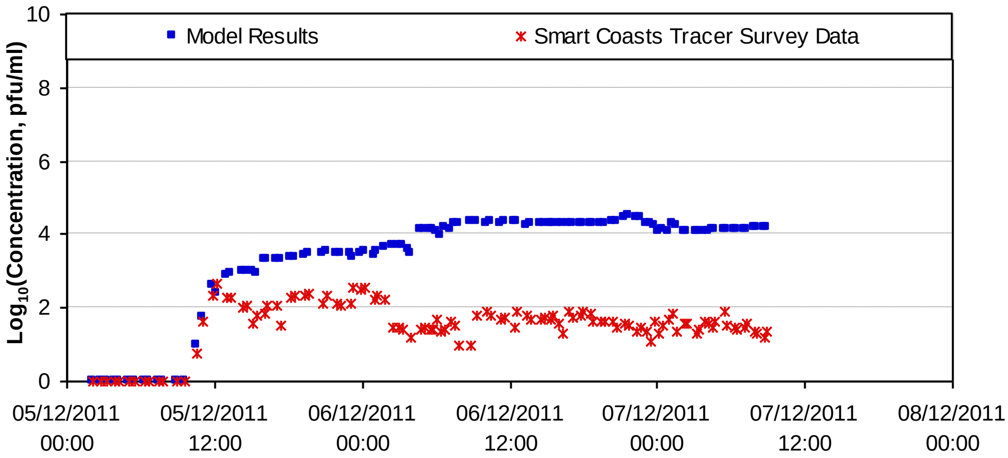
Figure 4-3: Modelled and measure tracer concentrations measured at Swansea DSP Survey 1, Tawe River release



4.1.4 River Clyne Release

4.1.4.1 Both model predictions and survey data (Figure 4-4) indicate a strong connectivity between River Clyne and Swansea DSP. The time when the released tracer reached the Swansea DSP was well predicted by the model.

Figure 4-4: Modelled and measure tracer concentrations measured at Swansea DSP Survey 1, ClyneRiver release



4.2 SURVEY 2

4.2.0.1 Comparison of model and survey results at Swansea Bay DSP for Survey 2 are presented in Figures 4-5 to 4-8. Results are similar to Survey 1, with model results agreeing well with the tracer data, with the connectivity of the tracer with the bathing water being well predicted. As with Survey 1, model predictions of tracer concentration are consistently higher than observed.

4.2.1 Afan WwTW Outfall release

4.2.1.1 Both model predictions and survey data indicate that the release tracer did not reach Swansea DSP (Figure 4-5).

4.2.2 River Tawe (Fish Pass) Release

4.2.2.1 Both model predictions and survey data indicate a strong connectivity between River Tawe and Swansea DSP (Figure 4-6). The time when the released tracer reached the Swansea DSP was well predicted by the model.

4.2.3 River Neath Release

4.2.3.1 It should be noted that Coliphage MS2 was observed at Swansea DSP before the tracer release and there was a large variation of concentration in the samples taken before 12/03/2012 15:00 (Figure 4-7). This would suggest that the observed Coliphage MS2 before 12/03/2012 15:00 was unlikely to be from the tracer release. The greater consistence in tracer samples after 12/03/2012 15:00 would suggest this material is from the release. This period also corresponds with the model predictions of tracer arrival at the DSP. Both survey and model suggest connectivity between the river Neath and Swansea DSP.

Figure 4-5: Modelled and measure tracer concentrations measured at Swansea DSP Survey 2, Afan WwTW release

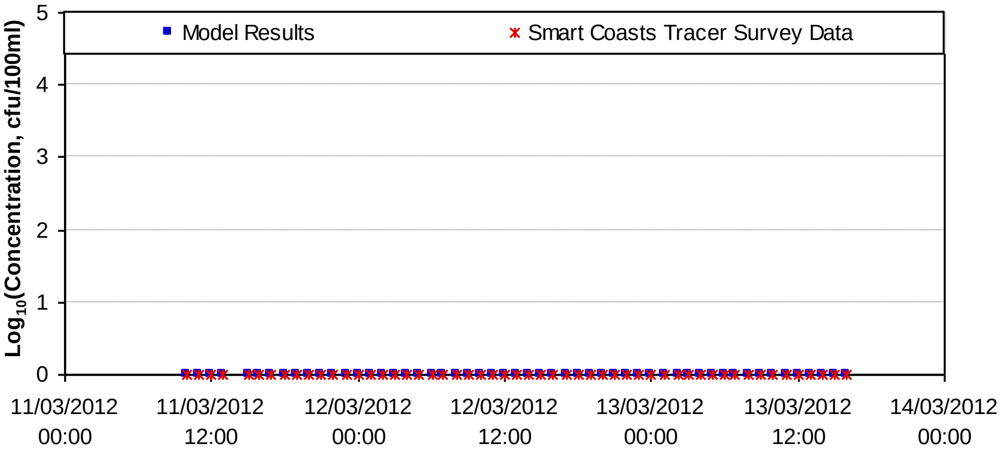


Figure 4-6: Modelled and measure tracer concentrations measured at Swansea DSP Survey 2 Tawe River release

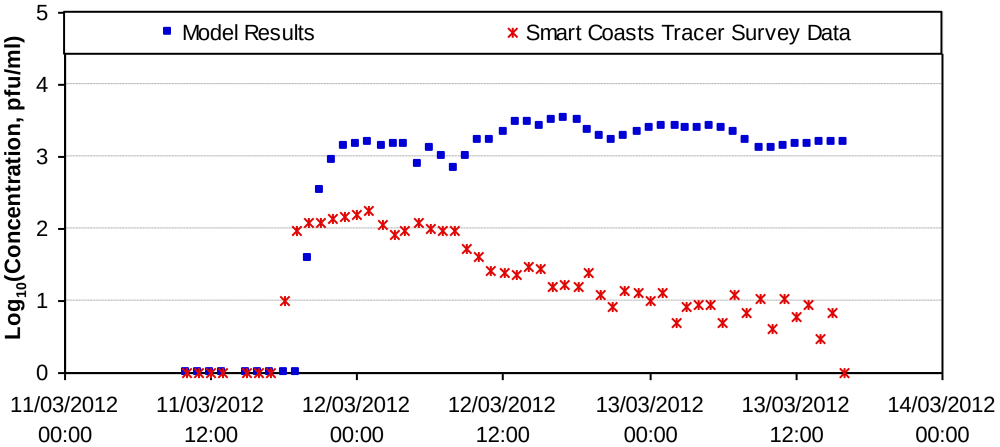
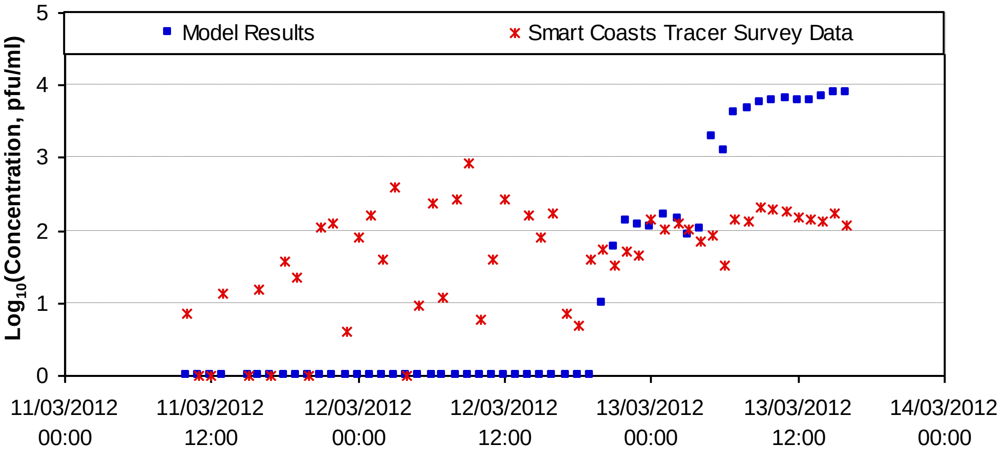


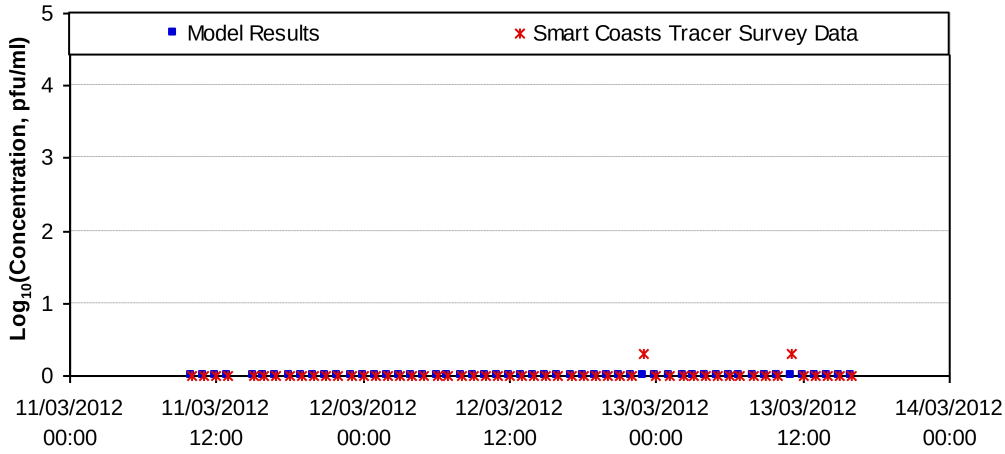
Figure 4-7: Modelled and measure tracer concentrations measured at Swansea DSP Survey 2 Neath River release



4.2.4 River Afan Release

4.2.4.1 Model predictions and survey data indicate the tracer did not reach the Swansea Bay DSP (Figure 4-8).

Figure 4-8: Modelled and measure tracer concentrations measured at Swansea DSP Survey 2 Afan River release



4.3 SURVEY 3

4.3.0.1 Comparison of model and survey results for Survey 3 are presented in Figures 4-9 to 4-12. Results are similar to Survey 1, with model results agreeing well with the tracer data, with the connectivity of the tracer with the bathing water being well predicted. As with Survey 1, model predictions of tracer concentration are consistently higher than observed.

4.3.1 Baglan SPS Outfall Release

4.3.1.1 Model results (Figure 4-9) indicated the tracer would not reach the Swansea DSP. This is supported by the tracer samples, although low Bacillus atrophaeus concentration was observed at the end of survey, indicating a possible, low connectivity.

4.3.2 River Tawe (Fish Pass) Release

4.3.2.1 Both model predictions and survey data indicate that the release tracer did not reach Swansea DSP (Figure 4-10).

4.3.3 Swansea WwTW Release

4.3.3.1 Both model predictions and survey data (Figure 4-11) indicate that it took three tidal cycles for the tracer to reach the Swansea DSP at low concentrations. Good agreement between predicted concentration and survey data is seen.

Figure 4-9: Modelled and measure tracer concentrations measured at Swansea DSP Survey 3 Baglan SPS Long Sea Outfall (LSO) release

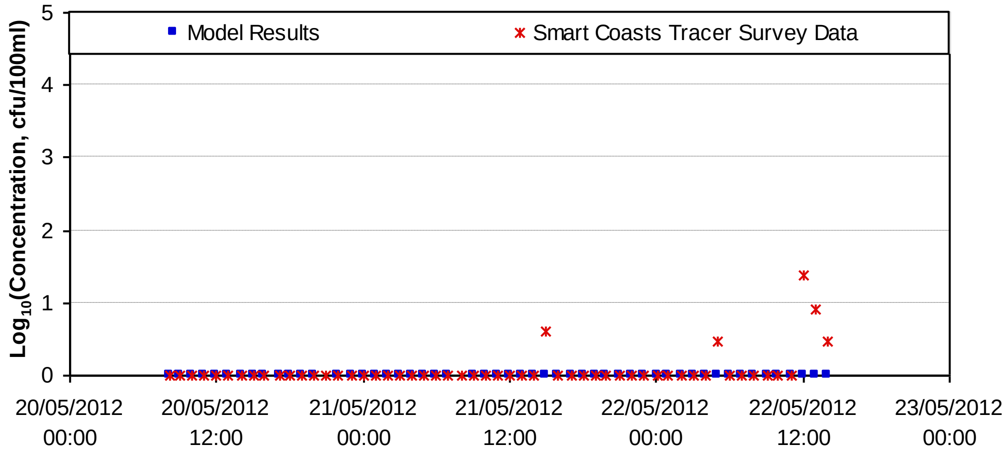


Figure 4-10: Modelled and measure tracer concentrations measured at Swansea DSP Survey 3 River Tawe release

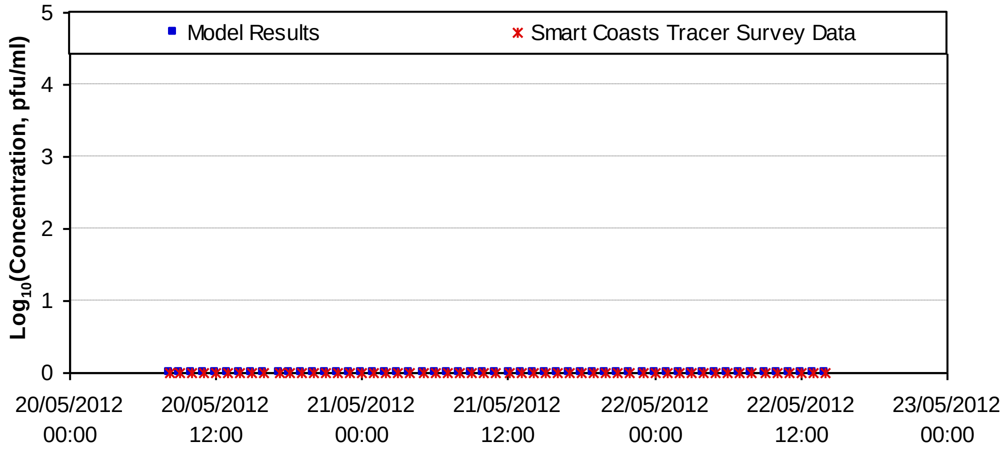
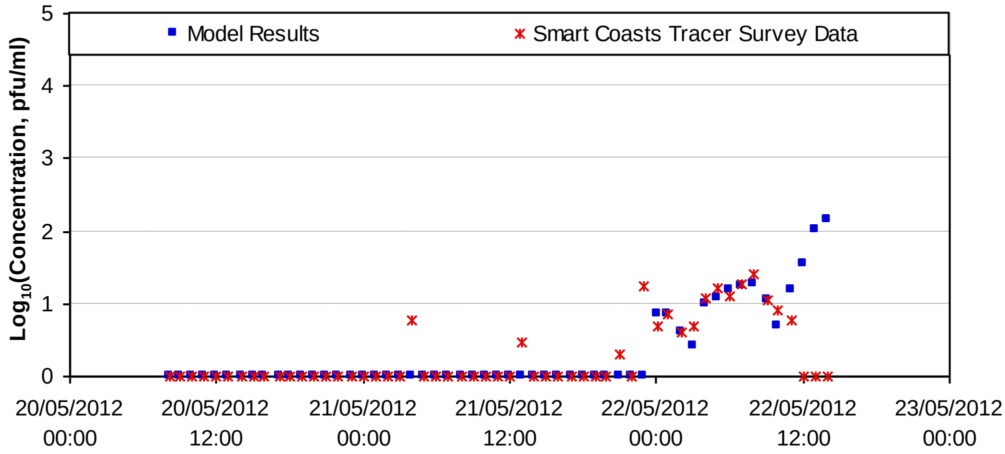


