Christchurch Bay & Harbour FCERM Strategy

Coastal Processes Report

Bournemouth, Christchurch and Poole (BCP) Council and New Forest District Council (NFDC)

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Quality information

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1. Introduction

1.1 Overview

AECOM has been commissioned by Bournemouth, Christchurch and Poole (BCP) Council to develop a Flood and Coastal Erosion Risk Management (FCERM) Strategy for the coastal frontage at Christchurch Bay & Harbour (herein referred to as 'the Strategy'). The Strategy extent is the coastal frontage between Hengistbury Head (immediately to the east of Hengistbury Head Long Groyne) and the landward (western) end of Hurst Spit. Within Christchurch Harbour, the Strategy extent is to Tuckton Bridge on the River Stour and Knapp Mill on the River Avon (see Figure 1-1).

Figure 1-1: Map of Strategy area

The aim of The Strategy is to provide an integrated plan for the Christchurch Bay & Harbour frontage, delivering sustainable and long-term management for coastal flood and erosion risks over the next 100 years. The Strategy will further develop the existing Poole & Christchurch Bay SMP2 policies adopted in 2011 and update the information provided in the 2012 Christchurch Bay & Harbour FCERM Study using the most up-to-date data and guidance. It is recommended that SMP policies are reviewed on a regular basis to account of new information; it should be noted that it is the intent of the SMP management group to review the SMP policies following completion of this strategy to ensure that the SMP and strategy remain aligned. A map of the existing SMP policies is shown overleaf in Figure 1-2 (note that the map shows the policies for the entire SMP frontage (Poole and Christchurch Bays).

The Strategy will be developed collaboratively by AECOM, and the Project Board consisting of officers of BCP Council, New Forest District Council (NFDC) and the Environment Agency (EA).

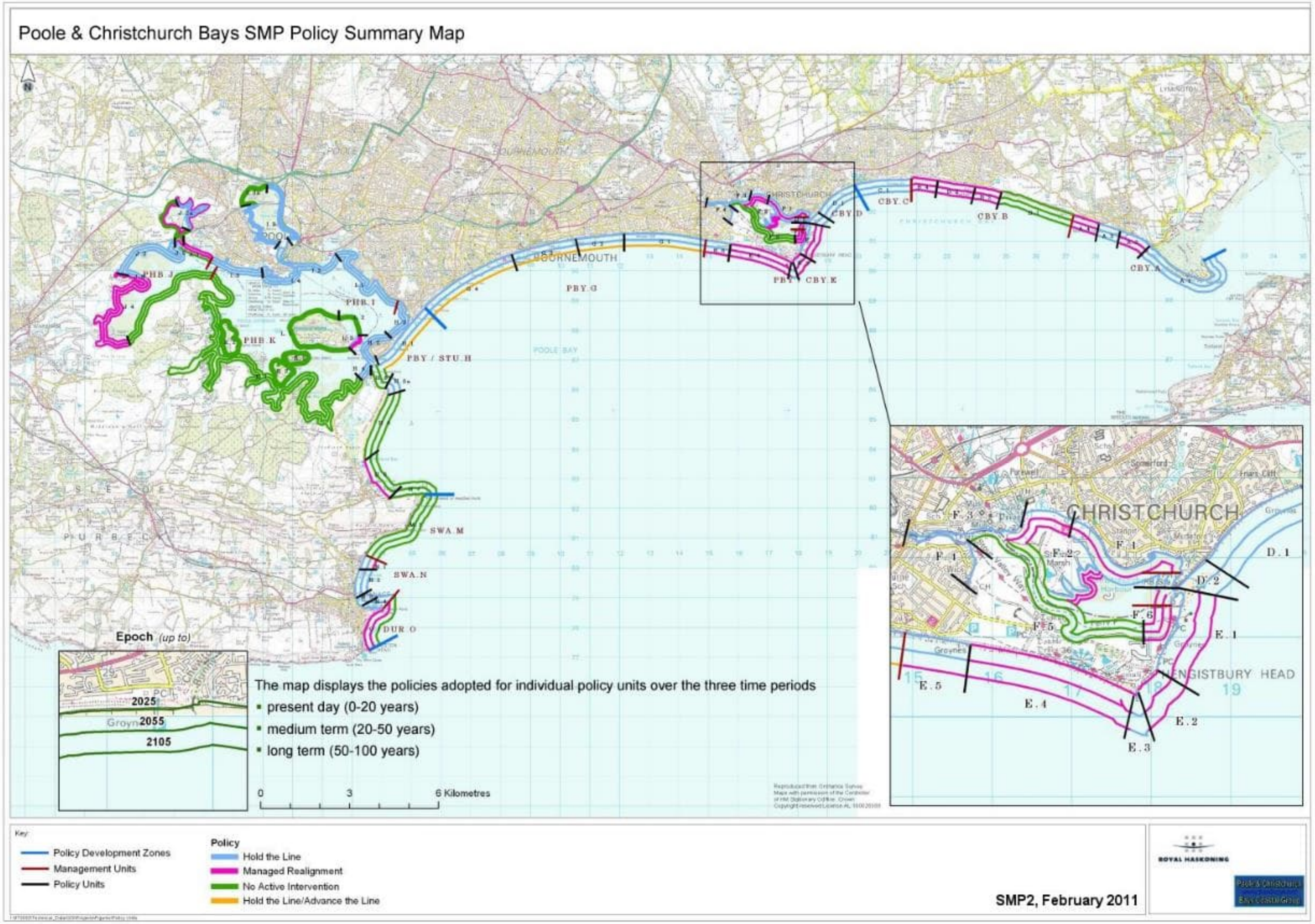


Figure 1-2: SMP policy summary map (obtained directly from the SMP). Christchurch Harbour and Bay are located to the east of Poole Bay.

1.2 This Report

This report provides details of the coastal processes within the Strategy area. A vast amount of academic and industry research into the coastal processes within Christchurch Bay has previously been undertaken and this report is not intended to be an exhaustive summary of this work. Instead, this report focusses on summarising the key findings from the research that are of most relevance to the Strategy development. The report structure is as follows:

1) Introduction
2) Hydrodynamics – a summary of the tide conditions, extreme water levels, sea level rise, wave conditions, river levels and tri-probability research
3) Geology and sediment dynamics – a summary of the regional geology, geomorphology, sediment dynamics and intertidal habitat within the area
4) Flood and erosion risk – a summary of the tidal flood risk and coastal erosion risk in the study area
5) Summary and recommendations.

The findings presented in this report will be used throughout the Strategy development, with particular reference in the following tasks:

- In the development of the sediment transport modelling using the MIKE modelling software
- To inform the baseline scenarios for the option and economic appraisal tasks
- In the development and the appraisal of flood and erosion risk management options for the Strategy, during the long listing phase, short listing phase and in the selection of the preferred strategic options
- When communicating with stakeholders throughout the Strategy development.

2. Hydrodynamics

2.1 Tides

2.1.1 Tide Conditions

The tidal regime within Christchurch Bay is complex due mainly to the shape of the English Channel coastline, the location of the Bay and shallow water effects. To a lesser extent the tides are also affected by the proximity of the Isle of Wight and propagation of the tide into the constricted entrance to the Western Solent. The local tidal range within Christchurch Bay is relatively small (i.e. mean spring tidal range of 1.5m at Bournemouth), compared to adjacent locations along the South Coast, due to the small amplitude of the main semi-diurnal tidal harmonics resulting from the proximity to a so-called 'degenerate amphidromic point' located to the north-west of Bournemouth. An amphidromic point is a location where the tidal range is zero which is referred to as 'degenerate' when it is over land.

Local conditions are further complicated by the interaction of flows within Poole Bay, in/out of Christchurch Harbour and tides propagating through the English Channel. This section summarises the existing published extreme water levels and tidal current information and sea level rise (SLR) projections due to climate change over the next 100-year period.

The nearest location of tidal data from the UK National Tide Gauge Network is at Bournemouth with the elevation of the standard tidal planes provided in Table 2-1 below (source: National Tide and Sea Level Facility which are based on predicted tides for the period 2008 to 2026.

Table 2-1 Standard tidal planes (Bournemouth)

Tide	Level	
	mCD	mOD
Highest Astronomical Tide (HAT)	2.64	1.24
Mean High Water Springs (MHWS)	2.07	0.67
Mean High Water Neaps (MHWN)	1.69	0.29
Mean Sea Level (MSL)	1.60	0.20
Mean Low Water Neaps (MLWN)	1.59	0.19
Mean Low Water Springs (MLWS)	1.03	-0.37
Lowest Astronomical Tide (LAT)	0.03	-1.37

There are also operational tide gauges within Christchurch Harbour and at Lymington. However, the Bournemouth tide gauge is considered to provide the best representation of tidal conditions for Christchurch Bay given that the measured water levels within the Harbour are at times influenced by fluvial conditions. The Lymington tide gauge is within the Western Solent where the tides are amplified relative to conditions on the open coast.

The shape of the tide curve in Christchurch Bay is also distorted by shallow water effects resulting in an extended double high water that is a common feature within the Solent region. In addition to being associated with weak tidal currents, the limited tidal variation results in the erosive influence of waves and currents being focussed within a narrow width of intertidal rather than being distributed across a wider area within the coastal zone, as would be the case with a larger tidal range. The small tidal range may also impose constraints in terms of construction activities due to the reduced variation in water depths limiting vessel drafts at high water and access to structures at low water

2.1.2 Tidal Currents

Current speeds within Christchurch Bay are typically weak with local increases due to shallow bathymetric features such as the Christchurch Ledge to the west and Shingles Bank to the east. As the tide floods from the west, the current speed is locally increased due to the sudden reduction in water depth over both of these features, as shown in Figure 2-1 which is based on output from a hydrodynamic model previously developed by HR Wallingford (2017). To the east of the Strategy area, as defined in Figure 2-1, current velocities are shown to increase significantly as the flow is funnelled through the Hurst narrows before entering the Western Solent.

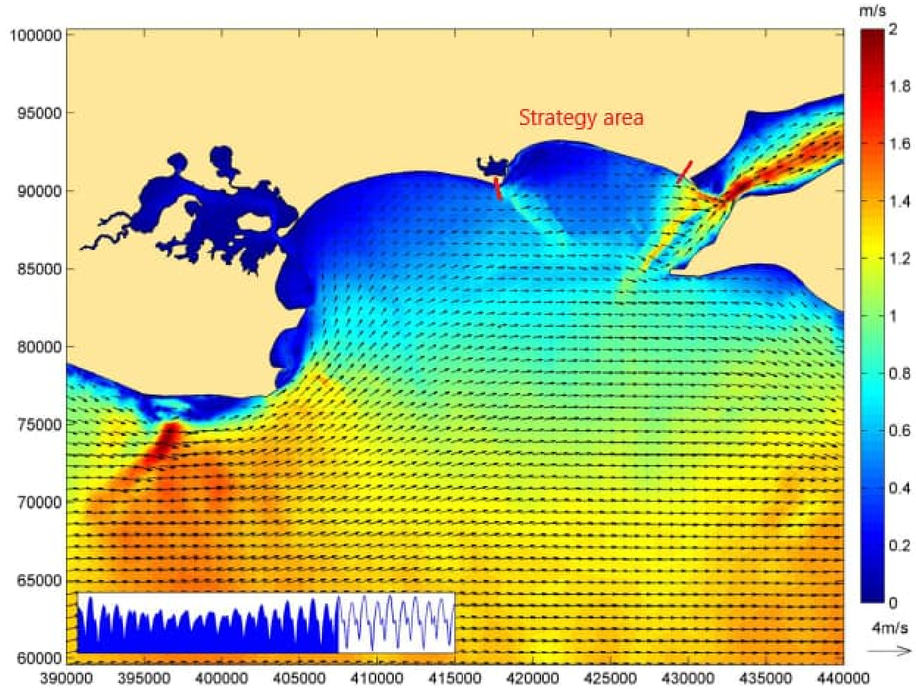


Figure 2-1 Current patterns during the flood tide to the west of the Isle of Wight (obtained and edited from HR Wallingford, 2017)

A similar pattern is found during the ebb tide with particularly high currents experienced at the Hurst Narrows between Hurst Spit and the Isle of Wight coastline, as shown in Figure 2-2. However, due to the influence of the Shingles Bank directing the outflow from the West Solent to the south-west, currents within Christchurch Bay are shown to be weaker during this phase of the tide.

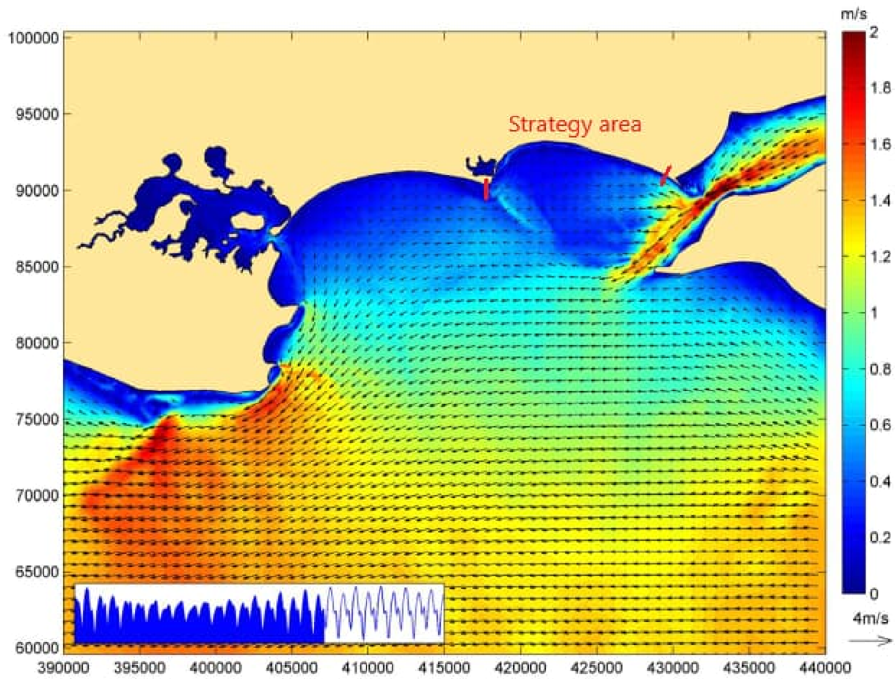


Figure 2-2 Current patterns during the ebb tide to the west of the Isle of Wight (obtained and edited from HR Wallingford, 2017)

The strong south-westerly currents have an important influence on sediment transport processes, as discussed in more detail in Section 3.3.

Tidal conditions within Christchurch Harbour are controlled by tidal flows through the narrow entrance channel, known as The Run, which interact with fluvial flows from the rivers Stour, Avon and other minor tributaries. The freshwater flow from the rivers provides a significant ebb tide dominance (JBA, 2017) which, during high flow conditions, counteracts the flood tide resulting in a constant ebb flow within The Run. Sedimentary processes within the Harbour are therefore found to be dominated by fluvial processes.

2.2 Extreme Water Levels

2.2.1 Storm Surge

Storm surges result from the passage of low pressure systems passing through the English Channel which elevate the water surface above predicted astronomical tide levels. Storm surges often coincide with increased levels of wave activity leading to an increased risk of coastal erosion and/or overtopping of sea defences. It is therefore important to have an appreciation of how extreme water levels vary across the study area, as covered in the following section.

2.2.2 EA CFB Dataset

The EA Coastal Flood Boundary (CFB) Dataset update was published in 2018 (EA, 2018). This dataset is an update from the 2011 dataset and now includes extreme water levels for the harbours, as well as for the open coast. Table 2-2 contains this data for relevant points along the study area frontage and Figure 2-3 shows the location of each point which are spaced along the coastline at approximately 2 km intervals. The base year for this data is 2017 and return periods range from 100% Annual Exceedance Probability (1:1 year return period equivalent) to 0.01% AEP (1:10,000 year return period equivalent). The dataset provides estimated values along with the 2.5 and 97.5 percentiles.

Table 2-2 Extreme sea levels for selected points from the CFB dataset (EA, 2018)

Location	Extreme Sea Levels (mOD) for given Return Period (values for 2017)				
	1 in 1 (100% AEP)	1 in 10 (10% AEP)	1 in 50 (2% AEP)	1 in 100 (1% AEP)	1 in 200 (0.5% AEP)
4674	1.43	1.65	1.81	1.88	1.94
4672	1.43	1.66	1.82	1.89	1.96
4670	1.44	1.67	1.83	1.90	1.97
4668	1.44	1.68	1.84	1.91	1.98
4666	1.44	1.68	1.84	1.91	1.99
4664	1.45	1.69	1.85	1.92	1.99
4662	1.45	1.69	1.86	1.93	2.00
4660	1.45	1.70	1.87	1.94	2.01
4658	1.46	1.71	1.88	1.95	2.02

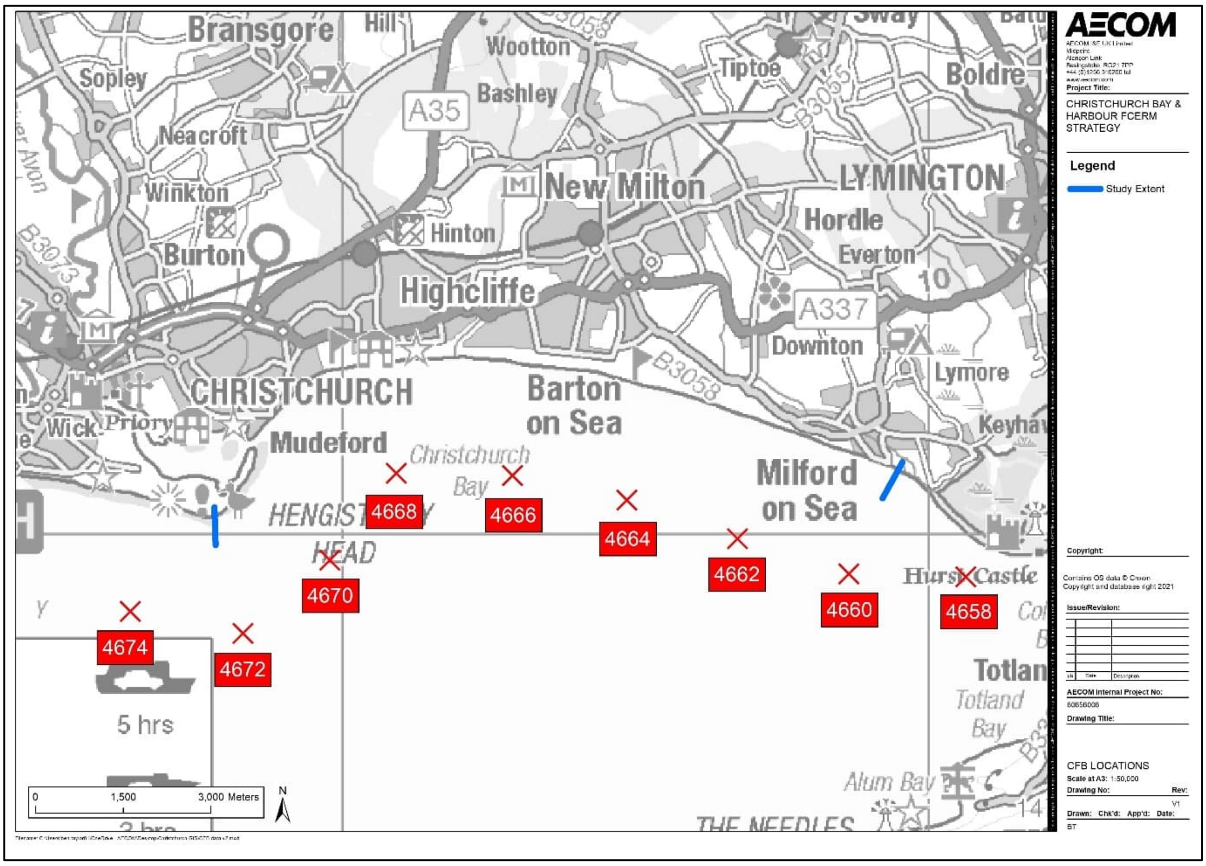


Figure 2-3 Locations of the data extracted from the CFB database (EA, 2019).

