Appendix 6.1

Swansea Bay Tidal Lagoon Coastal Processes: Model Setup, Calibration and Validation

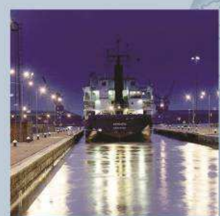
Tidal Lagoon (Swansea Bay) Plc

Swansea Bay Tidal Lagoon Coastal Processes: Model Setup, Calibration and Validation

Report R.2108TN

December 2013

Creating sustainable solutions for the marine environment





Tidal Lagoon (Swansea Bay) Plc

Swansea Bay Tidal Lagoon Coastal Processes: Model Setup, Calibration and Validation

Date: December 2013

Project Ref: R/4124/1

Report No: R.2108TN

Version	Details of Change	Date
1.0	Draft	28/05/2013
1.1	PEIR Final	17/06/2013
1.2	ES final	01/12/2013

Document Authorisation		Signature	Date
Project Manager:	A M Fulford		01/12/2013
Quality Manager:	P A Whitehead		01/12/2013
Project Director:	W S Cooper		01/12/2013

ABP Marine Environmental Research Ltd
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ

Tel: +44 (0) 23 8071 1840 **Fax:** +44 (0) 23 8071 1841
Web: www.abpmer.co.uk **Email:** enquiries@abpmer.co.uk

ABPmer is certified by:

Disclaimer:

- *Any 'Draft' issue of this report, and any information contained therein, may be subject to updates and clarifications on the basis of any review comments before 'Final' issue. All content should therefore be considered provisional, and should not be disclosed to third parties without seeking prior clarification from ABP Marine Environmental Research Ltd ("ABPmer") of the suitability of the information for the intended disclosure and should not be relied upon by the addressee or any other person.*

- *Unless previously agreed between the addressee and ABPmer, in writing, the 'Final' issue of this report can be relied on by the addressee only. ABPmer accepts no liability for the use by or reliance on this report or any of the results or methods presented in this report by any party that is not the addressee of the report. In the event the addressee discloses the report to any third party, the addressee shall make such third party aware that ABPmer shall not be liable to such third party in relation to the contents of the report and shall indemnify ABPmer in the event that ABPmer suffers any loss or damage as a result of the addressee failing to make such third party so aware.*

- *Sections of this report rely on data supplied by or drawn from third party sources. Unless previously agreed between the addressee and ABPmer, in writing, ABPmer accepts no liability for loss or damage suffered by the addressee or any third party as a result of any reliance on third party data contained in the report or on any conclusions drawn by ABPmer which are based on such third party data.*

Swansea Bay Tidal Lagoon Coastal Processes: Model Setup, Calibration and Validation

Contents

Page

Tables

Figures

1.0 Introduction

1.0.0.1 ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by Tidal Lagoon (Swansea Bay) Plc (TLSB), to undertake a coastal process study for the development of a proposed tidal lagoon. The proposed development is within Swansea Bay, to the north of the Central Bristol Channel, with the coastal processes study being supported by numerical modelling tools.

1.0.0.2 This document provides a detailed description of the models used, their set-up and the calibration / validation stage of the numerical modelling study, designed to assess the potential impacts of the proposed development.

2.0 Model Design

2.0.0.1 The coastal process modelling utilises the Danish Hydraulic Institute's (DHI) MIKE21 system. Two primary modules were applied to form the basis of the coastal processes study:

i. MIKE21-FM-HD (Hydro-dynamic model); and
ii. MIKE21-FM-SW (Spectral Wind-wave model).

2.0.0.2 It is noted here that further modelling tools are utilised within the coastal processes assessment (specifically tools to inform the assessment of the fate of any sediment plumes from the construction phase, and an assessment of potential effects on sediment transport processes across the study area). The application of these further modelling tools is reported within the ES (along with a description of any calibration exercises undertaken).

2.0.0.3 To effectively model the physical processes within the study area a two-dimensional horizontal (2DH) model was selected, using an unstructured finite element mesh linking far-field and near-field in a single grid scheme. An assessment of the baseline environment using the data collected during the metocean survey (as provided in the TLSB Preliminary Environmental Information (PEI) report and the Environmental Statement (ES))) has revealed little evidence of consistent differences in flow velocity and direction with depth, that might otherwise suggest a three-dimensional (3D) model would be better suited to this assessment.

2.0.0.4 To create a model capable of providing descriptions of the hydrodynamic and wave characteristics across the study area, consideration was first given to the extent of the model domain. As a rule, the limits of the model domain should be of sufficient distance from the 'scheme' (in this case, the tidal lagoon development) so that any feedback effects on the propagation of the tide and wave parameters is effectively contained within the domain; thereby not invalidating the boundary conditions.

2.0.0.5 For the present undertaking, the numerical model previously used during the Environmental Impact Assessment (EIA) stage of both the Severn Estuary Tidal Power study and the Atlantic Array Offshore Windfarm project was adapted to focus on the proposed tidal lagoon within Swansea Bay.

2.0.0.6 The extent of the hydrodynamic model mesh is defined by the following boundaries (see Figure 6.1.1):

i. Northern boundary: Across Caernarfon Bay from the Lleyn Peninsula (Wales) to Eire;
ii. Eastern inshore boundary: Upper Severn Estuary;
iii. Southern offshore boundary: Offshore, parallel to the southern Cornish coast; and
iv. Western offshore boundary: Perpendicular to southern Eire coast.

2.1 Bathymetry

2.1.0.1 The mesh used by the model has been designed to resolve key processes over both near- and far-field extents. To achieve this, the resolution of the mesh was increased to approximately 20m x 20m over the particular areas of interest, notably in the near-field (across the proposed development site) and in the far-field (along the adjacent coastlines and covering the approach channels to the local ports). The locations of higher mesh resolution were also influenced by the identification of specific receptors during the scoping stage of the project. Detail of the increased mesh resolution in these areas is shown in Figure 6.1.2.

2.1.0.2 Across the study area, the regions of the greatest interest (as defined by the higher resolution mesh, described above) have been resolved with the most up-to-date bathymetry data, and at a relatively higher spatial resolution. The areas of coarser gridding, within the model mesh, apply across the far-field and relates to areas in the channel which largely remain more stable (as discussed in the Coastal Processes chapter of the PEI and ES (ABPmer, 2013a & 2014d)).

2.1.0.3 High resolution bathymetry data has been collected specifically for use in the study by Titan Surveys using multibeam survey equipment. This survey covered the proposed development area at a resolution of 1m x 1m.

2.1.0.4 Additional locally detailed bathymetric data within the study area has been obtained from various sources, including (but not limited to) Associated British Ports (ABP), the United Kingdom Hydrographic Office (UKHO), and the Neath Estuary Working Group. For the intertidal areas an aerial survey from 1991 provides the best available data for Swansea Bay and is preferred to any equivalent LiDAR data which appears to have incomplete coverage locally. A more detailed description of a number of input bathymetry datasets is provided in the Bathymetry Data Preparation Report (ABPmer, 2013b).

2.1.0.5 The datasets described above were obtained for use in the current study in order to ensure the highest resolution data coverage across both the near-field region (within the proposed lagoon site) and the far-field region adjacent to the proposed lagoon site (the wider Swansea Bay region; including the intertidal area and the Neath Estuary, the Central

Bristol Channel outside of Swansea Bay and the south Wales coastline between Porthcawl and Worms Head). These datasets represent a significant increase in resolution compared to the existing model bathymetry for this study area, which was 'tailored' for a different study area. The data also represents the most contemporary bathymetric datasets available for the study area.

2.1.0.6 For the remainder of the model domain, bathymetry data from a series of existing ABPmer hydrodynamic models were used. These data include bathymetry of the Inner, Central and Outer Bristol Channel, Scarweather Sands and the Helwick Bank.

2.1.0.7 All bathymetry data were reduced to a common datum (mean sea-level, which is approximately 0.15m below Ordnance Datum Newlyn (ODN) at Swansea) using the relevant correction method. For older bathymetry data a locally constant Chart Datum (CD) value was used; whilst more recent data used the VORF (vertical offshore reference framework) correction, supplied by the UKHO. Once corrected, all data were interpolated across the model mesh using a natural neighbour interpolation method.

2.1.0.8 Notwithstanding the provenance and characteristics of the various bathymetric datasets used in the numerical modelling study, the ability of the model to replicate hydrodynamic and wave conditions across the study area is demonstrated by the present calibration exercise. Providing that the model can be shown to be fit for purpose when compared to measured data across both the near and far-field regions, it can be considered that the bathymetric data described above is sufficient for the requirements of the numerical modelling study.

2.2 Tidal Modelling

2.2.0.1 The tidal model has been configured using the MIKE21-FM-HD module. This module is a 2D, depth-averaged model, which applies a flexible mesh (FM) element grid and is used to provide a description of tidal flows. The flexible mesh enables the far-field, near-field and structure scale processes to be accounted for in one model, with approximate mesh element dimensions ranging between 20m x 20m to 12,000m x 12,000m. The mesh extent is shown in Figure 6.1.1.

2.2.0.2 Additional information with regard to tidal characteristics within the study area can be found within the Coastal Processes chapter of the Preliminary Environmental Information (PEI) report and Environmental Statement (ES) (ABPmer, 2013a & 2014d).

2.2.1 Boundary Conditions

2.2.1.1 Open boundary conditions in the tidal model are specified as spatially and temporally varying water levels, covering a spring - neap tidal cycle and coinciding with the deployment of the metocean survey equipment (as described in Section 3). Fluvial inputs are included as mean discharge rates from the local rivers. Although the mean discharge has been used for the purposes of model calibration, it is anticipated that the subsequent assessment phase of the study will include consideration of different discharge scenarios (e.g. extreme events).

2.2.1.2 The open water level boundaries, located as defined by the model extent discussed in Section 2, and shown in Figure 6.1.1, are situated in order to encompass both near and far-field effects, and describe a whole-system response to the proposed development. The offshore boundaries extend out to the southern tip of Eire and the northern coast of France in order to adequately capture the tidal approaches to the Bristol Channel, whilst also extending to the northern coast of Wales. This model extent allows sufficient focus to be applied to the near-field effects in and around the proposed development, whilst also allowing for an assessment of the extent of any far-field effects to be made.

2.2.1.3 The boundary water levels were derived from a harmonic analysis of water level timeseries data, which identified a total of 15 harmonic constituents. These constituents were subsequently applied to create a timeseries of variation in astronomic tidal water levels, with which to drive the 2D hydrodynamic model.

