Mumbles Conceptual Understanding

Mumbles PAR

Arup

March 2017

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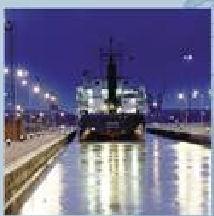



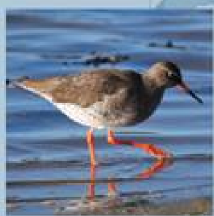

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Notice

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1 Introduction

1.1 Study

The aim of the project for City and County of Swansea (CCS) is to investigate options for managing coastal flooding and erosion risk and preparation of a Project Appraisal Report (PAR) at Mumbles. Improvements in the defences and flood risk are essential to fulfil the Councils' aspirations for regeneration and improved tourism along the promenade at Mumbles.

ABPmer has been commissioned to review the coastal processes to determine the parameters that affect flood risk at Mumbles. Extremes and overtopping analysis has also been completed to determine the volumes of wave overtopping of the defences for different return period events under existing conditions, and allowing for climate change. The ABPmer elements of the study have been completed via two deliverable documents containing:

- **Process Understanding (this document)** - A summary of the coastal processes affecting the defences and the conceptual understanding of the dynamics of the Bay, particularly with respect to the influence on the defences and stability of the beach and foreshore.

- **Extremes Analysis (separate document) –** This sets out the wave modelling and results for the overtopping analysis for various sections of the Mumbles defences (ABPmer 2017).

1.2 Coastal flood risk

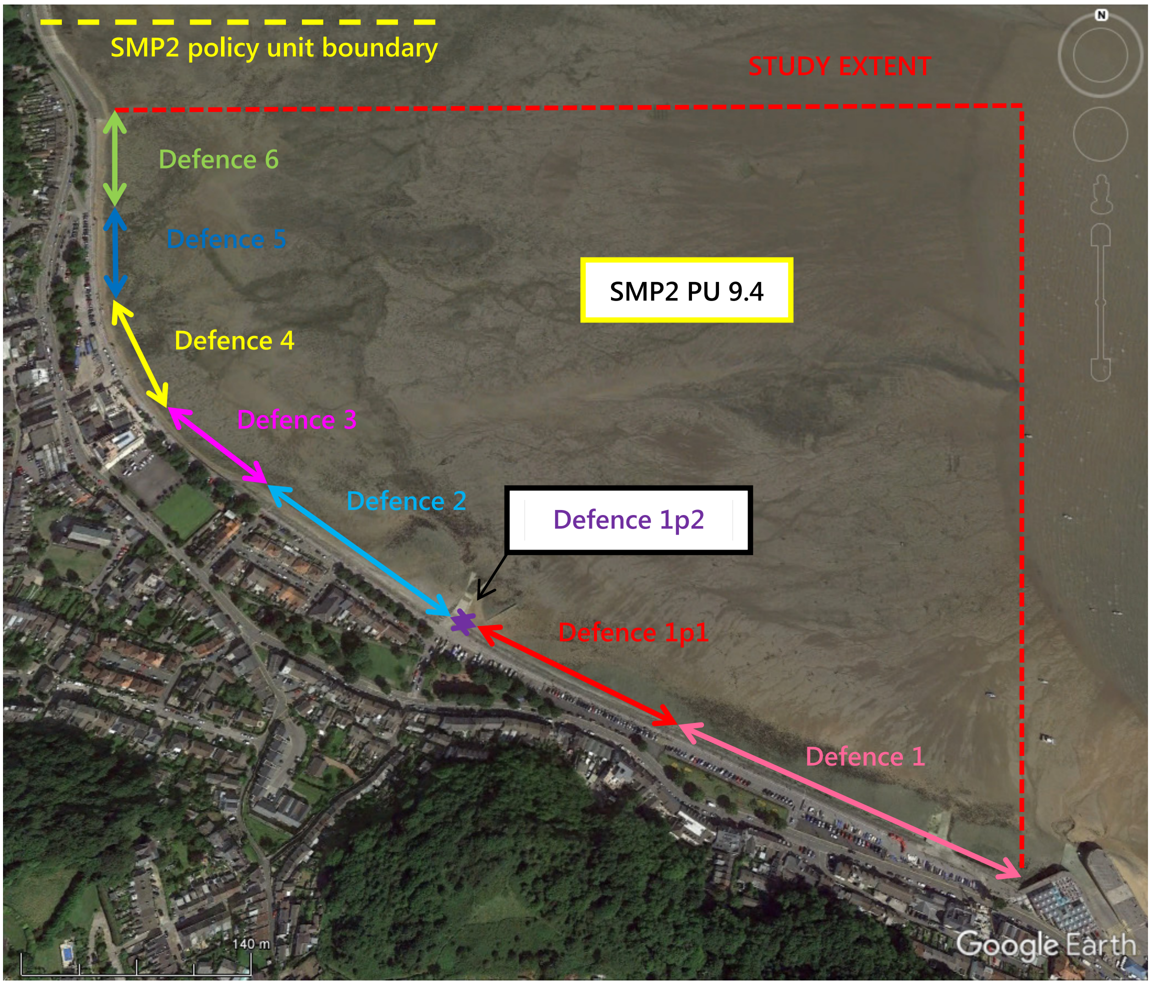
Contributing factors to coastal flooding are Mean Sea Level (MSL) and its rise due to climate change, storm surge levels, tidal heights, incident wave heights, wind speeds and existing coastal defence structures. These are all highly variable both spatially and temporally. Gaining an understanding of the physical process interaction with the shoreline is important to providing flood risk analysis such as overtopping rates and inundation levels.

The commissioned work assesses coastal flood risk from offshore sources (i.e. those mentioned above), and not from terrestrial or fluvial influences.

2 Site Description

2.1 Mumbles

The coastline within this report is a 1.2 km long exposed east to north-east facing intertidal foreshore to the west side of Swansea Bay, located SSW of Swansea and due east of Port Talbot. The southern extent of the site is located immediately west of a 50 m long NNW facing slipway, upon which a restaurant is located alongside a general storage area for local fishing vessels. A promenade lying immediately adjacent to the sea defences then runs north-west for around 450 m with raised grass areas and car parking immediately behind. A second 30 m north-east facing slipway is present in the mid-section of the promenade, with a small boat storage area immediately behind. The promenade then rotates in an increasingly clockwise direction for around 700 m to the northern extent of the site, behind which is located a mixture of residential and commercial properties, a recreational bowls green and additional visitor car parking.



Map data ©2016 Google. Image © 2016 Terrametrics. Data © SIO, NOAA, U.S. Navy, NGA, GEBCO.

Figure 1. Aerial imagery of Mumbles defences

2.2 Existing sea defences

The promenade at Mumbles consists of a concrete wall of varying finishes and crest heights. For the overtopping analysis eight differing defence sections have been identified, ranging from vertical to near vertical stone and concrete walls with various elevations and facing angles (Figure 1). Brief descriptions of the defences are provided below:

- **Defence 1** – Located at the eastern-most end of the site, consisting of a stone revetment with a crest of 5.83 mODN and a small set-back wall with a crest level of 6.8 mODN. The defence has a facing angle of 24 degrees.
- **Defence 1p1** – Similar to Defence 1 but contains a low point (5.76 mODN) along the stone revetment, along with matching set-back wall of crest level 6.8 mODN and facing angle of 24 degrees. The defence lies immediately in front of promenade car parking and a small boatyard making used of the slipway in Defence 1p2.
- **Defence 1p2** –A smooth concrete slip way with a crest of 5.76 mODN and a small set-back wall with a crest of 6.8 mODN. The defence has a facing angle of 32 degrees.
- **Defence 2** - A stone revetment with sprayed concrete on the face. The defence has a crest level of 6.07 mODN, with a small set-back wall of crest level 6.77 to 8.07 mODN and a defence facing angle of 34 degrees.
- **Defence 3** – This defence lies immediately in front of recreational ground, tennis courts and bowling green. It is formed of a concrete retaining wall with a parapet of height 6.00 mODN at the crest and a small set-back wall of crest level 6.7 to 7.0 mODN. The defence has a facing angle of 50 degrees.
- **Defence 4** - A concrete retaining wall with a parapet at the crest. The defence has a crest level of 6.85 mODN. A small set-back wall with a crest level of 7.55 to 7.85 mODN in height. The defence has a facing angle of 64 degrees.
- **Defence 5** - A concrete retaining wall with a parapet at the crest. The defence has a crest level of 6.48 mODN. A small set-back wall with a crest level of 7.18 to 7.48 mODN in height. The defence has a facing angle of 78 degrees.
- **Defence 6** – The northern-most defence section consists of a concrete retaining wall, with a parapet at the crest of 6.7 mODN and a small set-back wall of crest levels between 7.4 to 7.7 mODN. The defence has a facing angle of 83 degrees.

It should be noted that the set-back wall is considered for the purpose of the PAR as a '*de facto*' defence.

2.3 Shoreline management policy

The study area lies within the Lavernock Point to St Anne's Head SMP (Halcrow 2012) Area 9. The SMP long term plan for Area 9 notes that 'Reducing the risk of coastal erosion and flooding to residential, commercial and industrial assets is the main policy driver along this frontage, and therefore the recommended policy is to hold the line by maintaining and upgrading existing defences, subject to the future availability of public funding for coastal erosion and flood risk management' (Halcrow 2012). The specific unit containing the Mumbles frontage is as follows:

- Unit 9.4: Norton to Mumbles Head (Mumbles frontage). A hold the line (HTL) strategy exists for all three epochs in order to manage coastal erosion and flooding risk to the promenade, the A4067 highway and commercial/residential development (Halcrow 2012). Issues of surface water drainage were also identified.

3 Process Understanding

This section describes the marine and coastal physical processes within the study area. This baseline has been tailored towards providing sufficient detail for the PAR options appraisal. Of particular interest is the nature of the beach and foreshore in front of the defences along with waves and water levels which will directly interact with coastal defence structures.