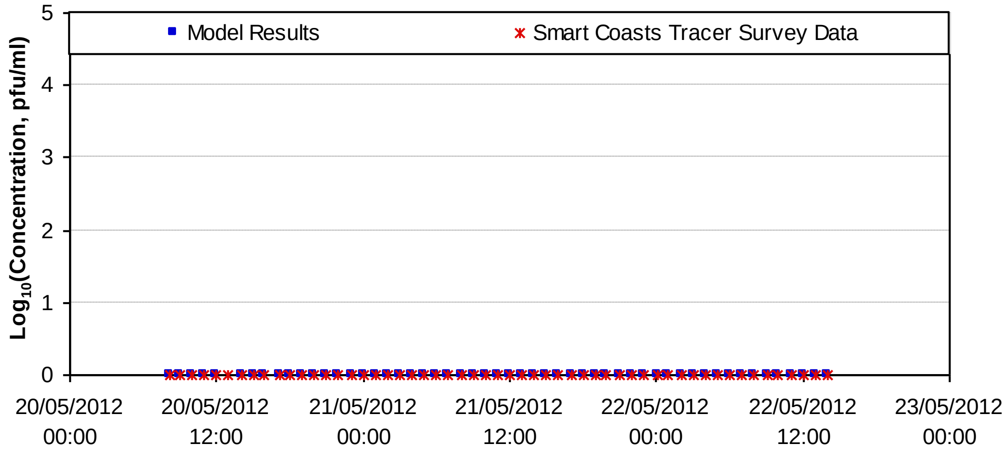
Figure 4-11: Modelled and measure tracer concentrations measured at Swansea DSP Survey 3 Swansea WwTW LSO release



4.3.4 River Clyne Release

4.3.4.1 Both model predictions and survey data indicate that the release tracer did not reach Swansea DSP (Figure 4-12).

Figure 4-12: Modelled and measure tracer concentrations measured at Swansea DSP Survey 3 River Clyne release



4.4 Discussion and Conclusions

4.4.0.1 The model tends to produce higher concentrations than observed in the survey. This may be due to a number of factors, but most likely reflects the nature of the tracer releases. In most cases tracers are released to fresh water and at the water surface, in which case full vertical mixing of tracers may not occur. Where tracers have to pass through shallow water areas in the rivers or along the beaches, some tracer may also be lost to the channel or river bed, or may become trapped in shallow areas on a falling tide. It is interesting to note that when the tracer was released from the Swansea WwTW, i.e. in deep water where it is likely to be well mixed, the model and survey concentrations agreed very well.

4.4.0.2 It is also interesting to note that connectivity varies depending on local conditions. For example in Surveys 1 and 3 no connectivity is seen between the Swansea DSP and the River Tawe in either model or field data, yet on Survey 2 there is clear connectivity. This is most likely the effect of wind; wind direction and speed can significantly influence the trajectory of the River Tawe discharge plume. Similarly, the connectivity between the River Clyne and the DSP is clearly seen in Survey 1, but no connectivity is seen in Survey 3.

4.4.0.3 Overall, the results of the tracer surveys are well replicated in the model, particularly the presence or not of tracer, the time for tracer to be observed after release and the pattern of tracer concentration observed at the DSP.

4.4.0.4 Given the results of the validation of the model against the Smart Coasts tracer study, confidence in the AD model is considered good and the model is considered fit for use for the tidal Lagoon EIA.

5 STORM-IMPACT VALIDATION

5.0.0.1 Validation of STORM-IMPACT has been undertaken by comparing STORM-IMPACT predictions against NRW routine designated sampling points (DSP) sample data, collected at both Swansea Bay bathing water and Aberafan bathing water.

5.0.0.2 The validation is made against a historical sewerage network configuration, prior to planned and ongoing improvements to the network system. STORM-IMPACT has been applied to the 2008-2011 bathing seasons. This allows results to be determined for a similar period to which the rBWD is applied, and also represents a period of poor bathing water performance due to high summer rainfall. Summer rainfall in the period 2008 to 2010 was approximately 40% higher than the previous four year period and 2011.

5.1 INPUT SOURCES AND ASSUMPTIONS

a) Assessment is based on a four year period from 2008 and 2011.

b) Discharges from Swansea WwTW, Afan WwTW and CSOs pertinent to the study are based on output from the Swansea and Afan network models.

c) Langdon Road pumping station operates at a reduced pass forward flow rate. This represents the condition prior to refurbishment in 2012-2013.

d) Discharges from River Tawe, Neath and Afan are derived from NRW gauging records, and discharges from smaller streams are derived from local hydrological models.

e) NRW samples the Swansea Bay DSP over a period two hours before and after HW, as sampling at low water periods presents a potential safety risk. STORM-IMPACT has been modified to only use model output for this smaller sampling window, to allow direct comparison with NRW sample data.

5.2 VALIDATION AGAINST NRW DSP SAMPLE DATA

5.2.1 Designated Sampling Point Sample data

5.2.1.1 The predicted impacts on Swansea Bay bathing water and Aberafan bathing water were analysed and compared to the current bathing water performance indicated by the NRW sample data. Comparisons are made on a statistical basis, i.e. the NRW DSP sample concentration frequency distribution is compared with that derived from the STORM-IMPACT model. Comparisons are made directly between distributions and as fitted log normal distributions, as required by the rBWD.

5.2.1.2 Comparisons are made between statistical distributions and cumulative histograms of STORM-IMPACT output against bathing water sample data to assess the general fit between STORM-IMPACT and sample data. Comparisons are also made at the key percentile concentrations (90%ile and 95%ile) used to determine Class under the rBWD.

5.2.1.3 Figures 5-1 to 5-4 shows comparisons of EColi and IEnterococci concentration distributions at the Swansea Bay and Aberafan bathing water. In each figure there are two plots, with the top plot showing the concentration frequency distribution (represented as log of the concentration) and the bottom plot the cumulative percentage exceedence histogram. The bar charts represent the model output and sample data, while the lines represent a log-normal fit to the sample data as required by the rBWD.

5.2.1.4 In general, model performance is best evaluated by comparing the STORM-IMPACT prediction (presented as pink bars in the plots) against the log-normal distribution of the sample data (presented as a blue line in the plots). This provides the most realistic approximation of actual bathing water performance against that derived by NRW from the DSP sampling; STORM-IMPACT generates more than 2 million data points over four bathing seasons, compared to 80 DSP samples.

5.2.1.5 Table 5-1 provides a comparisons of STORM-IMPACT predicted concentrations against EA bathing water data at key percentiles, and resulting bathing water performance under the rBWD classifications. Percentile concentrations of sample data are calculated assuming a log-normal distribution. STORM-IMPACT predicted percentile concentrations are calculated directly from the model output.

Table 5-1: Comparison of STORM-IMPACT predictions and bathing water samples against rBWD standards: 2008-2011

a) E Coli	Swansea Bay		Aberafan	
	DSP Data (log normal)	STORM-IMPACT Predictions	DSP Data (log normal)	STORM-IMPACT Predictions
90-percentile (cfu/100ml)	744	733	273	334
95-percentile (cfu/100ml)	1513	1616	577	742
Indicative rBWD performance	POOR	POOR	SUFFICIENT	SUFFICIENT
b) I Enterococci	Swansea Bay		Aberafan	
	DSP Data (log normal)	STORM-IMPACT Predictions	DSP Data (log normal)	STORM-IMPACT Predictions
90-percentile (cfu/100ml)	265	318	64	124
95-percentile (cfu/100ml)	516	591	117	259
Indicative rBWD performance	POOR	POOR	GOOD	SUFFICIENT

Figure 5-1: Swansea Bay DSP concentration distribution comparisons for EColi: 2008-2011: top = distribution plot; bottom = cumulative histogram

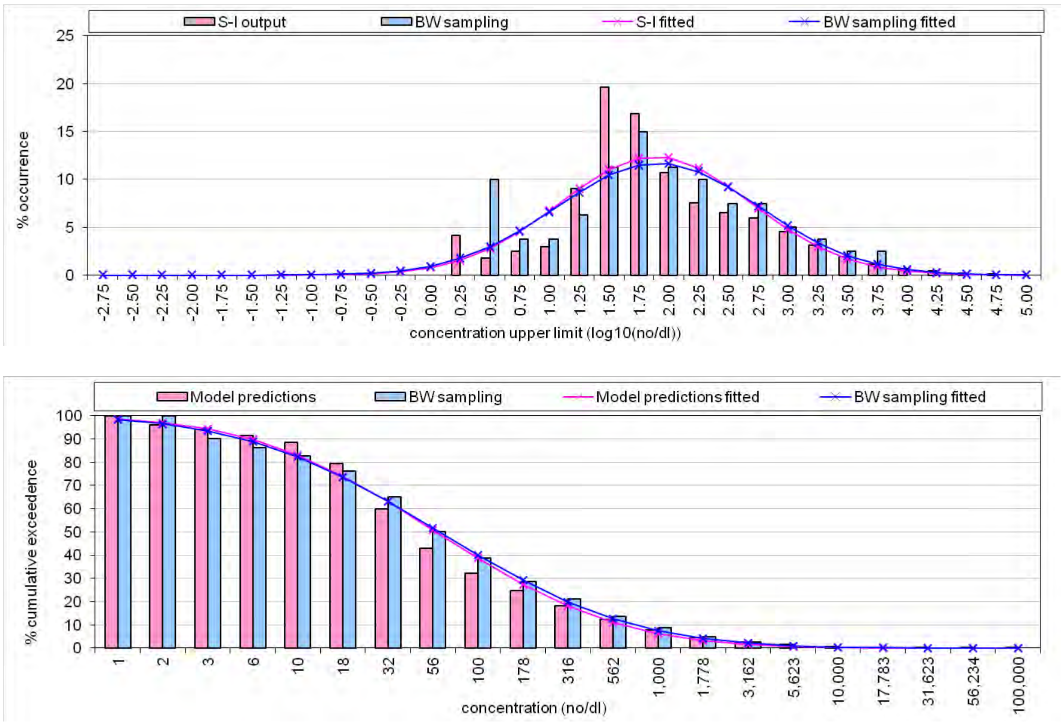


Figure 5-2: Swansea Bay DSP concentration distribution comparisons for I Enterococci 2008-2011: top = distribution plot; bottom = cumulative histogram

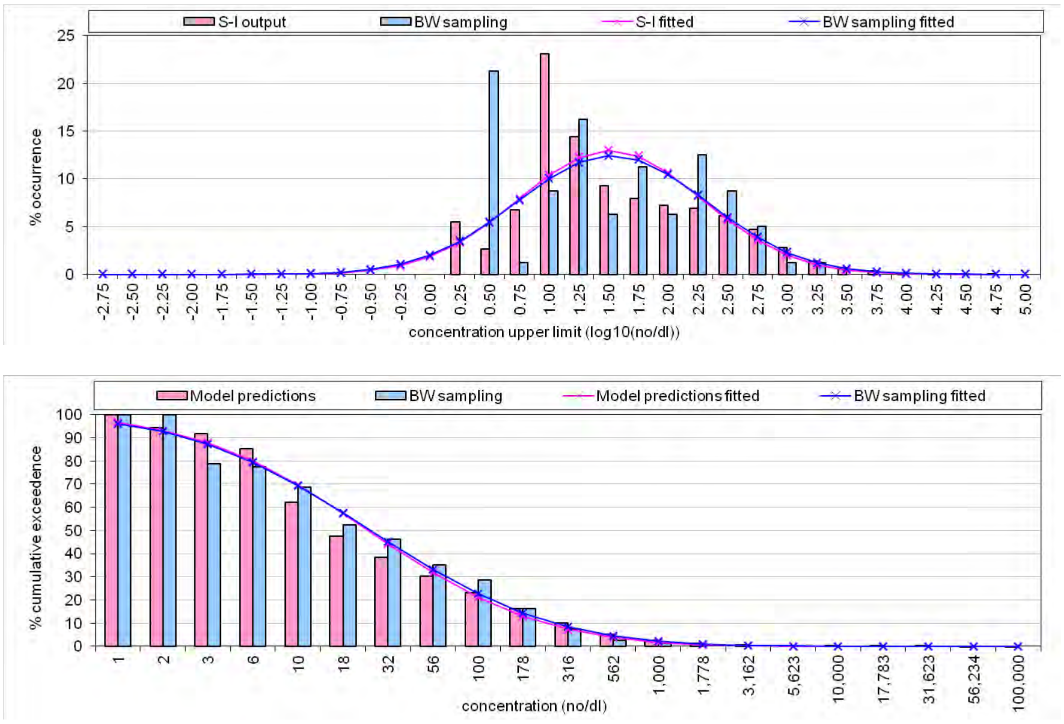
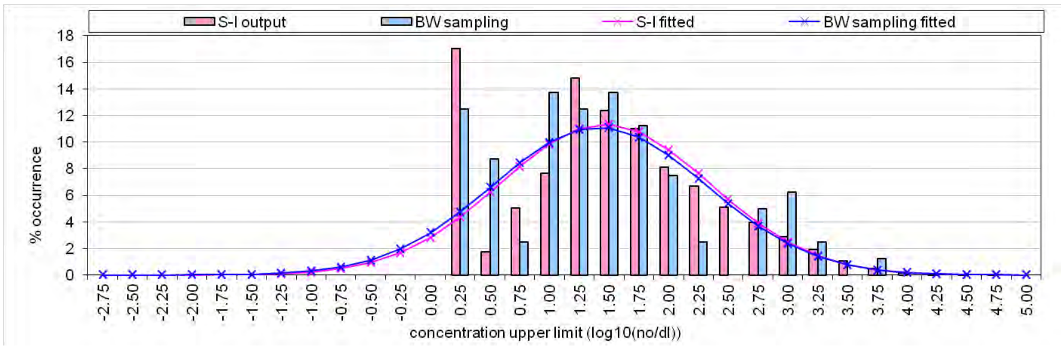


Figure 5-3: Aberafan DSP concentration distribution comparisons for E Coli: 2008-2011 top = distribution plot; bottom = cumulative histogram