2.2.3 Sea Level Rise

The UK Climate Projections 2018 (Met Office, UKCP18) dataset provides a range of sea level rise (SLR) estimates based on different emission scenarios. The UKCP18 information comes under four Representative Concentration Pathways (RCP), which capture the assumptions in each scenario and the differences in the predicted increase in temperature. These are RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

The EA publish advice upon how FCERM projects should use this guidance (Environment Agency, 2020, available at gov.uk website https://www.gov.uk/guidance/flood-and-coastal-risk-projects-schemes-and-strategies-climate-change-allowances). The latest available advice, released in July 2021, is to use the RCP8.5 70th percentile for design purposes and use RCP8.5 95th percentile as a sensitivity test to consider more serious events and adaptability. The RCP8.5 pathway represents, "*a world in which global greenhouse gas emissions continue to rise. It is a potential future where the nations of the world choose not to switch to a low-carbon future*", under which we could expect to experience an increase in global mean surface temperature of 4.3°C (Met Office, 2018).

The SLR values for the RCP8.5 70th and 95th percentiles are presented in Table 2-3. Table 2-4 shows the projected extreme water levels in the future, considering the RCP9.5 70th percentile sea level rise projection, for the CFB chainage locations 4674 and 4658 (chainage positions located at either end of the Strategy frontage).

Table 2-3 Expected values for sea level rise over the next 100 years according to UKCP18 for RCP8.5

Sea Level Rise Values in metres		
Year	**70th %ile**	**95th %ile**
2021	0	0
2041	0.13	0.16
2071	0.41	0.53
2121	1.03	1.39

Table 2-4 Extreme sea levels at CFB chainage locations 4674 and 4658 considering the UKCP18 RCP8.5 70th percentile sea level rise projections

Location	Year	Extreme Sea Levels (mOD) for given Return Period				
		1 in 1 (100% AEP)	1 in 10 (10% AEP)	1 in 50 (2% AEP)	1 in 100 (1% AEP)	1 in 200 (0.5% AEP)
4674	2017	1.43	1.65	1.81	1.88	1.94
	2021	1.45	1.67	1.83	1.90	1.96
	2041	1.58	1.80	1.96	2.03	2.09
	2071	1.87	2.09	2.25	2.32	2.38
	2121	2.49	2.71	2.87	2.94	3.00
4658	2017	1.46	1.71	1.88	1.95	2.02
	2021	1.48	1.73	1.90	1.97	2.04
	2041	1.61	1.86	2.03	2.10	2.17
	2071	1.90	2.15	2.32	2.39	2.46
	2121	2.52	2.77	2.94	3.01	3.08

2.3 Wave Conditions

The most powerful waves are predominantly waves are from the south to south-west sector and are associated with the longest fetch lengths and swell waves from the Atlantic. As waves approach the shore, they are modified inshore by shoaling and refraction and as summarised on the SCOPAC Christchurch Bay website (available at https://www.scopac.org.uk/scopac_sedimentdb/chrst/chrst.htm); various studies (Henderson, 1979 and HR Wallingford, 1999) indicate that there are high concentrations of wave energy on Hengistbury Head and at Barton-on-Sea.

By comparison, the western sector of Christchurch Bay is less affected by south-westerly swell waves, but more exposed to waves approaching from the south-east. Overall, wave energy at the coastline increases from west to east due to the increased exposure to the predominant, south-westerly waves.

The complex offshore bathymetry of Christchurch Bay (particularly the shoals of Christchurch Ledge, Dolphin Bank and Shingles Bank) exerts a major refraction and focusing effect on incoming waves so that the resultant nearshore wave climate is spatially complex and difficult to model. Wave energy divergence occurs between Mudeford Sandbank and Highcliffe. See Figure 3-1 later on in the report for a map of the key bathymetric features at the site.

Although less frequent, waves from the east to south-east sector can also mobilise large quantities of sediment in short periods resulting in sediment being transported offshore or temporarily from east to west (in the opposite direction to the long term longshore drift direction).

Live wave data is readily available for the open coast near Milford-on-Sea (Directional Waverider buoy located 427261E, 90395N) as part of the South-East Regional Coastal Monitoring Programme (SERCMP), which furthers the understanding of beach response under different wave climates and directly informs beach management activities (Figure 2-4). The Regional Coastal Monitoring Programme also gathers wave data from the Boscombe Directional wave rider buoy located in Poole Bay (411410E, 90213N) to the west of the Strategy study area. Data from Boscombe wave rider buoy has not been analysed in this report but is available from the Channel Coastal Observatory website if required.

There is limited penetration of waves through The Run into Christchurch Harbour due to the narrow width and orientation of this channel relative to the predominant wave direction. As a result wave action within the harbour results from local, wind-generated waves which are limited by the available fetch lengths (JBA, 2017).

2.3.1 Milford Wave Buoy Analysis

The Milford wave buoy, owned by New Forest District Council, was first deployed in May 1996. It was replaced with a directional wave rider buoy in November 2005. From May 1996 to October 1996 the buoy recorded 3-hourly data, and until January 2005, hourly data. From that point forward, the buoy has collected half-hourly data with a 98% data quality recovery rate. The Channel Coastal Observatory undertake an annual analysis of the wave data collected by the buoy and summarise this in an annual wave site report (available at https://coastalmonitoring.org/reports/#southeast). Key information from the 2020 version of the report (most recent version) is presented in Figure 2-4 below.

Location	
OS	427261 E 90395 N
WGS84	*Latitude:* 50° 42.75' N *Longitude:* 01° 36.91' W
Instrument type	
Datawell Directional Waverider Mk III	
Water depth	~10m CD

Buoy in situ off Milford on Sea. Photo courtesy of Fugro GB Marine Limited

Location of buoy (Google mapping, image ©2016 TerraMetrics)

Figure 2-4 Details of the Milford wave buoy (Channel Coastal Observatory, 2020)

As the buoy has been deployed for a period greater than 5 years, return periods for significant wave heights have been calculated by the Channel Coastal Observatory. The return periods have been calculated for periods of up to 10 times the record length using a peaks over threshold method and generalised pareto distribution (GPD). Based on this analysis, the 1:1 year significant wave height is estimated to be 3.39m whilst the 1:200 year significant wave height is estimated to be 4.81m.

Table 2-5 Significant wave height return periods for Milford wave buoy (Channel Coastal Observatory, 2020)

Observation period	May 1996 to December 2020	
Return period	Significant wave height (m)	Comments
0.25	2.79	No depth limitations
1	3.39	
2	3.64	
5	3.94	
10	4.14	
20	4.33	Depth-limited at MLWS
50	4.54	
100	4.68	
200	4.81	

Figure 2-5 below shows the significant wave height recorded during storm events identified since 1996. As can be seen, the Valentines Storm which occurred on 14th February 2014 recorded the largest significant wave height of approximately 4.5m since monitoring began which is estimated to represent a 1 in 50 year storm event. This is also shown in Table 2-6 which shows the annual maximum significant wave height recorded since 1996.

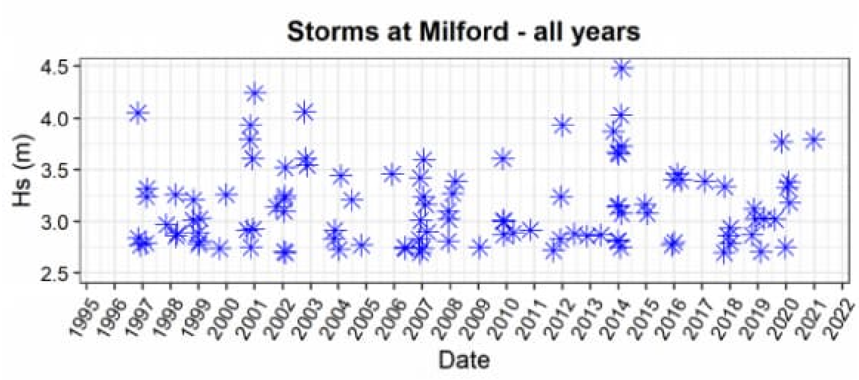


Figure 2-5 Significant wave heights measured at Milford wave buoy during storms (obtained from Channel Coastal Observatory, 2020)

Figure 2-6 shows the wave rose for the significant wave height data collecting since 1996. As can be seen, the dominant wave direction is from the south-west sector.

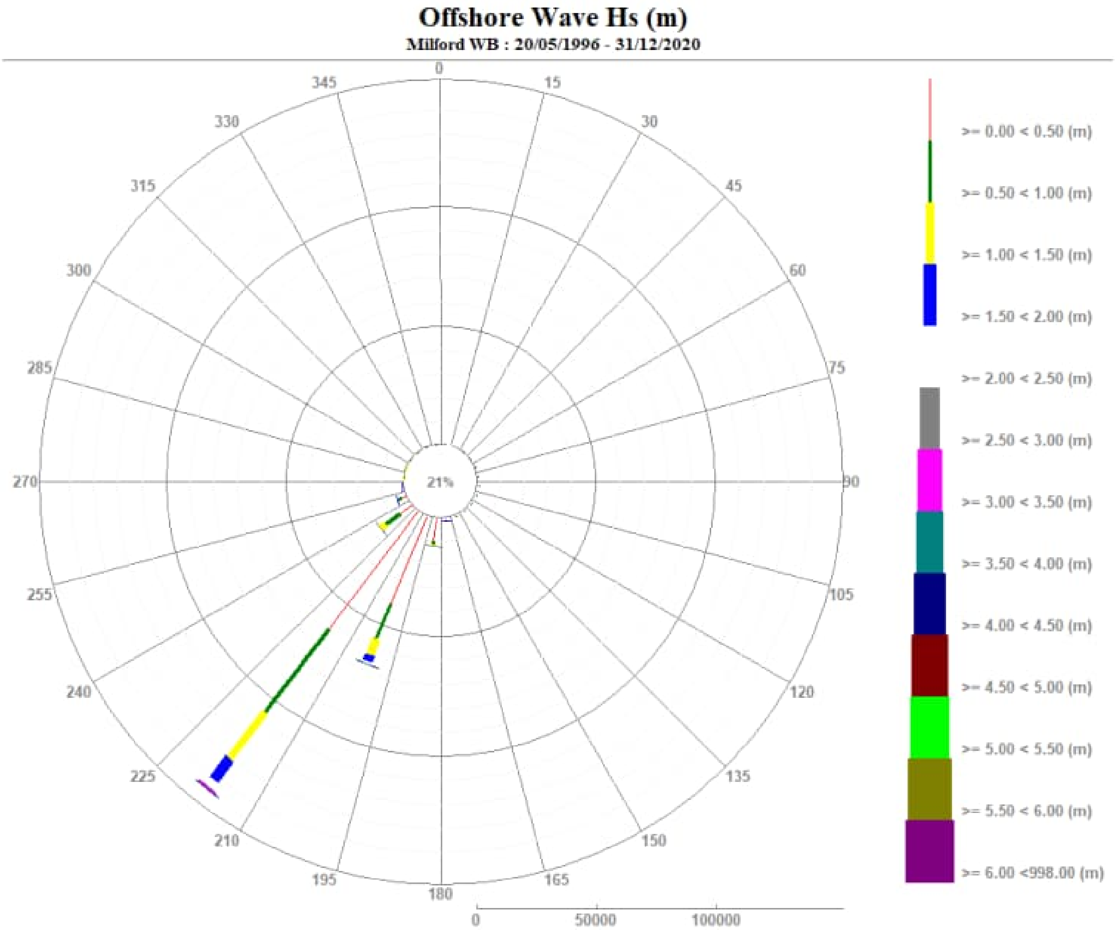


Figure 2-6: Wave rose for Milford, obtained from the Channel Coastal Observatory (2020)

Table 2-6 Annual statistics – annual maximum significant wave height measured at the Milford buoy (unless otherwise stated, source of data is from Channel Coastal Observatory, 2019)

Annual maximum significant wave height (A_{max})			
Date	A_{max} (m)	**Date**	A_{max} (m)
28-Oct-1996	4.05	14-Nov-2009	4.08
24-Feb-1997	3.32	31-Mar-2010	2.96
27-Oct-1998	3.21	13-Dec-2011	3.24
24-Dec-1999	3.23	03-Jan-2012	3.93
31-Dec-2000	4.09	28-Oct-2013	3.93
01-Jan-2001	4.07	14-Feb-2014	4.50
15-Oct-2002	4.06	31-Dec-2015	3.43
14-Nov-2003	2.92	08-Feb-2016	3.48
31-Jan-2004	3.44	03-Feb-2017	3.41
02-Dec-2005	3.53	09-Nov-2018	3.14
03-Dec-2006	3.51	02-Nov-2019	3.77 (source: correspondence with BCP team)
18-Jan-2007	3.64	27-Dec-2020	3.79 (source: correspondence with BCP team)
10-March-2008	3.42		

Analysis of the Milford wave buoy data shows the significance of the 2000/01 and 2013/14 winters which had a high frequency of storms with large wave heights. The 14th February 2014 storm is of particular note as it damaged a large number of beach huts in the Strategy area. At Avon beach, beach hits were destroyed and emergency work was needed. At Hordle, approximately 80 timber beach huts washed away and at Milford-on-Sea many of the 119 blockwork beach huts were destroyed, with only 40 remaining intact (see Figure 2-7). The huts at Milford have since been replaced with pre-cast concrete hut units.

Figure 2-7: Photograph of damaged beach hut at Milford-on-Sea following February 2014 storm (obtained from NFDC)

During the Valentines Storm a significant amount of wave overtopping also occurred, particularly at the eastern boundary of the Strategy frontage around Hurst Road and Hurst Road East car park. Here, the Marine Café had to be evacuated with the property being flooded to approximately 1m deep. Windows on both ground floor and first flood being smashed by shingle thrown up by wave overtopping. Approximately 2,000 tonnes of shingle needed to be removed from the adjacent car park after being thrown over the defences by wave overtopping. See Figure 2-8 for a photograph of the damage caused by wave overtopping in this location.

Figure 2-8: Photograph of damage caused by wave overtopping to the east of Hurst Road East car park in February 2014 (obtained from NFDC)

The SCOPAC Storm Analysis Project (2020) identifies of 2013/14, 2015/16 and 2016/17 as severe in terms of the frequency and magnitude of storms on the South Coast region. There is the suggestion that the frequency of storms may be increasing although longer observed data sets are needed to establish this. For example, it is understood the December 1989 storms were particularly severe but there is a lack of data to compare with recent events. The SCOPAC Storm Analysis study shows as well as an exceptional number of extreme sea level events, that a peak in wave power (derived using Hs and Tp) was found in 2013/14 which is coincident with the highest winter of wave bimodality within the data set (a wave characteristic which still needs to be better understood but where the coast is impacted simultaneously by swell and wind waves as assessed by spectral data, and which can be a “worst case” event for causing deformation and high overtopping of mixed and gravel beaches). Whilst the bimodality of sea conditions at Milford is generally less pronounced than at other sites along the south coast, it does appear to play an important role in determining the more extreme conditions affecting flood risk and coastal erosion. For example, mixed and shingle beaches in the Bay (in particular Hurst Spit) appear to be sensitive to beach draw down and erosion caused by bimodal seas during storms and even during moderate conditions.

There were several notable storms in early and late 2020, notable Storms “Ciara” and “Dennis” (9th to 16th February) and “Aiden” and “Bella” (late October/early November and then 27th December).

2.3.2 Climate Change Allowances

The Environment Agency (EA) Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities (2018) gives percentage change allowances for extreme wave heights for two different epochs. Wave heights may change due to changes in water depths that result from Sea Level Rise (SLR) and the frequency, duration and severity of storms and winds is also expected to change (EA, 2018). Table 2-7 shows the allowances that should be used for waves over the next 100 years due to climate change. The 2018 guidance does state that there are large uncertainties in these values. Changes in wave period and direction are small and harder to interpret.

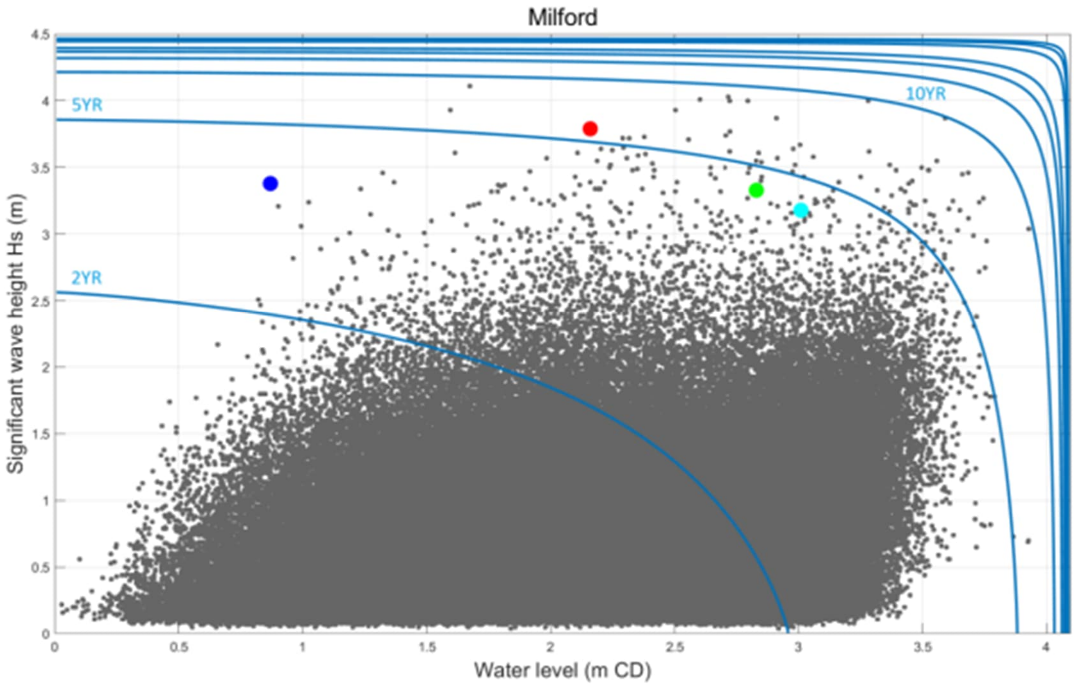
Table 2-7 Recommended national precautionary sensitivity ranges for offshore wind speed and wave height.