3.1 Offshore seabed characteristics

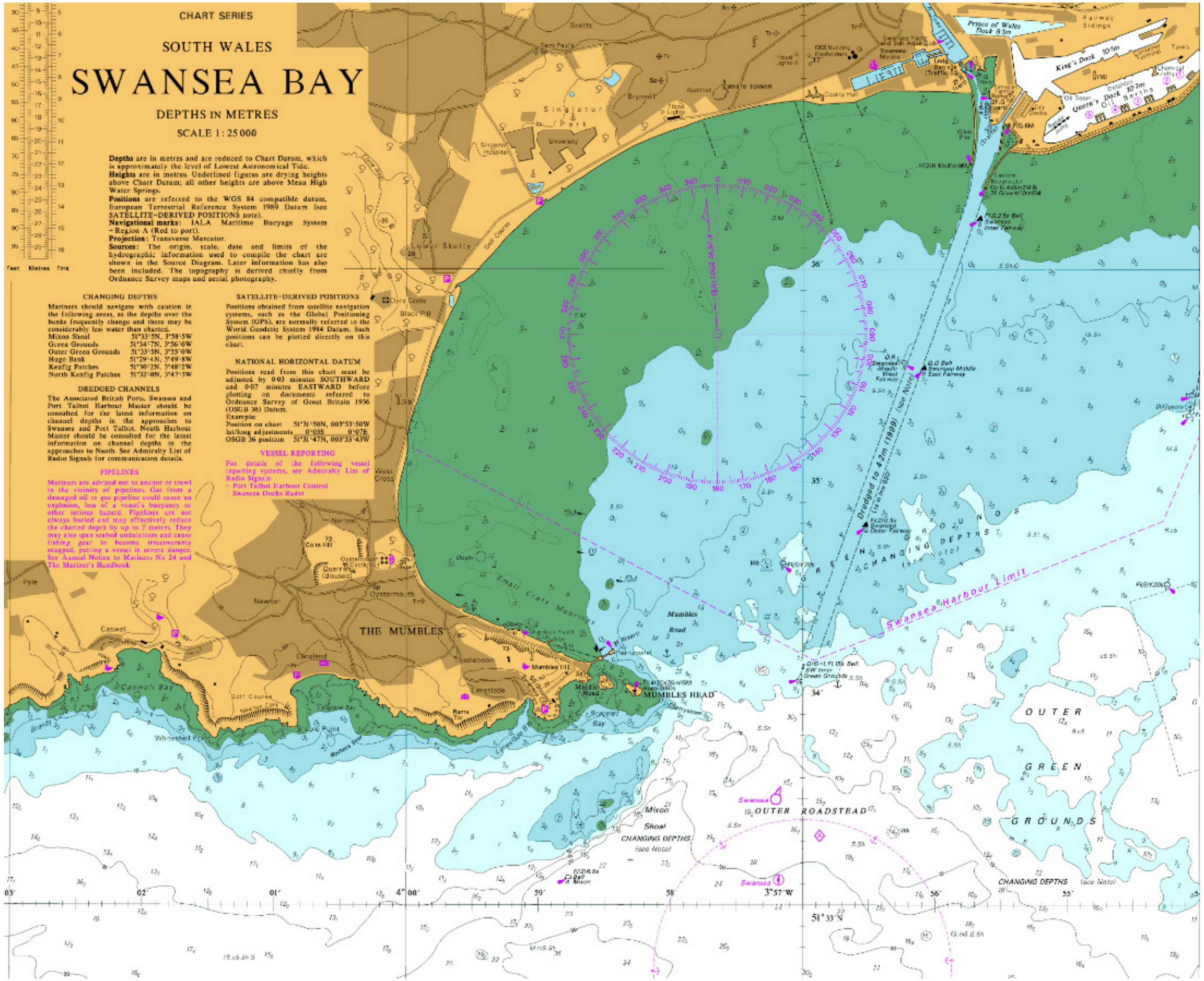
The Bristol Channel is relatively deep, with maximum depths of approximately 60 m near its entrance. Depths decrease eastwards to about 20 m near Lavernock Point. A shallower shelf area, ranging in width from 4.5 to 20 km, extends along the northern side between the Gower Peninsula and Lavernock Point. Much of the Inner Bristol Channel sea floor lacks accumulated sediments due to the strong tidal currents. Areas of slightly muddy sands occur in northern Swansea Bay (British Geological Survey, 1986; Pantin, 1991). The thickness of sediments is generally less than 10 m (Pye & Blott, 2009).

The sediment regime of the Bristol Channel is an ebb-dominated system (Halcrow 2005). The resulting net sediment transport is westwards in the centre of the Bristol Channel with a circulation within Swansea Bay.

Out in the Bristol Channel the coarse grained sediments form low amplitude dunes and mega-ripples. The medium to fine sand exhibit either higher amplitude dunes or plane bed features. The bed morphology that occurs is dependent on the local near-bed current speeds (Collins, 1993). The principal sediment source is the reworking of Quaternary sediments in the offshore zone. Large quantities of finer sediments (mud and fine sand) are supplied to the Bristol Channel by the rivers (mainly the River Severn) and supplemented with coastal cliff erosion (Pye & Blott, 2009).

At Mumbles the seabed morphology is gently sloping within the Bay, with relatively uniform depth contours of 0-5 m Chart Datum (mCD) leading offshore. Two sandbanks are located offshore of Mumbles Head, the Mixon Shoal directly to the south and the Outer Green Grounds to the east. Here depths are reduced to below 3 mCD from greater than 12 mCD. These banks along with the Mumbles Head interact to influence the tidal and wave processes within Swansea Bay and the study area in particular. Swansea Bay is also partially separated from the deeper waters along the Central Bristol Channel by the linear sandbank, Scarweather Sands.

The seabed features are shown in the Admiralty Chart provided as Figure 2 in mCD. Further detail on the local bathymetry has been provided from the ABPmer model bathymetry as shown in Figure 3 to mODN.



Source: UKHO, 1999

Figure 2. Admiralty chart data for Mumbles located on the western extent of Swansea Bay, units mCD

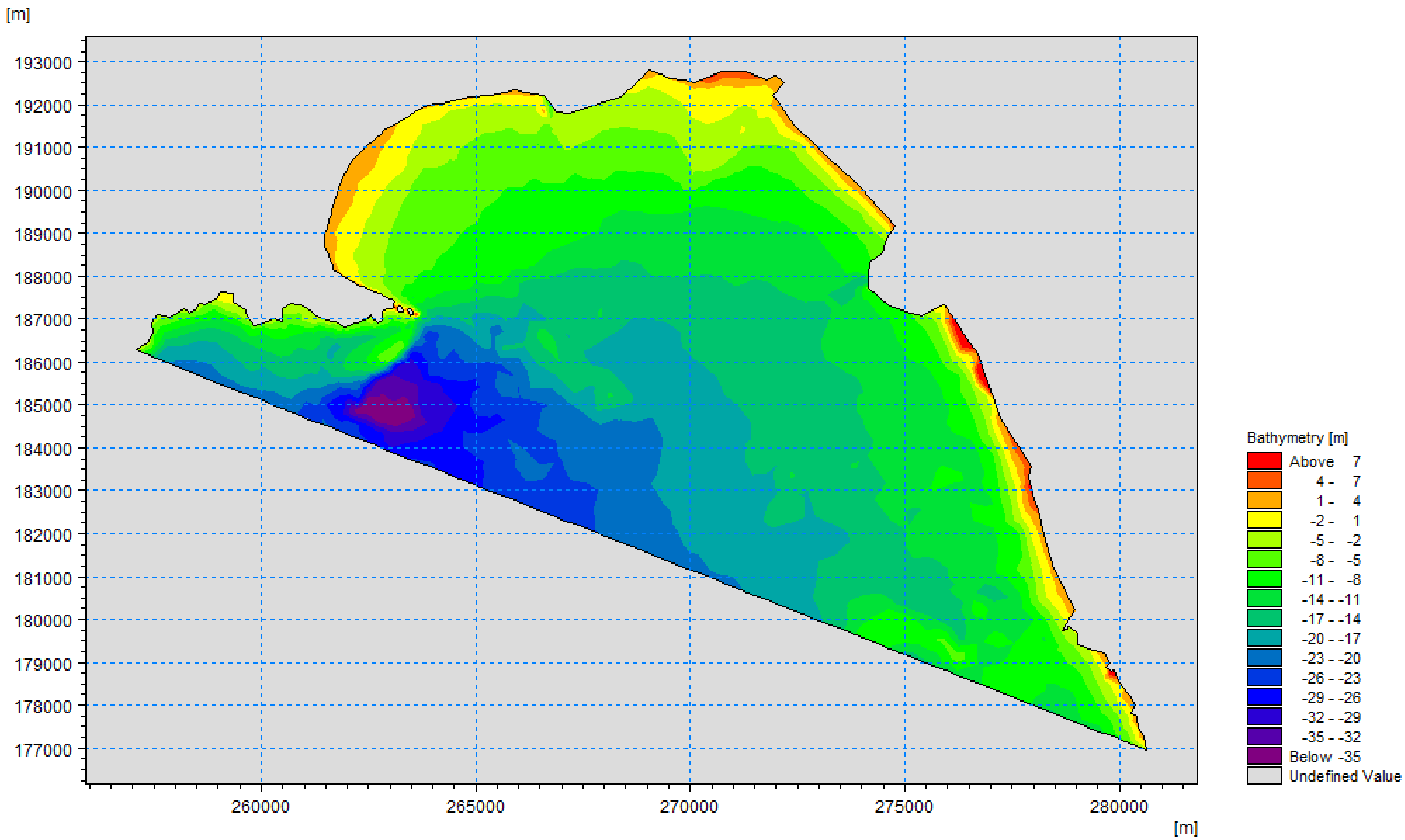


Figure 3. Nearshore Bathymetry (ABPmer SEASTATES model bathymetry in mODN)

3.2 Coastal change

The geomorphological character of the South Wales coast is controlled by resistant rock outcrops, and the southern coastline of the Gower Peninsula containing Mumbles Head is dominated by hard limestone cliffs. The outcrops give rise to a series of headlands, sections of cliffed coast with intertidal shore platforms, and intervening Bays backed by sandy beaches and dunes (Pye & Blott, 2009).

Sediment transport, current flow and wave activity is controlled by the natural coastal configuration, particularly Mumbles Head and the offshore shoals. These processes have been further modified over time by coastal development and Port Talbot outer harbour as well as the interventions including the Swansea channel, Neath estuary training wall and maintenance dredging activity.

There is limited sediment on the western side of the Bay and is related to storm activity from the southeast, which re-suspends and transports deposited sediments initially brought to the eastern side of the Bay by predominant south-westerly wave conditions (ABPmer 1997). Potential exchange between this area of the Bay and the Mixon Shoal is also suggested to occur (Halcrow 2012). Longshore sediment transport within Swansea Bay is generally to the south east, with potential re-circulation of sediment in a clockwise direction due to the tidal residual (Collins *et al.*, 1979; Heathershaw & Hammond, 1980; Uncles, 1982). This residual is currently suggested to operate as a closed sediment system, with limited input of new sediment from deeper parts of the Bristol Channel or nearby estuary systems (Pye & Blott 2009).

3.2.1 Mumbles frontage

The Bay shape as illustrated in Figure 4 which shows deeper water at the toe of the defences in the southern half of the study area and topographic profiles located throughout the intertidal (Figure 5, Figure 6 and Figure 7). The defence toe level in the northern sections of the frontage (profile 203) is greatest in vertical height (2.7-2.75 mODN), whilst the lower (2.1-2.3 mODN) are to the south at profile 202, i.e. just above Mean High Water Neap (MHWN) level. Surveys between 2009 and 2013 suggest small variations in level at the toe of the defence, with very little change in overall foreshore level (Pye & Blott 2013). Between 2009 and 2013 the northern defences at the location of the profile experienced a drawdown of 0.05 m, whilst the southern-most defence section experienced a build-up of material around 0.2 m between 2010 and 2013.

