S E A T O N B E A C H M A N A G E M E N T P L A N

Coastal Processes Baseline

Prepared for

East Devon District Council

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Contents

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SECTION 1

Introduction

1.1 Background and Study Area

This report has been prepared for East Devon District Council (EDDC), and their partner, the Environment Agency, as part of the Seaton Beach Management Plan (BMP). The BMP covers the coastline from Seaton Hole, in the west, to Harbour Wall, on the east side of the River Axe, and the Axe River up to the Axe Bridge, as shown in Figure 1.1.

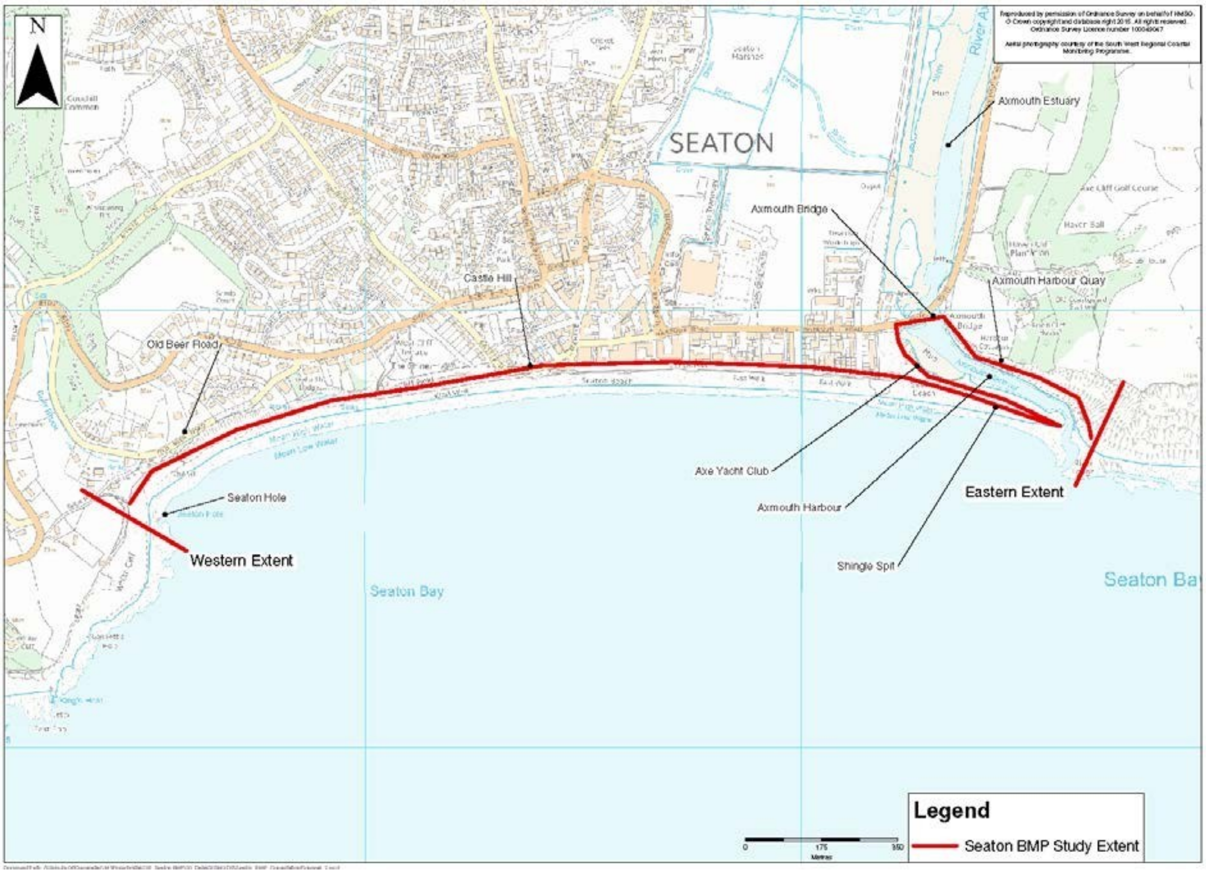


Figure 1.1 Seaton BMP Study Area

1.2 The Basis of this Report

This Coastal Processes Baseline Report is a supporting document to the BMP. Studies covering coastal defences, environment and economics are being undertaken separately and a detailed options appraisal will be completed as part of the BMP process.

Within the study area there are a number of issues relating to coastal flood and erosion risk management and it is important for these to be considered in order to define any future sustainable management activities within the BMP. This report aims to address the issues and questions that relate specifically to the coastal processes operating in the study area, and will be used to inform the management options stage of the BMP. A summary of the key issues and questions developed specifically to guide the development of this report in order to answer the broader objectives of the projects scope are presented in Table 1.1 below. The evidence to address these questions is provided throughout the report, with a final summary of all the findings presented in Section 7.

Table 1.1 Issues and questions to be addressed by the BMP

Issue	Question Number	Question
It has been speculated that infilling of the King's Eye Hole and construction of the concrete groyne at King's Hole (Beer) has reduced the volume of sediment reaching the Seaton coastline.	1	**Do sediment linkages exist between Beer and Seaton?**
	2	**Has construction of the concrete groyne at King's Hole (Beer) affected the rate/volume of material transported from Beer to Seaton?**
At the western end of the BMP frontage, near Seaton Hole, beach levels fluctuate considerably and the cliffs are eroding.	3	**To what extent has fluctuating beach levels influence erosion of the cliffs?**
Seaton has a long history of flooding, with overtopping of the seawall occurring during several storms. The beach fronting the Seaton seawall is observed to ramp-up against the seawall, which has been proposed to increase wave- run-up and overtopping.	4	**To what extent, and when, does the beach appear to build-up against the seawall at Seaton?**
For several decades, material dredged from the Axe Estuary has been disposed of within trenches dug into Seaton Spit. However, there are concerns that this practice is now threatening the integrity of the seawall at Seaton.	5	**How has the disposal of dredge material within Seaton Spit affected its behaviour and could it be detrimental to its integrity?**

SECTION 2

Information Reviewed

There are a number of existing studies that have been undertaken to examine the coastal processes operating along this coastline. These have been used to develop the baseline information presented in this report. Where there are data gaps, some new analysis has been completed as part of the present study, including an assessment of aerial imagery and detailed beach profile analysis.

The table below provides a summary of the key data sources that have been used to produce this report, including a brief description and details of how they have been used. A full list of references is provided in Section 8 of this report.

Table 2.1 Summary of key data sources used

Name of Report	**Author**	**Brief Description**	**How Utilised in this Coastal Processes Baseline**
Annual Monitoring	Plymouth Coastal Observatory (PCO), various	Annual monitoring reports are produced which assess the change in beach profiles. Topographic and hydrographic data is also collected and interrogated and the results provided within the monitoring report.	Used for baseline information. Data collected as part of the monitoring programme has also been used in this study including aerial photography and beach profile data, of which new analysis has been undertaken.
Sediment Transport Study update	SCOPAC, 2012	Overview of principle sediment sources and sediment transport mechanisms.	Used for baseline information.
South Devon and Dorset SMP2	Halcrow, 2011	An update to SMP1, provides a large-scale assessment of the risks associated with coastal evolution and sets high level management policy for the shoreline. Includes a baseline process analysis.	Used for baseline information and assessments of future shoreline change.
Futurecoast	Halcrow, 2002	A study completed in advance of the SMP2s to provide a detailed review of existing literature on coastal processes and historical shoreline change, as well as new predictions of future shoreline change for the coastline around England and Wales.	Used for baseline information and assessments of future shoreline change.
Seaton Coastal Study	Posford Duvivier, 1994	A review of coastal processes and erosion and beach depletion in 1989/1990 and 1992, identification of solutions to address beach depletion and any related constraints and benefits.	Used for baseline information.

SECTION 3

Physical Setting

The following section provides an overview of the physical setting of the BMP study area. It includes a description of the geology of the coastline and how it has changed over the Holocene to form the coastline present today, contemporary hydrodynamic influences on the shoreline and the sedimentary regime operating along the coastline. The information presented in this section draws from existing studies; a fuller explanation of the wider scale interactions can be found in Futurecoast (Halcrow, 2002), the South Devon and Dorset SMP2 (Halcrow, 2011), and SCOPAC's Sediment Transport Study update (2012).

3.1 How the Coastline Formed

3.1.1 Geological Evolution

Seaton is located on the fringe of the low-lying Axe Valley, which is bounded to the west and east by high cliffs and fronted by a barrier beach. The present-day coastline is a result of varying geology laid down over time, major geological earth movements and subsequent changes in sea level that has given rise to differential erosion. A summary of these key geological events is provided below, and draws from information provided by Seaton Museum (Seaton Museum, 2017) and SCOPAC (2012):

- Varying geology laid down during (some 252 to 66 million years ago (mya)):
    - firstly, mudstones (in the Triassic period, 252 to 201 mya),
    - followed by sandstone, then limestone, then chalk (in the Cretaceous period, 145 to 66 mya).
- Subsequent folding and faulting in response to major earth movements some 66 to 1.6 mya (during the Tertiary period):
    - During this time a major fault formed at a location now known as Seaton Hole, which caused the western side of the fault to drop relative to the east. This is evident today where the Cretaceous sandstone, limestone and chalk deposits that form White Cliff, lie alongside the mudstone cliffs that extend east from Seaton Hole to Seaton (as shown in Figure 3.1 and Figure 3.2).
- Sea level rise during the last interglacial (130,000 to 116,000 years ago) resulted in the formation of landsliding complexes (SCOPAC, 2012).
- Sea level fall (by up to 100m) during the last glacial (110,000 to 11,700 years ago) resulted in the weathering/mass movement of the cliffs via landslides to form debris slopes at the toes of the cliffs, specifically across the nearshore and offshore (Gallois and Davis, 2001).
- Most recently, sea level rise that began some 11, 500 years ago, resulted in different patterns of change (as described by SCOPAC, 2012):
    - Reoccupation of the debris slopes at the toe of the cliffs by the sea.
    - Mobilisation and evacuation of the debris.
    - New exposure of the cliffs to new weathering and erosion processes resulting in new cliff failures.
    - Continued coastal cliff recession and large-magnitude events, which created debris fans and boulder aprons.
    - Eastward and onshore transport of this debris is speculated to have resulted in the formation of a barrier beach, which lay seawards of the current coastline.

- Subsequent onshore migration of the barrier beach.
- Segmentation of the barrier as headlands emerged in the cliffs, resulting in the formation of pocket beaches.

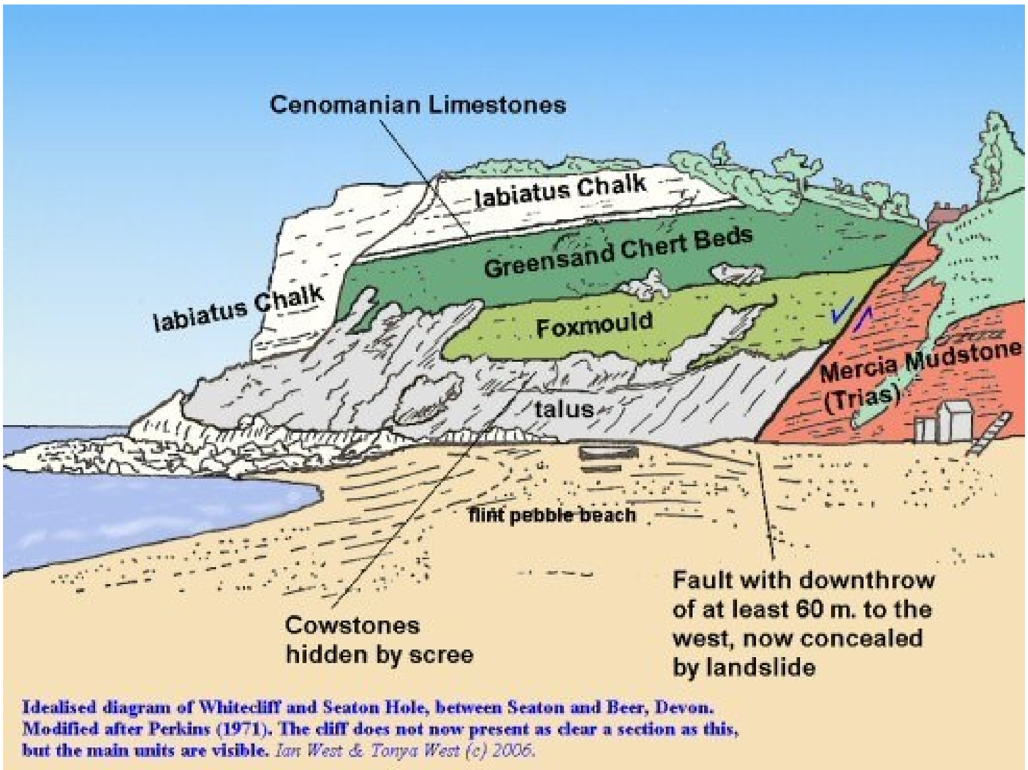


Figure 3.1 Juxtaposition of Triassic sandstone, chalk and limestones with Cretaceous mudstones at Seaton Hole
Source: Ian West and Tonya West © 2006, modified after Perkins (1971). Diagram used with permission of Dr Ian West (http://www.southampton.ac.uk/~imw/Beer.htm)

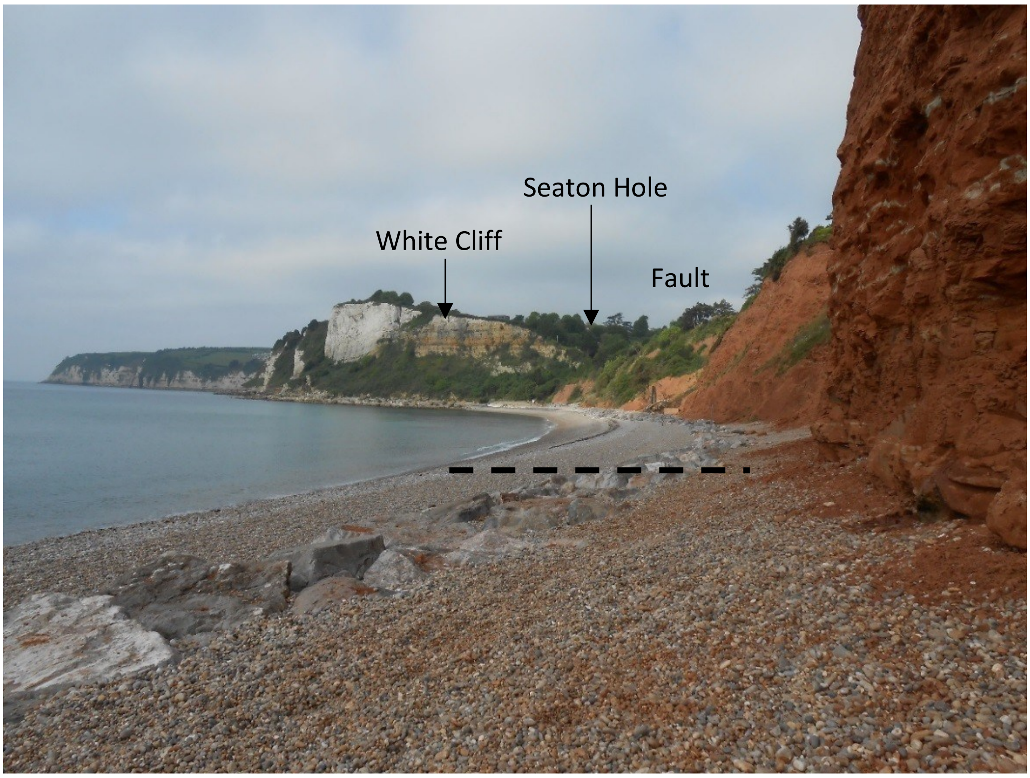


Figure 3.2 Photograph showing the geological fault at Seaton Hole
Photograph taken during site visit 24th May 2017, looking west

3.1.2 Geomorphological Evolution

At the very western limit of Seaton Bay, at White Cliff, the cliffs are high and steep and formed of sandstone, limestone and chalk that is largely resistant to erosion. Adjacent, the cliffs at Seaton Hole are high and comprised of sandstone overlying softer mudstone, but they reduce in height towards Seaton and the low-lying land of the Axe Valley as the overlying sandstone is replaced by the softer mudstone (Halcrow, 2011). A rock platform extends into the nearshore at White Cliff and Seaton Hole and there is also a small outcrop of rock in the vicinity of the Hideaway Café, as observed from aerial photography in Figure 3.3 and shown in the bathymetry in Figure 3.4. The rock platform is understood to be made of mudstone (Posford Duvivier, 1994).

The Axe Estuary is fed by the River Axe and River Coly. Large areas of saltmarsh and mudflat have formed by the accumulation of silt brought down by the rivers over a long period of time, however, today much of the original saltmarsh and mudflat has been reclaimed.

To the east of the Axe Estuary, the high cliffs are characterised by a complex coastal slope that is the result of long-sustained processes and products of landsliding (SCOPAC, 2012). Such landsliding can be triggered by a combination of prolonged intensive rainfall, ground water levels and the effect on rock structure, and marine toe erosion. As observed along the western limits of the study area, a rock platform extends seawards from the Haven Cliffs, at the mouth of the Axe Estuary; this is generally covered by beach deposits, but is occasionally exposed.

The cliffs and valley are fronted by a shingle barrier beach, comprised of a mix of boulder and gravel fractions (chert) in the vicinity of Seaton Hole, and flint and gravel (chert) between Seaton Hole and the Axe Estuary (SCOPAC, 2012). Eastwards of the Axe Estuary, the barrier is comprised of an increasing mix of coarse gravel and boulders fed by landslide debris (SCOPAC, 2012). A map showing the distribution of sediments on the beach, as recorded by PCO (2009), is presented in Figure 3.3.

