



Weston Bay Beach and Dune Management Plan

North Somerset Council

December 2013
Final Draft Report
9Y0510

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SUMMARY

This Beach and Dune Management Plan describes an investigation of the contemporary and historic geomorphic change of Weston Bay and the Axe Estuary, North Somerset, and its potential implications for coastal flood risk. The plan provides management options that aim to ensure that the beach and dunes provide effective flood protection into the future.

Three main types of coastal flood defence are present within the study area: sea walls in the northern half of the beach, sand dunes in the southern part of the beach and flood embankments lining the Axe Estuary. Historic mapping, survey data and field observations have been used to assess changes in the form of the beach and dunes and to interpret flows of sediment transport.

It is found that the beach has historically remained relatively stable with a general movement of sediment from north to south.

In the north of the bay there appears to be seasonal variation in the level of the beach whereas in the central area (in the vicinity of the Tropicana) a trend of accretion has been observed. Beach recycling is undertaken in this area on an annual basis. The dune system fronting Weston-super-Mare Golf Course is considered to be robust and there is strong evidence historically to confirm longer term growth both in height and width. There is a general retreat of the saltmarshes at the mouth of the Axe Estuary. However, this is not seen as being an immediate issue of concern in terms of flood defence.

The plan considers the effectiveness of the existing management options in place and recognises the need for adjustments in the management options to compensate for sea level rise.

In the north the recently constructed sea wall provides a 1 in 200 year standard of protection. The level of the wall can be raised by 1.0m to accommodate sea level rise and sustain the standard of protection. The timeframe for increasing the crest level of the sea wall will be informed by regular monitoring of the beach level and sea level rise.

In terms of the dune system, it is considered that there is potential for seaward migration. It is recommended that a buffer zone is created at the toe of the dune system to allow for this migration to occur, along with an increased frequency of monitoring.

Low spots have been identified on the western flood embankment along the River Axe. It is recommended that a detailed survey is carried out to provide a better understanding of the standard of protection along this part of the embankment and to inform maintenance works.

CONTENTS

	Page
1 INTRODUCTION	1
1.1 Background	1
1.2 Scope of the Report	1
1.3 Location and Surroundings	3
1.4 Key Uses and Features on the Weston Bay Frontage	4
1.4.1 Defences	4
1.4.2 The Principal Built Features	6
1.4.3 Activities	7
1.5 Strategic Shoreline Management Approach	8
1.5.1 SMP2 Preferred Policies – Brean Down to Anchor Head (Halcrow 2010)	9
2 BASELINE ENVIRONMENT OF WESTON BAY	11
2.1 Water Environment	11
2.1.1 Bathing Waters	11
2.1.2 Estuarine Water Quality	11
2.1.3 Resource Use	11
2.1.4 Recreational Use	11
2.2 Biodiversity	11
2.2.1 Designated sites	11
2.3 Habitats and Species	12
2.3.1 Coastal and Marine Ecology Habitats	12
2.3.2 Terrestrial Ecology Habitats	13
2.3.3 Birds	14
2.3.4 Mammals	14
2.3.5 Fish	15
2.4 The Historic Environment	15
2.5 Socio-Economics, Community and Recreation	17
2.5.1 Non-Designated Sites and Buildings	17
2.5.2 Public Rights of Way	17
3 GEOMORPHOLOGY AND COASTAL PROCESSES	18
3.1 Introduction	18
3.2 Geology	18
3.3 Geomorphic Setting	19
3.3.1 Overview	19
3.3.2 Typical Cross-shore Profile	21
3.3.3 Historic change	22
3.3.4 Beach Material	24
3.3.5 The Dune System	24
3.4 Environmental Forces	25
3.4.1 Water Levels	25
3.4.2 Wind Climate	25
3.4.3 Wave Climate	26
3.4.4 Wave Direction and Transformation within the Bay	27

3.4.5	Tidal Flows	29
3.4.6	Climate Change	31
4	ENGINEERED FLOOD DEFENCES	33
4.1	Historic Flood Events	33
4.2	Flood defence	33
4.2.1	Sea Wall in the North of the Bay	33
4.2.2	Beach Recycling	33
4.2.3	Flood Defence at the River Axe and Uphill	34
5	EXAMINATION OF BEACH BEHAVIOUR	36
5.1	Introduction	36
5.2	General Behaviour and Development of the Beach Shape	36
5.3	Sediment Transport Analysis	42
5.3.1	General Trends of Sediment Movement	43
5.4	Implications for management	45
5.4.1	The Weston–super–Mare Frontage	45
5.4.2	Sand Dune	47
5.4.3	Salt Marsh Area	51
6	FLOOD RISK ALONG THE AXE ESTUARY	56
6.1	General	56
6.2	Uphill Area	58
6.3	Western Flood Embankment	59
6.4	Future Development and Impact of the Open Coast	61
7	THE IMPACT OF SEA LEVEL RISE ON WESTON BAY	62
7.1	North of the Bay	62
7.2	Ridge of Dunes in the South	64
7.3	The Axe Estuary	65
8	DISCUSSION OF MANGEMENT	67
8.1	Introduction	67
8.2	Policy Unit 7e06 – Royal Sands to Anchor Head	67
8.2.1	The Northern Part of the Bay	67
8.2.2	The Beach in the Vicinity of the Tropicana	68
8.3	Policy Unit 7e05 - The Dunes	68
8.4	Policy Units 7e02 to 7e04 – Axe Estuary	69
9	CONCLUSIONS	71
10	REFERENCES	73

1 INTRODUCTION

1.1 Background

The Weston Bay Beach and Dune Management Plan commissioned by North Somerset Council (NSC) covers Weston Bay from the Brean Cross sluice on the Axe Estuary to Anchor Head at the north end of Weston Bay.

To date, NSC has undertaken annual beach management in Weston Bay looking to meet the operational needs in terms of sea defence and beach amenity. In the northern part of the bay, a recently improved sea wall forms the main defence to Weston-super-Mare. To the southern part of the town, the ridge of sand dunes fronting the golf course forms the sea defence. It is considered that these dunes are relatively robust; however, a detailed assessment has not previously been undertaken.

The purpose of this commission is, therefore, to produce a Beach and Dune Management Plan based upon available beach monitoring data, results from modelling studies, and other relevant studies. The requirement for a Beach and Dune Management Plan was also identified in the action plan for the second round North Devon and Somerset Shoreline Management Plan 2 (SMP2) produced by Halcrow in 2010.

1.2 Scope of the Report

The Beach and Dune Management Plan follows the guidance in the CIRIA Beach Management Manual (CIRIA 2010), co-authored by Royal HaskoningDHV, to establish the methodology to manage the beach and dunes between Brean Cross sluice and Anchor Head and will be required to meet the following objectives:

- Collate historical evidence to consider erosion and sediment volume trends to inform the plans;
- Identify whether the current trends are cause for concern;
- Identify beach trigger levels to protect the sea defences;
- Identify beach and dune trigger levels for the area south of Royal Sands;
- Make recommendations for future work and monitoring;
- Provide management plan/s to cover the area of study;
- Provide advice to landowners and local residents on future protection of property and dunes;
- Agree maintenance regimes for the beach and dunes;
- Agree the methodology for beach clearance operations; and
- Ensure the management proposals take account of the areas environmental designations and are agreed with Natural England.
- Describe historical drivers for development
 - Storm events
 - Previous management type
 - Management issues e.g. overtopping, scour, breaching

The main objective of this beach management plan is to provide an assessment of the behaviour of the beach, relating this primarily to its key role as part of the defence

system and how this interacts with other important uses and benefits the beach brings to the area. This initial section of the report provides a general description of the area and highlights the principal features associated with the beach and seafront. Latter sections of the report discuss the evolution of the beach geomorphology and its current behaviour, assessing this in relation to present management. The study examines how the beach can be managed in order to maintain its overall function, looking at that present management and the potential need to adapt this into the future.

The scope of the study has been extended to the south, considering also management issues relating to the SMP recommended policy for managed realignment within the Axe.

1.3 Location and Surroundings

Weston Bay is located on the north coast of Somerset facing westward out on to the Bristol Channel. The bay provides the frontage to the main settlement of Weston-super-Mare. The beach down to mean low water is owned by North Somerset Council (previously owned by the Smith-Piggott family Estate). The area covered within this Beach and Dune Management Plan is shown in Figure 1.1, denoted at either end by two black arrows. This area stretches from Brean Cross sluice on the Axe Estuary in the south, to Anchor Head at the north end of Weston Bay.

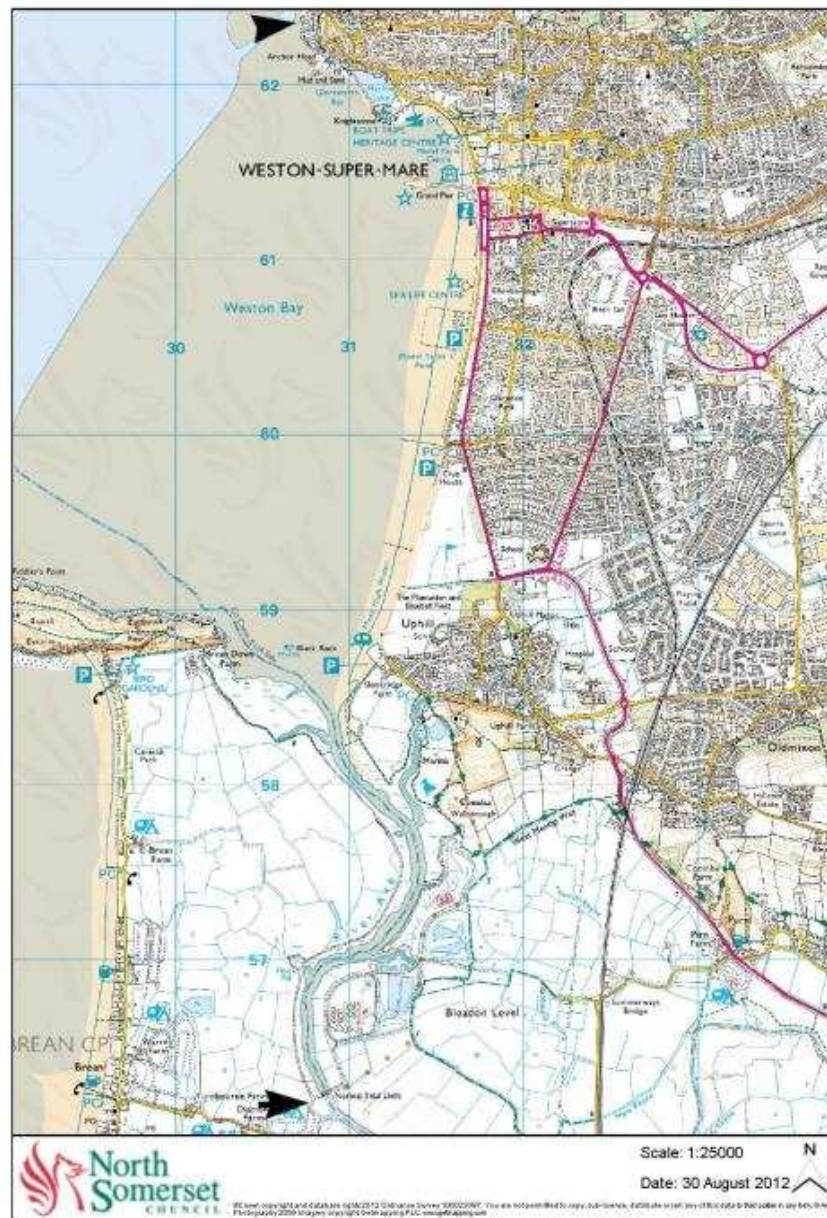


Figure 1.1 – Site Location Plan

The main frontage at Weston-super-Mare has recently seen an upgrade of the sea defences, completed in 2010. Royal HaskoningDHV completed the detailed design and construction supervision of this sea defence scheme. It is an area of high amenity value and there are existing beach management operations in place. To the south, the dunes and the golf course are considered to provide a relatively robust defence.

With a population of approximately 80,000, Weston-super-Mare occupies the majority of the central and northern areas of the hinterland. Further south, Weston-super-Mare Golf Club has existed since 1892 immediately landward of the sand dunes. The golf course is split in two by an access road to the beach which leads to the settlement of Uphill.

South of the golf course the Axe Estuary runs in a north/south direction. Both sides of the estuary have flood alleviation embankments and two tidal sluices exist along this line of defence, at Brean Cross and Uphill.

Weston Bay has an intertidal zone of approximately 2km which is comprised largely of sand banks and lower mud flats. The intertidal zone dries out to form a line between Birnbeck Island in the north and Brean Down in the south. The topography of the bay generally comprises a gentle downward gradient seaward that steepens into the deeper area of the Bristol Channel.

1.4 Key Uses and Features on the Weston Bay Frontage

Several structures have been constructed on Weston Bay over the last century. These structures along with other uses and features are identified on Figure 1.2 and are briefly described below in this section.

1.4.1 Defences

The main sea defence for the northern part of the bay has existed in the form of a stone parapet sea wall since the 1880s. The sea wall was upgraded to provide a defence standard of a 1 in 200 return period as part of the Weston-super-Mare Seafront Enhancement Project in 2010. The defence sits directly to the front of the main seafront road over the northern section, with properties immediately to the rear of the road. Further south, to the south of the Grand Pier, the frontage is laid out as open space with areas of grass and planting, car parking and roads. The main properties lie to the rear of this open space.

The main flood defence to the south is the Uphill dune system. The dune provides the main open coast flood defence to the golf course, to the village of Uphill and to the south of Weston-super-Mare.

The Axe estuary is protected by lengths of embankment, protecting land to the west through to the open coast of the Berrow Flats. To the east the defences provide protection to Uphill and to the extensive flood plain of the Somerset Levels.

These defences are discussed in more detail in Section 4.



Figure 1.2 – Key Uses and Features of Weston Beach

1.4.2 The Principal Built Features

The Marine Lake

The marine lake is located at the northern tip of the Weston-super-Mare beach. Marine Lake has long been an important Weston-super-Mare seaside attraction, but its appearance has evolved over time. Originally known as Glentworth Bay, it had a pebble and shingle beach, swept twice a day by the tide, with Knightstone Island to the south. The marine lake was built in 1927 to allow visitors to the seaside resort to swim when the tide was out.

The marine lake suffered storm damage in 1981, and the marine lake causeway was in poor condition and with signs of erosion. The causeway provides extra protection to the town from coastal flooding, dissipating large waves.

Between August 2007 to August 2010, Royal HaskoningDHV was involved in the Weston-super-Mare Seafront Enhancement Project. As part of this scheme, the marine lake underwent major refurbishment works, beginning in August 2007. The marine lake was drained by breaking through the causeway at two locations, new sluice gates were installed in the breaches so that the water levels in the lake could be controlled and regularly drained to reduce sediment build up. Steel sheet pile and precast concrete toe beams and deck slabs were installed to strengthen the causeway. Finally, two phases of marine lake dredging removed 23,000m³ of silt to improve water quality.

The Grand Pier

The Grand Pier is located at the northern end of the Weston-super-Mare beach. Work started on the structure in 1903 and in 1904 the deck and theatre opened. Throughout the next 20 years light amusements were added as well as a landing stage.

In terms of structure, the Grand Pier is 400 metres long and is supported by 360 original cast iron piles from 1904 with 71 new steel piles added in 2010. Following a devastating fire in 2008, the entire structure was refurbished in 2010 to give a minimum 25 years to first maintenance of any structural element.

The refurbished pier was reopened in October 2010 and now offers conference facilities, rides and attractions, food and beverage outlets, a cinema and a 250m Go-Kart circuit. To date, the Grand Pier is the largest UK Pier development for over 100 years.

The Seaquarium

The Weston-super-Mare Seaquarium was opened in 1995, and was placed upon the first seaside pier to be built in Great Britain for over 85 years. Situated on the beach, the aquarium provides panoramic views across the estuary of Wales.

The Tropicana

The Tropicana is centrally situated on the Weston-super-Mare beach, located south of the Seaquarium. It was built in 1937 and became, together with the Grand Pier, one of the major features and attractions on the seafront in Weston-super-Mare.

The two-storey building has a Mendip Stone Art Deco architecture frontage and was first developed as a 950 square metres swimming pool, including an art deco diving board. The establishment was first known as "The Pool", becoming branded as the Tropicana in 1983. The diving board was demolished in 1982.

The Tropicana closed in 2000 following a period of decline in the latter part of the twentieth century. Since its closure there have been two major planning applications for the site (Mace Estates and Henry Boot Plc), neither of which were progressed.

In October 2012, an outline planning application was submitted by The Trop (WsM) Ltd (a group of business people campaigning to refurbish the Tropicana) to North Somerset Council for redevelopment of the Tropicana. The proposal included reconstruction of the pool to provide an Olympic sized swimming pool and beachside entertainment facility for residents and visitors to the region. In 2012, an application was also made for the demolition of the building and to restore the site to beach. The potential influence of such action on the coastal processes and behaviour of the beach has been considered.

The Secretary of State has refused permission for demolition and Trop (WSM) is now working on funding plans for redevelopment.

1.4.3 Activities

General Amenity

Weston super mare is a popular destination for holidays and day trips. The beach offers a variety of activities including walking, donkey rides, land yachts/land kite board/ power kites which are undertaken along specific areas of the beach. The Axe Estuary is also home to Weston Bay Yacht Club.

Beach Cleaning

The beach is regularly cleaned with removal of sand and vegetation, alongside general litter. During the winter the cleaning takes place at weekly intervals, whereas during the summer cleaning is daily. In the south, it is understood that cleaning takes place up to the toe of the dune.

The RHL Beach Race

The RHL Beach Race is a motor cross/quad bike event that has taken place on Weston–super–Mare beach for the last 30 years. The race is staged on the beach and involves a significant movement of beach material to form jump like obstacles. This international event is known to attract thousands of spectators. After the completion of the RHL Beach Race the material used to form the race obstacles is transported to the northern area of the beach as part of the management. This has not been a formalised operation and there have been periods, when the Grand Pier was being refurbished, when movement of sediment was not undertaken.

Beach Parking

The beach to the front of Royal Sands and the area in the vicinity of the former caravan site at Uphill are used as car park areas, providing an important facility supporting use of the whole area. This has been set out formally, with parking up to the toe of the dune. The area is compacted to a degree by the traffic of vehicles.

The Weston-super-Mare Golf Course

The golf course lies to the back of the dunes. The golf has been in existence for over 100 years and is an important amenity feature of the area. There has been a continuing pressure for encroachment of the dune in to the area and this has been resisted by

clearance of sand and management of vegetation. The golf course extends to the area south of the dunes on the southern side of the Uphill road.

Caravan Site

There is a small area of land at the southern end of the frontage that is defended locally by a sea wall. This area was formerly a caravan park and extends in to the active part of the beach, therefore influencing beach behaviour at the entrance to the Axe Estuary. The caravan site is currently closed.

1.5 Strategic Shoreline Management Approach

Weston Bay falls into the North Devon and Somerset Shoreline Management Plan 2 (Halcrow 2010). The bay itself is split into six policy units, from 7E01 to 7E06. The locations of these Policy units are illustrated in Figure 1.3. The focus of this Beach Management Plan is primarily on Policy Units 7e02 to 7e06.



Figure 1.3 – SMP2 Policy Unit Boundaries and Tidal Estuary Limits

The draft policies for the relevant Policy Units as set out in the North Devon and Somerset Shoreline Management Plan 2 (SMP2) are described in this section. To summarise, the document recommends hold the line with local retreat for the Axe

Estuary East Bank. For Uphill to South Weston-super-Mare, hold the line with possible long term retreat and for the town area of Weston-super-Mare a policy of hold the line is the recommended policy. The following extracts from the SMP2, outline the preferred plan (hyperlink contained within references).

1.5.1 SMP2 Preferred Policies – Brean Down to Anchor Head (Halcrow 2010)

Axe Estuary

7e02 to 7e04

Summary of preferred plan recommendations and justification

Plan:

The long term plan across this whole area is to continue to minimise flood risk to the wider area of the Somerset Levels in the most sustainable way. Along the west (left) bank of the Axe Estuary, policies and implementation measures also need to take account of future management of the open coast between Berrow and Brean Down. Therefore the two statements should be read in conjunction with each other.

The long term vision for the estuary is to return it to a more natural, less constrained, state whilst continuing to provide defence against the risk of flooding in a way that it is environmentally acceptable and economically viable. The estuary is not able to return to a fully natural state as flow will remain controlled by the Brean Cross Sluice. There are however a number of locations within the Axe Estuary which offer potential opportunities for set back defences, using shorter and smaller (and less costly) defences.

Further studies are necessary to determine the viability, approach, timing and consequences of realignments, and any measures that would need to be put in place to manage risk and facilitate realignment. Although considerable nature conservation and biodiversity opportunities could be realised through this approach, this would produce changes to currently designated sites and potential impacts on habitats further inland. Although the aim would be to defend key assets, there could be potential impacts on a number of non-designated archaeological features and areas of farmland. Therefore, in the short term the present defences are to be maintained whilst retired line options are investigated more fully.

Along the west bank of the River Axe, there would be no change in the short and possibly medium term before moving towards managed realignment in the medium to long term. This would ultimately result in the loss of homes and businesses in the long term but flood risk to the wider Somerset Levels and to Brean and Berrow from the Axe Estuary would be managed. The mouth of the River Axe could potentially move position to the south of Brean Down in the very long term. If this were to occur then it could have implications for sediment circulation along the Burnham-on-Sea to Brean coast as well as within Weston Bay.