Immediately outward of the defence toes at Mumbles an extensive intertidal zone ranging from 70-200 m in the south to 700 m in width to the north. The upper foreshore is mixed sand and gravel in front of the southern defence sections, with initial gradient of 1:9 over approximately the first 50 m (Figure 6) before shallowing in gradient to around 1:100 for the remaining intertidal extent to MLWS level, containing a mixture of mud, sand and gravel which appears relatively consolidated in form. In front of the northern sections the upper foreshore is similar in gradient to the wider intertidal (Figure 7).

Change in foreshore elevation throughout the site between 2006 and 2011 established via LiDAR datasets suggest a stable lower foreshore, similar to the topographic profile surveys. Most change within the study intertidal area below MHWN level is negligible (±0.05 m, Figure 8). Localised patches of erosion and accretion are associated with the two slipway structures, and along the toe of defences. It should be noted that the apparent alternating level variation at the toe of the defence throughout the southern extent of the promenade is likely to be partially due to resolution between the two datasets (2 m for 2006, 1 m for 2011). Overall, however, Figure 8 suggests there are sections along the frontage for both erosion and accretion which may vary over time. Whilst profile 202 suggests accretion, it is likely adjacent areas could be eroding a similar amount.

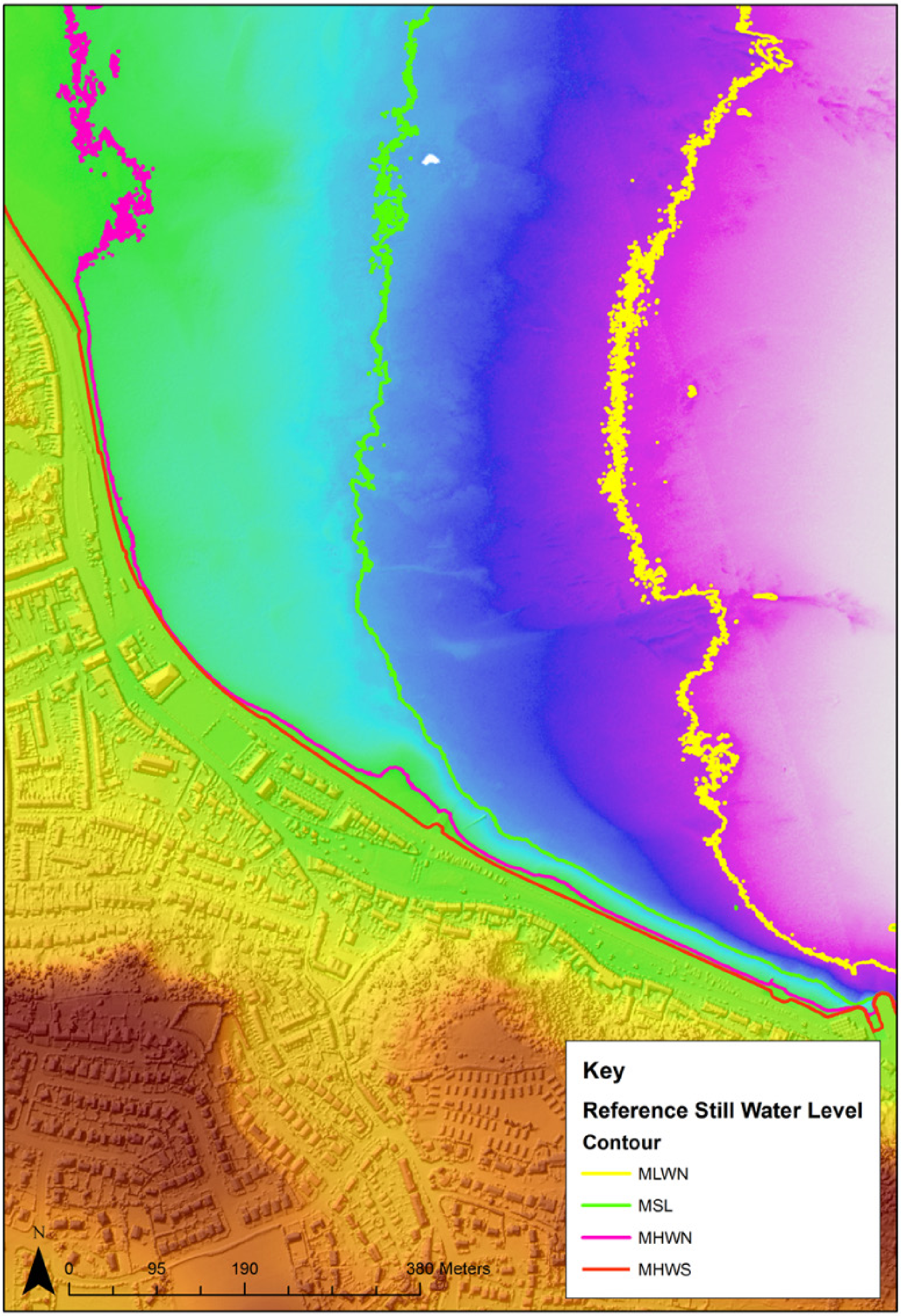
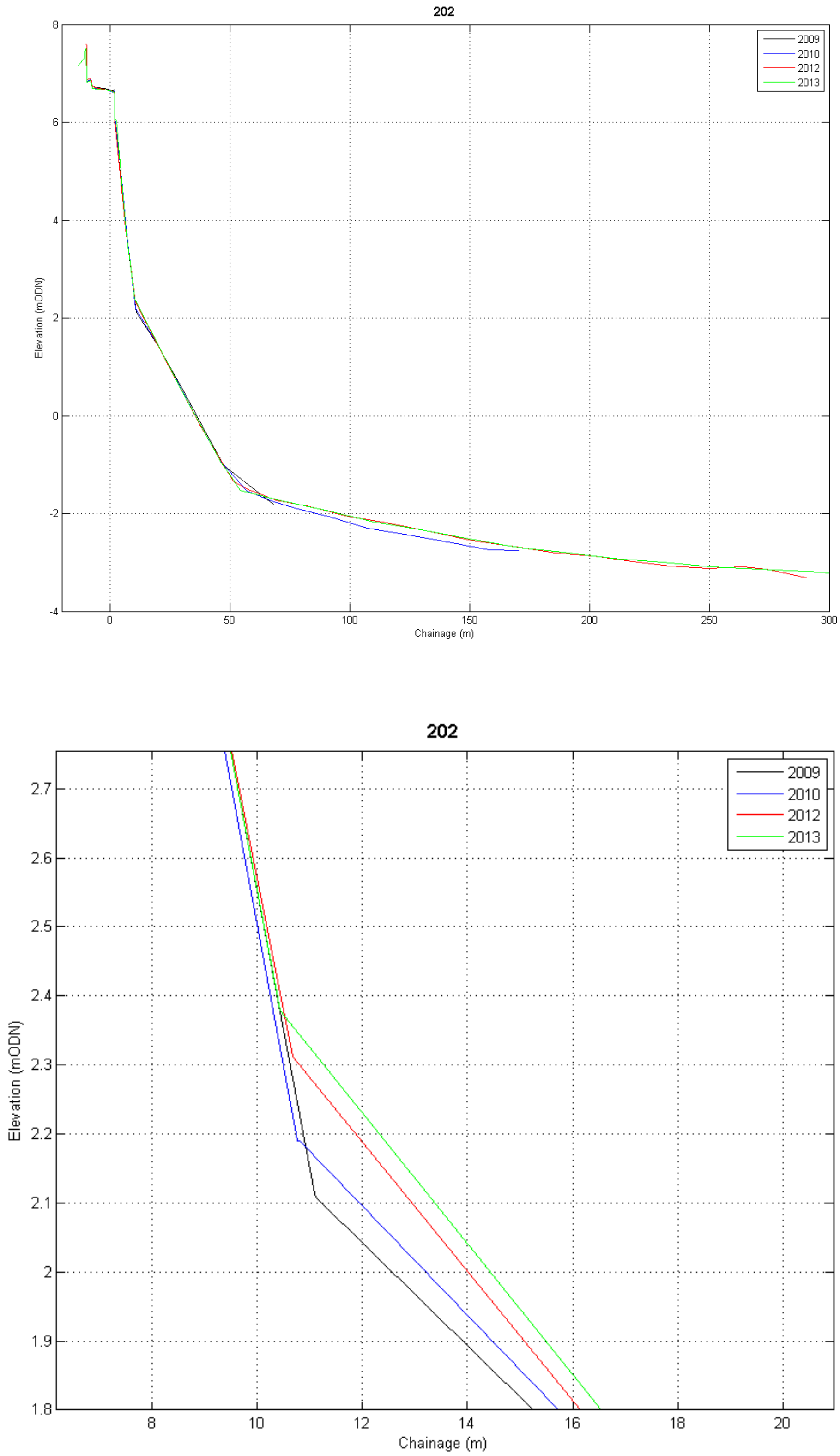


