

Appendix D
Coastal and estuarine processes

Coastal and estuarine processes

D.1 Introduction

This stretch of coastline has been subject to a significant amount of study in recent years, with the primary studies including:

- Exe Estuary Coastal Management Study (Halcrow, 2008)
- Dawlish to Teignmouth Sea Wall Feasibility Study (Halcrow, 2009)
- South Devon and Dorset Shoreline Management Plan (Halcrow, 2010)
- Exe Estuary Flood and Coastal Erosion Risk Management Strategy (Halcrow/Atkins, 2013)
- Teign Estuary Coastal Management Study (Halcrow, 2014).

The assessment is split between discussion concerning both large scale and local scale processes which are important for the following reasons:

- Large-scale and long-term understanding is necessary to assess the sustainability of management options and to take into account any long-term trends or drivers of coastal change.
- Shorter-term and smaller-scale understanding is therefore also important because it identifies local detail and variations from the larger-scale.

D.2 Large-scale understanding

D.2.1 Interactions

Large-scale coastal process interactions can be examined in two discrete units- as described in the South Devon and Dorset Shoreline Management Plan (Halcrow, 2010)- Straight Point to Holcombe; and Holcombe to Teignmouth. The location of these units are shown in Figure D-1.

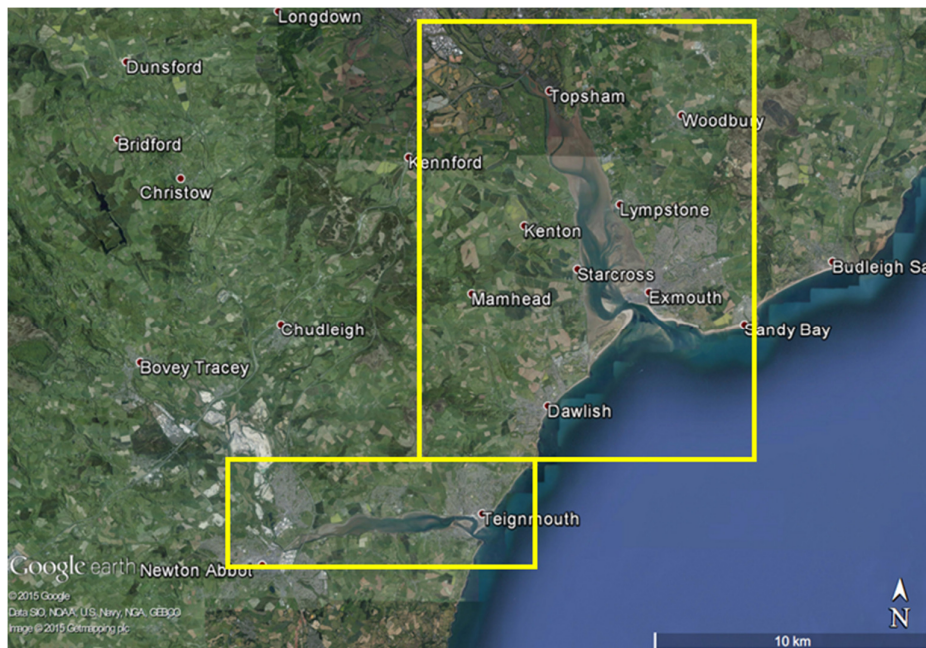


Figure D-1: Large-scale process units

D.2.1.1 Straight Point to Holcombe

The first section of coast extends from Straight Point in the east to Holcombe in the west, and includes the highly dynamic entrance to the Exe Estuary that dominates the coastal processes of this area, as well as the estuary itself. The coastal processes within this unit are summarised graphically in Figure D-2.

The evolution of this shoreline has occurred following inundation as a result of sea level rise during the Holocene marine transgression (c.10,000 years BP). The original River Exe exploited a dip in the geological beds to flow out to the sea through a wide low-lying valley that extended between Dawlish and Straight Point. At this time there would have been erosion of the flanks of the Exe valley as a result of sub-aerial processes.