Applies around all the English coast	1990 to 2055	2056 to 2115
Offshore wind speed	+5%	+10%
Extreme wave height	+5%	+10%

2.4 Joint / Tri Probability

2.4.1 Milford Wave Buoy Joint Probability

In the annual report on the Milford wave buoy the Channel Coastal Observatory have undertaken an analysis of joint return periods for tidal water levels and significant wave height based on 0.5 hourly records and calculated using a copula function. Figure 2-9 below is extracted from the Channel Coastal Observatory report and the cloud of grey points shows the measured joint wave heights and water levels at Milford and Lymington, respectively, plotted against each other based on all available data (1996 - 2020). The blue contour lines provide a fit to the combinations of wave height and water level with an equal joint probability of occurrence, as annotated for return periods of 2, 5 and 10 years. The coloured circles show the four largest storm events (classified by wave height) recorded in 2020 overlaid on the plot using the corresponding water levels for each case. By relating their position to the joint probability contours, it is then possible to estimate the corresponding joint probability of the conditions for these storm events.



Date/Time	Symbol	H_s (m)	Water level elevation		Joint Return Period
			OD	CD	
27-Dec-2020 04:30:00	red circle	3.79	0.18	2.16	1 in 5 years
09-Feb-2020 16:30:00	blue circle	3.38	-1.12	0.87	1 in 2 years
14-Jan-2020 23:30:00	green circle	3.33	0.85	2.83	1 in 2 years
16-Feb-2020 04:30:00	cyan circle	3.18	1.03	3.01	1 in 2 years

Figure 2-9: Measured joint wave heights and water levels measured at Milford and Lymington respectively, obtained from the Channel Coastal Observatory (2020).

2.4.2 Christchurch Harbour Tri-Probability

Both the River Avon and River Stour flow into Christchurch Harbour. In 2015 a tri-probability study was undertaken by JBA (2015) to better understand the relation between extreme flood events in the River Avon, the River Stour and extreme water levels for the open sea. A key objective of this study was to provide information on the probability of these separate sources of flood risk to inform future flood studies in terms of defining test conditions to be considered in hydraulic flood models. It is therefore necessary to consider the combined effect of river flows and water levels on flood risk.

The results of the study provide a useful insight into the combined probability of different sources of flood risk which can be used to define conditions representing extreme flood events with a defined return period. However, return periods of less than 50 years were not considered and therefore the study findings for lower return periods are not conclusive.

The duration of the event window considered was found to be important; with a 3-day event window resulting in the most reliable assessment. Extreme flows in the rivers showed a 'modest' dependence with a 10% likelihood of a 1 in 100 year flow from both rivers occurring at the same time. Extreme flows for the River Avon and extreme water levels showed high dependence for a longer event window. A lower level of dependence was found for extreme flows in the River Stour, showing that they do behave differently.

It was concluded that there is limited dependence between extreme river flows and water levels and noted that the limited 15-year record of coincident measured data means that the prediction of extreme conditions is subject to high uncertainty. A probabilistic approach involving multiple simulations would therefore be required for a more realistic assessment of flood risk.

For the purposes of a strategic level study, the 2015 study provides information that can be used to define realistic extreme flood events for the combined sources. However, a further update to the study may be required to support a more detailed assessment of local flood risk in this area.

3. Geology and Sediment Dynamics

3.1 Regional Geological Setting

The present-day coastline has largely been shaped by glaciation and the associated rise and fall of sea levels. The last period of glaciation occurred approximately 9,000 years ago and was most influential towards a rise in sea levels resulting in a breach of the chalk ridge which ran westwards from The Needles on the Isle of Wight. More than 220 km^2 of land was subsequently eroded resulting in the current plan shape of both Poole and Christchurch Bays.

In terms of the underlying geology, soft Tertiary sands and clays are found across the coastal zone of the Bay. Hurst Spit at the eastern end is comprised of shingle deposits overlying a clay layer. From Milford-on-Sea to Hengistbury Head, the cliffs of Tertiary deposits reach heights of up to 30m. Hengistbury Head is particularly important because it offers increased resistance to erosion due to the presence of ironstone nodules within the cliff material (Defra, 2002).

Christchurch Ledge is a submerged rock platform which causes local increases in current speeds (see section 2.1.2). The ledge also presents a risk to navigation and influences the sediment dynamics of the area.

3.2 Geomorphology

Natural geomorphological coastal features within Christchurch Bay include Hurst Spit, Mudeford Sandbank and Hengistbury Head, each of which provides a controlling influence on the shape of the coastline. The Mudeford Sandbank feature also separates Christchurch Harbour from the open coast.

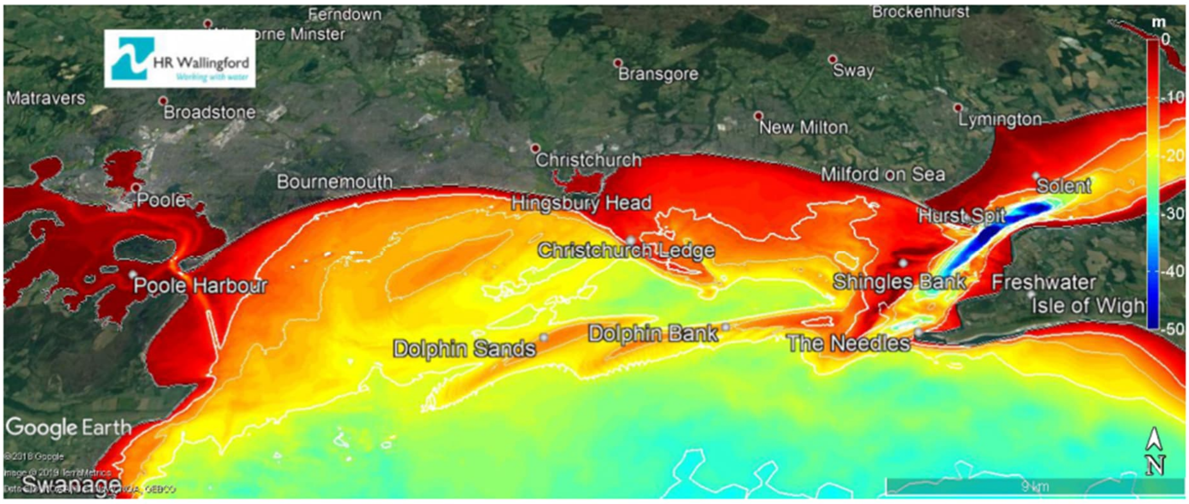


Figure 3-1 Key features within the Christchurch Bay study area (obtained from HR Wallingford (2019))

Important bathymetric features include unnamed inshore banks within the 10m depth contour. The narrow entrance to Christchurch Harbour, known as the run, is an important feature where distinct local tidal and wave conditions have generated a 'delta' of sands and gravels located either side of the harbour entrance. Attributed to transport and deposition on the flood tide. Other key features are the Christchurch Ledge to the west and Shingles Bank to the east which, as can be seen from the reduction in the current speed as the tide propagates into the Bay (Figure 3-1), have a controlling influence on local currents. Other significant features further offshore include Dolphin Sands and Dolphin Bank located just inside the 20m contour which also influence currents within the Bay and potentially waves during more extreme, south-westerly storm conditions.

Hengistbury Head at the western limit of the study area is known to provide a stabilising influence on the plan shape of the coastline within Christchurch Bay by acting as an 'anchor point'. It provides an important sheltering effect to Christchurch Harbour protecting it from waves propagating from the south-west. Although the cliff material is erodible, it is more resistant to erosion than other sections of cliff and this natural effect is enhanced by the Hengistbury Head Long Groyne. The Long Groyne was constructed in 1937-39 and the coastline has since adapted to being in its current position / alignment. BCP currently has plans to replace/upgrade the long groyne within its existing footprint to minimise the risk of the uncertain impacts on the coastline.

Hurst Spit at the eastern limit of the study area is an internationally known multi-recurved barrier approximately 2km in length. Prior to its substantial modification during the 1980s, it had a crest elevation of between 2 and 4m above mean sea level. This has been raised to 7m, tapering to 5m at Hurst point as a result of comprehensive stabilisation completed in 1996. The spit influences the shape of the coastline in the Bay and the overall planform of the spit appears to have been stable since at least the mid eighteenth century. Nonetheless, the spit is a dynamic landform that has adjusted to the impacts of historically infrequent major storms by steadily receding landwards (SCOPAC, 2012).

3.3 Cliff Erosion Mechanisms

Much of Christchurch Bay is backed by eroding cliffs of up to 30m in height. The cliff-forming strata comprise Tertiary sands and clays (i.e. soft rock cliffs) which dip 0.5 to 1.0 degree towards the east-north-east and strike nearly parallel to the coastline, so that progressively younger beds outcrop from Hengistbury Head (Hengistbury Formation) to Hordle and Milford (Headon Formation). These substrate materials are overlain by a mantle of Pleistocene Plateau Gravels and thick Holocene brickearth deposits (SCOPAC, 2012). The dip of the beds and their orientation and underlying geology has a significant bearing on the erosion and stability of the cliff.

The eroded material from the cliffs is reworked as beach material, with the coarser plateau gravel deposits being a particularly important supply of material to the mixed beaches. In the locations where coastal defences are in place, the defences have reduced the natural supply of material to the beaches.

Soft rock cliff recession is controlled by a range of factors, but it is the continued exposure of the cliff toe to marine erosion that is often the key driver behind the recession process. The degree to which a cliff toe is exposed to erosion is determined by a number of factors, such as the erodibility of the cliff toe material, the dip/orientation of the geological beds within the cliff (which impacts the cliff stability), the local hydrodynamic conditions and longshore distribution of wave energy, and the level of protection offered to the cliff toe by beach material or coastal defences.

In Christchurch Bay, large parts of the frontage have had coastal engineering works undertaken to improve the stability of the cliffs (however, there are also sections of the coastline that remain undefended, particularly in the NFDC part of the frontage where large lengths have no defences). The cliffs at Barton-on-Sea are stabilised by a scheme constructed in the 1960’s consisting of a sheet pile cut-off wall and counterfort drains. At Highcliffe, the cliffs are stabilised by a counterforte drains and vegetation planting, with the addition of rock armour and rock groynes to protect the toe. The Highcliffe scheme was constructed in stages (geographically) between 1970-73 and from 1985-91.

The engineering works play an important role in the cliff erosion and also determine which erosion processes have the most influence along different parts of the frontage. For example, at Hordle cliffs, which are currently undefended, the rate of erosion is greatly influenced by beach levels and exposure of the cliff toe. Whereas at Barton-on-Sea, where extensive coastal protection works are in place, the cliff recession is due to cliff instability linked to groundwater processes and rainfall. Here, the cliff stabilisation works, constructed in the 1960s, have generally been successful in reducing slope failures. However, to the west of Barton-on-Sea the drainage system has failed allowing ground movement and cliff recession to occur again.

Anecdotal evidence indicates that the cliffs in Christchurch Bay typically erode in a cyclical pattern, with sections of cliff failing before a period of stabilisation. For the exposed sections of cliff, for example at Hordle, the timing of cliff failures typically coincides with stormy periods. For the defended sections of cliff, for example at Barton-on-Sea the cliff failures can coincide with recent periods of high rainfall. At Barton-on-Sea, typically movement in the cliffs is observed if rainfall exceeds 80mm per month for two successive months (as per communications with local engineers). Cliff stabilisation works are in place at this location, designed to reduce the risk of slope failures.

3.4 Sediment Dynamics

3.4.1 Open Coast Sediment Dynamics

The report by HR Wallingford (2019) includes a description of the sediment transport model that was configured using sediment grain size data compiled separately (Wilson, 2018) and is shown in Figure 3-2. This shows how the sediment grain size is much coarser in Christchurch Bay compared to Poole Bay as a result of the increase exposure to waves from the south-west and the strong currents passing through the narrows between Hurst Spit and the Isle of Wight.

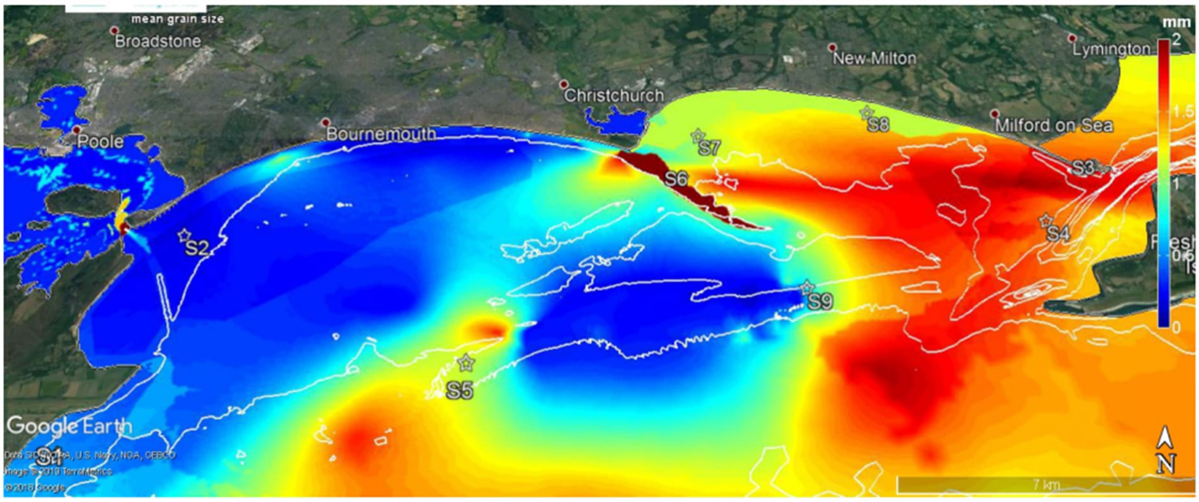


Figure 3-2 Distribution of grain size as applied in the Telemac model (obtained from HR Wallingford, 2019)

Christchurch Bay is widely regarded as a largely self-contained sediment circulation system with median sediment grain size generally increasing (coarsens) from west to east (SCOPAC, 2012). Littoral sediment transport is mainly from the west to east as a result of wave-induced currents acting in combination with the tides. Tidal currents result in the offshore movement of finer sediments leaving the coarser material inshore. It is noted that, whilst they are less frequent, storm conditions from the east/south-east are also able to mobilise large quantities of sediment over short periods which is then transported offshore.

In addition to the controlling influence of the natural geology, as described in Section 3.2, human intervention has also played a part in shaping the coastline of the Bay over the past 100 years. Coast protection and sea defence structures including sections of seawall, rock revetment and numerous groynes have been constructed over this period to resist the natural erosive forces and provide a more stable coastline. These hard-engineered structures have been used in combination with softer engineering solutions, such as beach replenishment and recycling, to provide additional protection, reduce the rate of erosion of soft cliff material and supplement material into the system that would otherwise have been provided by cliff erosion.

Figure 3-3 provides the most recent interpretation of sediment transport within the study area from SCOPAC. This analysis has been supplemented by a recent tracer pebble study that was undertaken between Milford and Sea and Hurst Spit at the eastern end of the Strategy frontage (NFDC, Coastal Partners, 2021). This study provides additional detail on the sediment transport patterns for this eastern end of the frontage. Between July 2019 and December 2020 the movement of the tracer pebbles was recorded from two locations at Milford (M1 and M2) and six locations on Hurst Spit (H1 to H6).

At both Milford on sea locations (M1 and M2) the tracer study found that the dominant drift direction was to the south east. Of the pebbles deployed at M1, the maximum movement distance was over 1km to the south east over this time period, however, the vast majority of pebbles remained within approximately 200m of the original location. Of the pebbles which moved the furthest, the pebbles bypassed not only the wooden and rock groynes at Milford but also the rock revetment fronting Sturt Pond, with an average transport rate of 729m/yr. At M2, there was a lower rate of pebble retrieval suggesting loss of pebbles offshore. Of those which were retrieved, the vast majority of pebbles remained with 100m of the original deployment location. The maximum distance travelled by a tracer pebble was 1.2km, equating to an average transport rate of 883m/yr.

The tracer pebble survey indicates that material can bypass the beach control structures at Milford, but it was noted that transport rates at Milford were around 20% lower than those calculated along the main trunk of Hurst Spit. These findings suggest that the beach control structures at Milford are still allowing some material to bypass but are working to slow transport rates in this location.

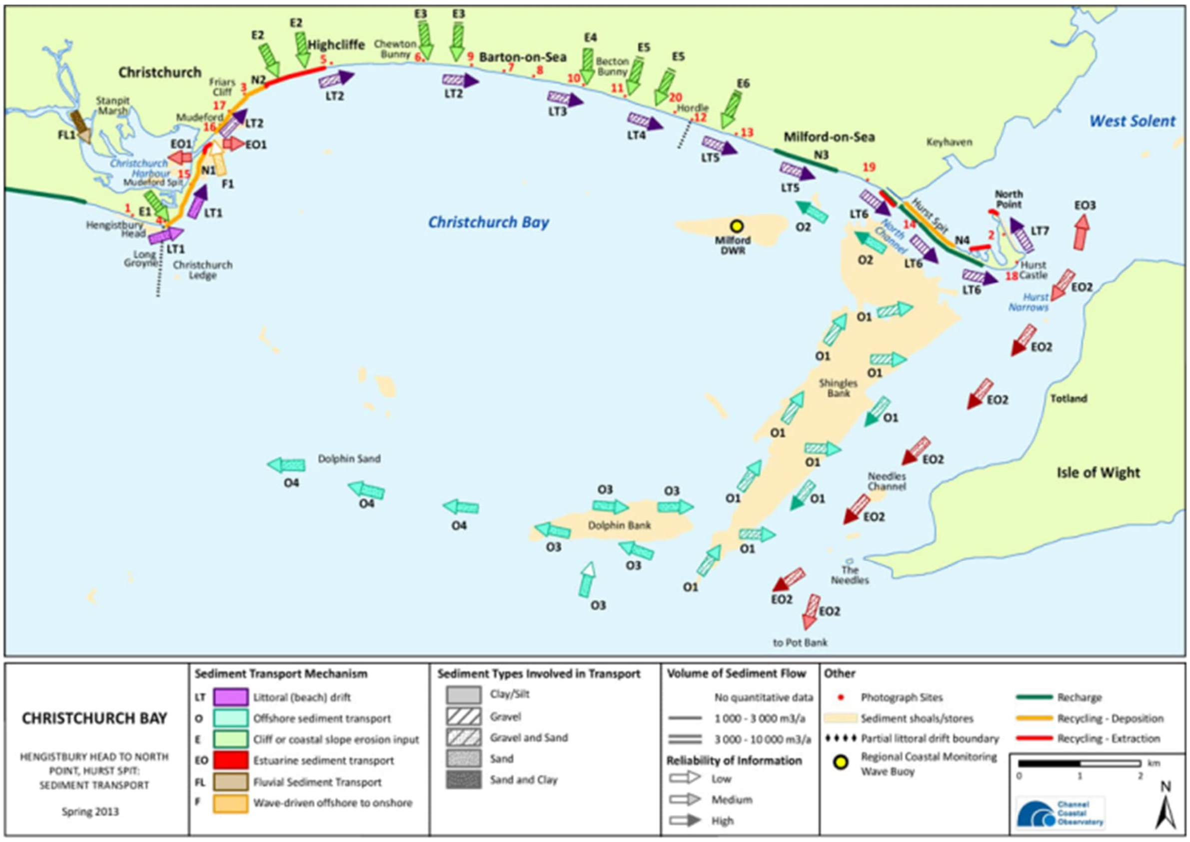


Figure 3-3 Schematic diagram of residual sand transport pathways in Christchurch Bay (obtained from SCOPAC, 2012)

Sediment recycling is a regular beach management activity within the bay. Sediment recycling taking place along the Mudeford Sandbank (SMP unit CBY1) and Highcliffe (SMP unit CBY2) frontages. The recharge of beach material has been used at Milford-on-Sea (SMP unit CBY6) and Hurst Spit (SMP unit CBY7) with recycling also used within this management unit. Table 3-1 below presents a summary of the beach management practices within the Bay.