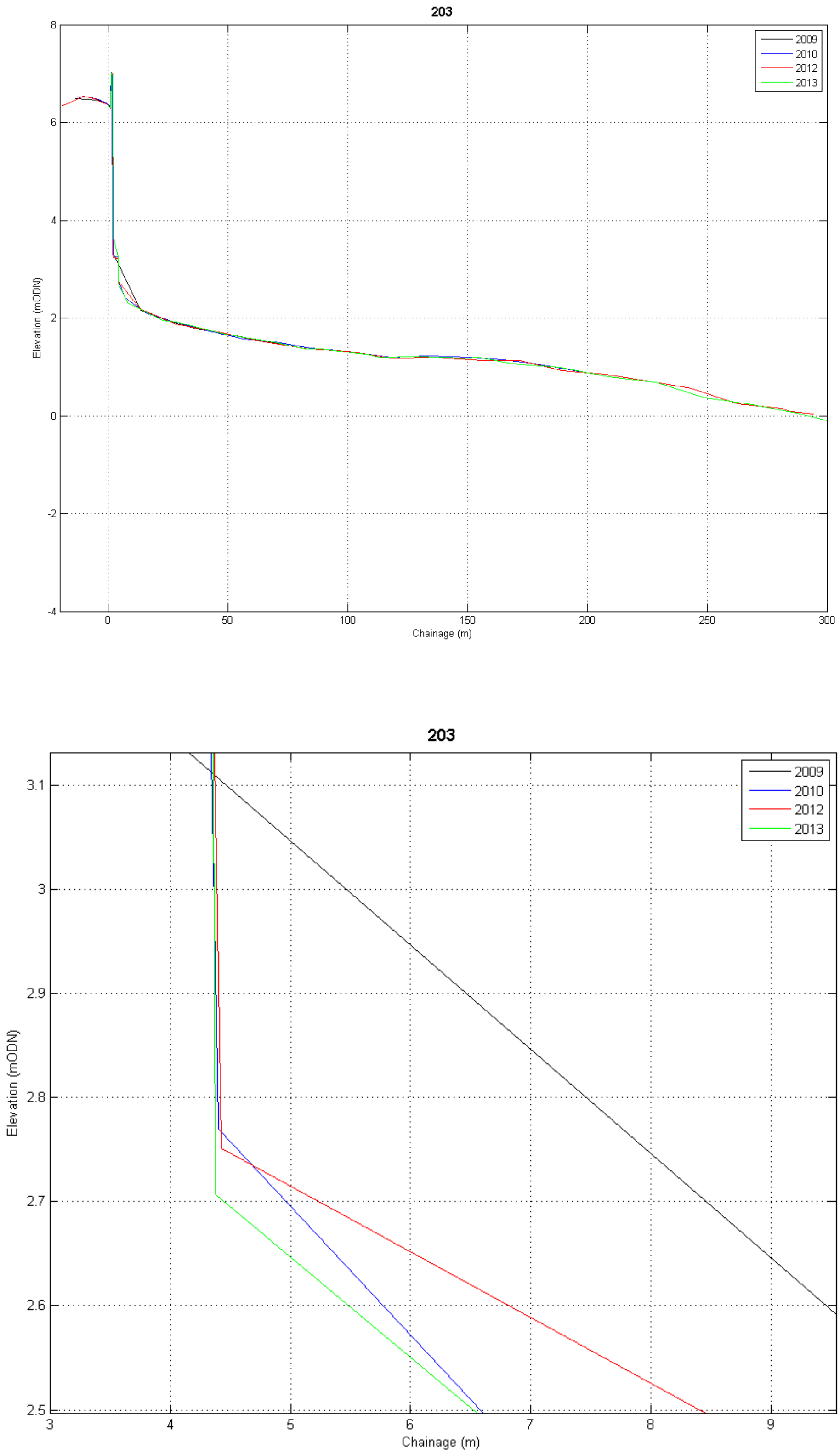
Figure 4 **Relative still water levels (mODN) throughout the site at Mumbles in respect to LiDAR**

Figure 5. Locations of topographic profiles along Mumbles defences



An Increase in level of around 0.2 m at the toe of the defence can be seen between these dates

Figure 6. Topographic profile surveys between 2009 and 2013 at section 202



Drawdown of around 0.05 m at the defence toe can be seen between 2010 and 2013.
Note the exclusion of the 2009 due to a lack of point density.

Figure 7. Topographic profile surveys between 2009 and 2013 at section 203

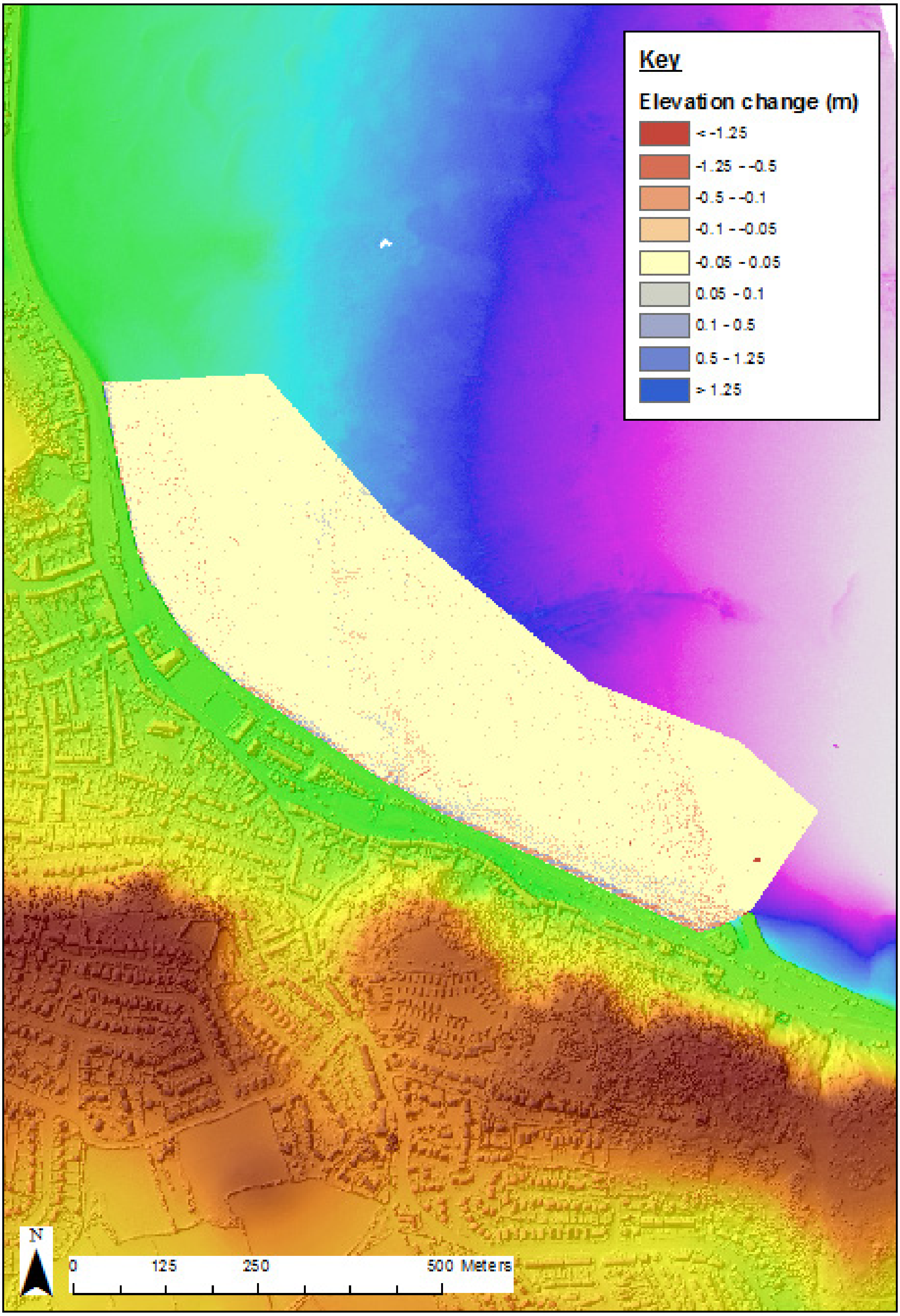


Figure 8. Foreshore elevation change between 2006 and 2011 throughout the Mumbles intertidal

3.3 Future evolution

Much of the current dynamics within Swansea Bay are related to human activity, and central and northern extents of the Mumbles study area are formed by reclaimed land with the natural coastline around 75 m landward of its current position (Arup 2017). As a result, much of the future evolution of the coastline is dependent on future management strategies.

The SMP predicts that under the Do Nothing Scenario sea level rise will result in increased exposure and pressure on the existing defences. However throughout the short term epoch (present day to 2029) the existing defences are expected to remain intact, with only small localised failure. Consequently the shoreline position should remain stable, with little change. The consolidated foreshore at Mumbles and the limited supply of sediment to the wider Bay is likely to restrict the rate of foreshore level change throughout the epoch.

The limited supply of sediment to western areas of the Bay along with increasing sea level rise is likely to lead to an overall steepening of the intertidal foreshore and a lowering of foreshore levels in the medium term (2029-2059), increasing the pressure on the defences of which are expected to fail in this epoch. A rapid recession is likely to be seen over throughout areas of reclaimed land such as the Mumbles frontage, leading to increased flood risk due to wave overtopping.

Long term (2059-2109) rates of change in the overall shoreline position throughout the Mumbles frontage following widespread failure of the defences in the medium term epoch is expected to reduce due to the resistant underlying geology of Mumbles Head. Cliff recession rates of <10 m are expected, with cliff fall events the most likely drivers for future shoreline advancement. If the defences were allowed to fail along the eastern and northern frontages of Swansea Bay then this could result in changes to the large scale dynamics of the Bay system and increased tidal flows.

3.4 Water levels

3.4.1 Tidal water levels

The study area is within the Bristol Channel, which is a hyper-tidal environment with a spring tidal range in excess of 8 m. This is due to the behaviour of the tidal wave originating in the North Atlantic and the funnelling effect of the channel, which in turn modifies the behaviour of the tidal wave. Within the study area, the tidal range is approximately 8.4 m during spring tides, reducing to 3.9 m during neap tides (Table 1), which is characteristic for coastal locations within the Outer Bristol channel. The conversion from chart datum to ordnance datum (at Newlyn) for Mumbles and Port Talbot is -5.0 m and -5.3 m respectively.

Table 1. Tidal characteristics at Mumbles and Port Talbot

Location	Reference Still Water Level							Mean Range (m)	
	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT	Spring	Neap
Mumbles (mCD)	10.5	9.5	7.2	5.2	3.3	1.1	0.1	8.4	3.9
Mumbles (mODN)	5.5	4.5	2.2	0.2	-1.7	-3.9	-4.9		
Port Talbot (mCD)	10.8	9.7	7.3	5.4	3.5	1.1	0.2	8.6	3.8
Port Talbot (mODN)	5.6	4.5	2.1	0.2	-1.7	-4.1	-5.0		

Source: UKHO, 2016.

The hyper-tidal range (and bathymetry) at Mumbles means that the existing sea defences throughout the length of the frontage are only in direct contact with still water levels for short periods of the tidal cycle, particularly on neap tides. Reference still water levels calculated from LiDAR (Figure 4) suggest that the toe of the sea defences are in direct contact with wave conditions at Mean High Water Springs (MHWS), with Mean High Water Neap (MHWN) level also suspected to be in close proximity (within 10 m). Depths of water at the defence toe under 'normal' tidal conditions is rarely greater than 2.5 m but is likely to be in the order of 1.5 m higher for extreme water levels.

Photographs taken during a spring tide level close to HAT (10.37 mCD on 09/09/2010) show water levels to be within close proximity of the defence crest despite near calm wave conditions within the Bay (Figure 9). Mean Sea Level (MSL) and Mean Low Water Neap (MLWN) contours range between 25–310 m and 60 - 600 m from the defence toes respectively, depending on location along the defences.

Exposure to wave overtopping is likely to be limited temporally by the tidal state in normal conditions, particularly within northern sections of the sea defences due to the bathymetry changes where the waves pass over a wider shelving foreshore, helping to dissipate the wave energy before reaching the coastal defence. During storm conditions, still water levels will be higher giving greater exposure to higher waves, albeit still considerably attenuated by the shelving foreshore. This effect will however be less for the southern sections of the frontage.