The barrier beach is understood to have once been a long-continuous feature, located further offshore, that extended from Otterton Ledge to Chesil Beach, where it attaches to the Isle of Portland (SCOPAC, 2004). Gradual roll-back and retreat of the barrier in response to sea level rise and erosion processes, has resulted in the segmentation of the barrier between headlands (which formerly developed due to varying geological resistance to erosion (Halcrow, 2011)). Today, the barrier beach is nestled within discrete bays along the coast, such as at Beer and Seaton.

At the eastern end of the BMP study area, the barrier beach extends eastward from the foot of the cliffs at Seaton Hole and across mouth of the Axe Estuary, where it forms a spit and diverts the river mouth to the east. The spit is understood to have formed as a result of the longshore transport of material along the barrier beach from west to east (Halcrow, 2011), a process which discussed further in Section 3.3.2. Both the beach and spit are reported to have remained relatively stable, in terms of overall position, over the past 100 years, with short-term changes occurring in response to storms (Halcrow, 2011).

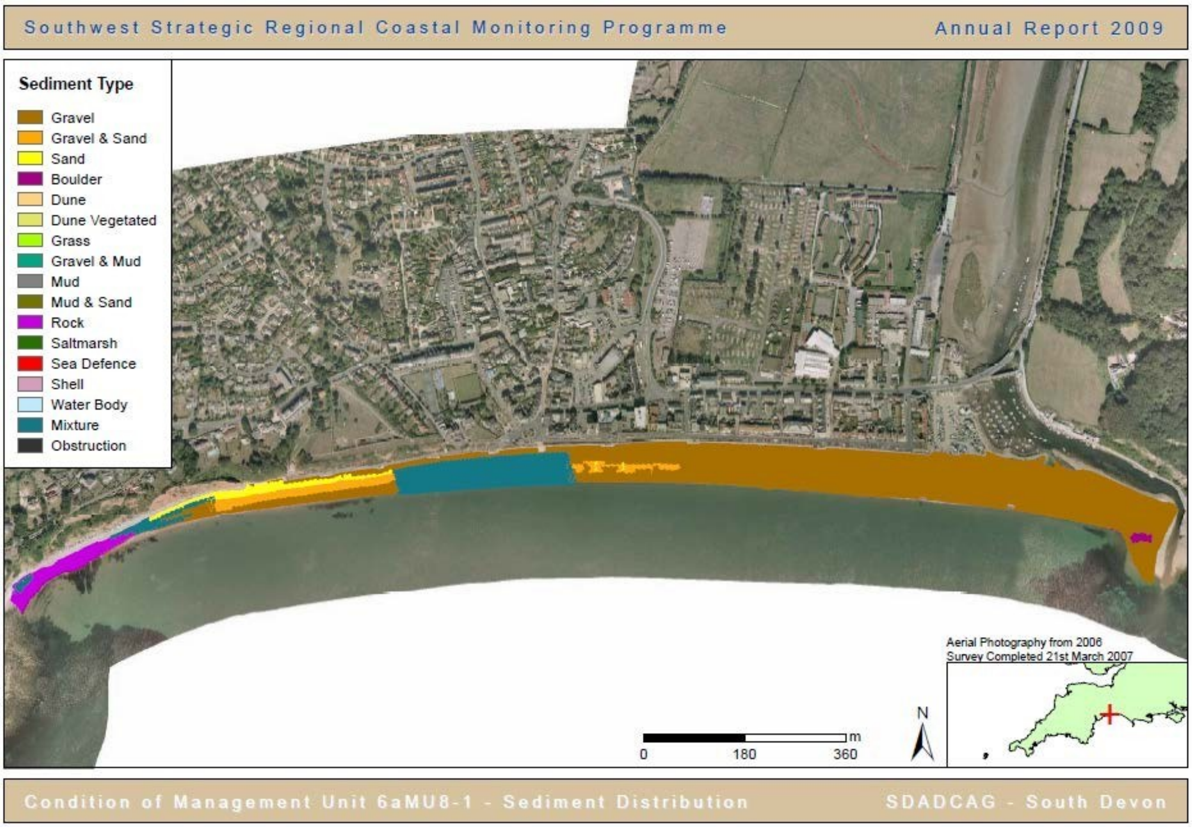


Figure 3.3 sediment distribution on the foreshore at Seaton
Source: PCO, 2009

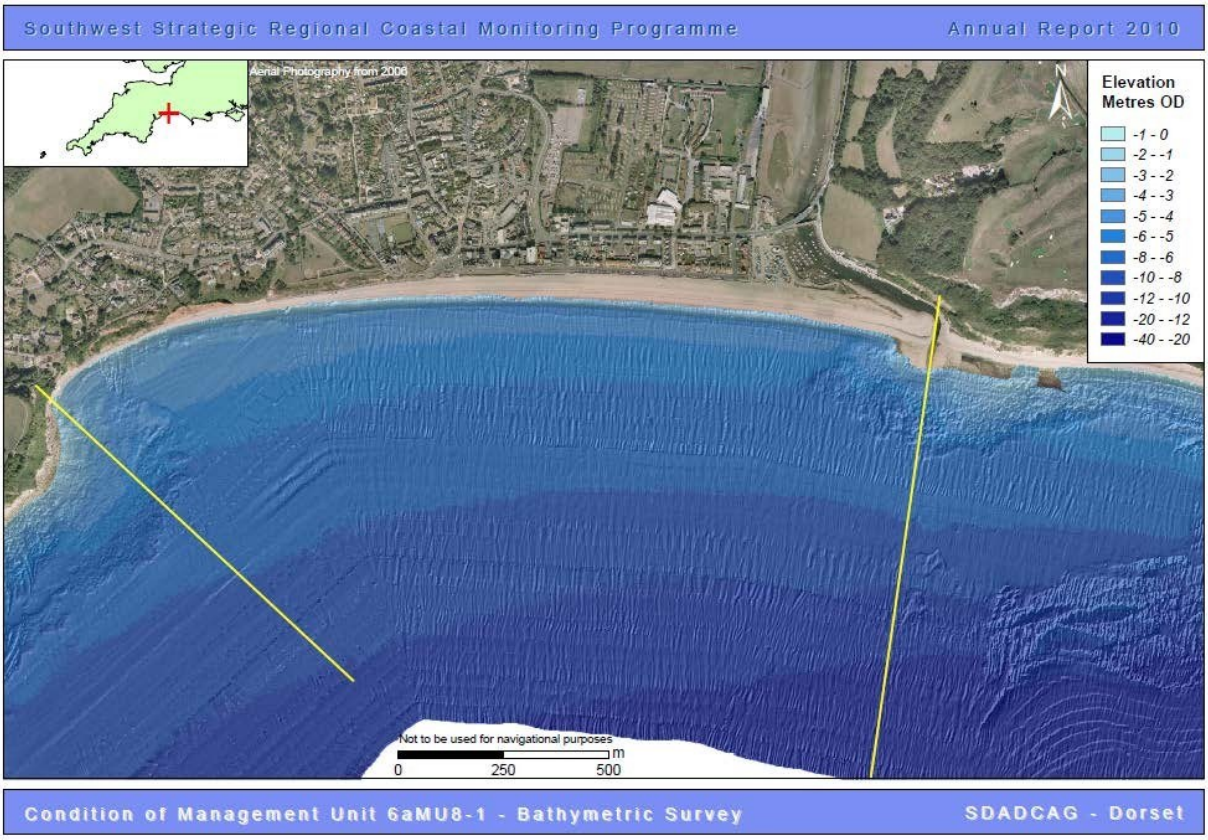


Figure 3.4 Bathymetry of the seabed in the vicinity of Seaton
Source: PCO, 2010

3.2 Tides and Waves

3.2.1 Tides

This is a meso-tidal coastline with a spring tidal range of 3.7m for Lyme Regis, the nearest tide data point to Seaton. A full list of tide levels for Lyme Regis is presented in Table 3.1.

A review of tidal currents was completed for the Seaton Coastal Study (Posford Duvivier, 1994). For a location 6km south-east of Beer Head, it is reported that tidal current speeds are low and on a spring tide, do not exceed 0.51m/s. Further inshore at Seaton, it is reported that there is a 2 to 3 knot (0.51 – 1.03 m/s) east to west tidal stream (*Pers. Comms.*, Angus Walker, 2017).

Table 3.1 Tide levels (mOD) Lyme Regis, the nearest tide data point to Seaton (UKHO, 2013).

Tidal Condition	Tide Level (mOD) (UKHO, 2013)
Highest Astronomical Tide (HAT)	2.45
Mean High Water Spring (MHWS)	1.95
Mean High Water Neap (MHWN)	0.75
Mean Sea Level (MSL)	0.09
Mean Low Water Neap (MLWN)	-0.65
Mean Low Water Spring (MLWS)	-1.75

3.2.2 Sea Level Rise

The anticipated implications of climate change for the south coast of England are accelerated sea level rise, increased wave heights and increased occurrence and severity of storms (Royal Haskoning, 2011). The latest sea level rise scenarios are provided in Table 3.2 and indicate that over the next 100 years, sea level rise could be in the order of 0.28m to 0.51m, depending on the scenario considered.

Table 3.2 Cumulative sea level rise scenarios (mm/year)
Based on data presented in UKCP09 and latest guidance issued by the Environment Agency 2011a[1]

Scenario:	Low 50%ile	Med 95%ile	Upper End*	Surge for Upper End	Upper End + Surge	H++
2017 to 2025	0.03	0.05	0.03	0.23	0.20	0.05
2017 to 2055	0.11	0.24	0.26	0.61	0.35	0.48
2017 to 2116	0.28	0.51	1.09	1.79	0.70	2.30

*Although the upper end value is actually less than the medium 95%ile derived from the UKCP09 data, it is based on data within the current EA guidance note (2016).

3.2.3 Extreme Water Levels

Still water level is defined as the water surface elevation at a point in time, including the mean sea level and storm surge (an increase in level caused by the effects of wind and atmospheric pressure changes associated with a storm), but excluding the effect of waves.

Extreme still water levels can lead to a risk of flooding and the level of risk will depend on the tide level and surge height at that time. For the purpose of coastal planning and design, a method has been adopted which enables predictions to be made about when and how frequently these extreme

[1] This guidance has been reissued (2016), but with no changes to the parameters used here.

water levels could occur. The method involves the statistical analysis of existing water level data to determine the likelihood of a particular water level occurring and expressing this in terms of levels attributed to their respective average return period and equivalent annual exceedance probability (AEP).

In 2011, the Environment Agency undertook a national R&D project (Environment Agency, 2011b) to estimate extreme water levels for a number of locations around the coast of England, Scotland and Wales, for a range of return periods. The relevant extreme water levels for Seaton are presented in Table 3.3, showing that for a 1:200 year event, extreme water levels could be in the order of 7.45mOD, increasing up to 8.12mOD in 100 years' time.

Table 3.3 Extreme water levels for Seaton
Sourced from: Environment Agency 2011b; levels based on 'Med 95%ile' sea level rise scenario; refer to Table 3.2

Year	***Increase in Sea Level (m)***	**Extreme Water Levels (mOD) by return period (1 in X years) and AEP (%)**								
		1 (100%)	**5 (20%)**	**10 (10%)**	**20 (5%)**	**50 (2%)**	**100 (1%)**	**200 (0.5%)**	**500 (0.2%)**	**1000 (0.1%)**
2017	0	2.7	2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4
2025	0.051	2.7	2.9	3.0	3.0	3.1	3.2	3.3	3.4	3.5
2055	0.209	2.9	3.1	3.2	3.2	3.3	3.4	3.5	3.6	3.6
2117	0.671	3.2	3.4	3.4	3.5	3.6	3.7	3.7	3.9	3.9

3.2.4 Typical Waves

Measured wave data in the vicinity of the BMP study area does not exist, so typical wave conditions for Seaton have been obtained from modelled data. These models utilise real-time data from wave buoys; these buoys are located at specific locations along the coast and the models generate a synthetic record of wave climate for locations in-between. The models include a wave hindcast model undertaken by the Met Office, and more recently, an inshore wave model, undertaken by HR Wallingford on behalf of the Environment Agency. More details regarding the collection of real-time wave data and the models used are provided below in Section 3.2.4.1, along with a summary of the modelled wave conditions at Seaton in Section 3.2.4.2.

3.2.4.1 Wave Modelling Background

- Measured wave data is collected via two Datawell Directional Waverider MkIII buoys, both of which are operated by the Channel Coast Observatory (CCO). The first is located to the west at Dawlish and the second located to the east at West Bay (see Figure 3.5). The buoys form part of the strategic wave monitoring network, 'Wavenet', run by the Centre for Environment, Fisheries and Aquaculture Science (Cefas), and which provide a single source of real-time wave data for areas at risk of flooding around the UK.
- The Met Office use the data collected by the Waverider buoys to run a wave hindcast model (WaveWatch III), which is runs from January 1980 to the period when data was last collected (at time of writing, this is December 2016). This model generates a synthetic record of offshore waves for a 10,000-year record of over 500,000 events for a series of data points along the coastline (as shown by the dots in Figure 3.6). The data point closest to Seaton is '406', as also shown in Figure 3.6.
- As part of the Environment Agency's SON project to improve knowledge of coastal boundary conditions (i.e. water levels and waves), the Met Office wave hindcast model outputs were used to run a wave model (SWAN) to provide data on the inshore wave climate around the UK coastline. Similarly, to the Met Office model, there are a series of data points, the closest to Seaton being '1011', as shown in Figure 3.7.

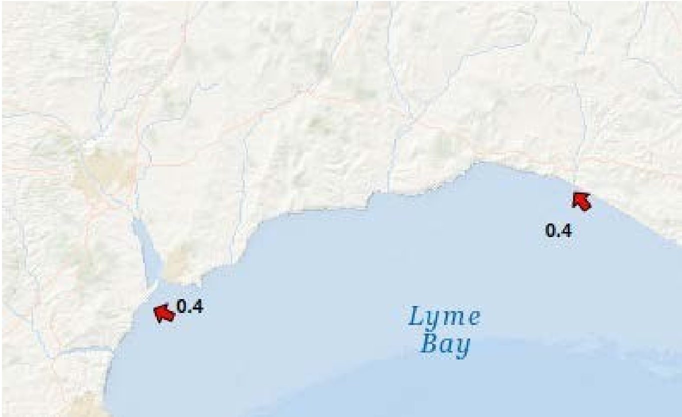


Figure 3.5 Locations of Cefas 'Wavenet' Datawell Directional Waveride buoys, including Dawlish and West Bay
Source: http://wavenet.cefas.co.uk/Map

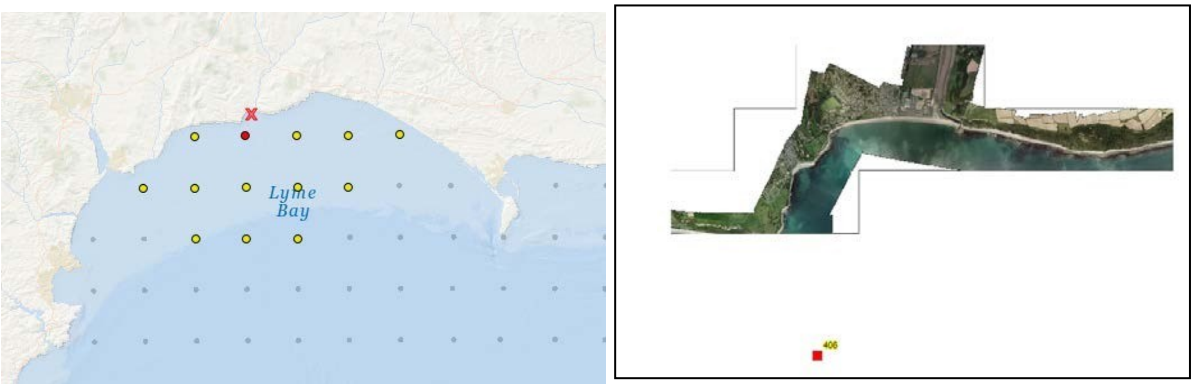


Figure 3.6 Met Office hindcast model data points (yellow dots), with data point '406' shown by red dot and 'x' on the left and a red square on the right
Source: http://wavenet.cefas.co.uk/hindcast

Figure 3.7 Map showing location of SoN data point, 1011', which is located closest to Seaton

3.2.4.2 Modelled Wave Data for Seaton

The offshore wave climate at Seaton is dominated by prevailing waves from the south west and south south-west (refer to Figure 3.8). However, the inshore wave climate at Seaton is dominated by a predominant south and south-south-westerly wave regime, with less frequent waves approaching from the south and south-south-east (refer to Figure 3.9). SCOPAC (2012) report that the coastline at Seaton is afforded a degree of shelter from incoming south and south-westerly waves by Beer Head (SCOPAC, 2012).

In a previous modelling exercise for the Futurecoast project (Halcrow, 2002), offshore wave data from the Met Office Wave Model was transformed inshore to a prediction point off Seaton at -4.37mO.D; the results indicate a dominance for south-easterly conditions, as shown in Figure 3.10. This difference may reflect changes in the real-time data or differences in the modelling approaches taken.