Table 3-1: Summary of recent beach management practices within Christchurch Bay

Location	Year	Intervention
Mudeford Sandbank	On 8 occasions between June 2002 and November 2017	Moving sediment from where it accumulates at the spit tip (adjacent to the harbour entrance) back to eroded areas/groyne bays along the bank – but not including the 5 groyne bays closest to the Long Groyne. On average approx. 1,000m^3 of material has been moved in each intervention.
Avon Beach and Friars Cliff	6 sets of works between June 2011 and June 2018. May-June 2021	Between June 2011 and June 2018, movement of 57,000m^3 of material eastwards from the harbour entrance delta and/or nearshore bars, onto the upper beach between Avon and Highcliffe. Aim of interventions were to increase beach levels. In May-June 2021 beach levels topped up at Avon Beach and Friars Cliff, across 4 groyne bays using material recycled from Highcliffe Beach.
Highcliffe Beach	May-June 2021	Material added to Highcliffe Beach using material recycled from Highcliffe's eastern groyne bays
Highcliffe to Chewton Bunny	Between 1985 and 1991	Filled with 73,000m^3 of imported shingle which has been largely retained by the rock groynes in this location

Milford-on-Sea	2004, 2006, then annually since 2008	Total volume of approx. 40,000m^3 since 2004. Average of 2,500m^3 per intervention. Objective of intervention is to protect the toe of the coastal defences.
Hurst Spit	1996, Annual	Major recharge in 1996. Subsequent recycling of material annually

Key points to note from Figure 3-3 are the natural sediment sources from Poole Bay and cliff erosion at Hengistbury Head and between Highcliffe and Milford-on-Sea. There is an exchange of sediment at the mouth of Christchurch Harbour and a supply of fluvial sediment from the upstream river sections. The figure also captures the consistent trend of littoral sediment transport from west to east along the entire frontage. Around the Shingles Bank, the pattern of transport is generally clockwise with transport to the north-east associated with the predominant waves from the south-west and transport to the south-west resulting from the strong ebb tide currents from the West Solent.

An understanding of historical trends in offshore sediment stores will be important for the assessment of potential future behaviour. A detailed study was previously undertaken (Channel Coastal Observatory, 2014) which included analysis of the change in area of key features within Christchurch Bay over the period 1960 to 2005. These include Mudeford Sandbank, The Shingles Bank (source of sediment for Hurst Spit nourishment in 1996), Dolphin Bank and Dolphin Sands. The findings suggest that whilst Dolphin Bank has remained relatively stable, other features have experienced some losses and gains in plan area although overall, the net change appears to be small suggesting that each of these features is currently stable. However, with increased storminess due to climate change, there is potential for features to respond differently in the future. Although beyond the scope of a coastal strategy study, consideration should be given to the consequences of future climate change on such features, particularly where they have a controlling influence on nearshore processes.

3.4.2 Harbour Sediment Dynamics

Based on the SCOPAC (2012) assessment of sediment transport processes within Christchurch Bay, the main sources of sediment into the Harbour are from the fluvial source (River Stour and River Avon) and the exchange of marine sediment load through the entrance. Supply of fine sediment from fluvial sources is believed to contribute to net accretion within the Harbour making it a sink for sediment. Given that previous measurements of currents show that the ebb tide is stronger than the flood tide currents, deposition of marine sediment within the Harbour is believed to be limited.

SCOPAC outlines how previous studies have estimated potential sediment supply from the River Stour and River Avon. However, there appears to be considerable uncertainty in the calculations. Rendel Geotechnics and the University of Portsmouth (1996) calculated a maximum combined bedload input of 150 tonnes a^{-1}, but actual quantity is probably less than 10% of this total due to numerous weirs and sluices on both rivers. Gao and Collins (1995) calculated bedload input as 320-640m3a^{-1}, based largely on a theoretical calculation and also estimated suspended sediment discharge potential as being close to 70,000 tonnes a-1, but actual delivery is unlikely to exceed 10,000 tonnes a^{-1}.

3.4.3 Mudeford Sandbank

The Mudeford Sandbank is a natural sand spit feature extending from Hengistbury Head to the mouth of the Harbour. An access road runs along part of the sandbank behind the beach huts which occupy approximately a 900m length of the sandbank. The sandbank is defended by rock groynes (constructed between 1988 and 1990 and upgraded in 2000) and a revetment and historically has benefited from small-scale beach nourishment. Some dunes are found in places along the sandbank which provide a natural defence and aeolian transport is therefore likely to be an important factor in terms of sediment movement.

The direction of littoral transport is northwards, towards the Harbour entrance. Historically the cliff face to the east of Hengistbury Head provided sediment to the sandbank, but the SMP outlines how this source of material has ceased since the installation of groynes in 1986. The numerous rock groynes (12 groynes) along the sandbank appear to be functioning well, retaining sediment within the groyne bays and in some cases where accretion has reached the seaward end of the groyne, by-passing of sediment appears to take place. However, at its narrowest point the sandbank is only approximately 70m wide and given the relatively low land levels, the sandbank is susceptible to overtopping and potentially breaching, particularly under a future climate change scenario.

In the past the sandbank has breached on several occasions during the 19th and mid-20th centuries. Breaching of the sandbank in the future could potentially have much a wider impact in terms of future flood risk and habitat loss due to increased exposure of areas within the harbour to wave action and coastal flooding.

Modelling of a breach scenario using an integrated wave, hydrodynamics and sediment transport MIKE21 model has been undertaken to support the definition of the baseline and the Strategy development. Full details of the MIKE21 breach modelling can be found in the Christchurch FCERMS Modelling Report (AECOM, 2022). In summary, the modelling indicated that the most likely location for a future breach along the Sandbank was in groyne bay 5 which is located centrally along the Sandbank where the width is smallest. Should a breach occur, based on projected rates of erosion, the estimated breach timing is estimated to be in 25-30 years if no further coastal management is undertaken. However there is uncertainty in this projection as it is based on extrapolating average rates of erosion and a breach could occur sooner or later than this depending on the frequency and severity of storms. Breach assessments were carried out for both a narrow breach (25m) and a wider breach (90m) and the impacts on water levels, current speeds, waves and sediment transport within Christchurch Harbour were investigated. The results indicate that there would be minimal impacts on water levels within the harbour during a breach but there are impacts on currents, waves and sediment transport. For the larger 90m breach, the wave heights within the harbour are expected to increase, with larger waves simulated on the far side of the harbour at Stanpit, Waterside Road and Fisherman's Bank Road. In these locations on the north side of the harbour the wave heights are increased by 0-1-0.15m relative to the scenario with no breach of the Sandbank.

3.4.4 Hurst Spit

Hurst Spit is located immediately to the east of the Strategy boundary but its evolution over time will play an important role in the future of coastal management within Christchurch Bay. Options for managing Hurst Spit in the future are to be collaboratively developed and appraised with the adjacent Hurst Spit to Lymington Flood and Coastal Erosion Risk Management (FCERM) Strategy that is ongoing and being developed in parallel to this Strategy.

As part of the Hurst Spit to Lymington FCERM Strategy an independent expert panel has provided input to determine the likely evolution of the spit under a scenario where no further coastal management is undertaken. The resulting report determined the following:

- It is almost certain (86%-99% chance) that over the next 10 years, if beach management is withdrawn that the spit will undergo narrowing due to erosion of the barrier from the seaward side.
- It is likely (56-70% chance) that overwashing and roll back of the barrier will occur over the next 10 years if beach management is withdrawn. The amount of rollback is likely to be in the order of 20-50m. The barrier is almost certain (86-99% chance) to have rolled back by 50-100m in 50 years, and in excess of 100m in 100 years' time.
- Despite the above, it is highly likely (71-85% chance) that the barrier will remain as a continuous barrier above normal tides for the next 10 years. Narrowing and rollback would result in a lower crest level that will be wider with a more shallowly graded seaward slope.
- Over the next 50 years, it is likely (56-70% chance) that the barrier will remain as a continuous barrier, although it is almost certain (86-99% chance) that there will be periods where access is lost as a result of storm events. The certainty of a continuous barrier over the 50-100 year period reduces to about as likely as not (46-55% chance).
- Over the next 10 years it is highly unlikely (16-30% chance) that the barrier will disconnect from the breakwater (at Saltgrass lane). However, over the next 50 years it is highly likely (71-85%) chance that it will disconnect due to the shoreline reorientation required to accommodate the rollback distance.
- Over the next 10 years, it is highly unlikely (16-30% chance) that any crest lowering will develop into a permanent breach that will remain open. Over the next 50 years, the likelihood increases by remains unlikely (31-45%). Over the next 100 years it is about as likely as not (46-55% chance) that a permanent breach will form. If it were to occur, it is likely to occur where Mounts Lake comes away from the barrier.
- There is a remote chance (1-15% chance) of a permanent breach forming to the west of the Castle over the next 10 years. Over the next 50 years, it is highly unlikely (16-30% chance) that a permanent breach will form in this location. Over the next 100 years it remains unlikely 31-45%) that a breach will form here.

- It is very likely that North Point will accrete if beach management is stopped. This will lead to North Point extending further in a north westerly direction.

3.5 Beach Levels

Through discussions with the NFDC coastal engineers it is understood that there is a trend of lowering beach levels in some locations along the frontage. Beach levels can be linked to rates of cliff recession in soft cliff settings and there is also a link between low beach levels increased vulnerability of hard defences to toe exposure / failure. Therefore a deeper understanding of beach level trends is important for the Strategy development. The Channel Coastal Observatory collect regular beach profiles in the bay and summarise the results of these profiles in an annual survey report for the Hurst Spit to Hengistbury Head frontage, with the most recent version published in May 2021 (available at: https://coastalmonitoring.org/reports/#southeast). In the annual report, beach level results are provided for different survey units at several levels including:

- Direct comparison with previous survey
- Tables with latest annual interim profile Cross Sectional Area (CSA) change and m^2 as %
- Graphs of change in CSA through time
- Survey unit maps summarising beach profile change over annual monitoring period
- Survey unit maps summarising beach profile change from baseline year to 2020
- Topographic difference models.

A summary of the results presented in the Channel Coastal Observatory report (2020) is provided in Table 3-2 below and Figure 3-4 to Figure 3-11 for the key areas along the frontage.

Table 3-2: Summary of beach level analysis from the Channel Coastal Observatory

Area	Observation	Monitoring report (latest available)
Milford-on-Sea	Since the baseline year of 2000, there has been significant erosion across the entire beach. This is particularly evident to the area of the seawall failure west of the White House. Beach erosion in this area likely a contributing factor to seawall failure. Between April 2019 and June 2020 the majority of the beach eroded, with the most significant losses around the area of seawall failure west of the White House and significant losses to much of the beach east of the White House.	Analysis from 2020 report
Hordle Cliff to Highcliffe (including Barton-on-Sea)	Between the year 2000 to 2019, there were three main bands of change to the beach over this period. Lower beach formed a sand bar. Majority of the beach above the sand bar had eroded, although there was a band of accretion along the upper beach. Between April 2018 and March 2019 there was a general trend of erosion at Hordle Beach. Discussions with NFDC coastal engineers suggests Hordle Beach has lowered significantly in recent years. As a result, a number of beach hut licenses have recently been terminated due to the erosion.	Analysis from 2019 report
Becton to Hordle	Between the year 2002 to 2019, there was significant erosion and lowering of the beach across the survey unit over this period.	Analysis from 2019 report

Area	Observation	Monitoring report (latest available)
	Over the shorter term, between 2016 and 2019, some accretion was observed at the upper beach on the eastern side of the unit. Elsewhere in the unit, an erosion trend occurred.	
Naish to Barton-on-Sea	Between 2002 and 2017 there was an erosion trend at both the west and eastern ends of the survey unit and an accretion trend in the middle of the unit.	Analysis from 2017 report
Mudeford Quay to Highcliffe	Since the baseline year of 2002, the beach at Highcliffe at the eastern extent has accreted. There has been erosion to some of the groyne bays at Friars Cliff and the undefended west side of Steamer Point. The groyne bays at Avon Beach at the western extent have accreted, although there is an area of located erosion by Christchurch Harbour entrance. The regular beach recycling has the potential to influence the beach trends in this location. Between the period 2019-2020 changes were variable, with some areas accreting and others eroding.	Analysis from 2020 report
Mudeford Sandbank	Since the baseline year of 2003, the proximal and distal ends of the spit have accreted with the sand dunes growing in size, whilst the groyne bays around the middle of the spit have eroded. In the short term between spring 2019 and spring 2020, there were only minor changes to the beach with only two profiles showing a change greater than 5m^2 in cross sectional area.	Analysis from 2020 report

As outlined in Table 3-2 and illustrated in Figure 3-4 to Figure 3-11, the beach levels along significant lengths of the Strategy frontage have eroded since the early 2000's. Of particular note are the levels at Milford-on-Sea, where low beach levels are thought to have been a contributing factor to the recent seawall failure (a Westover, in early 2020) and also the Mudeford promenade collapse in 2008. Parts of the Highcliffe to Mudeford Quay frontage are also eroding as are parts of Mudeford Sandbank and the Becton to Hordle frontage.

The main area of beach accretion is at the rock groyne section of the Highcliffe frontage, which has shown significant accretion since 2002 suggesting the rock groyne structures are working effectively in this location. However, there is potential for these structures to be having a negative impact on sediment availability further to the east as the structures are artificially holding material in place and preventing it from progressing further downdrift. There is likely to be some bypassing of material through the rock groyne system but the amount of material moving east is expected to be much less than in a situation with no rock groynes. The build-up of material in the rock groyne bays at Highcliffe provides a source of material for ongoing beach recycling within the bay. For example, in May-June 2021 material was moved from this location to adjacent sections of the frontage at Avon Beach and Friars cliff to the west (see Table 3-1). As part of the option development and appraisal stage, the Strategy will consider the optimal beach recycling approach and consider where sediment is best placed from this location should it continue to accrete. This could include for example a continuation of recent recycling by moving material to the west, or alternatively by placing a portion of the recycling material to the east of the groyne bays to increase the amount of sediment moving from west to east within the bay, thus bypassing the rock groyne system. The relative merits of different approaches will be considered as part of the detailed option development and appraisal process.

As explained in the Christchurch Bay Beach Management Technical Note (BCP, May 2021), another factor to consider is the seasonal changes in the beach profiles at the study site which change according to variation in the energy from winter/summer waves. In the less energetic summer conditions, a wider berm forms above the intertidal area. In the winder, sediment is eroded away by waves and the tides. This does not completely leave the system, rather builds up offshore were waves discharge energy over the bar before reaching the upper beach. As the beach undergoes a period of calmer weather, sediment moves back onshore again.

The bars and delta around Mudeford Sandbank and Avon form a complex natural feature likely serving a crucial protective role to Avon beach including in dissipating inshore wave energy and allowing post storm recovery (BCP, 2021). Sediment transport and the role of natural features will be considered in detail during the option development and appraisal, including the potential impacts of sediment nourishment / recycling on adjacent areas.

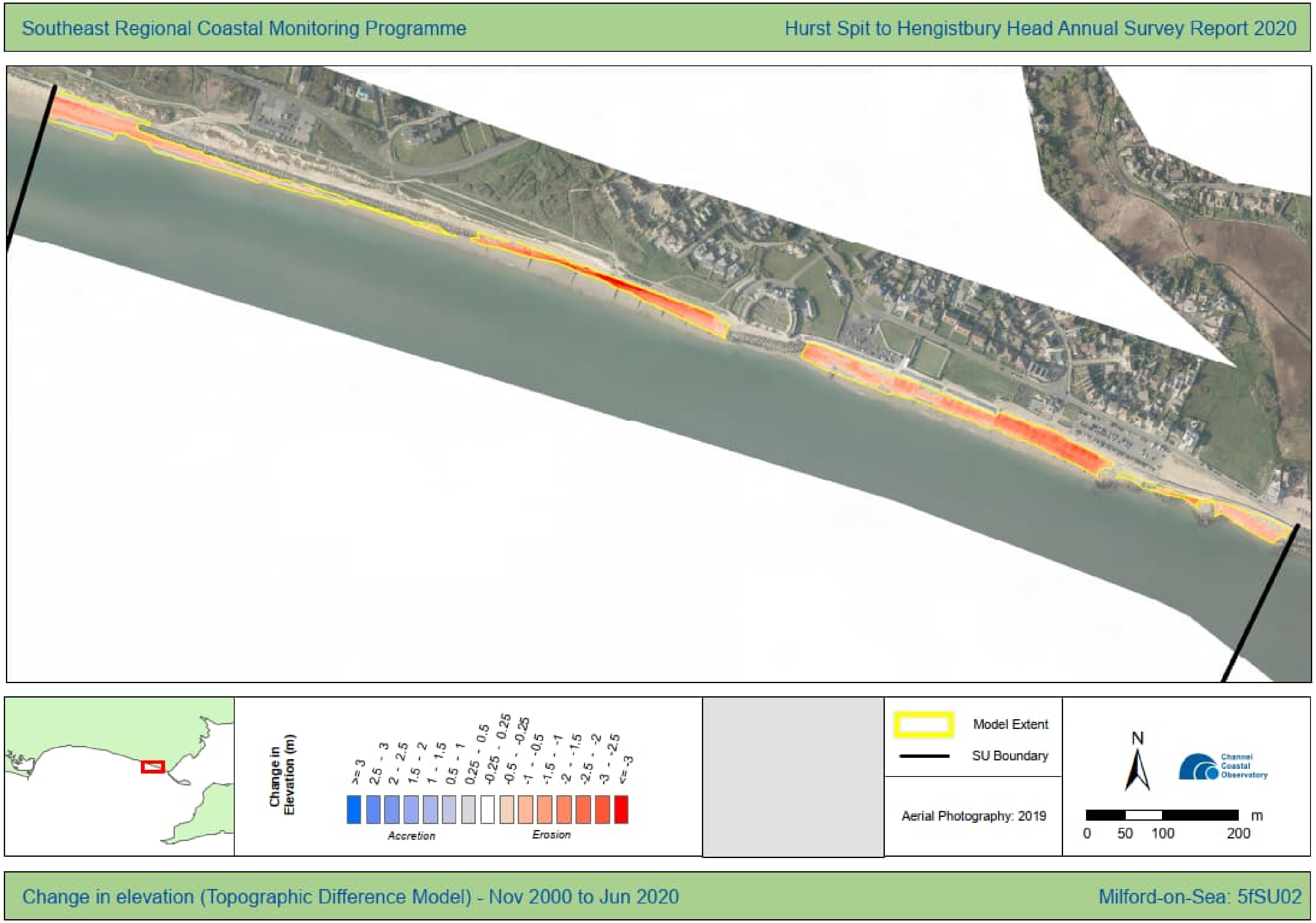


Figure 3-4: Beach profile elevation change at Milford-on-Sea between November 2000 and June 2020. Figure obtained from the Channel Coastal Observatory (2020).