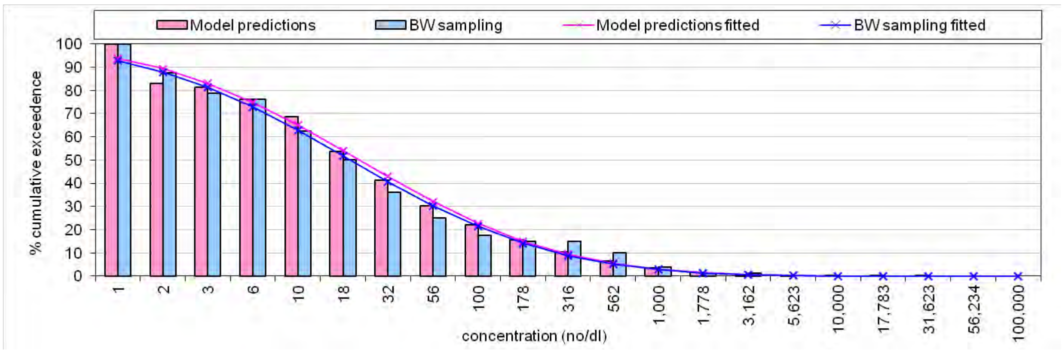
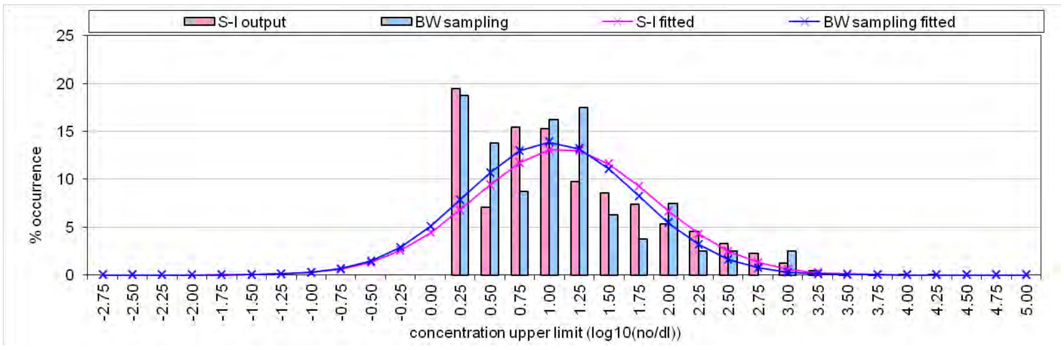
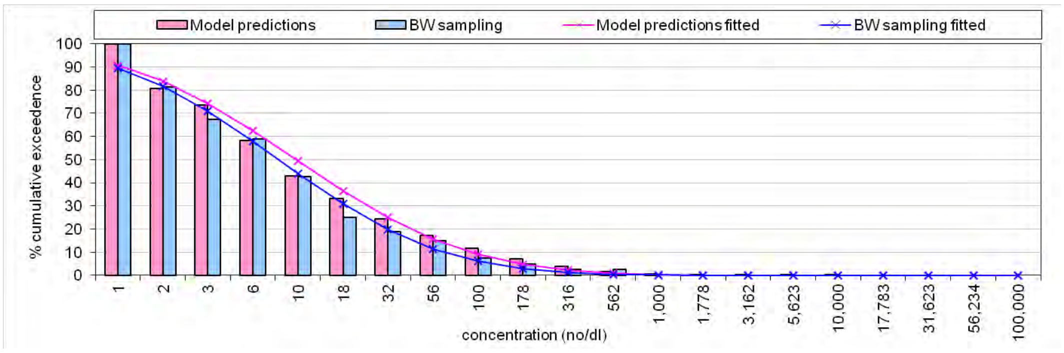


Figure 5-4: Aberafan DSP concentration distribution comparisons for I Enterococci 2008-2011: top = distribution plot; bottom = cumulative histogram





5.2.2 Discussion

E Coli

5.2.2.1 Comparisons of the concentration distribution and cumulative histogram plots (Figures 5-1 and 5-3) show a good fit between the STORM-IMPACT predictions and NRW sample data at the Swansea and Aberafan DSPs, although the model slightly over predicts concentration at Aberafan DSP. Best fit was achieved with an average decay rate (T_{90}) of 55 hours.

5.2.2.2 At the key percentiles (90%ile and 95%ile) good agreement between STORM-IMPACT predictions and NRW sample data is seen. At Swansea Bay, model predictions are typically within 5% of DSP sample results, and tend to give conservative results, i.e. higher concentrations than observed. At Aberafan, the model over-predicts concentration by approximately 20% to 30%, providing a high degree of conservatism.

I Enterococci

5.2.2.3 Comparisons of the concentration distribution and cumulative histogram plots Figures 5-2 and 5-4) show a good fit between the STORM-IMPACT predictions and NRW sample data at Swansea DSP, although the model generally over predicts concentration at Aberafan DSP. Best fit was achieved with an average decay rate (T_{90}) of 70 hours.

5.2.2.4 At Swansea Bay DSP good agreement between STORM-IMPACT predictions and NRW sample data is seen at the key percentiles, with model predictions typically 15% to 20% higher than DSP sample results, giving a conservative over prediction of concentration, or under-prediction of compliance. At Aberafan, IE concentrations predicted by STORM-IMPACT are approximately twice those observed, leading to a high degree of conservatism in the predictions.

5.2.2.5 Overall, the STORM-IMPACT model provides a high degree of conservatism in its predictions of bathing water FIO concentration percentiles and class. This conservatism comes from two main factors, firstly the use of wet years for the analysis and secondly from adopting a precautionary approach to input loads and decay rates. Conservatism is unlikely to significantly affect results when considered as relative changes, which will be the primary concern of the assessment for the EIA. However, conservatism must be considered when assessing results against absolute standards, e.g. bathing water class, and allowance made for possible under-prediction of class.

5.3 VALIDATION AGAINST SMART COASTS EVENT DATA

5.3.0.1 During the Smart Coasts study, intensive microbiological sampling was undertaken during the 2011 bathing season. The sampling was undertaken to estimate FIO budgets from sewage and riverine sources with coincident sampling at the Swansea Bay DSP. The DSP monitoring included sampling every 30 minutes for 12 hours at regular intervals over the bathing season. This type of extended, high frequency data set is not normally available and provides a valuable additional data set for STORM-IMPACT validation. The data allows STORM-IMPACT to be validated for dry periods and specific events, providing an additional level of confidence in ensuring the phasing, patterns and magnitudes of storm events are well represented.

5.3.0.2 The STORM-IMPACT model was run for the periods when the microbiological samples were collected at the Swansea DSP. River and network flows were determined from available records and models. Concentrations were defined from the Smart Coasts data. Tides and winds were selected from the STORM-IMPACT database to best match conditions measured during the sampling.

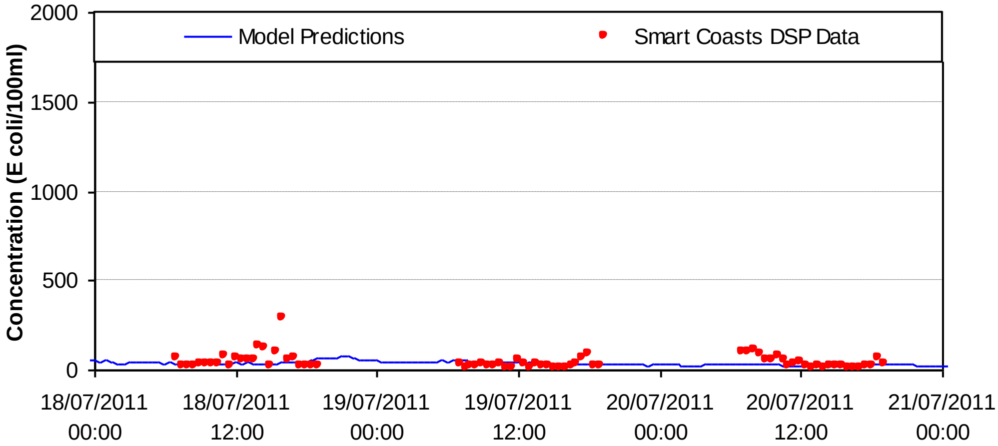
5.3.0.3 Comparison plots of FIO concentrations between model predicted and Smart Coasts DSP data are provided in Figures 5-4 to 5-13. The figures cover dry and wet conditions under spring and neap tides.

5.3.1 Dry Weather

5.3.1.1 Figure 5-5 and 5-6 compare sample data and model predictions for spring tides under two wind conditions.

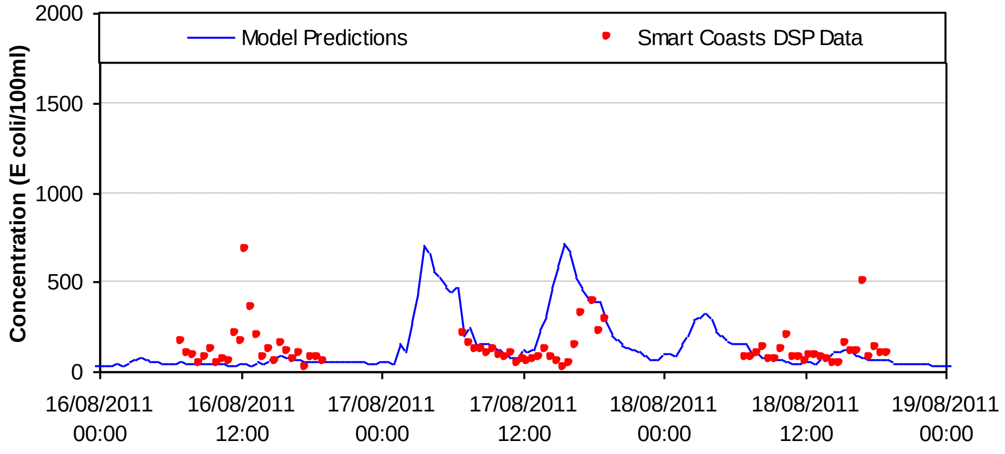
5.3.1.2 Under a north westerly wind (Figure 5-5) model predictions are a good fit with sample data, with both indicating low concentrations in dry weather, typically less than 50 EC/100ml. There is more variation in the sample data, due to natural variation in the input concentrations and environmental conditions which cannot be fully represented in the model.

Figure 5-5: Swansea DSP measured and predicted concentration s: E Coli, spring tide, north westerly wind.



5.3.1.3 Under a south easterly wind (Figure 5-6) greater variability is seen in the sample data, which is well matched in model predictions. Concentrations are slightly elevated over the north westerly wind condition, reaching 200 EC/100ml or higher on occasion. A short rainfall event on 16 August is clearly seen as an increase in concentrations in the samples and the model predictions.

**Figure 5-6: Swansea DSPmeasured and predicted concentration s:
E Coli, spring tide, south easterly wind (small rainfall - 16/08/2011).**



5.3.1.4 Figure 5-7 and 5-8 compare sample data and model predictions for neap tides under two wind conditions.

5.3.1.5 Figure 5-7 shows results under a south westerly wind while Figure 5-8 shows results for a north westerly wind. Concentrations are slightly higher under the south westerly wind in both the samples and the model, although the model shows a tendency to slightly over-predict. Fit is better for the north westerly wind.

**Figure 5-7: Swansea DSPmeasured and predicted concentration s:
E Coli, neap tide, south westerly wind**

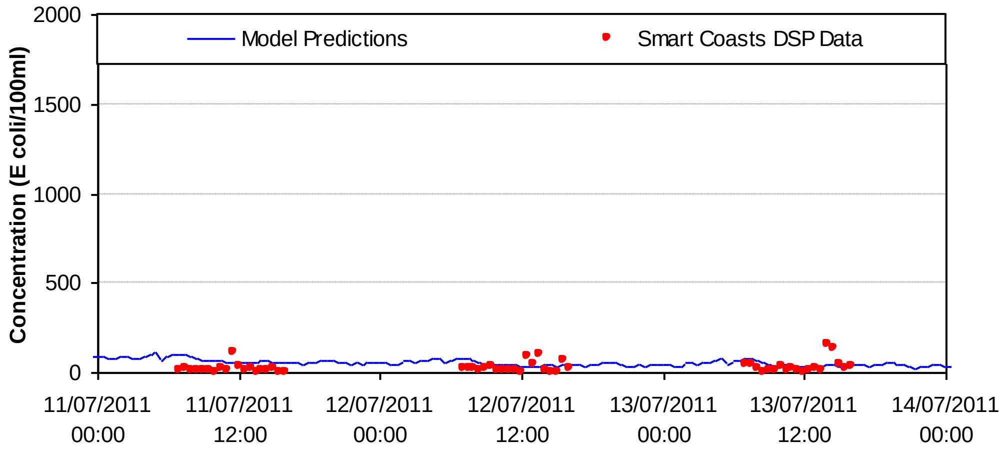
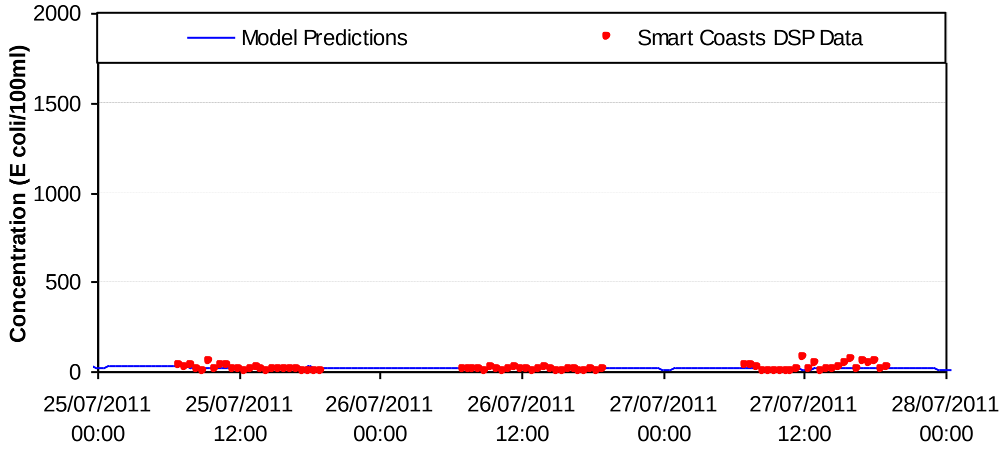


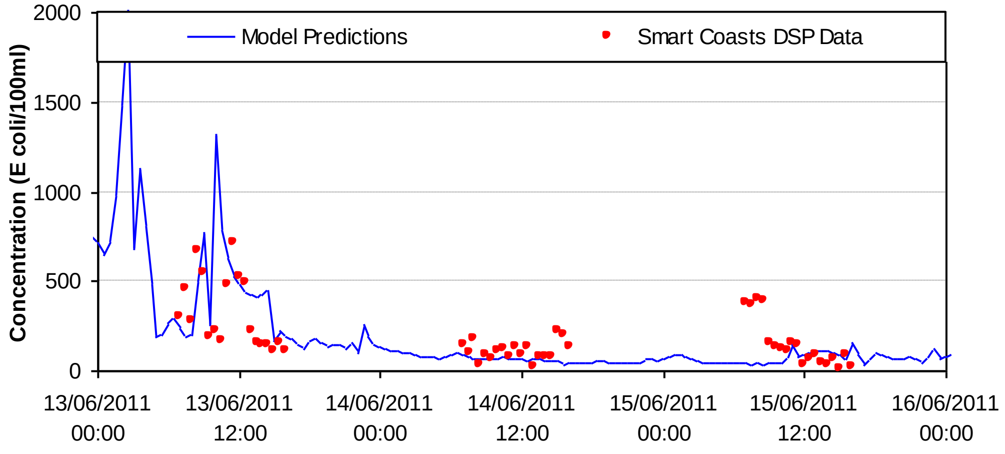
Figure 5-8: Swansea DSP measured and predicted concentration s: E Coli, neap tide, north westerly wind (small rainfall - 16/08/2011)



5.3.2 Wet Weather

5.3.2.1 Figures 5-9 to 5-13 compare sample and model results under a range of storm conditions on spring tides. Under a north westerly wind (Figure 5-9), the model predicts the storm concentrations well, together with the reduction in DSP concentrations after the storm. As discussed previously (Figure 5-5), the model does not fully represent the degree of variation in the sample data, as the variability in discharge concentrations and environmental conditions will be greater during storm conditions. However, the trend and mean concentration are predicted well.

Figure 5-9: Swansea DSP measured and predicted concentrations: E Coli, spring tide, north westerly wind (heavy rainfall –12/06/2011).



5.3.2.2 Figures 5-10 and 5-11 present model and sample results under a south westerly wind. The model reproduces dry weather concentrations well, and the response to the storm event. The range of concentrations is accurately reproduced. During the second storm event in Figure 5-11 the model peak concentration slightly lags the survey data.

Figure 5-10: Swansea DSP measured and predicted concentration s: E Coli, spring tide, south westerly wind (rainfall - 05/07 and 06/07/2011).