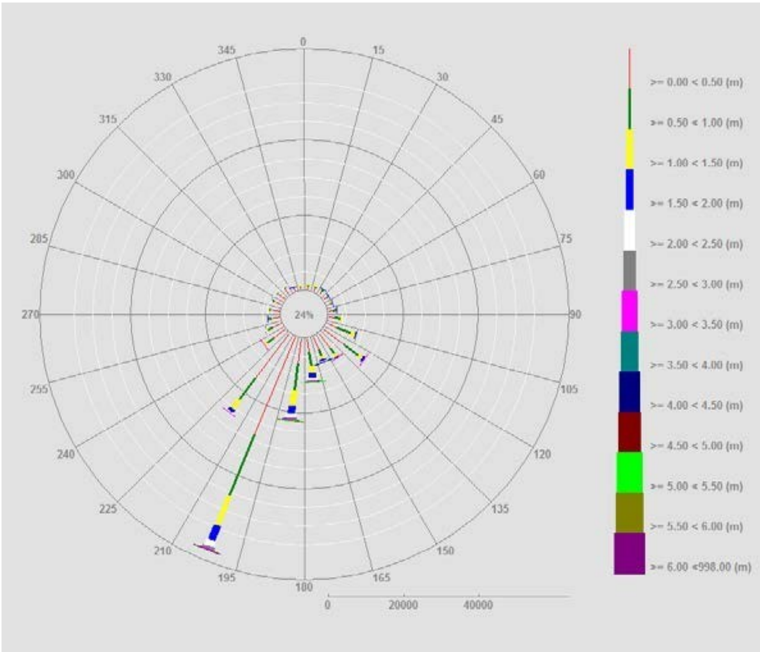


Figure 3.8 Offshore wave conditions at Seaton

Met Office WaveWatch III hindcast wave record for location '406' between 1/1/1980 and 31/12/2016

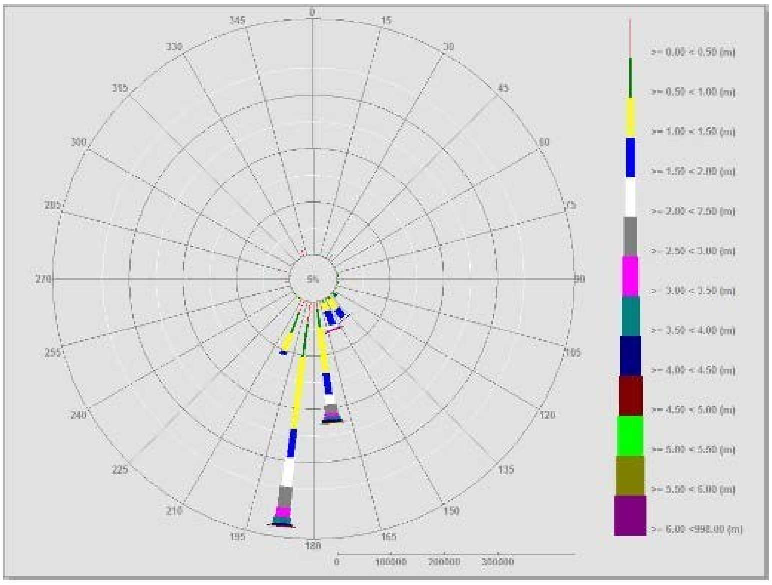


Figure 3.9 Inshore wave conditions at Seaton, generated from SoN data

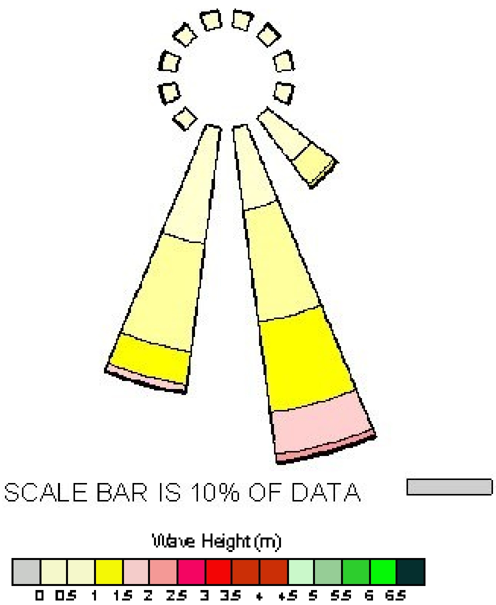


Figure 3.10 Results of wave modelling for Seaton
Source: Halcrow, 2002

3.2.5 Storm Waves

No data on storm waves in the vicinity of Seaton was available at the time of writing this report. A history of past storms events, their direction and the impact that they had on the coastline is provided in Section 4, Shoreline Appraisal and Issues, Table 4.4 and Table 4.5.

3.2.6 River Flow

Little is documented on the flow of water through the estuary, however, Halcrow (2002) report that there is a mean discharge of 5 cubic metres per second (cumecs), increasing to a maximum of 108 cumecs in flood.

3.2.7 Flood Risk

The coastline at Seaton has a long-history of flooding. As documented by Posford Duvivier (1994), storm events have resulted in flooding at Seaton several times in the past including November 1924, January 1925, December 1978 and February 1979. The flooding that occurred in February 1979 was severe and in response a new seawall was constructed, however, more flooding occurred following a storm in December 1989, when the seawall was overtopped (more detail is provided in Section 4.3.2). A number of flood events along the Seaton frontage have occurred since, including 2006, when insufficient warning to close the flood gates resulted in overflow through the gates and flooding of the seafront, and in 2014 when the seawall was once again overtopped. It was also noted during the project site visit on the 25th May 2017, that the Axe Yacht Club boat yard is regularly flooded by storm waves that enter through the estuary.

Future anticipated flood risk can be determined by taking account of the presence of coastal defences, the height of shoreline and the hydrodynamic conditions being considered, i.e. extreme still water levels, return period and the inclusion of wave run-up and wave overtopping. Flood risk mapping completed by the Environment Agency (presented in Figure 3.11) shows the predicted areas of land that could be inundated by coastal water in the absence of defences/channel improvements and under two scenarios;

- Flood zone 3: shows the area that could be affected by flooding:
    - from the sea by a flood that has a 1 in 200 year return period (or a 0.5% chance of being exceeded in any year);

- o or from a river by a flood that has a 1 in 100 year return period (or a 1% chance of being exceeded in any year).
- Flood zone 2: shows the area that could be affected by extreme flooding from the sea and rivers, with a 1 in 1000 year return period (or a 0.1% change of being exceeded in any year).

It should be noted that the flood zones are a projection of still water level, and do not include wave run-up or wave overtopping. However, recent work completed for the Lyme Bay Coastal Flood Forecasting Phase 2 shows the present-day flood risk from wave overtopping of coastal defences under a range of extreme return period events (refer to Figure 3.12).

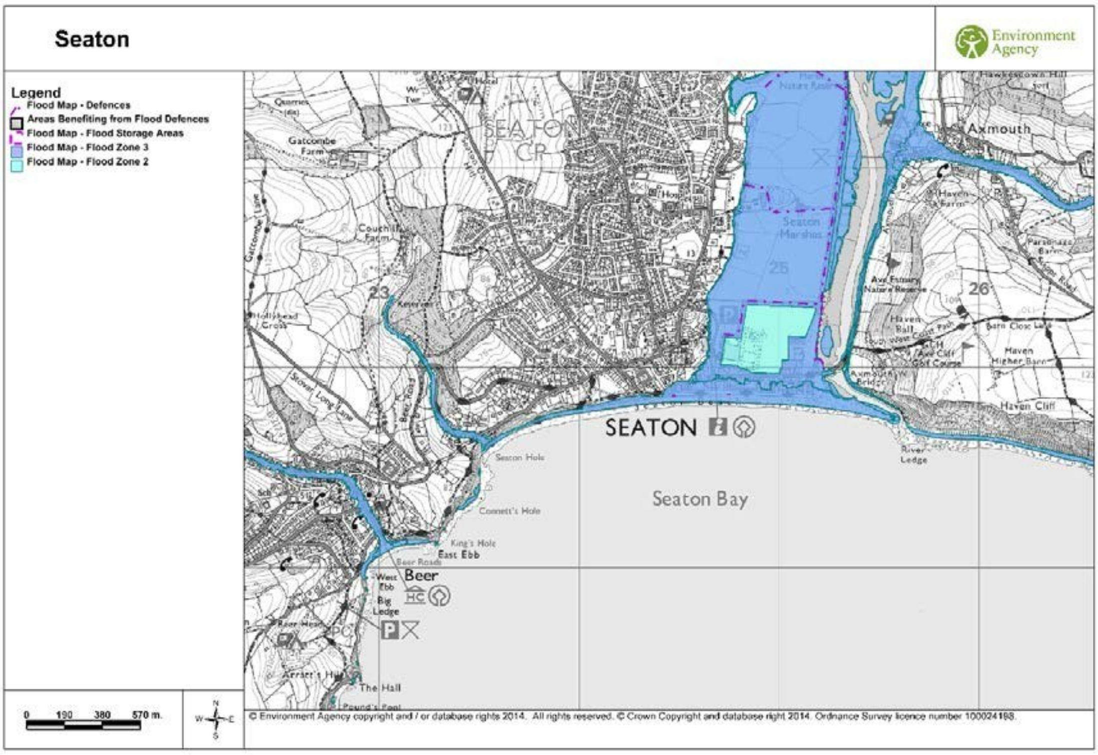


Figure 3.11 Flood Risk Map

Source: Latest mapping sourced from Environment Agency for this project

Figure 3.12 Present Day Flood Risk from Wave Overtopping of Coastal Defences Under a range of Return Periods

Source: CH2M, 2017b

3.3 Sediment Dynamics

SCOPAC (2012) produced a map of the principle sediment sources and sediment transport mechanisms for the area between Beer Head and Lyme Regis, refer to Figure 3.13. A summary of the sediment sources and sediment transport in and directly adjacent to the BMP study area are provided in Sections 3.3.1 and 3.3.2 and respectively.

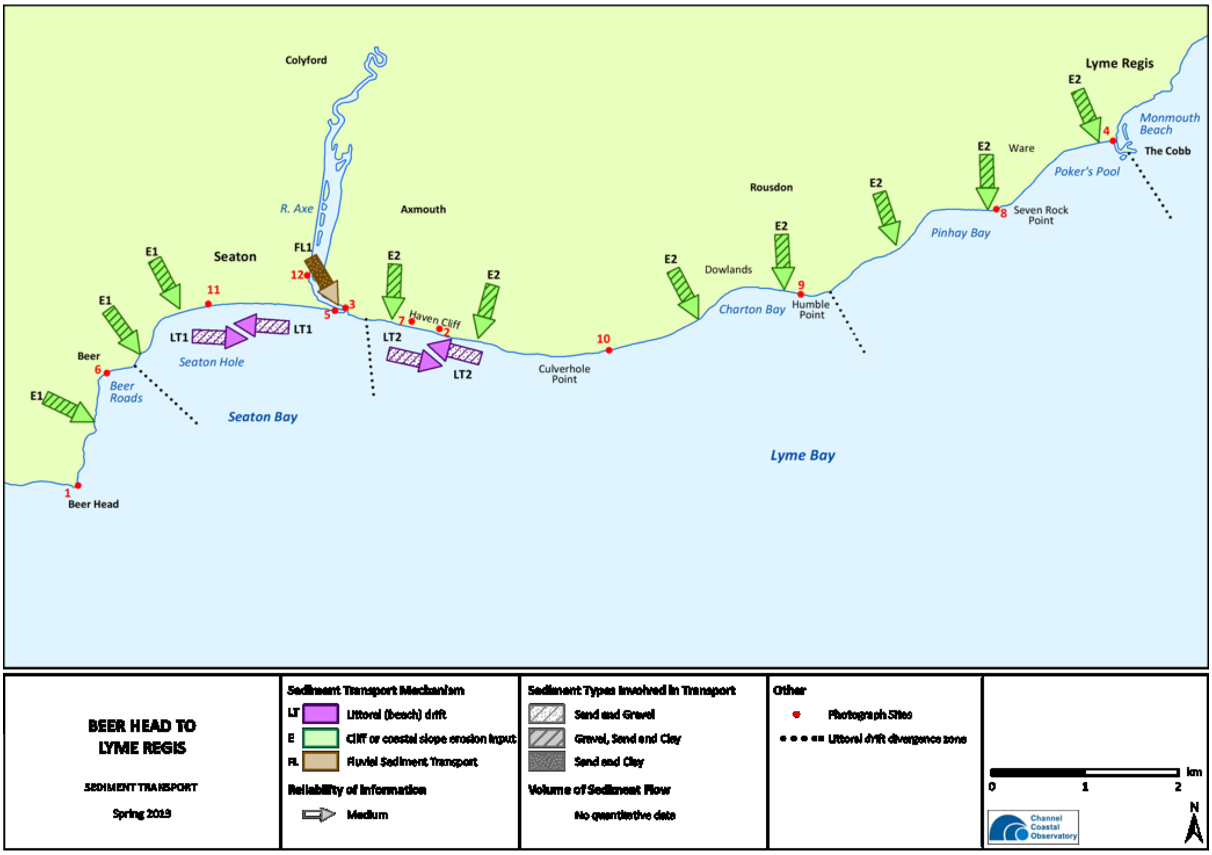


Figure 3.13 Sediment transport at Seaton and the surrounding area

Source: SCOPAC, 2012

3.3.1 Sediment Sources

Sediment is sourced from a number of locations within the study area; these are described below.

1. Erosion of the sandstone, limestone and chalk cliffs at White Cliff, however, they are largely resistant to erosion and protected at to some extent by the talus at the toe, so inputs from the cliffs are likely to be small.

2. Erosion of the mudstone cliffs between Seaton Hole and Seaton provides a source of fine sediment to the beach below (Halcrow, 2011), as observed during the Defence Condition Assessment being undertaken for the BMP, and as shown in Figure 3.14. Past estimates of sediment supply suggest that the input is small (Posford Duvivier, 1994), but Posford Duvivier and British Geological Survey (1999) calculated a contemporary yield of approximately 6,000m^3 per year (all fine sediment). A further 12,000m^3 per year of fine material was calculated as being supplied from erosion of the shoreface. However, SCOPAC (2004) reported a high level of uncertainty regarding this supply.

3. There is a supply of sediment from the River Axe/River Coly into the Axe Estuary, which Rendel Geotechnics and the University of Portsmouth (1996) have estimated to be 600m^3/year of fine sediment and 100m^3/year of coarse sands and gravels. There is strong ebb tide flushing of material entering the Axe inlet from seaward, however, it remains uncertain as to how much of this material is stored in the estuary and how much is flushed back out from the estuary (SCOPAC, 2012).

4. Erosion of material from the cliffs east, however, quantities and transport pathways are uncertain.
5. Onshore supply of fine sediment (clay, silt and fine sand) (SCOPAC, 2012), initially eroded from the cliffs updrift and downdrift of Seaton before being transported offshore in suspension, and then back onshore, but to a different location under suitable hydrodynamic conditions.

Figure 3.14 Photographs showing release of fine material from eroding cliffs directly onto the beach
Photographs taken during Defence Condition Assessment 14th June 2017, facing east

3.3.2 Sediment Transport Pathways

The key sediment transport pathways into, along and from the BMP study area include:

- Tidal currents, both offshore and inshore of Seaton, are reported to be low (refer to Section 3.2.1), and are incapable of transporting gravel, although have the capacity to move finer grained material along the coast (Posford Duvivier, 1994).
- A net eastwards longshore movement of gravel and sand, which occurs in response to the dominant wave influence from the south, south-south-west.
    - Generally, there is no discernible net transport between the discrete and closed pocket beaches at Beer, Seaton and the coastline to the east (SCOPAC, 2012). However, when wave energy is particularly intense, it is thought that there may in fact be some connectivity (SCOPAC, 2012), with the potential for transfer between Beer, Seaton and the coastline to the east. This is evident from observations made at Beer, where has been a build-up of beach material in the lee of the concrete groyne, refer to Figure 4.2.
    - Studies indicate a net west to east movement of gravel and sand material along the coastline along the BMP study area in response to this predominant wave direction (Posford Duvivier, 1994 Halcrow, 2011; SCOPAC, 2012). This is also evident by the presence of the spit that acts to deflect the Axe Estuary mouth to the east. Rates of longshore transport are considered to be low and intermittent, and estimated to be in the order of 3,000 to 3,600m³ per year (Posford Duvivier, 1994).
    - It is thought (Posford Duvivier, 1998a, 1998b; Futurecoast, 2002; SCOPAC, 2004; 2012) that there is also some sediment transport eastwards across the mouth of the estuary. SCOPAC (2004) provides a probable mechanism for this process: (i) firstly material enters the channel from the west driven by wave action (as well as small amounts of shingle from fluvial processes) and then, (ii), this is then flushed a short distance offshore by a combination of tidal and river flow, before being moved back onshore by wave action.

- A net westward movement of sediment (drift reversal) can occur under during periods when high-energy south-easterly winds and waves are prevalent, usually during the winter (SCOPAC, 2012). It is observed from aerial photography that the Axmouth harbour arm traps some of this material, however, the extent to which material accumulates in its lee is unknown. Posford Duvivier (1998a) suggest that there may be a drift divide at, or close to, Culverhole Point (located approximately 2km to the east of Seaton), with east to west movement along the gravel and boulder beach towards Axmouth:
    - Posford Duviver (1994) suggest that prolonged/extreme easterlies bring sediment to Seaton beach, where it accumulates and naturally replenishes the beach.
    - Material is not thought to move directly across the mouth of Axe Estuary (Posford Duvivier, 1994), but is firstly drawn seawards towards the bar/delta from where it makes its way westwards. In doing so, material is reported to bypass the training wall in the mouth of Axe Estuary during storms.
- Local variations in drift direction are also reported to occur as a result of:
    - The rock outcrops (rock platforms, namely at Seaton Hole and at several sites between Haven Cliffs and Pinhay Bay (Pitts, 1983)); and
    - Changes in the incident wave direction; it is reported that gross drift rates are potentially high over short periods and can operate in both east to west and west to east directions (Posford Duvivier, 1994; Axe Yacht Club, 2001).
- Approximately 1,500m^3/year of material is currently removed from the harbour within the Axe Estuary, via dredging practices, and disposed of within the Axe Spit; these operations are discussed in more detail in Section 4.4.1.