2.3 Wave Modelling

2.3.0.1 Wave modelling has been undertaken using the MIKE21-FM-SW modelling software. This model applies a similar flexible mesh as the HD model, and enables waves to be simulated from a variety of user specified directions, without altering the orientation of the grid.

2.3.1 Boundary Conditions

2.3.1.1 For the calibration and validation stage, open boundary conditions in the wave model are specified as spatially and temporally varying wave height, period, direction and spreading for an eight-week period between February and April, 2012 (coinciding with the deployment of the metocean survey equipment, as described in Section 3). This eight-week period incorporates a number of large and small wave events. In addition, the water surface acts as an open boundary to winds, with a temporally and spatially varying wind boundary (as described for the SEASTATES model, below) applied across the model domain.

2.3.1.2 The boundary data used in this study were derived from the ABPmer SEASTATES model. This is a regional model covering the entire UK continental shelf which is driven by wind and swell conditions obtained from the NOAA (National Oceanic and Atmospheric Administration) global atmospheric model. The SEASTATES model has previously undergone extensive model calibration, but a study specific calibration check was carried out using measured wave data from the Waverider buoy at Scarweather. This was undertaken to ensure that the wave boundary conditions, subsequently extracted for the detailed wave assessment, were providing a suitable wave climate within the study area. The ability of the detailed MIKE21-FM-SW model, used for this study, to adequately represent wave conditions across the study area was tested during its own calibration and validation procedure, and the results of this exercise are described further in the Section 4.3 of this report.

2.4 Implementation of Structures

2.4.0.1 Whilst not specifically included in the baseline modelling stage, for the assessment phase the proposed lagoon structure is intended to be implemented through adjustment of the model bathymetry to replicate the design dimensions of the lagoon wall. In addition, the bathymetry within the proposed lagoon will be adjusted to take account of the dredging activity anticipated to create the lagoon walls. With regards to the exchange of water through the turbines in the wall, the MIKE21-FM-HD modelling software includes a module for the assessment of structures placed within the model domain. This will be utilised, along with the design conditions for power generation, to include transfer of water into and out of the lagoon based on the difference in water level inside and outside of the lagoon structure.

3.0 Data to Support modelling

3.0.0.1 Both hydrodynamic and wave datasets have been collected, in order (among other uses) to assist with the calibration and validation of the numerical models. The datasets are described in greater detail in the main PEI and ES chapter for Coastal Processes, Sediment Transport and Contamination (Chapter 6), although a summary of the datasets used here, is provided in the following sections.

3.0.0.2 The collected data covers both the near-field (with metocean deployments undertaken within the proposed lagoon site), and across the far-field region (with water level data at Mumbles, Swansea and Port Talbot, wave data at Scarweather and flow measurements at a number of current mooring sites located within the Central Bristol Channel, adjacent to Swansea Bay (Figure 6.1.2)

3.0.0.3 It should be noted here that the model cannot be proven to exceed the accuracy of the observed data.

3.1.1 Tidal Data

3.1.1.1 The calibration and validation of the model was tested against numerous measured datasets, with comparisons taken against modelled tidal elevations, depth averaged flow speeds and associated directions. Calibration and validation data were obtained from a number of different sources, taken from a range of instrument types and collection periods. The locations of all comparison points over both the near-field and far-field regions are shown in Figures 6.1.1 and 6.1.2.

3.1.1.2 The following data were available for the calibration and validation of the hydrodynamic model:

I. Water level data from the National Tide and Sea Level Facility (NTSLF) tide gauge network from both near-field locations (Mumbles), and far-field locations (Fishguard, Milford Haven, Ilfracombe, Hinkley Point, Newport and Avonmouth), and predicted water level data from near-field tide stations at both Swansea and Port Talbot;

II. Water level, current speed and direction measurements from the TLSB Metocean Survey programme - at two near-field locations (Site 1 and Site 2) within the proposed lagoon development area (Titan, 2012), and at approximate water depths of between 4m and 10m below MSL; and

III. Current speed and direction data from British Oceanographic Data Centre (BODC) current moorings deployed in the Central Bristol Channel, outside of Swansea Bay (far-field). The current moorings provide an historic record of current flow. The sites used in the calibration and validation exercise were selected as those collecting data representative of depth-averaged flow conditions (as opposed to near-bed or near-surface flows) and also having a sufficiently long enough data record to allow for the derivation of harmonic constituents (subsequently used to produce a prediction of current flows over the model run-period).

3.1.1.3 An assessment of performance across both near and far-field regions is aimed at providing further confidence in the application of the modelling tools.

3.1.2 Wave Data

3.1.2.1 The calibration and validation of the model was tested against a series of measured datasets, with comparisons taken against modelled wave heights, wave periods and wave directions. Measured data were obtained at three locations, (see Figure 6.1.2 for locations) from two different sources, as described below:

i. Wave height, wave period and wave direction from the Waverider buoy at Scarweather; and

ii. Wave height, wave period and wave direction from the TLSB Metocean Survey programme - at two locations (Site 1 and Site 2) within the proposed lagoon development area (Titan, 2012), at approximate water depths of between 4m and 10m below MSL.

3.1.2.2 The temporal resolution of some of the data listed above was found to vary when compared against the model output. Where this was found to be the case, comparative timesteps were extracted from the data to ensure consistency. In those cases where data gaps exist in the measured data, these gaps were not filled or interpolated.

3.1.3 Metocean Deployments

3.1.3.1 The TLSB Metocean Survey deployments spanned a period of 3 months between the 16 February and 16 May 2012, and comprised two sites within Swansea Bay (see Figure 6.1.2 for locations). As detailed in the main PEI and ES chapter for Coastal Processes, Sediment Transport and Contamination (Chapter 6), the data collected as part of this survey contributes to the primary evidence available to characterise the hydrodynamic conditions found at the proposed lagoon location, and is therefore considered important to the near-field calibration and validation of the numerical models. It should be re-emphasised, however, that the numerical models cannot be demonstrated to exceed the accuracy of this measured data, no matter the extent of model calibration and validation that is undertaken. Taking this into consideration, a brief discussion of the metocean datasets is provided below.

3.1.3.2 The Nortek AWAC devices deployed at each site were located approximately 0.45m from the bed, with a further 0.4m blanking distance between the instruments and the first depth cell (bin) (Titan, 2012); i.e. the bottom 0.85m of the water column is excluded from the survey data. The absence of this data has implications on the reported depth-average flow speeds, whereby the characteristically slower tidal flows at the bed are excluded, thereby potentially leading to the reporting of an increased depth-averaged flow. Such an issue is less significant in deep water, however, at Site 1 (where maximum water depth on the spring high-water is approximately 9m, and average water depth over a spring-neap cycle is approximately 3.8m), the relative proportion of the water column not measured can be considerable. A similar over-reporting of flow speeds is also likely to occur at Site 2, albeit to a lesser relative extent due to the slightly greater water depths experienced at the site. It should also be noted that due to the inshore location of Site 1, i.e. within the intertidal zone, the metocean survey equipment was periodically exposed at low water on spring tides. Analysis of the measured data identified that relatively large changes in flow speed and direction are evident close to LW when the depth of water over the equipment is minimal. As such, the measured flow speeds and directions at Site 1 near to LW should be considered with caution; however, erroneous data caused by instrument exposure to the air was identified and removed from the analysis.

3.1.3.3 In summary, although the depth-averaged flow speeds measured at the deployment sites are expected to be greater than those simulated by the numerical model, the measured flow speed pattern (i.e. the peaks and troughs over the tidal cycle) and flow direction will remain largely unaffected by the absence of the near-bed measurements. As such, the data collected through the TLSB metocean survey remains invaluable to the calibration and validation of the numerical models, particularly in the near-field environment.

4.0 Calibration and Validation

4.0.0.1 The comparison of modelled water levels, currents and wave parameters against field data is the standard approach to calibrating a numerical model. This process requires adjustment of certain model parameters to achieve the best performance of the model. Further validation of the model without any additional adjustment to the model parameters is carried out using data covering an alternative period.

4.0.0.2 In each of the tables presenting model calibration results (Section 4.2 onwards), the differences are derived by subtracting observed values from modelled values. For water levels, flow speeds, wave heights and periods a positive value indicates that the model is over-predicting observed values, whilst a negative value indicates that the model is under-predicting the observed values. Where model inaccuracies are expressed as percentage differences, these are determined by dividing the '[modelled-measured]' differences by the measured value before multiplying by 100 and taking a mean.

4.1 Calibration and Validation Guidelines and Performance Metrics

4.1.0.1 In the absence of a widely adopted industry standard for the definition of calibration requirements, the numerical models were considered against a set of performance metrics defined in a recent guidance note, developed by ABPmer (2013c) based on a variety of statistical measures. It is important to note that statistical measures only play a part of the 'fit-for-purpose' assessment of model performance, with further discussion required to provide a more detailed understanding of the suitability of the model. In addition to the performance metrics, experience has shown that visual checks are an important part of the model calibration and validation process. Visual checks can identify patterns between the measured and modelled timeseries that may not be as obvious from the performance metrics, i.e. unique changes in flow speed and direction with time, which is an important process when trying to simulate the hydrodynamic regime of any given area.

4.1.0.2 Under certain conditions, models can meet statistical calibration standards but appear to perform poorly in a visual comparison; conversely, seemingly accurate models judged visually can fall outside of statistical standards. It is also important to account for and fully consider the limitations in the calibration datasets and agree the quality and accuracy of the observation records before comparing to the modelled output (further information regarding the collected metocean data is given in the Coastal Processes chapter of the PEI report and ES). Generally consistent inaccuracies can be explained or justified, whilst short-term variations can, in some circumstances, be due to meteorological effects on collected data.

4.1.0.3 The performance metrics detailed in the ABPmer (2013c) guidance note are presented below and provide a comparative measure for both temporal and peak features of the calibration data, thus providing an initial fit-for-purpose assessment of the numerical models; which is further substantiated by visual checks. Results are presented as a range of magnitude difference, percentage difference and Root Mean Square (RMS) values.

4.1.1 Water Levels

i. *Mean surface elevation difference:* Calculated as the mean difference (bias) in water level across the full spring-neap timeseries (model minus observed value). The mean difference is also expressed as a percentage of the mean tidal range;

ii. *Mean phase difference*: Calculated as the mean magnitude of time difference between the model and observed data, over a spring neap cycle; and

iii. *RMS surface elevation*: This value is calculated as the RMS value for surface elevation difference, over a spring neap cycle.