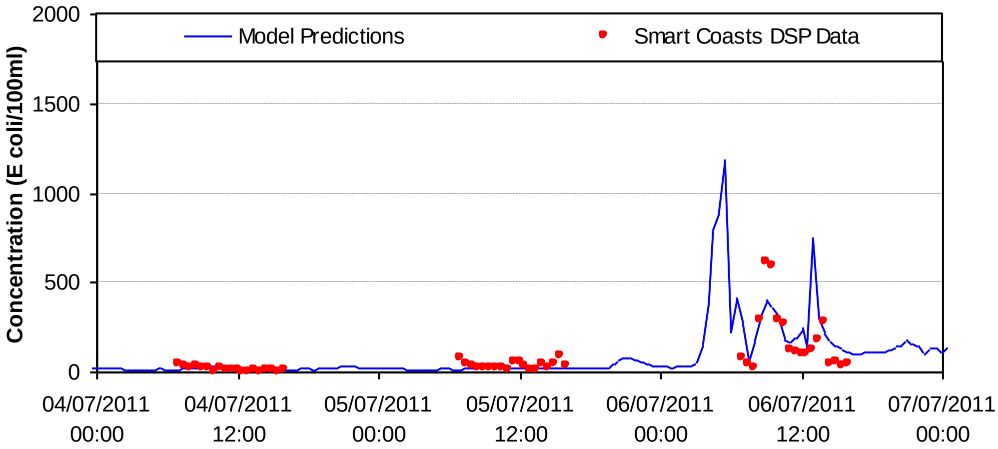
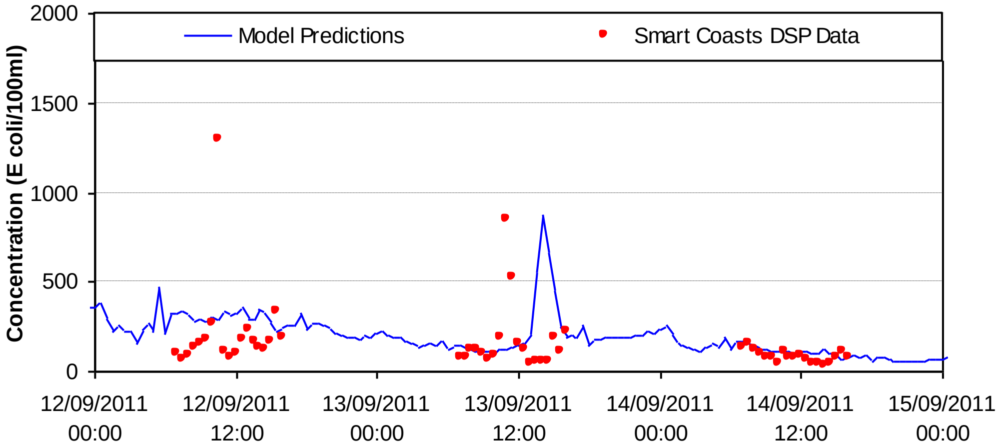
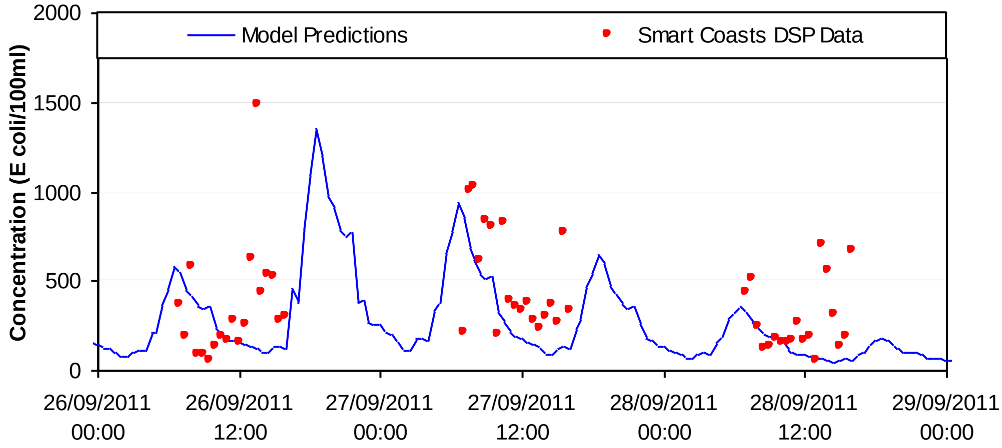


Figure 5-11: Swansea DSP measured and predicted concentration s: E Coli, spring tide, south westerly wind (rainfall - 12/09 and 13/09/2011).



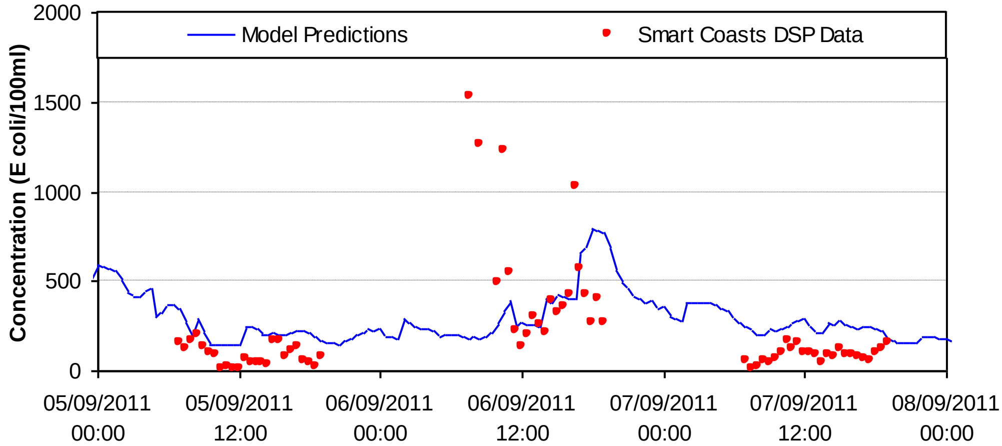
5.3.2.3 Figure 5-12 presents model and sample results under a south easterly wind. The model reproduces the general trend in the data well, although there is considerable more scatter in the DSP sample concentrations. The effects of a large storm on water quality over several days can be clearly seen, with elevated FIO concentrations throughout the sample period. This may also be due to the south easterly wind, which would tend to prevent the discharge from local streams and CSOs dispersing offshore. During the initial peak, the model slightly leads the sample data. A clear semi-diurnal pattern can be seen in the model results, which is broadly matched in the sample data.

Figure 5-12: Swansea DSP measured and predicted concentrations: E Coli, spring tide, south easterly wind (rainfall - 25/09/2011).



5.3.2.4 Figure 5-13 shows results for a neap tide and north westerly wind. The model reproduces the survey data well on 06/09/2011, although slightly over predicts concentrations over the day before and after.

Figure 5-13: Swansea DSP measured and predicted concentration s: E Coli, neap tide, south westerly wind (rainfall - 06/07, 05/09 and 07/09/2011).



5.3.3 Discussion

5.3.3.1 The results of the validation against the Smart Coasts DSP sampling indicate that the STORM-IMPACT model is capable of reproducing dry weather and storm event concentrations well at the Swansea Bay DSP. The shape and magnitude of the response of the DSP to storm events is reproduced well.

5.3.3.2 In general, the model predicts the mean concentration at the DSP, although it cannot reproduce the observed variability in the sample concentrations. This is largely because it is not possible to represent the variability in the input concentrations within the model, particularly in wet weather, as there is not sufficient data with which to define this.

5.4 CONCLUSIONS

5.4.0.1 STORM-IMPACT has been validated against long-term NRW DSP monitoring data and short term high frequency data collected by the Smart Coasts study.

5.4.0.2 Validation against the NRW DSP sample data is good, with best fit achieved for decay rates of 55 hours for E Coli and 65 hours for I Enterococci. These decay rates tend to lead to over-prediction of FIO concentrations at the key 90 and 95%iles required to determine class under the rBWD. For a comparative study of this kind, the degree of over-prediction seen is considered acceptable and provides a precautionary level of conservatism in the results.

5.4.0.3 Validation against the Smart Coasts DSP sample data has shown that STORM-IMPACT can accurately predict the response of the Swansea Bay DSP to variable FIO loadings under a wide range of tide and wind conditions.

5.4.0.4 Given the results of the validation of the STORM-IMPACT model against the NRW and Smart Coasts DSP samples, confidence in the model is considered good and the model is considered fit for use for the tidal Lagoon EIA.

6 WIND SENSITIVITY APPLICATIONS

6.0.0.1 Figures 6-1 to 6-5 present results of a series of sensitivity applications designed to assess the effects of wind on the dispersion of microbiological FIOs. Results are presented for an E Coli FIO for two cases, which represent the likely range of concentrations that would be experienced over a typical year:

a) **The dry weather geometric mean concentration,** typical of FIO bacteria concentrations under the effects of continuous dry weather discharges. This represents the normal background condition.

b) **The 95%ile storm concentration**, provides an indication the high FIO bacteria concentrations that would be expected in response to a large rainfall event.

6.0.0.2 It should be noted the plots are not an instantaneous concentration, but a composite representing geomean or 95%ile concentration in each model cell during the dry or wet period.

6.0.0.3 Figure 6-1a shows dry weather geomean concentrations under the Baseline condition with no wind applied in the model. 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, which discharges at HW and experiences relative little initial dilution.

6.0.0.4 With the Lagoon in place (Figure 6-1b), the distribution of bacteria is largely unchanged, although the area of high concentration at the Swansea WwTW outfall is now contained within the Lagoon impoundment.

6.0.0.5 Figures 6-1c and 6-1d show the 95%ile concentrations during the storm event. The high discharge loads from multiple sources lead to high concentrations during storm events; these high concentrations are not sustained for long, typically 24 hours or so.

6.0.0.6 In the Baseline case (Figure 6-1c), highest concentrations are seen along the Swansea foreshore, in response to local CSO discharges and increased inputs for local rivers and streams. As these discharges occur between high and low water, the discharge plumes tend to become attached to the shoreline, limiting dispersion. The impacts of the plume from the River Tawe can be seen extending some distance into the bay, along a line from the River Tawe to Mumbles Head.

6.0.0.7 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 large river plumes.

6.0.0.8 Further high concentrations can be seen at the mouth of the River Afan, around Port Talbot Docks, and around the discharge from the Afan WwTW Long Sea Outfall (LSO). The Aberafan bathing water DSP is located within a relatively low concentration area between these plumes.

6.0.0.9 Further plumes can be seen around the Baglan pumping station LSO, and the Knab Rock (Mumbles) storm outfall. The plumes from Baglan and Knab Rock can be seen to merge along a line south of Mumbles Head and extend north east towards Afan.

6.0.0.10 From Figure 6-1d it can be seen that construction of the Lagoon would be expected to have a number of effects on plume behaviour within Swansea Bay. These are:

a) The Swansea WwTW plume is effectively trapped within the Lagoon during the flood tide. This slightly reduces its impact on Swansea Bay, from the outfall location towards the Neath estuary and offshore towards Mumbles Head. When the plume is released during ebb generation it is more dispersed and has less impact on the area of the bay to the west of the Lagoon;

b) The discharges from the Tawe and Neath become attached to the Lagoon wall. This limits the lateral dispersion of the plumes and enhances offshore transport and concentrations in the plumes in the central bay area are reduced. The plume from the Tawe has slightly less impact along the Swansea frontage, reducing concentrations in the area between the Tawe and Clyne rivers. Concentrations around Blackpill are slightly increased as a result of reduced tidal flows in this area;

c) Changes in flow patterns in the area between the turbines and Mumbles Head lead to an increase in the transport of offshore water into the western part of the bay. This enhances the exchange of bay and offshore water increasing the dispersion and dilution of bacteria and can be seen in Figures 6-1c and 6-1d as a reduction in concentration to the south and west of the Lagoon;

d) Changes in tidal flows in the offshore area cause the concentration of bacteria south of a line between Mumbles and Port Talbot to increase, shifting the impacted area to the south. There is also a slight increase in concentration between the Baglan and Afan LSOs; and

e) Changes in flow around Mumbles head lead to a slight increase in concentration along the Gower coast.

6.0.0.11 Figures 6-2 and 6-3 present the model sensitivity results for the same discharge scenario, but with south easterly and south westerly winds applied in the model.

6.0.0.12 The south easterly wind causes a residual movement of water to the north west (Figure 6-2c). This tends to cause greater plume concentrations along the Swansea and Afan shorelines, as seaward dispersion is reduced, for example the Tawe discharge has a greater impact along the Swansea coastline. The presence of the Lagoon has little effect on plume dispersion in these areas (Figure 6-2d).

6.0.0.13 The south westerly wind causes plume movement towards the Afan shoreline (Figure 6-3c). Concentrations between the Tawe and Neath estuaries are increased as the Tawe plume moves further east under the influence of the south westerly wind. The change in trajectory of the Tawe plume reduces impacts along the Swansea shoreline. Afan impacts are slightly increased over the Baseline, as the Neath and Afan river plumes move shoreward. With the Lagoon in place the impact along the Swansea seafront is reduced (Figure 6-3d), possibly due to higher flow velocities increasing offshore dispersion, which in turn leads to elevated concentrations towards the Lagoon.

6.0.0.14 Results presented in Figures 6-1 to 6-3 suggest that the presence of the Lagoon will alter the distribution of bacteria FIOs within Swansea Bay, particularly those from sources close to the Lagoon, e.g. the 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 area. However, the changes in concentration are small and the impacts of the Lagoon on bacteria FIO distributions in Swansea Bay would be expected to be relatively low.

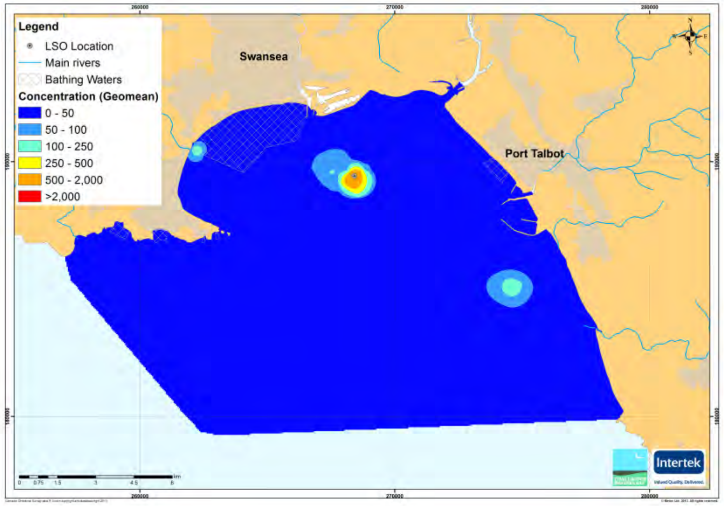
6.0.0.15 The results of the wind applications demonstrate how changes in wind speed and direction can modify FIO concentrations around Swansea Bay, particularly during storm events. Due to the highly variable nature of FIO concentrations in response to discharge load, decay, tide and wind these effects must all be considered when assessing microbiological impacts for bathing and shellfish water performance investigations. Wind effects are less important for those determinands with less variable loads and which do not decay rapidly in the marine environment. With this in mind wind has been applied to a number of model applications, i.e.:

a) Microbiological Sensitivity runs, designed to assess general changes in plume behaviour under average or typical conditions, are run for a no wind scenario, the effects of wind are subsequently covered in the STORM-IMPACT assessment;

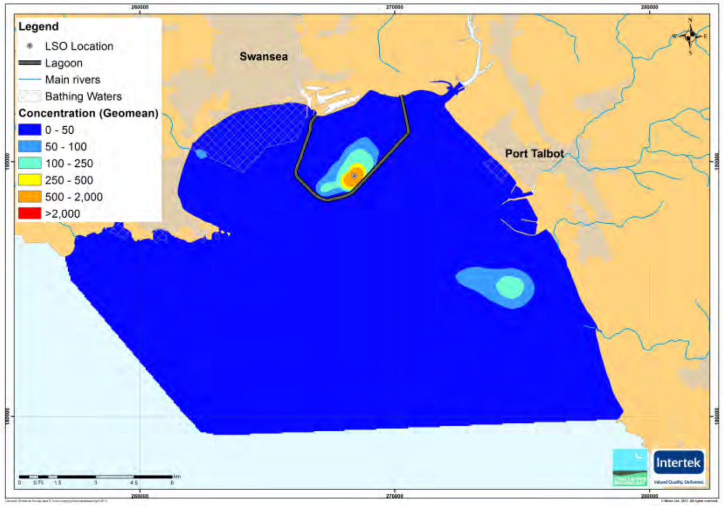
b) STORM-IMPACT applications, designed to assess performance of bathing and shellfish waters under a wide spectrum of load, tide and weather conditions, are run with a full set of statistically representative wind and tide conditions;

c) WFD applications are run with a no wind condition; as these runs typically represent long durations with relatively steady loads where the no wind condition provides a reasonable average.