SECTION 4

Shoreline Appraisal and Issues

This coastline between Seaton Hole and the Axe Estuary has been subject to much change over time, with changes in land use and the construction of coastal defences along the length of the coastline. This section of the report includes an appraisal of the shoreline, including a review of the local geomorphology of the coastline, its history in terms of coastal defence, and shoreline change. Key issues relating to the shoreline have been identified as part of the BMP (refer to in Section 1.2) and where appropriate new analysis has been completed to help address these issues and answer the questions raised.

Considering the geomorphology of the shoreline and the defence history, the coastline has been divided into a series of units, and appraised accordingly. The units are listed below and shown in Figure 4.1. It is important to consider the linkages with the coastline downdrift and updrift of the study area as changes at these locations can have a direct influence on the coastline at Seaton. Therefore, for this section of the report only, consideration is given to the coastline downdrift, at Beer, and updrift, at Haven Cliff.

1. Beer
2. White Cliff
3. Seaton Hole to Seaton Spit, including sub-units Seaton Hole to West Seaton and Seaton and Seaton Spit
4. Axe Estuary
5. Haven Cliff

Figure 4.1 Map showing coastal units defined for the BMP

4.1 Beer

It is understood that limited sediment transport takes between Beer and Seaton since Beer Head forms a barrier to longshore transport towards the east. However, the rock platform (discussed in Section 3.1.2) could provide a route for the transport of coarse sediment around the headland and it is suggested that there could be periodic pulses of sediment transported around the headland during certain events (Halcrow, 2011). The infilling of King's Eye Hole and the construction of a concrete groyne at King's Hole at Beer during the early 1970s has reduced/inhibited longshore transport to the east and resulted in accretion of the beach there (SCOPAC, 2012). This is evident from a review of historical photographs held by the Seaton Museum, which showed a much narrower beach at Beer in 1877 compared to 2016 aerial imagery, which is shown in Figure 4.2; and LiDAR data, which has been collected as part of the South West Regional Coastal Monitoring Programme and shows accretion between March 2006 and March 2017 (refer to Figure 4.3). Unfortunately, beach profile data is not collected at Beer, so it has not been possible to quantify the changes observed and determine how they may link to the coastline at Seaton, Therefore, it is only observed from the aerial photography and LiDAR, that the material that has built-up in the lee of groyne could have otherwise been transported to Seaton.

Figure 4.2 Photograph showing infilling of King's Eye Hole (left) and aerial photograph showing the concrete groyne at Beer (right)

Source: Left – Dave Turner, EDDC and Right – © 2015 Google Earth

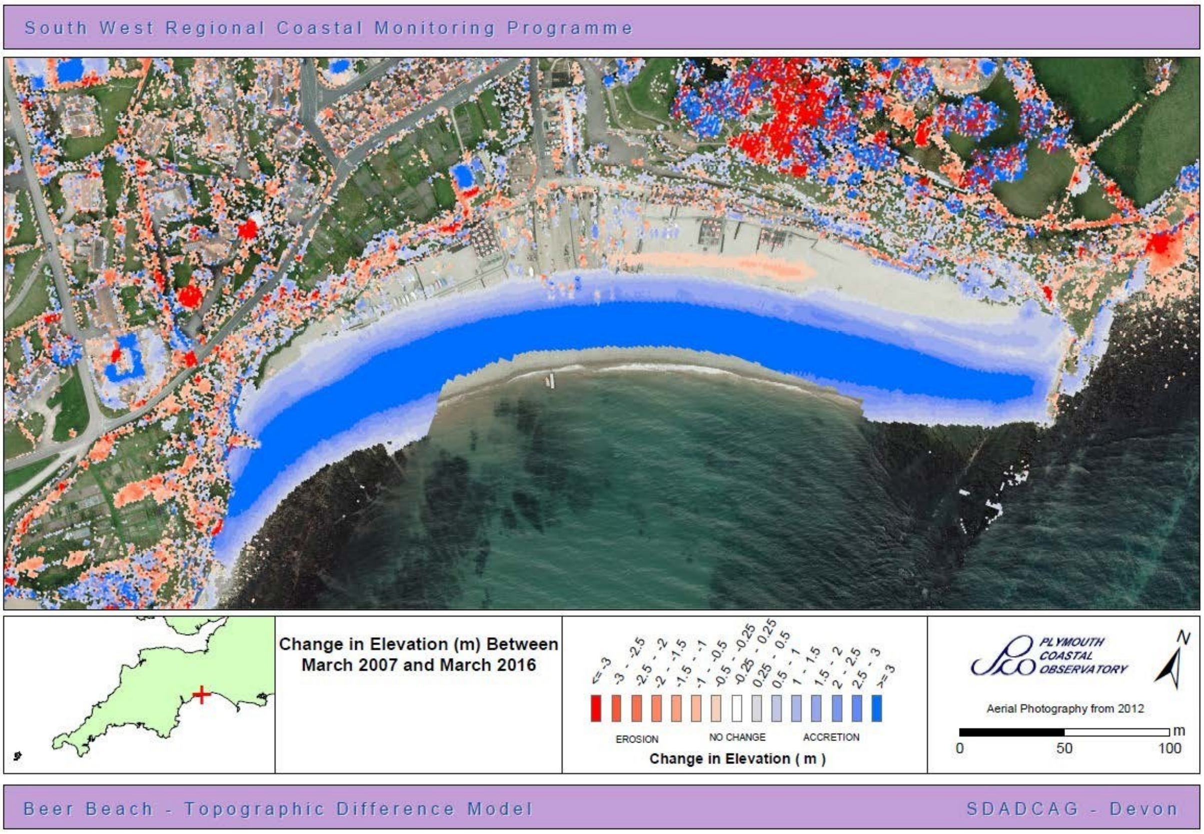


Figure 4.3 Aerial photograph showing the concrete groyne at Beer

4.2 White Cliff

The cliffs between Beer Head and Seaton Hole are comprised of sandstone, limestone and chalk and have been largely unchanged over the past century, with only infrequent, localised failures occurring (SCOPAC, 2012). Erosion generally occurs via cliff failure, such as rockfalls and landslips. The cliff face is sheer with a debris toe at the bottom that is covered by vegetation and consists of large rock boulders and is fronted by a shingle beach and rock platform (comprised of mudstone) (refer to Figure 4.4).

White Cliff, between Seaton and Beer Head, is recorded to have been relatively stable between 1903 and 1933, with an isolated area of 10m erosion along the cliff top, opposite Cliff Edge House (Posford Duvivier, 1994).

Figure 4.4 White Cliff geomorphology and defences

Photographs taken during Defence Condition Assessment 14th June 2017, facing west

4.3 Seaton Hole to Seaton Spit

4.3.1 Seaton Hole to West Seaton

The cliffs between Seaton Hole and West Seaton are comprised of sandstone and reduce in height from west to east. They are fronted by a shingle beach comprised of flints, gravel (chert) and some pebbles from the Budleigh Salterton beds to the west (Posford Duviver, 1994). The beach is underlain by a rock platform at Seaton Hole (comprised of mudstone) and sand substrate. The cliffs have a long history of erosion via marine erosion at the toe and the occurrence of (simple) landslides (Halcrow, 2011). Several major landslips occurring in recent years, including 1996, 2000 and 2012 and 2013. As such the cliff toe is now protected by a number of coastal defences structures, which are reported to have slowed the rate of cliff recession (Halcrow, 2011) and are described below:

- At the junction of White Cliff and Seaton Hole, there is a storm water outfall, which following its construction, was later protected by rock gabions and sandbags that were built between 2001 and 2005.
- A rock revetment, consisting of loose 'stones' (understood to be boulders) collected from the scree at the foot of the cliffs to the west at White Cliff, was constructed in the early 1970s, in response to localised erosion at Seaton Hole apparent during the 1960's and 1970's. The revetment was later encased in concrete to prevent displacement during wave attack (Posford

Duvivier, 1994). On-top of the structure is now a handrail and provides a means of foot-access to the beach, as it links the public footpath through the cliffs to the beach at Seaton Hole.

- Sometime prior to the 1960's, the West Walk Promenade was constructed and extended from Seaton, westward along the toe of the cliffs to what is now the Hideaway Café. It is reported, and evident from historical photographs held by Seaton Museum, that the promenade once extended further eastwards from the West Walk Promenade to Seaton Hole, however, this section was destroyed by a storm in 1915 and was not replaced (Posford Duvivier, 1994).
- Sometime prior to 1974, a 60m long concrete wall gravity structure (known as Check House Seawall) was constructed to the west of the West Walk Promenade and is set-back slightly to protect the toe of the cliff from marine erosion (Posford Duviver, 1994). Collapse of the wall has resulted in ad-hoc maintenance, including:
    - A seawall sprayed with concrete and with drainage, concrete toe, and access steps (David Roche Geo-Consulting, 2015);
    - A small headwall & small stream outfall (Posford Duvivier, 1997); and
    - Gabions in-filled with concrete sand bags and stone in 2005 (David Roche Geo-Consulting, 2015).
- During 1996/1997, improvements were made to the West Walk Promenade with the construction of a 370m long concrete seawall with stone buttresses/roundheads at 80m from the western end of the Seaton seawall to what is now the Hideaway Café. Remedial measures were undertaken in 1993 to protect the toe of the seawall (Posford Duvivier, 1994).
- Sometime in the 1990's, there was placement of rock armour stone along 65m of the cliff toe following increased erosion of the cliffs behind the depleted beach which resulted from the 1989/1990 storms (Posford Duvivier, 1994), also see Table 4.5.
- A 385m rock revetment, understood to be constructed in 1997 (Posford Duvivier, 1997). At the time of the site visit (25th May 2017), the rock revetment was observed to be buried in places beneath the shingle beach.

The cliffs at Seaton Hole and West Seaton are subject to periodic failure events, which are well documented and are summarised below. Various rates of cliff erosion have been predicted but are based on an average rate of cliff recession caused by numerous events and do not take account of erosion that could occur during a single event. As they are therefore considered misleading, they are not reported here.

- **Summer 2012 and winter 2012/2013:** Landslip at Old Beer Road (David Roche Geo-Consulting, 2013; 2016). Sherrell (2012) reports that the landslip that resulted in the cracking along Old Beer Road as triggered by the saturation of the overburden soils and weathered mudstone in the upper part of the cliff.
- **13th September 2000:** Landslip at Seaton Hole, with mass movement estimated to be in the region of 1,000m^3 to 5,000m^3 (David Roche Geo-Consulting, 2000).
- **1996:** Landslip at Seaton Hole (observed from photos held by Seaton Museum)
- **1990s:** 70m erosion Old Beer Road (Posford Duvivier, 1994)
- **1970s to 1990s:** Prior to construction of the 65m long rock armour stone, local observations suggest cliff top erosion of 10m over a 20-year period (Posford Duvivier, 1994).
- **1960s – 1970s:** Local erosion of the cliff toe at Seaton Hole (Posford Duvivier, 1994).
- **Between 1903 and 1933:** Over a period of 30 years, 5m of erosion reported to have occurred at Seaton Hole (Posford Duvivier, 1994). It is not clear from the report whether this erosion occurred during one event or a series of events over time.

Today debris, as well as man-made structures are observed to be falling out from the cliffs as they erode, which is a health and safety issue. For example, see Figure 4.5, which shows the old emergency overflow from Seaton Hole sewerage pumping station at the cliff toe.

Figure 4.5 Photographs of the cliffs at Seaton Hole
Photograph taken during defence condition assessment 28th June 2017, looking south-west

The beach between Seaton Hole and West Seaton has been subject to fluctuations over time, with periods of substantial beach loss and depletion during storms (discussed in more detail in Table 4.5), followed by beach recovery.

- Historic photographs (see Figure 4.6) show how the beach in 1871 was very low, but had recovered by 1898; a state that continued until 1907.
- More recently, a review of borehole data for the Seaton Coastal Study (Posford Duvivier, 1994), indicates that the beach levels in 1973 were similar to those in 1992.
- Storms in 1989/1990 and 1992 depleted the beach of material exposing the underlying bedrock, and the impact between Seaton Hole and West Seaton is clearly visible from the photograph presented in the Seaton Coastal Study (Posford Duvivier, 1994) (see Figure 4.7).
- Most recently, a photograph taken during the defence condition assessment on the 25th June 2017 shows a wider shingle beach than in 1992, indicating beach recovery.

More detailed analysis of beach profile data for Seaton Hole to West Seaton has been undertaken for this report and is presented in Section 4.3.2.

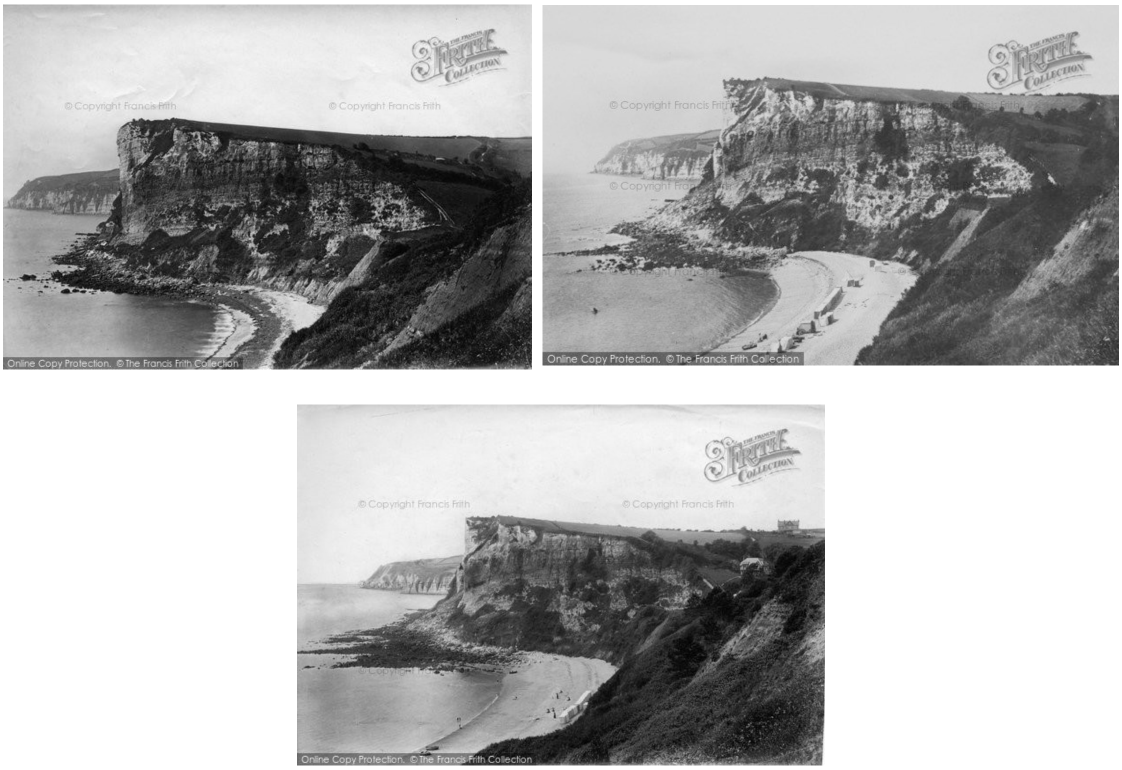


Figure 4.6 Historical photographs showing White Cliff, Seaton Hole and the western end of Seaton beach in 1871, 1898 and 1907

Source: Copyright The Francis Frith Collection

Figure 4.7 Photograph of beach between Seaton Hole and West Seaton, assumed to date 1993/1994

Source: Posford Duvivier, 1994

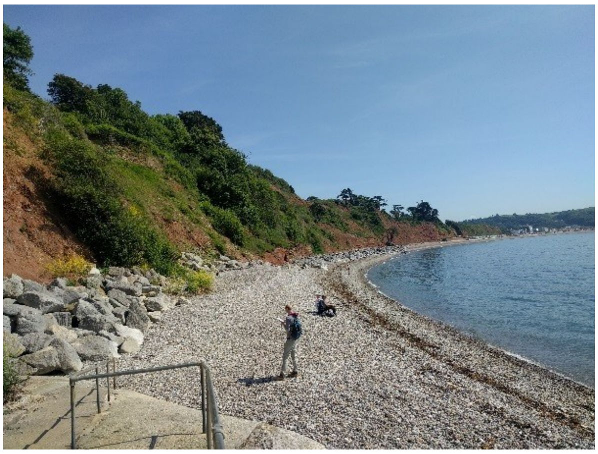


Figure 4.8 Photograph of beach between Seaton Hole and West Seaton

Photograph taken during defence condition assessment 28th June 2017, looking east

4.3.2 Seaton and Seaton Spit

4.3.2.1 Seaton

Seaton Town has developed on the western bank of the Axe Valley, but in more recent times in its south-eastern quarter, development has encroached onto former saltmarsh and mudflat. A shingle beach exists along the length, which extends eastward to form Seaton Spit at the mouth of Axe Estuary (refer to Figure 4.9 and Figure 4.10). The beach and spit are comprised of shingle (gravel chert), flints and pebbles from the Budleigh Salterton Beds), formed by the long term longshore transport of material from west to east. The shingle beach is underlain by a sandy substrate and in places a rock platform.

A seawall with access points controlled by flood gates protects Seaton from erosion and flooding and extends from the foot of Castle Hill to the junction of the Esplanade with Trevelyan Road. The modifications to the coastline are described in more detail below.