Along the east bank of the River Axe and from the east side of the mouth towards Uphill, the plan is to provide defence against the risk of flooding in a realigned position. There are opportunities here for further managed realignment to create habitat. This would continue to protect homes and businesses against flood risk, as well as key infrastructure including the A38 and M5, the mainline railway and associated facilities.

This would also provide potential benefits to the Severn Estuary SSSI, SAC, SPA and Ramsar site by creating intertidal habitat in areas of Managed Realignment. However, holding the realigned defence

position in the long term may eventually cause coastal squeeze (narrowing of the shoreline) and loss of intertidal habitat.

Realignment may also have potential impacts on a number of non-designated archaeological features, depending upon extent of realignment, which would be determined through further detailed study.

Uphill to Weston-super-Mare (Anchor Head)

7e05 and 7e06

Summary of preferred plan recommendations and justification

Plan:

The significant socio-economic assets along this frontage justify a long term plan to continue to minimise the risk of flooding and erosion to Weston-super-Mare, Uphill and the wider area of the Somerset Levels. The beach and dunes are important to tourism value in this area and are also important natural defences at Uphill. The plan will involve the appropriate management of the existing dune system at Uphill. Between Uphill and Weston-super-Mare the dunes may become unsustainable as a defence, therefore set-back defence may be required to minimise flood risk to people and property.

Through beach and dune management, as well as maintenance of sea walls at Weston-super-Mare, there will be continued protection against flood risk for a significant number of homes and businesses in Weston-super-Mare and Uphill, as well as key infrastructure including the A370 and M5, the mainline railway and associated facilities.

Beach width is likely to reduce over time as sea levels rise, with potential for habitat loss due to narrowing of the shoreline where hard defences are present. Loss of intertidal habitats could impact upon the Severn Estuary Special Area of Conservation, Special Protection Area for Birds and Ramsar site as well as the amenity value of the area.

Critically in relation to the Beach Management Plan, the SMP2 recommends the following actions.

Policy unit	Action
7e02 7e04	Investigate opportunities for Managed Realignment in the Axe Estuary to inform future management decisions on where and when it may be appropriate to implement realignment and for what habitat creation gain. In unit 7e02, assessment of realignment options needs to also consider interactions with the open coast at Brean (Policy Unit 7d45).
7e04 7e06	Develop a Dune and Beach Management Plan for Weston Bay frontage to ensure future dune and beach management, along with monitoring and maintenance of associated hard defence structure is adequate to address flood and erosion risk whilst acknowledging the significant amenity use of this beach. This should include any requirements for additional monitoring to improve information available for future management decisions as well as assessment of the flood risk to determine the long term sustainability of the dunes as a natural defence.

2 BASELINE ENVIRONMENT OF WESTON BAY

Options for managing coastal hazards must be developed with due consideration of environmental conditions and constraints. For this reason the following section identifies the key elements of the current environment within and around Weston Bay. A full Habitats Regulations Assessment is provided in Appendix A.

2.1 Water Environment

2.1.1 Bathing Waters

Weston Bay is designated as European bathing water. Results for the last five years have been classified as Minimum (2008 and 2012), Higher (2009-2011). Wessex Water has a multimillion pound program to reduce foul spill and improve water quality.

2.1.2 Estuarine Water Quality

Weston Bay falls within the Severn Lower Water Body (GB530905415401) of the Severn Estuary River Basin Management Plan (RBMP) (Environment Agency, 2009). The current ecological quality of the unit is Moderate; chemical quality is Good; with a predicted ecological and chemical quality of Moderate and Good respectively.

2.1.3 Resource Use

No recognised commercial exploitation of Weston Bay has been identified.

2.1.4 Recreational Use

In terms of amenity, Weston Bay is popular with locals and tourists and has designated areas for wind and water sports, with boat trips occurring around Weston Bay and further afield. The beach is popular with swimmers, anglers, and walkers and there are several car parks situated along the bay (at Locking Road, Seafront area, Melrose & Carlton Street), as well as in designated areas of beach.

2.2 Biodiversity

2.2.1 Designated sites

The beach is part of the following key designated nature conservation sites:

- Severn Estuary Special Area of Conservation (SAC);
- Severn Estuary Special Protection Area (SPA);
- Severn Estuary Ramsar;
- Severn Estuary Site of Special Scientific Interest (SSSI);

The key European sites (SAC, SPA, Ramsar) extents within the study area are presented on **Figure 2.1**.

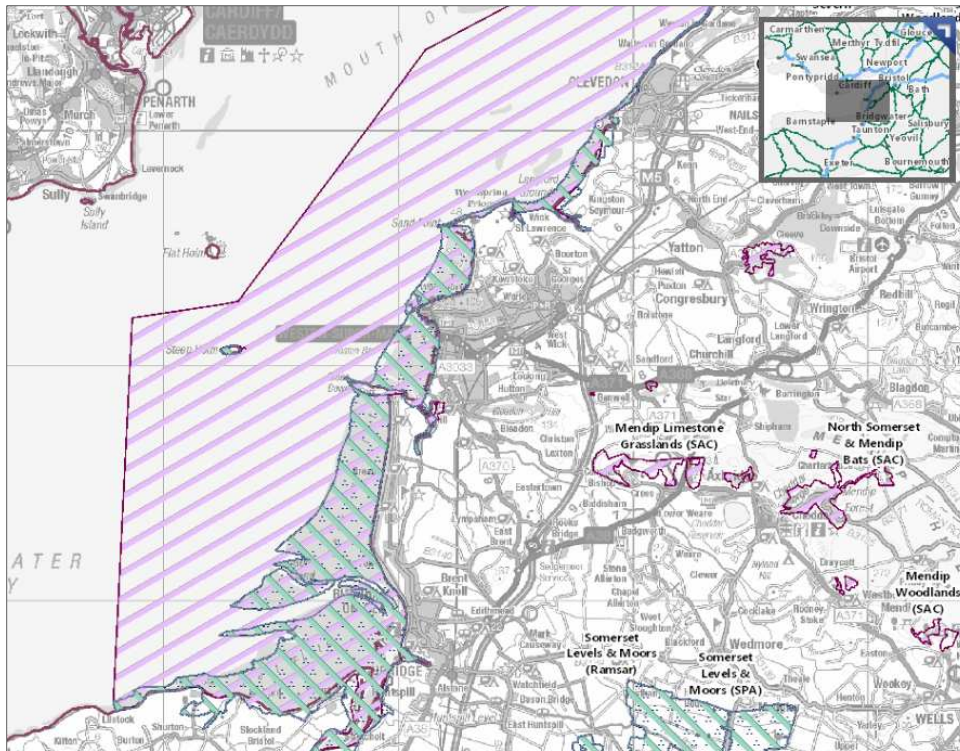


Figure 2.1 – European designated sites (Source: <http://magic.defra.gov.uk>)

2.3 Habitats and Species

2.3.1 Coastal and Marine Ecology Habitats

The predominantly unconsolidated sediments of Weston Bay (i.e. muds and sands), form the basis of the structure of the estuarine habitats. These habitats include inter-tidal mudflats and sandflats, hard substrate (rocky shore) towards the northern and southern limits of the bay, saltmarsh communities along the tidal section of the River Axe; and coastal grazing and floodplain marsh (**Figure 2.2**). The inter-tidal habitats of Weston Bay form part of the Severn Estuary SAC and Ramsar sites and provide an ecosystem of great national importance for a wide range of fish and bird species – for feeding, breeding, resting and migration.

To the south of Weston Bay there is a vegetated coastal dune system (a Biodiversity Action Plan (BAP) habitat), which has a southwest/northeast alignment and provides the front line of flood defence for Weston- super-Mare Golf Club and the properties behind. The sand dune comprises a single ridge that generally stands between 15m and 20m high (see **Figure 3.6, Section 3**).

2.3.2 Terrestrial Ecology Habitats

The southern and northern ends of Weston Bay and inland of the sand dune system within the hinterland contain pockets of various terrestrial BAP habitats (**Figure 2.3**).

These include the following:

- Ancient or semi-natural woodland;
- Lowland meadow;
- Lowland calcareous grassland;
- Traditional Orchards; and Maritime cliff and slope.

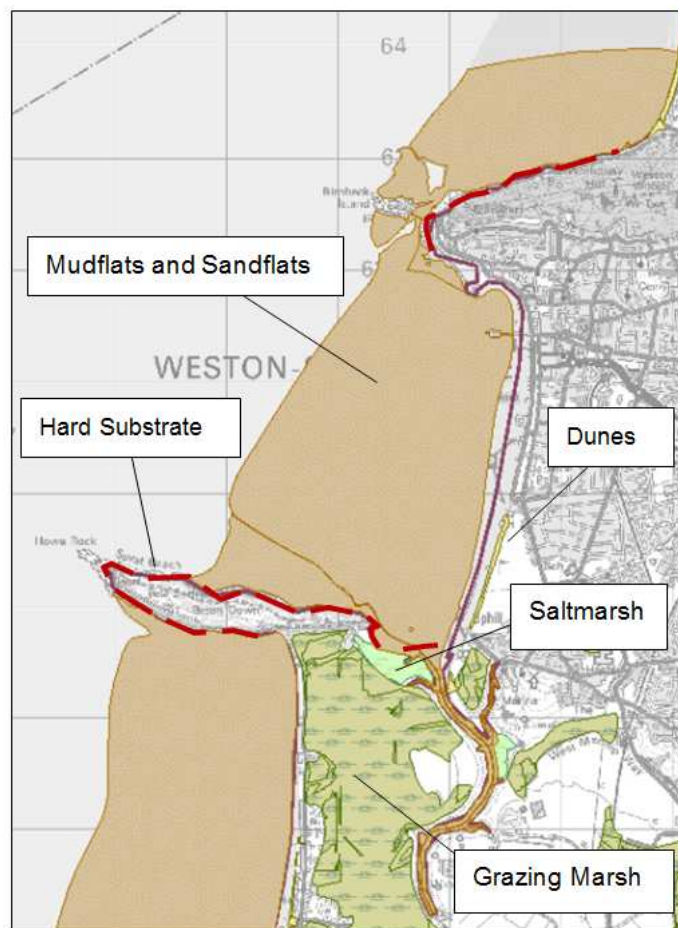


Figure 2.2 Coastal and marine habitats of Weston Bay
(Source: <http://magic.defra.gov.uk>)

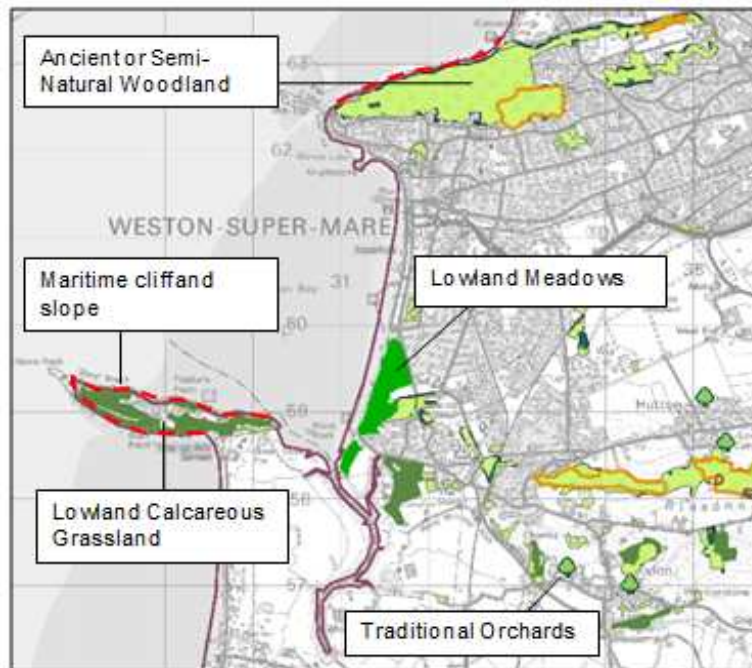


Figure 2.3 Terrestrial ecology habitats of Weston Bay
(Source: <http://magic.defra.gov.uk>)

2.3.3 Birds

The inter-tidal habitats of Weston Bay such as the mudflats and sandflats, saltmarshes and hard substrate habitats (see **Figure 2.2**) provide support to a wide range of designated wintering and migratory waterbirds of the Severn Estuary SPA/Ramsar. The Severn Estuary SPA/Ramsar designations provide protection to these waterbirds and their supporting inter-tidal habitat. Key species found in the area are redshank, dunlin, shelduck and gadwall.

In addition to the presence of wintering and migratory waterbirds in Weston Bay, the dune system, scrub, surrounding fields/grasslands and woodlands provide a wide range of habitats for breeding and feeding birds of many species, including rare 'visitors' such as corn bunting (*Emberiza calandra*) and hoopoe (*Upupa epops*).

2.3.4 Mammals

No species specific data was available, although based on NBN Gateway (<http://data.nbn.org.uk>) the following key mammals have the potential to occur within the area covered by the Beach and Dune Management Plan for Weston Bay:

Terrestrial Mammals

- Long-eared Bat (*Plecotus*);
- Lesser Horseshoe Bat (*Rhinolophus hipposideros*);
- Common Pipistrelle (*Pipistrellus pipistrellus*);
- European Water Vole (*Arvicola amphibious*);
- European Otter (*Lutra lutra*); and
- Eurasian Badger (*Meles meles*).

2.3.5 Fish

Migratory fish species use Weston Bay as a major route between sea (estuary) and river, with the River Axe regularly containing such species as salmonids and eel (*Anguilla anguilla*).

2.4 The Historic Environment

There are four Scheduled Monuments and numerous listed buildings within the study area of the Beach and Dune Management Plan for Weston Bay (**Figure 2.4**). Key listed buildings include:

- Grand Pier (Grade II listed building);
- Birnbeck Pier (Grade II* listed building);
- Coalbrookdale Fountain (Grade II listed building);
- Sea Front Pavilions (Grade II listed building);
- Chapel of the Royal Hospital (Grade II listed building).

The majority of the foreshore of Weston Bay is designated as Conservation Area (**Figure 2.5**) and containing non-designated archaeological sites (**Figure 2.6**).

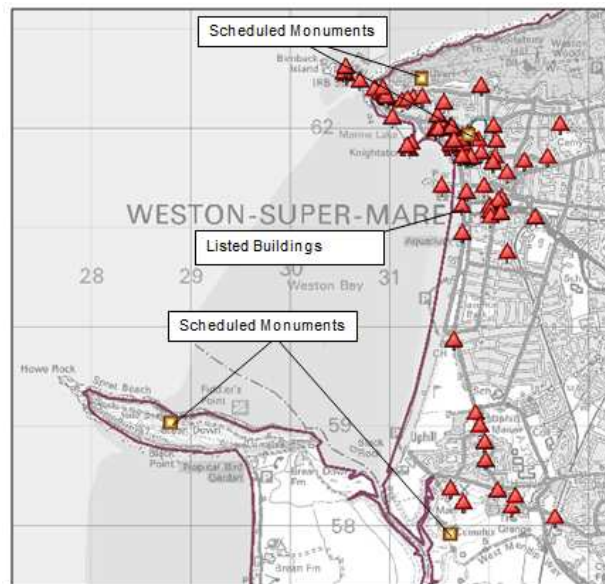


Figure 2.4 - Historic environment of Weston Bay (Source: <http://magic.defra.gov.uk>)



Figure 2.5 - Conservation Areas of Weston Bay (Source: <http://map.n-somerset.gov.uk>)



Figure 2.6 - Archaeological sites of Weston Bay
(Source: <http://map.n-somerset.gov.uk>)

2.5 Socio-Economics, Community and Recreation

2.5.1 Non-Designated Sites and Buildings

2.5.1 Weston-super-Mare occupies the majority of the central and northern areas of the hinterland within the study area. Several structures including the Yacht Club building have been constructed on Weston Bay over the last century. These structures along with other uses and features are detailed in **Section 1.4**.

2.5.2 Public Rights of Way

2.5.3 There are various Public Rights of Way (PRoW) used by walkers, bird watches and anglers predominately along the northern and southern areas of Weston Bay providing access to Marine Lake, the beach and various foreshore locations near Uphill. A major footpath also traverse's around Brean Down Nature Reserve (Black Point).



Figure 2.7 – Plan Illustrating Public Rights of Way

3 GEOMORPHOLOGY AND COASTAL PROCESSES

3.1 Introduction

The basis of the beach management plan is in identifying the trends in coastal processes that occur within Weston Bay and the level of defence that will exist moving forward. To understand these trends it is important to understand the geology and geomorphic features. This section describes the geological and geomorphic conditions and identifies the coastal forces driving the shoreline change.

Information on historic change has largely been obtained from historic maps, aerial photographs, and aerial laser survey data (Light Detection and Ranging, LiDAR). The available sources of information on large scale geomorphic change are recorded in Table 3.1.

Table 3.1 – Available Data Sources

Date	Type	Notes
1843-1912	Historic Map	Ambiguous Dating
1919-1943	Historic Map	Ambiguous Dating
1940	Aerial Photographs	
1991	Aerial Photographs	
1999	Aerial Photographs	
2005	Aerial Photographs	
2007	LiDAR	
2008	LiDAR	
2009	Aerial Photos	
2009	LiDAR	
2010	LiDAR	
2011	LiDAR	
2012	LiDAR	Recorded but unavailable

3.2 Geology

The headlands of Anchor Head in the north and Brean Down in the south are the two controlling features that form the northern and southern limits of the bay, respectively. Anchor head extends approximately 1.5km west from the general alignment of the beach towards Birnbeck Island and comprises a mixture of carboniferous oolite and limestone. Brean Down extends approximately 3.5km west to Howe Rock, predominantly comprising Birnbeck Limestone and unnamed dolomites.

The wide intertidal zone at Weston-super-Mare consists of a mixture of silt and mudflats. The upper part of the beach comprises sand deposits with sand dunes in the southern part of the bay forming the frontage of Weston-super-Mare Golf Club. The British Geological Survey suggests that, prior to the development of the hinterland and the main defences, windblown sand existed up to 1km inland.

3.3 Geomorphic Setting

3.3.1 Overview

Figure 3.1 illustrates the topography of Weston Bay. While the main bay may be seen to be formed in a shallow curve, in general, the back shore of Weston Bay is relatively straight forming a north/south alignment. To the north of the Grand Pier, the bay curves more sharply to the west to Knightstone Harbour, and continues seaward to the Marine Lake which historically formed a natural cove.

The northern half of the bay forms the frontage of the urbanised hinterland of Weston-super-Mare. Weston is protected by sea walls that extend between Anchor Head and the northern limit of the sand dunes. Between 2007 and 2010 the standard of defence was increased as part of the Weston-super-Mare Seafront Enhancement Project. This is discussed in further detail later in the report.

The sea wall extends to the southern half of the bay where it connects to a single ridge dune system to provide a continuous defence. This dune system forms the primary protection to Weston-super-Mare Golf Club and the settlement of Uphill. To the south there is a further section of sea wall between the end of the sand dune and the Axe Estuary which provides protection to the southern part of the golf course, the village of Uphill and more locally a former caravan park at the southern end of the frontage.

In the north of the bay the intertidal zone is approximately 1.4km wide, increasing to 2km wide in the south where the tidal estuary of the River Axe discharges across the foreshore to the north of Brean Down. Tidal conditions continue within the River Axe for approximately 2km inland, with the tidal sluices at Uphill and further south at Brean Cross.

Figure 3.1 highlights the slightly different shape and alignment of contours within the bay at different water levels.

To the north the defence line curves more sharply around to Knightstone Harbour, in effect reducing the width for an upper beach to develop. As a result beach levels at the northern end are typically around 2.5m OD to 3m OD at the sea wall, and the line of defence lies within the normal active zone of the tide.

South of the Grand Pier the hard defence line curves further inland in the area of the Tropicana, creating width for development of the upper beach.

To the south of the Tropicana, as the defence line runs through to the natural dune, the upper beach area is in part taken up by the formation of the dune.

To the far south, the dune and defence line follows the alignment established further to the north, while the lower foreshore defined by the 2.5m OD contour curves around to the back of Brean Down, forming more a delta shape associated with the outfall of the Axe.