Figure 6-1: Comparison of Baseline and Lagoon operation impacts on microbiological (E Coli) water quality – no wind



a) **Baseline dry weather geomean**

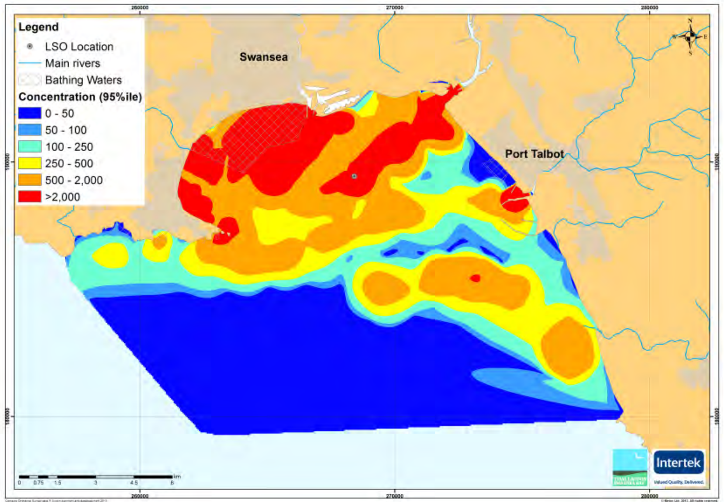


b) **Lagoon dry weather geomean**

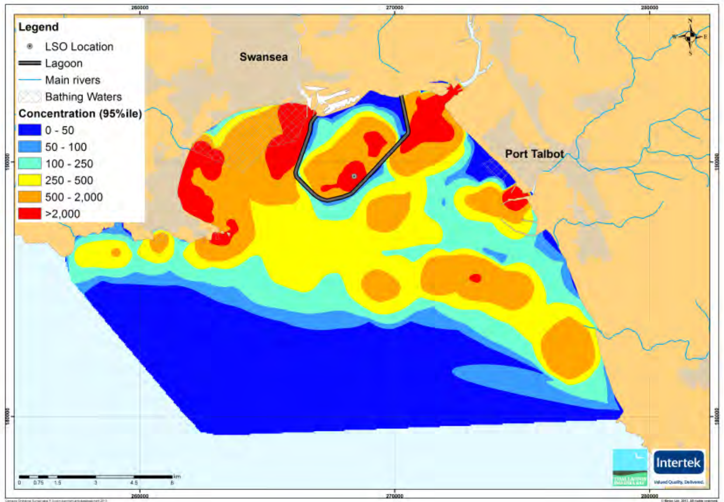
E Coli /100ml
Background loads
Spring tide
No wind
T_{90} = 50 hours

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

Concentration (Geomean)
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000



c) **Baseline wet weather 95%ile**



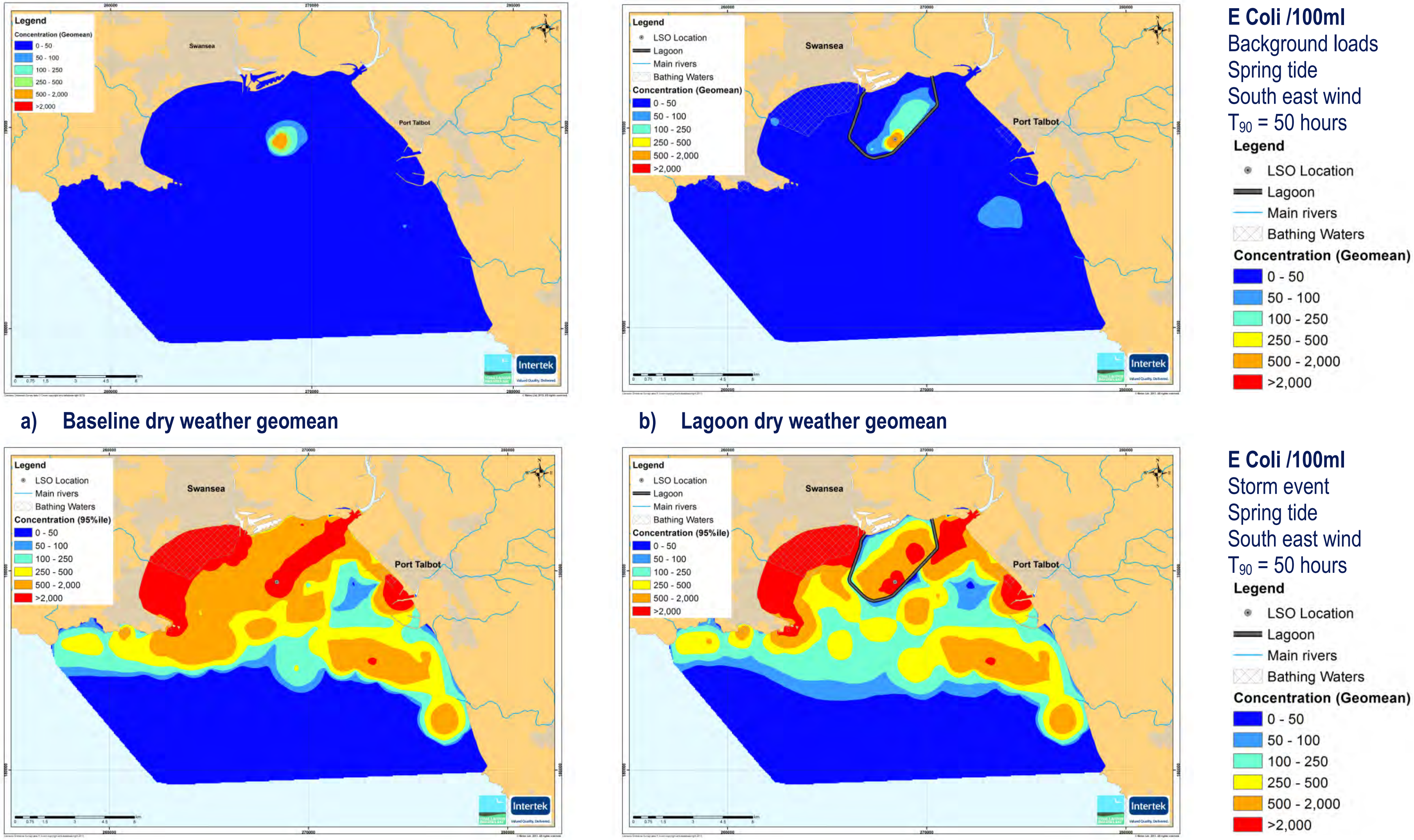
d) **Lagoon wet weather 95%ile**

E Coli /100ml
Storm event
Spring tide
No wind
T_{90} = 50 hours

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

Concentration (Geomean)
- 0 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 2,000
- >2,000

Figure 6-2: Comparison of Baseline and Lagoon operation impacts on microbiological (E Coli) water quality – south easterly wind



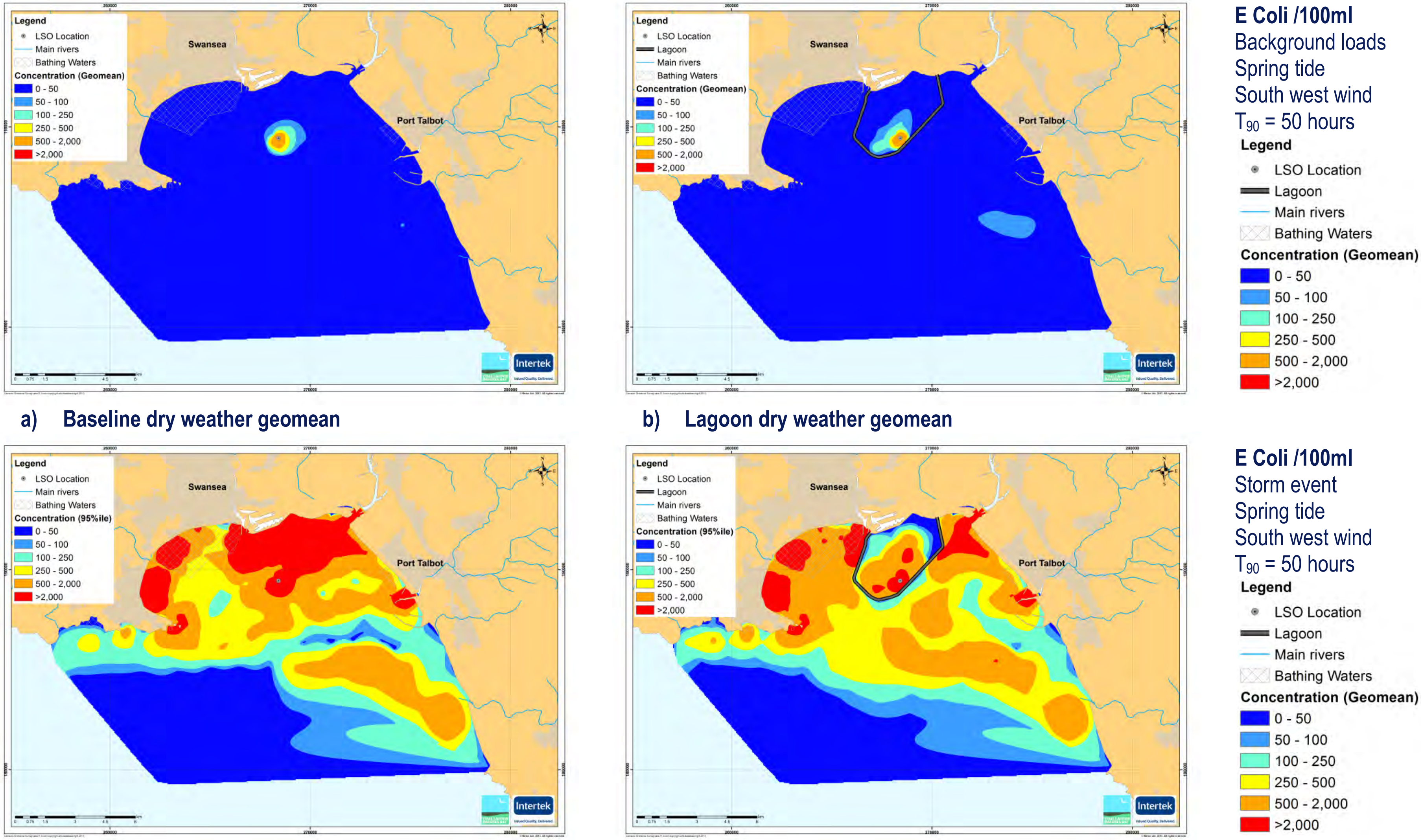
a) **Baseline dry weather geomean**

b) **Lagoon dry weather geomean**

c) **Baseline wet weather 95%ile**

d) **Lagoon wet weather 95%ile**

Figure 6-3: Comparison of Baseline and Lagoon operation impacts on microbiological (E Coli) water quality – south westerly wind



a) **Baseline dry weather geomean**

b) **Lagoon dry weather geomean**

c) **Baseline wet weather 95%ile**

d) **Lagoon wet weather 95%ile**

7 MICROBIOLOGICAL SOURCE INPUTS

7.0.0.1 Bacteria loads from both point sources (WwTW/CSO) and diffuse sources (river/stream) are included in the impact assessment. Loads from each input source are defined by flows and bacterial concentrations, and are derived from:

a) Storm spill discharges from DCWW assets were derived from the output of the Swansea network model and Afan network model provided by Grontmij.

b) Discharges from the Swansea WwTW and Afan WwTW are based on output from the network model.

c) Discharges from the River Tawe, Neath and Afan are based on NRW gauging records over the period 2008 to 2011. Discharges from smaller streams are derived from local hydrological models with the 2008 to 2011 rainfall data providing input. This approach allows concurrent storm spills and river flows to be used in the assessment.

d) Discharge concentrations from all sources are based on available historical sample data and intensive sample data collected during the recent Smart Coasts study.

7.1 POINT SOURCES

7.1.0.1 Table 7-1 provides a full list of point sources, including their representative model discharges, receiving watercourse and bacteria concentrations adopted in the assessment.

Table 7-1: List of point sources, representative model discharges and concentrations

Input Source	Watercourse	Model Discharge	E Coli (cfu/100ml)	I Enterococci (cfu/100ml)
Swansea WwTW FE	Sea	D36	$1.3x10^5$	$8.2x10^4$
Swansea WwTW Overflow	Sea	D36	$3.0x10^6$	$5.0x10^5$
Baldwins Crescent SPS	Sea	D02	$3.0x10^6$	$5.0x10^5$
Cricketers CSO	Sea	D05	$3.0x10^6$	$5.0x10^5$
CSO 10 Norton Road	Sea	D13	$3.0x10^6$	$5.0x10^5$
CSO 12 Palmyra Court	Sea	D13	$3.0x10^6$	$5.0x10^5$
CSO 130 Huntington Close	Sea	D07	$3.0x10^6$	$5.0x10^5$
CSO 15 Elmgrove Road	Sea	D21	$3.0x10^6$	$5.0x10^5$
CSO 16 Mayals Road	Sea	D03	$3.0x10^6$	$5.0x10^5$
CSO 95	Sea	D04	$3.0x10^6$	$5.0x10^5$
Dunns Lane CSO	Sea	D12	$3.0x10^6$	$5.0x10^5$
Dunns Lane Outfall**	Sea	D12	$3.0x10^6$	$5.0x10^5$
Knab Rock CSO	Sea	D43	$3.0x10^6$	$5.0x10^5$
Newton Road CSO	Sea	D12	$3.0x10^6$	$5.0x10^5$
Sandfields CSO	Sea	D17	$3.0x10^6$	$5.0x10^5$
Village Lane CSO	Sea	D20	$3.0x10^6$	$5.0x10^5$

Input Source	Watercourse	Model Discharge	E Coli (cfu/100ml)	I Enterococci (cfu/100ml)
CSO 139	River Tawe	D48	$3.0x10^6$	$5.0x10^5$
CSO 989	River Tawe	D48	$3.0x10^6$	$5.0x10^5$
High Street CSO	River Tawe	D08	$3.0x10^6$	$5.0x10^5$
Birchgrove SPS	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
Brynhyfryd CSO	River Tawe	D43	$3.0x10^6$	$5.0x10^5$
CSO 100	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
CSO 101	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
CSO 101A	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
CSO 102	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 103	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 104	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 105	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 106	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 107	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 108	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 109	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 116	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
CSO 117	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
CSO 125	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
CSO 125A	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
CSO 126	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
CSO 60	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
CSO 64A	River Tawe	D43	$3.0x10^6$	$5.0x10^5$
CSO 69	River Tawe	D43	$3.0x10^6$	$5.0x10^5$
CSO 69A	River Tawe	D43	$3.0x10^6$	$5.0x10^5$
CSO 72	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 73	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 80	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
CSO 81	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
Cwmbwrlais CSO	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
DRUMMAU ROAD SPS	River Tawe	D44	$3.0x10^6$	$5.0x10^5$
FORGE COTTAGES CSO	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
GLAIS 2 CSO	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
GLAIS CSO (ST)	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
GLAIS CSO 3	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
GLAIS SPS 1	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
GLAIS SPS 2	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
Hafod CSO	River Tawe	D48	$3.0x10^6$	$5.0x10^5$