4.1.2 Current Speeds

I. *Mean flow speed difference*: Calculated as the mean difference between the magnitudes throughout the full spring-neap cycle. This is also calculated as a percentage value relative to the maximum observed speed;

II. *Mean flow direction difference*: Calculated as the mean of the difference in flow direction recorded throughout the full spring-neap cycle;

III. *RMS of peak flow*: This value is the RMS error of peak flow speed difference. This is calculated using the same method as above, upon the application of a time adjusted fit; and

IV. *Scatter index*: The scatter index is calculated as the RMS error, normalised by the mean value.

4.1.3 Waves

a) Mean significant wave height difference;
b) Mean wave period difference;
c) Mean wave direction difference; and
d) Scatter Index.

4.1.3.1 Calculations of Scatter Index are only carried out on the timeseries data of wave height and period. Since wave direction is derived from vector quantities, it cannot be treated in the same way as the other wave parameters and, hence, only bias calculations are used (and subsequently placed into context against the directional spreading of the measured wave data).

4.1.4 Recommended Values

4.1.4.1 The following model performance metrics are offered from ABPmer (2013b) with final values dependent on the reliability of each observational record.

Water levels

4.1.4.2 Mean level differences should be within ±0.2m, while the percentage differences should be within 15% of spring tidal ranges and 20% of neap tidal ranges. Water level phasing at high and low water should be to within ±20 minutes, while RMS scores should be less than 0.2.

Flows

4.1.4.3 Modelled speeds should be within ±0.2m/s or ±10 - 20% of equivalent peak observed speeds, while modelled directions should be within ±20° of observed directions, and phasing within ±20 minutes. RMS scores should be less than 0.2, while Scatter Index scores should be less than 0.5.

Waves

4.1.4.4 Mean wave heights should be within ±10% of observed heights whilst mean periods should be within ±20% of observed periods. Wave directions should be within ±30° of observed directions. In addition, for wave height and period, the Scatter Index scores should be less than 35.

4.1.4.5 In addition to the statistical analysis of the numerical models, as described above, a further assessment of the model performance throughout the calibration period has been carried out. For this assessment, a further set of tolerances has been applied to the results from the hydrodynamic model and an analysis of the frequency (throughout the calibration period) that the tolerances are met has been undertaken. The tolerances applied to this stage of the calibration are taken from the Foundation for Water Research (FWR) guidelines for coastal models (FWR, 1993), and are described as follows:

i. For water levels, an absolute tolerance of ±0.1m or a relative tolerance of ±10% of the measured spring tidal range;

ii. For current speed, an absolute tolerance of ±0.1m/s or a relative tolerance of ±10% of the peak measured current speed;

iii. For current direction, a tolerance of ±30°; and

iv. For phasing, a tolerance of ±15 minutes.

4.1.4.6 In an attempt to further describe the relative levels of calibration between sites, a qualitative scale of fit has been applied, based on the FWR guidelines and described as follows:

'Excellent Fit'	-	Calibration tolerances are achieved >90% of the time
'Very Good Fit'	-	Calibration tolerances are achieved >80% of the time
'Good Fit'	-	Calibration tolerances are achieved >70% of the time
'Reasonable Fit'	-	Calibration tolerances are achieved >60% of the time
'Poor Fit'	-	Calibration tolerances are achieved <60% of the time

4.1.4.7 In addition to allowing comparison of the relative level of calibration between sites to be made, this qualitative scale also assists in making a comparison between the visual 'fit' of the data (as provided, for example, by a timeseries plot of modelled versus measured data) and the statistical assessment of model performance.

4.2 Tidal Model

4.2.1 Calibration of Water Levels and Currents

4.2.1.1 The model was calibrated for a 14-day period during March 2012, a period which included both representative mean spring and neap tides. To achieve calibration, adjustments were made to water levels along the offshore boundaries as well as minor changes to the bed roughness, until the required level of accuracy was achieved. Modelled tidal elevations were compared against measured data at the metocean survey sites and other local water level stations and current gauges, in order to provide a quantitative assessment of inaccuracies in tidal characteristics. The locations of these sites are in the vicinity of the lagoon development site and surrounding area, with specific locations identified in Figure 6.1.2.

4.2.1.2 To quantify model calibration, a series of quantitative statistics have been calculated to compare water levels, current speeds and directions. The statistical assessment includes derivation of the metrics listed in Sections 4.1.1 and 4.1.2 of this report, and the results are presented in Tables 6.1.1 to 6.1.3. Current data is not available from the local tide stations used to assess the replication of water levels (Mumbles, Swansea and Port Talbot). Therefore, the assessment of model performance with regard current speed and direction is carried out at the two metocean survey sites, 1 and 2, along with data collected from a series of current moorings in the Central Bristol Channel, adjacent to Swansea Bay.

Table 6.1.1. Calibration of modelled water levels against metocean survey and tide gauge data

Location	Water Level Bias (m)*	Water Level (% Tidal Range)*	Water Level RMS (m)	Phase RMS (min)
Metocean Site 1	0.02	0.3	0.18	0
Metocean Site 2	-0.01	-0.1	0.18	0
Mumbles	0.00	0.0	0.20	0
Swansea	0.16	1.8	0.22	-10
Port Talbot	0.12	1.3	0.21	-10

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

Table 6.1.2. Calibration of modelled flow speeds against metocean survey data

Location	Flow Speed Bias (m/s)*	Flow Speed Bias (% Max Speed)*	RMS (m/s)	Scatter Index
Metocean Site 1	-0.03	-10.1	0.05	0.30
Metocean Site 2	-0.04	-6.9	0.06	0.25
Current Mooring A	-0.06	-5.2	0.16	0.30
Current Mooring B	0.04	4.9	0.07	0.18

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

4.2.1.3 Since current direction is derived from vector quantities, this parameter cannot be treated in the same way as current speed and water level. Scatter plots are therefore unhelpful and attention has been given instead to bias calculations that examine differences between modelled and measured current directions. The results are shown in Table 6.1.3.

Table 6.1.3. Calibration of modelled flow directions against metocean survey data

Location	Flow Direction Bias (°)*
Metocean Site 1	-4.4
Metocean Site 2	4.2
Current Mooring A	5.9
Current Mooring B	-3.3

* Positive bias values indicate that the model is over-predicting (clockwise rotation); negative values show under-prediction (anti-clockwise rotation).

4.2.1.4 Table 6.1.4 provides the results of an assessment into the frequency that tolerances are met, throughout the calibration period. The results include both the near-field and far-field calibration locations, in order that a comparison of the model performance across the domain can be made.

Table 6.1.4. Qualitative summary of hydrodynamic model fit against calibration data

Region	Location	Percentage of Time Tolerances Are Met (%)			Phase (Minutes)	Qualitative Description of Fit
		Water Level	Current Speed	Current Direction		
Water Level Sites						
Near-field	Metocean Site 1	100.0	-	-	0	Excellent
	Metocean Site 2	100.0	-	-	0	Excellent
	Mumbles	100.0	-	-	0	Excellent
	Swansea	100.0	-	-	-10	Excellent
	Port Talbot	100.0	-	-	-10	Excellent
Far-field	Ilfracombe	100.0	-	-	0	Excellent
	Fishguard	85.8	-	-	0	Very Good
	Milford Haven	100.0	-	-	-15	Excellent
	Avonmouth	96.0	-	-	+15	Excellent
	Hinkley Point	97.7	-	-	0	Excellent
Current Sites						
Near-field	Metocean Site 1	-	97.1	70.3	-	Good
	Metocean Site 2	-	90.7	89.9	-	Very Good
Far-field	Current Mooring A	-	72.6	93.0	-	Good
	Current Mooring B	-	94.6	94.1	-	Excellent

4.2.2 Summary of Tidal Hydrodynamic Calibration

4.2.2.1 Comparison plots of water levels, current speeds and directions are provided in Figures 6.1.3 to 6.1.5.

4.2.2.2 The quantitative statistics show that, generally, the model representation of water levels at the two metocean survey sites and at the local tide stations (Mumbles, Swansea and Port Talbot) is good, with the bias values <0.2m. The phase RMS values are all well within the ±20 minutes guidance limit, whilst the bias values at each site are all within 2% of the tidal range, showing the water levels to be well within the ±15% guidance value. RMS values for the two metocean sites are shown to be within the 0.2 guidance limit, whilst it is noted that the RMS values for Swansea and Port Talbot fall very slightly outside of the recommended 0.2 limit (at 0.22 and 0.21, respectively). It should be re-emphasised that these are guidance values and are typically more appropriate to the open coast where the hydrodynamic regime is characteristically less complex, i.e. these values are considered acceptable for an estuarine/embayment environment. Visual inspection of the timeseries in Figure 6.1.5 shows that this is likely to be a result of a slight over-prediction in Low Water levels by the model, however, the phasing and water levels throughout the rest of the tidal cycle are shown to be well replicated by the model. In addition, the shallow nature of Site 1 is clearly demonstrated in the model calibration results (as shown in Figure 6.1.3), whereby the site can be seen to dry out at low water over spring tides, thus replicating the pattern observed in the measured data.

4.2.2.3 With regards to current speed, it is shown that at all sites the values are well within the recommended ±10 - 20% guidance limit, whilst the Scatter Index scores are also well within the limit of 0.5. In contrast, a visual inspection of the timeseries presented in Figures 6.1.3 and 6.1.4 for the metocean survey sites clearly shows the under-prediction of peak current speeds by the model, when compared to the measured data. As discussed previously in Section 3.1.3, this under-prediction will have resulted from reduced near-bed flows (i.e. within 0.85m of the bed) being excluded from the measurements due to the limitations of the instrumentation utilised, thereby reporting slightly higher depth-averaged flows than the true value. In reality, the depth-averaged currents at these two locations are likely to be considerably more similar to the modelled velocities. Although there is an offset between the modelled and measured peak flows at these sites, which was to be expected, the timeseries clearly show that the model is fully capable of simulating the complex flow speed patterns (i.e. peaks and troughs) seen at the two sites within Swansea Bay. Outside of Swansea Bay, comparison of the modelled and measured data at Current Moorings A and B once again illustrates that the model is able to replicate the hydrodynamic conditions extremely well. Based upon guidance provided by Cefas (2009), the model is in 'very good' agreement with the observed data; i.e. the difference between the peak modelled and observed velocities is less than 0.05m/s.