During the marine transgression, channel and deltaic sediments that formed the mouth of the once wider (and further offshore) Exe Estuary, along with those released from cliff erosion to the south were swept up by the rising sea levels and transported landwards to approximately the present shoreline configuration. Fine sediments were deposited within the Exe Estuary whilst coarser sands and shingle were deposited at the entrance of the estuary, forming spits, tidal deltas and sandbanks.

Contemporary sediment supply to this area no longer occurs from the offshore source that formed the present estuary system. Any potential sediment source from cliff erosion between Dawlish Warren and Holcombe is prevented by the presence of defences along this section of coast.

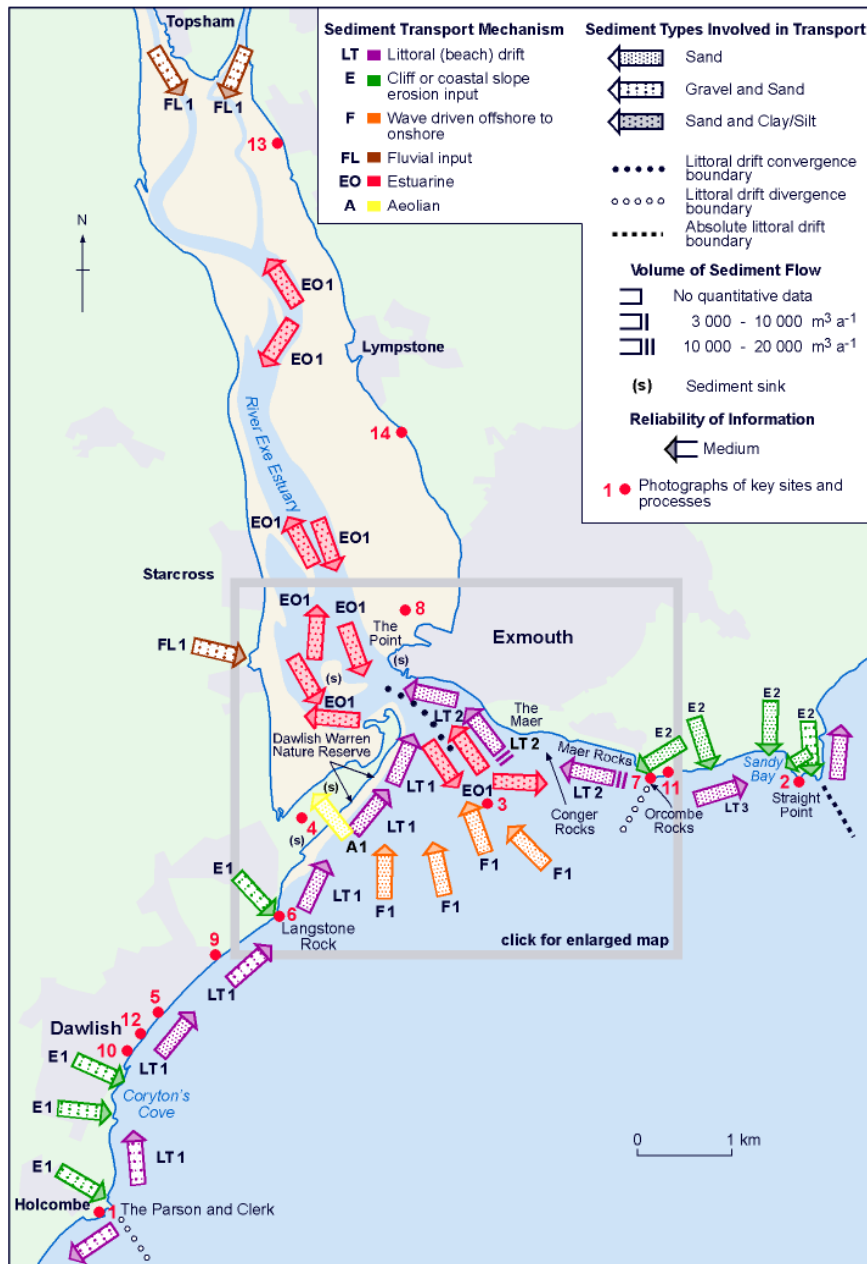


Figure D-2: Straight Point to Holcombe sediment transport (from SCOPAC, 2004)

At one time the entrance of the Exe consisted of two spits, one on either side of the mouth at Exmouth and Dawlish that oscillated in growth. Following development at Exmouth, the eastern spit is now largely fixed in position, leaving Dawlish Warren as the only active spit across the mouth of the Exe. Despite the 'entrapment' of sediment in Exmouth spit, both of these spits form part of a complex sediment transport system along with the flood (Bull Hill Bank) and ebb (Pole Sands) tidal deltas of the Exe (Halcrow, 2007). The sediment transport at the mouth of the Exe is shown in greater detail in Figures D-3 and D-4.