Input Source	Watercourse	Model Discharge	E Coli (cfu/100ml)	I Enterococci (cfu/100ml)
Landore CSO	River Tawe	D33	$3.0x10^6$	$5.0x10^5$
LONLAS SPS	River Tawe	D45	$3.0x10^6$	$5.0x10^5$
Millers Arms CSO	River Tawe	D45	$3.0x10^6$	$5.0x10^5$
MTS Ynysforgan	River Tawe	D43	$3.0x10^6$	$5.0x10^5$
Mynydd Garnllwydd CSO	River Tawe	D53	$3.0x10^6$	$5.0x10^5$
Petreguinea Road CSO	River Tawe	D48	$3.0x10^6$	$5.0x10^5$
Unknown 1	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
Unknown 2	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
Unknown CSO 1	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
Unknown CSO 2	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
Unknown SPS	River Tawe	D42	$3.0x10^6$	$5.0x10^5$
Vicarage Road CSO	River Tawe	D45	$3.0x10^6$	$5.0x10^5$
White Rock CSO	River Tawe	D47	$3.0x10^6$	$5.0x10^5$
CSO 17 Derwen Fawr Road	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
CSO 21 Rhyd Y Dyfaid	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
CSO 22 Sketty Green	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
CSO 34 Whitehorne Place*	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
Glan Yr Afon Road	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
Sketty Park Drive CSO	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
SS61927602	River Clyne	D15	$3.0x10^6$	$5.0x10^5$
Vivian Road CSO*	River Clyne	D18	$3.0x10^6$	$5.0x10^5$
Bryn Road CSO	Singleton Park	D18	$3.0x10^6$	$5.0x10^5$
Glanbrydan Avenue CSO	Singleton Park	D47	$3.0x10^6$	$5.0x10^5$
Oakwood Rd CSO*	Singleton Park	D18	$3.0x10^6$	$5.0x10^5$
Park Place CSO*	Singleton Park	D18	$3.0x10^6$	$5.0x10^5$
Singleton Park CSO	Singleton Park	D18	$3.0x10^6$	$5.0x10^5$
CSO 13 Linden Tree	Washinghouse	D21	$3.0x10^6$	$5.0x10^5$
CSO 14 Alderwood Road	Washinghouse	D21	$3.0x10^6$	$5.0x10^5$
Fabian Way PS	River Neath	D49	$3.0x10^6$	$5.0x10^5$
Afan WwTW FE	Sea	D37	$4.3x10^5$	$1.7x10^5$
Afan WwTW Storm - Long	Sea	D37	$3.0x10^6$	$5.0x10^5$
Afan WwTW Storm - Short	Sea	D01	$3.0x10^6$	$5.0x10^5$
CSO12	Sea	D38	$3.0x10^6$	$5.0x10^5$
Briton Ferry PS Out	River Neath	D41	$3.0x10^6$	$5.0x10^5$
Briton Ferry SP	River Neath	D41	$3.0x10^6$	$5.0x10^5$
CSO15	River Neath	D41	$3.0x10^6$	$5.0x10^5$
GGRAVETMP	River Neath	D41	$3.0x10^6$	$5.0x10^5$
Unknown Outfall7	River Neath	D41	$3.0x10^6$	$5.0x10^5$

Input Source	Watercourse	Model Discharge	E Coli (cfu/100ml)	I Enterococci (cfu/100ml)
012_OF4	River Neath	D49	$3.0x10^6$	$5.0x10^5$
Unknown Outfall6	River Neath	D49	$3.0x10^6$	$5.0x10^5$
CSO11_Out	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO13	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO20	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO22	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO24	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO32	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO50	River Neath	D50	$3.0x10^6$	$5.0x10^5$
CSO9	River Neath	D50	$3.0x10^6$	$5.0x10^5$
018_store	River Neath	D51	$3.0x10^6$	$5.0x10^5$
026_OUT2	River Neath	D51	$3.0x10^6$	$5.0x10^5$
026_OUT3	River Neath	D51	$3.0x10^6$	$5.0x10^5$
CSO_003new	River Neath	D51	$3.0x10^6$	$5.0x10^5$
CSO_007new	River Neath	D51	$3.0x10^6$	$5.0x10^5$
CSO10	River Neath	D51	$3.0x10^6$	$5.0x10^5$
CSO27	River Neath	D51	$3.0x10^6$	$5.0x10^5$
CSO35	River Neath	D51	$3.0x10^6$	$5.0x10^5$
003_TANK	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO14	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO21	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO23	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO25	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO38	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO39	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO41	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO49	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO65	River Neath	D52	$3.0x10^6$	$5.0x10^5$
NEW CSO_017	River Neath	D52	$3.0x10^6$	$5.0x10^5$
PS_Out	River Neath	D52	$3.0x10^6$	$5.0x10^5$
Unknown Outfall2	River Neath	D52	$3.0x10^6$	$5.0x10^5$
Unknown Outfall8	River Neath	D52	$3.0x10^6$	$5.0x10^5$
CSO_048 NEW	River Neath	D53	$3.0x10^6$	$5.0x10^5$
CSO28	River Neath	D53	$3.0x10^6$	$5.0x10^5$
CSO42	River Neath	D53	$3.0x10^6$	$5.0x10^5$
CSO160_Out1	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
CSO202	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
CSO204	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$

Input Source	Watercourse	Model Discharge	E Coli (cfu/100ml)	I Enterococci (cfu/100ml)
CSO205_Out	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
CSO209	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
CSO216	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
Lon Y Cariadon HWK CSO	River Cynffig	D27	$3.0x10^6$	$5.0x10^5$
CSO101	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO102	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO103	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO104	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO107	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO109	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO110	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO112	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO114	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO115	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO116	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO119	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO123	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO125	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO126	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO128	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO129	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO131	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO134	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO135	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO155	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO156_Out1	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO157	River Afan	D46	$3.0x10^6$	$5.0x10^5$
CSO211	River Afan	D46	$3.0x10^6$	$5.0x10^5$
Cymmer CSO	River Afan	D46	$3.0x10^6$	$5.0x10^5$
New sco_136	River Afan	D46	$3.0x10^6$	$5.0x10^5$
Unknown Outfall1	River Afan	D46	$3.0x10^6$	$5.0x10^5$
Unknown Outfall3	River Afan	D46	$3.0x10^6$	$5.0x10^5$
Unknown Outfall4	River Afan	D46	$3.0x10^6$	$5.0x10^5$
Unknown Outfall5	River Afan	D46	$3.0x10^6$	$5.0x10^5$

* Asset removed under the AMP5 improvements
** New asset under the AMP5 improvements

7.2 DIFFUSE SOURCES

7.2.0.1 Table 7-2 provides a list of diffuse sources, and average dry and wet weather concentrations determined from the sample data collected under the Smart Coasts study. The Smart Coasts data has been used to predict time-varying concentrations in the rivers / streams using rainfall–concentration relationships.

7.2.0.2 Figure 7-1 shows comparisons of dry and wet weather concentrations (blue line) derived from the relationships used in this study with corresponding measured concentrations (red squares) from the Smart Coasts samples.

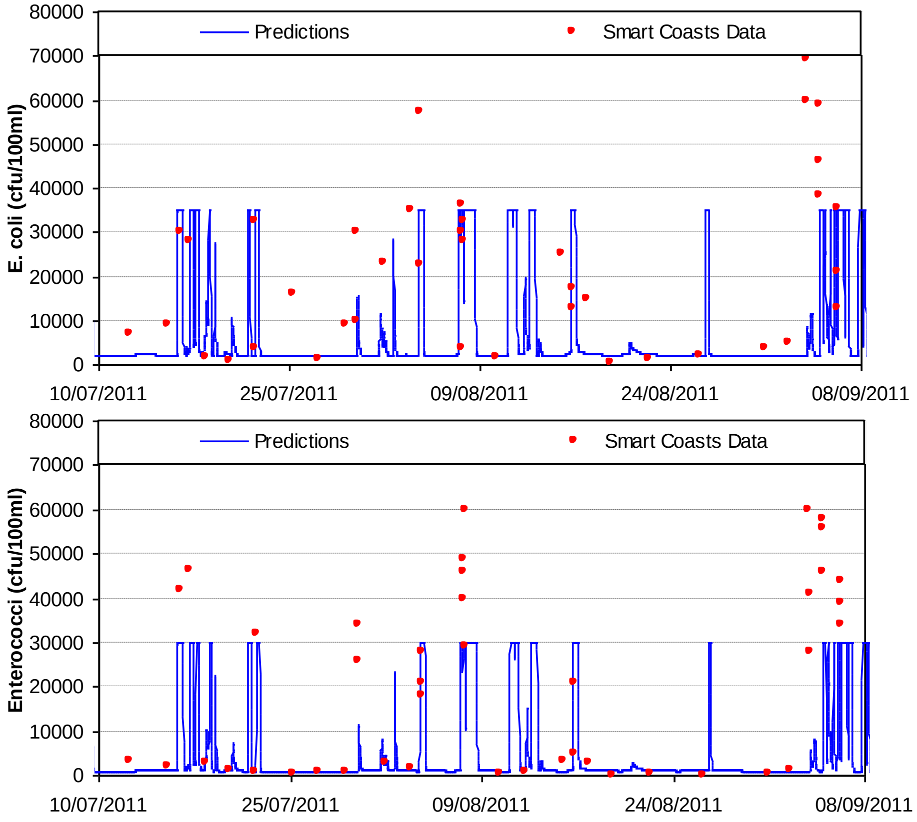
7.2.0.3 The fit between the rainfall / concentration relationship and the measured data is considered reasonable, given the naturally high variability in FIO concentrations in rivers. This approach is considered to provide a more accurate and robust assessment of storm loads, by including the response of bacteria concentration to rainfall (river flow) during storm events. Applying a single concentration could lead to an under- or over-prediction of diffuse load.

Table 7-2: List of diffuse sources, representative model discharges and concentrations

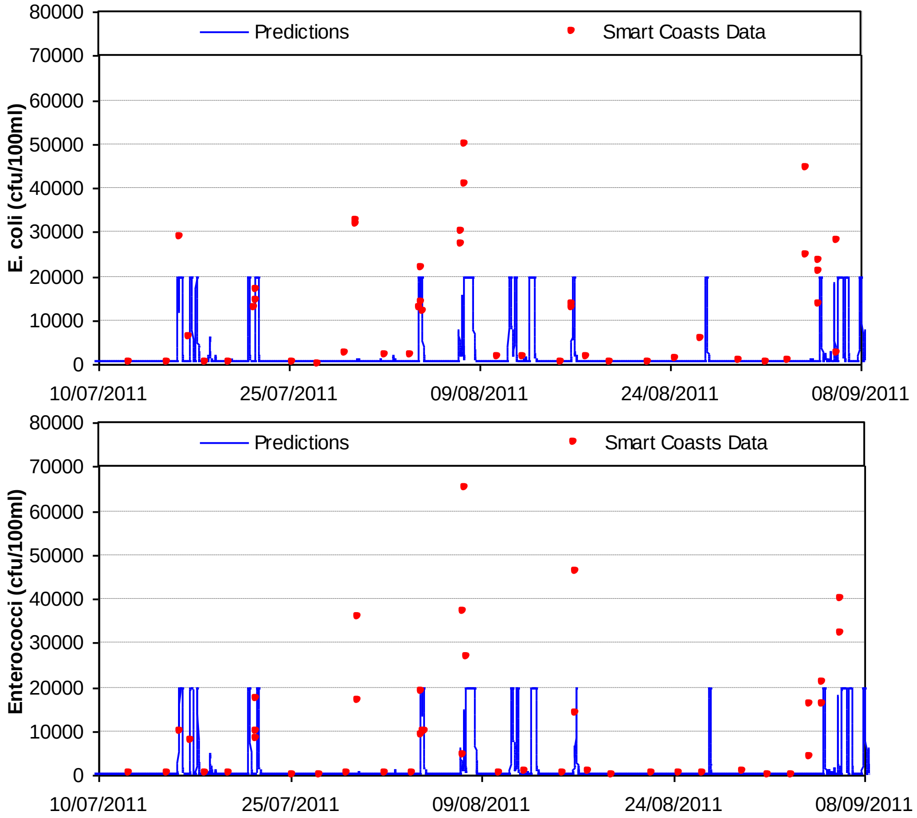
Input Source	Model Discharge	E Coli (cfu/100ml)		I Enterococci (cfu/100ml)	
		Dry	Wet	Dry	Wet
Washinghouse Brook	D21	2.0×10^3	3.5×10^4	1.0×10^3	3.0×10^4
Brock Hole Stream	D03	1.0×10^3	2.0×10^4	5.0×10^2	2.0×10^4
River Clyne	D15	1.2×10^3	3.0×10^4	8.0×10^2	2.5×10^4
Singleton Park Stream	D18	4.0×10^3	3.5×10^4	1.5×10^3	3.5×10^4
River Tawe	D47	1.0×10^3	8.0×10^3	2.0×10^2	1.5×10^3
River Neath	D53	5.0×10^2	5.0×10^3	2.0×10^2	1.5×10^3
River Afan	D46	5.0×10^2	5.0×10^3	2.0×10^2	1.7×10^3
Town Drain	D48	1.0×10^4	2.0×10^5	1.0×10^4	2.0×10^5