4.2.2.4 Analysis of the model outputs identifies that current directions are within the recommended ±20° of observed directions at each comparative site, with slight directional bias around the time of HW slack (as shown in Figures 6.1.3 and 6.1.4); with an anti-clockwise bias at Site 1 and Current Mooring B, and a clockwise bias at Site 2 and Current Mooring A. Deviations between flow directions at and immediately around LW and HW slack are to be expected, as tidal flows can be insufficient to cause a predominant flow direction. Throughout the rest of the tidal cycle, comparison of the modelled and measured flow directions shows very good agreement, particularly identifying the rotary and semi-rotary nature of the tidal flows within Swansea Bay.

4.2.2.5 In general, the comparison of the modelled and measured datasets, both statistically and visually, would suggest a very good to excellent calibration agreement. Overall, Table 6.1.4 shows that the model is providing an 'excellent' representation of water levels and a 'very good' representation of current speeds and directions, both in the near-field (within Swansea Bay) and the far-field region (adjacent to Swansea Bay and in the further reaches of the Bristol Channel).

4.2.3 Validation of Water Levels and Currents

4.2.3.1 The validation of water levels and currents predicted by the numerical model was assessed and validated over an alternative 14-day period during April 2012, and covering a different spring-neap cycle to that used during the calibration stage. During the validation period, maximum spring tidal range at Swansea was the same as during the calibration period at 8.9m. Tables 6.1.5 to 6.1.7 compare water levels, current speeds and current directions from the model with field measurements at the same sites used in the calibration exercise.

4.2.3.2 The results for water level, current speed and direction validation generally follow those from the calibration run, showing good agreement between the model and the measured data.

Table 6.1.5. Validation of modelled water levels against metocean survey and tide gauge data

Location	Water Level Bias (m)*	Water Level Bias (% Tidal Range)*	Water Level RMS (m)	Phase RMS (min)
Metocean Site 1	0.13	1.4	0.21	0
Metocean Site 2	0.02	0.2	0.15	0
Mumbles	-0.10	-1.0	0.15	0
Swansea	-0.03	-0.3	0.17	0
Port Talbot	-0.14	-1.4	0.23	0

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

4.2.3.3 Modelled current speeds and directions for the same sites as used for the model calibration were compared with measured values for the defined validation period and the results are shown in Tables 6.1.6 and 6.17.

Table 6.1.6. Validation of model flow speeds against measured data

Location	Flow Speed Bias (m/s)*	Flow Speed Bias (% Max Speed)*	RMS (m/s)	Scatter Index
Metocean Site 1	-0.03	-10.0	0.05	0.29
Metocean Site 2	-0.03	-6.5	0.05	0.23
Current Mooring A	-0.05	-5.3	0.12	0.29
Current Mooring B	0.02	3.1	0.05	0.15

* Positive bias values indicate that the model is over-predicting; alternatively negative values show under-prediction.

Table 6.1.7. Validation of model flow directions against measured data

Location	Flow Direction Bias (°)*
Metocean Site 1	-7.5
Metocean Site 2	3.6
Current Mooring A	6.9
Current Mooring B	-2.3

* Positive bias values indicate that the model is over-predicting (clockwise rotation); negative values show under-prediction (anti-clockwise rotation).

4.2.4 Summary of Tidal Hydrodynamic Validation

4.2.4.1 The validation results in Tables 6.1.5 to 6.1.7 show a similar trend to those identified during the model calibration exercise (Tables 6.1.1 to 6.1.3). Since comparisons of measured and modelled timeseries data for the validation period remain similar to those presented for the calibration period (Figures 6.1.3 to 6.1.5), associated plots covering the validation exercise are not presented.

4.2.4.2 For water levels, the quantitative statistics once again show that the model representation of water levels at the two metocean survey sites and at the local tide stations (Mumbles, Swansea and Port Talbot) is good, with the bias values <0.2m, whilst the phase RMS values are also well within the ±20 minutes guidance limit. As previously seen during model calibration, some of the water level RMS values fall outside of the recommended 0.2 guidance limit (0.21 at Site A and 0.23 at Port Talbot), once again attributed to slight variations between the modelled and measured LW level. In general, however, tidal levels and phasing at each of the comparative locations were once again replicated well within the model during its validation. This strong agreement is also seen for current speed and direction, where the bias values remain well within the ±10 - 20% of the peak observed speeds guidance limit, whilst the bias values for direction also remain well within the guidance limit of ±20°. Based upon guidance provided by Cefas (2009), the validation model results for peak flow velocities are within the range of 'good' to 'very good' agreement with the observed data at all comparison sites, both within Swansea Bay and further afield.

4.2.4.3 In summary, the validation results (comparing the hydrodynamic parameters across the site for a different period of time than that used for the calibration exercise), confirm that the tidal model provides an effective representation of the tidal conditions both in the near-field (within Swansea Bay) and far-field regions (adjacent to Swansea Bay in the Bristol Channel), with generally very good agreement with the observed data. As such, the model is considered fit-for-purpose with respect to the project scope.

4.3 Wave Model

4.3.0.1 The MIKE21-FM-SW module allows the simulation of the growth, decay, and transformation of both locally wind-generated waves and swell in offshore and coastal areas using a directionally decoupled parametric formulation. The SW model is run using the same bathymetry as for the hydrodynamic model.

4.3.1 Calibration of Wave Parameters

4.3.1.1 The wave model was run as a time-series for an eight-week period, between February and April 2012, incorporating a number of large and small wave events. For calibration purposes, the wave parameters predicted by the model were compared against measured data from the metocean survey over an approximately two-week period during February 2012. A different period of time was used during the validation exercise, as described in Section 4.3.3.

4.3.1.2 Wave measurements from the field were available from the metocean sites as well as the Waverider buoy at Scarweather. The results of the model were compared against data gathered from these sites and comparison plots are shown in Figure 6.1.6 and Figure 6.1.7, with a quantitative statistical assessment provided in Tables 6.1.8 to 6.1.10. The model accuracy was derived in the same way as the tidal assessment, comparing the differences in significant wave height, period and direction between the modelled and the observed data.

Table 6.1.8. Calibration of wave heights

Location	Bias (m)*	Bias (% Obs. Height)*	Scatter Index
Metocean Site 1	-0.01	-1.2	28
Metocean Site 2	0.07	4.9	34
Scarweather	0.14	5.0	14

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

Table 6.1.9. Calibration of wave period

Location	Bias (s)*	Bias (% Obs. Period)*	Scatter Index
Metocean Site 1	1.40	5.6	28
Metocean Site 2	2.90	19.5	35
Scarweather	-0.39	-6.6	11

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

4.3.1.3 Since wave direction is derived from vector quantities, it cannot be treated in the same way as other wave parameters (height and period). As such, scatter plots are therefore unhelpful and attention has been given instead to bias calculations that examine differences between modelled and measured wave directions. The results are shown in Table 6.1.10.

Table 6.1.10. Calibration of mean wave direction

Location	Bias (°)*	Mean Directional Spreading (°)
Metocean Site 1	15.4	64
Metocean Site 2	7.4	59
Scarweather	-4.1	23

* Positive bias values indicate that the model is over-predicting (clockwise rotation); negative values show under-prediction (anti-clockwise rotation).

4.3.2 Summary of Wave Calibration

4.3.2.1 The quantitative statistics for the wave model calibration show that wave heights are, in general, replicated to within 5% of the observed wave heights at each comparative site, thus satisfying the recommended guidance limit of within ±10%; the Scatter Index values also remain within the 35 guideline limit. The statistics for wave period show that bias values are within the ±20% limit for all three comparative sites, with the Scatter Index scores also within the guidance limit of 35.

4.3.2.2 Bias value calculations for the Scarweather wave buoy and the metocean sites would suggest a slightly improved agreement between the modelled and measured datasets in deeper water, particularly further offshore at Scarweather (see Figure 6.1.2 for location), where wave propagation will be considerably less hindered by wave transformation processes. A visual check of the model and observed data comparison for Scarweather (shown in Figure 6.1.6), shows good agreement in the wave heights (both amplitude and phasing), whereby the wave model can clearly be seen to replicate the appropriate wave conditions during this period of time.

4.3.2.3 The wave climate within Swansea Bay will be considerably different to that recorded at the Scarweather Buoy, like seen at the metocean sites (Figure 6.1.7), with wave transformation processes (i.e. shoaling and refraction) becoming more dominant within the Bay in conjunction with the sheltering effect provided by the Mumbles, whereby diffraction will take place around Mumbles Head. Due to these complex processes, agreement between numerical models and measured data is inherently difficult. This being said, the wave height bias calculations for the metocean sites also illustrates relatively good agreement, albeit with a slight under and over-prediction at Sites 1 and 2, respectively. Visual inspection of the timeseries data also suggests a relatively good agreement between the modelled and measured data, in which the general pattern of increasing and decreasing wave heights are replicated well. Of greater importance, however, is the effective simulation of a storm event which occurred just after 2 days, with minimal variation in time and extent.

4.3.2.4 With respect to wave direction, the calculated bias for both metocean sites suggests that the modelled waves tend to approach from a slightly more westerly direction than the observed waves, whilst at Scarweather the modelled waves tend to approach from a slightly more southerly direction; although still being well within the guideline limit of ±30°. The greatest difference between modelled and measured wave direction takes place at Site 1, located across the intertidal. It is across expansive intertidal areas where good agreement between modelled and measured data is typically most difficult, principally due to the increased rates of wave refraction and shoaling that will take place in the shallow water, but also due to data collation limitations associated with the instrumentation; i.e. the insufficient depth of water around and at LW on spring tides. This being said, comparison of the modelled and measured wave directions would suggest good agreement.

4.3.2.5 In general, the comparison of the modelled and measured datasets, both statistically and visually, would suggest a very good calibration agreement for the wave parameters, particularly at the Scarweather site.

4.3.3 Validation of Wave Parameters

4.3.3.1 Validation was carried out by comparing model results (wave height, period and direction) with measured data collected during March 2012, and over a different period to that used during the calibration exercise. Comparisons in wave height, period and wave direction are tabulated below (Tables 6.1.11 to 6.1.13), showing the quantitative statistics for each parameter.