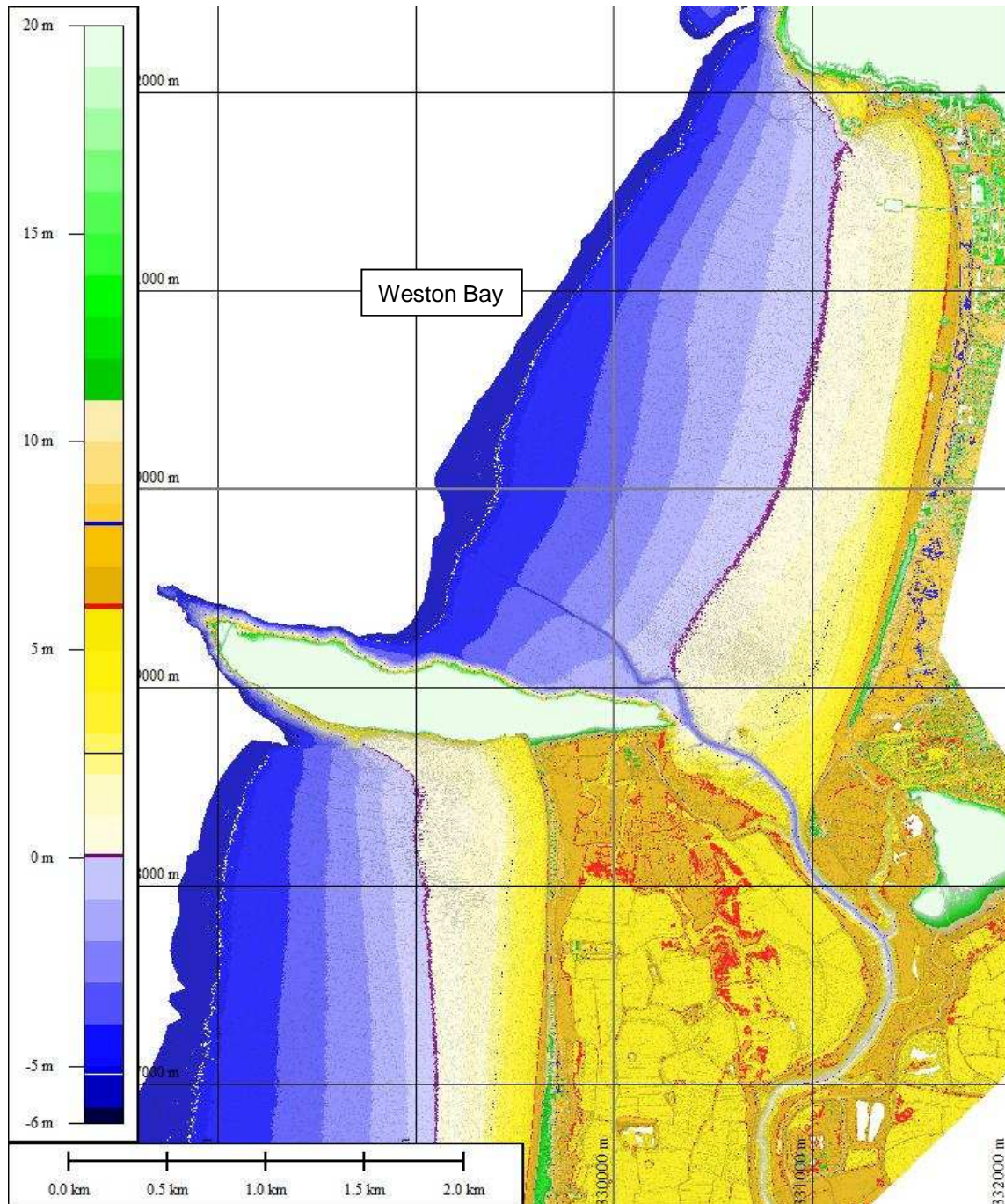


Figure 3.1 – General Topography of Weston Bay 2011

In comparison to the north of the bay there has been very little intervention in the south. The key features are the intertidal salt marshes, Black Rock and the estuary of the River Axe. These features are shown below in Figure 3.2.



Figure 3.2 – Features at the South of the Bay

It may be seen that the course of the river cuts through the accumulated sand beach at the southern end of the dunes. The low water channel then meanders slightly to the south of Black Rock, before opening out across the lower foreshore. There is an old training bank running to the north east from Black Rock, this possibly has encouraged the channel to run to the west, between Black Rock and Brean Down

3.3.2 Typical Cross-shore Profile

A typical profile through the centre of Weston Bay is illustrated below in Figure 3.3. The section is in a location that cuts through the sea wall in the area of the Tropicana. Extreme water level events representing a mean high water spring, a 1 in 1 year and a 1 in 100 year return period are shown on the figure. The figure identifies a significant change in gradient of the beach at a chainage of around 400m. This is considered to signify the change in beach material from sand to finer sediments and the progression of the mudflats seaward.

A further change in gradient occurs at the horizontal chainage of approximately 1500m as the sea bed falls away into the Bristol Channel. This steepening is a result of erosion due to the relatively strong tidal driven currents of the Bristol Channel.

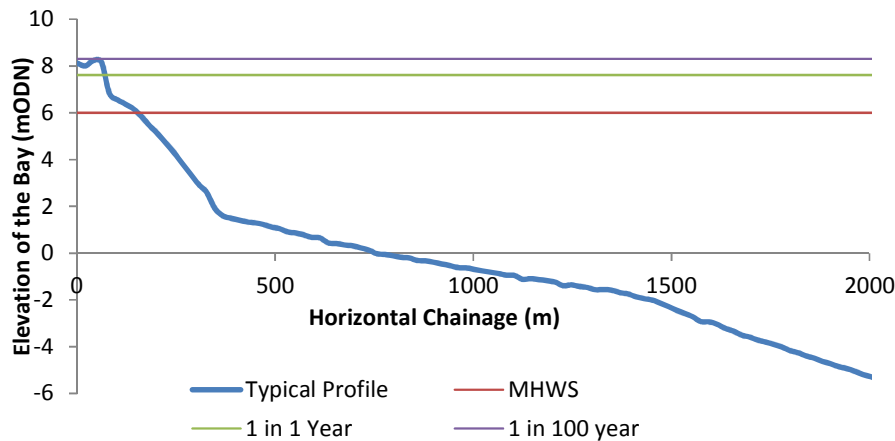


Figure 3.3 – Typical Profile and Extreme Water Levels

3.3.3 Historic change

Historic maps have been obtained from North Somerset Council and outline the high water mark of ordinary tides which are illustrated on Figure 3.4. Information shown on historic maps is generally assumed to be approximated. However, they do demonstrate the following:

- The high water mark has generally migrated seaward over the last 150 years suggesting an overall accretion has occurred over the last century. It appears that the seaward movement is more significant in the southern part of the bay, with a minimal change occurring in the vicinity of the Seaquarium.
- Over this southern section of the Bay it is noted that the more major change occurred between the 1843/1893 mapping and that of 1919/1943. This was also picked out during the analysis of the influence of the Tropicana (RHDHV 2012). Detail relating to this change was considered specifically in relation to the area of the Tropicana and this cross-sectional change is shown in Figure 3.5. It was highlighted as being uncertain the degree to which this was a result of the construction of the Tropicana. Reviewing this against other information over a broader area would suggest that it was part of a larger scale change, with overall growth of the southern frontage.
- It is noted that while the area around the Tropicana tended to stabilise, the indication is for continued growth of the southern beach area.
- The historic maps indicate that the location of the transition from sand to finer material has not moved significantly between the 1843 to 1893 map and the 1945 onwards maps. This suggests the composition of intertidal material has been relatively stable over the last century.



Figure 3.4 – Comparison of Average High Water Mark from Historic Maps and 2009 Aerial Photography

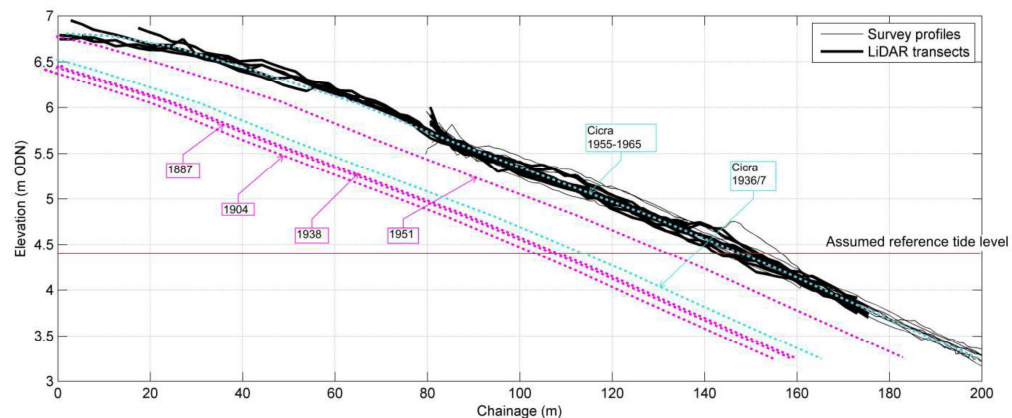


Figure 3.5 - Comparison between recent and estimated historic profiles for the southern side of the Tropicana. Data courtesy of the Channel Coastal Observatory

3.3.4 Beach Material

Wessex Coastal Sediment Study (Wessex, 2012) identifies the types of sand mud and silt that are present in Weston Bay and has been used to inform this section of the report. A plan illustrating the distribution of clay, silt, sand and gravel across the bay is contained in Appendix B.

In terms of beach material, Weston Bay comprises a sandy back shore. The sand/mud visual interface is of the order of 500m from the high water mark. In general the D_{50} within the intertidal zone is in a narrow range from about 190 to 210 microns to a depth of around 2m. For locations C6 to C13 (as per Appendix B) the thickness of the sand layer exceeds 2m (the base of the core sample) for most of the length of the bay, reducing to around 1m adjacent to the cliffs at either end. The banks of the River Axe Estuary are mainly comprised of silt.

3.3.5 The Dune System

To the south of the bay, the dune system lies in a southwest/northeast alignment which provides the front line of flood protection for Weston-super-Mare Golf Club. The sand dune comprises a single ridge that generally stands between 15m and 20m high. Figure 3.6 illustrates the surface elevation of the sand dune and demonstrates the dune is wider and taller towards its northern end becoming narrower in the south.

It is, however, noted that the dunes, to the southern end of the dune system, have developed significantly over the last century, supporting the historical evidence that there has been a general accumulation of sediment. This is discussed in more detail in section 4.5.

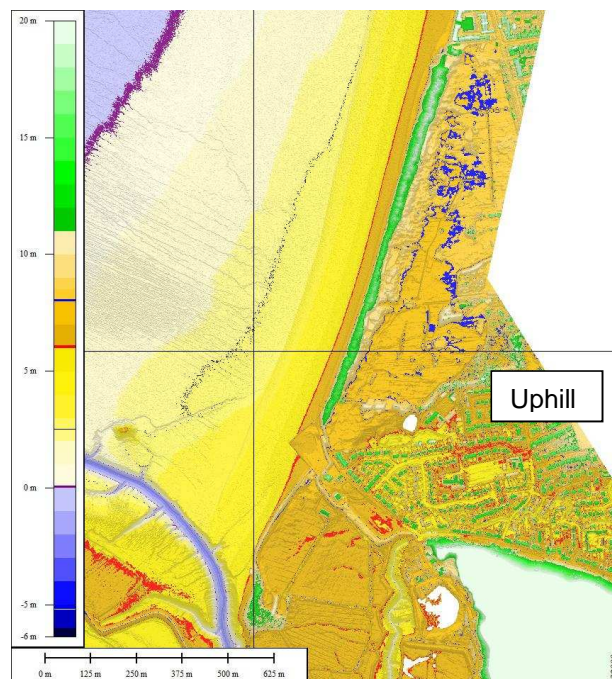


Figure 3.6 – Elevation of the Sand Dunes (Courtesy of the Coastal Channel Observatory)

Figure 3.6 shows how the sea wall fronting the former caravan park extends out beyond the alignment of the toe to the dune. This wall cuts across the line of the MHWS (shown as the red line on the figure). Although this wall is not part of the defensive line it is clear that it holds the southern end of the dunes forward.

South of the former caravan park, the local defence embankment appears to have been developed along the line an old spit forming the entrance to the Axe estuary. The old distil head of the spit is shown as slightly higher ground. The main flood defence to Uphill Village runs back from the return of the former caravan site wall, with the line of the old spit forming the forward defence, with the area enclosed by a low embankment along the line of the Uphill Great Rhyne.

3.4 Environmental Forces

3.4.1 Water Levels

Water levels in Weston Bay are shown in Table 3.2. Admiralty Tide Tables were used to calculate the mean high and low water levels of spring tides (MHWS and MLWS), whilst extreme water levels were obtained from a recent Environment Agency study into extreme coastal water levels the UK (Environment Agency, 2011a). These water levels have been adjusted to represent conditions in 2013, using the sea level trends associated with the 95th percentile of the UKCP09 medium emissions (A1B) scenario of sea level rise (in accordance with Environment Agency 2011b).

Table 3.2 2013 Tide levels and extreme water levels

Scenario	Level above Chart Datum (m)	Level above Ordnance Datum* (m)
MLWS	0.8	-5.20
MHWS	12.00	6.00
1y Return Period	13.62	7.62
2y Return Period	13.71	7.71
5y Return Period	13.84	7.84
10y Return Period	13.94	7.94
20y Return Period	14.04	8.04
50y Return Period	14.19	8.19
100y Return Period	14.31	8.31
200y Return Period	14.43	8.43
500y Return Period	14.61	8.61
1000y Return Period	14.76	8.76

*Ordnance Datum is 6m above Chart Datum (Weston-super-Mare)

3.4.2 Wind Climate

Wind data has been obtained from Appendix C of the Severn Estuary Shoreline Management Plan. The wind rose is located on Flat Holm and the main wind direction is from the south-westerly and north-easterly sectors with the maximum wind speed related to the south westerly winds (Figure 3.7). Wind waves can be generated anywhere within the estuary, but their size is dependent on the fetch distance across which the wind blows to enable wave generation (SMP 2010). The longest fetch is clearly associated with winds from the southwest through to the northwest. Locally, significant wind waves may, however, be generated from the north east.

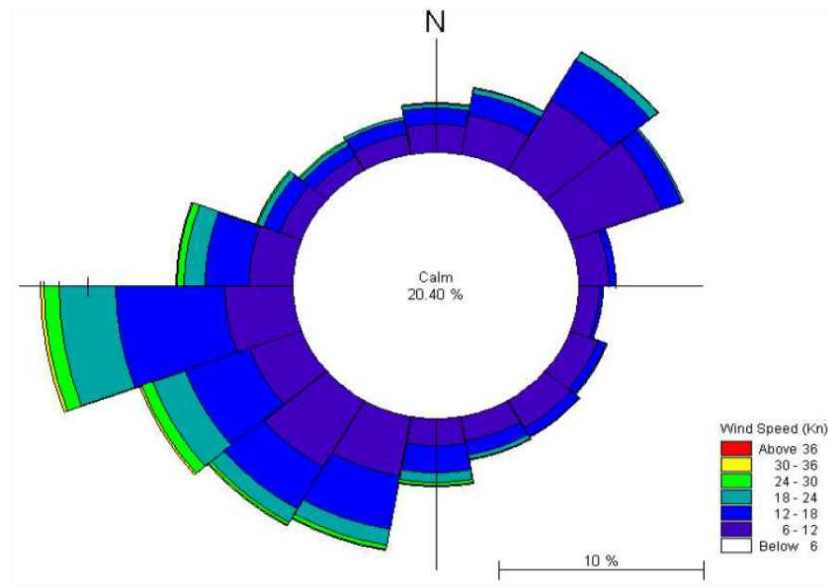


Figure 3.7 – Flat Holm Wind Rose (SMP 2010)

3.4.3 Wave Climate

Wave data was available from two sources, the Coastal Boundary Conditions Project (Environment Agency 2011a), and observational data, courtesy of the Channel Coastal Observatory (CCO) website.

The coastal boundary data were derived from simulations of eight years of swell wave activity, undertaken by the Met Office. The closest location at which these data were available was at Wave ID 271, which is approximately 25km south of Swansea, and roughly 60km west northwest of Weston Bay.

Two full years of observational wave data were obtained from the CCO database. These observational data were recorded around 2km west of Knightstone Harbour (51.3543N 3.0175W), as illustrated in Figure 3.8. The data record runs from September 2009 to September 2012, however data is not available for 2011 as the wave buoy was out of action at this time).



Figure 3.8 - Location of Nearshore Wave Buoy

Further details of the wave climate and modelling are included as Appendix C to this report.

3.4.4 Wave Direction and Transformation within the Bay

The wave rose illustrated in Figure 3.9 shows the typical inshore wave climate for Weston Bay based on the observational data, courtesy of the Channel Coastal Observatory (CCO). This describes the wave climate as being dominated by waves from the west and southwest.

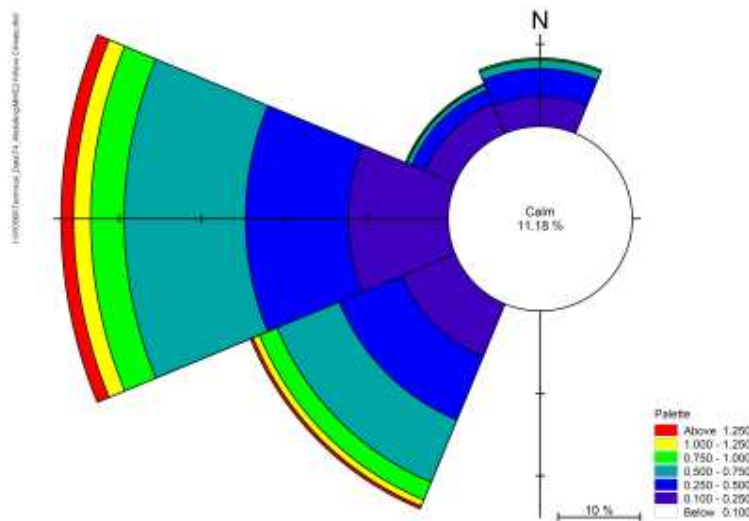


Figure 3.9 – Wave Climate Rose Based on the Wave Buoy Data

Simulations of the transformation of waves within the Severn Estuary and Weston Bay have been carried out using Spectral Wave (SW) Modelling. The investigation looks at both swell waves and (local) wind generated waves. The model outputs suggest that the wave climate in the bay is dominated by locally generated waves. The modelling report is included as Appendix C and key figures are discussed below.

Figures 3.10 to 3.12 illustrate three output plots representing a 16.97ms^{-1} wind with a direction of 261° which represents an extreme wind condition recorded on the wind rose (Figure 3.7).

Figure 3.10 illustrates the nature of the wind wave model within the Bristol Channel, highlighting the continuing increase in wave height from west to east resulting from the constant wind condition being applied within the boundary of the model.

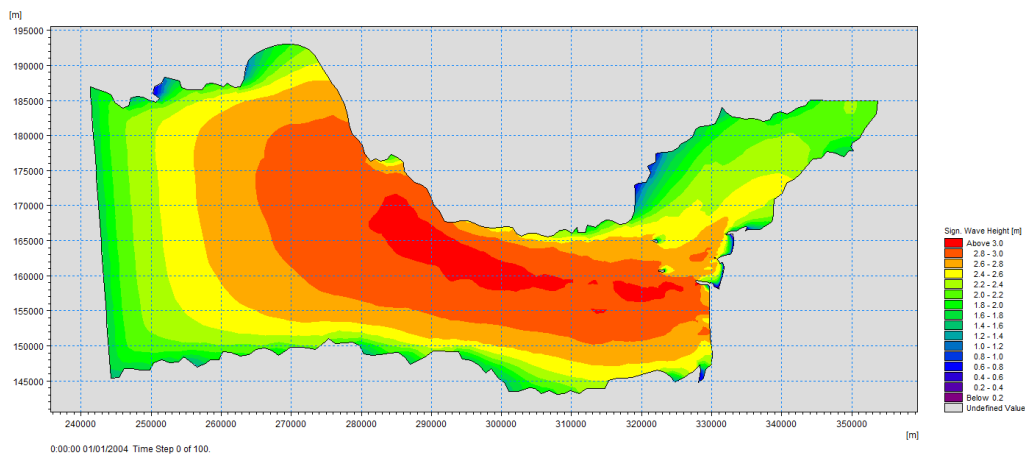


Figure 3.10 – Transformation of waves in the Severn Estuary Bristol Channel

Figure 3.11 illustrates waves passing by Flat Holm and Steep Holm and into Weston Bay from the Severn Estuary/Bristol Channel. The figure demonstrates the relative protection that is provided to Weston Bay by Steep Holm with significantly larger waves observed to the south of Brean Down.

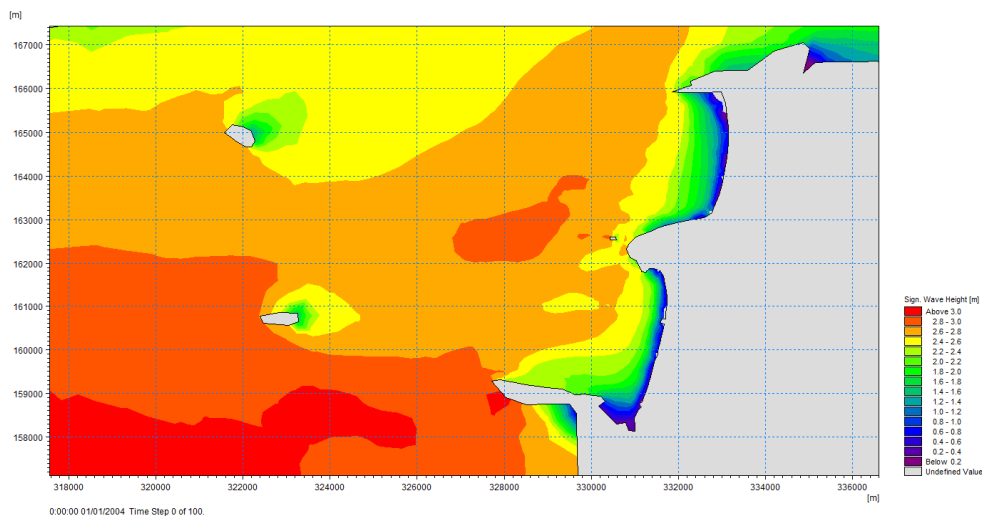


Figure 3.11 – Transformation of waves from the Bristol Channel

Figure 3.12 illustrates that wave height reduces gradually as the wave passes over the bay and in the vicinity of the back shore the wave height reduces sharply. In general the wave energy is more intense at the northern end of the bay, although some protection is provided by Knightstone Harbour in the northern corner. In the south of the bay the headland of Brean Down provides relative shelter. The figure shows that central areas of the bay are more exposed to wave energy, particularly in close proximity to the Tropicana where there is a peak in wave height.