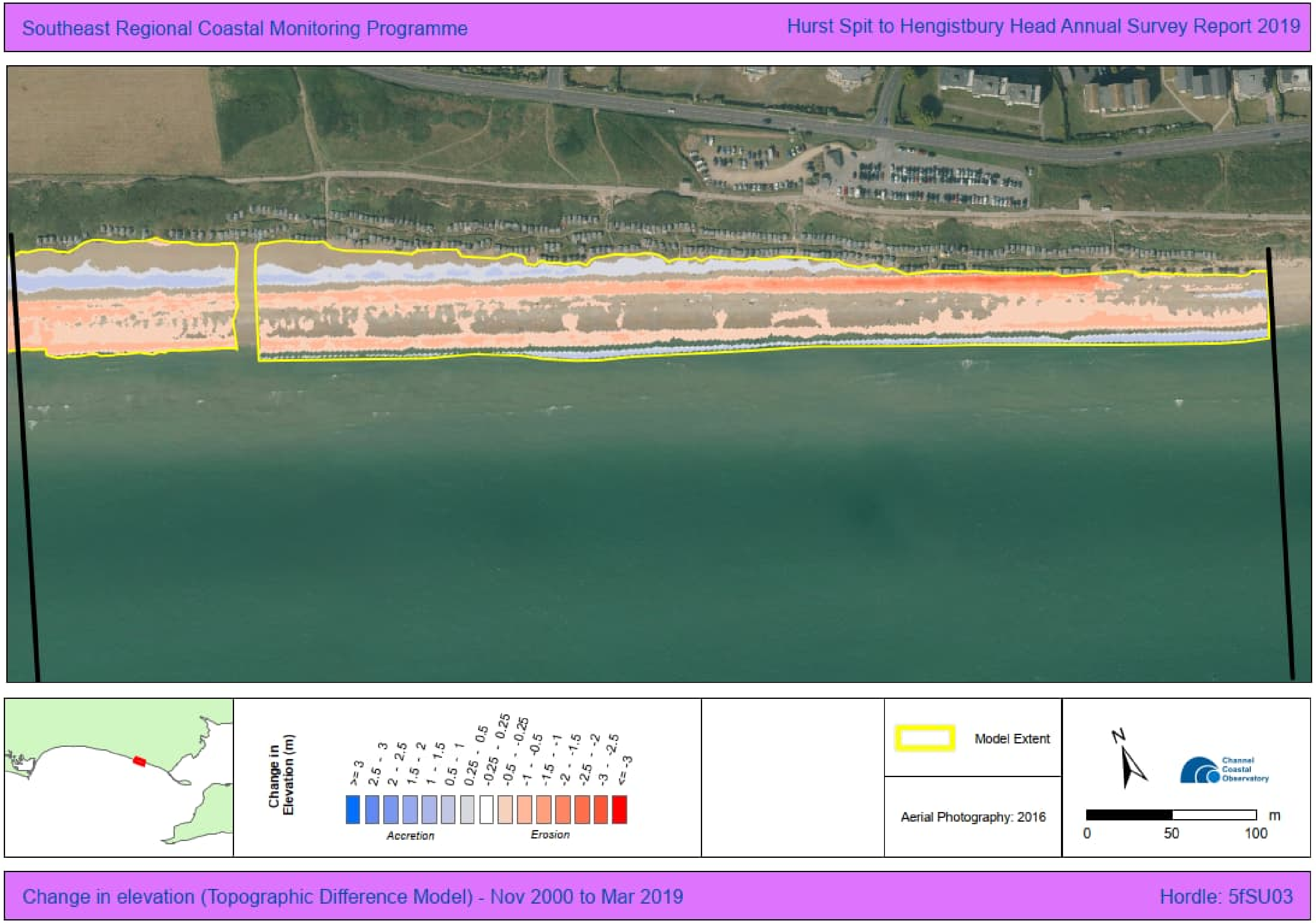


Figure 3-5: Beach profile elevation change at Hordle between November 2000 and March 2019. Figure obtained from the Channel Coastal Observatory (2019).

Figure 3-6: Beach profile elevation change at Becton to Hordle between May 2002 and May/June 2019. Figure obtained from the Channel Coastal Observatory (2019).

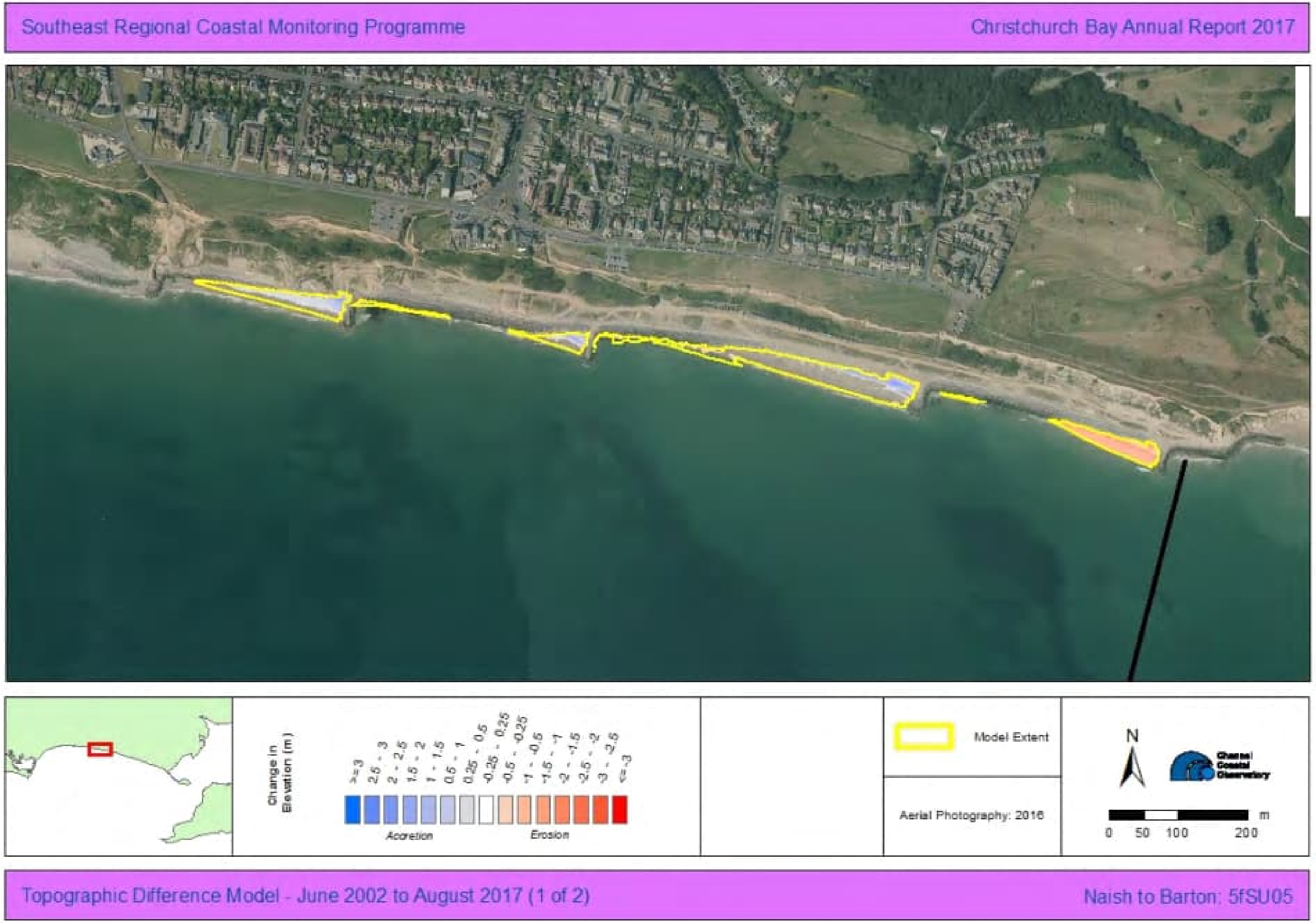


Figure 3-7: Beach profile elevation change at Naish to Barton-on-Sea (1 of 2) between 2002 and 2017. Figure obtained from the Channel Coastal Observatory (2017).

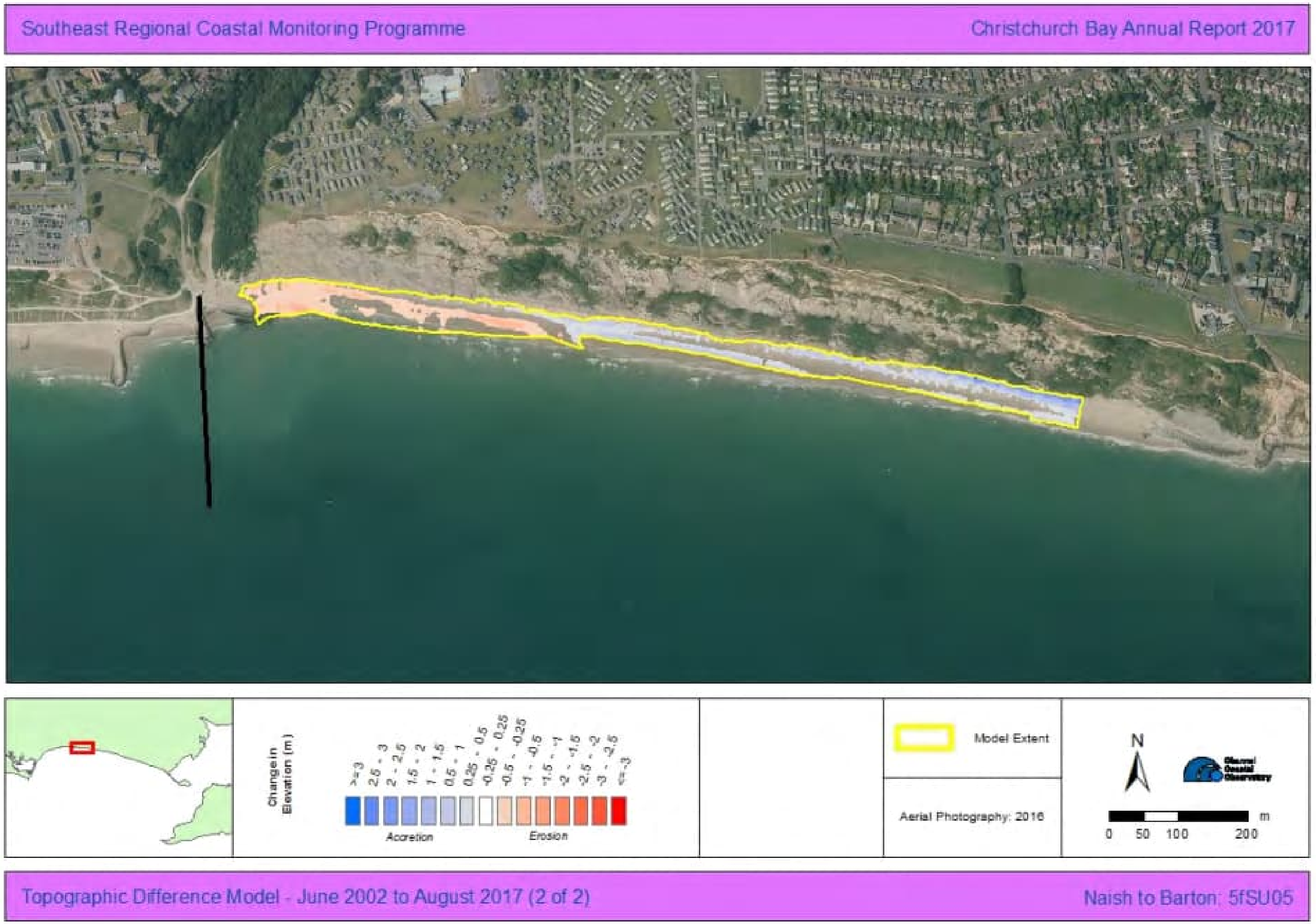


Figure 3-8: Beach profile elevation change at Naish to Barton-on-Sea (2 of 2) between 2002 and 2017. Figure obtained from the Channel Coastal Observatory (2017).

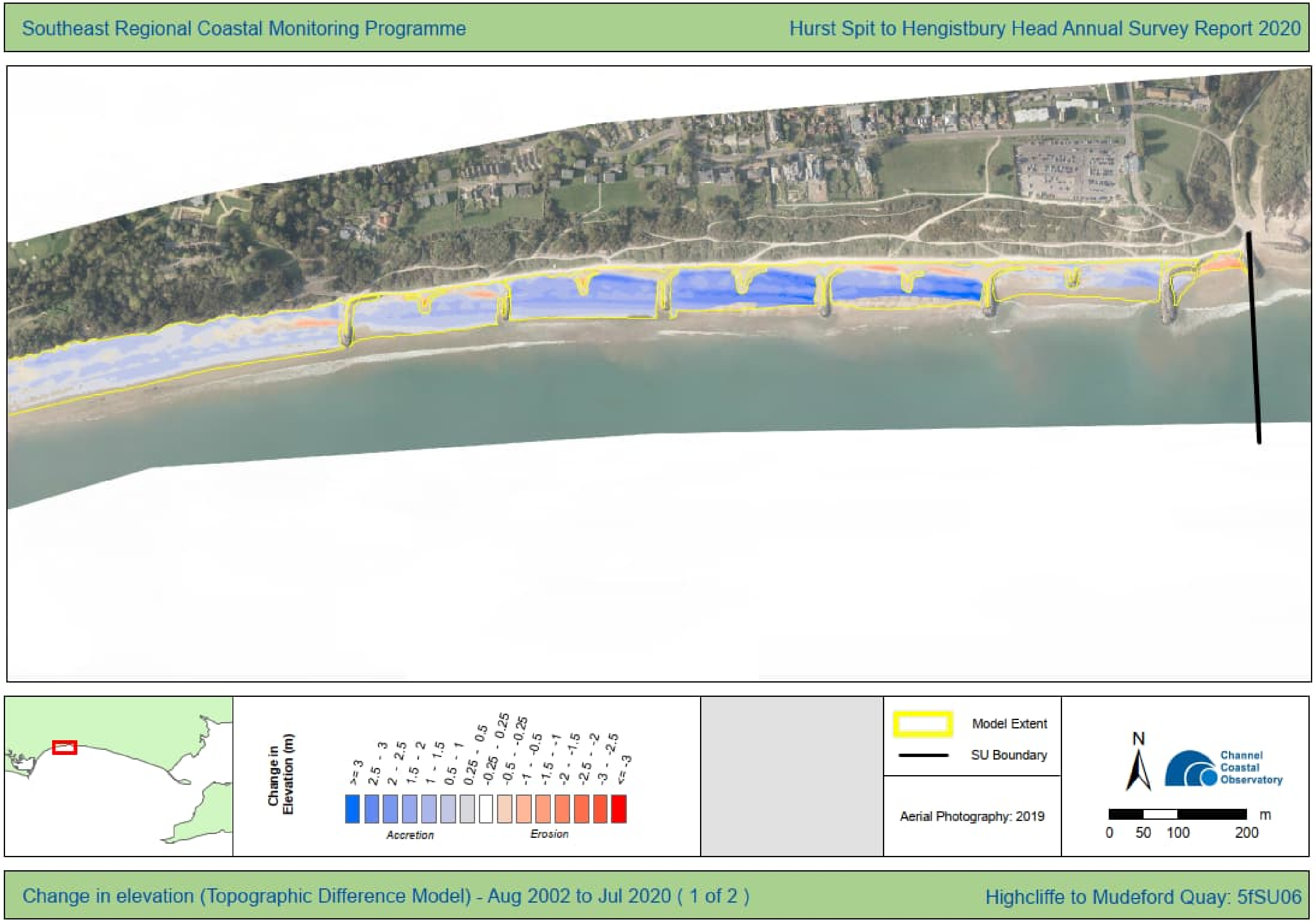


Figure 3-9: Beach profile elevation change at Highcliffe to Mudeford Quay (1 of 2) between 2002 and 2020. Figure obtained from the Channel Coastal Observatory (2020).