Figure 9. Calm conditions throughout Mumbles defences at near HAT levels on 09/09/2010

3.4.2 Surge

The Bristol Channel is affected by storm surges which are generated by the movement of Atlantic depressions across the UK. The most significant storm surges are associated with the events which track southerly across Ireland and generate strong south westerly winds. These winds force water up the Bristol Channel. The occurrence of surge events within the Bristol Channel has the potential to increase water levels by up to 2 m. At Mumbles the largest surge height recorded by the tide gauge between 1990 and 2014 measured approximately 1.8 m (ABPmer 2005), whilst the greatest negative surge was around -0.90 m on the 13th February 2005 (NTSLF, 2013). The highest measured water level at the Mumbles gauge over this time period was 5.63 mODN, recorded on the 8th October 2006, which relates to a relatively small positive surge of approximately 0.22 m on a very large spring tide; equivalent to 0.12 m greater than HAT.

ABPmer (ABPmer, 2005 and cited in Tidal Lagoon Power, 2014) undertook a detailed analysis of surge heights at the Mumbles tide gauge for a 15-year period from 1990 to 2004. The key result from this analysis was that extreme surge events do not tend to result in extreme water levels, with peak surges typically occurring a number of hours before or after HW. Had the 1.81 m positive surge actually coincided with a period of high astronomical tides (rather than around 3.5 hrs after HW), it would have resulted in a considerably greater extreme water level.

Should a positive surge occur during the flood tide, this may lead to an increased rate of tidal rise and a potential enhancement of flow speeds along the Bristol Channel and within Swansea Bay. Similarly, a negative surge event during an ebb tide may lead to an increased rate of tidal fall, once again resulting in a potential enhancement of flow speeds. Where these respective surge events occur at corresponding times of peak flow speeds, particularly during larger spring tides (when tidal flows are already relatively high), there is an increased potential for seabed scour and shoreline erosion (Tidal Lagoon Power 2014).

UKCP09 predictions for future change in storm surge across the region indicate an increase in the 1 in 50-year storm surge height of up to 0.8 mm/yr (Lowe *et al.*, 2009). This projected increase remains an uncertain estimate as there is inherent difficulty in predicting storm surge events due to the complicated interaction of many marine and meteorological factors.

3.4.3 Extreme water levels

The Environment Agency coastal flood boundary dataset (CFBD) provides an assessment of extreme water levels in proximity to Mumbles as summarised in Table 2 for the locations shown in Figure 10. These provide the extreme water levels associated with different return periods using a base year of 2008, and then adjusted using UKCP09 data to include sea level rise for epochs 2018 and 2118. Table 2 indicates that existing extreme water levels around Mumbles are in the order of around 6.2 mODN up to the 1 in 200 year event.

Generally, it is the coincident occurrence of extreme surge heights with high water levels that is considered to bring about extreme water levels within the study region. Observed occurrences of extreme water levels at Mumbles between 1989 and 2014 showed a maximum height of 5.755 mODN, recorded on the on 20 February 2007 (Table 3). This level (without any wave activity) would have been almost coincident with the primary crest level of defence section 1p2 at the slipway. Between 1989 and 2014, there were nineteen occurrences of water levels at or above HAT (Table 3).

Table 2. Extreme water levels for base year of 2008 (Environment Agency CFBD, 2011) and adjusted for 2018 and 2118 epochs

Return Period (Years)	Environment Agency Chainage 490 (mODN)	Epoch 2018 (mODN)	Epoch 2118 (mODN)
1:1	5.47	5.52	6.28
1:10	5.74	5.79	6.55
1:20	5.83	5.88	6.64
1:50	5.95	6.00	6.76
1:75	6.01	6.06	6.82
1:100	6.05	6.10	6.86
1:200	6.15	6.20	6.96
1:1000	6.39	6.44	7.20

Source: Environment Agency, 2011

Table 3. Water levels reaching (or above) HAT at Mumbles with associated dates

Date and Time	Water level (mODN)
20/02/2007 08:00	5.755
03/01/2014 07:00	5.684
28/09/2007 19:00	5.648
19/02/2007 07:00	5.647
08/10/2006 19:00	5.628
29/08/1992 19:00	5.627
02/03/2014 07:00	5.625
10/03/2008 08:00	5.611
09/03/1989 07:00	5.599
30/03/2006 07:00	5.594
01/02/2014 07:00	5.589
03/02/2014 09:00	5.583
29/09/2007 20:00	5.56
27/10/2007 19:00	5.56
28/10/2007 07:00	5.545
30/08/1992 20:00	5.526
21/02/2007 09:00	5.475
17/10/1997 19:00	5.473
02/02/2014 08:00	5.467

3.4.4 Relative sea level

The Bristol Channel has historically experienced changes in relative sea levels. More recently, the general trend for the southwest of the United Kingdom (UK) (as given at Newlyn, between 1916 and 1996) is of an increase in relative mean sea-level at an average rate of 0.17 ±0.012 cm per year (Woodworth, *et al*., 1999). A further analysis of the tide gauge data from Mumbles over a shorter period (between 1990 and 2010) suggests a rate of increase of 0.11 cm per year.

Future changes in relative sea level (RSL) are quoted as the net effect of geological adjustments in land levels and the projected absolute changes in mean sea level. A summary of the UKCP09 relative sea level rise projections up to 2100 for the grid cell 23261 at the Mumbles, based on the medium emission scenario, for the range of confidence intervals are provided in Table 4. For the climate change simulations the medium emission scenario 95 percentile for an epoch *circa* 100 year in the future was calculated at 0.75 m 2118 as per Welsh Government Adapting to Climate Change Guidance (2011).

Table 4. Medium emission scenario predicted relative sea level rise since 1990 (in m) for Mumbles

Year	Confidence Intervals 95 %ile
2000	0.044
2010	0.093
2018	0.135
2020	0.146
2030	0.203
2040	0.265
2050	0.331
2060	0.401

Year	Confidence Intervals 95 %ile
2070	0.476
2080	0.555
2090	0.639
2100	0.727
2118	0.889

Source: UKCP09 Grid Cell 23261

A general increase in RSL may result in a number of effects, such as, displacing the high water mark towards the shoreline, enabling wave energy to move further towards the coast (exposing the shoreline to greater periods of wave and tidal energy) and increasing potential flood risk. The magnitude of these effects will vary depending upon the rate of predicted sea level rise and the timing relative to the 18.6 year lunar nodal cycle variations (which may impart a larger variation in amplitude over shorter timescales).

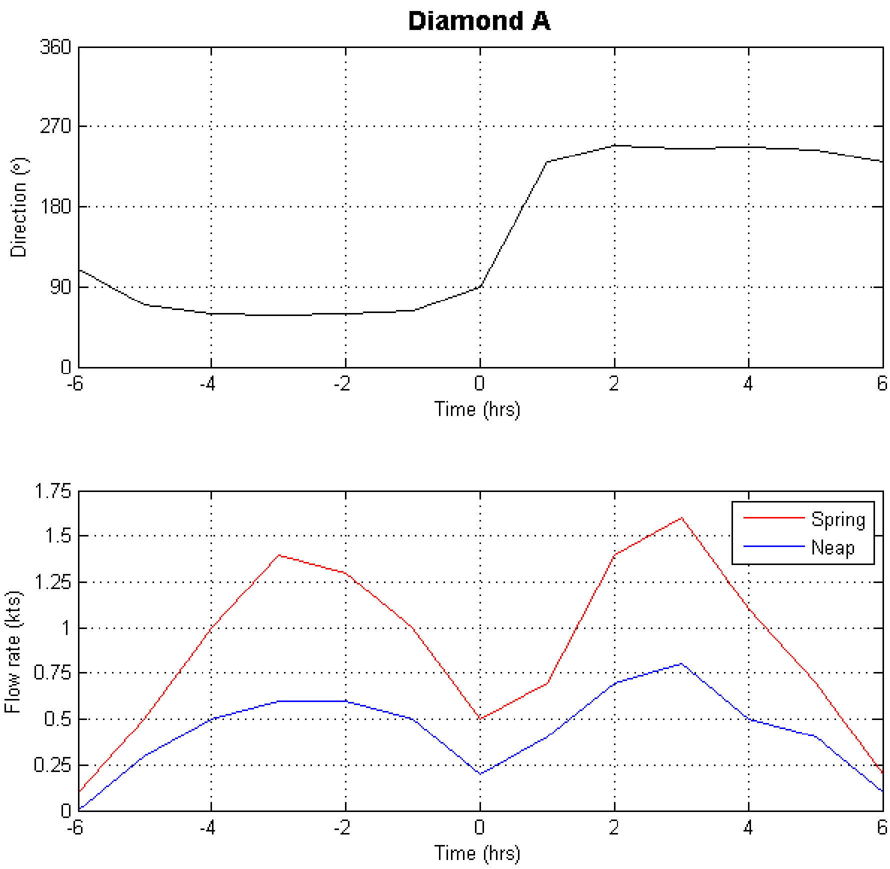
Figure 10. Location of Environment Agency Extreme water level extraction point 490 in relation to Mumbles

3.5 Currents

3.5.1 Tidal currents

The tidal regime within the Bristol Channel is characterised by strong tidal flows, on an east-west axis, as a result of the large tidal range and channel morphology. The current speeds vary spatially both along and across the coastline in line with channels, sandbanks and intertidal flats. The large tidal range within the Bristol Channel influences the extent to which waves interact with the seabed and able to supply additional forcing to the tidal current regime.

Tidal stream data located approximately 2 km southeast of Mumbles Head (Figure 11) suggest peak current speeds during spring tides are 1.6 kts (0.8 m/s), with neap rates lowering to a maximum of 0.8 kts (0.4 m/s). Peak flow is higher on the ebb than the flood, adhering to the ebb dominance of the wider region. Flow direction is approximately rectilinear, with flood tides flowing ENE and the ebb tides in a WSW direction.



Source: UKHO, 1999

Figure 11. Tidal stream data offshore of Mumbles Head

Within the intertidal, flood tide flow initially passing around the Mumbles Head diverges within the Bay, creating an anti-clockwise eddy (ABPmer 1997). On the ebb flow is generally directed in a south to south-westerly direction, draining the Bay before being forced in a south-easterly direction around Mumbles Head. Current speeds are generally reduced within the intertidal to 0.5-0.7 kts (0.25-0.35 m/s) during spring tides, and 0.2-0.4 kts (0.1-0.2 m/s) during neaps.

3.6 Waves

3.6.1 Regional wave climate

The Bristol Channel is exposed to both long period swell waves generated in the Atlantic and shorter period wind-waves generated locally within the Channel, which are limited by wind speeds and fetch length. The largest waves and most frequent direction for waves to approach the study area are from a WSW direction, with waves undergoing refraction and shoaling effects around the Mixon Shoal, Mumbles Head and over the Outer Green Grounds (Figure 2).