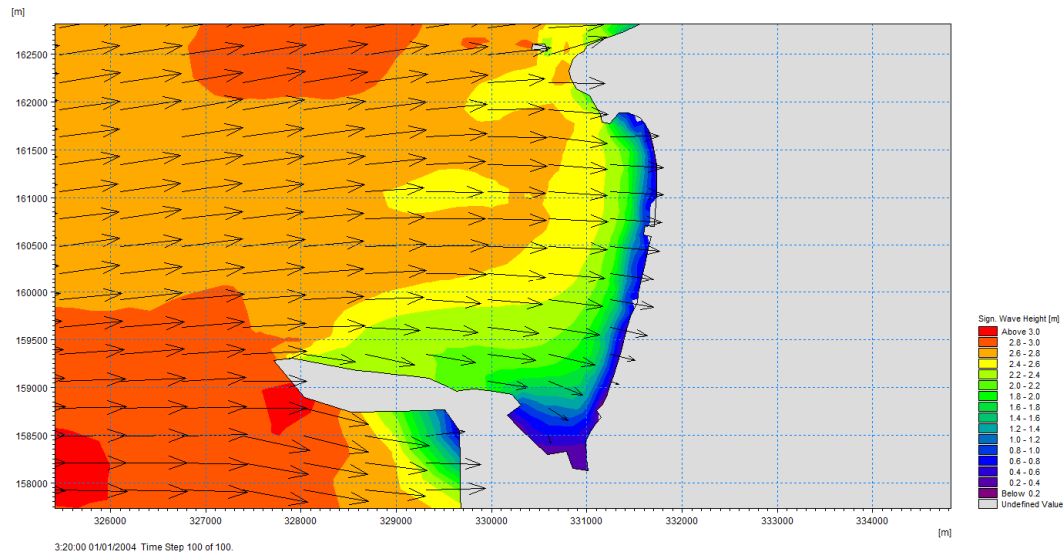


Figure 3.12 – Transformation of Waves within Weston Bay

Figure 3.12 illustrates velocity vectors of the waves (which may be equated to wave direction). With the exception of the far north and south, waves generally approach the bay normally. In the north there appears to be minimal diffraction and the curvature of the bay means that waves are approaching at a slight angle to the alignment of the backshore defences. In the south of the bay the vectors suggest that diffraction and refraction is occurring in the southern corner.

3.4.5 Tidal Flows

Figure 3.13 illustrates general direction of the tidal currents within the Bristol Channel. A study of currents within Weston Bay (and Sand Bay) was conducted in 1965 (HRS Wallingford, 1965). Typically, on the flood spring tide velocities are in the order of 1m/sec across the line of the headlands. On the ebb, peak velocities are slightly greater, particularly at the head of Brean Down, with flows up to 1.5m/sec.

Within the bay, a large clockwise gyre was identified by the study on the flood. This is shown in Figure 3.14 (blue arrows show the indicative pattern of flow based on the float tracks) which provides more detail of current behaviour within the bay during spring flood and ebb tides. This gyre with velocities typically of the order of 0.5 to 0.7 m/sec persists over high-water and through the early part of the ebb.

There is, therefore, a strong bias of flow direction from north to south over much of the upper mudflats and upper beach within the main bay. This tends to reinforce or be reinforced by the flow from the Axe, running west along the northern face of Brean Down.

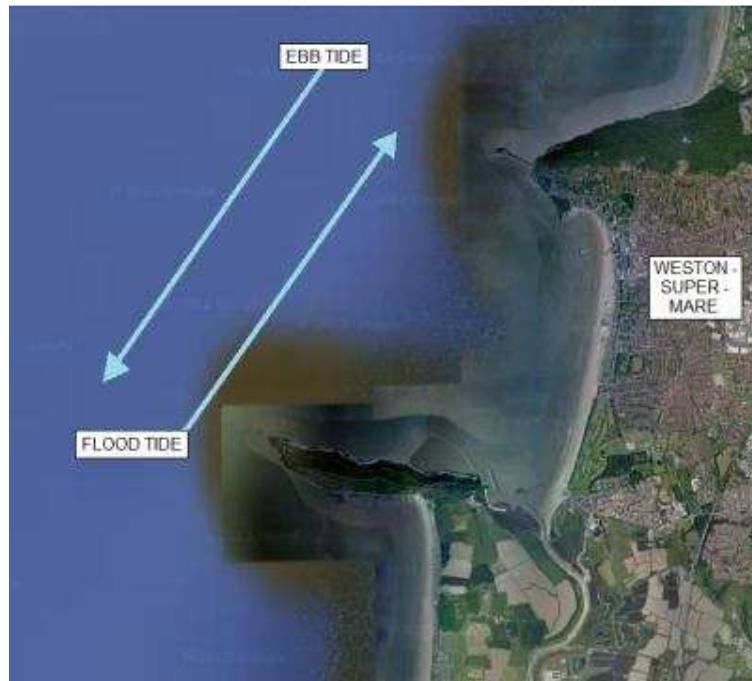
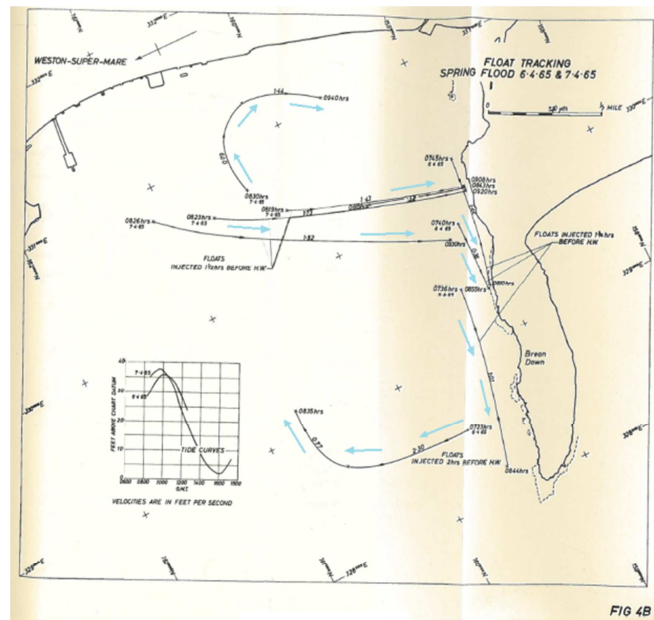
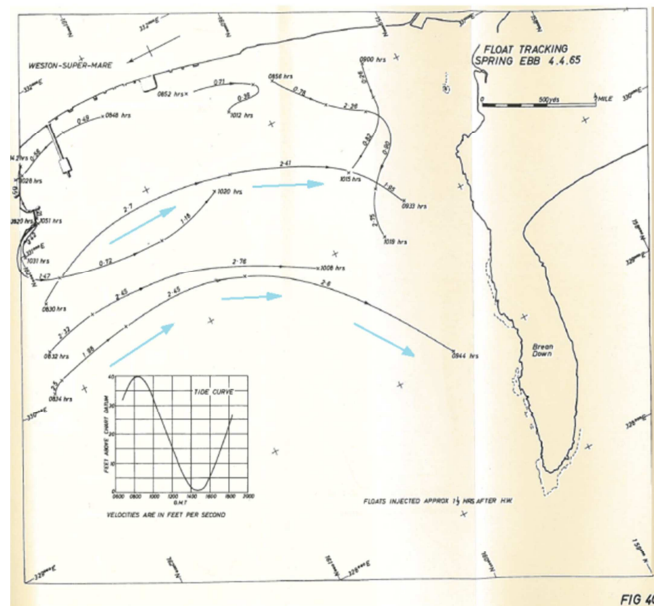


Figure 3.13 – General behaviour of Tidal Currents within the Severn Estuary

The flow across the headlands is quite strong enough to transport fine sediment. Within the bay flows over the lower foreshore could move fine sediment, tending to move this to the south. It may also influence sediment raised in suspension by wave action.



FLOAT TRACKING
SPRING FLOOD



FLOAT TRACKING
EBB FLOOD

Figure 3.14 – Flood and Ebb Tidal Flows within Weston Bay (HRS Wallingford 1965)

3.4.6 Climate Change

Global climate change is expected to influence coastal hydrodynamic conditions, and, therefore, has the potential to change future coastal flood vulnerability. However, the

nature and scale of such changes are quite uncertain. Historically, it is very likely that the mean rate of sea level rise was 1.7 [1.5 to 1.9]mm per year between 1901 and 2010 for a total sea level rise of 0.19 [0.17 to 0.21]m (IPCC 2013). Looking forward, it is necessary to make certain assumptions about the impacts of climate change, and the following has been assumed:

- Sea level rise will follow the 95th percentile of the UKCP09 'Medium Emissions' scenario (as advised in Environment Agency, 2011a)
- Surge conditions will not change (as implied in Environment Agency, 2011a)
- Offshore wave conditions will not change (the evidence provided by UKCP09 for significant change in the near-term is weak).

In general, therefore, sea level rise is likely to be the main factor influencing the behaviour of the coast. With sea level rise, the typical response is for the shoreline to attempt to set back in line with increasing water levels. Typically, where such movement is constrained by hard defences the width of the upper beach reduces.

To a degree this is seen in principle in the present situation around Weston Bay; where at the northern end of the bay, the defences are forward of the natural alignment of the bay and the beach levels are at a lower level. Where the defence is slightly set back (in the area of the Tropicana), there is width for the upper beach to exist and function naturally. If this analogy is taken forward with sea level rise, the natural alignment of the whole bay sets back, the length of defence in advance of this natural alignment will extend further south and the width of upper beach over the central section of the defended frontage will reduce.

Coupled to this, with increased water levels, there will be less freeboard between still water level and the crest of the defences. The risk of wave overtopping will therefore increase.

Notwithstanding the above, with respect to the natural dune frontage, the situation is potentially more complex. Typically, the same processes could develop such that the basic alignment of the dunes would attempt to set back. However, due to the trend for sediment to infill to the south, there is the potential for further growth of the beach resulting in growth of the dunes to the south as has been seen in the past. This is discussed further in terms of future management in Section 7.

4 ENGINEERED FLOOD DEFENCES

4.1 Historic Flood Events

There has been significant flood events recorded in Weston Bay. The earliest recorded flood event was recorded in 1903 and caused a failure to the sea wall in the north. In more recent history, flood events have occurred in 1981, 1990 and 1996. The 1981 event caused widespread flooding in Weston Bay and the surrounding area. This section identifies the engineering works that have been undertaken to reduce the risk of flooding.

4.2 Flood defence

4.2.1 Sea Wall in the North of the Bay

The flood defence for the northern part of the bay has existed in the form of a stone parapet sea wall since the 1880s. The sea wall begins at Anchor Head and continues to the northern limit of the golf course. During the storm of 1903, the wall was damaged and in the storm of 1981 the sea wall was severely overtopped.

More recently the sea wall was upgraded to provide a defence standard of a 1 in 200 return period as part of the Weston-super-Mare Seafront Enhancement Project. The construction took place between August 2007 and August 2010, and was undertaken in three phases:

- Improvement of the Marine Lake;
- Construction of the Parapet/Splash Wall in the northern section;
- Construction of the masonry wall in the south;

The current crest level of the Weston-super-Mare sea wall is +9.05m, but has been designed to be raised to a level of +10.05m between the road and the promenade in response to future sea level rise. North Somerset Council is responsible for the hard defences at Weston Bay.

4.2.2 Beach Recycling

Historically, Weston's beach recycling programme has moved beach material from the southern area of the beach to the northern end to counter act the general trend of sediment transport. Material is sourced from the Weston Beach between the Tropicana and Uphill (dependant on where the levels look higher) and deposited in the vicinity of Knightstone Harbour (as illustrated in Figure 4.1). The specific volume of sediment transported north in this way is not recorded in detail, however, anecdotal evidence suggests that approximately 16,000m³ of beach material is transported north each year.



Figure 4.1 – Weston–super–Mare Beach recycling areas

The majority of this material is moved in the autumn after the RHL Beach Race. In preparation for the race, beach material is piled up to form features on the course, which is constructed on the foreshore. Instead of returning the material to its original position after the race, it is distributed to the north of the bay.

There was no significant haulage to the north of the beach (Knightstone) between July 2008 and October 2010 due to the Grand Pier being cordoned off. Furthermore there are no records of quantities moved since October 2010, as much of the redistribution was undertaken as a good will gesture by the race organisers.

Between April and October beach material is also moved up to the Tropicana as part of the Sand Sculpture Competition and is not returned to its original location. This is not considered to be of such a scale as to have a significant impact on the balance of sediment across the bay.

4.2.3 Flood Defence at the River Axe and Uphill

Defence within the Axe is provided by:

- flood embankments;
- two tidal sluices at (Brean Cross and Uphill); and
- Automatic flood gates in the vicinity of Uphill Sluice.

The flood alleviation embankments create a tidal catchment between Brean Down and Uphill Cliff. The eastern embankment has a minimum crest level of 8.01mAOD rising to 8.77mAOD.

With regards to the tidal sluices, Brean Cross Sluice is designed to prevent tidal water from flowing up the River Axe into the catchments low lying wetlands (Weetwood 2011). The Sluice at Uphill prevents water flowing into the low lying areas within the settlement of Uphill. The flood gates exist in the vicinity of the sluice at Uphill, at the entrance to the boat yard.

A flood risk assessment has previously been undertaken by Weetwood Environmental Engineering as part of the Phase 1: Bleadon levels, Weston–super–Mare development. Despite this flood risk assessment being site specific, the report identifies the sources of flooding that threaten the general area. The EA has confirmed that the dominant source of flood risk is tidal.

5 EXAMINATION OF BEACH BEHAVIOUR

5.1 Introduction

This section investigates how the natural features have evolved over time and interprets sediment transport based on the observational data. This is supported by examining LiDAR data, aerial and historic photos, and the results of Sediment Transport Technical Appendix D. This section also considers the specific area in more detail and discusses the implications for management.

5.2 General Behaviour and Development of the Beach Shape

Due to the protection from the headlands in the north and the south, the bay is considered to be a relatively closed system with minimal sediment exchange between the neighbouring bays. The main sediment source is considered to be from the Bristol Channel.

The lower part of the bay appears to have remained relatively stable over the last century and there is no evidence that this lower foreshore has eroded significantly. The general profile of this lower area of the bay is convex supporting the notion of a net balance between sediment supply and loss, to and from the Bristol Channel. The area is worked by both wave and tidal currents. Wave action works the intertidal zone and there is generally an abundance of suspended fine sediment. However, as the system appears to be balanced, it is considered that the tidal currents within the bay do not have the strength to transport a significant net quantity of material out of the bay.

As demonstrated in Figure 3.4, the alignment of the beach has generally remained unchanged over the past century. In the north of the bay, the construction of the sea wall in 1887 has held the line in front of the town. In the south the natural formation of the sand dune ridge defines the line which has appeared to accrete. Historic photos from circa 1900 provide evidence that the southern sand dunes were not as substantial as they are today. In addition, the British Geographical Survey, showing relic deposits of sand in land, suggests that prior to the development of Weston-super-Mare, blown sand may have existed up to 1km inland. Quite possibly, the introduction of the sea wall to the northern part of the bay disrupted the natural alignment of the backshore, increasing sediment drift to the south. This might then suggest that the formation of the sand dune ridge, over the last 100 years, may be in response to the construction of the sea wall and readjustment of sediment within the back shore of the bay.

Figure 5.1 illustrates the change in elevation of the bay between 2007 and 2011 using the available LiDAR data. The figure demonstrates that over the 4 year period there is generally less than the 1m change in elevation across the majority of the intertidal area of the bay, with exception of some very isolated areas.

Monitoring has been undertaken by the Channel Coastal Observatory and has been reported in the South West Regional Coastal Monitoring Programme Annual Survey Report (ASR 2011). The key elements of this document relating to Weston Bay are contained in Appendix E. A total of 14 profiles have been monitored between 2007 and 2011 and analysis illustrates that in general, accretion is taking place for the majority of profiles. The ARS states that in the period between the base line in 2007 to spring 2011.

"Overall the trend remains for accretion since 2007, although as with the shorter term analysis, profile 7e00121 at the northern end of the bay has eroded, in this case by 12% and lost between 5m² and 15m² of material. Profile 7e00118 (also in the north) has also lost material, although it has only changed by 2%."

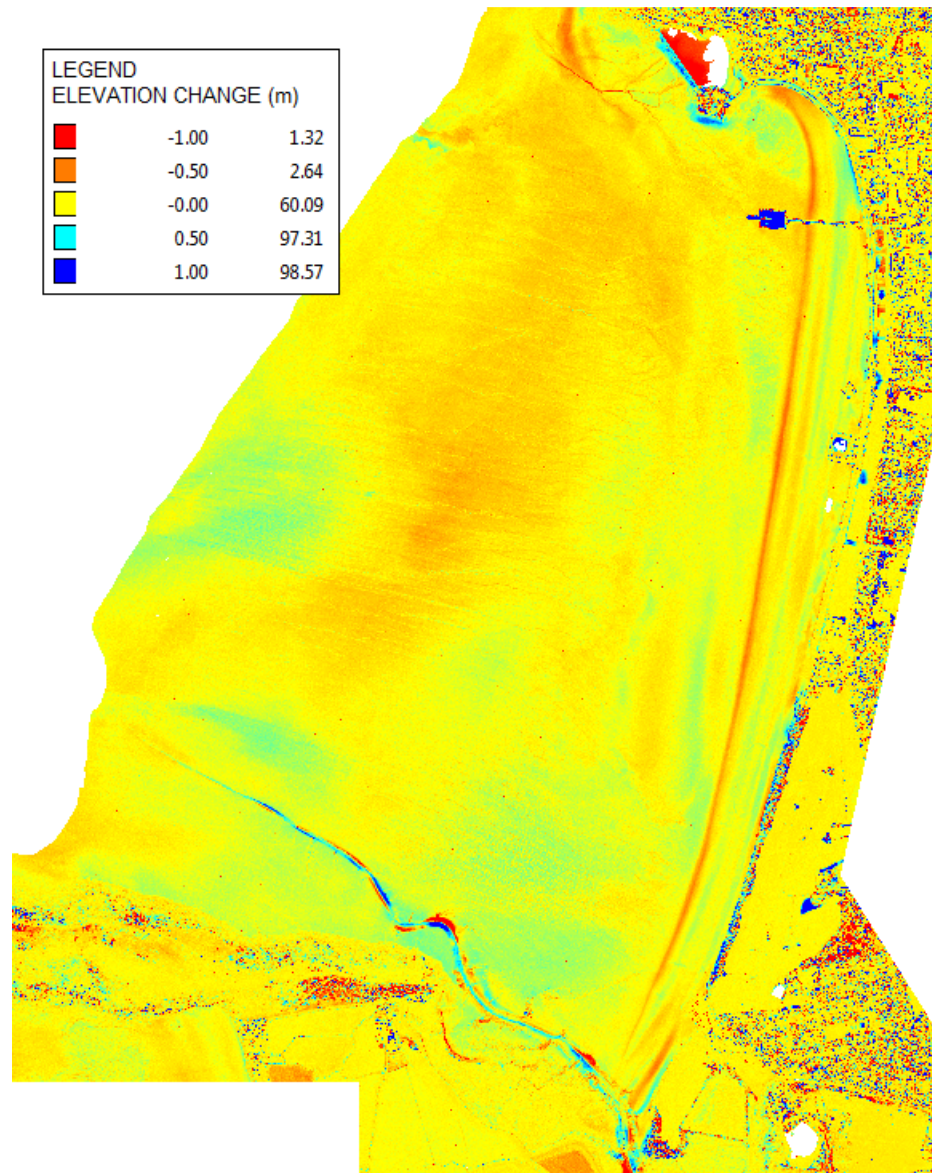
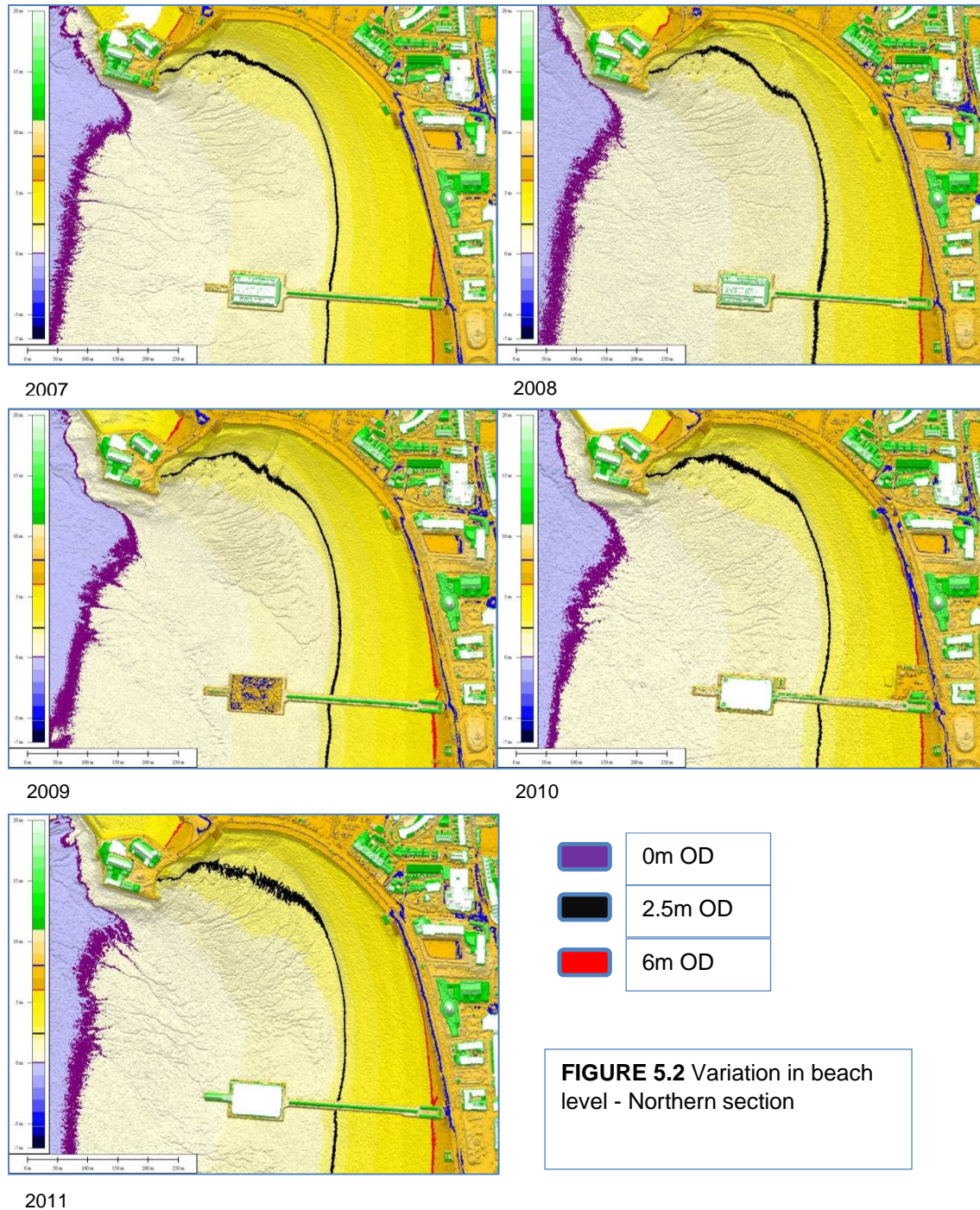


Figure 5.1 – Change in Surface Elevation between 2007 and 2011

A more detailed year on year analysis is shown in Figure 5.2 – North, Figure 5.3 – Central and Figure 5.4 – South. This sets the overall variation shown in Figure 5.1 in context.