- A 750m long concrete seawall and wave return wall was constructed in 1980 by the South West Water Authority (now property of the Environment Agency) in response to severe flooding and damage following storms in 1979 (Posford Duvivier, 1994). The wall extends from the bottom of Castle Hill in the west to the eastern end of the esplanade, adjacent to the Axe Yacht Club, and is referred to as the Seaton seawall hereafter. Various access points have been built into the seawall, including an access ramp at the bottom of Castle Hill, which include flood gates to be closed at times of flood risk.
- Numerous concrete-encased storm water outfalls exit to the sea along the length of the seawall.

A key issue for the Seaton frontage is one of overtopping. The seawall today is regularly overtopped and Posford Duvivier (1994) report that the crest height of the sea wall was reduced from the design crest height to a height of +7.0m OD during the design stage to not adversely affect the sea views of local people.

Figure 4.9 Seaton
Aerial image © 2015 Google Earth

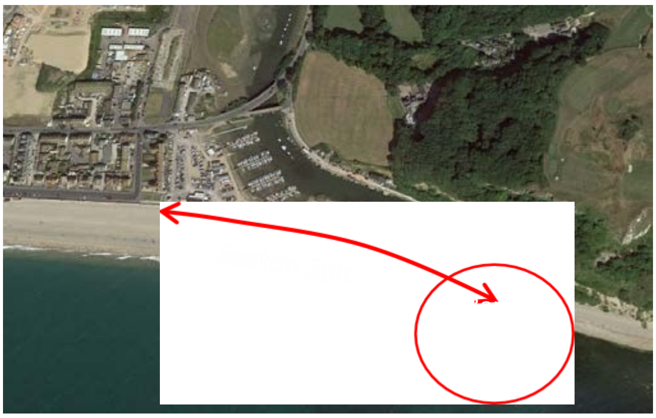


Figure 4.10 Seaton Spit, the 'bar' and delta (below)
Aerial image © 2015 Google Earth

4.3.2.2 Seaton Spit and Estuary Mouth

Seaton Spit diverts the mouth of the Axe Estuary to the east and has grown in response to long term west to east transport of shingle. A recurve is present at the distal end of the spit, which could have formed as easterly waves approach the shoreline, or because the spit is able to roll landwards into the estuary mouth. It has been previously reported that the spit is located at a drift convergence zone, which may explain why it has generally remained stable over the years (Posford Duvivier, 1994). The landward side of the spit is protected from open coastal processes is therefore considered within the Axe Estuary unit (see Section 4.4).

Seaton Spit is undefended along its seaward face but has been subject to various management activities over the years, including:

- The deposition of dredge spill within trenches dug into the beach between; a practice that has been undertaken since the late 1970s (and is discussed in more detail in Section 4.4);
- Assumed to be artificial additional height and volume added to the eastern portion of the spit in February 2006 following erosion caused by the storms in November 2005 (Pritchard, 2006). The source of the additional sediment is not specified in the report.
- Construction of a reinforced concrete wall in front of the Axe Yacht Club (Pritchard, 2006).

A severe storm in 1978/1979 resulted in overwashing/rollback of the spit into the harbour behind (see also Table 4.5), and following storms during the winter 1995/1996, the spit significantly narrowed (Author unknown 1, 2000). However, evidence suggests that overall the spit has remained stable in more recent years. A review of aerial images from 2001 to 2017 (refer to Figure 4.11) shows that the spit has retained its overall form and shape, with a significant change occurring in 2005 (assumed to be the November 2005 storm noted by Pritchard above) when the spit narrowed and the recurve at the distal end of the spit changed to form a single point. However, subsequent recovery returned the spit to its former width and shape, as observed from the 2016 aerial photo.

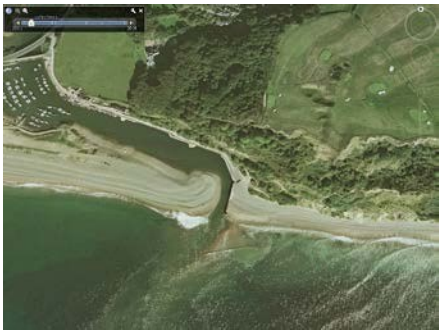
At the mouth of the estuary, exists a bar of material, although it is rarely a linear feature that runs parallel to the coast, rather a dynamic feature that is continuously changing shape in response to tides and waves. The bar is comprised of shingle and gravel, as observed during a site visit on the 24th May 2017 (see Figure 4.12). The Axe Estuary is understood to be ebb-dominant (Halcrow, 2002; SCOPAC, 2012). The presence of an estuary delta has been questioned (SCOPAC, 2012), however, it is evident from aerial photos and observations of the spit that a delta does exist at the mouth of the estuary. Pritchard (2006) suggests that the delta (referred to as a ‘Fan Shaped Shingle Plateau’) is a ‘new phenomenon’ and its formation could be linked to an increase in the number of days of south-easterly conditions compared to the prevailing south-westerly conditions, over the past two years.

In the past, the bar is reported to have extended across the mouth of the Axe Estuary during conditions of south-westerly waves and sustained strong west to east drift (Parkinson, 1985). However, it has been proposed that intensification of ebb tidal current velocities due to river channel training walls, and the construction of a short breakwater on the east side of the mouth, has kept the exit open in recent decades (SCOPAC, 2012). The bar is dynamic and takes many forms; these have been typified into four scenarios (see Figure 4.13) and supported by observations made from aerial photography, refer to Figure 4.14.

2001

Aerial image © 2015 Google Earth. © 2017 Infoterra Ltd & Bluesky Image NASA.

2002



Aerial image © 2015 Google Earth. © 2017 Infoterra Ltd & Bluesky Image NASA.

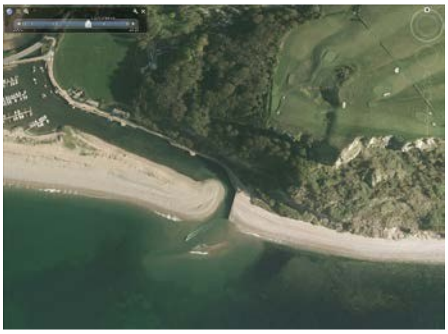
2005 *Year of Erosion

Aerial image © 2015 Google Earth. © 2017 Getmapping Plc.

2006

Aerial image © 2015 Google Earth. © 2017 Infoterra Ltd & Bluesky.

2010



Aerial image © 2015 Google Earth. © 2017 Getmapping Plc.

2013

Aerial image © 2015 Google Earth. © 2017 DigtialGlobe.

2016

Aerial image © 2015 Google Earth.

Figure 4.11 Aerial images of Seaton Spit 2001 to 2016

Figure 4.12 Photograph showing the estuary bar
Photograph taken during site visit 24th May 2017, looking south-east

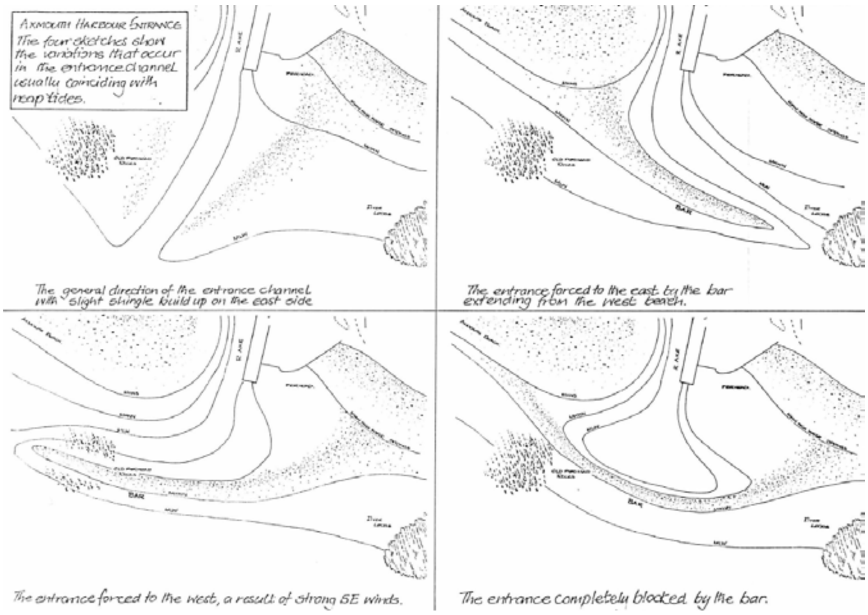


Figure 4.13 Typical morphology of the estuary bar/delta
Source: Author unknown, no date specified

2012 Aerial Image. Source: Channel Coast Observatory

2016 Aerial Image. Source: © 2015 Google Earth

Figure 4.14 Aerial photographs showing estuary mouth bar and delta

4.3.2.3 Beach Change

Existing data, observations made from aerial photography and anecdotal evidence all confirm that the shingle beach, and less frequently the spit, is subject to much fluctuation, sometimes resulting in the exposure of the underlying sandy substrate. To appraise the changes further, a detailed review of beach profile data and assessment of change has been completed as part of the present study.

Review of Annual Monitoring

A review of Plymouth Coastal Observatory's (PCO) Annual reporting on beach profile change has been undertaken for the coastline between Seaton Hole and Seaton Spit. The reporting is based on data collected between 2007 and 2017 for the Southwest Regional Coastal Monitoring Programme (SWRCMP). The review compares the reported cross-sectional area change from one year to the next for the profiles between Seaton Hole and the Axe Estuary (profiles 6a01197 to 6a01157, see Figure 4.15); unfortunately, beach profile data for the coastline at Beer and to the east at Haven Cliff is not collected and included in the annual reporting. The results of the analysis are presented in Table 4.1 and the key findings summarised in Figure 4.15 and below.

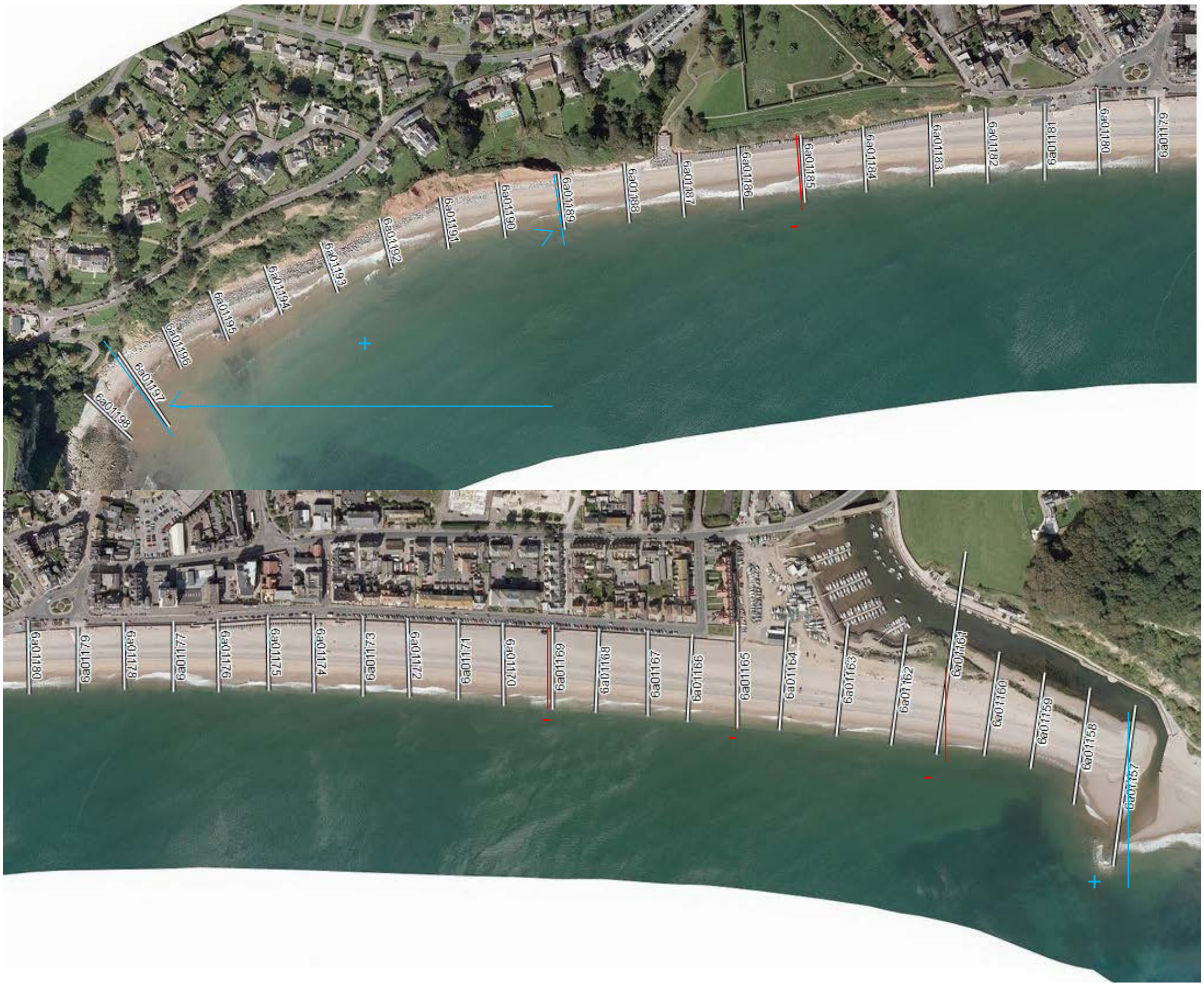


Figure 4.15 Map showing location of beach profiles with positive cross-sectional change shown in blue and negative cross-sectional change in red

- There is a clear trend of ***negative cross-sectional area change*** (i.e. erosion) during years;
    - 2007-2008;
    - 2009-2010;
    - 2011-2014; and
    - 2015-2016.

- There is a clear trend of ***positive cross-sectional area change*** (i.e. accretion) during years;
  - 2008-2009;
  - 2010-2011;
  - 2014-2015 (all profiles accreted); and
  - 2016-2017.
- Periods of erosion tend to be followed by periods of accretion, indicating recovery of the beach within a year of the erosion event.
- The sum of the cross-sectional change for all profiles and all years' (2007 to 2017) outputs is positive. This could indicate that the beach between Seaton Hole and the end of the Axe Estuary (profiles 6a01197 to 6a01157) is accreting. This would suggest that there is a contemporary supply of shingle to the beach, be it from downdrift (west), updrift (east), erosion of the backshore cliffs or offshore.
- At a few profile locations, the cross-sectional area change between 2007 and 2017 is positive, indicating accretion; these locations include:
  - Profiles 6a001197 to 6a01189 (Seaton Hole to Check House Seawall) – ***these findings should be treated with caution; the latest PCO report (PCO, 2016) suggests that the large changes at profile 6a01193, reflect the profiles short length and not the material loss or gain and as observed from reviewing the beach profile data in SANDS (see Section 4.3.2.4 below); this can arise due to restricted access at the time of survey due to cliff hazards***; and
  - Profile 6a001157 (distal ned of the spit).
- At a few profile locations, the cross-sectional area change between 2007 and 2017 is negative, indicating erosion, however, it should be noted that PCO consider cross-sectional area change of less than 5m^2 to represent no change, and therefore these locations could in fact be considered to be stable. These locations include:
  - Profile 6a01185 (opposite the shelter, see Figure 4.16);
  - Profiles 6a01169, 6a01165 and 6a01161 (eastern end of Seaton to the spit), see Figure 4.17.

Table 4.1 Beach profile change at Seaton, % change in cross-sectional area where red indicates a reduction (red 0 = less than 0, overshadowed by rounding)
Source: Beach profile data sourced directly from PCO for years 2007 to 2017

Location	Profile Reference	Year of Survey											Baseline Comparison	Trend
		2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	SUM OF CHANGE 2007 to 2017	2007-2016	
Seaton Hole to West Seaton	6a01197	5	26	-18	8	1	-17	21	23	9	42	99	123	**Accreting**
	6a01193	-27	230	-14	24	-3	-43	-60	94	-28	253	424	173	**Accreting**
	6a01189	-28	22	-12	16	3	-5	-35	4	6	67	40	7	**Accreting**
Seaton	6a01185	-14	-15	0	27	-7	6	-10	3	-3	18	6	-2	**Stable/ eroding**
	6a01181	-4	-10	-2	6	5	4	-5	8	-6	7	3	1	**Stable**
	6a01177	0	-3	-1	2	2	0	-1	4	-2	1	1	1	**Stable**
	6a01173	-3	4	0	1	0	-2	1	2	2	-3	0	0	**Stable**
	6a01169	-3	5	-1	0	-3	-2	6	1	2	-5	-1	-1	**Stable/ eroding**
	6a01165	0	-2	1	0	-2	-2	5	0	3	-6	-4	-5	**Stable/ eroding**
Seaton Spit	6a01161	2	-3	3	-1	-4	1	1	2	0	-5	-3	-3	**Stable/ eroding**
	6a01157	5	-13	-6	22	-1	-29	18	42	-25	23	36	14	**Accreting**
ANNUAL SUM OF CHANGE		**-67**	**240**	**-51**	**104**	**-9**	**-90**	**-59**	**183**	**-42**	**392**			
Trend			**Accretion**		**Accretion**				**Accretion**		**Accretion**			

Figure 4.16 Photograph of beach at the location of eroding beach at profile 6a01185 (approximate position shown by red line)

Photograph taken during defence condition assessment 28th June 2017, looking east

Figure 4.17 Map showing locations of eroding profiles at eastern the end of Seaton, including 6a01169, 6a01165 and 6a01161

Source: Photo Channel Coast Observatory, 2009

4.3.2.4 New Beach Profile Analysis

Beach profile analysis has been completed for the BMP study area to assess the change in cross-sectional area and volume of the beach for three separate sections, including;

- Seaton Hole to West Seaton – profiles 6a01198 to 6a01188 (excluding 6a01181 due to insufficient data);
- Seaton – profiles 6a01187 to 6a01165; and
- Seaton Spit – profiles 6a01164 to 6a01157.