Table 6.1.11. Validation of wave heights

Location	Bias (m)*	Bias (% Obs. Height)*	Scatter Index
Metocean Site 1	-0.06	-9.1	19
Metocean Site 2	0.12	8.6	21
Scarweather	0.37	11.0	15

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

Table 6.1.12. Validation of wave period

Location	Bias (s)*	Bias (% Obs. period)*	Scatter Index
Metocean Site 1	1.90	7.8	32
Metocean Site 2	2.10	14.0	29
Scarweather	-0.96	-10.0	17

* Positive bias values indicate that the model is over-predicting; negative values show under-prediction.

Table 6.1.13. Validation of wave direction

Location	Bias (°)*	Mean Directional Spreading (°)
Metocean Site 1	17.2	64
Metocean Site 2	8.8	59
Scarweather	-4.1	23

* Positive bias values indicate that the model is over-predicting (clockwise rotation); negative values show under-prediction (anti-clockwise rotation).

4.3.4 Summary of Wave Validation Statistics

4.3.4.1 The validation results in Tables 6.1.11 to 6.1.13 show a similar level of accuracy in wave parameters as they did for the calibration exercise (Tables 6.1.8 to 6.1.10). As such, associated plots covering the validation exercise are not presented. The quantitative statistics once again show that the models representation of wave height, wave period and wave direction are very good and generally within the recommended guidance values.

4.3.4.2 In summary, it is considered that the validation results further illustrate good agreement between the modelled and measured wave parameters both in the near-field and far-field region. As such, the wave model is considered fit-for-purpose for assessing the potential effects of the proposed tidal lagoon development. It is worth noting here that the intended approach to the assessment of potential effects on the wave regime is to focus on a series of wave events for given return periods (rather than assessing for a timeseries of varying wave conditions). In this way, the assessment can be targeted to specific events, as informed by the results of the metocean survey.

4.4 Summary of Model Calibration and Validation

4.4.0.1 The results presented above show that the numerical models have been successfully calibrated and validated against available up-to-date field measurements to provide a sufficiently accurate representation of the hydrodynamic and wave regimes within the study area. The calibration process involved the adjustment of various parameters within the numerical model (whilst ensuring any adjustment was scientifically realistic) until the respective model output reached an acceptable 'fit' with the comparative field measurements. In general, the model outputs from the calibration and validation exercises were in excellent agreement with the observational data.

4.4.0.2 Although the modelling approach carries a small net residual difference, related to any uncertainties that may be present in the observational data or the models themselves, this difference to a large extent is removed at the scenario testing stage as results will be comparable to the calibrated baseline; i.e. [Scheme ± residual difference] - [Baseline ± residual difference] = [Effect of scheme], hence the net residual difference is effectively removed from the respective results. This approach ensures that when the proposed tidal lagoon is assessed within the Environmental Statement, only the effects of the scheme are measured against the baseline and therefore, they do not incorporate the net residual differences (uncertainties) from the calibration stage. In essence, any deficiencies in the model will be insignificant with respect to the project scope, with both the tidal and wave models being considered fit-for-purpose and suitable as a tool to assess the effects of the TLSB on coastal processes.

5.0 References

ABPmer, 2013a. Preliminary Environmental Information (PEI) - Chapter 6.0: Coastal Processes, Sediment Transport and Contamination. ABP Marine Environmental Research Ltd, Report No. R2139. June 2013.

ABPmer, 2013b. Swansea Bay Tidal Lagoon: Bathymetry Data Preparation. ABP Marine Environmental Research Ltd, Report No. R.2111TN.

ABPmer, 2013c. Numerical Model Calibration and Validation Guidance. ABP Marine Environmental Research Ltd, File Note R/1400/112.

ABPmer, 2014d. Environmental Statement - Chapter 6.0: Coastal Processes, Sediment Transport and Contamination. ABP Marine Environmental Research Ltd.

Cefas, 2009. WP9 Blackwater synthesis report. Liam Dernand and John Aldridge.

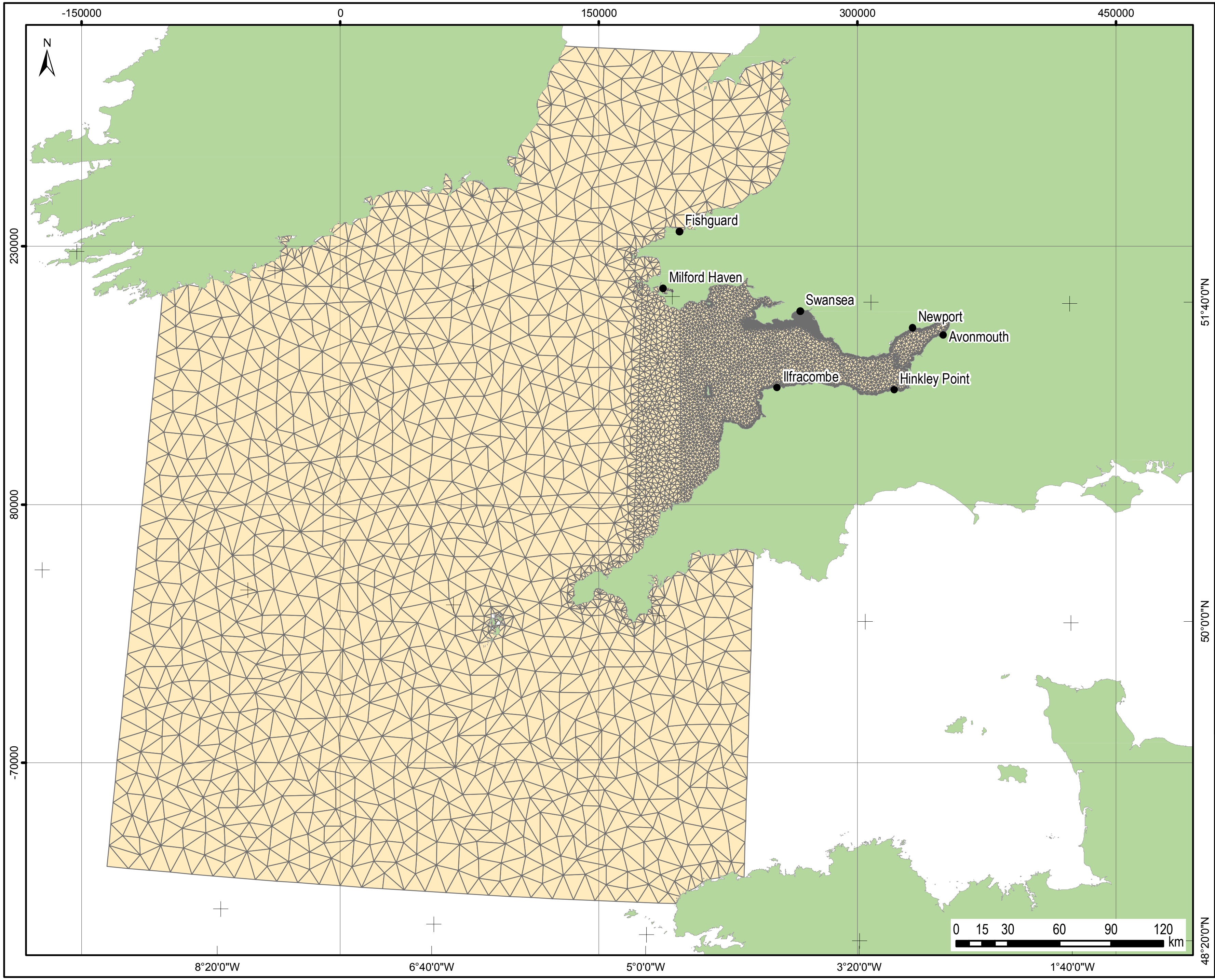
FWR, 1993. A Framework for Marine and Estuarine Model Specification in the UK. Foundation for Water research, March 1993.

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

6.0 Abbreviations

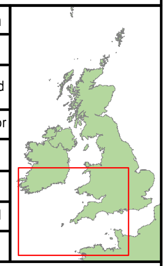
2D	Two-dimensional
2DH	Two-dimensional horizontal
3D	Three-dimensional
ABP	Associated British Ports
ABPmer	ABP Marine Environmental Research Ltd
ADCP	Acoustic Doppler Current Profiler
AWAC	Acoustic Wave and Current
BODC	British Oceanographic Data Centre
CD	Chart Datum
DHI	Danish Hydraulic Institute's
º	Degree(s)
ºN	Degrees North
EIA	Environmental Impact Assessment
ES	Environmental Statement
FM	Flexible mesh
FWR	Foundation for Water Research
HD	Hydro-dynamic
HW	High Water
LiDAR	Light Detection and Ranging
LW	Low Water
m	Metre(s)
m/s	Metres per second
mMSL	Metres Mean Sea Level
MSL	Mean Sea Level
NOAA	National Oceanic and Atmospheric Administration
NTSLF	National Tide and Sea Level Facility
ODN	Ordnance Datum Newlyn
PEI	Preliminary Environmental Information
RMS	Root Mean Square
SW	Spectral Wind-wave
TLSB	Tidal Lagoon Swansea Bay Plc
UK	United Kingdom
UKHO	United Kingdom Hydrographic Office
VORF	Vertical offshore reference framework