Figure 7-1: Comparisons of derived concentrations against Smart Coasts data

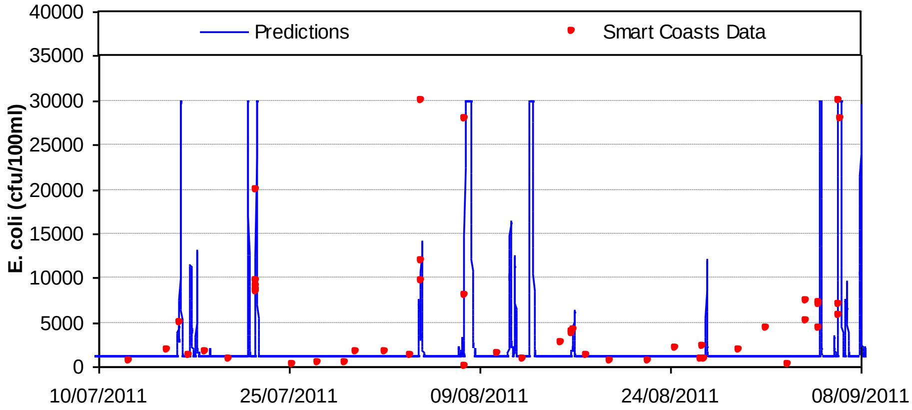
Washinghouse Brook

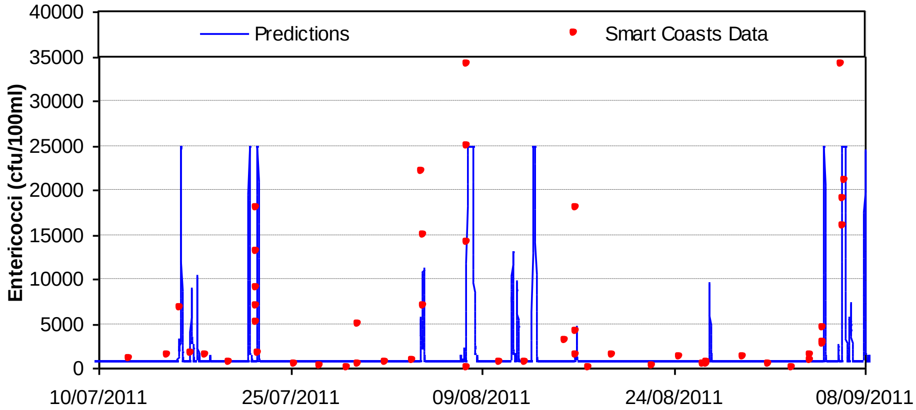


Brock Hole Stream

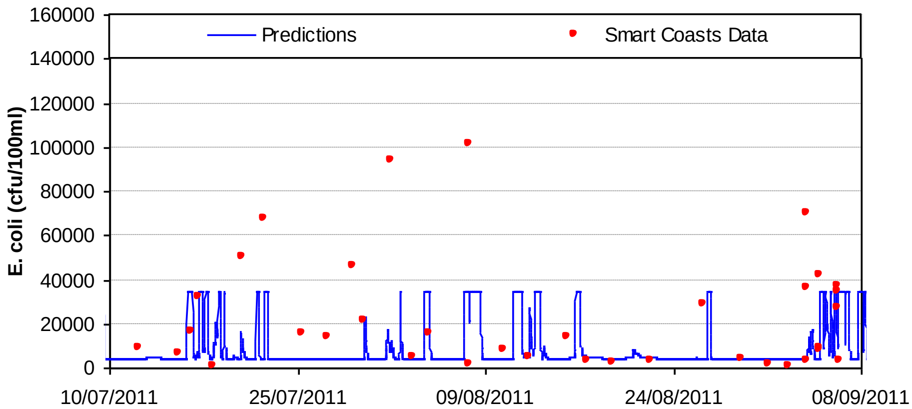


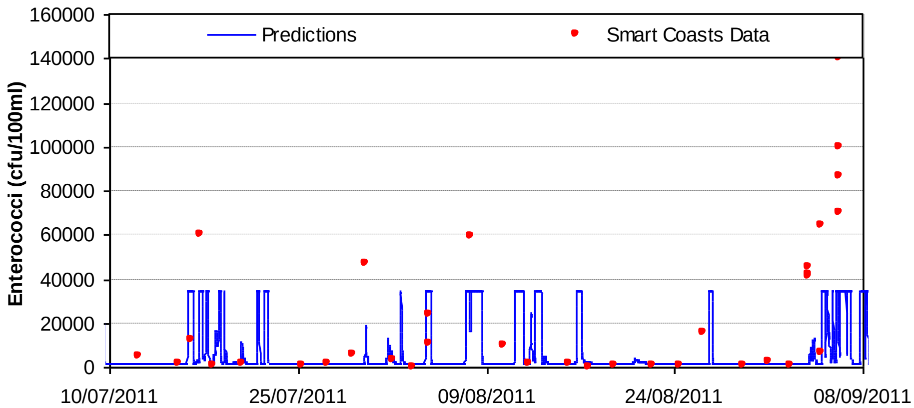
River Clyne



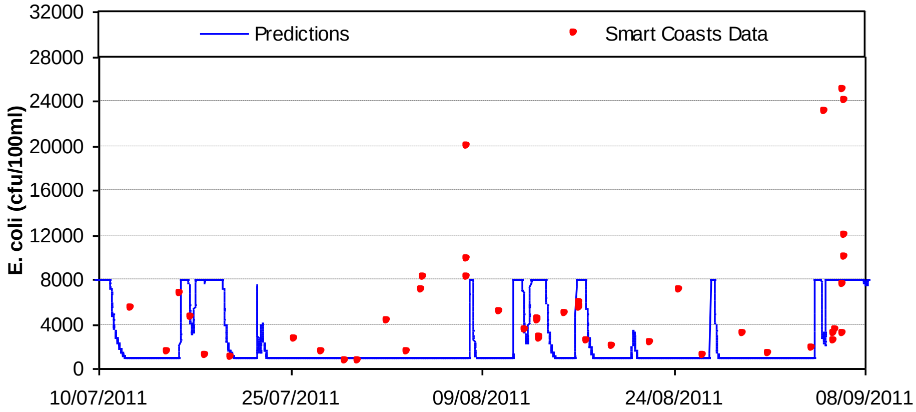


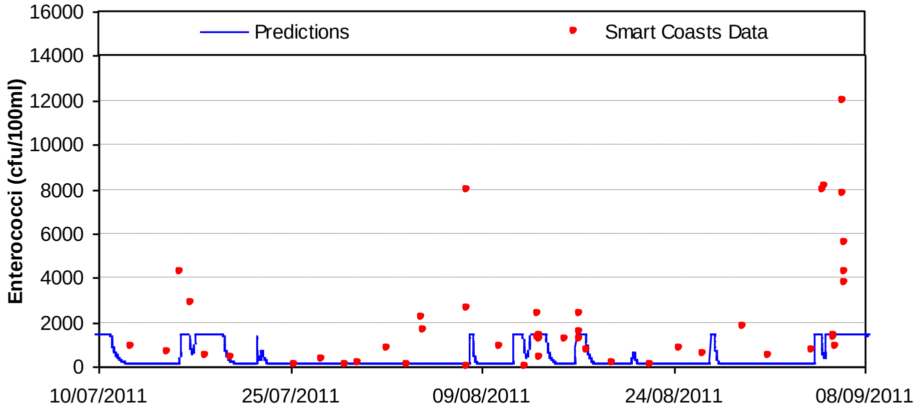
Singleton Park Stream



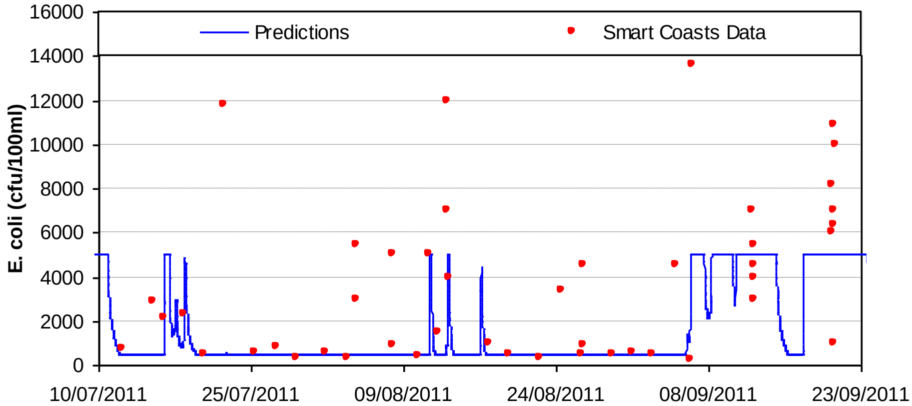


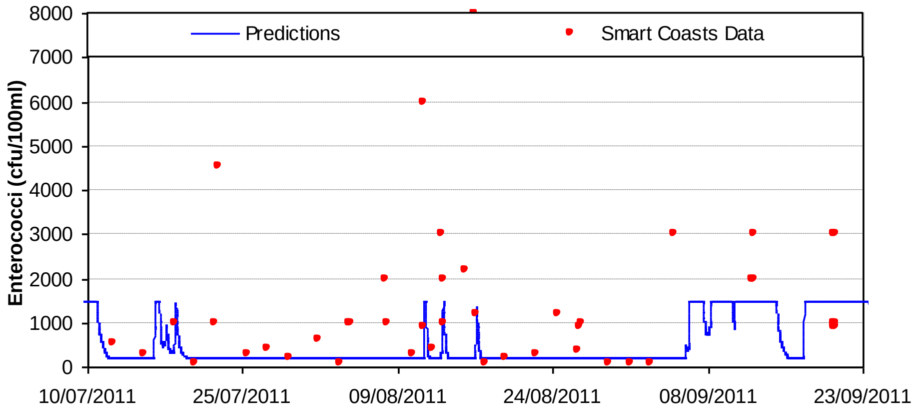
River Tawe



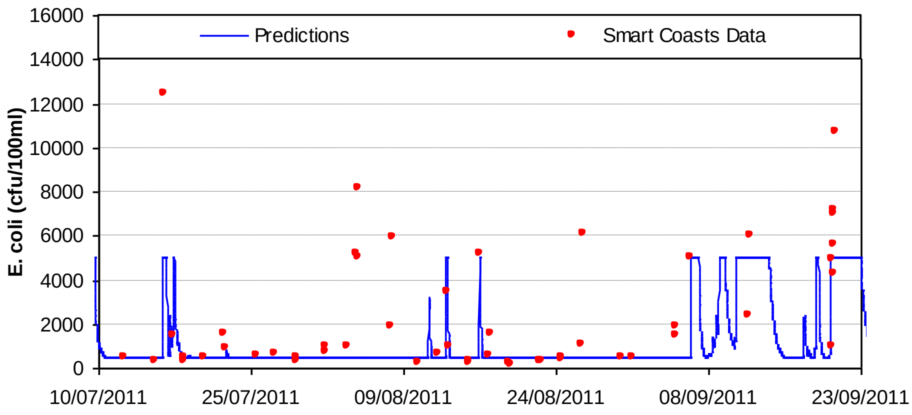


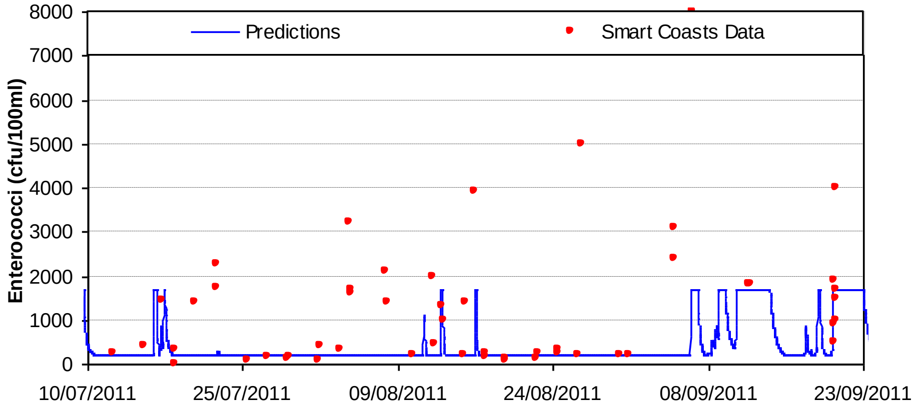
River Neath





River Afan


16000
14000
12000
10000
8000
6000
4000
2000
0
E. coli (cfu/100ml)
Predictions
Smart Coasts Data
10/07/2011
25/07/2011
09/08/2011
24/08/2011
08/09/2011
23/09/2011


8000
7000
6000
5000
4000
3000
2000
1000
0
Enterococci (cfu/100ml)
Predictions
Smart Coasts Data
10/07/2011
25/07/2011
09/08/2011
24/08/2011
08/09/2011
23/09/2011

8 WFD SOURCE INPUTS

8.0.0.1 The following section provides a summary of the derivation of discharge loads for the WFD applications. Due to the nature of these applications the discharge flows and concentrations may vary from those used in the microbiological model applications.

8.1 FLOW

8.1.0.1 Table 8-1 provides a list of the mean and, where appropriate, 10 %ile flows for rivers and point sources adopted in the WFD modelling. Sources include significant inputs to Swansea Bay, and other potentially significant sources within the model domain. These additional sources are included to provide a more complete assessment: as many of the determinands considered are conservative and will disperse over a much larger area than bacteria, which are subject to decay.

Table 8-1: Modelled Flows

Input Source	Mean flow (m^3/s)	10 %ile flow (m^3/s)
River Tawe	12.800	31.04
River Neath	12.710	31.38
River Afan	5.350	12.23
River Clyne	0.728	1.77
River Cynffig	3.007	7.29
River at West Cross	0.674	1.63
Pennard Pill	1.548	3.75
Oxwich Marsh	0.757	1.84
Swansea WwTW	0.732	N/A
Afan WwTW	0.641	N/A
Tata New Outfall	0.370	N/A
Oxwich WwTW	0.003	N/A
Overton WwTW	0.002	N/A
Southgate WwTW	0.008	N/A

8.1.0.2 These flows were derived from:

a) Flows for the rivers Tawe, Neath and Afan were based on measured data provide by the National River Flow Archive[1]. These data together with the catchment area at the gauge and at the downstream point on the river are provided in Table 8-2.

b) Mean and 10%ile flow were calculated by scaling the measured flows by the ratio of the catchment areas at the gauge and the downstream point.

[1] [1] NRFA. http://www.ceh.ac.uk/data/nrfa/data/search.html

Table 8-2: Measured and calculated flows – Rivers Tawe, Neath and Afan

Input Source	Flow Gauge	Catchment Area (km²)	Overall Catchment Area (km²)	Measured Mean Flow (m³/s)	Measured 10%ile Flow (m³/s)	Calculated Mean Flow (m³/s)	Calculated 10%ile Flow (m³/s)
River Tawe	Ynystanglws	227.70	236.15	12.330	29.9	12.80	31.04
River Neath	Resolven	191.03	260.82	9.309	22.98	12.71	31.38
River Afan	Marcroft	89.42	0.95	5.150	11.77	5.35	12.23

8.1.0.3 Flows for the rivers Clyne, Cynffig, Pennard Pill, Oxwich Marsh and the river at West Cross were based on measured flows at Ynystanglws on the River Tawe. Flows for these more minor rivers were calculated by scaling the measured flows by the ratio of catchments areas. Estimated flow statistics together with the catchment area of each more minor river is provided in Table 8-3.

Table 8-3: Measured and calculated Flows – Minor Rivers

Input Source	Overall Catchment Area (km²)	Measured Mean Flow (m³/s)	Measured 10 %ile Flow (m³/s)
Clyne River	13.43	0.73	1.77
Afon Cynffig	55.47	3.01	7.29
River at West Cross	12.43	0.67	1.63
Pennard Pill	28.55	1.55	3.75
Oxwich Marsh	13.97	0.76	1.84

8.1.0.4 Flows for the wastewater treatment works (WwTW) Swansea and Afan and the Tata new outfall were based on CREH sampling data recorded in 2011 at these 3 WwTWs. The mean flows are presented in Table 8-4.

Table 8-4: Minor WwTWs flow statistics

WwTW	Mean flow (m³/s)
Swansea WwTW	0.707
Afan WwTW	0.641
Tata LSO	0.370

8.1.0.5 Flows for the Oxwich WwTW, Overton WwTW and Southgate WwTW were based on average flow rates from NRW sampling data recorded between 2006 and 2009 at these 3 WwTWs. The mean flows are presented in Table 8-5.