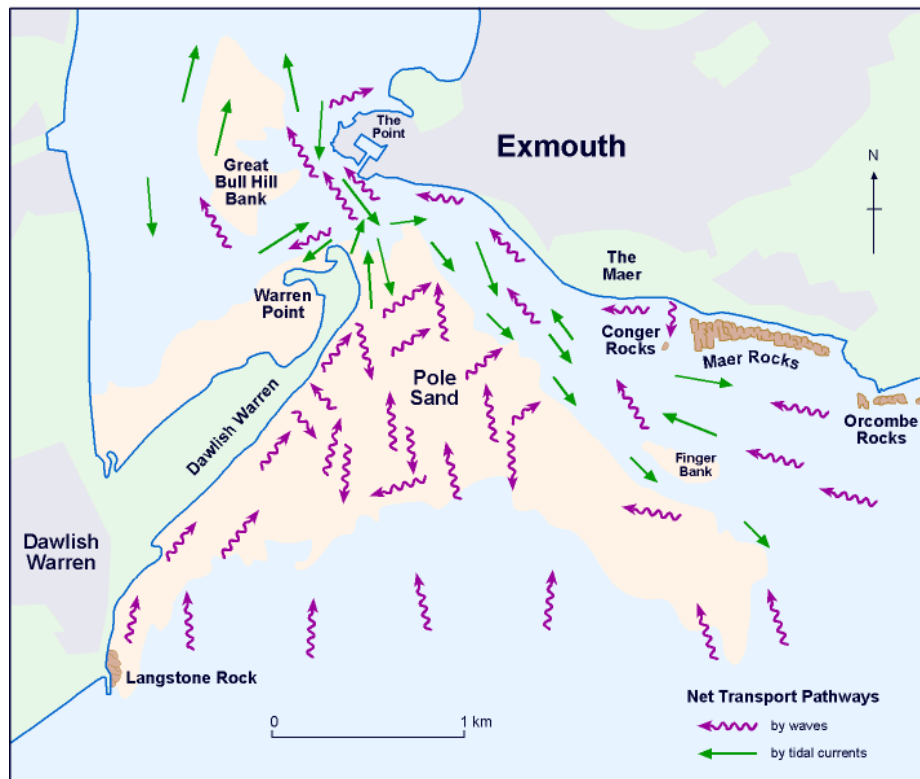


Figure D-3: Outer Estuary sediment transport vectors (from SCOPAC, 2004)