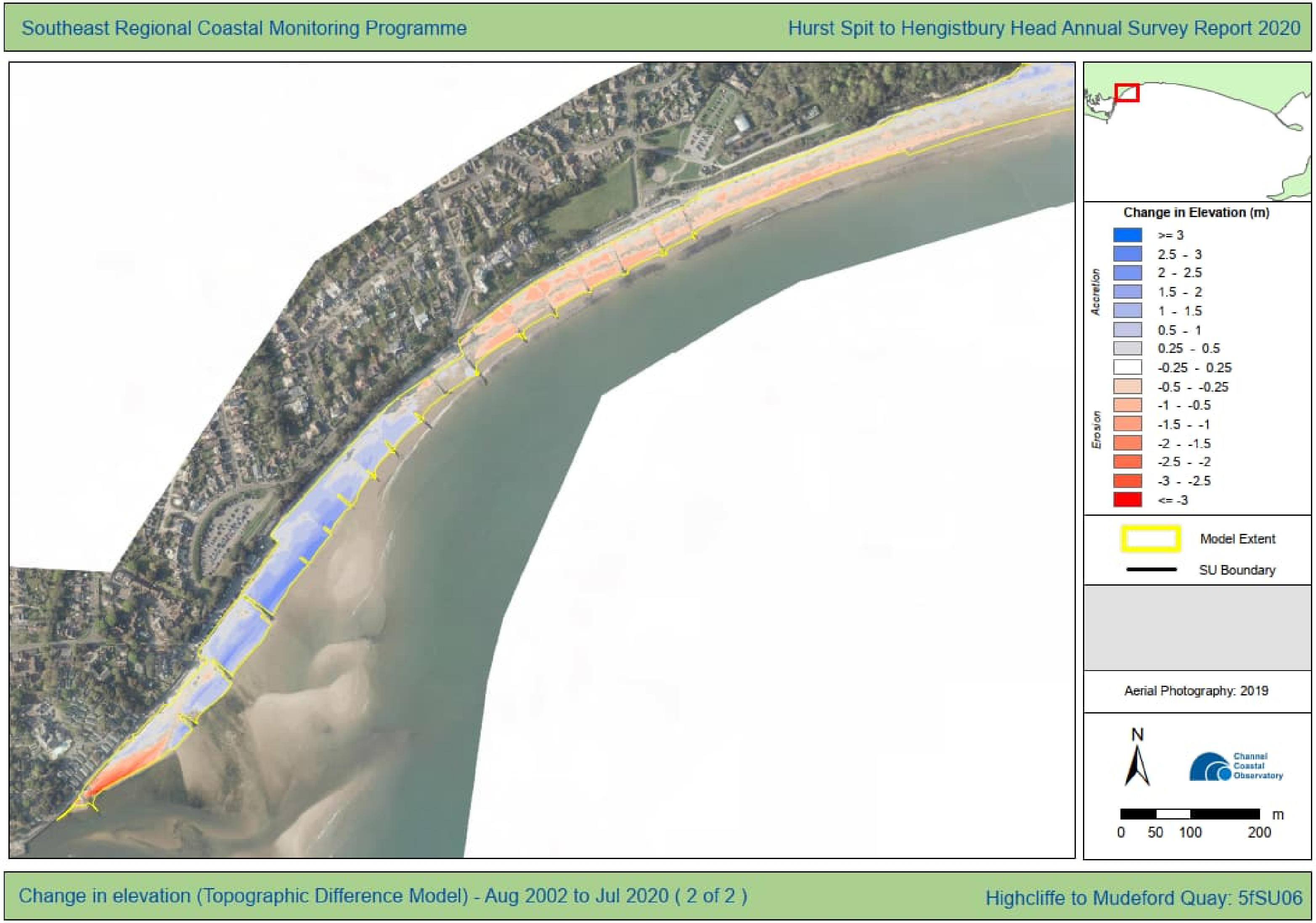


Figure 3-10: Beach profile elevation change at Highcliffe to Mudeford Quay (2 of 2) between 2002 and 2020. Figure obtained from the Channel Coastal Observatory (2020).

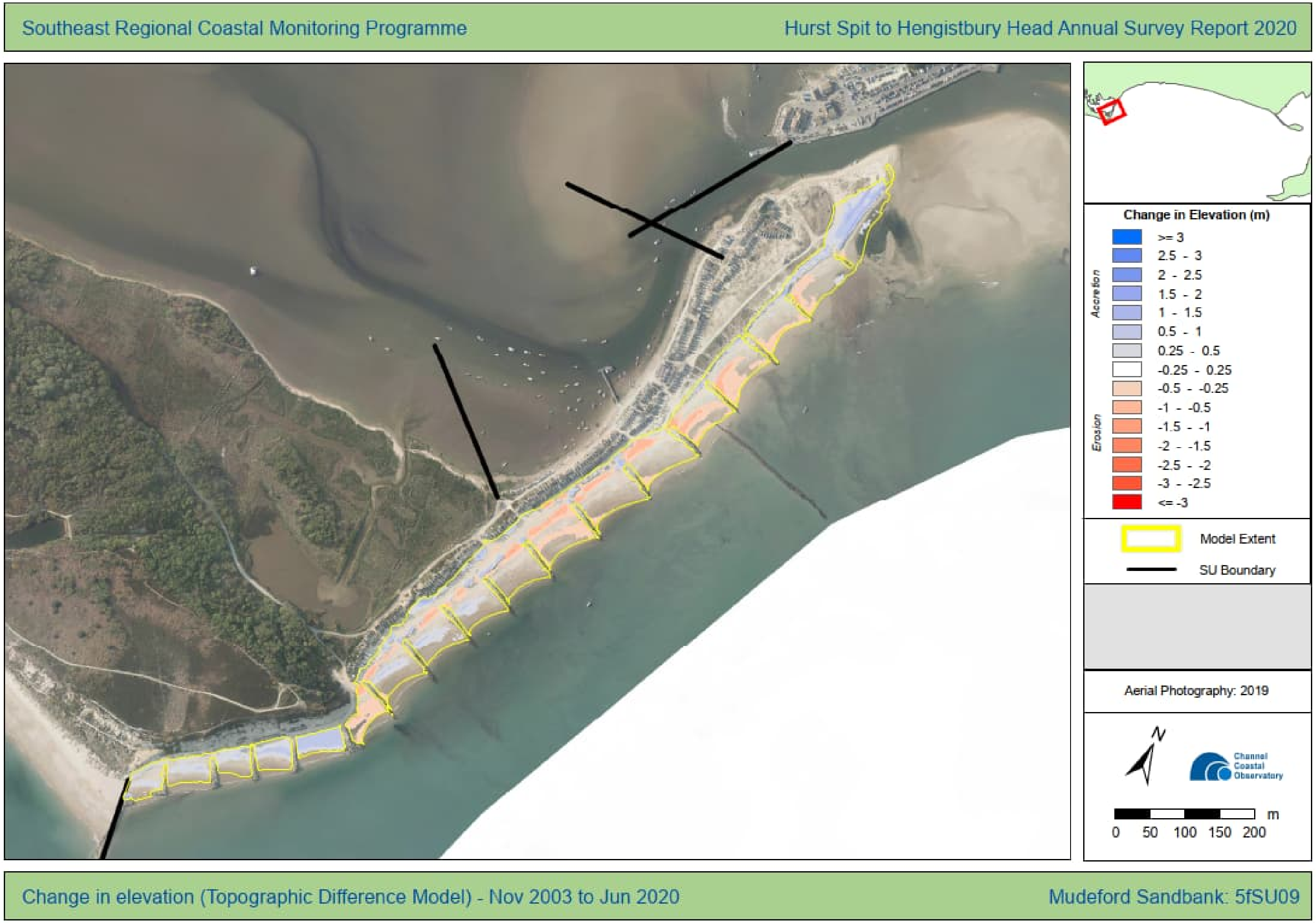


Figure 3-11: Beach profile elevation change at Mudeford Sandbank between November 2003 and June 2020. Figure obtained from the Channel Coastal Observatory (2020).

3.6 Intertidal Habitat

The main intertidal habitats within Christchurch Harbour include mud/sandflats and saltmarsh areas. The future maintenance of these areas will rely on sediment supply, predominantly from the river being able to keep pace with sea level rise. If there are constraints on the supply of sediment, the distribution of habitat type will change over time, potentially leading to the loss of both mudflat and saltmarsh. This process will be further exacerbated where these areas are backed by hard defences resulting in ‘coastal squeeze’.

Figure 3-12, Figure 3-13 and Figure 3-14 have been produced to illustrate the potential loss of saltmarsh habitat area in the future within Christchurch Harbour due to sea level rise over the next 100 years. The saltmarsh habitat areas are shown in brown / green and have been estimated by considering the harbour bed elevation with respect to the tide levels.

Typically, a natural intertidal system shows a vertical zonation of habitats and species, relating to the frequency of tidal inundation. Mudflats are typically located at the lower elevations between the Lowest Astronomical Tide (LAT) and Mean High Water Neaps (MHWN) whereas saltmarsh is found higher up, between MHWN and the Highest Astronomical Tide (HAT). The saltmarsh habitat is zoned vertically, with pioneer species which can withstand tidal immersion by as many as 600 tides a year typically located between MHWN and Mean High Water (MHW). Higher up, between MHW and HAT, upper and transitional saltmarsh vegetation can withstand only occasional inundation (JNCC, 2014). An intertidal habitat can therefore be modelled by splitting the habitat into vertical zones of vegetation which differ according to the surface elevation relative to tide levels (e.g. Gardiner et al. 2007 (BRANCH study of coastal habitat change); Blott and Pye, 2004; Chapman, 1960; Leggett and Dixon, 1994; Pye and French, 1993). The modelled relationship between bed elevation and tides is shown in Table 3-3 below.

Table 3-3: Modelled relationship between surface elevation and tide levels for saltmarsh habitat areas

Intertidal habitat	Vegetation location based on surface elevation relative to tide level
Sub-tidal	< Lowest Astronomical Tide (LAT)
Mudflat	Lowest Astronomical Tide (LAT) to Mean High Water Neaps (MHWN)
Pioneer saltmarsh vegetation	Mean High Water Neaps (MHWN) to Mean High Water (MHW)
Upper / mid saltmarsh vegetation	Mean High Water (MHW) to Mean High Water Springs (MHWS)
Transitional vegetation	Mean High Water Springs (MHWS) to Highest Astronomical Tide (HAT)
Land	> Highest Astronomical Tide (HAT)

With anticipated sea level rise in the future, tidal water levels are expected to shift upwards by approximately 0.41-0.53m by 2071 and 1.03-1.39m by 2121 (see Table 2-3). Should the rate of sea level rise exceed the rate at which the harbour bed levels accrete, then the habitable areas for saltmarsh in the harbour will diminish. Figure 3-12 to Figure 3-14 assume that the harbour bed levels will remain the same over the next 100 years (i.e. no accretion) and that no land will be made available for the saltmarsh to roll inland (i.e. coastal squeeze). This is an overly precautious assumption but helps to illustrate the potential saltmarsh habitat loss should no accretion occur and sea levels rise as expected. As can be seen, under this scenario, the habitable saltmarsh area decreases significantly between present day (Figure 3-12) and 2071 and 2121 (Figure 3-13 and Figure 3-14 respectively).

To improve the resilience of the estuary to future climate change, consideration should be given to managed realignment within the Harbour and/or increasing sediment supply, potentially through the use of dredged material (if/when this is undertaken) rather than removing sediment from the system. It is noted that dredging of channels has been undertaken in the past to reduce flood-risk but it is not known if this practice is still ongoing. Dredging may also be undertaken to improve navigation but again it is not known if this is currently undertaken on a regular basis.

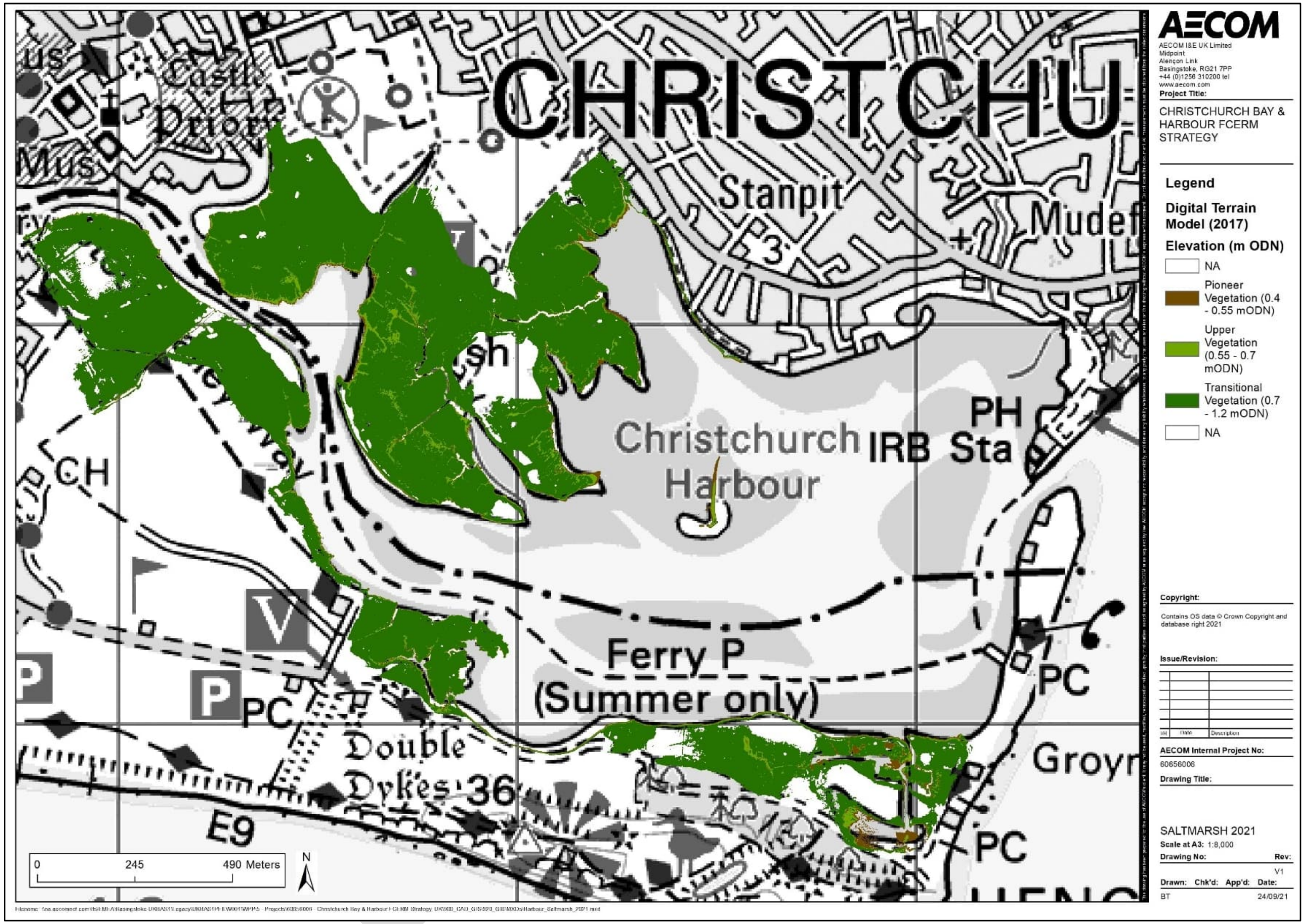


Figure 3-12: Modelled saltmarsh habitat extent based on surface elevation and tide levels, 2021.

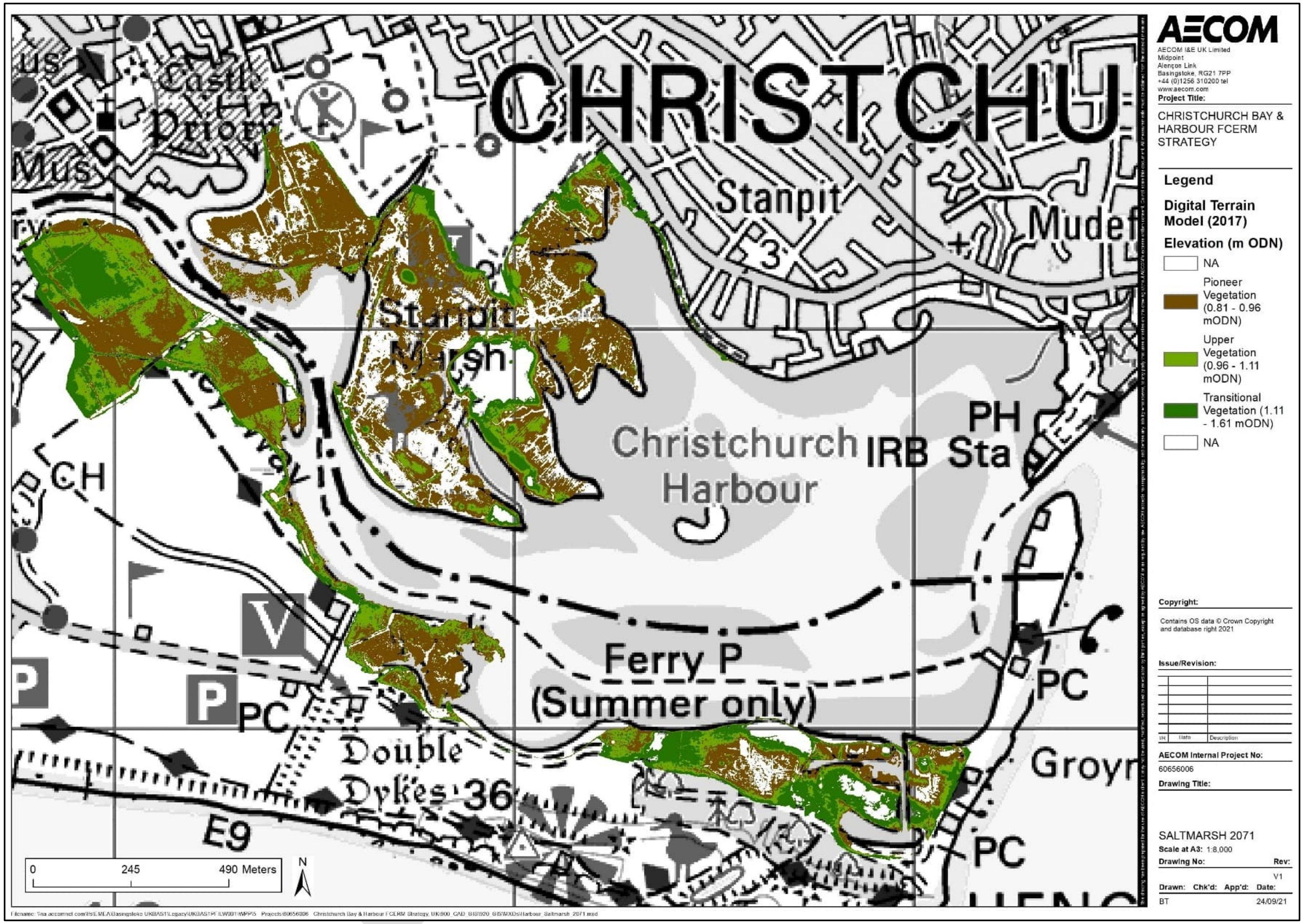


Figure 3-13: Modelled saltmarsh habitat extent based on surface elevation and tide levels, 2071.