Data from the Scarweather WaveNet buoy located south of Mumbles Head in the Outer Bristol Channel (Latitude 51° 25'.99N, Longitude 003° 55'.99W) at 35 m water depth is used to inform the offshore wave climate. At this buoy Figure 12 indicates an average significant wave height (Hs) of 2.1 m and peak wave period (Tp) of 9.1 seconds was observed for the period between July 2005 and November 2015. Waves dominantly approached from WSW for nearly 50% of the time, with significant wave heights of up to 7 m. The largest recorded significant wave height in the time series is 11.11 m on the 10 May 2014.

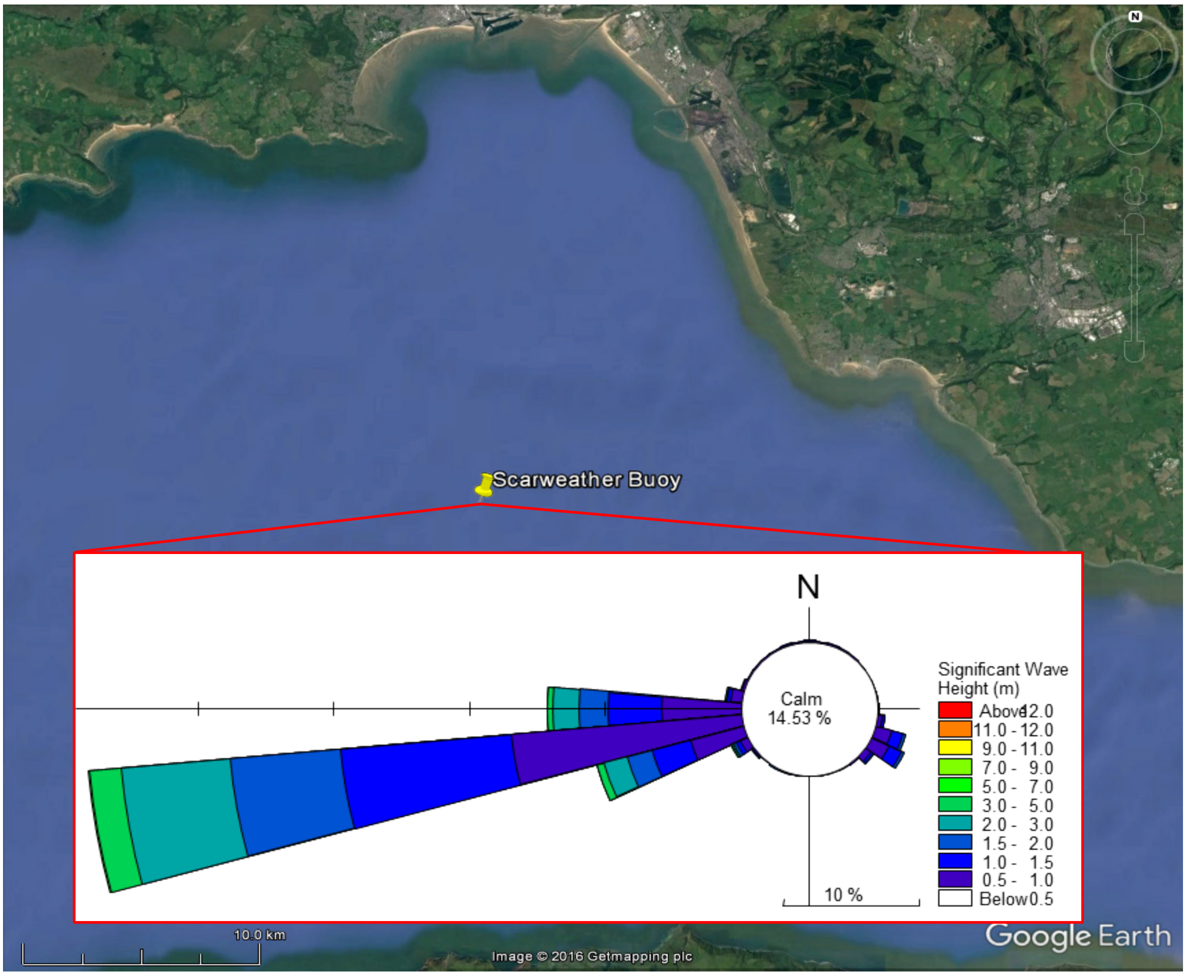


Figure 12. Significant wave height at the Scarweather WaveNet buoy between July 2005 and November 2015

3.6.2 Local wave climate

Mumbles Head provides a considerable sheltering effect for the promenade front within the western side of Swansea Bay, and therefore offshore wave buoys such as Scarweather will not accurately represent the wave climate experienced at Mumbles. To represent conditions throughout the defence frontage ABPmer's SEASTATES hindcast model (ABPmer, 2013, ABPmer 2016) has been applied to show the nearshore wave climate (Figure 13 and Table 5) by transforming a 37 year hindcast time series of wave heights and water levels to toe of the defences at Mumbles. Wave extraction points were selected based on a combination of LIDAR data across the foreshore and the known height of the toe from existing drawings. This method is discussed further in the supporting modelling and wave overtopping assessment (ABPmer 2017).

Table 5. Average wave statistics at the toe of the defences at Mumbles

Defence Toe	Average Significant Wave Height Hs (m)	Average Peak Wave Period Tp (s)	Mean Wave Direction (°)
1	0.07	2.3	139
1p1	0.07	2.3	140
2	0.07	2.2	120
3	0.07	2.2	117
4	0.07	2.1	112
5	0.07	2.2	111
6	0.07	2.3	109
Locations are shown in Figure 13			

Across the Mumbles defences average significant wave height (Hs) and peak wave period (Tp) values are consistently reduced to values less than 0.1 m and 2.3 s respectively (Table 5). Toe locations throughout the southerly defence sections (mainly 1 and 1p1) experience a greater spread of wave direction (particularly from northwest directions) due to the morphology of the Bay.

Sheltering, diffraction and refraction of waves around Mumbles Head occurs prior to reaching the defences. The resulting effects can be seen for spring tides in September 2010; where despite water levels close to HAT near calm conditions (Hs 0-0.1 m) are seen throughout the defence sections (Figure 14) despite the modelled wave field suggesting offshore waves of Hs values over 1 m (Figure 15). Theses clearly show a shielding effect from the Mumbles Head, hence the calm conditions along the frontage.

In contrast frequent wave overtopping is evident during smaller magnitude south-easterly conditions (Figure 16), where sheltering from the Mumbles Head is less evident and waves are reduced only by refraction and shoaling over the foreshore. During this event Hs values along the defence sections had heights of 0.3-0.4 m from their initial offshore values of 0.7-0.8 m (Figure 17). However it should be noted that events occurring from this direction are considerably lower in frequency (<10% between 2005 and 2015) compared to south-westerly directions (Figure 12).

Figure 18 shows that locally wind generated waves of periods 2-3 s created within Swansea Bay from northerly and north-easterly direction impact the defence sections at Mumbles at near perpendicular angles to the defences, with similar or larger Hs values (0.3-0.5 m) to those from south-easterly directions where wave overtopping events have been witnessed. Throughout the SEASTATES hindcast duration such events are rare in occurrence (<5%, Figure 13), but demonstrate potential for wave overtopping events as a result of both wind and swell generated waves.

There is a proposal for the construction of a tidal lagoon in Swansea Bay. Studies undertaken in association with the consenting process identified that under extreme scenarios, extreme waves at Mumbles could be increased due to reflections from the lagoon wall. A precautionary flood risk assessment was completed for the Mumbles frontage. The assessment demonstrated no increase to flood risk. However there was an identifiable difference from waves from a south westerly direction (noting that the frontage is generally sheltered from these conditions). Using the lowest point on the sea wall (5.74 mODN) the scenario used an assessment water level of 6.2 mODN which resulted in direct inundation. The assessment concluded that the associated waves increased 0.05-0.07 m higher resulting in an increase in relative overtopping of between 0.4 and 2.6%. Iterative calculations showed that an increase of wall height between 0.06 m and 0.19 m would be required to offset the increase from the Lagoon (Tidal Lagoon Swansea Bay 2014).

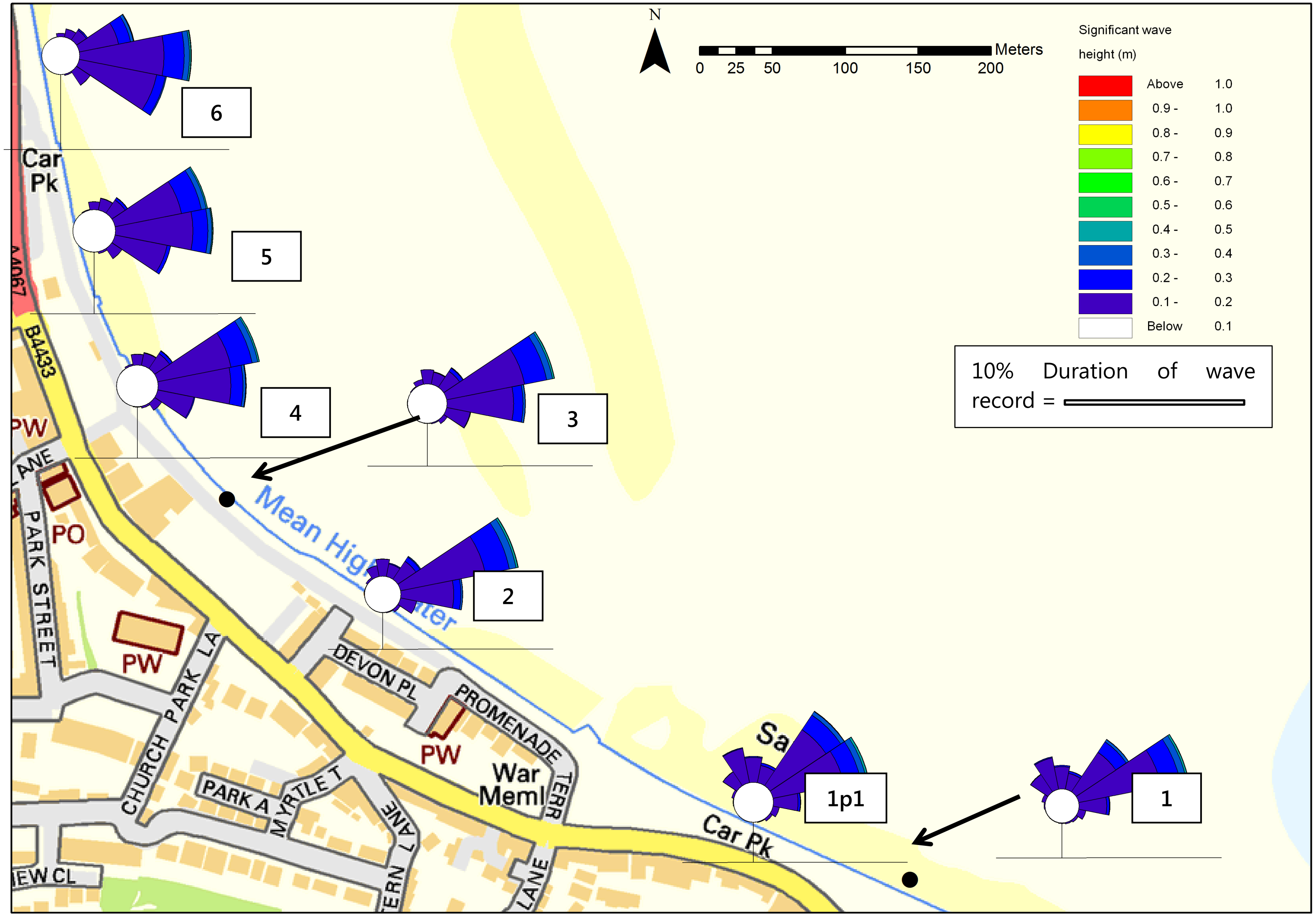


Figure 13. **ABPmer SEASTATES modelled significant wave heights at defence toe locations throughout Mumbles defence sections**