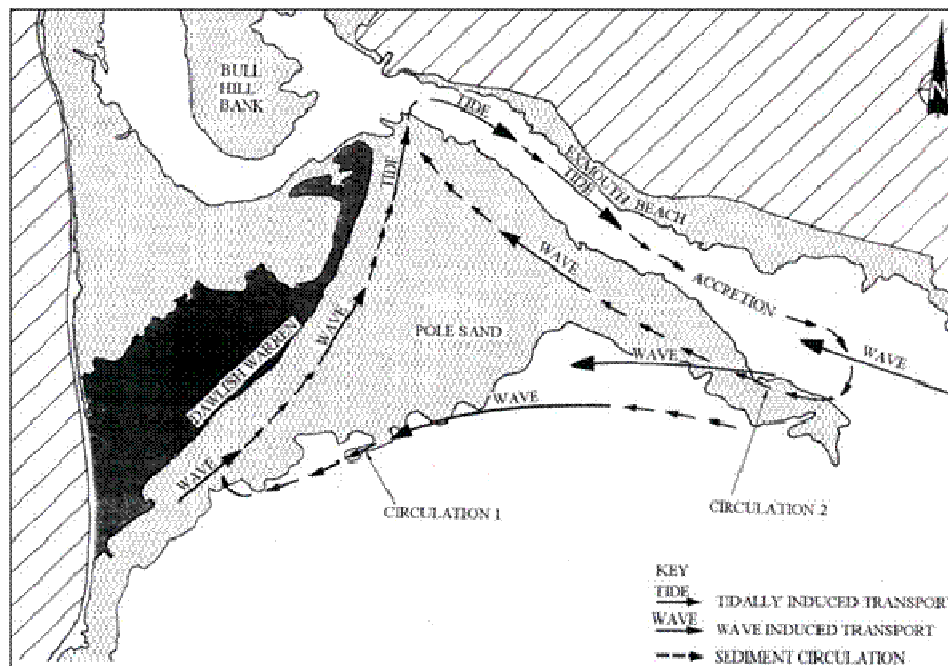


Figure D-4: Sediment circulation within Exmouth approach channel and over Pole Sand (Posford Duvivier, 1998).

Cliff recession between Dawlish and Teignmouth has led to the emergence of the Parson and Clerk headland at Holcombe due to local variations in geological resistance, and around which very little (if any) sediment transport occurs. SCOPAC (2004) states that there is no evidence of sediment bypassing

the headland at Holcombe, and postulates that this area may be a drift divide with material possibly moving offshore in this area.

Tidal currents in this area are generally weak except at the tidal inlet of the Exe Estuary, where tidal exchange drives strong currents within an ebb dominant regime. In addition, the orientation of the shoreline means it is not directly exposed to waves from the Atlantic, other than those that are diffracted around Start Point. The exposure of this section of coast to waves from the east and south-east is more significant, although the effects on the entrance to the Exe Estuary are greatly modified by the presence of Pole Sands.

Pole Sands has a significant impact upon the coastal processes of a wider area as a result, affecting wave climate and tidal flows and causing the clockwise circulation of sand at the mouth of the Exe Estuary. The circulation pattern has a significant effect upon the adjacent shorelines, leading to local reversals in littoral drift from the general south-west to north-east along the Dawlish shoreline, to an east to west transport along the Exmouth shoreline.

The ebb tidal delta of the Exe is part of a dynamic sediment transport system that also includes the spit at Dawlish Warren and the flood tide delta of Bull Hill Bank. During storm events sand and shingle is driven from Pole Sands and the beaches at Dawlish Warren and Exmouth, which can experience significant depletion in beach levels and volumes as a result of storm wave activity, into the channels at the mouth of the Exe Estuary. Following storm events, the clockwise sediment transport regime that is caused by the presence of Pole Sands, leads to the return of beach material to the shoreline, helping to restore the beaches to some extent (Halcrow, 2007).

D.2.1.2 Holcome to Hope's Nose

The second section of coast extends from Holcombe to Hope's Nose and includes the River Teign, which was once a tributary of the once wider Exe estuary system that extended much further offshore than it does at present. An overview of the coastal processes in this section are provided in Figure D-5.

The frontage between Holcombe and Teignmouth consists of cliffs that are fronted by sections of shingle beach whose sediment source is the erosion of the backing cliffs, although this process is largely prevented at the present time due to the construction of the railway line in the mid-19th century. The offshore area is generally gently sloping and featureless, except for the sedimentary features around the mouth of the Teign Estuary.

The south side of the Teign Estuary mouth is marked by The Ness at Shaldon, which is a cliffed headland (ABPmer, 2006). The section of coast that extends southwards from the Teign Estuary to Hope's Nose comprises steep cliffs that are indented by many small headlands and bays that are occupied by sandy pocket beaches. The reason for the large amount of indentation is due to the cliffs along this section of coast being comprised of a complex alternation of shales, limestones, slates and mudstones (SCOPAC, 2004) that all erode at slightly different rates.

Tidal currents in this area are generally weak except at the tidal inlet of the Teign Estuary, where tidal exchange drives strong currents within an ebb dominant regime. In addition, the eastwards orientation of the shoreline means it is not directly exposed to waves from the Atlantic, other than those that are diffracted around Start Point. The exposure of this section of coast to waves from the east and south-east is more significant.