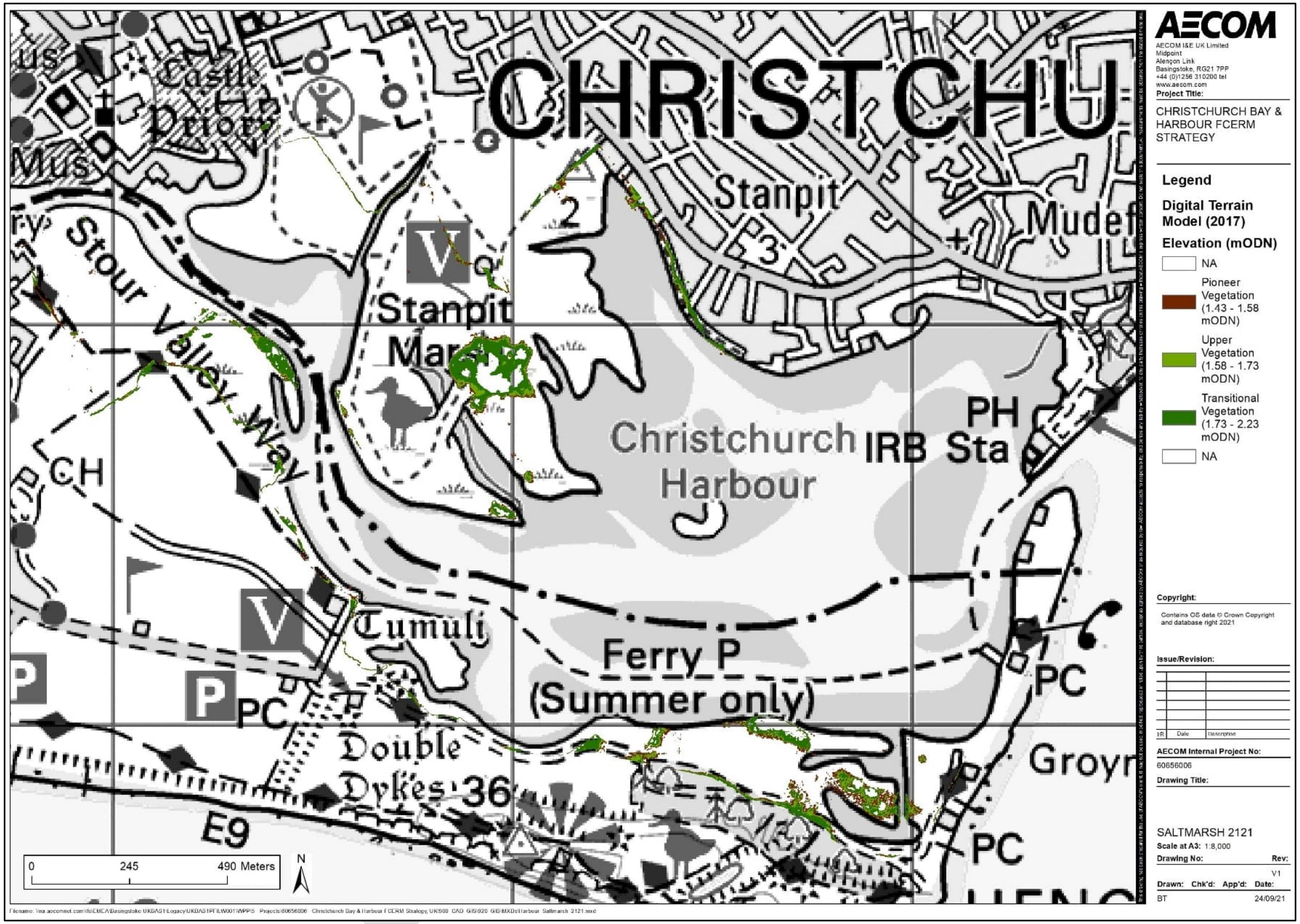


Figure 3-14: Modelled saltmarsh habitat extent based on surface elevation and tide levels, 2121.

4. Flood and Erosion Risks

4.1 Tidal Flood Risk

The understanding of tidal flood risk across the Strategy frontage can be informed from the Environment Agency flood mapping (available at https://flood-map-for-planning.service.gov.uk/). Figure 4-1 shows Environment Agency Flood Zone 2 and Figure 4-2 shows Environment Agency Flood Zone 3.

Flood Zone 2 is described as areas with between 0.1%-1% chance of flooding from rivers in any year or between 0.1-0.5% chance of flooding from the sea in any year.

Flood Zone 3 is described as areas that have a 1% or greater probability of flooding from rivers or 0.5% or greater probability of flooding from the sea in any year.

As can be seen, the tidal flood risk is concentrated around the low-lying Christchurch Harbour and at Milford-on-Sea at the eastern end of the Strategy frontage. Milford-on-Sea is lower lying than the open coast frontage to the west and is at risk of tidal inundation flooding from the Keyhaven area to the East (to the north of Hurst Spit). The risk of flooding from this direction will be assessed through collaboratively working with the adjacent Hurst Spit to Lymington FCERM Strategy. Parts of the open coast frontage at Milford-on-Sea are also at risk from wave overtopping flooding, such as around the Hurst Road East Car Park which has experienced wave overtopping in the past, and which may not be fully represented in the Environment Agency flood zones. Between Christchurch and Milford on Sea the topography is generally steeper with a high cliff line, ensuring the risk of sea flooding is low.

Detailed flood modelling of Christchurch Harbour generated through the Lower River Avon Study has been made available to the Strategy. This includes new modelling of fluvial / tidal risk and mapping around Christchurch Harbour and has been used to inform the baseline assessment of flood risk in the harbour for the option appraisal and economic assessment. Figure 4-3 below shows the flood extent and depth for a present day 0.5% AEP return period event (1:200 year).

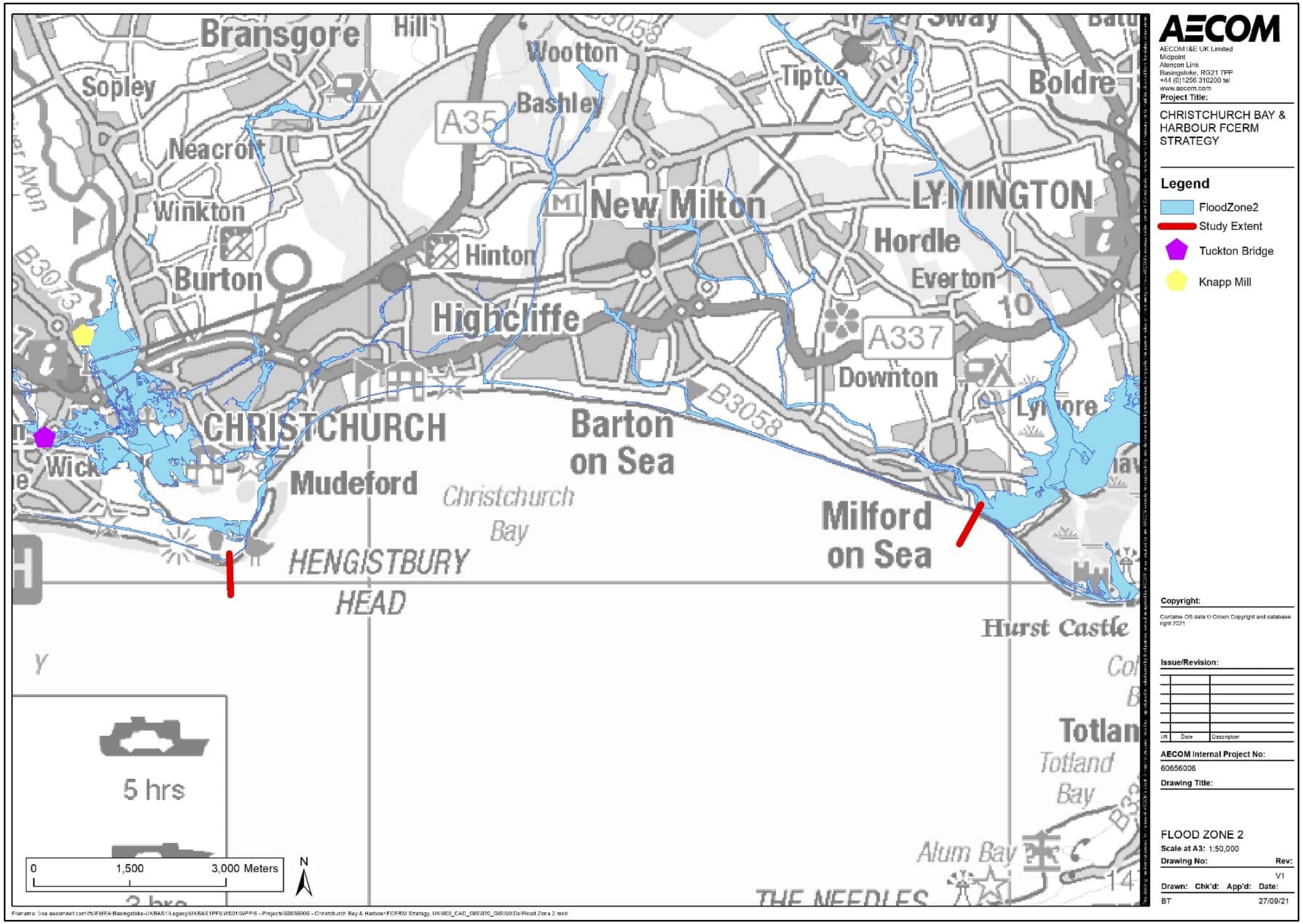


Figure 4-1: Environment Agency Flood Zone 2.

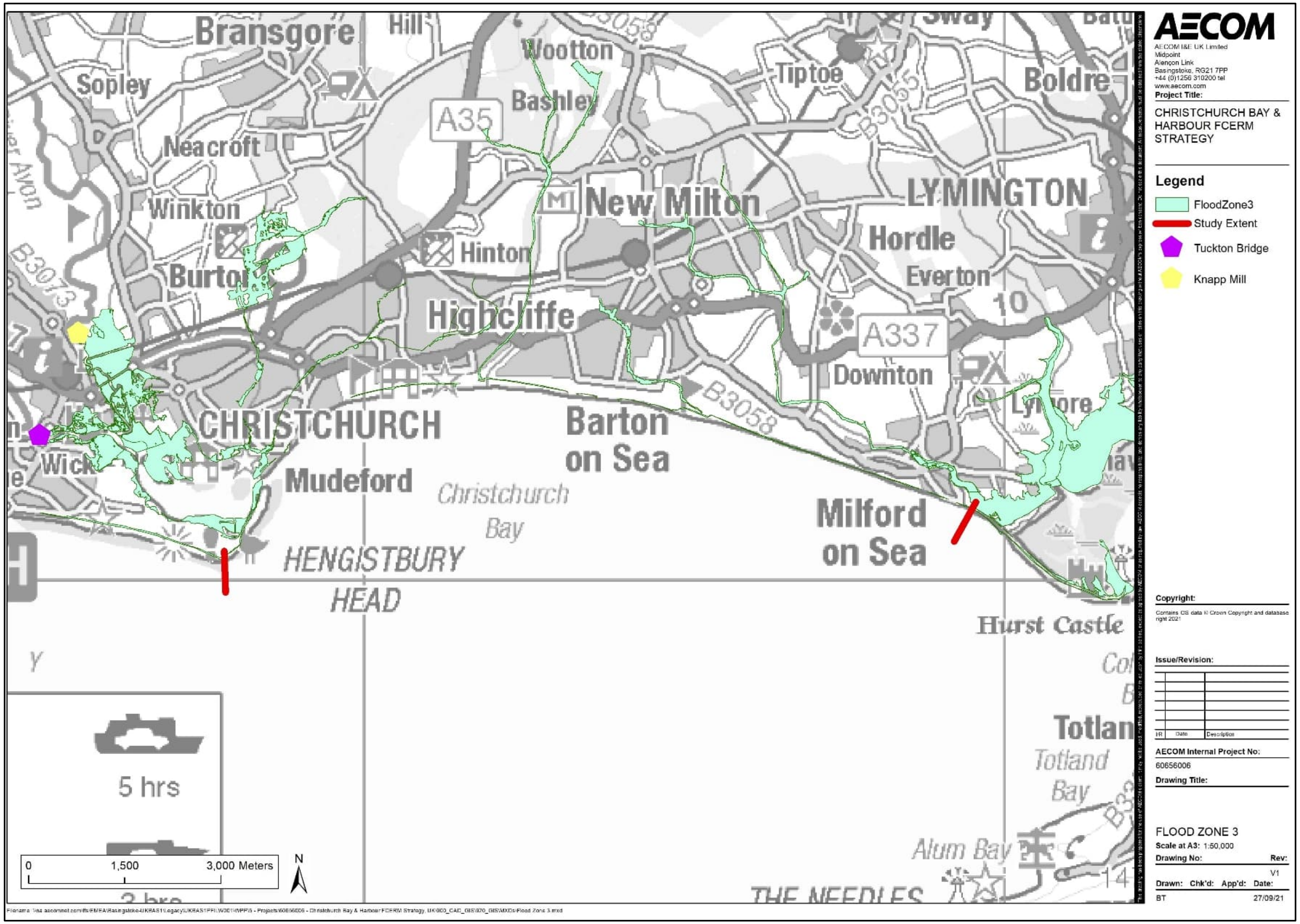


Figure 4-2: Environment Agency Flood Zone 3.

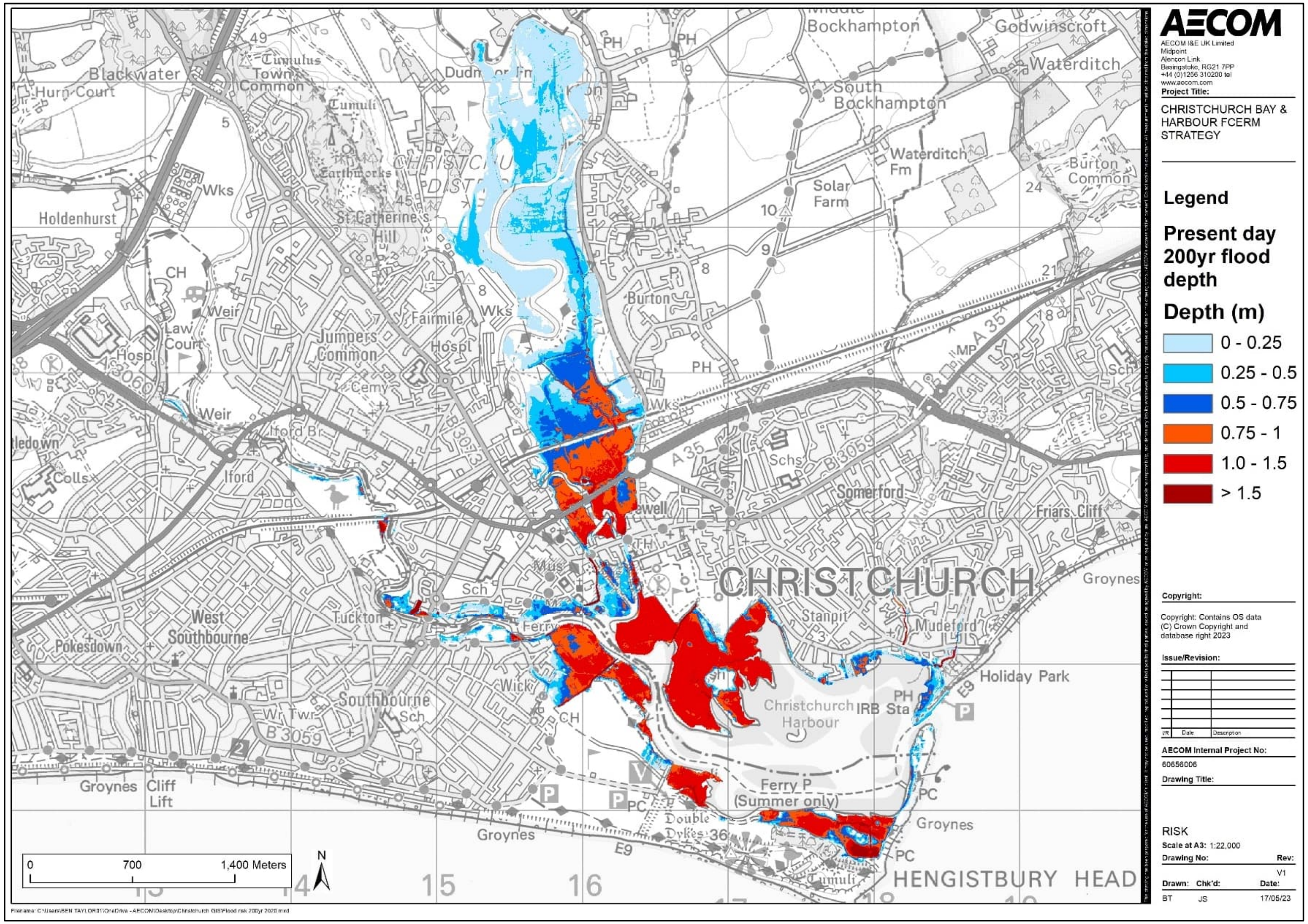


Figure 4-3: Present day 0.5% AEP coastal flood extent, as provided by the Lower River Avon Study (Environment Agency, 2022)

4.2 Coastal Erosion Risk

Coastal erosion zones for the frontage were produced in the Poole and Christchurch Bays Shoreline Management Plan 2 (2010). The zones for a No Active Intervention coastal management approach are presented in Figure 4-4 to Figure 4-6.

The location projected to erode the most over the next century by the SMP2 is the currently undefended Naish Cliffs immediately to the east of Chewton Bunny. At Chewton Bunny the coast transitions from a hard defended area at Highcliffe to the west (BCP frontage), to an undefended, actively eroding cliff line to the east (NFDC frontage). The management of the erosion at Chewton Bunny is an important element for the Strategy to consider. If left to erode naturally, there is a risk that the hard defences at Highcliffe could be outflanked, leading to the failure of the defences over time. The wider impact that this may have on sediment transport processes within the bay, and also on the coastline alignment is uncertain, but will be considered in more detail as the Strategy progresses.

With the exception of the Chewton Bunny area, the projected erosion is relatively uniform across the Strategy frontage with erosion areas generally increasing through time. The assets at risk from coastal erosion will be investigated in detail when developing the economic baseline and assessment.

Immediately to the east of the Strategy frontage, the erosion risk to Hurst Spit is not shown in Figure 4-4 to Figure 4-6 but remains an important consideration for the Strategy development as the spit is an important feature for the geomorphology of the bay and adjacent areas (i.e. Hurst to Lymington). The Hurst Spit to Lymington Strategy has estimated that Hurst Spit could potentially rollback in the order of 100-1000m with a Do Nothing scenario, which far exceeds the erosion rate at Milford on Sea. It is uncertain how the transition between the different retreat rates at Milford on Sea and at Hurst Spit would manifest. The most likely situation would be an increase rate of erosion at the transition between the two management units. A sensitivity analysis will be undertaken on the damages and benefits associated with a greater and lesser transition between the two erosion ates. In an event where the Spit breaches, the wave energy interacting with the coastline in the lee of the spit (i.e. Keyhaven) would expect to increase (the spit currently shelters this area). This would be expected to increase the flood risk in this area and also impact the saltmarsh habitat behind the spit.

More recently, the National Coastal Erosion Risk Mapping (NCERM) has been produced by the Environment Agency (original version 2012, updated in 2018). This GIS dataset shows the projected rate of erosion around the country's coastline from a base date of 2005. It is intended as an up-to-date and reliable benchmark dataset showing erosion extents and rates for three time periods; Short Term (0-20 years), Medium Term (20-50 years) and Long Term (50-100 years). It provides three confidence intervals for each time period; 5th, 50th and 95th for the No Active Intervention scenario and with implementation of SMP policies scenario. The dataset does not provide erosion zones but rather rates along a single polyline. For the purpose of this assessment and Strategy development, the rate values have been mapped in GIS to create erosion zones.

The NCERM dataset does not provide full coverage of the Strategy area and only has erosion rate projections for the area between Barton-on-Sea and Milford-on-Sea. The No Active Intervention scenario and 50th percentile rates for this area have been utilised to create the zones shown in Figure 4-7. Compared to the SMP erosion zones for this area, the NCERM dataset (50th percentile) shows a greater erosion area. This is also shown in Table 4-1, which shows the erosion distances between Barton-on-Sea and Milford-on-Sea. A decision on which dataset to use for the economic and option appraisal baseline will be taken in due course by the project team.