Figure 14. Small magnitude wind generated waves along Mumbles frontage, despite southwesterly waves of heights in excess of 1 m off Mumbles Head (Figure 15)

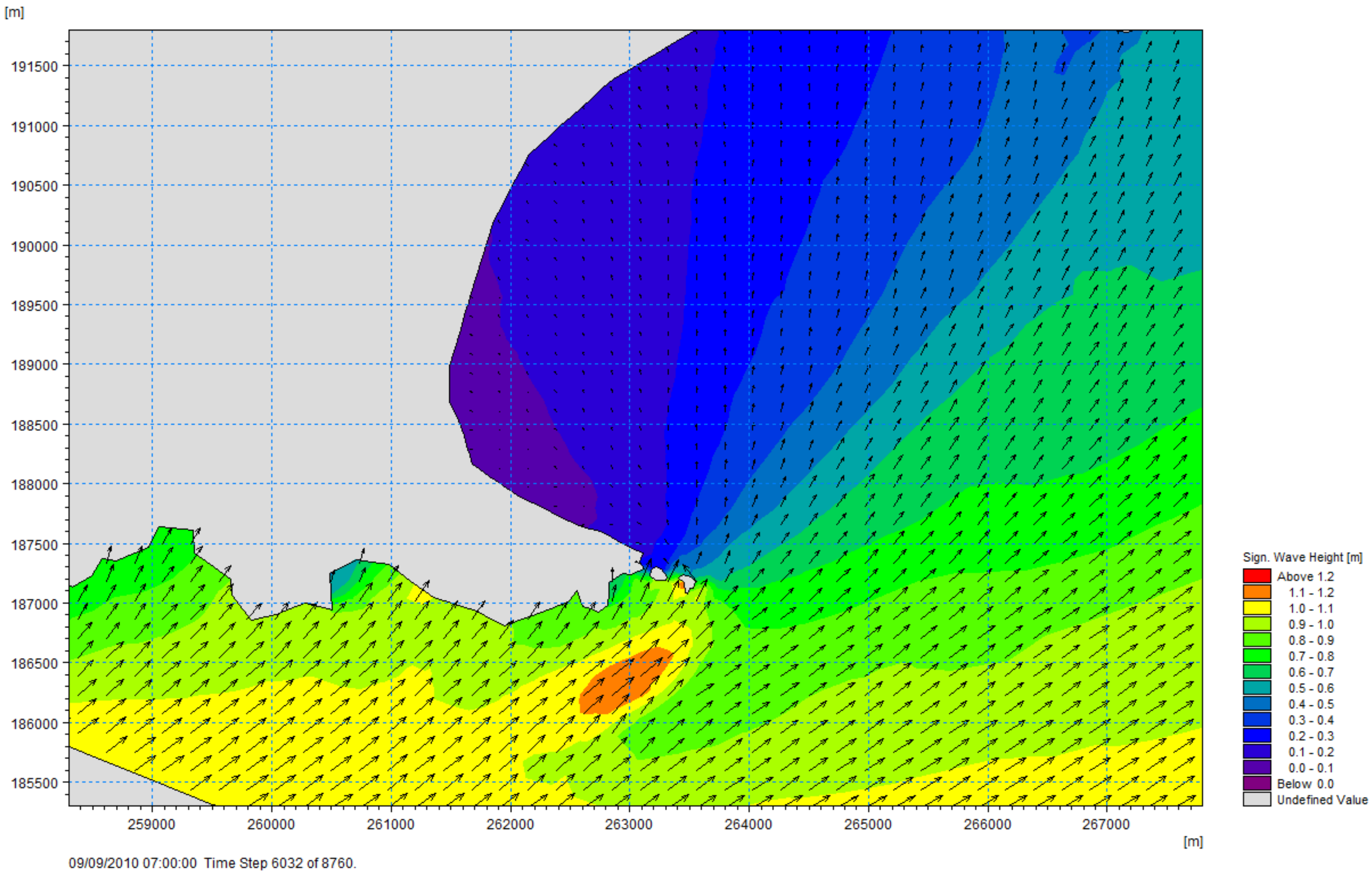


Figure 15. SEASTATES model significant wave heights (m) extracted for southwesterly wave conditions on 09/09/2010

Figure 16. **Overtopping events throughout defence sections on 03/03/2010, where wave conditions were from a southeasterly direction (Figure 17)**

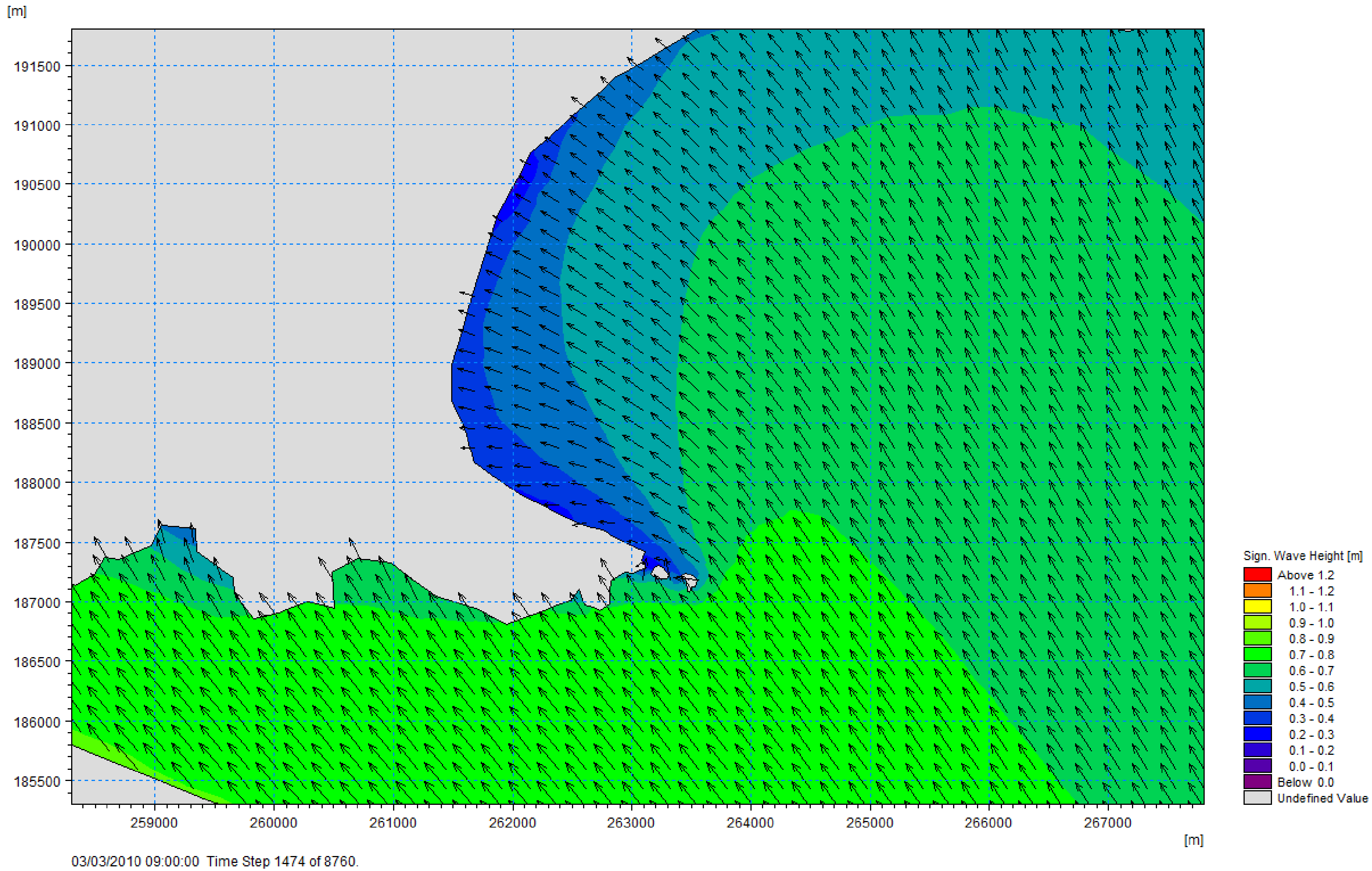
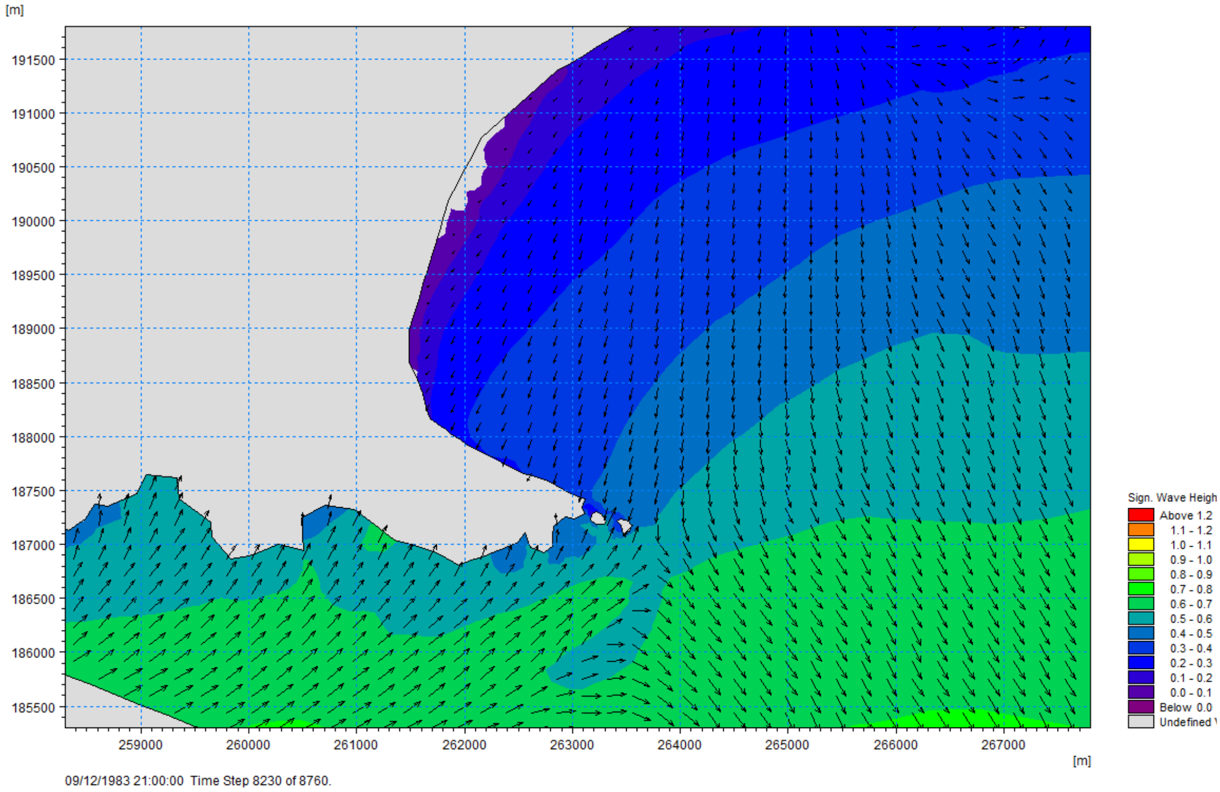