The analysis was completed using CH2M's SANDS programme and beach profile data collected by PCO for the SWRCMP. Since PCO survey only selected profiles on a regular basis, the analysis is limited to years 2007, 2012 and 2017. **As noted in Section 4.3.2.3 above, caution should be given to the figures generated for Seaton Hole to West Seaton as the profile data appears to have been affected by the presence of the cliff, rock revetment and accumulation of material on the rock revetment/at the cliff toe and restricted access during the survey due to cliff hazards; together this could bring about errors in the data.* A summary of the key changes is presented in Table 4.3 and Table 4.3. Full results from the beach profile analysis are presented in Appendix A.

It is evident from the beach profile analysis that:

- The cross-sectional area and volume of the beach between Seaton Hole and West Seaton has increased between 2007 and 2017. **It should be noted that the profiles show that beach within this section is very volatile and varies considerably in height and width depending on the survey, and further, as mentioned above the results could potentially be driven by errors in the data.*
- The cross-sectional area and volume of the beach at Seaton decreased between 2007 and 2012, but increased between 2012 and 2017; the net result being an overall decrease. However, the difference was small and therefore it is concluded that the overall net change is one of stability. It is observed from the beach profile data plotted in SANDS for 2007 to 2016, that the beach levels at the seawall do vary;
    - At West Seaton, between profiles 6a01187 and 6a01181, beach levels are observed to fluctuate considerably, by as much as 2m at profile 6a01185; however, they do not reach the height of the esplanade.
    - At the bottom of Castle Hill (between profiles 6a01180 and 6a01177), beach levels do not reach the height of the esplanade, but at the seawall, they fluctuate in the region of 0.6m.
    - Along the western and central esplanade, between profiles 6a01176 and 6a01173, beach levels at the seawall are relatively stable, fluctuating by only approximately 0.1m.
    - Along the central and eastern esplanade, as far as the Axe Yacht Club, between profiles 6a01172 and 6a01165, beach levels at the seawall fluctuate by approximately 0.6m and reach the height of the esplanade.
- The cross-sectional area and volume of the beach at Seaton Spit has increased between 2007 and 2017.

Table 4.2 Beach profile cross-sectional area change* above MLWS
**Change is calculated by taking the sum of the difference in CSA of the profiles within in section over time*

	Change in CSA (m^2) **March 2007 to March 2012**	**Change in CSA (m^2)** **March 2012 to April 2017**	**Change in CSA (m^2)** **Total Change March 2007 to April 2017**
Seaton Hole to West Seaton	73	125	199
Seaton	-155	137	-18
Seaton Spit	-77	260	183
		Subtotal (Seaton and Seaton Spit)	***165***
		Total Change (Seaton Hole to West Seaton)	***364***

Table 4.3 Beach profile volume change*
**Change is calculated by taking the sum of the difference in volume of the profiles within in section over time*

	Volume Change (m^3) **March 2007 to March 2012**	**Volume Change (m^3)** **March 2012 to April 2017**	**Volume Change (m^3)** **Total Change March 2007 to April 2017**
Seaton Hole to West Seaton	4,584	6,060	10,644
Seaton	-7,741	7,459	-281
Seaton Spit	-5,674	13,117	7,443
		Subtotal (Seaton and Seaton Spit)	***7,162***
		Total Change (Seaton Hole to West Seaton)	***17,806***

4.3.2.5 Beach Response to Storms

Historical and anecdotal information indicates that this coastline is susceptible to storms, with beach draw down in the past resulting in significant (albeit temporary) beach loss.

A high-level storms analysis for the BMP extent has been completed, which has looked at the occurrence of storms in the historical record and assessed, where possible, the impact of those storms. The analysis has also considered the impact of more recent storm events, including the 2014 storms, drawing upon post storm report produced by Plymouth Coastal Observatory (PCO, 2014a; 2014b).

Storm Events

Wave data collected by the West Bay Directional Waverider Buoy (discussed in Section 3.2.4.1) and analysed by Plymouth Coastal Observatory (PCO, 2014a) for the SWRCMP provides the best available measured storm wave data for the BMP area. PCO's analysis of wave height for periods when wave conditions exceeded a pre-defined 1 in 1 year return period are shown in Table 4.4.

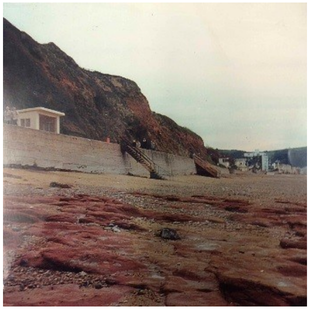
Table 4.4 Storms exceeding 1 in 1 year return period at West Bay since deployment in 2006
Source: (PCO, 2014a)

Date	Wave Height (m)	Estimated Return Period
14th February 2014	6.22	> 1 in 10 years
8th February 2014	5.36	> 1 in 2 years
5th February 2014	7.08	Greater than 1 in 50 years
24th December 2013	6.42	> 1 in 30 years
28th October 2013	5.17	> 1 in 1 year
7th June 2012	5.07	> 1 in 1 year
3rd January 2012	5.55	> 1 in 3 years
14th November 2009	6.00	> 1 in 10 years
10th March 2008	5.05	> 1 in 1 year
6th March 2007	5.61	> 1 in 3 years

Other storms have been identified through the review of existing literature, historical imagery and anecdotal evidence; and where possible an assessment of the impact of the storm on the beach has been made. A summary is provided in Table 4.5.

Table 4.5 Summary of storm events and the impact on the beach

Date	Storm Description	Impact on Beach	Data Source
January / February 2014	South-westerly	Wave overtopping of the seawall	PCO (2014c)
November 2005	Not reported	Overtopping of the spit and significant of the spit.	Pritchard (2006)
2000/2001	Severe gales	Erosion of the end of the spit, over-widening of the mouth and significant erosion along the seaward face of the spit.	Axe Harbour Management Company Ltd (2001)
November 1998	Not reported	Steepening and exposure of sand and ramping-up against the seawall  	Historic photograph supplied by EDDC for the BMP
Winter 1995/1996	Not reported	The spit was 'dangerously narrowed'.	Author unknown 1 (2000)

Date	Storm Description	Impact on Beach	Data Source
November 1995	Not reported	Erosion of the shingle spit, on both seaward and landward sides. Disposal trench exposed and previously buried dredged material exposed.	Historic photographs supplied by EDDC for the BMP
September 1995	Easterly	Low beach levels 	Posford Duvivier (1997) Historic photograph supplied by EDDC for the BMP
December 1989 to July 1993 / 1994	Not reported	Low beach levels. Comparison of a pre-storm beach profile and survey data suggests a loss of 110,000m³ of sediment between Seaton Hole and the western end of the seawall. Losses at Sidmouth during the same storm are reported to have been of the same magnitude.	SCOPAC (2012) Posford Duvivier (1994) Posford Duvivier (1997)
1993	Not reported	Overtopping of the spit and flooding of the estuary, requiring removal of shingle from the harbour and entrance.	Author unknown 2, 2015
September 1993	Not reported	Significant loss and depletion of the beach, with exposure of bedrock in front of the West Walk Esplanade over its whole length.	Posford Duvivier (1994)
29th January 1993	Not reported	Beach erosion and depletion of sediment resulting in exposure of sand substrate and rock platform. 	Observed from notes/photos held by Seaton Museum
30th August 1992	South south westerly storm, estimated to be less than a 1: 50 year event.	Significant loss and depletion of the beach, with exposure of bedrock in front of the West Walk Esplanade for approximately 100m.	Posford Duvivier (1994)
Winter 1989/1990	South-westerly winter storms, estimated to be less than a 1: 50 year event.	Substantial loss and depletion of the beach between Seaton Hole and the eastern end of the West Walk Promenade. It is estimated using numerical modelling that longshore movement of material (grainsize not specified but assumed to be shingle) during this storm could have been in the order of 8,000 to 9,000m³. Exposure of bedrock at Seaton Hole. Increasing beach quantity east towards Seaton.	Posford Duvivier (1994)
16/17th December 1989	A combination of a: • A prolonged period (four weeks) of	Bedrock exposed due to depletion of beach. Beach pushed up to form a shingle ridge approximately +7.0m OD in height.	Posford Duvivier (1997)

Date	Storm Description	Impact on Beach	Data Source
	north-easterly to easterly wind and waves prior to the storm. • South-south-west storm wind and waves during the storm.	Overtopping of the seawall and flooding of Seaton town.	Posford Duvivier (1994)
13th February 1979	East-south-east storm, estimated to be a 1: 50 year event.	Extensive flooding. Overtopping of the spit.	Pritchard (2006) Posford Duvivier (1997) Posford Duvivier (1994) Observed from notes/photos held by Seaton Museum
December 1978	Not reported	Flooding	Posford Duvivier (1997)
1970	Not reported	Flooding	Observed from notes/photos held by Seaton Museum
1969	Not reported	Not reported	Observed from notes/photos held by Seaton Museum
1932	Storm	Shingle transported onshore and flooding	Observed from notes/photos held by Seaton Museum
January 1925	Not reported	Flooding	Posford Duvivier (1997)
November 1924	Not reported	Flooding	Posford Duvivier (1997)
Early 1900s	Not reported	Seawall was overtopped and the beach depleted	Posford Duvivier (1994) in SCOPAC (2012)

Beach Response to the 2014 Storms

Specific analysis has been undertaken by PCO to investigate the impact of the series of severe storms in January and February 2014 (PCO, 2014a; 2014b). PCO used LiDAR data to prepare a map of beach elevation change between 25th November 2011 and 15th May 2014, as shown in Figure 4.18.

Several key observations are made, as described below.

- A decrease in beach levels between Seaton Hole and West Seaton. **It should be noted that these findings are not reflective of the positive changes in cross-sectional area and volume observed from the beach profile data.*
- A decrease in upper beach levels and increase lower beach levels between West Seaton and the Esplanade, just west of Burrow Road, (half way along the Seaton frontage); this is indicative of beach draw-down.
- A decrease in beach levels along the upper beach and increase of the middle and lower beach at the eastern end of Seaton and along Seaton Spit and around the estuary bar/delta.

- FiA decrease in beach level along the top of Seaton Spit. It has also been reported that 40% of the eastern end of the spit was lost following the January/February 2014 storms (Author unknown 2, 2015); it is assumed that this is referring to material lost from the top of the spit as observed from the LiDAR difference plot, and from the post-storm beach profile data, discussed in the next Section.

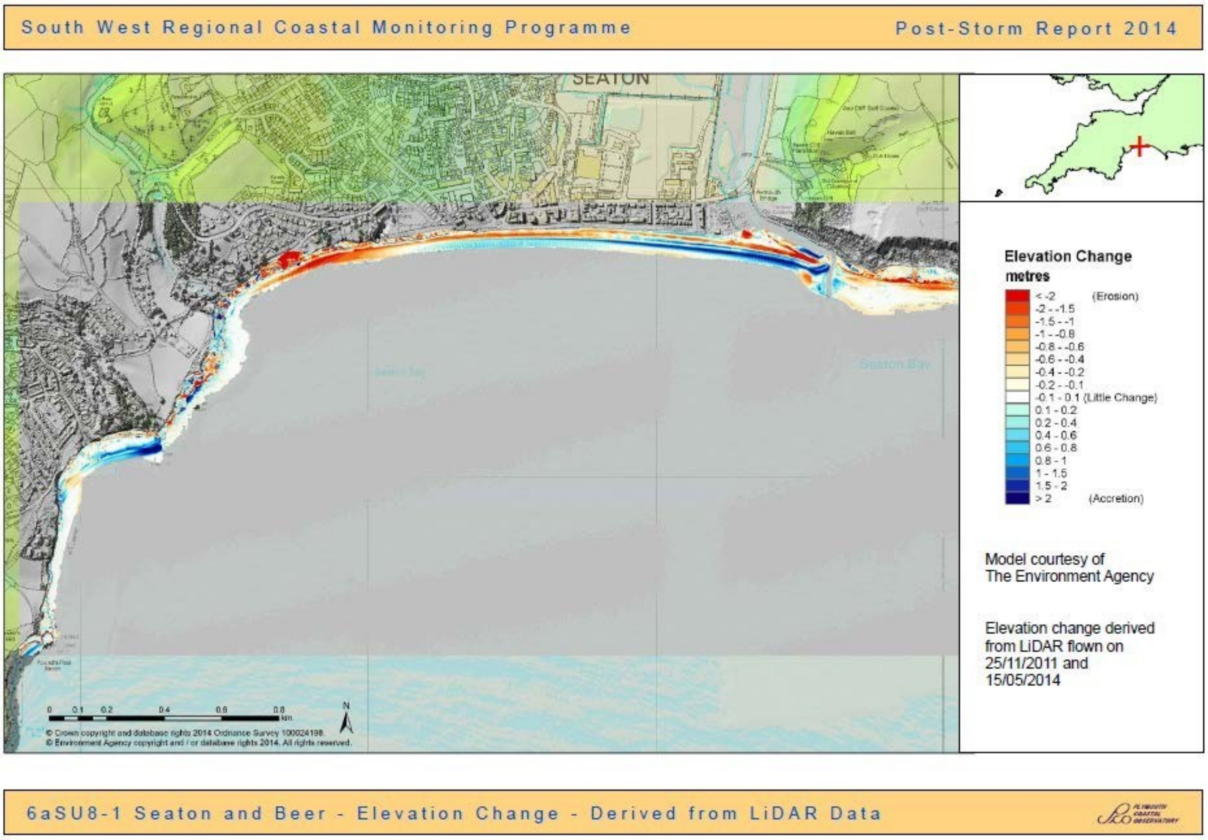


Figure 4.18 LiDAR topographic difference model plot for Seaton, showing the change in elevation between November 2011 (pre-storm) and May 2014 (post storm) (PCO, 2014b)

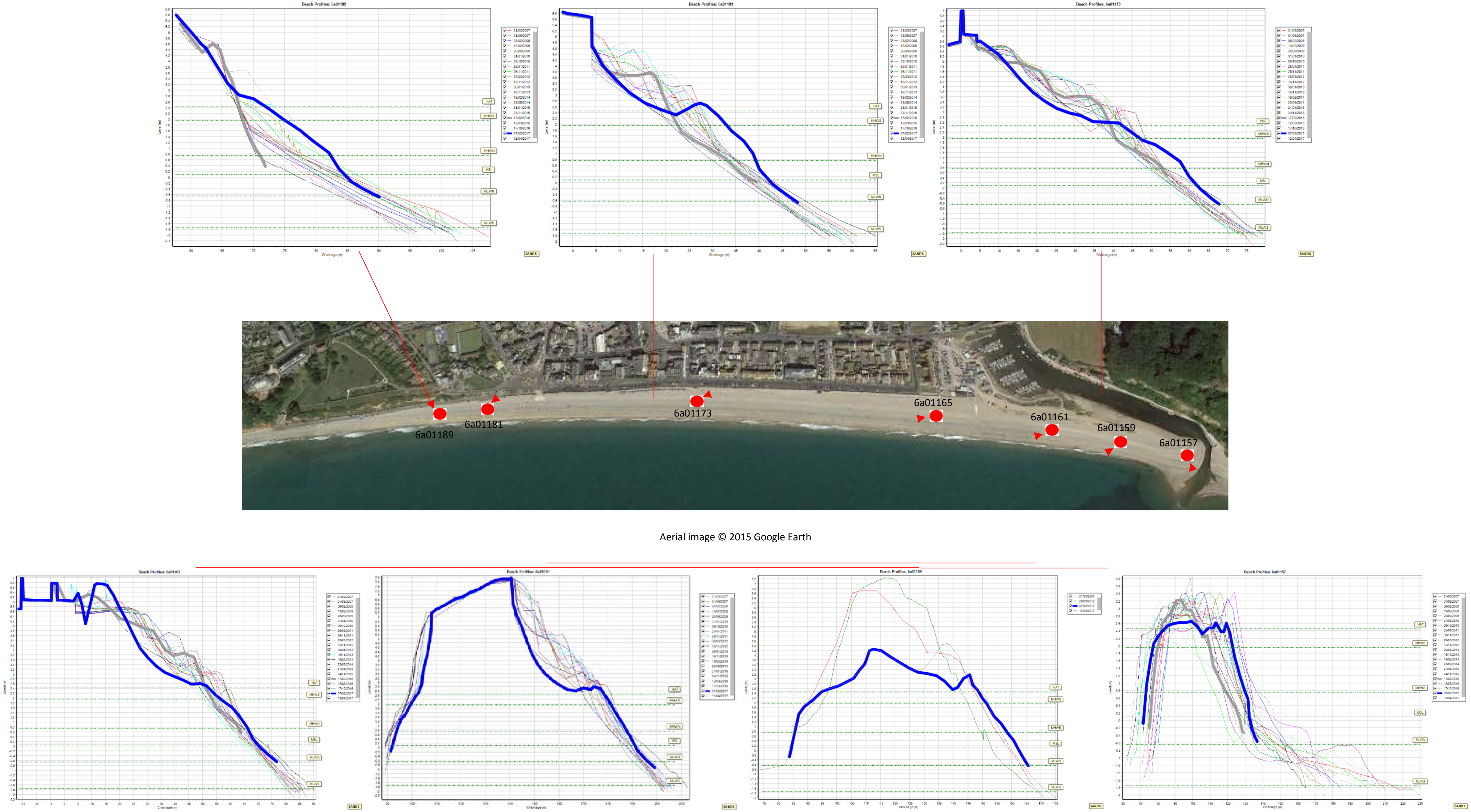
Beach Response to 2016 and 2017 Storms

As part of the SWRCMP, the response of the beach to storms has been assessed and post-storm profile data is available for 2016 and 2017. It is assumed that the 2016 post-storm profile was surveyed in response to the storm that occurred on the 6th February 2016, which was from the south-west, and from another storm that occurred sometime before the 7th February 2017; the direction of the storm is unknown. The data indicates that during storms there is significant redistribution across the frontage, with some profiles exhibiting build-up whilst others exhibit significant sediment loss. The varying response of the beach to storms from one location to another and from one storm to another, suggests that the response of the beach is very sensitive to the direction of the prevailing storm waves.