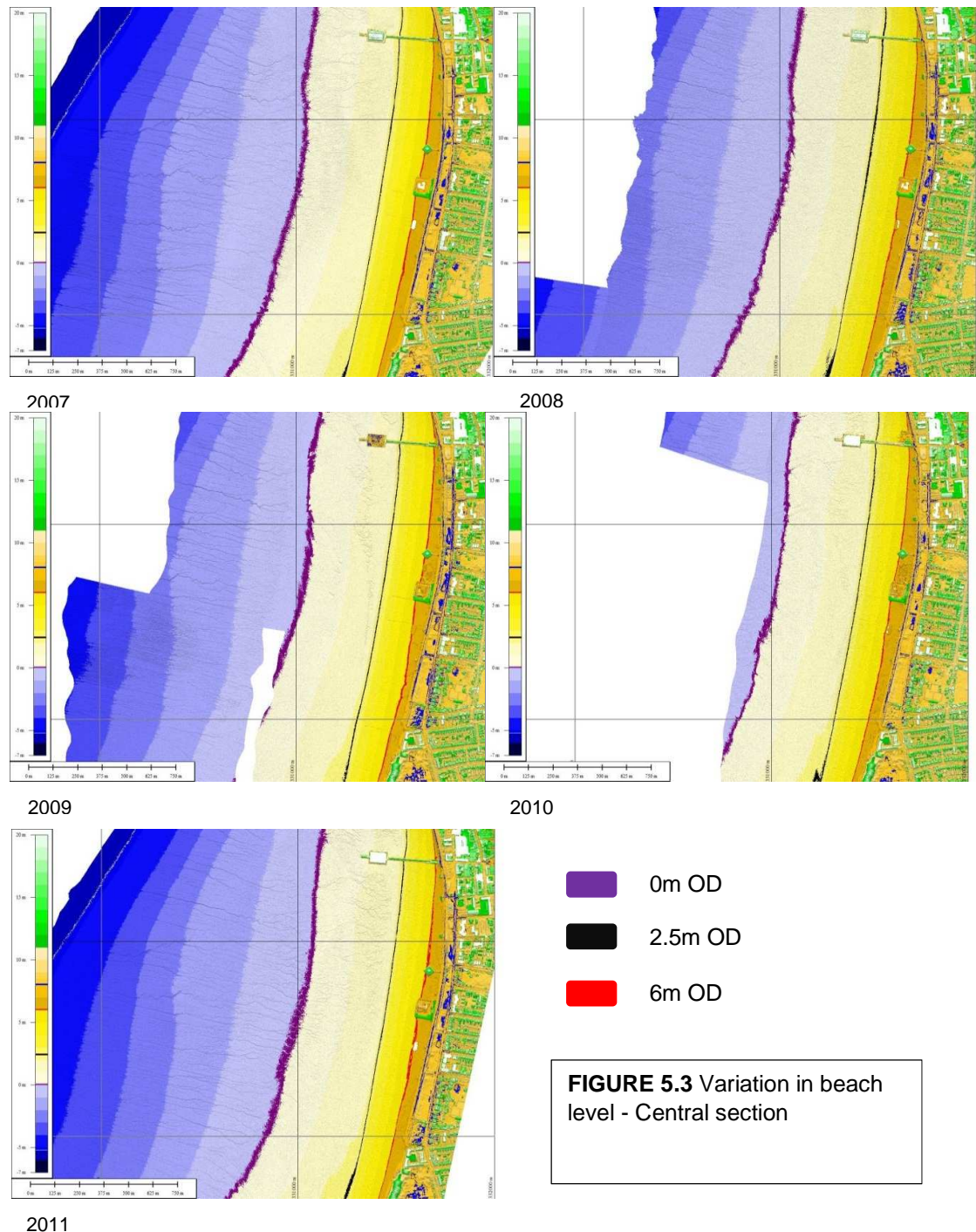
Northern section



While the overall shape within this northern section (Figure 5.2) shows little change, there is in detail quite significant variation. Between 2007 and 2008, there is a slight flattening of the upper beach at the northern end. The 6m OD contour just north of the

Pier shows little change. In 2009 the 6m OD contour tends to set back at the Pier but extend further north, and this persists through 2010 to 2011. There is no real evidence that the cessation of recycling during the works to the Pier had a significant affect and the works compound appears to have had little impact on the upper beach.

Central Section



Over the central section (Figure 5.3), as with the northern section, there is little overall change. The Tropicana provides a useful benchmark to note change around the 6m OD contour.

To the south of the Tropicana, this 6m contour cuts back slightly between 2008 and 2009. The upper beach builds out again over the period 2009 to 2011.

The change in the upper beach tends to be reflected in an opposite way in the response of the 2.5m OD contour and possibly at the 0m OD contour. So associated with the set back of the upper beach, the 2.5m contour moves slightly seaward, reducing the slope of the beach.

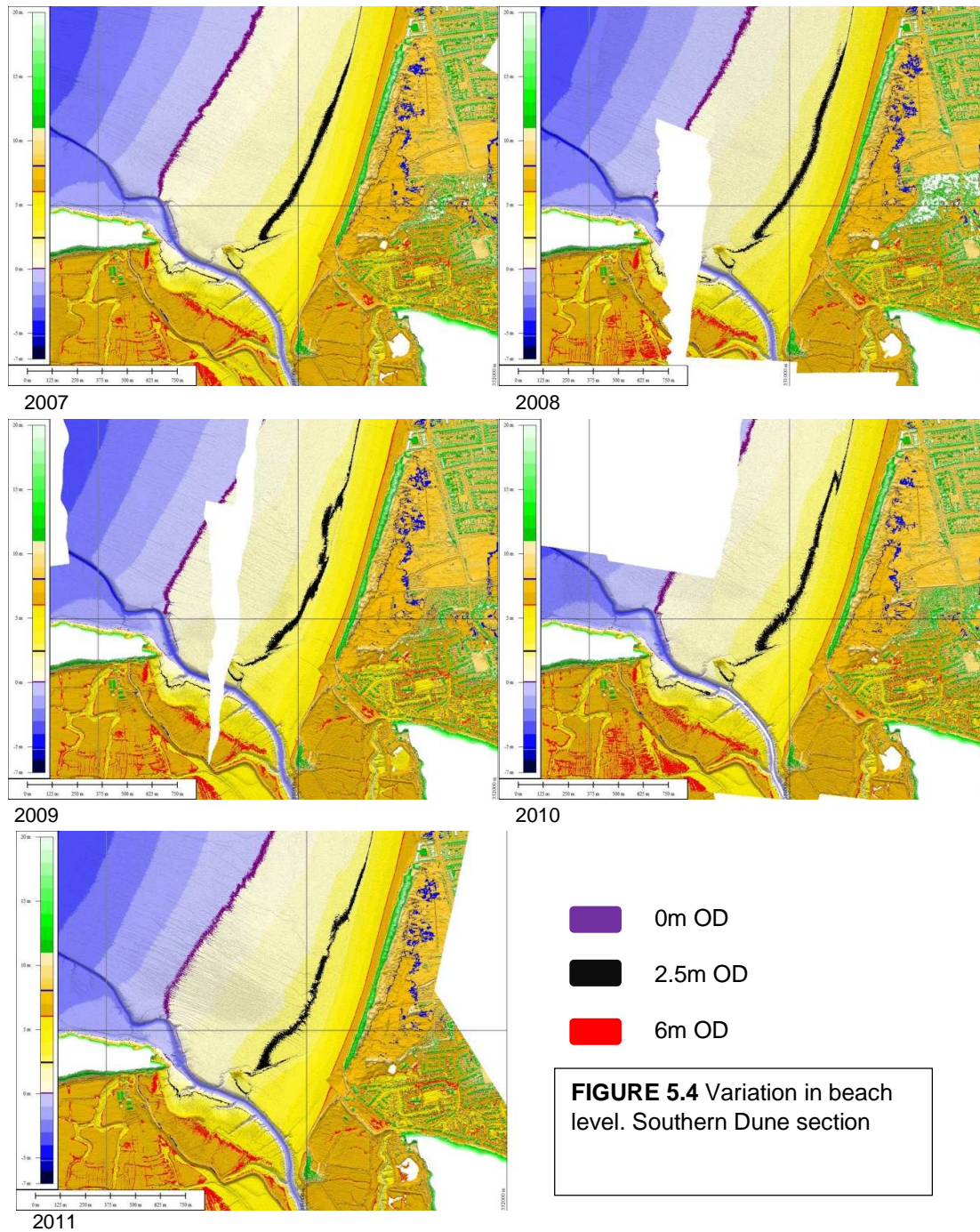
Southern Section

At this southern end there does tend to be slightly greater movement, although still within a relatively defined shape. In contrast to the central section, the beach and lower foreshore appears to work more in unison. Movement seaward of the 0m and 2.5m contours tends to be accompanied by movement seaward of the upper beach and dune. There also appears to be some interdependence between the central section of the dune, and the beach to the north, and the local beach to the south of the uphill road.

The dune, in part, cuts back between 2008 and 2009 but has then rebuilt by 2011. The 2.5m contour over the central section moved landward while that contour at the southern end moved seaward along the dune frontage.

This suggests a significant sensitivity to wave direction, with the potential for complex differential sediment drift patterns adjusting the whole beach area under different wave direction conditions. This is consistent with the slight but significant changes in wave behaviour discussed above.

At the southern end of the bay, there is an area of saltmarsh, to the south of the channel of the Axe. This area appears to be affected most by the slight meandering of the lower water channel. This is discussed in more detail later.



Overall Summary

Overall it is concluded that while generally the bay shape is quite stable, locally there can be quite rapid movement as the beach across the whole bay adjusts to different wave conditions. Much of the change in the beach appears to be in a cross shore direction.

In examining the changes year on year, it becomes apparent that the lower foreshore is generally very stable over the central and northern sections of the bay. It is possible to identify shallow creeks running across this area which exhibit only minor change from one year to the next. It is possible that on a more major storm there could be more movement within this area. The lower foreshore at the southern end does show greater movement. The change seen from the contours would, however, be amplified because of the shallow gradient of the sea bed.

It is recognising that the present data is quite limited and taken at different times of the year, and only provides a snap shot change. However, based on the changes seen, the influence of sediment recycling, especially in the autumn prior to the winter storms may only have a minor influence on beach behaviour. Possibly it does prevent local build-up of sediment in places along the upper beach as discussed below.

5.3 Sediment Transport Analysis

An analysis of sediment transport within the bay has been undertaken and is included as Technical Appendix D. The modelling outputs have identified that there is a typical net movement of sediment of $14,559\text{m}^3/\text{year}$ from north to the south. This is based on the average potential net sediment transport of the five cross-shore profiles. It remains uncertain to what degree this southerly movement is generally balanced by the replenishment undertaken each year.

The tidal current information suggests that the ebb tidal current (north to south) is the slightly more dominant current across the outer limit of the bay. However, this principally influences the boundary between the bay and the Bristol Channel. Within the bay, the north to south gyre has the potential to move fine sediment to the south over the upper part of the lower foreshore. It is, however, considered that the longshore transport along the upper beach is primarily wave driven.

The wave buoy data identifies the most frequent wave conditions arriving from 270° and Figure 3.12 illustrates the direction the waves approaching the shore. In the north of the bay the wave approach the shoreline at an angle and are considered to be the main driver of the southern movement of sediment. However, because the upper beach, overall, is very clearly closely attuned to the net wave energy, even slight changes in direction can generate significant change in direction of sediment movement.

A typical example, taken from Appendix D, of one of the analysis profiles in the centre of the bay is shown in Figure 5.5, highlighting this larger gross transport both to the north and the south. This also identifies that while there is gross movement both north and south, the predominant net transport is around the change in gradient from the lower to upper beach. This would change slightly on higher water levels under different storm conditions.

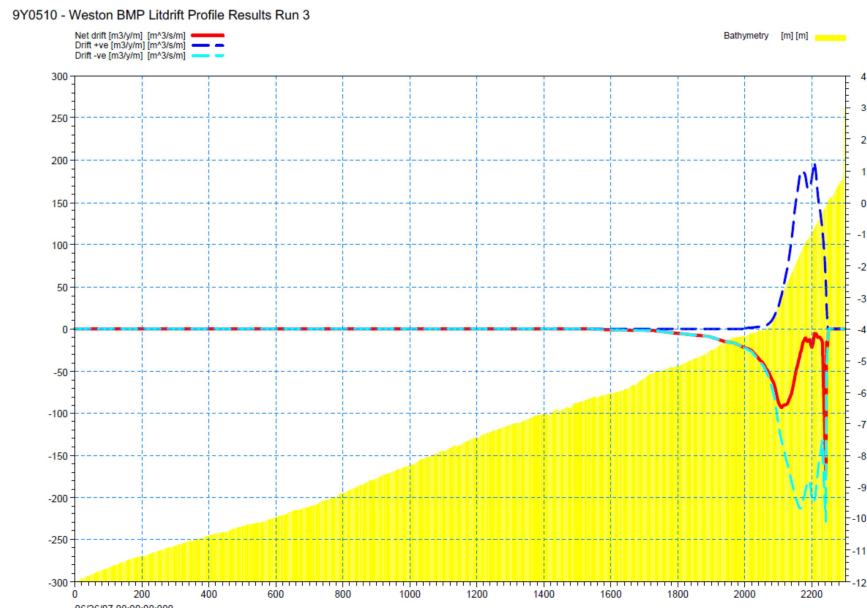


Figure 5.5 - Sediment transport profile at profile 3 to the south of the Tropicana

It is also suggested that under a specific severe storm, depending on the direction of waves, there could be significant drift either to the north or the south. This is supported to a degree by the review of beach levels above. It is suggested that there is broad scale change in the orientation of the lower part of the upper beach, which if even by a few degrees can result in the movement of relatively large volumes of sediment. It is also suggested by the beach change analysis that there may be areas of slight wave focussing moving sediment differentially north and south from a particular section of the beach. This is not necessarily identified by the wave modelling.

5.3.1 General Trends of Sediment Movement

In general there is a net drift north to south over the lower part of the upper beach. This will directly affect the beach in front of the sea wall over the northern section where the wall encroaches into the active zone of the beach. Over the upper part of the upper beach, where the defence alignment is set slightly further back there is likely to be far smaller sediment movement and the modelling suggests that there can be net movement to the north as well as to the south.

This is shown schematically in Figure 5.6.

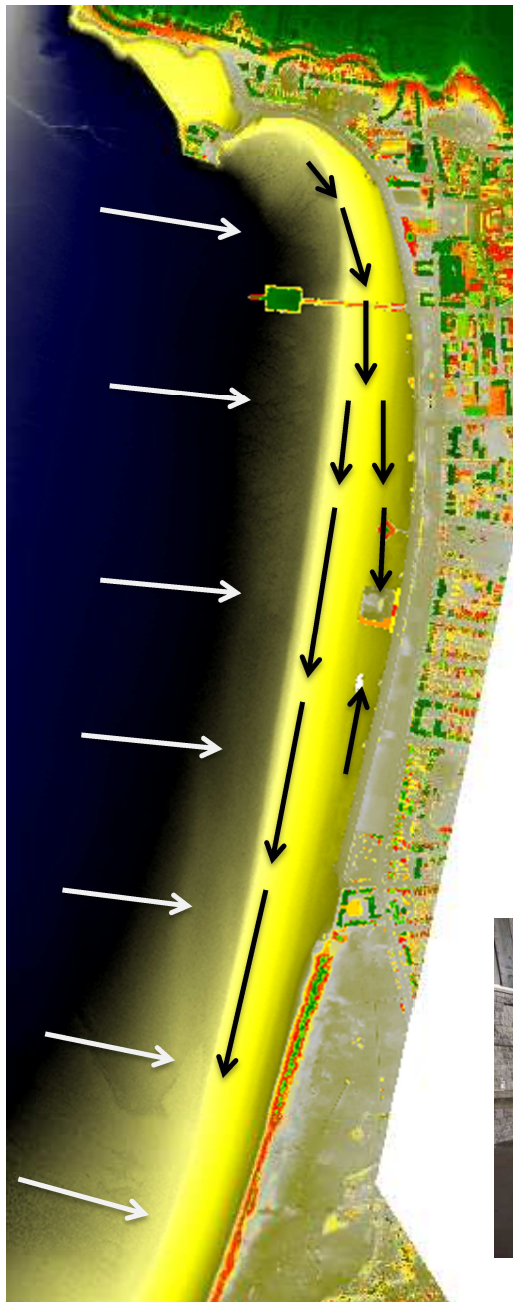


Figure 5.6 illustrates the net wave driven movement of sediment based on modelling. The Black arrows represent the movement of sediment and the white arrows represent the typical wave directions (based on Figure 3.12). It is notable that there is a northern movement of sediment to the south of the Tropicana. There are three indicators suggesting this movement is taking place:

- The wave direction to the south of the Tropicana;
- The maximum width of the beach being in the vicinity of the Tropicana; and
- Photographic evidence suggesting that sand is accreting against the southern wall of the Tropicana. (See inset Photograph)



Figure 5.6 – Directional Movement of Sediment on Weston Beach

5.4 Implications for management

Three areas are considered in more detail in the context of the above analysis.

5.4.1 The Weston–super–Mare Frontage

Management of the beach in the northern areas of the bay forms a key element of beach management plan as the protection of the urbanised areas of the hinterland depends on it. It is clear from Figure 5.7 that this area can be subject to significant change in elevation where the bay curves around towards Knightstone Island, although the analysis indicates that this change functions within certain limits and that there is no evident long term trend of erosion. The structural integrity of the sea wall does rely to a certain degree on a sufficient beach level to avoid slip zone failure resulting from scour but this is not seen as being an immediate problem.

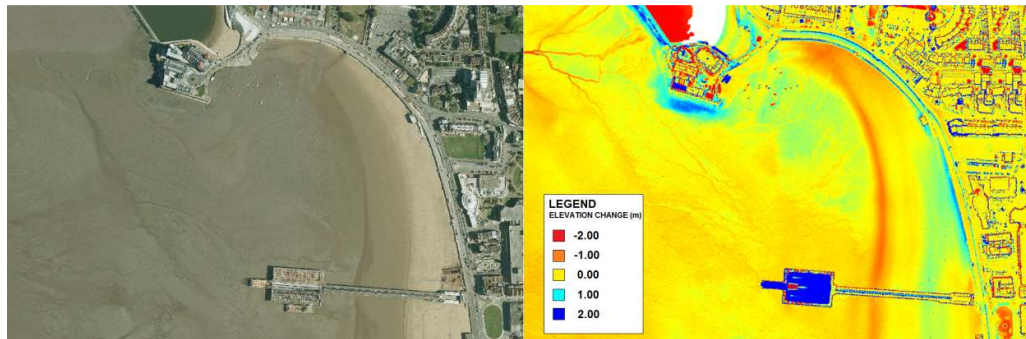


Figure 5.7 – 2007 – 2011 Change in Elevation in the North of the Bay

Figure 5.7 shows a significant reduction in elevation in the north between 2007 and 2011 (up to 14,000m³ of material within the red band). It is considered that the erosion occurs as a result waves arriving from the west, meeting the sea wall at Knightstone Island and wrapping around the curvature of the bay, focusing in the northern corner. The wave energy then continues south, and initiates the general north to south longshore movement of sediment.

The quantity of recycled beach material moved north each year has not been recorded but it is known that recycling was not undertaken between July 2008 and October 2010. It is also noted that there is significant variation even when recycling has been undertaken. It is, therefore, considered that the erosion illustrated in Figure 5.7 may provide representation of the typical fluctuation in the behaviour of the beach without intervention. On this basis, recommendations of how to manage the northern part of the beach are to be based on trigger levels rather than adjustments to existing beach re-nourishment operations.