Figures



Numerical model mesh

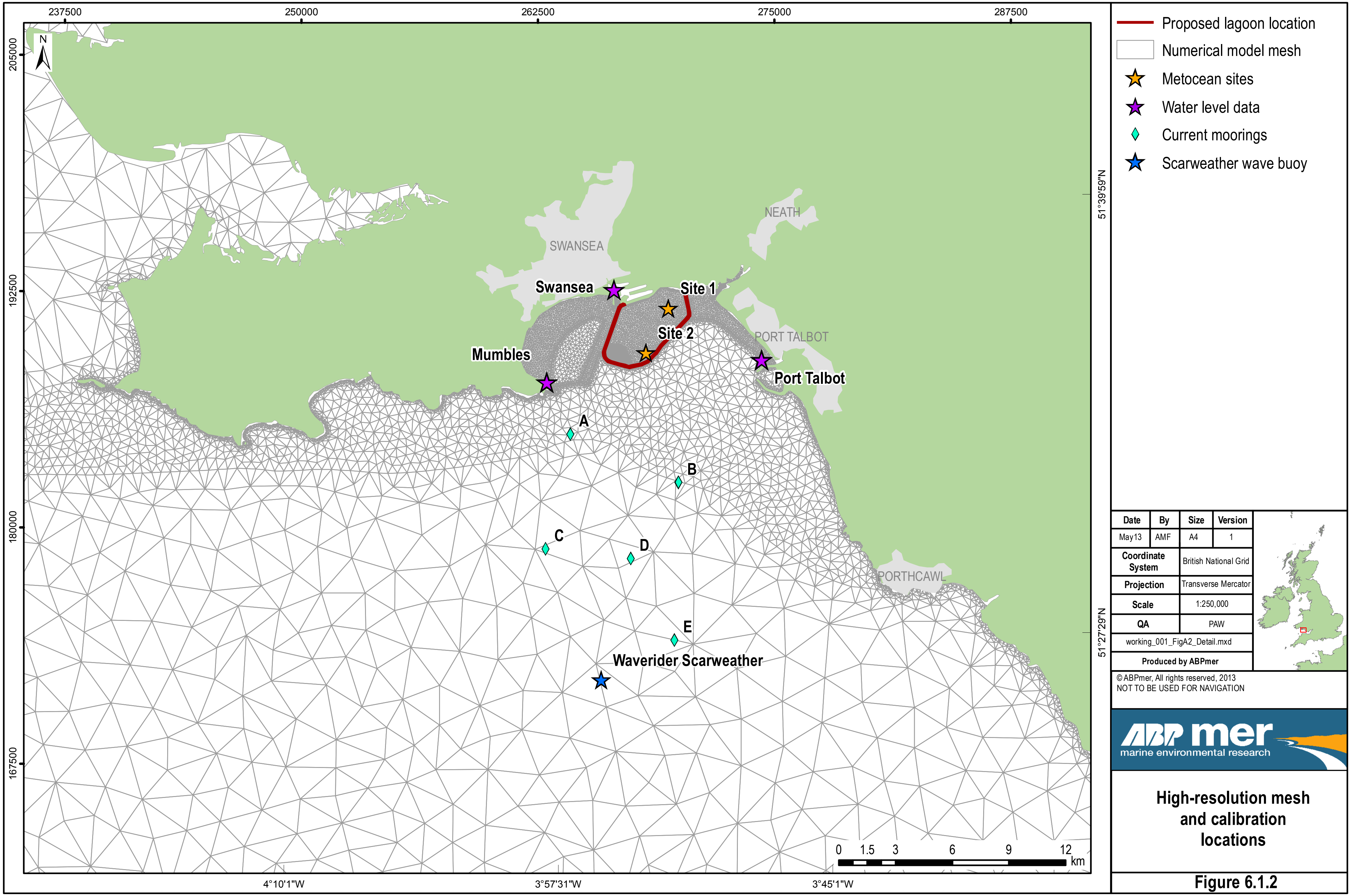
Date	By	Size	Version
Jun 13	AMF	A4	1
Coordinate System	British National Grid		
Projection	Transverse Mercator		
Scale	1:3,000,000		
QA	PAW		
working_001_FigA1_Mesh_extent.mxd			
Produced by ABPmer			



ABP mer
marine environmental research

Extent of hydrodynamic numerical model mesh

Figure 6.1.1

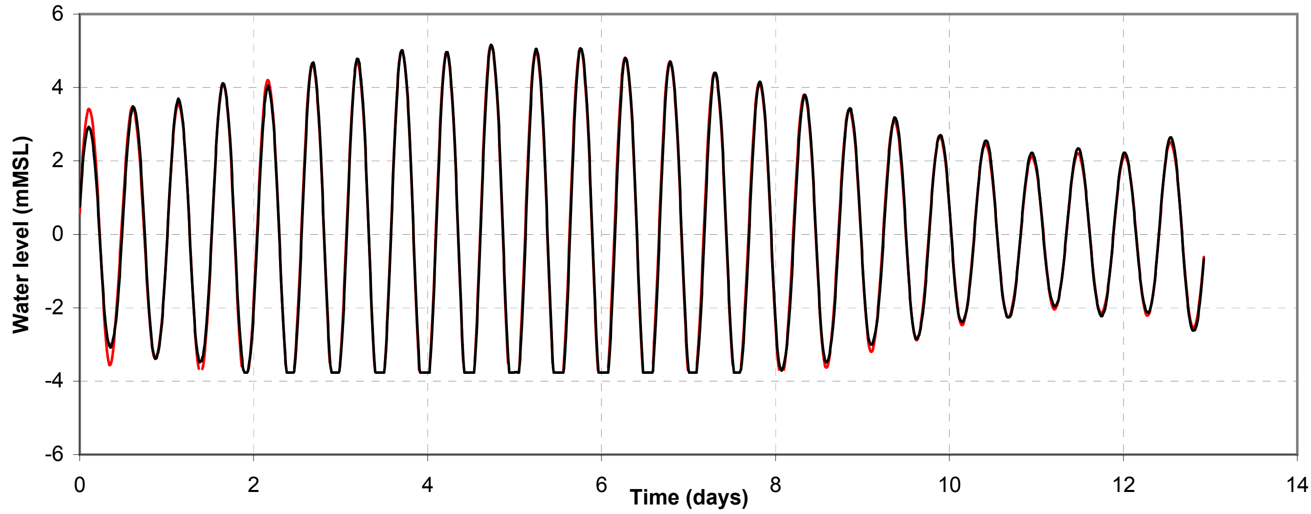


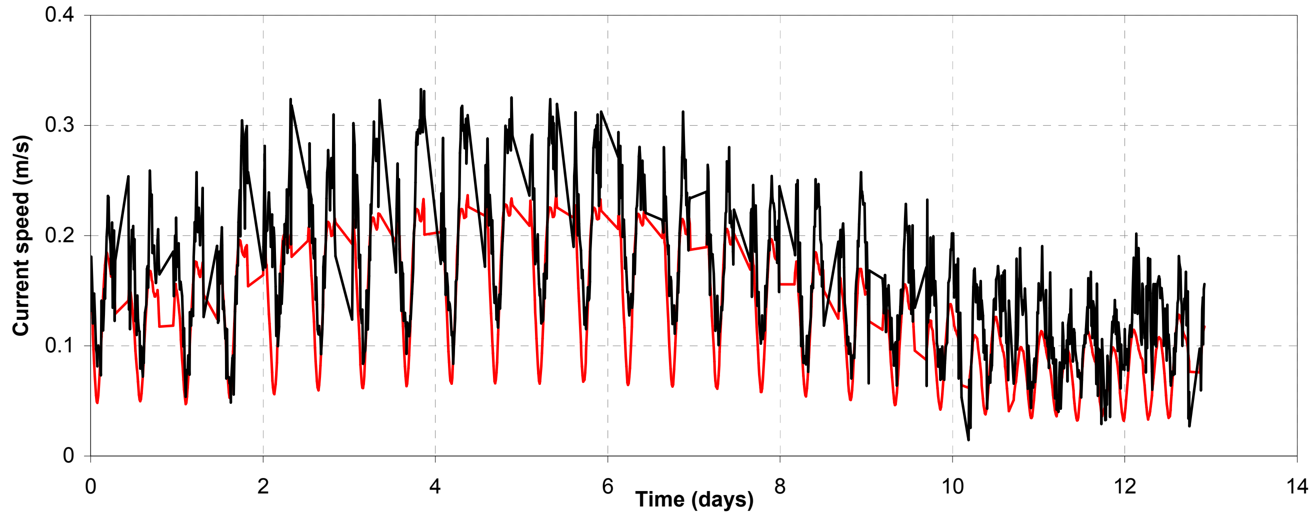
Date	By	Size	Version
May13	AMF	A4	1
Coordinate System	British National Grid		
Projection	Transverse Mercator		
Scale	1:250,000		
QA	PAW		
working_001_FigA2_Detail.mxd			
Produced by ABPmer			

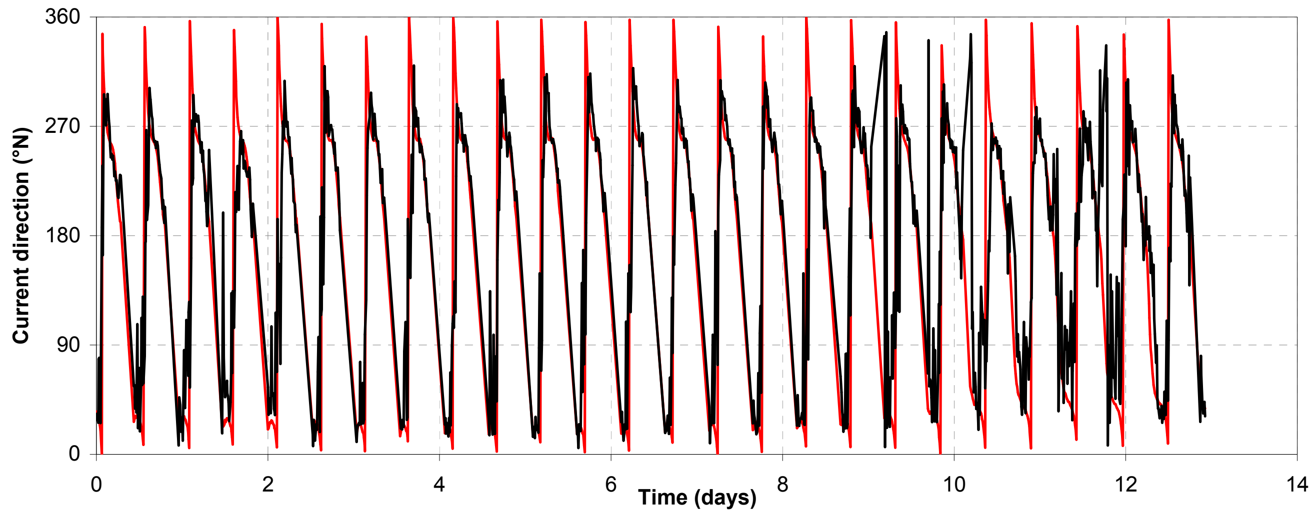
ABP mer marine environmental research

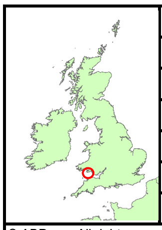
High-resolution mesh and calibration locations