Figure 4.19 illustrates post-storm profiles at a number of locations, compared to the more normal year on year changes. Some key observations have been made from the data:

- At the western extent of the Seaton seawall, opposite the bottom of Castle Hill (profile 6a01181), during both storms the beach lowered in front of the seawall, forming a berm or ridge further down the profile. During the 2016 storm, the berm formed around 3.6mOD, whilst during the 2017 storm, the berm formed at a much lower level, around HAT (2.6mOD). Unlike other profiles, the beach at this location tends to develop a single berm during storms whereas elsewhere a series of ridges form across the beach; this may be related to the volume of material on the beach. It is also noted that over time, the beach height at the seawall is observed to vary by over 1m.

- At the centre of Seaton beach (profile 6a01173), the beach immediately in front of the seawall appears to have remained relatively stable during the two storms, with the build-up of material above HAT during the 2016 storm but draw-down of the beach to below HAT during the 2017 storm.
- At the eastern end of Seaton beach (profile 6a01165), the beach was generally unaffected by the 2016 storm (which could be due to the beach level at the time). The 2017 post-storm profile was actually surveyed at the same time that the trench had been opened for the disposal of the dredged material (removed during winter 2016) and is therefore the profile above HAT is not reflective of post-storm beach behaviour. However, it is observed from the profile that during this time there was also some draw-down of material below MHWS (1.95mOD). Similarly, to the two profiles to the west, formation of a berm below HAT during the 2017 storm.
    - There is a clear trend for beach build-up of Seaton beach immediately in front of the seawall and an onshore movement of material when storm waves approach from the south-west. The opposite has occurred during 2017, so it is assumed that the storm waves may have approached the coastline from a different direction, perhaps the south or south-east.
- At the western end of the spit (profile 6a01161), material was eroded from the erosion of the base of the cliffed-beach / above HAT and deposited on the foreshore below HAT (2.45mOD) (i.e. drawn down). Although the profile appears to show significant cut-back of the upper beach to form a cliffed- faced, this erosion occurred previously sometime between the 16th November 2013 and 19th February 2014 (possibly the severe storms that occurred in January and February 2014, described above). Since then, the beach at the base of the beach (below a height of 5.5m) has fluctuated but the upper cliffed-beach remains largely unchanged.
- At the centre and distal end of the spit (profile 6a01159 and 6a01157), the 2017 storm resulted in lowering of the spit, but with deposition of material on both the landward and seaward face; which may have been caused by a combination of overtopping/overwashing and draw-down. The 2016 storm resulted in narrowing of the distal end of the spit, but a survey the following month shows widening of the spit, suggesting a rapid recovery.



Aerial image © 2015 Google Earth

Figure 4.19 Beach profiles for post-storm surveys, where a notable change outside of the general profile change is marked by a profile in bold (2016 storm in grey and 2017 in blue)

**Note that the 2017 post-storm profile for profile 6a01165 was surveyed at the same time the trench was dug for the disposal of dredge material*

4.4 Axe Estuary

The Axe Estuary unit covers the river mouth, including the west and east banks, up to the Axmouth Road Bridge. Much of the estuary has been reclaimed and today the estuary is described as a single spit enclosed valley type estuary that is partially infilled (Halcrow, 2002). The estuary tidal regime is ebb dominant and ebb tidal currents are considerably fast (Halcrow, 2002).

The present harbour was a small trading port until construction of the railway branch line in 1886, which assisted in the development of Seaton as a holiday destination. Following storm damage in the 1870s, the entrance reportedly narrowed and the harbour became derelict (Author unknown 1, 2000). A map showing the estuary mouth in its formerly undeveloped state in 1949/1950 is presented in Figure 4.20. Regeneration of the harbour began in the 1950s, with further development since the 1970s by East Devon District Council also, who have become custodians and the statutory authority for the harbour. In 1988, the Axe Harbour Management Company was formed, and the harbour is now leased to them, who sub-lease the western side to the Axe Yacht Club and the eastern side to the East Devon Fisherman's Association.

A summary of the actions taken to develop the harbour are included below, more detail can be found in the 'Defence Baseline':

- Construction of a quay walls along the eastern side of the estuary in the 1800's (Author unknown, 2000), later extended with rock walls and concrete walls and renovated in 1996 (Prichard, 2006).
- Extraction of material from the landward side of the spit for bank repair in the late nineteenth century (Parkinson, 1985).
- Development of the harbour basin in the 1970s including excavation of the estuary and construction of a rock gabion bastion at the seaward end of the spit to create a mooring basin in 1977 (Author unknown 1, 2000).
- Construction of a harbour arm on the eastern side of the estuary mouth, which was extended in May 2001 (Pritchard, 2006).
- Subsequent reclamation of the shingle beach and spit as development around the harbour basin and spit continued and construction of various ad-hoc defences on the landward side of the spit in order to stabilise the bank and thereby maintain the harbour. Such defences included secondary fencing and rock armouring in 1995/1996 (Author unknown 1, 2000), bag work (Pritchard, 2006) and a geotextile curtain.
- Dredging of material from the harbour and its disposal within trenches dug into the spit (this is discussed in more detail in Section 4.4.1).

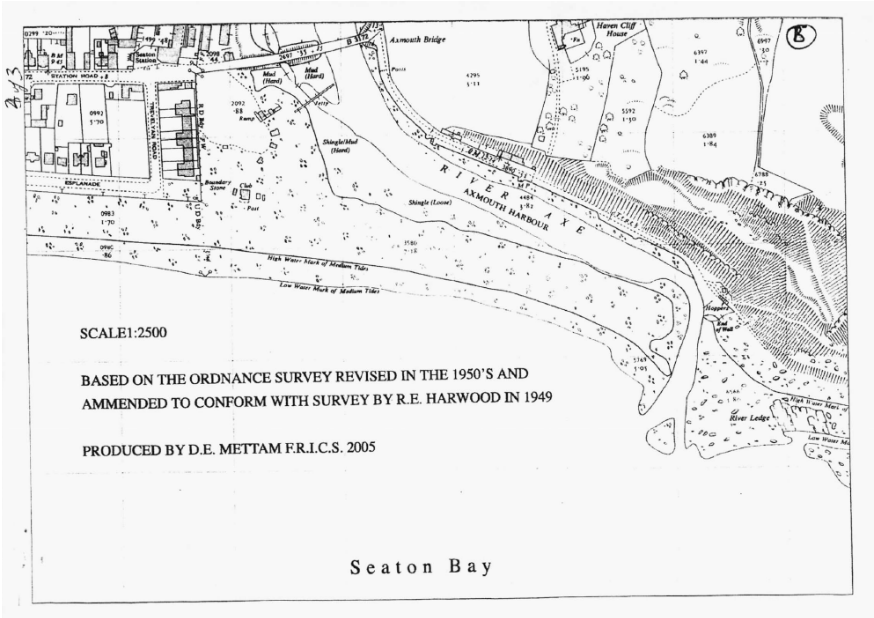


Figure 4.20 Ordnance Survey map of the Axe Estuary in 1949/1950
Source: Mettam, 2005

4.4.1 Dredging

Dredging is undertaken in the Axe Harbour Basin by the Axmouth Harbour Management Company Limited and Axe Yacht Club to remove accumulated silt brought down by the river. Siltation within the harbour is suggested to occur at a rate of approximately 18 inches per year (Site Visit Notes, 2017).

Dredging has been taking place since the 1970s, when silt was first removed by excavators and other methods thereafter. Since 2008, suction dredging has been used to remove the silt from the estuary. Dredged material is pumped into and disposed of within a series of trenches dug into the shingle spit; this includes an eastern trench located 130m west of the distal end of the spit, used between 1978/1979 and 2008, and more recently a trench in front of the Axe Yacht Club that has been used since 2008. The locations of the trenches are shown in Figure 4.21, with the open trench in the spit shown in Figure 4.22.

Today, the inlet of the Axe is dredged to maintain the Axe Yacht Club access channel to -1.0mOD. Typically, 1000 – 1500 tonnes of silt is dredged from the harbour (Site Visit Notes, 2017), which is suggested to equate to 1,500m^3 per year (David Turner, East Devon Council, Pers. Comms., 2016). In 2017, 800m^3 of dredge material was buried in front of the seawall (Site Visit Notes, 2017). The harbour is dredged over the winter period and during the day not weekends as to minimise disruption.

Historically disposal of dredge material by the methods described was granted consent by the National Rivers Authority (NRA, now subsumed into the Environment Agency) in 1993 (Author unknow 2, 2015), with no objections by the Ministry of Agriculture, Fisheries and Food (MAFF) (now the Department for Environment, Food and Rural Affairs (Defra)) or English Nature (now Natural England) (Author unknown 1, 2000). It is also reported (Author unknown 2, 2015) that MAFF required that dredge material was disposed of within the spit to help reinforce and raise it, following overtopping in 1993. On the 2nd January 1996, exemption under the 'Waste management Licensing Regulations 1994' was granted by the Devon County Council Environment Department (Author unknow 2, 2015).

The latest guidance from the Environment Agency is that dredging operations (including both dredging and disposal) are excluded from the requirement for a Flood Risk Activity Environmental permit for the reason that the Harbour Authority is considered a protected statutory body, whereby the specific operation of dredging is considered as a protected statutory undertaking to maintain the operation of the harbour (Environment Agency, *Pers. Comms.*, 2017). However, ahead of the outcomes of the Seaton BMP, the Environment Agency note that this exclusion is on the assumption that dredge material will be placed within the reception trench shown by the blue hatched area on the map in Figure 4.23 and above mean high water.

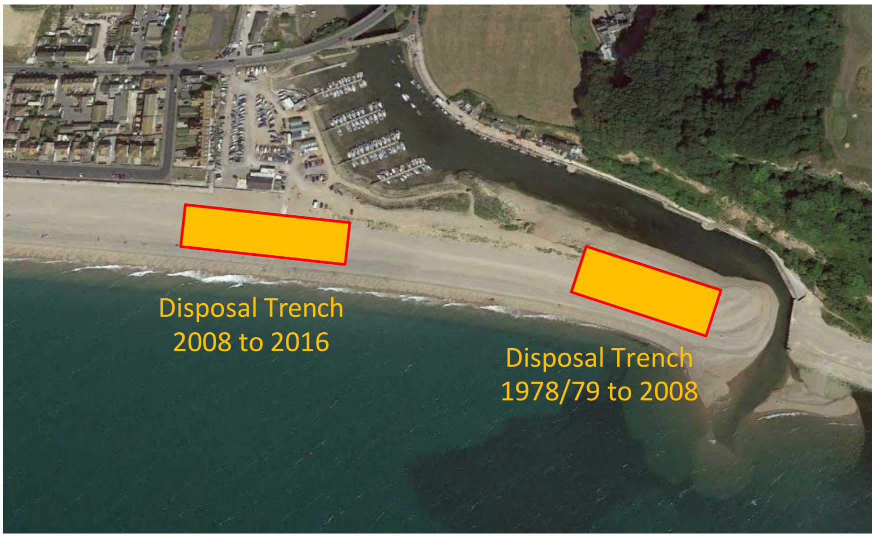


Figure 4.21 Map showing approximate locations of dredge disposal sites
Aerial image © 2015 Google Earth

Figure 4.22 Trench for disposal of dredge material 2009/2010
Source: Author unknown 0, no date specified

Figure 4.23 Permitted dredge disposal zone for 2016/2017 arisings
Source: Environment Agency, Pers. Comms., 2017

4.4.1.1 Impacts of Dredging and Disposal

Disposal of the material within the eastern trench has raised the height by 2m above the existing height of the shingle spit and has created a higher and wider beach crest than would occur naturally.

A previous study (CH2M, 2015) concluded that the disposal of dredged material into the spit has the potential to affect the ability of the shingle spit to respond to storms and therefore is likely to increase its vulnerability to catastrophic failure under extreme events. The key impact results from the reduced permeability of the spit due to the introduction of fines, which will become compacted under the weight of the overlying shingle (CH2M, 2015). This increased compaction means that less wave energy is absorbed by the feature and there is a risk of increased wave run up (i.e. the maximum vertical extent of wave uprush) and drawdown and offshore movement of material under storm action.

The result of mixed sized sediments and increased compaction is also likely to lead to the development of vertical cliffs in the beach at, or above, mean high tide, because the higher percentage of interstitial material sand and silt between the pebbles means the beach has a much higher angle of repose than a gravel only beach (CH2M, 2015). Both vertical cliffs and exposed compacted interstitial muds were observed on the spit during the site visit in May 2017, refer to Figure 4.24.

In turn, cliffing can also increase wave reflection on beaches and thereby further reduce beach levels in front due to scour action by waves.

Figure 4.24 Photographs of the Seaton Spit, showing cliffing and exposed compacted interstitial sand and silts
Photographs taken during site visit 24th May 2017, top looking west, and bottom, looking north-west

The review of beach monitoring data (refer to Section 4.3.2.3), shows that the section of beach (profile 6a011650) currently being used for the disposal of dredge material, and identified by the Environment Agency as a suitable site for the disposal of 2016/2017 material, is showing a trend for erosion; it is also dynamic and has suffered from erosion during storms (refer to Figure 4.25). Therefore, consideration and identification of alternative sites for disposal should be considered as a high priority.

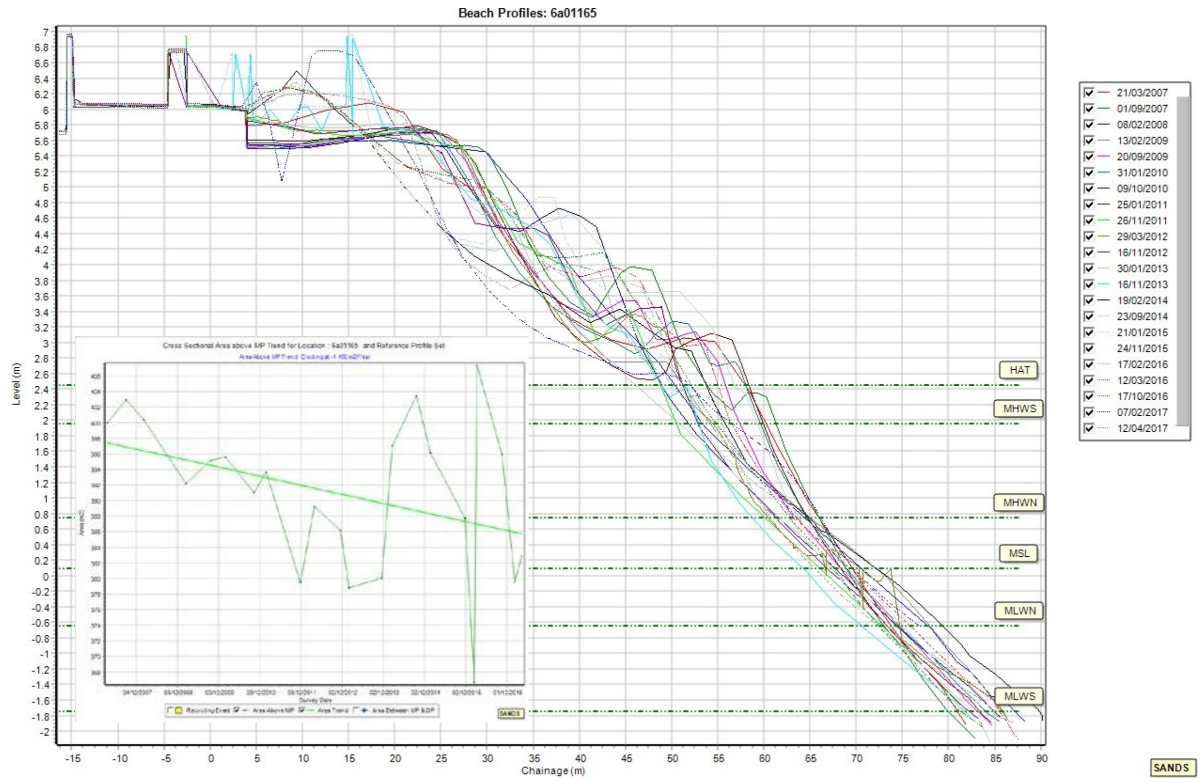


Figure 4.25 Beach monitoring data for profile 6a01165, inset with plot of beach cross-sectional area change (m^2)

4.5 Haven Cliff

Haven Cliffs, comprised of mudstones, sandstones and chalk (Posford Duvivier, 1994), are high and steep and fronted by a shingle beach, boulder beach and rock platform. The cliffs are eroding via a series of land sliding complexes and erosion of the cliff top is estimated to be in the order of 0.55m/year to 1.3m/year (Posford Duvivier, 1994). The cliff toe is afforded some protection from erosion by the shingle beach (Posford Duvivier, 1994), but the beach does not prevent erosion.