More detailed monitoring is required in this area to confirm or adjust the behaviour identified to date. This is discussed in more detail later.

The construction of the Weston–super–Mare Seafront Enhancement Project also took place within the period of the data range which may also have had an effect on the beach elevations. An area of accretion directly south of Knightstone Harbour during

construction is known to be a deposit of fine dredged material as part of the construction. Since then the beach has re-adjusted with overall reduction in beach volume between 2007 and 2012.

This appears to confirm that sediment introduced into the area is rapidly redistributed.

Further south along the defended section of the bay, the upper beach is considered to be more stable. There is no indication that movement of sediment from the north is impacting on the area.

An analysis was undertaken of the influence of the Tropicana and the potential consequences of removal of this structure. In general, it is seen that the Tropicana sits within a wider area of upper beach and potentially only influences the broader scale beach behaviour on more extreme storms.

The study concluded, from information garnered from historic maps and photographs, that in the two or three decades following the construction of the Tropicana, the beach volume increased significantly. This increase in volume has resulted in the High Water mark moving seaward, which in turn has the effect of reducing flood risk.

In relation to the cross shore movement, identified above, the study notes that the Tropicana may have influenced this, but this is by no means certain.

Events that tend to lower the beach level would tend to cause the structure to trap more sediment (raising the beach). Similarly events that tend to raise the beach would tend to cause the structure to be less effective in capturing sediment (allowing the beach to lower). This tends to support the possibility that the Tropicana is having an active role in regulating the volume of the beach. The evidence is, however, indicative rather than definitive. The apparent accretion may be an artefact of the poor historic record, and if it did occur then this might have been due to other causes, either natural or anthropogenic.

In summary

At the northern end of the defended frontage:

- There is no clear evidence that recycling of sediment from the south, with the quantity presently recycled, has a substantial positive influence on beach levels generally within the Knightstone Harbour area. Imported sediment is likely to be redistributed quite rapidly, returning levels to a relatively stable equilibrium. However, from visual observations the sand layer is very limited, with a consolidated layer of mud beneath. It seems that the sand can be quite quickly eroded to expose the mud. This interaction needs to be examined further through improved monitoring and there may be benefit derived from the recycling in reducing overall loss of the consolidated mud. Recycled sediment may also contribute to sediment accumulation against the wall along the frontage to the north of the Grand Pier.
- There is insufficient monitoring information to confirm the above and this needs to be addressed. In particular there needs to be better information on the variation in beach levels with a potential focus on seasonal and post storm variation.

- At present there is no record of undermining of the walls due to reducing beach levels and the current standard of defence is based on wave overtopping with existing beach levels in place.
- The potential impact of sea level rise is considered later.

Along the central and southern section of hard defence:

- There is a relatively good upper beach width with no evidence showing long term erosion. In fact the historic evidence suggests that over much of the area the upper beach has grown.
- The movement of sediment either in terms of using sediment to build the RHL race features or its subsequent removal as part of the informal recycling operations do not appear to have a damaging impact on the integrity of the beach.
- At present the level of the upper beach forms an important element of the flood defence.
- The Tropicana potential acts to regulate change in the upper beach width. However, it is not envisaged that the potential removal of the Tropicana would result in a broad scale change in beach behaviour. The potential increase in variation of beach width would need to be considered in relation to the present standard of defence.
- There is, therefore, the need for improved monitoring particularly examining in more detail the variation of the cross shore profile and seasonal variation.
- The potential impact of sea level rise is considered later.

5.4.2 Sand Dune

The sand dunes are the first line of defence for the majority of the southern part of the bay. Figure 5.8 illustrates a change in elevation analysis, carried out using LiDAR data captured in 2007 and 2011 to determine how the dunes have developed over a 4 year period. It is recognised that the LiDAR used in this analysis is filtered and therefore an increase or decrease in elevation could result from a growth or cutting down of vegetation. It is considered the analysis remains a useful indicator of how the dune has evolved over this period.



Figure 5.8 – Change of Elevation of the Sand Dunes between 2007 and 2011 (red represents erosion blue represents accretion)

Historic photos have been obtained from the Weston-super-Mare Golf Club centenary journal which captures the golf course and sand dunes around the turn of the 19th century. The fence line in Photos 5.1 and 5.2 is thought to represent the seaward line of the sand dune that exists today. Based on these photos there is significant evidence that historically, the sand dunes were much less prominent in the past, suggesting there has been an accretion of sand over the past century to form the 15m – 20m ridge that exists today.

Photos 5.1 and 5.2 – Historic Photos of the Golf Course (Left Photo, Driving at the 3rd hole, circa 1900 - Right Photo, Playing from a Bunker, circa 1900)

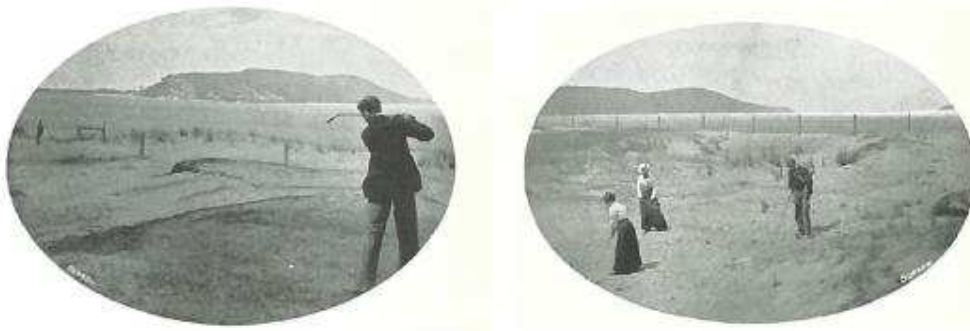


Figure 5.9 compares the aerial photos that have been taken in 1940 and 2009. The figure illustrates that the dunes were present in 1940. However, the 2009 aerial photo suggests that the dune vegetation has migrated principally seaward since the 1940s.

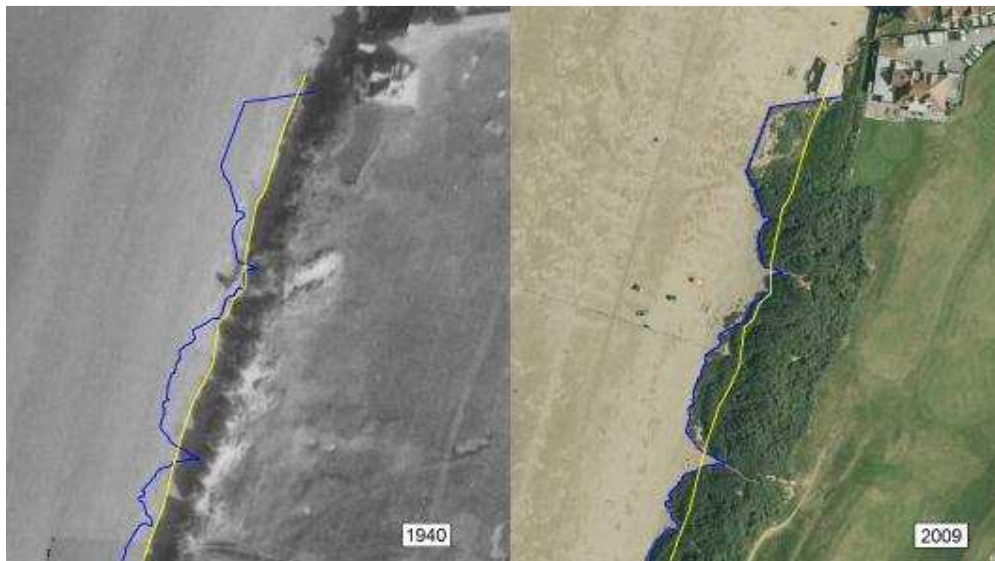


Figure 5.9 – Typical Comparison between 1940 and 2009

On-site observations have confirmed that the majority of the vegetation takes the form of buckthorn. The buckthorn, that in places exceeds a height of 2m, is dissected by a series of sandy pathways that run between the beach and the golf course.



Figure 5.10 – Change in Vegetation between 1991 and 2009

Figure 5.10 illustrates significant differences between the condition of the dunes in 1991 and 2009. The blue and red lines represent the frontages of the vegetation in 1991 and 2009 respectively.

In 1991 vegetation on the dune is not continuous. There were wide sand blow outs present and subsequently, a considerable amount of sand lay on the golf course. By 2009, the frontage of the vegetation on the dune had moved seaward. The vegetation on the dune appears continuous and more robust.

Figure 5.10 also demonstrates that in 1991 there was a clear definition between the sand and finer material and it was in close proximity to the dune. In 2009 the transition was less defined and the beach appears to be wider. It is also noted that there is significantly less exposed sand on the golf course.

The evidence suggests that the dune has become increasingly robust over time. It was noted that the activity along the beach, coupled to efforts of the golf course to limit migration of the dune vegetation in land during the 1980s and early 1990s, coupled to the use of the dunes as a stadium for spectators during the beach race had left the dune in a perilous state. It is understood that the sand dunes are mostly owned by the golf club, however they provide flood protection to the wider area.

At present it is considered that improved management of the dunes has improved the situation.

As part of the coastal study prior to improvement of the defences to the north an analysis was undertaken of the robustness of the dunes.

This considered the possibility of a breach under a 1:200 year storm event. Two different cases were considered. The first examined the impact of the 1:200 year storm followed by a storm of a 1:1 year return period. The second considered two consecutive 1:200 year storms. The results of the second scenario are shown in Figure 5.11.

Although the second scenario did indicate a substantial weakening of the natural defence, possibly the more significant feature of the analysis was the way in which

sediment actually accretes over the foreshore rather than being lost to the upper beach system.

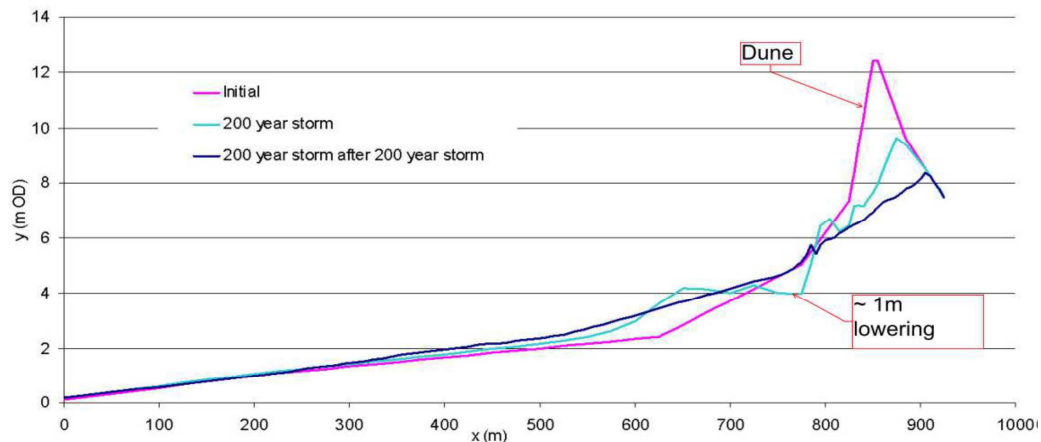


Figure 5.11 - Beach and dune profiles towards the south of Weston Bay before and after two 1:200 year storm events, (from Royal Haskoning (2004)).

Given the trend of accretion and the capacity for the beach and dune to grow together, it seems probable that damage to the dune following a severe storm would be naturally repaired.

Therefore dunes do not appear to be at risk from breach. They do still have limited width and with the general long term trend for accretion in this area there is scope for allowing the dunes to develop further forward. This might be achieved through reducing the beach cleaning activities along the front face of the dune. This is discussed in more detail later.

Locally, the interface between the dune and the hard defence at the southern end creates an area of greater vulnerability. This is discussed in more detail in Section 6 with respect to flood risk associated with the Axe Estuary.

In summary

- The dunes provide an essential component of defence to the Golf Course, the Village of Uphill and the wider hinterland.
- Over the last two decades their condition has improved, although they remain as a single ridge, fixed dune system. Their further growth is limited by management activities; preventing their migration in land and restricting their growth over the foreshore area.
- Their possible response to sea level rise is discussed latter. However, it is considered that increasing their foreshore width would contribute to their longer term resilience, potentially working to support an overall capacity for this area of the bay to accrete with sea level rise.
- The hard defence at the southern end of the dune, particularly the presence of the former caravan site wall, may have acted to support the line of the dunes to the north. At the same time (discussed later) the alignment and nature of these harder defences is seen as creating a potential weak spot in the defence.

- The interaction between the southern section of the dunes and the level of the beach in this area is quite probably intrinsically linked to changes at the mouth of the estuary. There is a need for improved longer term monitoring, in association with considering further how change in management of flood defence within the estuary may impact on this area.

5.4.3 Salt Marsh Area

There is a small area of saltmarsh to the south of the Axe estuary in front of the main flood embankment. The LiDAR analysis has identified erosion of this area due west of Black Rock. The aerial photos identify a lighter material being eroded overlain by saltmarsh. However, its colouration and the erosional processes occurring suggest this area is relatively soft in comparison to Brean Down.



Figure 5.12 – Erosion of the Salt Marsh in the South of the Bay

The line of erosion is located approximately 70m seaward of the current frontage of the existing flood alleviation embankment. Three transects have been extracted from the LiDAR data, the locations of which are identified on Figure 5.12. The profiles are illustrated in Figure 5.13 to 5.15. The figures provide representations of profiles taken in 2007 and 2011. MHWS has also been illustrated on each of the figures.

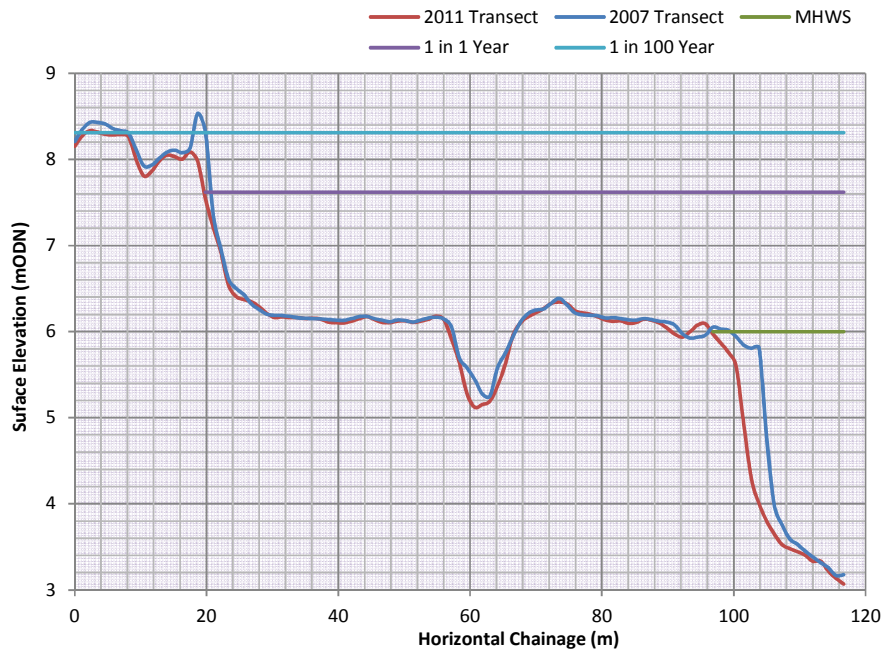


Figure 5.13 – Cross Section at Transect 1

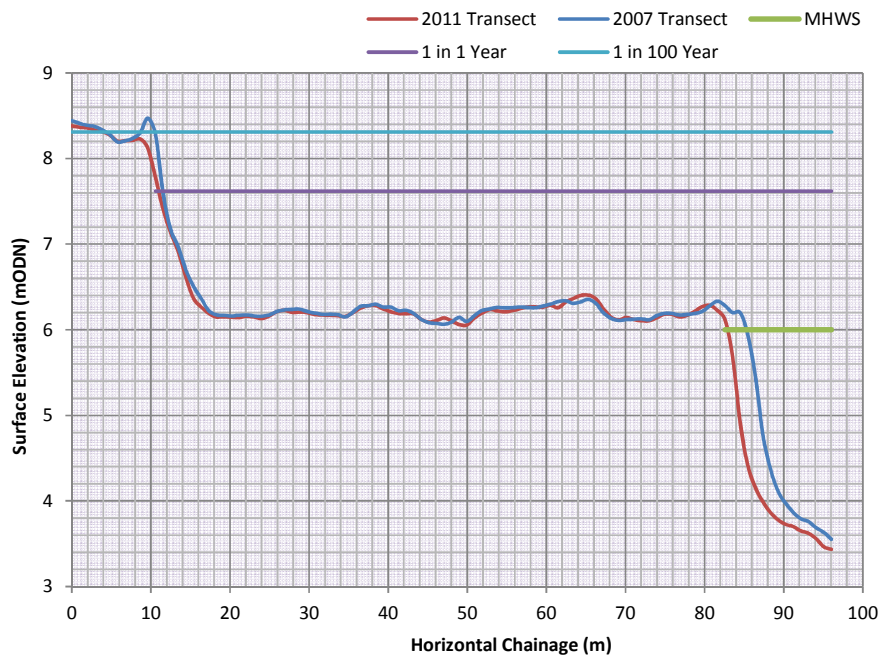


Figure 5.14 – Cross Section at Transect 2

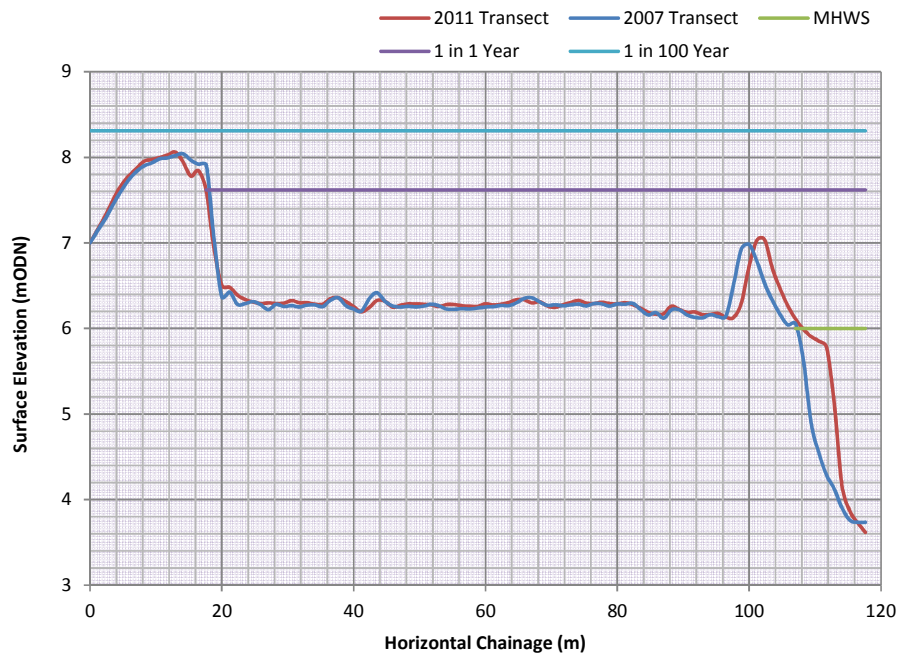


Figure 5.15 – Cross Section at Transect 3

The figures above demonstrate that a general retreat of between 2 - 4 meters at the edge of the salt marsh has occurred between 2007 and 2011. The salt marsh is provided protection from the most extreme wave conditions (from the Bristol Channel in the west) by Brean Down. There is more exposure from smaller waves generated locally by northerly winds. There may also be an influence of the meanders of the Axe channel. It is therefore considered that this erosion at the salt marsh is likely be a result from a combination of these two effects linked to the development within the Axe.

Figure 5.16 shows the historic maps for 1891 to 1912, compared to that of 1919 to 1943.

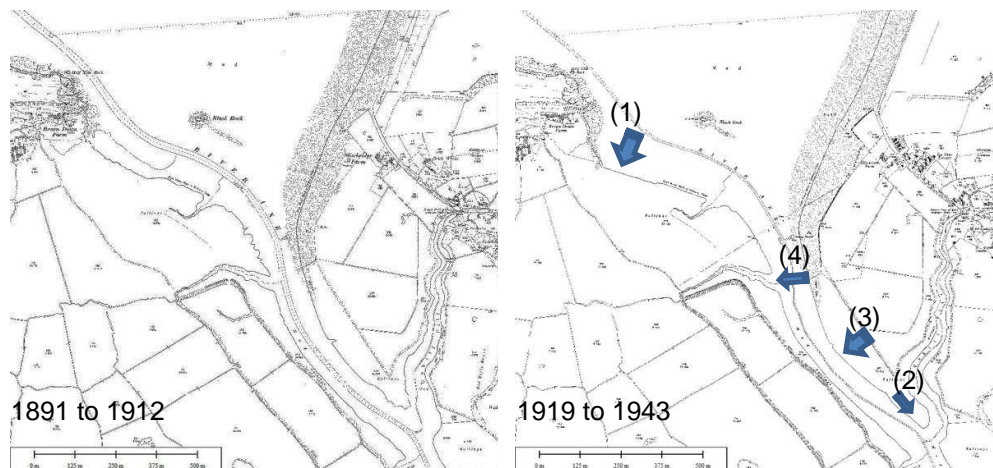


Figure 5.16 - Comparison of entrance at the mouth of the Axe.