Table 8-5: Minor WwTWs flow statistics

WwTW	Mean flow (m³/s)
Oxwich WwTW	0.003
Overton WwTW	0.002
Southgate WwTW	0.008

8.2 DISSOLVED OXYGEN, BOD AND AMMONIA LOADS

8.2.0.1 Dissolved Oxygen, BOD and ammonia loads have been modelled for two cases:

a) winter high flow conditions; and

b) summer low flow conditions

8.2.0.2 A number of assumptions are common to both simulations.

i) BOD and ammonia concentrations from the rivers Tawe, Neath, Clyne and Afan were derived from the 90 percentile from NRW river sampling data. Data were taken from the nearest site upstream of the tidal limit and analysed over the available data record.

ii) DO concentrations from the rivers Tawe, Neath, Clyne and Afan were derived from NRW river sampling data.

iii) Loads from smaller rivers Cynffig, Pennard Pill, Oxwich Marsh and the river at West Cross are based on the same concentrations as the River Clyne. This was selected as the rivers have a similar catchment area and mean flow to the Clyne.

iv) BOD and ammonia concentrations from Swansea WwTW, Afan ATW, Tata new outfall, Oxwich WwTW, Overton WwTW and Southgate WwTW were derived from the 90 percentile from available NRW and DCWW sample data.

v) DO concentrations from Swansea WwTW, Afan ATW, Tata new outfall, Oxwich WwTW and Southgate WwTW were based on. typical WwTW DO effluent concentrations. A study of WwTWs in the River Lee catchment2 found that WwTW DO concentrations averaged 7.4 mg/l with a minimum of 3 mg/l and a maximum of 12.3 mg/l.

vi) Overton WwTW was set at a lower dissolved oxygen level due to the higher levels of BOD and ammonia.

vii) Boundary concentrations were derived from sampling NRW Water Information Management System (WIMS) database at a location to the south of Swansea Bay (WIMS No.74094).

8.2.1 Winter High Flow Conditions

8.2.1.1 Dissolved oxygen, BOD and ammonia loads from both point sources (WwTW/CSO) and diffuse sources (river/stream) are included in this assessment. Loads from each input source are defined by flows and water quality parameter concentrations, and are derived from:

a) Storm spill discharges from DCWW assets were derived from the output of the Swansea Bay network model provided by Grontmij.

b) Discharges from the Swansea WwTW are based on output from the network model.

[2] D.L. Snook and P.G. Whitehead. Water quality and ecology of the River Lee. Hydrology and Earth System Sciences.8(4), 636 to 650. 2004. www.hydrol-earth-syst-sci.net/8/636/2004/hess-8-636-2004.pdf

c) Discharges from the Tawe and Neath are based on NRW gauging records over the period 2001 to 2011. Discharges from smaller streams are derived from local hydrological models with the 2001 to 2011 rainfall data providing input. This approach allows concurrent storm spills and river flows to be used in the assessment.

d) The model temperature was set to 7°C and the model salinity to 31 practical salinity units (psu).

8.2.1.2 Table 8-6 provides a list of point sources included and DO, BOD and ammonia concentrations adopted. A list of diffuse sources is given in Table 8-7. The boundary and background conditions are provided in Table 8-8.

Table 8-6: List of point sources and concentrations

Ref*	Input Source	Watercourse	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
1	Swansea WwTW FE	Sea	5	15.9	37.50
1	Swansea WwTW Storm Overflow	Sea	5	28.0	3.28
2	CSO 12 Palmyra Court	Sea	5	28.0	3.28
3	CSO 105	River Tawe	5	28.0	3.28
4	CSO 107	River Tawe	5	28.0	3.28
5	Birchgrove SPS	River Tawe	5	28.0	3.28
6	CSO 108	River Tawe	5	28.0	3.28
7	CSO 109	River Tawe	5	28.0	3.28
8	DRUMMAU ROAD SPS	River Tawe	5	28.0	3.28
9	White Rock CSO	River Tawe	5	28.0	3.28
10	CSO 139	Tawe Estuary	5	28.0	3.28
11	High Street CSO	Tawe Estuary	5	28.0	3.28
12	Mynydd Garnllwydd CSO	River Tawe	5	28.0	3.28
13	CSO 125	River Tawe	5	28.0	3.28
14	FORGE COTTAGES CSO	River Tawe	5	28.0	3.28
15	CSO 125A	River Tawe	5	28.0	3.28
16	Unknown CSO 1	River Tawe	5	28.0	3.28
17	CSO 116	River Tawe	5	28.0	3.28
18	CSO 117	River Tawe	5	28.0	3.28
19	CSO 126	River Tawe	5	28.0	3.28
20	Sketty Park Drive CSO	River Clyne	5	28.0	3.28
21	CSO 100	River Tawe	5	28.0	3.28
22	Cwmbwrlais CSO	River Tawe	5	28.0	3.28
23	CSO 60	River Tawe	5	28.0	3.28
24	CSO 81	River Tawe	5	28.0	3.28
25	GLAIS SPS 1	River Tawe	5	28.0	3.28
26	GLAIS SPS 2	River Tawe	5	28.0	3.28
27	GLAIS CSO (ST)	River Tawe	5	28.0	3.28
28	GLAIS CSO 3	River Tawe	5	28.0	3.28

Ref*	Input Source	Watercourse	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
29	GLAIS 2 CSO	River Tawe	5	28.0	3.28
30	Unknown SPS 2	River Tawe	5	28.0	3.28
31	Fabian Way PS	Neath Estuary	5	28.0	3.28
32	CSO 103	River Tawe	5	28.0	3.28
33	LONLAS SPS	River Tawe	5	28.0	3.28
34	CSO 16 Mayals Road	Sea	5	28.0	3.28
35	Hafod CSO	River Tawe	5	28.0	3.28
36	Vicarage Road CSO	River Tawe	5	28.0	3.28
37	CSO 73	River Tawe	5	28.0	3.28
38	CSO 72	River Tawe	5	28.0	3.28
39	CSO 80	River Tawe	5	28.0	3.28
40	Knab Rock CSO	Sea	5	28.0	3.28
41	Village Lane CSO	Sea	5	28.0	3.28
42	Newton Road CSO	Sea	5	28.0	3.28
43	Landore CSO	River Tawe	5	28.0	3.28
44	CSO 69A	River Tawe	5	28.0	3.28
45	CSO 64A	River Tawe	5	28.0	3.28
46	Brynhyfryd CSO	River Tawe	5	28.0	3.28
47	CSO 69	River Tawe	5	28.0	3.28
48	CSO 101A	River Tawe	5	28.0	3.28
49	Unknown 1	River Tawe	5	28.0	3.28
50	Unknown 2	River Tawe	5	28.0	3.28
51	CSO 101	River Tawe	5	28.0	3.28
52	Unknown CSO 2	River Tawe	5	28.0	3.28
53	CSO 95	Sea	5	28.0	3.28
54	CSO 17 Derwen Fawr Road	River Clyne	5	28.0	3.28
55	CSO 21 Rhyd Y Dyfaid	River Clyne	5	28.0	3.28
56	Vivian Road CSO	River Clyne	5	28.0	3.28
57	CSO 22 Sketty Green	River Clyne	5	28.0	3.28
58	Bryn Road CSO	Singleton Park Stream	5	28.0	3.28
59	Glanbrydan Avenue CSO	Singleton Park Stream	5	28.0	3.28
60	Singleton Park CSO 23	Singleton Park Stream	5	28.0	3.28
61	Singleton Park CSO 24	Singleton Park Stream	5	28.0	3.28
62	CSO 34 Whitehorne Place / Furzeland Drive	River Clyne	5	28.0	3.28
63	Glan Yr Afon Road d025 250	River Clyne	5	28.0	3.28
64	Cricketers CSO	Sea	5	28.0	3.28
65	Sandfields CSO	Sea	5	28.0	3.28
66	CSO 989	Tawe Estuary	5	28.0	3.28

Ref*	Input Source	Watercourse	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
67	Petreguinea Road CSO	River Tawe	5	28.0	3.28
68	CSO 106	River Tawe	5	28.0	3.28
69	CSO 104	River Tawe	5	28.0	3.28
70	CSO 13 Linden Tree	Washinghouse Brook	5	28.0	3.28
71	CSO 14 Alderwood Road	Washinghouse Brook	5	28.0	3.28
72	CSO 130 Huntington Close	Sea	5	28.0	3.28
73	CSO 102	River Tawe	5	28.0	3.28
74	Baldwins Crescent SPS	Sea	5	28.0	3.28
75	MTS Ynysforgan	River Tawe	5	28.0	3.28
76	Millers Arms CSO	River Tawe	5	28.0	3.28
77	CSO 15 Elmgrove Road	Sea	5	28.0	3.28
78	CSO 10 Norton Road	Sea	5	28.0	3.28
79	Dunns Lane CSO	Sea	5	28.0	3.28
80	Afan WwTW	Sea	5	13.9	22.96
81	Tata New Outfall	Sea	5	3.5	23.60
82	Oxwich WwTW	Sea	5	64.0	38.58
83	Overton WwTW	Sea	1	327.6	84.40
84	Southgate WwTW	Sea	5	30.2	20.82

Table 8-7: List of diffuse sources and concentrations

Input Source	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
River Tawe	9.92	2.60	0.145
River Neath	10.52	2.02	0.123
River Clyne	10.60	2.43	1.982
River Afan	8.74	1.72	0.050
Brock Hole Stream	10.60	2.43	1.982
Singleton Park Stream	10.60	2.43	1.982
Washinghouse Brook	10.60	2.43	1.982

Table 8-8: Winter Boundary and background concentrations

Input Source	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
Background	8.551	1.147	0.031
Boundary	8.425	1.067	0.026

8.2.2 Summer Low Flow Conditions

8.2.2.1 Table 8-9 provides a list of the input loads for dissolved oxygen, biochemical oxygen demand (BOD) and ammonia for all point source and diffuse sources adopted in this assessment. The boundary and background conditions are provided in Table 8-10. The model temperature was set to 15°C and the model salinity to 35psu.

Table 8-9: Dissolved oxygen (DO), biochemical oxygen demand (BOD) and Ammonia loads

Input Source	DO(mg/l)	BOD(mg/l)	Ammonia(mg/l)
River Tawe	9.917	3.5	0.2593
River Neath	10.518	2.17	0.07
River Afan	8.739	1.72	0.05
River Clyne	10.6	2.43	1.982
River Cynffig	10.6	2.43	1.982
River at West Cross	10.6	2.43	1.982
Pennard Pill	10.6	2.43	1.982
Oxwich Marsh	10.6	2.43	1.982
Swansea WwTW	5	15.9	35.75
Afan WwTW	5	13.86	22.96
Tata New Outfall	5	3.5	23.6
Oxwich WwTW	5	64	38.58
Overton WwTW	1	327.6	84.4
Southgate WwTW	5	30.2	20.82

Table 8-10: Summer boundary and background concentrations

Input Source	DO (mg/l)	BOD (mg/l)	Ammonia (mg/l)
Background	8.551	1.147	0.031
Boundary	8.425	1.067	0.026

8.3 NUTRIENT LOADS

8.3.0.1 Table 8-11 provides a list of the nutrient concentrations for point source and diffuse sources adopted in this assessment. Nutrient loads are represented by dissolved available inorganic nitrogen (DAIN) and dissolved available inorganic phosphorus (DAIP). Only nitrogen loads are used for the study, as this is the significant limiting nutrient in marine waters, phosphorous loads are included for completeness. Loads from each input source are defined by mean flows and nutrient concentrations. Loads were derived as follows:

a) Nutrient loads from the rivers Tawe, Neath, Clyne and Afan, Swansea WwTW and Afan WwTW and the Tata new outfall are based on annual nutrient inputs provided in a recent (2012) report for NRW by the Centre for Research into Environment and Health (CREH)[Ref 5], which provides an assessment of nutrient sources and budgets for Swansea Bay.

b) Loads from smaller rivers are based on the same nutrient concentrations as the River Clyne. This was selected as the rivers have a similar catchment area and mean flow to the Clyne.

c) Loads from Oxwich WwTW, Overton WwTW and Southgate WwTW were based on the average from NRW and DCWW sample data.

d) Boundary and background concentrations were derived from NRW WIMS sample site No.74094 (Table 8-12).

Table 8-11: List of nutrient concentrations

Input Source	DAIN(ug/l)	DAIP(ug/l)
River Tawe	1112	32
River Neath	841	21
River Afan	853	13
River Clyne	1442	36
River Cynffig	1442	36
River at West Cross	1442	36
Pennard Pill	1442	36
Oxwich Marsh	1442	36
Swansea WwTW	20886	1171
Afan WwTW	14242	930
Tata New Outfall	12281	0
Oxwich WwTW	26025	5100
Overton WwTW	41486	9625
Southgate WwTW	20774	12500
Offshore Boundary	237	29

Table 8-12: Boundary and background concentrations

Input Source	DAIN(ug/l)	DAIP(ug/l)
Background	237	29
Boundary	237	29

8.4 TEMPERATURE AND SALINITY

8.4.0.1 Temperature and salinity have been modelled for two cases:

a) winter high flow conditions; and

b) summer low flow conditions

8.4.0.2 An assumption is common to both simulations, that boundary concentrations were derived from NRW WIMS sample site No.74094.

8.4.1 Winter High Flow Conditions

8.4.1.1 Temperature and salinity from both point sources (WwTWs) and diffuse sources (river/stream) are included in this assessment. Loads from each input source are defined by flows and water quality parameter concentrations, and are derived from discharges from the Tawe and Neath based on NRW gauging records over the period 2001 to 2011. Discharges from smaller streams are derived from local hydrological models with the 2001 to 2011 rainfall data providing input. This approach allows concurrent storm spills and river flows to be used in the assessment.

8.4.1.2 Table 8-13 provides a list of point sources included and temperature and salinity adopted. The boundary, background and atmospheric conditions are provided in Table 8-14.

Table 8-13: List of point sources and winter concentrations

Input Source	Temperature (°C)	Salinity (psu)
River Tawe	4	0
River Neath	4	0
River Afan	4	0
River Clyne	4	0
River Cynffig	4	0
River at West Cross	4	0
Pennard Pill	4	0
Oxwich Marsh	4	0
Swansea WwTW	4	0
Afan WwTW	4	0
Tata New Outfall	4	0
Oxwich WwTW	4	0
Overton WwTW	4	0
Southgate WwTW	4	0
Baglan Power Station	12	31

Table 8-14: Winter Boundary and background concentrations

Input Source	Temperature (°C)	Salinity (psu)
Sea Background	7	31
Sea Boundary	7	31
Air	5.2	N/A

8.4.2 Summer Low Flow Conditions

8.4.2.1 Table 8-15 provides a list of the input temperature and salinity for all point source and diffuse sources adopted in this assessment. The boundary and background conditions are provided in Table 8-16.

Table 8-15: List of point sources and summer concentrations

Input Source	Temperature (°C)	Salinity (psu)
River Tawe	15	0
River Neath	15	0
River Afan	15	0
River Clyne	15	0
River Cynffig	15	0
River at West Cross	15	0
Pennard Pill	15	0
Oxwich Marsh	15	0
Swansea WwTW	15	0
Afan WwTW	15	0
Tata New Outfall	15	0
Oxwich WwTW	15	0
Overton WwTW	15	0
Southgate WwTW	15	0
Baglan Power Station	20	31

Table 8-16: Summer boundary and background concentrations

Input Source	Temperature (°C)	Salinity (psu)
Sea Background	15	31
Sea Boundary	15	31
Air	15	N/A

9 REFERENCES

1. Titan, 2012b. Swansea Bay Tidal Lagoon Current/Wave Monitoring Final Overview Report. Titan Environmental Surveys Ltd. Report CS0343.
2. Intertek (2013) Swansea Bay Tidal Lagoon Water Quality - Hydrodynamic Model Update and Validation Report; P1609_RN3290_Rev0, August 2013.
3. Centre for Ecology and Hydrology Report, 2005, “The Revitalised FSR/FEH Rainfall Run-off Method”, CEH Report, December 2005
4. Kay, D et al (2005): Decay of intestinal enterococci concentrations in high-energy estuarine and coastal waters: towards real-time T90 values for modelling faecal indicators in recreational waters’: Water Research Vol 39 (2005), 655–667.
5. Centre For Research Into Environment And Health CREH (2012) A Preliminary Assessment of Nutrient Sources and Budgets for Swansea Bay - Final Report.2013.