Figure 6.1.2









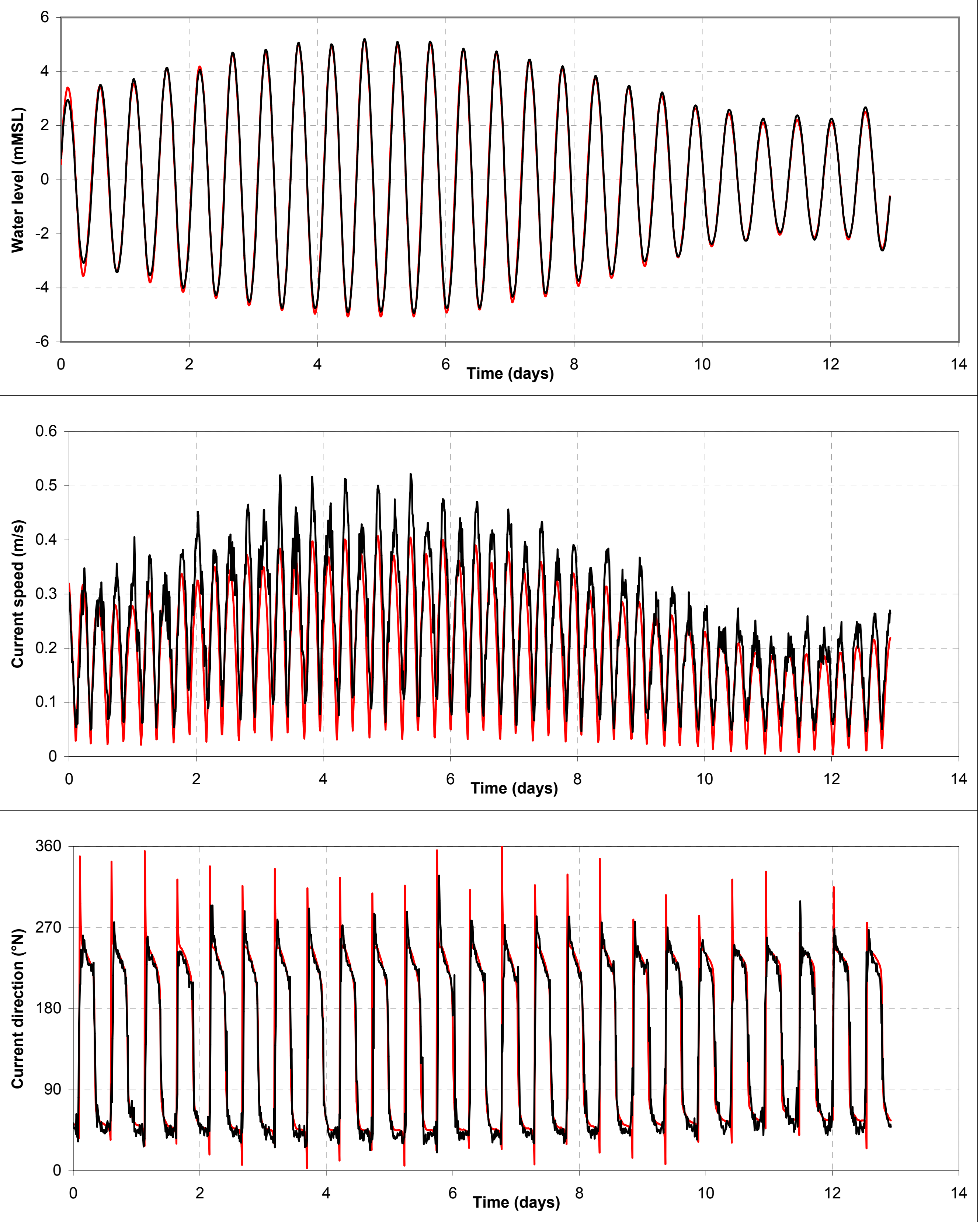
Date	By	Size	Version
May 13	AMF	A4	1
Projection		n/a	
Scale		n/a	
QA		PAW	
SBTL_Calib_Fig-Control_v4-2.xls			
Produced by ABPmer			

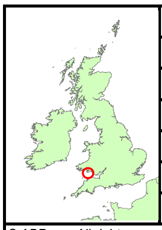
--- measured

--- modelled

Timeseries comparison for tidal data at Site 1

Figure 6.1.3





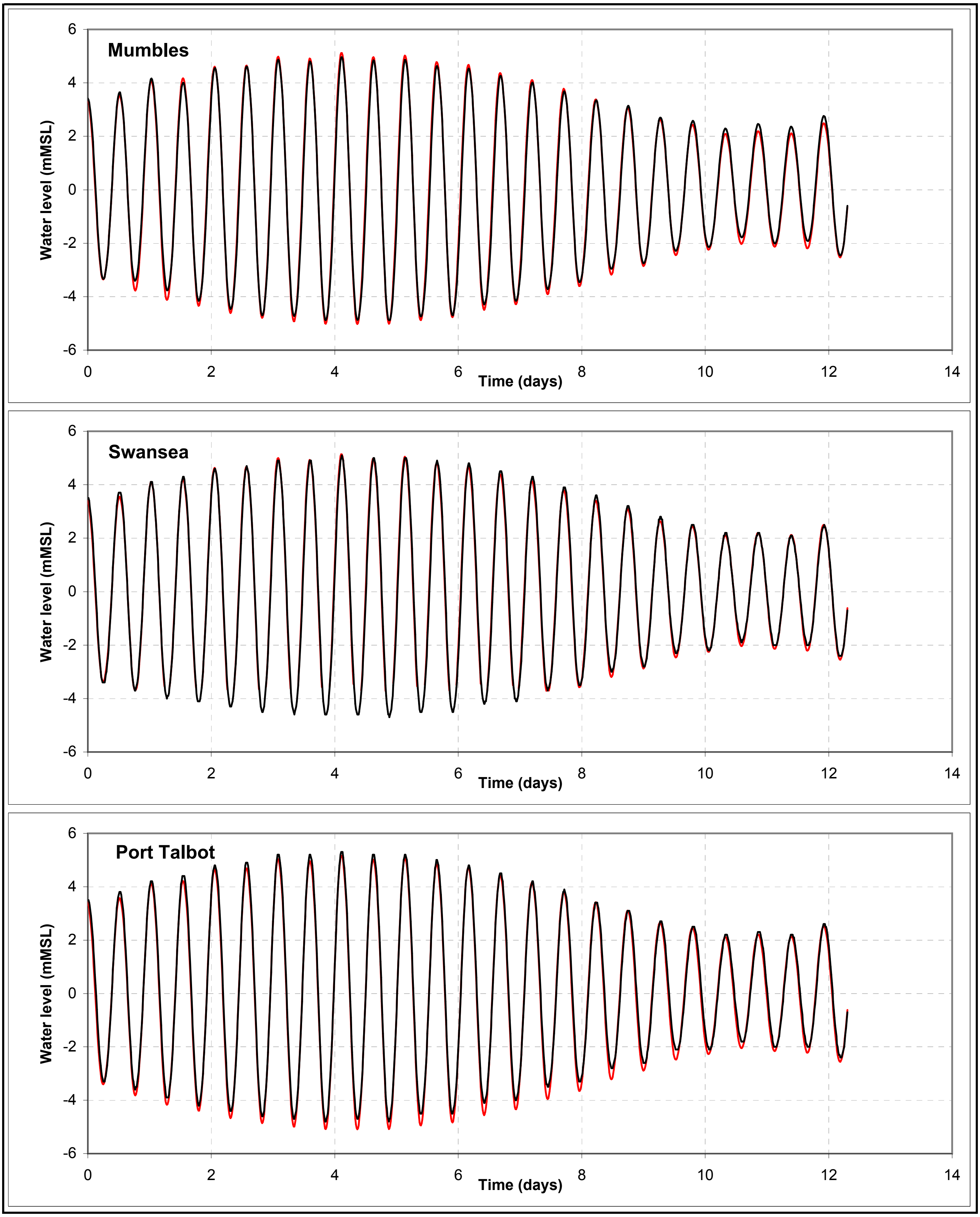
Date	By	Size	Version
May 13	AMF	A4	1
Projection		n/a	
Scale		n/a	
QA		PAW	
SBTL_Calib_Fig-Control_v4-2.xls			
Produced by ABPmer			

--- measured

--- modelled

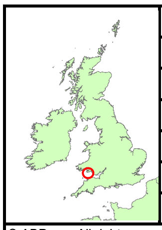
Timeseries comparison for tidal data at Site 2