The comparison shows erosion of the saltmarsh in the location considered above (1). Within the entrance to the estuary there appears to have been associated changes. Most obvious is the growth of the spit across the mouth of the Uphill Great Rhyne (2) and coupled to this the growth of the western mud bank (3) and slight erosion of the eastern frontage (4). Overall, the comparison suggests that there had been some infill of the whole estuary with a narrowing of the low water channel.

This pattern of change is consistent with the sediment movement to the south but is likely also to the estuary's longer term response to reduced tidal prism (i.e. the volume of water within the estuary.)

The net effect of this change could then be interpreted as a slight shift in the alignment of the channel at the entrance, shifting the alignment slightly further to the north with the outer channel then returning slightly to the south across the saltmarsh frontage. Typically also, the reduced tidal prism might result in a reduction in the level of ebb delta, which might then allow increased wave exposure on the outer area of saltmarsh.

Much of this has to be speculation but potentially explains the changes observed through to the present day.

In general the MHWS level lies below the edge of the salt marsh. The 1 in 1 year water level demonstrates that the area between the edge of the saltmarsh and the flood embankment is frequently subjected to flooding. It is considered that water run in off the flat section could also be a minor contributing factor towards the erosion. This run off could be a result of both rain and extreme water levels.

Looking ahead, the continuation of this erosion could lead to an increased vulnerability of the embankment through wave attack. However, without a comprehensive ground investigation and monitoring, and put in the context of change that has been occurring over a longer period of time, it is not clear whether the rate of erosion will be sustained. It is recommended that a standalone investigation is carried out as part of the monitoring programme.

Furthermore, analysis of the LiDAR data shows that over part of the embankment length the crest level would not provide protection during a 1 in 100 storm event (8.31m ODN). This is discussed further in relation to the estuary defences as a whole in the following section.

In summary

- The current erosion of the saltmarsh is not seen as being an immediate issue of concern in terms of flood defence.
- The initial change within the area appears to have occurred historically and the current increased rate of erosion may be linked to some further change associated with the broader scale area. It seems unlikely, therefore, that the current rate of erosion, seen over a four year period, should indicate a long term rate that would be sustained.
- This is based on a speculative assessment of limited information and needs to be developed based on continued monitoring.

- It is put forward as an argument that the changes are fundamentally linked to changes that have and may still be occurring within the estuary / open coast interface.
- The above assessment needs to be taken forward and acknowledged in developing the management plan for the defences within the estuary.

6 FLOOD RISK AND FLOOD DEFENCES ALONG THE AXE ESTUARY

6.1 General

Although the actual flood risk management along the line of the Axe is not directly related to the management of the beach, it is suggested above that local change within the estuary may have consequences for the behaviour of the beach. It is also recognised that there is a significant risk of flooding from both fluvial and tidal sources associated with the Axe Estuary. The location of the Axe River and Estuary can be seen in Figure 6.1 which illustrates both fluvial and tidal flooding without defences. However, the flooding shown in this figure is not only from the Axe but also from all other fluvial and tidal sources in the vicinity, including tidal flooding from Brean to the west and Weston-super-Mare to the north and fluvial flooding from sources such as Uphill Great Rhyne which runs into the Axe Estuary. Due to the significant risk of flooding from the Axe it has been considered appropriate to include examination of this within the Beach Management Plan. The wave transformation simulations illustrate that the Axe Estuary is generally exposed to minimal wave energy and therefore the main risk of flooding from the sea is posed by extreme water levels which can also be associated with tide locking.

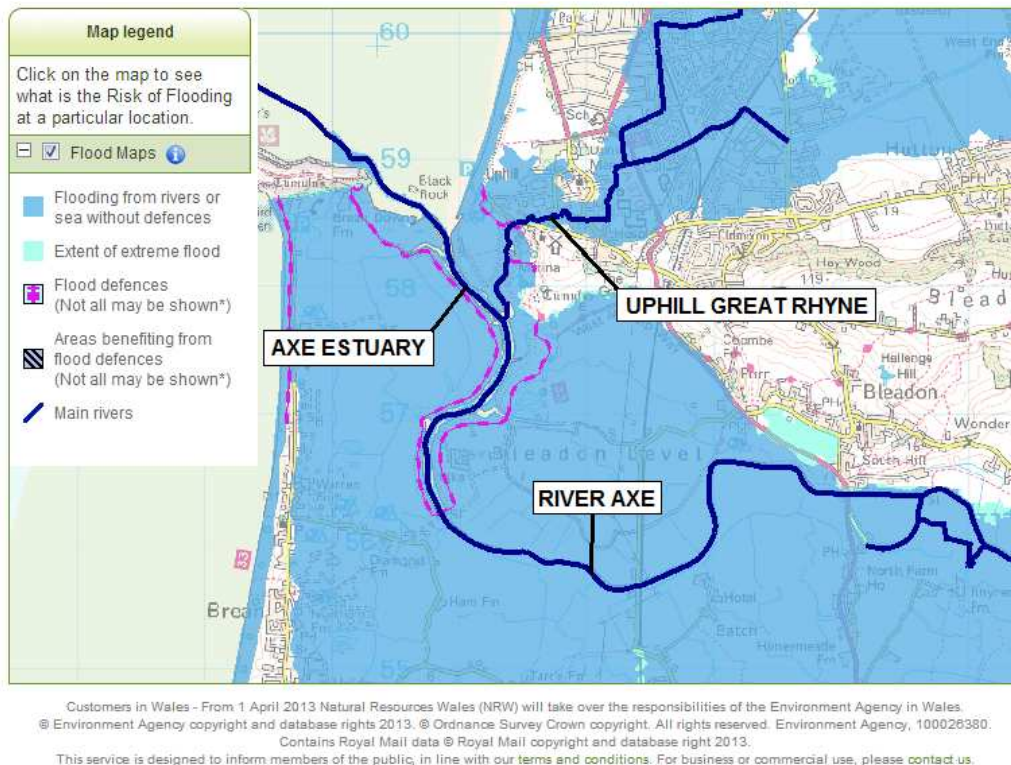


Figure 6.1 – EA Flood Map showing flooding from all fluvial and tidal sources without defences in the area of the Axe Estuary

Figure 6.2 shows the main flood embankments within the estuary. It may be seen that to the western side of the main channel there is effectively a continuous bank running through from the high ground of Brean Down through to the tidal sluice at Brean Cross.

To the north and eastern side of the channel the main defence line runs from the southern extent of the dune, linking through to the high ground to the south of the village of Uphill. This defence is cut by the tributary of the Axe, the Uphill Great Rhyne, with the tidal limit being defined by the Uphill Tidal sluice. In front of this is an area protected to a lower standard by the uphill outer defences.

Further south, on this eastern side of the channel, there is short section of local defence running from the Uphill Great Rhyne over to high ground, with the high ground forming the defence through to the main flood embankment running south to the eastern side of the Brean Cross Sluice.

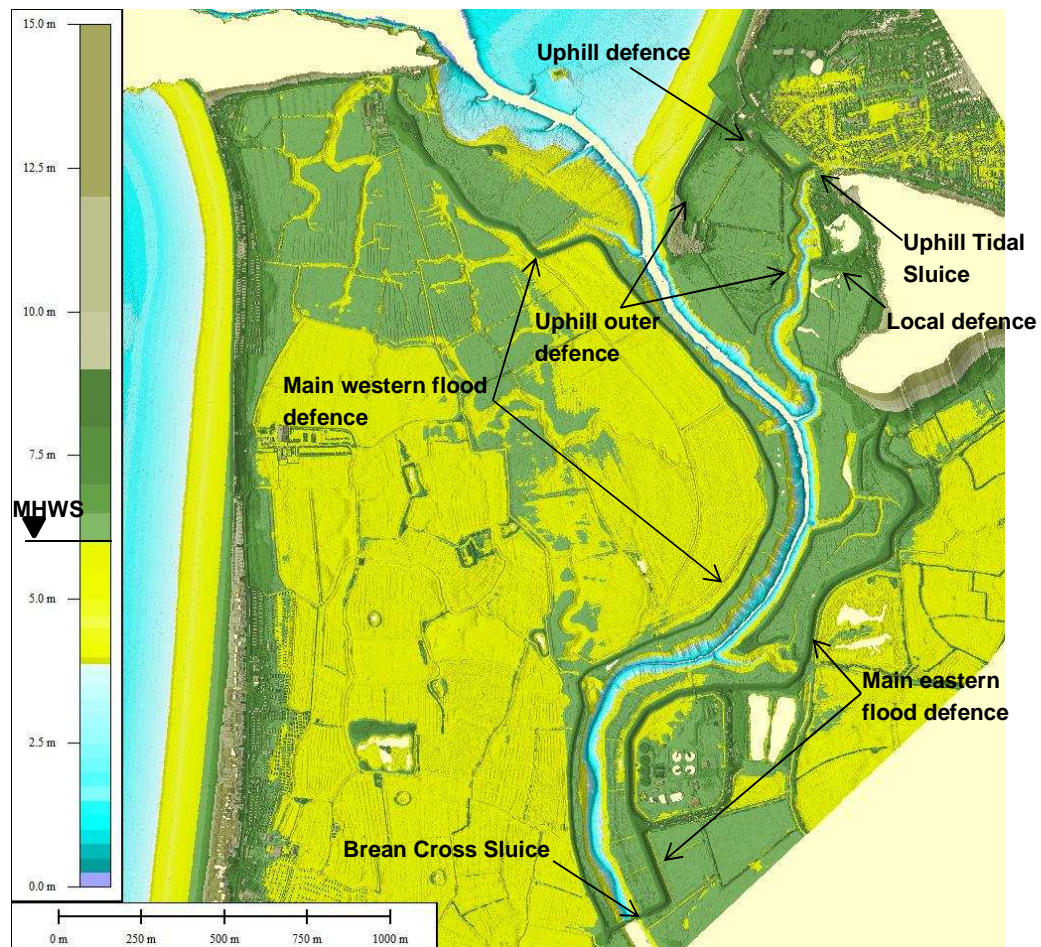


Figure 6.2 - Axe Estuary and Tidal Flood Defences

The areas shaded yellow indicates land which is below MHWS (6.0m ODN), as indicated on the legend on the left hand side of the Figure. This highlights the risk to Uphill and to the extensive area to the west. These areas and the defences associated

with these areas are discussed in more detail below. The levels of the defences are based on the filtered LiDAR and as such, in detail, the levels may vary slightly from those in the figures. However, the figures do highlight potential lower spots and where possible other information has been used to validate the LiDAR.

Flood flows through or over low/weak spots in the defence would need to be modelled in more detail to show how flood waters would actually spread over any area of land. Given the duration over which flooding might occur together with the constraint of the flow, any weak spot would not, therefore, necessarily extend over the full extent of the potential flood plain.

6.2 Uphill Area

Figure 6.3 highlights the areas of future potential weakness along the defensive line and low areas with important defences in place.

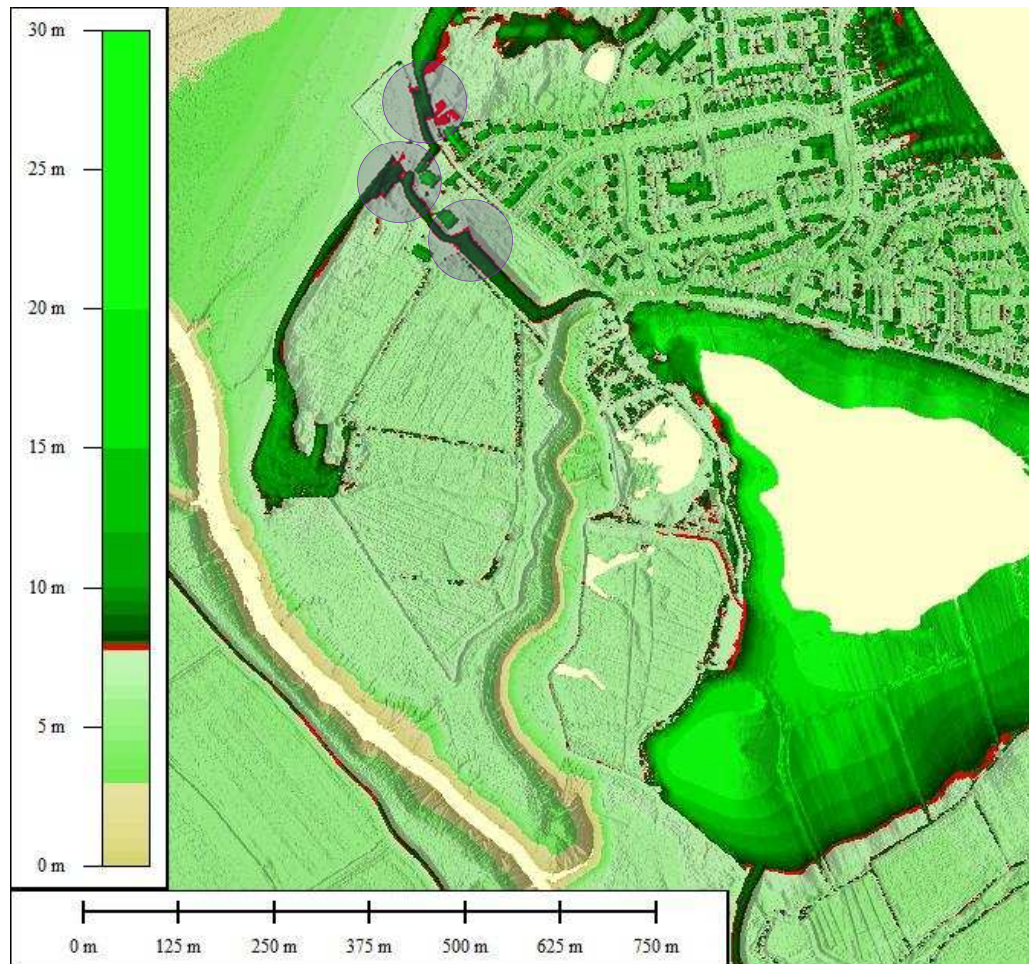
Equally the flood gates to the west of the defences are critical to the standard of protection at Uphill.

The main area of Uphill, therefore appears to have a competent defence to a 1:100yr level, although this remains critically dependent on the integrity of the dunes, particularly at the southern end.

The campsite wall is not part of the defensive line but is considered aid the build-up of sand at the southern end of beach.

Future areas of potential weaknesses have been identified at the southern area of the dunes adjacent to the road, potentially around the southern corner of the former caravan site and part way along the embankment towards the Sluice (highlighted with purple circles). On a 1:200yr water level (8.43m ODN) these weak area would be overtopped.

Along other sections of this defensive line, while the integrity is reliant on the narrower crest width, there are no additional weak spots identified. The defence width would become more critical on the open coast, as wave action would increase the risk of flooding.



6.3 **Figure 6.3 – Vulnerability to Uphill Area
Western Flood Embankment**

The western embankment comprises 3.5 km of flood embankment linking Brean Down to the Brean Cross sluice. Figure 6.4 provides a similar assessment of defence as above for the Uphill area. Areas highlighted in red represent low spots along the embankment. Low spots have been identified using LiDAR and have in part been validated with survey data provided by the Environment Agency.

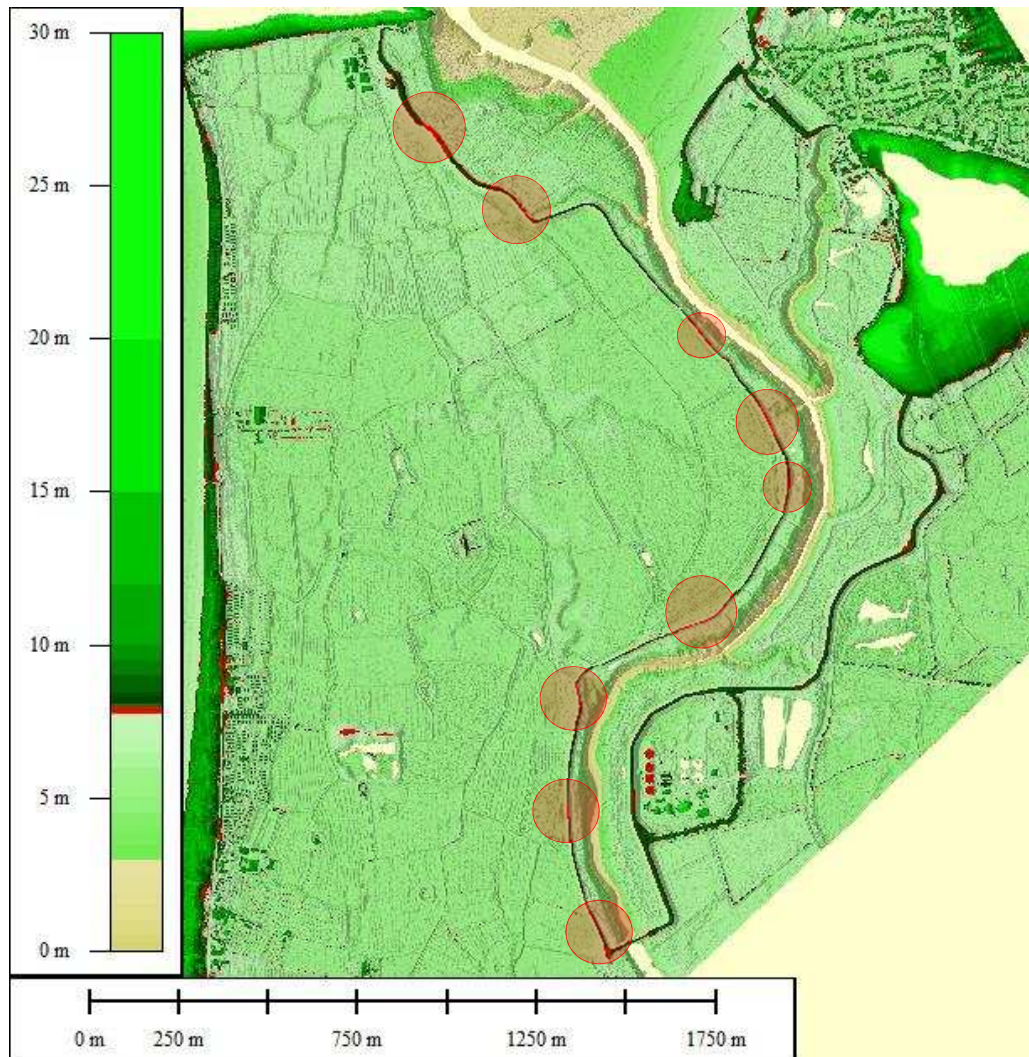


Figure 6.4 - Vulnerability of the Western Embankment

It is generally considered that there is a competent defence to the western flood plain during MHWS and a 1:2 year storm event.

At a water level with a return period of approximately 1:20 years (8.04m ODN), several lengths of defence are indicated to be below this water level. The low areas are highlighted with red circles in Figure 6.4. There is some suggestion that at the northern end of the embankment levels might be locally lower at around the 1:10yr level (7.94mODN) or potentially even lower.

It is also noted that in several cases the lower defence levels coincide with sections where previously there may have been creeks running into the flood plain area prior to protection. This might suggest settlement over areas of weaker substrata.

On a 1:100yr water level, virtually all of the defence would be overtopped. It is also noted that defences on the eastern bank of the estuary channel start being at risk of overtopping.

6.4 Future Development and Impact of the Open Coast

The earlier discussion of the saltmarsh area, particularly with respect to the historical mapping, suggests that the estuary, given the right conditions has had the capacity to accept sediment. Progressive opening up of areas to flooding may have a potential for warping up of land levels.

Countering this to some degree would be the fact that the increased tidal prism, might tend to attempt to widen the channel, particularly at the entrance.

Depending on this balance, it might be expected that the estuary may increase its ebb tidal delta in such a manner that might actually increase protection to the southern corner of Weston Bay, potentially supporting the development of the saltmarsh and the southern section of the dunes.

This is, as with the original assessment of saltmarsh change, recognised to be speculative. However, it is highlighted in relation to management of change in defence within the estuary, in that such change would need to be processed with some caution with appropriate monitoring in place to allow the development of the estuary management in an integrated way.

7 THE IMPACT OF SEA LEVEL RISE ON WESTON BAY

Sea level rise (SLR) is likely to cause a change to the geomorphological behaviour of the Beach at Weston Bay. The impact of SLR will vary across the bay due to the different types of coastal flood defence that exist.

In summary, where there is hard defence in the north of the bay, SLR will result in coastal squeeze or a reduction in the upper width of the beach. Further to the south, the dunes could migrate landward or indeed may develop forward with an associated change in profile shape. SLR is likely to result in an increase in the frequency of overtopping of the flood embankments lining the Axe Estuary and in association with this may result in changes locally to the southern part of the bay. This section investigates the effects of SLR in more detail.

For the purposes of the analysis within this section, SLR is taken as following the 95th percentile of the UKCP09 'Medium Emissions' scenario (as advised in Environment Agency, 2011a). This has to be taken purely as an indicative value of the rate of change. Table 7.1 shows the sea level adjustment periods and associated SLR used within this analysis.

Table 7.1 – Sea Level Rise

Return period water level	Sea Level Adjustment Period (Years)				
	Present day	10	25	50	75
	SLR (m)	0.05	0.14	0.32	0.52
MHWS	6	6.05	6.14	6.32	6.52
1:1yr	7.62	7.67	7.76	7.94	8.14
1:2yr	7.72	7.77	7.86	8.04	8.24
1:10yr	7.94	7.99	8.08	8.26	8.46
1:50yr	8.19	8.24	8.33	8.51	8.71
1:100yr	8.31	8.36	8.45	8.63	8.83

Note: All levels are m. ODN

Highlighted in the table are examples of indicative equivalent return periods. In year 50 a 1:1 year return period is equivalent to the present day 1:10 year. A condition with a 1:100 year return period now would be approximately equivalent to conditions that might occur on a 1:10 year period in 50 years.