Figure 17. SEASTATES model significant wave heights (m) extracted for southeasterly wave conditions on 03/03/2010



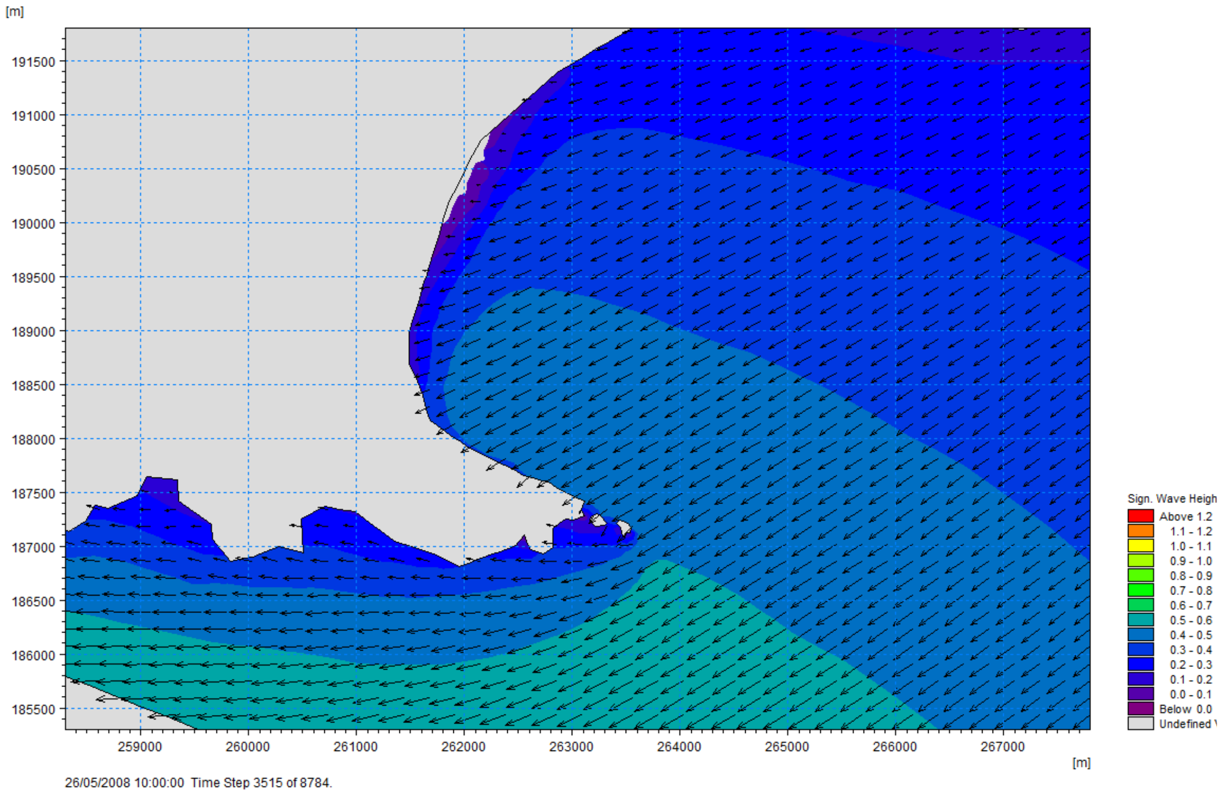


Figure 18. Maximum significant wave heights throughout the Mumbles nearshore extracted from the SEASTATES hindcast for maximum wind speed events from northerly and northeasterly directions

3.6.3 Extreme waves

The period between mid-December 2013 and mid-February 2014 according to the Met Office, was the stormiest period of weather the UK had seen for at least 20 years, with the storms during early and mid-February being particularly severe. Subsequent analysis (Haigh *et al*. 2016) has identified that this winter season contains the largest number of extreme sea level events in any season in the last 100 years. At the Scarweather buoy, on 12 February 2014 (which coincided with a neap tidal period), an Hs of 8.2 m was recorded, associated with peak wave period of nearly 12 seconds (and zero-crossing wave period Tz of 10.3 seconds), approaching from the west-southwest. Waves of a much smaller magnitude however, are likely to have reached Mumbles during this period, due to the sheltering effect of Mumbles Head and offshore dissipation of the longer period waves.

The Environment Agency assessment of extreme wave conditions for an offshore coastal location in proximity to Mumbles frontage, indicated waves heights of around 3 m and above for different return periods (Table 6 and Table 7). As represented in the observed data, the largest waves generally approached from the southwest.

Table 6. Environment Agency extreme swell waves (in metres) for Cell GL2395

Wave Approach Direction	Return Periods (years)					
	1:1	1:10	1:20	1:50	1:100	1:200
Southwest	3.48	3.90	4.00	4.11	4.18	4.24
Northwest	2.53	3.31	3.47	3.65	3.76	3.85

Table 7. Environment Agency extreme swell waves period (in seconds) for cell GL2395

Significant Wave Height (Hs, m)	Zero-crossing Wave Period (Tz, Seconds)					
	<8	8 - 10	10 - 12	12 - 14	14 - 16	>16
<1	0.5	0.26	0.13	0.08	0.03	N/A
1-2	0.37	0.32	0.17	0.08	0.05	0.01
2-3	0.27	0.41	0.24	0.06	0.01	N/A
3-4	0.24	0.48	0.26	0.02	N/A	N/A
4-5	N/A	1	N/A	N/A	N/A	N/A
Measures relate to percentage occurrence						

The results of this analysis and the model transformation of the data to the Mumbles, the extreme analysis and then sea defence overtopping analysis is presented in ABPmer (2017). This analysis provides information for locations near the toe of the sea defence, taking account of the refraction and diffraction effects around Mumbles Head, as well as the shoaling and refraction effect of the intertidal area of the Bay. These effects are not represented in the previous datasets described above.

4 Conceptual Understanding

Much of the western side of Swansea Bay experiences considerable modification of waves from the predominant south-westerly offshore climate seen at Scarweather. Limited modification of offshore generated waves occurs prior to interacting with the Mumbles Head, with the Mixon Shoal providing the main bathymetric obstruction. The Mumbles Head then provides a significant point of wave diffraction, refraction and sheltering, reducing overall wave heights and rotating the wave direction anti-clockwise around the head throughout western parts of the Bay. Further shoaling and anti-clockwise refraction then occurs throughout the intertidal foreshore containing the Mumbles defences. This dissipates the wave energy resulting in relatively low waves at the toe of the defences. Wave modelling shows waves from NE to SE sectors provide the greatest potential for larger waves to impact on the coastal defences at Mumbles. These waves will be for the most part short period (2-3 s) and are likely to impact on the defences almost perpendicular. Maximum wave heights from the 37 year SEASTATES record were of the order of 0.6 m. The southern sections of defences are likely to experience the highest waves due to lower overall bathymetry levels, narrower foreshore and steeper bed gradients in front of these defences. It should be noted that the predominant wave conditions are from the WSW and only *circa* 10-15% of waves come from the NE-SE sector, therefore the frequency of the higher wave heights at Mumbles is low.

Mumbles Head has an additional effect of reducing current speeds throughout the nearshore and intertidal, with lower flow rates seen throughout western parts of the Bay compared to offshore observations. An anti-clockwise eddy is seen throughout Swansea Bay, with a generally southeast current flow throughout western parts of the Bay.

The combination of wave and flows throughout western areas results in low rates of sediment transport in a relatively self-contained circulatory system compared to other regions within the wider Swansea Bay. The main exchange of sediment from offshore (albeit small) is likely to be from the Mixon Shoal.

Data suggests that the intertidal throughout Mumbles frontage is stable, with a very small decrease (*circa* 0.05 m over 4 years) in the upper foreshore level at the immediate toe of the sea defences throughout northern sections. At the southern defence toe there is evidence of both accretion and erosion (±0.2-0.3 m) over a period of 4 years. The small variations adhere to the predicted stability of the western side of the Bay within the SMP and previous studies.

The primary coastal defence consideration for the Mumbles frontage is therefore the need to increase the defence heights to account for extreme still water levels, particularly with the predicted risk in RSL. Whilst wave overtopping contributes to flood risk it is not the most significant factor. The consolidated foreshore is stable with risk of scour and foreshore lowering. However, there is limited ability for the foreshore to adapt to climate change and therefore the exposure of the defences to extreme water levels and wave attack will increase over time.

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6 Abbreviations/Acronyms

CCS	City and County of Swansea
CD	Chart Datum
CFBD	Coastal flood boundary dataset
DSM	Digital Surface Model
HAT	Highest Astronomical Tide
Hs	Significant wave height
HTL	Hold The Line
HW	High Water
LAT	Lowest Astronomical Tide
LiDAR	Light Detection And Ranging
mCD	Metres relative to Chart Datum
mODN	Metres relative to Ordnance Datum Newlyn
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
PAR	Project Appraisal Report
RSL	Relative Sea Level
SMP	Shoreline Management Plan
Tp	Peak wave period
Tz	Peak zero crossing period
UK	United Kingdom
UKCP09	UK Climate Projections 09
UKHO	United Kingdom Hydrographic Office

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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