Figure 6.1.4



--- measured

--- modelled

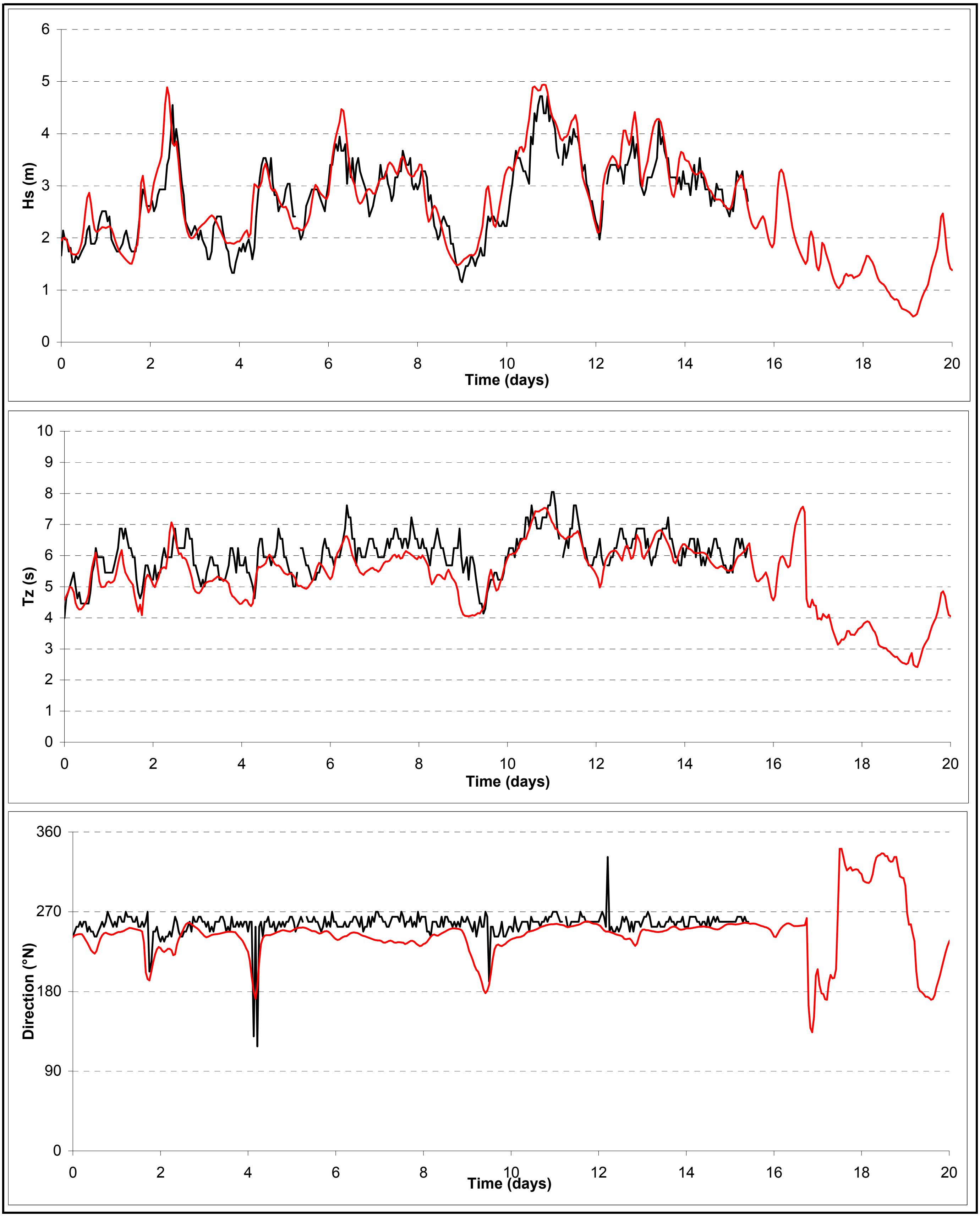


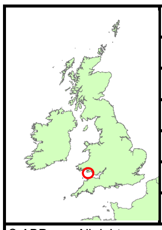
Date	By	Size	Version
May 13	AMF	A4	1
Projection	n/a		
Scale	n/a		
QA	PAW		
SBTL_Calib_Fig-Control_v4-2.xls			
Produced by ABPmer			

ABP mer marine environmental research

Timeseries comparison of water level at local stations

Figure 6.1.5





Date	By	Size	Version
May 13	AMF	A4	1
Projection		n/a	
Scale		n/a	
QA		PAW	
SBTL_Calib_Fig-Control_v4-2.xls			
Produced by ABPmer			

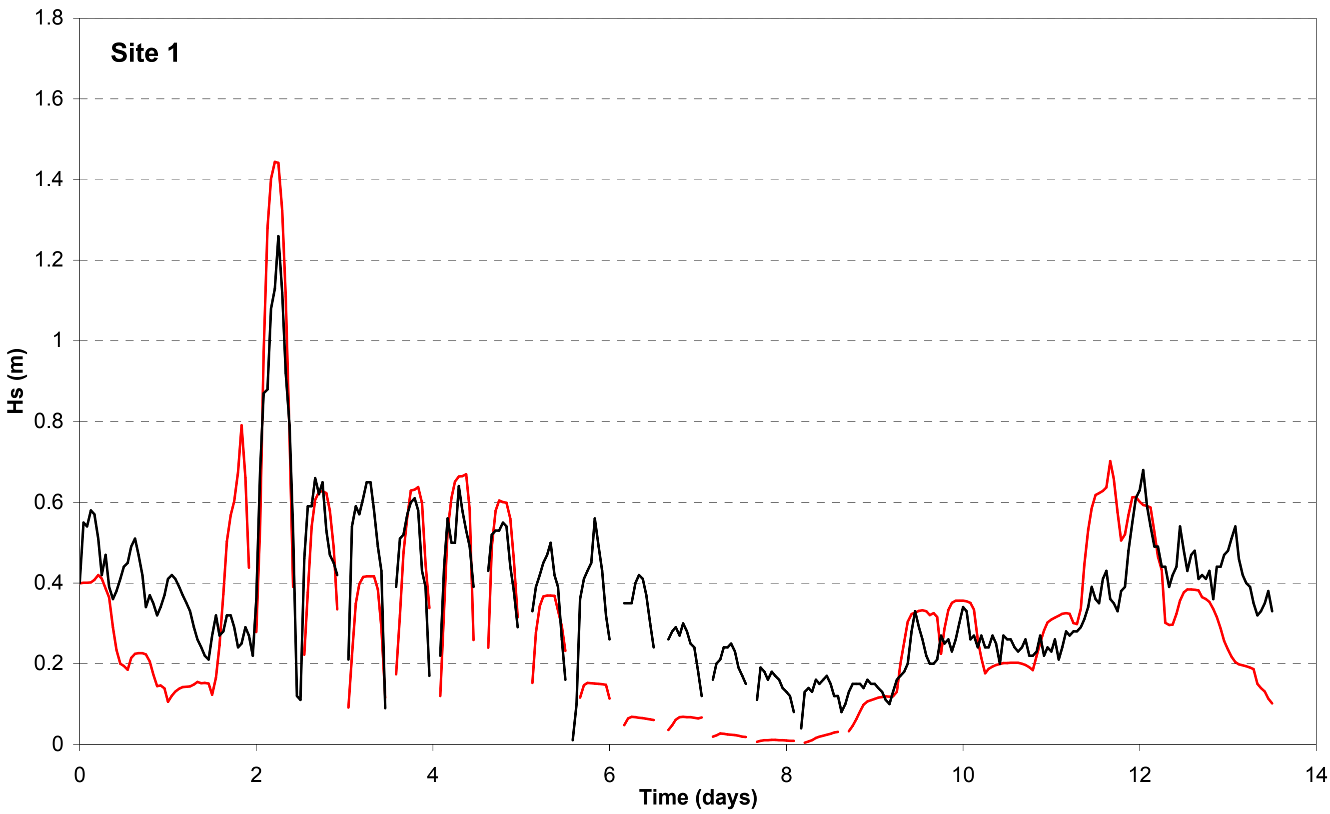
--- measured

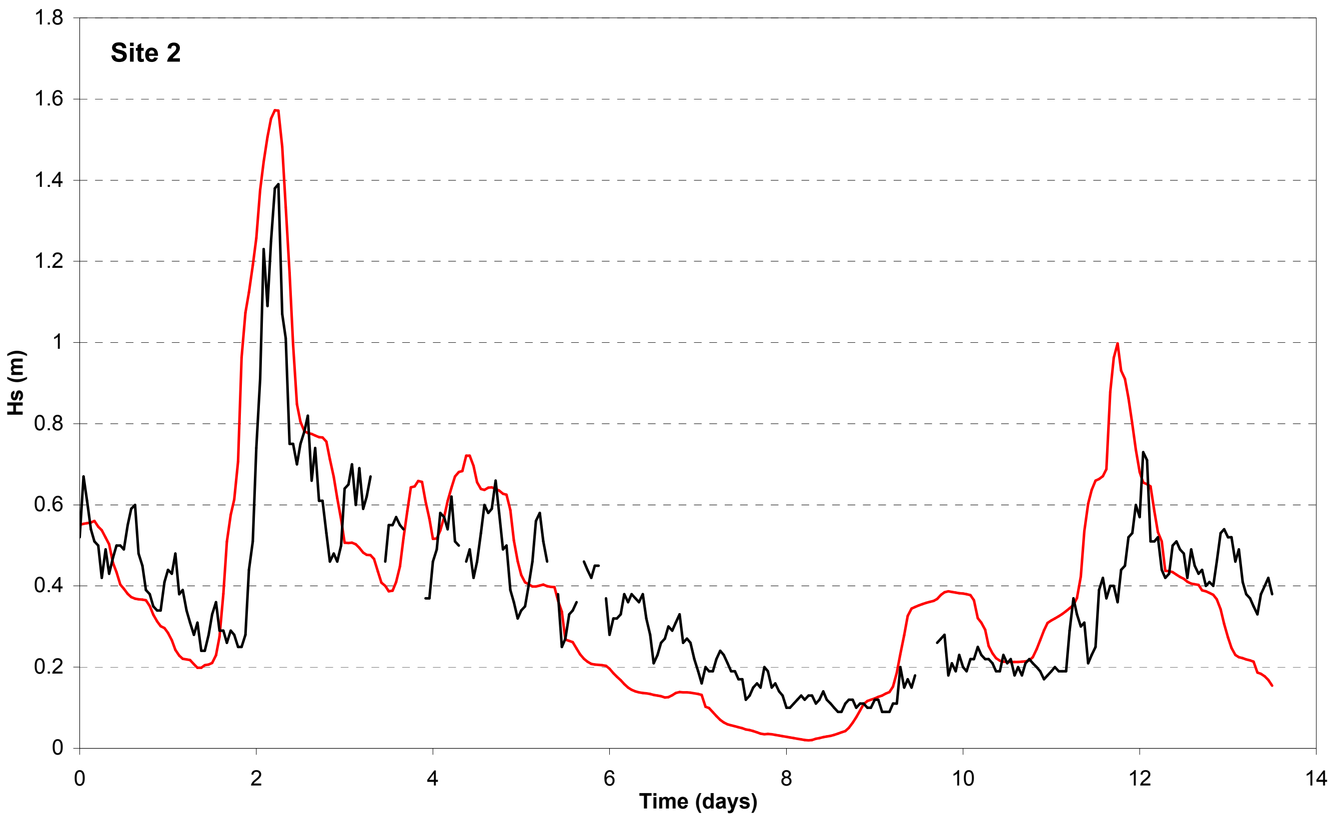
--- modelled

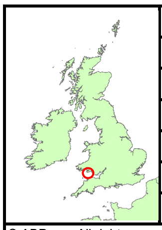
ABP mer marine environmental research

Timeseries comparison of wave data at Scarweather

Figure 6.1.6







Date	By	Size	Version
May 13	AMF	A4	1
Projection		n/a	
Scale		n/a	
QA		PAW	
SBTL_Calib_Fig-Control_v4-2.xls			
Produced by ABPmer			

--- measured

--- modelled

ABP mer marine environmental research

Timeseries comparison of wave height at Metocean Sites

Figure 6.1.7

ABP Marine Environmental Research Ltd (ABPmer)
Quayside Suite, Medina Chambers, Town Quay, Southampton SO14 2AQ

T +44 (0)23 80 711840
F +44 (0)23 80 711841
E enquiries@abpmer.co.uk

www.abpmer.co.uk

Creating sustainable solutions for the marine environment