The influence of sea level rise is considered by area below, drawing upon the in summary conclusions provided in Section 5.

7.1 North of the Bay

Hard coastal defences exist between the Marine Lake and just north of Royal Sands. Construction of the Weston–super–Mare Seafront Enhancement Project was completed in 2010 and the level of protection was increased from 1:5yr (2%) to 1:200yr (0.5%).

The current crest level of the sea wall is 9.05mODN. However, it is proposed that this would be raised to 10.05Modn between the road and the promenade in 25-50 years to

ensure that the standard of protection of 1 in 200yr (0.5%) can be sustained throughout the schemes life should predicted climate change occur.

Since the design of this scheme, further research has been carried out to gain a better understanding of extreme sea levels. It is considered that the additional 1m will be adequate to maintain the 1:200 year standard of protection, it is not clear at what point the enhancement would need to take place and this will depend on the actual rate of SLR observed.

In developing this approach the scheme has allowed for increased exposure or wave height directly due to increased water depth. However, two further aspects need to be considered in relation to this, both where there is increased uncertainty.

There is potential for the foreshore to lower due to the increased water level and associated increase in inshore wave energy. There is not necessarily an association between these factors. Two national studies have been undertaken into foreshore lowering and scour associated with seawalls as part of the Defra/ Environment Agency research programme (Erosion of cohesive shore platforms, 2007 and beach lowering in front of coastal structures 2003).

The first of these studies related more to lowering of clay and soft rock platforms (cohesive platforms). The second area of research focussed on the interaction between defences and the behaviour of the foreshore. The research recognises the complexity of the scour process saying: *“it is difficult to differentiate between erosion caused by the seawall and that due to 'regional' or widespread erosion. Most seawalls, after all, are built because the shoreline is eroding”*. In the case of Weston-super-Mare, at present there is no evidence to suggest a long term trend of erosion, further suggesting that the lowering that would occurred when the wall was constructed has reached a relative equilibrium.

This second study goes on to record the principal mechanism for scour as being the increased wave energy in front of a sea wall: *“Seawall toe scour occurs when the base of the wall can be acted upon by waves, either directly, when the sea level is higher than the bottom of the wall, or through wave run- up. The presence of a structure in relatively shallow water, for example, abruptly breaks the wave and the energy is dissipated within a much smaller zone than on a natural, unimpeded beach profile. This sudden release in energy is converted into turbulence and wave reflection. The extra kinetic energy released around the toe of the seawall induces lowering of the beach at the bottom of the wall.”*

However the study goes on to caution that *“Non-specialist texts have been written suggesting that this “vicious circle” of processes and effect continues indefinitely and thus that seawalls and revetments are the cause of the low beach levels that are commonly observed in front of them. While an attractive explanation for lay readers, it is often untrue. Many seawalls were built in response to pre-existing coastal erosion and beach lowering. Although they may not have remedied this natural regime of long-term erosion, they certainly are not in many cases to blame for its continuation.”* There is, therefore, some indication that as a beach lowers and flattens, so the direct impact of the wall may reduce, reaching in effect a position of equilibrium. This critically depends

on conditions remaining constant. With sea level rise, increasing water levels in front of a wall allowing increased wave heights could tend to increase energy and subsequently increase the potential for erosion but this is not necessarily the case.

The second aspect, linked to the first, is that of beach lowering exposing or undermining the toe of the wall. The project appraisal report (Royal Haskoning 2007) states the structural analysis indicates that 1m of beach drawdown could result in wall instability. From the above, local scour at the toe of the wall is probably the more likely response to sea level rise than a significant lowering of the whole foreshore, the risk of undermining is, therefore, a critical issue most probably in the medium term, rather than the short term. A scour protection apron was installed at the foot of the wall between Knightstone Harbour and the Grand Pier to counteract any erosion.

Without further study of overtopping in combination with the monitored response of the foreshore to sea level rise, particularly the variation in beach levels, it is not possible to define a specific future water level/foreshore trigger condition. A recommendation for a study into trigger levels is discussed in chapter 8.

In relation to the central area of defence, at present there is a good width of upper beach, acting as an element of the defence system. With SLR, it is likely that this area of upper beach would reduce. Further examination of this would be required to look at specific trigger levels in terms of upper beach width, in relation to the anticipated need to raise the crest of the wall behind.

7.2 Ridge of Dunes in the South

The ridge of sand dunes that exists towards the south of the bay forms the key coastal flood defence for Weston–super–Mare Golf Course and the settlement of Uphill. These dunes are considered to be reasonably robust with no significant signs of erosion and an increase in vegetation has been observed over the last 5 years. However, under current sea level conditions the dunes system is subject little wave attack.

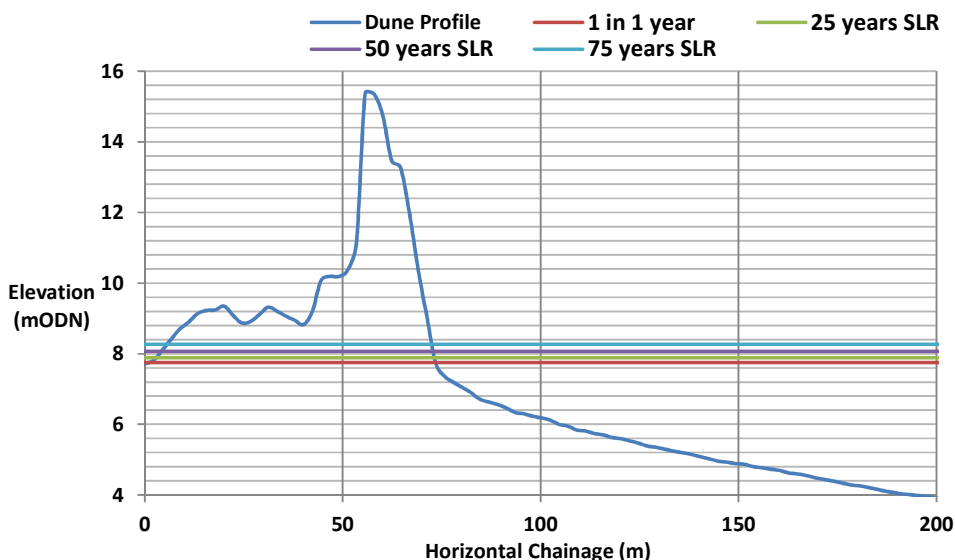


Figure 7.1 – The Effect of Sea Level Rise on a Typical Section of the Dune

Figure 7.1 illustrates a typical dune profile and where the 1 in 1 year extreme water level (with the addition of 25, 50 and 75 years sea level rise) is positioned relative to a typical dune profile. It is clear that under the existing profile, SLR will increase the frequency that the dunes will be subject to wave attack and will also change the focus points of the wave energy. This would cause increased erosion of the front face. The response of a natural mobile dune would be for landward migration. However, such a process tends to be a continuous and gradual adaptation, i.e. it is not the erosion of the front face that causes the roll back but rather that the dune is in a continuing process of change such that as sediment is moved from the front face there remains a width of active dune behind. Quite clearly this is not the situation with the Uphill Dunes as the dune is heavily vegetated and is managed on its rear face stopping migration in land. The situation then arises that with increased erosion the dune becomes narrower and more vulnerable to breach.

This sets out one possible scenario of response. An alternative view which is equally supported by existing evidence is that with SLR the whole beach area may accrete, keeping pace with SLR. The analysis within Chapter 5 confirms general movement of sediment in a southerly direction and the capacity for forward growth of the dune.

It is not possible to determine which scenario is more probable. However, in either case there it would be good management to encourage the forward development of the dune increasing its width. Monitoring is recommended to observe whether the southerly movement of sediment will be able to maintain the position of the dunes into the future and management is discussed further in section 8.

7.3 The Axe Estuary

The Axe Estuary is surrounded by flood embankments that are generally continuous with the exception of two tidal sluices that exist at Brean Cross and Uphill. The wave transformation modelling identifies this area as being subject to minimal wave action. Therefore attention is focused on the threat from extreme water levels.

To the western side of the estuary, existing minimum crest height of the flood embankments is around 8mODN, however this crest level only exists at low spot (i.e. the locations identified in section 6.4). This is considered to provide a protection against extreme water levels up to between 1:10yr and 1:20yr water levels. However, with between 50 years sea level rise (0.32m), the standard of protection afforded by the lower crest levels of the bank would be of the order of a 1:2 year event.

Without major raising of defence levels and addressing the specific weak spots identified in section 6, it would not be feasible to maintain the integrity of the whole western bank.

Increasing the crest levels of the flood embankments could maintain an acceptable standard of protection. However, the SMP considers the possibility of managed realignment in this area to mitigate SLR. These management options are discussed further in Section 8.

On the eastern side, there is already significant risk of flooding to the outer defence bank to the south of Uphill. With even modest rise in sea level, this bank would be expected to be overtopped more frequently than 1:2 year. The main bank would be more secure in the short term but with sea level rise over 50 - 75 years its current standard of protection is likely to reduce to that of 1:10.

Even over the next 25 - 50 years, the standard of protection could reduce to that of 1:50.

With SLR, regardless of future management of the defences within the estuary, the form and tidal prism of the estuary is likely to change. There is some capacity for the estuary to accrete and this may reduce the increase in volume. If defences are realigned, then depending on their location and the hydraulic performance of the estuary, there is the likelihood that overall flow into the estuary would increase. Certainly this will influence the development of the beach to the south of the bay and there is a suggestion is that this may assist in developing higher beach level within this area.

8 DISCUSSION OF MANAGEMENT

8.1 Introduction

As set out in Section 1.5, the areas of the bay that are most relevant to this beach and dune management plan are split into five policy units, as set out in the SMP2. In terms of management options Policy Units 7e02 to 7e04 cover the Axe Estuary whereas Policy Units 7e05 and 7e06 cover the main part of the beach from the Uphill to Anchor Head in the north. All the recommendations contained within this section are set out in an action plan which is included as Appendix F.

8.2 Policy Unit 7e06 – Royal Sands to Anchor Head

The Weston–super–Mare Seafront Enhancement Project was completed in 2010 to provide a flood defence with an improved 1 in 200 year standard of protection for the entirety of Policy Unit 7e06. The foundation of the splash wall has been designed to accommodate sea level rise by increasing height of the crest of the sea wall by 1.0m in the future. The project appraisal report (Royal Haskoning 2007) suggests that the requirement for this could occur in 25 years although it is considered that this should also be informed by future monitoring of sea level rise and beach levels.

In terms of beach management, Policy Unit 7e06 has been assessed in two sections:

- The Beach in the Vicinity of the Tropicana (southern area)
- The Northern Part of the Bay (northern area)

8.2.1 The Northern Part of the Bay

In the north of the Bay there is limited evidence of long term erosion to the north of the Pier, despite beach levels being lower in this area. The project appraisal report (Royal Haskoning 2007) states the structural analysis indicates that 1m of beach drawdown could result in wall instability. A reduction in the level of the beach would also increase the water depth at the foot of the structure, therefore increasing the wave height and subsequently overtopping.

In the short term it is recommended that the current beach replenishment activities are continued, even though there is no clear evidence of the benefit this accrues. Therefore, the beach level should be monitored to determine the degree to which recycled sediment may influence the area. Critically, monitoring should be undertaken more frequently to understand the variation in beach levels. This would initially give a better understanding of the risk of walls being undermined such that trigger levels would be established based on variation above the critical 1m level.

It is recommended that trigger posts are installed at the northern end of the bay. These will provide a reference point by which monitoring can be carried out by North Somerset Council as required. The locations of the posts will be positioned to provide representative cover of the frontage.

As this monitoring builds, it would be possible to examine further any trend of change in association with sea level rise. This would allow development of the programme for raising the crest of the sea wall.

In the longer term, large scale replenishment may be required to provide continued protection to the toe of the structure and minimise overtopping. However, a large deposit of sediment in the north may lead to accelerated erosion and therefore a control structure may be required to prevent this. This option was considered in the project appraisal of the recent works to the sea wall. This option was rejected as a means of providing adequate flood defence. In the suggestion above, the introduction of a control structure is aimed at retaining beach levels not in providing an alternative to the sea wall as the primary flood defence. The appraisal highlighted that it was only in this northern location that such a structure would be effective in relation to modifying wave action and hence beach lowering within the harbour. If control structures are required in the future a further investigation would be required.

8.2.2 The Beach in the Vicinity of the Tropicana

The analysis in Section 5 suggests that despite material being removed from the vicinity of the Tropicana as part of the recycling, this is the widest part of the beach and an area where sediment appears to be accreting. It is therefore considered that in the short term the existing management activities of this area are appropriate. However, it is recommended that the CCO continues to monitor this area to ensure the beach level is sustained.

The geomorphological impact of the potential demolition the Tropicana would also need to be closely monitored. The Coastal Process Assessment of the Proposed Demolition of the Tropicana Lido (Royal Haskoning 2012) states that the structure influences the Weston–super–Mare beach in two ways: it creates local deformations of the general beach profile and acts to regulate beach width. Absence of the Tropicana may make the beach more vulnerable to larger storm events, and trigger a tendency for it to revert to a reduced volume, if other measure were not taken to prevent this. As previously mentioned the Secretary of State has since refused permission for demolition.

8.3 Policy Unit 7e05 - The Dunes

In terms of the dunes within Policy Unit 7e05, the analysis in Section 5 indicates that the dunes provide an adequately competent defence at present. At present the dunes are considered to be robust and there has been increase in the presence of vegetation over the last 5 years. The southerly movement of sediment along the beach appears to be feeding the dunes and allowing them to maintain their position.

The critical issue in terms of management over the short to medium term is how the dunes will respond to SLR; whether the area will tend to accrete with SLR or whether the dunes will tend to be eroded. This has to be monitored, linking monitoring of the dunes to the wider beach area.

Beach cleaning currently takes place up to the toe of the dune and this has a potentially negative impact on the sand dunes in preventing forward development of the dune toe

and possible a further dune ridge. In either case noted above, increased width would be beneficial to longer term management.

It is recommended, therefore, that a buffer zone is created in front of the dune which could be achieved by installing wooden stakes at the toe of the dune. It would be recommended that this is initially at least 3m in width, potentially increasing as the toe of the dunes is re-established. This should be followed up with monitoring to gain a good understanding of whether the effect of this measure and over time whether the dune is eroding, accreting or migrating.

Should the beach levels remain constant and no increase is seen in the general area, then the approach to management would need to be reviewed. This might require that further width is allowed to the back of the dunes. This would need to be agreed with the Golf course.

8.4 Policy Units 7e02 to 7e04 – Axe Estuary

The main forms of flood defence within Policy Units 7e02 to 7e04 are the flood embankments that line the Axe Estuary and the tidal sluices at Brean Cross and Uphill. At present the flood embankments appear to have a standard of protection of between 1 in 10 and 1 in 20 year return period (at the lowest parts of the crest) suggesting they are likely to be subject to overtopping, which could lead a breach. The key points of the preferred plan for these policy units are as follow:

For Policy Unit 7e02 to 7e04 the long term plan is to continue to minimise flood risk to the wider area of the Somerset Levels in the most sustainable way. Along the west (left) bank of the Estuary, policies and implementation measures also needs to consider coast between Berrow and Brean Down.

The long term vision for the estuary is to return it to a more natural, less constrained state whilst continuing to provide defence against the risk of flooding in a way that is environmentally acceptable and economically viable.

Along the west bank of the River Axe, there would be no change in the short term and possibly medium term before moving towards managed realignment in the medium to long term. Along the east bank of the River Axe and from the east side of the mouth towards Uphill, the plan is to provide defence against the risk of flooding in a realigned position. There are opportunities here for further managed realignment to create habitat.

In the immediate future it is recommended that a survey is carried out at the critical locations (i.e. where the embankment meets Brean Down and the narrower pathway to flooding at Uphill and more generally where weak spots have been identified from the LiDAR). Analysis of the LiDAR in these locations has identified low lying ground which could be subject to flooding during an extreme water level event with a return period as frequent as 1 in 2 year.

There is also concern that some of these weak spots may coincide with old creeks passing under the embankment. Further consideration therefore needs to be given to the condition of the defence.

It is also recommended that a detailed survey of the entire embankment is carried out in the near future to identify the lowest section and gain a better understanding of the standard of defence.

In the short to medium term (considered to be in the region of up to 50 years) sea level is likely to rise by up to 0.31m. This in turn will increase the frequency and the severity of the overtopping to the flood embankment. Due to the economic value that this asset protects (the settlements of Brean and Uphill) it is considered worthwhile continuing maintenance of the flood embankment, however, the crest level may need to be increased to sustain the standard of protection.

The Severn Estuary Flood Risk Strategy states:

The River Axe embankments and Brean Rock Armour sea wall will be maintained as funding allows. Despite this, the River Axe embankments could become inadequate in 30-50 years. Based on the current prioritisation of funds, it is unlikely that public funding would be available to raise the defences substantially. At this point, landowners would need to consider the options available to them. The option to re-align the River Axe embankments is not being considered for at least 30 years, and even then will only be possible with the agreement from landowners.

Discussions regarding the future management of the River Axe embankments have been had with landowners.

The Beach Management Plan has identified the potential influence of the estuary management on the open coast. In assessing this and developing with landowners an appropriate action plan for management of defences, this potential link has to be considered further.

9 CONCLUSIONS

The Weston Bay Beach and Dune Management Plan commissioned by North Somerset Council (NSC) covers Weston Bay from the Brean Cross sluice on the Axe Estuary to Anchor Head at the north end of Weston Bay.

The main objective of this beach and dune management plan is to provide an assessment of the behaviour of the beach, relating this primarily to its key role as part of the defence system and how this interacts with other important uses and benefits the beach brings to the area. The plan also addresses the issue of how the beach will respond to sea level rise and recommends future management options.

In the north the sea wall has recently been upgraded to provide a defence standard of a 1 in 200 return period as part of the Weston-super-Mare Seafront Enhancement Project. In the south the dunes provide an essential component of defence to the Golf Course, the Village of Uphill and the wider hinterland. The flood defence in the Axe Estuary comprises flood embankment, two tidal sluices and automatic flood gates in the vicinity of Uphill Sluice.

The alignment of the beach has generally remained unchanged over the past century. Overall it is concluded that while generally the bay shape is quite stable, locally there can be quite rapid movement as the beach across the whole bay adjusts to different wave conditions. Much of the change in the beach appears to be in a cross shore direction. In terms of behaviour in more specific areas:

- In the north of the bay, the construction of the sea wall in 1880 has held the line in front of the town. However there appears to be a trend of erosion moving material south.
- In the central part of the Bay (in the vicinity of the Tropicana), there is a relatively good upper beach width with no evidence suggesting long term erosion. In fact, the historic evidence suggests that over much of the area the upper beach has grown.
- In the south the natural formation of the sand dune ridge defines the defensive line. There is strong evidence to confirm longer term growth both in height and width, historically.
- There is a general retreat of the saltmarshes at the mouth of the Axe Estuary of between 2 - 4 meters per year. However, this is not seen as being an immediate issue of concern in terms of flood defence.

Sea level rise is likely to be the main factor influencing the behaviour of the coast. With sea level rise, the typical response is for the shoreline to attempt to set back in line with increasing water levels. Typically, where such movement is constrained by hard defences the width of the upper beach reduces and there could potentially be increased exposure to wave overtopping.

In the northern part of the bay, the hard defences have been designed to a standard of 1 in 200 years which can be raised by 1m to ensure that this standard of protection of

protection can be sustained though out the schemes life should predicted climate change occur. However, there also is a possibility that beach lowering could expose or undermine the toe of the wall in the future. Without further study of overtopping in combination with the monitored response of the foreshore to sea level rise, particularly the variation in beach levels, it is not possible to define a specific future water level/foreshore trigger condition.

With regard to the sand dune, there are two possible scenarios. SLR will increase the frequency that the dunes will be subject to wave attack and will also change the focus points of the wave energy. This would cause increased erosion of the front face and the response of a natural mobile dune would be landward migration. However, an alternative view which is equally supported by existing evidence is that with SLR the whole beach area may accrete, keeping pace with SLR. In either case there it would be good management to encourage the forward development of the dune increasing its width. Monitoring is recommended to observe whether the southerly movement of sediment will be able to maintain the position of the dunes into the future.

To the western side of the Axe Estuary, existing minimum crest height of the flood embankments is around 8 mODN (at the low points). This is considered to provide protection against extreme water levels up to between 1:10yr and 1:20yr return periods. However, with between 50 - 75 years sea level rise the standard of protection afforded by the banks would be of the order of a 1:1 year event if the banks were not maintained. With potential low spot monitoring and/or improvements incorporated in to the EA asset management plan, a standard of protection of above 1 in 10 years could be maintained for a prolonged period.

On the eastern side of the embankment, there is already significant risk of flooding to the outer defence bank to the south of Uphill. With even modest rise in sea level, this bank would be expected to be overtopped more frequently than 1:1 year.

In the immediate future it is recommended that a survey is carried out at the critical locations along the embankment with a detailed survey of the entire embankment being carried out in the near future to identify the lowest section and gain a better understanding of the standard of defence.

In terms flood risk management in the Axe Estuary, increasing the crest levels of the flood embankments could maintain an acceptable standard of protection. However, the SMP considers the possibility of managed realignment in this area to mitigate SLR. The implications of the realignment are discussed in Section 7.3.

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