Table 4-1: Comparison of NCERM and SMP erosion distances in the area of overlap between Barton-on-Sea and Milford-on-Sea

Source	Time period	Erosion distance (cumulative)
NCERM	Short term (2005-2025)	Hordle Cliff – 40m Milford-on-Sea – 17m
	Medium term (2025-2055)	100m
	Long term (2055-2105)	200m
SMP	Epoch 1 (to 2025)	10-35m (varies)
	Epoch 2 (2025-2055)	35-80m (varies)
	Epoch 3 (2055-2105)	120-150m (varies)

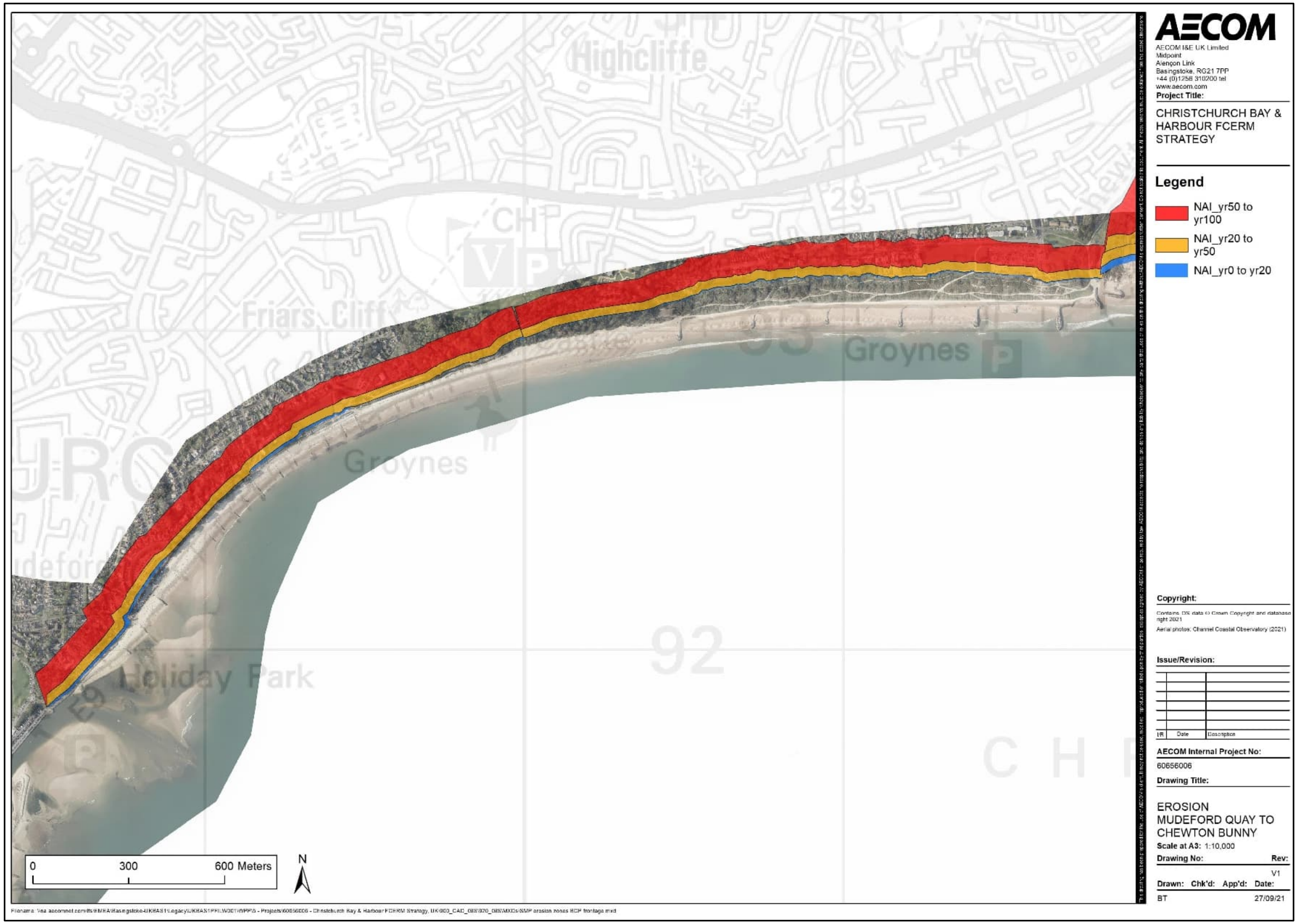


Figure 4-4: No Active Intervention Erosion Zones from the Poole and Christchurch Bays Shoreline Management Plan. Mudeford Quay to Chewton Bunny.

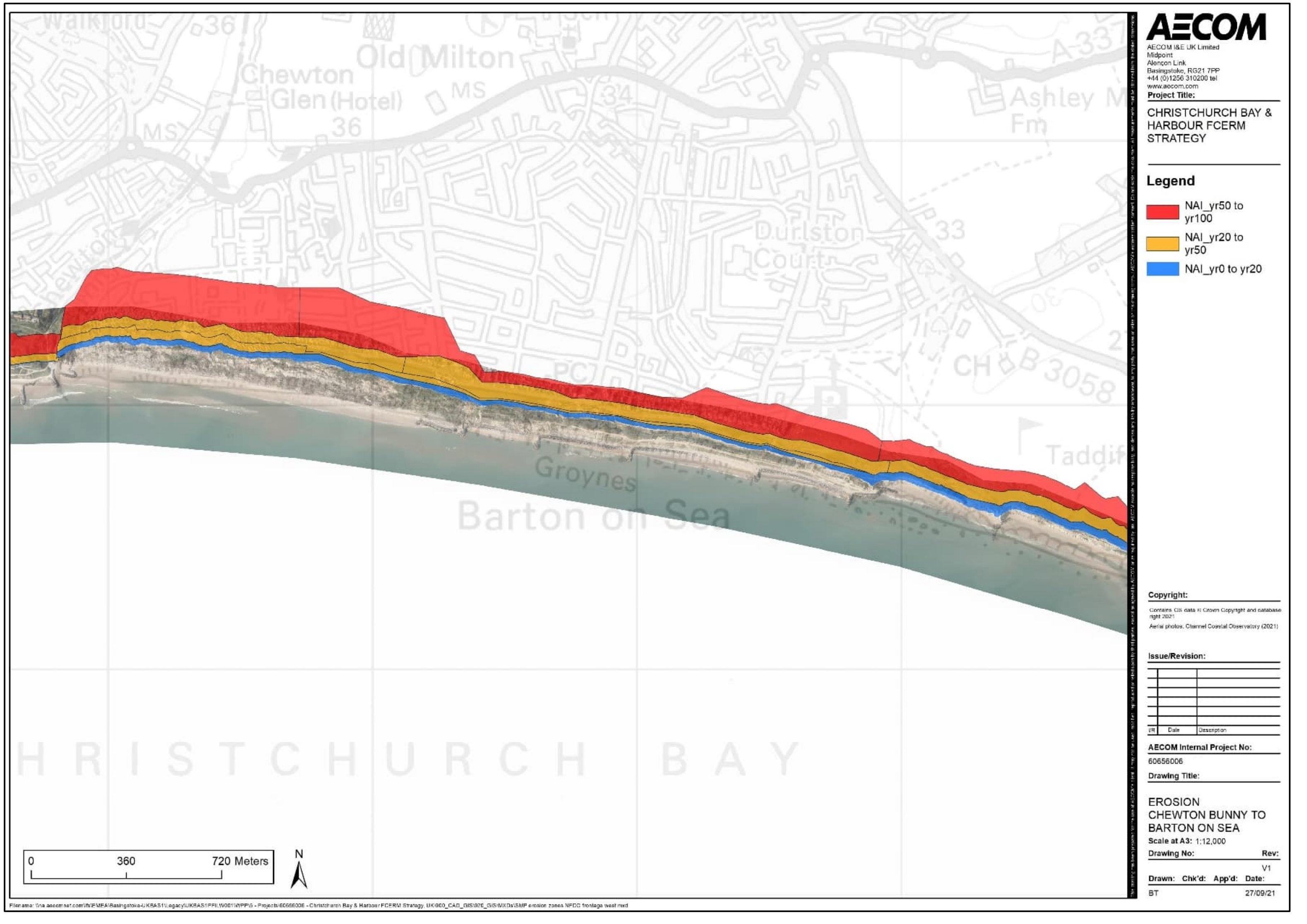


Figure 4-5: No Active Intervention Erosion Zones from Poole and Christchurch Bays Shoreline Management Plan. Chewton Bunny to Barton-on-Sea.

Figure 4-6: No Active Intervention Erosion Zones from Poole and Christchurch Bays Shoreline Management Plan. Barton-on-Sea to Milford-on-Sea.

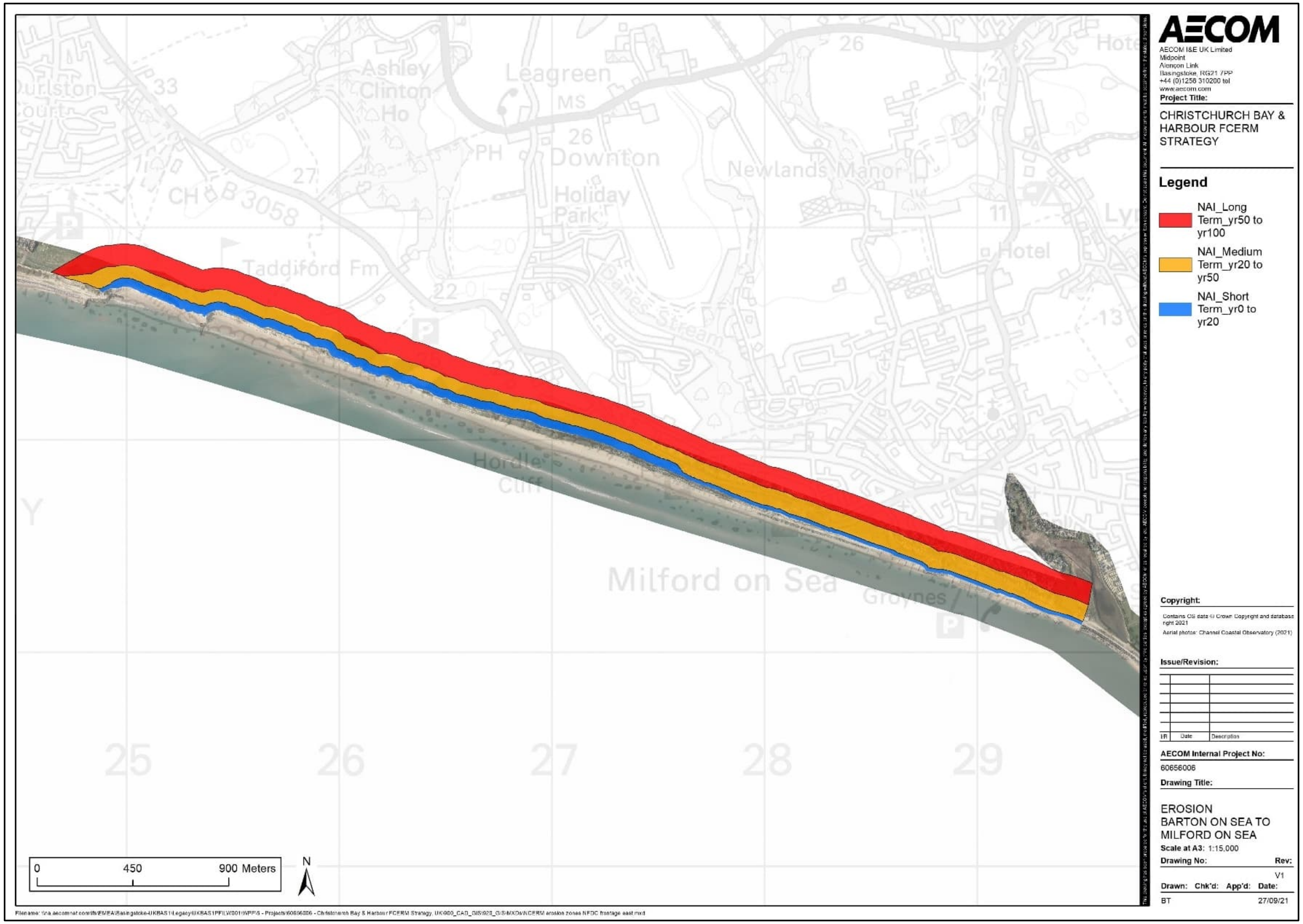


Figure 4-7: No Active Intervention Erosion Zones generated from the NCERM dataset. Barton-on-Sea to Milford-on-Sea.

5. Summary

This report provides details of the coastal processes within the Strategy area. A summary of the key points is provided below:

- The tidal regime within Christchurch Bay is complex due to the proximity of the Isle of Wight and propagation of the tide into the constricted entrance to the Western Solent. The local tidal range is relatively small, compared to adjacent locations along the South Coast, due to the small amplitude of the main semi-diurnal tidal harmonics.
- Current speeds within Christchurch Bay are typically weak with local increases due to shallow bathymetric features such as the Christchurch Ledge to the west and Shingles Bank to the east.
- Extreme tidal water levels for the Strategy frontage have been extracted from the Coastal Flood Boundary Dataset published in 2018.
- Based on the latest guidance, sea level rise is expected to be between 0.41-0.53m by 2071 and 1.03-1.39m by 2121 (according to the RCP 8.5 emissions scenario, 70^{th} and 95^{th} percentiles).
- Analysis of Milford wave buoy indicates that the dominant wave direction for the Strategy frontage is from the south-west sector. The 0.5% AEP return period significant wave height at the buoy is estimated to be 4.81m.
- Both the River Avon and River Stour flow into Christchurch Harbour and in 2015 a tri-probability study was undertaken by JBA (2015) to better understand the relation between extreme flood events in the River Avon, the River Stour and extreme water levels for the open sea. It was concluded that there is limited dependence between extreme river flows and water levels and noted that the limited 15-year record of coincident measured data means that the prediction of extreme conditions is subject to high uncertainty. A probabilistic approach involving multiple simulations would therefore be required for a more realistic assessment of flood risk.
- With respect to the geology of the area, soft Tertiary sands and clays are found across the coastal zone of the Bay. Hurst Spit at the eastern end is comprised of shingle deposits overlying a clay layer. From Milford-on-Sea to Hengistbury Head, the cliffs of Tertiary deposits reach heights up to 30m. Hengistbury Head is particularly important because it offers increased resistance to erosion due to the presence of ironstone nodules within the cliff material (Defra, 2002).
- Natural geomorphological coastal features within Christchurch Bay include Hurst Spit, Mudeford Sandbank and Hengistbury Head, each of which provides a controlling influence on the shape of the coastline.
- Much of Christchurch Bay is backed by eroding cliffs of up to 30m in height. The cliff-forming strata comprise Tertiary sands and clays (i.e. soft rock cliffs) which dip 0.5 to 1.0 degree towards the east-north-east and strike nearly parallel to the coastline, so that progressively younger beds outcrop from Hengistbury Head (Hengistbury Formation) to Hordle and Milford (Headon Formation). These substrate materials are overlain by a mantle of Pleistocene Plateau Gravels and thick Holocene brickearth deposits (SCOPAC, 2012).
- Christchurch Bay is widely regarded as a largely self-contained sediment circulation system with median sediment grain size generally increasing (coarsens) from west to east (SCOPAC, 2012). Littoral sediment transport is mainly from the west to east as a result of wave-induced currents acting in combination with the tides. A recent tracer pebble study at Milford on Sea and Hurst Spit demonstrates the dominant south-east direction of movement in this location, with some bypassing of coastal management structures noted. Tidal currents result in the offshore movement of finer sediments leaving the coarser material inshore. It is noted that whilst they are less frequent, storm conditions from the east/south-east are also able to mobilise large quantities of sediment over short periods which is then transported offshore.
- The Mudeford Sandbank is a sand spit feature extending from Hengistbury Head to the mouth of the Harbour. Breaching of the sandbank could potentially have much a wider impact in terms of future flood risk and habitat loss due to increased exposure of areas within the harbour to wave action and coastal flooding. Modelling of a breach scenario has been undertaken to support the Strategy development and further details can be found in the Christchurch FCERMS Modelling Report (AECOM, 2022).
- The beach levels along significant lengths of the Strategy frontage have eroded since the early 2000's. Of particular note are the levels at Milford-on-Sea, where low beach levels are thought to have been a contributing factor to the recent seawall failure (in early 2020) and also the promenade collapse in 2007. Parts of the Highcliffe to Mudeford Quay frontage are also eroding as are parts of Mudeford Sandbank and the

Becton to Hordle frontage. The main area of beach accretion is at the rock groyne section of the Highcliffe frontage, which has shown significant accretion since 2002 suggesting the rock groyne structures are working effectively in this location.

- The main intertidal habitats within Christchurch Harbour include mud/sandflats and saltmarsh areas. The future maintenance of these areas will rely on sediment supply, predominantly from the river, being able to keep pace with sea level rise. If there are constraints on the supply of sediment, the distribution of habitat type will change over time, potentially leading to the loss of both mudflat and saltmarsh. This process will be further exacerbated where these areas are backed by hard defences resulting in ‘coastal squeeze’.
- The tidal flood risk is concentrated around the low-lying Christchurch Harbour and at Milford-on-Sea at the eastern end of the Strategy frontage. Milford-on-Sea is lower lying than the open coast frontage to the west and is at risk of tidal inundation flooding from the Keyhaven area to the East (to the north of Hurst Spit). The risk of flooding from this direction will be assessed through collaboratively working with the adjacent Hurst Spit to Lymington FCERM Strategy. Parts of the open coast frontage at Milford-on-Sea are also at risk from wave overtopping flooding, such as around the Hurst Road East Car Park which has experienced wave overtopping in the past, and which may not be fully represented in the Environment Agency flood zones. Between Christchurch and Milford on Sea the topography is generally steeper with a high cliff line, ensuring the risk of sea flooding is low.
- The erosion risk along the frontage under a No Active Intervention coastal management scenario is relatively uniform. The area of Naish Cliffs to the east of Chewton Bunny is expected to have the greatest rate of erosion according to the Poole and Christchurch Bay Shoreline Management Plan projections. At Chewton Bunny the coast transitions from a hard defended area at Highcliffe to the west (BCP frontage), to an undefended, actively eroding cliff line to the east (NFDC frontage). The management of the erosion at Chewton Bunny is an important element for the Strategy to consider. If left to erode naturally, there is a risk that the hard defences at Highcliffe could be outflanked, leading to the failure of the defences over time.
- In the areas of overlap at Barton-on-Sea to Milford-on-Sea between the two erosion datasets (The SMP erosion lines and the NCERM erosion rates), the NCERM erosion rates exceed the Shoreline Management Plan rates.

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