A rock platform is shown to protrude from the cliffs and foreshore on the eastern bank side of the estuary mouth. Aerial photographs from 2006 and 2009 (refer to Figure 4.26) clearly show the shingle beach, boulder beach rock platform and the build-up of the bar material and estuary delta. It is inferred from the photographs that the rock platform has the potential to affect movement of material around the mouth of the estuary. It is possible that material held within the delta may supply the beach at Seaton under certain incident wave conditions, i.e. when prevailing conditions drive east to west sediment transport.

Figure 4.26 Aerial photographs of the Axe Estuary mouth and Haven Cliff beach in 2006 (left) and 2009 (right)
Source: Channel Coast Observatory, 2006 and 2009

SECTION 5

Conceptual Understanding of Shoreline Behaviour and Response

A conceptual understanding of shoreline behaviour and response has been developed based on a synopsis of the various data sources reviewed in this report and the new analysis undertaken. The conceptual understanding is summarised below.

- At a large scale, this coastline is controlled by the geology and geomorphology features. Varying geology laid down over time, major geological earth movements and subsequent changes in sea level have given rise to differential erosion and the emergence of a series of headlands and bays. To the west, this is by the more resistant sandstone, limestone and chalk deposits that make up Beer Head and White Cliff, east of there, the less resistant mudstone cliffs between Seaton Hole and West Seaton, to the centre, the low-lying Axe Valley and to the east, the Axe Estuary and Haven Cliffs.
- The beach is defined by a gravel/shingle barrier and sandy substrate that extends virtually along the entire length of the BMP study area. The barrier is thought to be derived predominately from Holocene deposits transported onshore as sea levels rose, added to over the years with material derived from erosion of the cliffs to the west and east.
- Wave data for Seaton indicate that the predominant wave direction is from the south and south-south-west, with less frequent waves approaching from the south and south-south-east. The wave climate directly influences sediment transport along the coast, so that sediment transport is predominantly from west to east. During storms, the beach is particularly dynamic, when the gravel/shingle ridge can be pushed up the beach; or drawn-down to the nearshore/offshore. It is thought that the behaviour of the beach can depend on its geographical location within Seaton Bay.
- Defences constructed along the coastline at Seaton have help to stabilise the cliffs to the west and fix the backshore position at Seaton. The construction of defences around the perimeter of the Axe Harbour basin also act to fix the backshore of Seaton Spit where it joins to the mainland. Ongoing dredging over the years prevents siltation of the harbour, but disposal of the dredge material within trenches dug into the spit and beach have changed the composition of the beach and is likely to have affected its permeability, potentially increasing the rate of erosion and potentially threatening the ability of the spit to respond naturally to storms. The distal end of the spit has experienced significant cut-back in the past, particularly between November 2016 and February 2017, and although made some recovery, the upper beach is defined by steep cliff face and compacted interstitial sand and silts are exposed on the foreshore.
- Significant beach depletion occurred during the 1989/1990, 1992 and 1993 storms. The beach between Seaton Hole and Seaton has since built back-up again and over the period 2007 to 2017 (period covered by beach monitoring data) is generally stable at the western end of Seaton, however, in places, it is very dynamic and the beach volume fluctuates above MLWS over time. This change could be considered to represent a period of recovery, and form part of a larger cyclic process of erosion and accretion occurring over a 20-30 year period. This is not dissimilar from the 40 year cycle of recovery identified at Sidmouth.
- An absence of beach control structures on the beach mean that it can respond naturally to storms, and as such is considered to generally be stable. However, changes to the beach profile that occur in a cross-shore direction whereby material is pushed up the beach in response to south-westerly storms could result in increased run-up and overtopping during storms.

SECTION 6

Projections of Future Change

A requirement of the present BMP study is to provide predictions of future shoreline change for the 'With Present Management' and 'No Active Intervention' scenarios. A number of broad-scale assessments have already been completed including Futurecoast (Halcrow, 2002), the South Devon and Dorset SMP2 (Halcrow, 2011), and in 2012, the Environment Agency's National Coastal Erosion Risk Mapping Project.

The SMP2 (Halcrow, 2011) predicts how the shoreline at Seaton would respond to a 'No Active Intervention' and 'With Present Management' policy, and the predictions are summarised here. However, as raised by the Axmouth Spit Report (CH2M, 2015), the dredging activities currently undertaken within Axmouth Harbour and subsequent disposal within the spit were not known about at the time of the development of the SMP2. Considering the information that is now known, the predictions of future change for Seaton Spit and Axmouth Harbour have been updated for the present study.

6.1 With Present Management

6.1.1 White Cliff

The cliffs and shoreline are presently undefended, so behaviour will be similar to the No Active Intervention scenario (see Section 6.2.1 below).

6.1.2 Seaton Hole to West Seaton

Erosion of the cliff toe behind the rock revetment at Seaton Hole will be prevented, thereby helping to reduce the rate of erosion of the cliffs. The defended sections of cliff, between Seaton Hole and West Seaton, will continue to help to keep the soft mud cliffs stable; however, the cliffs from above, would continue to experience simple landslide failures. Over time, narrowing of the beach could occur in response to future sea level rise as it becomes squeezed against the cliffs behind. Where defences occur, sea level rise could make the toe protection less effective and beach narrowing could cause the increased risk of failure of defences by undermining.

6.1.3 Seaton

The backshore will be held in position by the seawall. The beach and foreshore is anticipated to continue to undergo cyclic change in response to incident wave conditions and storms. Future sea level rise may result in narrowing and steepening of the beach as it attempts to roll back in response to higher sea levels.

6.1.4 Seaton Spit

The position and volume of the beach and spit would be maintained by the continuation of sediment feed from the west. It is anticipated that some roll back may occur as a result of overwashing during storm events. Continued deposition of dredge material within trenches dug into the spit will affect the ability of the spit to respond to incident wave conditions, potentially resulting in exacerbated cut-back, cliffing and narrowing of the beach as storm conditions vary in response to future sea level rise and any increase in the frequency of storm events.

Changes in sea-level and wave climate could also increase the risk of further overtopping of the spit. The continued defence at the western end of the spit may lead to a discontinuity in the plan form of the spit which could cause a breach in the spit.

6.1.5 Axe Harbour

On the western side of the estuary, ad-hoc defences will continue to fix the perimeter of the Axe Harbour basin in position. Continued dredging will reduce the rate of sediment build-up in the estuary, but reduce the overall resource of sediment in the system.

On the eastern side of the estuary, the training walls and quay walls will retain a stable inlet position except during periods of river flood. However, the impacts of changes to the shoreline updrift of here have not been considered by this report.

6.1.6 Haven Cliffs

Although there are currently no defences protecting this length of shoreline, the future behaviour of the cliffs will be determined by the presence of the river training wall and quay walls within the Axe harbour. The training wall is acting to hold the beach in front of the western end of the cliffs and the quay walls are acting to contain the river flow, thereby preventing erosion of the hinterland. With these structures in place, the beach width would be maintained and the harbour mouth fixed in position. The cliffs will continue to erode via active landsliding complexes at a frequency that is similar to present. This erosion would continue to provide a supply of material to the beach in 'pulses'.

6.2 No Active Intervention

The SMP2 (Halcrow, 2011) has been used to provide predictions of how the shoreline at Seaton would respond to a 'No Active Intervention' policy, and the information is summarised here.

6.2.1 White Cliff

The presently undefended cliffs would continue to experience only isolated failures at a similar frequency to that presently observed.

6.2.2 Seaton Hole to West Seaton

To the west, in the absence of the concrete covered revetment, the toe would become exposed to marine erosion and potentially increasing the rate of the cliffs there and adjacent, and there would be a new release of sediment to the foreshore, which may contribute to the beach stocks. The cliffs between Seaton Hole and Seaton would continue to experience toe erosion and simple landslide failures, releasing fine sediment to the shoreline.

6.2.3 Seaton

In the absence of the seawall, the backshore and shingle beach is likely to retreat and rollback. This section has a long history of flooding, which without the protection of the seawall would result in increasing overwash, overtopping and flood events. A barrier may form, but would depend on the rate at which the beach rolls back and the evolution of the beach and intertidal hinterland behind. The beach will receive an increased supply of sediment from the west and the undefended cliffs release material to the foreshore.

6.2.4 Seaton Spit

As for the 'With Present Management' scenario, the position and volume of the spit would be maintained by the continuation of sediment feed from the west. It is anticipated that some roll back may occur as a result of overtopping and overwashing during storm events. A barrier may form, but would depend on the rate at which the beach rolls back and the evolution of the beach and intertidal hinterland behind. Future sea level rise and any increase in the frequency of storm events could increase the risk of overtopping and overwash, which the risk of breach may reduce if a more natural barrier system were to form.

The problems associated with the disposal of dredge material in the spit would no longer apply, however, there would still be a legacy of historic fill which will affect how the spit is able to respond to prevailing conditions. In the short term, there could be a risk that the spit erodes through cutting-back, rather than rolling landwards, which may result in net narrowing. Once the fill has been washed out a more naturally functioning beach-spit system may resume.

6.2.5 Axe Harbour

On the western side of the estuary, the absence of defences and dredging practices would result in the landward face of the shingle spit becoming more mobile and dynamic, potentially improving the spit’s ability to respond to storms and the longer-term process of rollback in response to rising sea levels.

On the eastern side of the estuary, the absence of the defences and harbour arm, could lead to increased exposure of the toe of the high, inactive, cliffs to erosion. Such erosion of the cliff toe could lead to the re-activation of ancient major landslides. Failure of the landslides would result in the deposition of a sediment on the shoreline, which could ultimately lead to the blocking of the present Axe channel and the back-up of freshwater upstream, flooding the lower Axe valley. The pressure build-up behind the blockage would eventually cause a breach and a new tidal inlet would form towards the western side of the Axe valley which in turn would eventually be deflected back towards the east by coastal longshore processes.

6.2.6 Haven Cliffs

The absence of the river training wall and quay walls within the Axe harbour would affect the future behaviour of the Haven Cliffs. The beach in front of the cliffs would no longer be held in place, and likely to be subject to narrowing and more fluctuation. Without the training wall and quay walls, the mouth of the estuary and channel would be able to migrate. The cliff toe would be exposed to increased marine erosion, and the frequency of landsliding is likely to increase. This erosion would continue to provide an increased supply of material to the beach.

Key Issues, Uncertainties and Recommendations

7.1 Key Issues and Questions

A number of key issues and questions were developed specifically to guide the development of this report in order to answer the broader objectives of the projects scope, as identified in Section 1.2 and repeated below in Table 7.1. The evidence to address these questions is provided throughout the report and a summary is presented below in Table 7.1.

Table 7.1 Issues and questions addressed by the BMP

Issue	Question Number	Question	Summary of Findings
It has been speculated that infilling of the King's Eye Hole and construction of the concrete groyne at King's Hole (Beer) has reduced the volume of sediment reaching the Seaton coastline.	1	**Do sediment linkages exist between Beer and Seaton?**	**A sediment pathway is understood to exist between Beer and Seaton, with the rock platforms facilitating that movement.**
	2	**Has construction of the concrete groyne at King's Hole (Beer) affected the rate/volume of material transported from Beer to Seaton?**	**It is evident from aerial photography and LiDAR that sediment has built -up in the lee of the groyne, and given the above, it is possible that that material would have otherwise been transported eastwards. The extent to which this has impacted on the overall sediment budget to the east at Seaton Hole and Seaton remains unclear; historical photographs and beach profile show that even following depletion in the late 1980's/1990s, the beach has built back up at Seaton Hole.**
At the western end of the BMP frontage, near Seaton Hole, beach levels fluctuate considerably and the cliffs are eroding.	3	**To what extent has fluctuating beach levels influence erosion of the cliffs?**	**At the western end of the BMP frontage, between Seaton Hole and West Seaton, beach profile data suggests that the beach is accreting, however, this conclusion should be treated with some caution due to potential errors in the data. The level of the beach will determine the extent to which defences are exposed (or as observed, sometimes buried), and therefore how exposed the cliff toe is to erosion. However, as well documented, erosion of the cliffs at this location is also related to weathering and cliff failure from the top-down.**
Seaton has a long history of flooding, with overtopping of the seawall occurring during several storms. The beach fronting the Seaton seawall is observed to ramp-up against the seawall, which has been proposed to increase wave- run-up and overtopping.	4	**To what extent, and when, does the beach appear to build-up against the seawall at Seaton?**	**A review of beach profile data in SANDS, shows that in general beach levels at the seawall and esplanade do fluctuate, the exception is a small length of beach along the western and central esplanade, between profiles 6a01176 and 6a01173. Beach levels vary the most at the seawall at the of Castle Hill (by up to 2m), but from here along to the central section of Seaton Beach vary by approximately 0.6m but are not observed to have reached the height of the esplanade between 2007 and 2016. At the eastern end of the beach, as far as the Axe Yacht Club, beach levels do reach the height of the esplanade and vary by approximately 0.6m.**

Issue	Question Number	Question	Summary of Findings
			Beach material is observed to be pushed up against the seawall during storms along the length of the seawall. High-level beach modelling has been completed as part of the Defence Baseline and concluded that, when considering 'defined hydrodynamic conditions', material may be prevented from reaching the seawall if the beach was sufficiently wide, or if material were moved away from the seawall.
For several decades, material dredged from the Axe Estuary has been disposed of within trenches dug into Seaton Spit. However, there are concerns that this practice is now threatening the integrity of the seawall at Seaton.	5	**How has the disposal of dredge material within Seaton Spit affected its behaviour and could it be detrimental to its integrity?**	**Disposal of the material within the eastern trench has raised the height by 2m above the existing height of the shingle spit and has created a higher and wider beach crest than would occur naturally.** **The disposal of dredged material into the spit and its compaction beneath could affect the permeability of the shingle spit and therefore its ability to respond to storms, as less wave energy is absorbed by the feature and there is a risk of increased wave run up (i.e. the maximum vertical extent of wave uprush) and drawdown and offshore movement of material under storm action.**

7.2 Uncertainties

The key uncertainties and limitations to our understanding of the behaviour of the coastline at Seaton include:

- The sediment linkage between Beer and Seaton remains unclear as it has not been possible to identify a net cut-back at the beach updrift and the beach profile data for the western end of the beach between Seaton Hole and West Seaton is limited and unreliable. Therefore, it is not certain as to whether the material that has accumulated in the lee of the concrete groyne at Beer has had a long-term impact on the beach at Seaton or represents only a reduction in supply.
- As beach profile data is only available from 2007 to 2016, through the SWRCMP, there are inherent uncertainties relating to long-term trends which extend beyond 2007. As above, in some locations, particularly at the western end of the BMP study area between Seaton Hole and West Seaton, the data is limited and unreliable.
- It is evident from the review of existing data and new beach profile analysis completed for this study that the beach at Seaton is dynamic and volatile over short periods of time (i.e. from one survey to the next and in response to storms. Post-storm analysis shows a general easterly movement of material along the BMP coastline from west to east, with cross-shore changes resulting in both the build-up of material above HAT at some locations and the draw-down of material at others. This could be related to the wave direction, but, could also be a result of wave height or wave direction. Further analysis of the beach behaviour alongside wave climate could improve the certainty of this hypothesis.
- In response to severe storms in the late 1980's/early 1990's, the beach was depleted of material, however, since that time, the beach has built-up again. This behaviour may form part of a cyclical process (as observed at Sidmouth (CH2M, 2017b)), however, without a longer-term beach profile dataset, it is not possible to bring any certainty to this hypothesis.
- Review of existing data and review of aerial photographs clearly show the presence of dynamic estuary bar and delta at the mouth of the Axe Estuary, and build up material on the beach at the

foot of Haven Cliffs. The part that this plays in transporting material across the mouth of the estuary and potentially storing material removed from the beach at Seaton remains uncertain and clarification could come from further study.

7.3 Recommendations

In terms of monitoring coastal processes and behaviour, the following recommendations are made:

- As a minimum, on-going analysis of PCO beach profile data is recommended following each new survey. This will, over time, provide a longer data set from which to determine trends in beach behaviour. At present, PCO only monitor eleven profiles between Seaton Hole the distal end of Seaton Spit biannually, however, more accurate assessments of beach profile change, CSA and volumes could be made if the intervening profiles were monitored at the same frequency. This could be supported with in-depth analysis of LiDAR data.
- Although LiDAR data is available for Beer, presently beach profile data is not collected there. It is recommended that the SWRMP is extended to include regular beach profile monitoring at Beer. This will help to determine, in more detail locations of erosion and accretion, and provide the information necessary to estimate CSA and volume change. Detailed beach monitoring the beach at Beer and at the toe of Haven Cliffs could be used to help understand changes to the beach to the western and eastern boundaries of the BMP study area, thereby improve the existing knowledge on linkages to the west and east of Seaton. An action item arising from the SMP2 action was to undertake a strategic study for Beer; should this work be undertaken in the future when monitoring data is available, this could help to address the existing gap in knowledge and be used to improve the undertaking of beach behaviour at Seaton.
- Detailed bathymetric surveys would also help to improve the understanding of the sediment movement between the beach, nearshore and offshore. As recommended in previous reports around the mouth of the estuary to understand better the linkages between the nearshore and, the bar and delta.
- A consequence of erosion of the cliffs between Seaton Hole and West Seaton is the accumulation of debris at the cliff toe, for example an outfall pipe. Such items could represent a health and safety hazard to beach users and removal of such items should be considered.
- The deposition of dredged material within the spit has been flagged as a potential threat to its integrity and the content of the dredged material has also been questioned during the development of the BMP. The area currently identified as disposal site is also shown by beach profile data to have reduced in volume between 2007 and 2017. Options for the future disposal of dredged material at other locations and testing of the dredged material for potential contamination should be considered as a high priority.

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Appendix A
Beach Profile Analysis