The southern limit of this section of cliff is the headland at Hope's Nose, a hard limestone headland. Hope's Nose provides a strong geological anchoring control to the evolution of the shoreline to the north, which consists of softer, more readily eroded rocks. There is no sediment transport around Hope's Nose, nor is there any around the northern headland at Holcombe, leading SCOPAC (2004) to

suggest that this section of coast between Holcombe and Hope's Nose has a relatively independent shoreline transport and sediment budget system.

Within this system, there are variations in the direction of longshore transport. SCOPAC (2004) states that between Hope's Nose and Teignmouth, and from Sprey Point to Holcombe, net littoral drift is from south to north, while from Sprey Point southwards to the distal end of Den Spit, the drift is reversed and occurs from north to south. This reversal is associated with the complex anticlockwise circulation of sediment that occurs at the mouth of the Teign Estuary that is driven by a combination of wave and tide processes.

The indented nature of the shoreline from the Teign Estuary to Hope's Nose means there is no continuous sediment pathway and so material eroded from the cliffs is retained in the local pocket beaches.

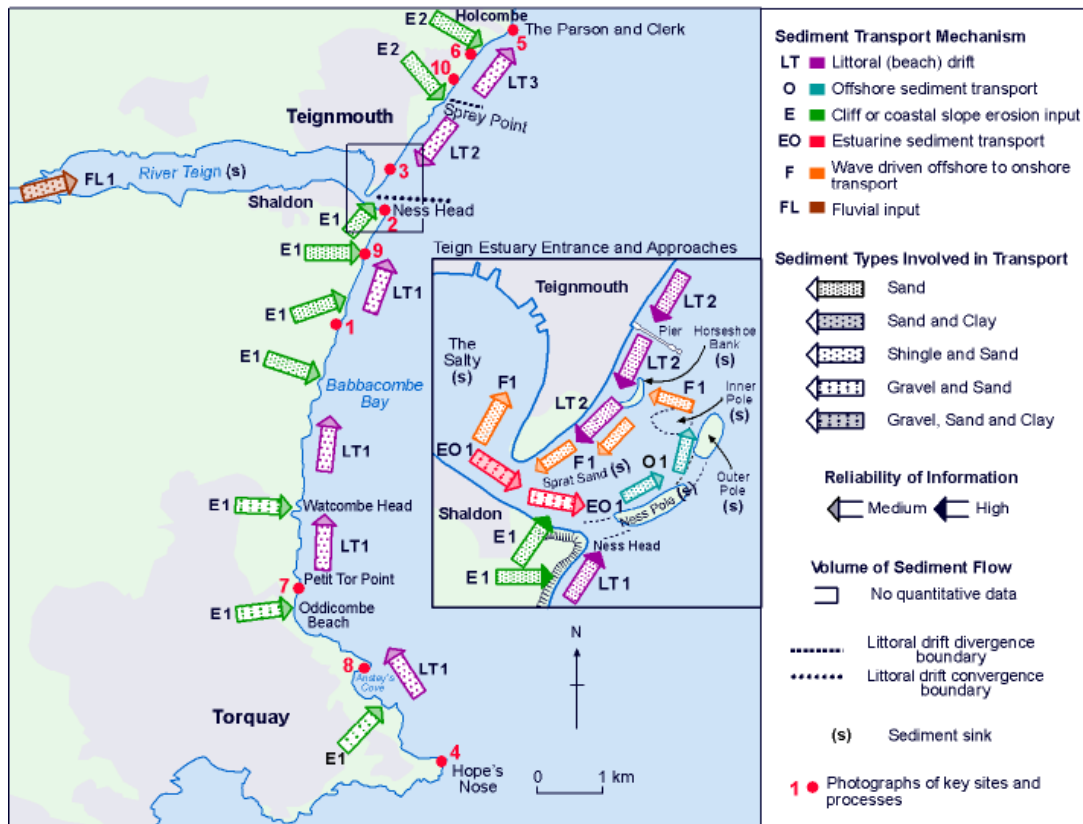


Figure D-5: Holcombe to Hope's Nose (including the Teign Estuary) sediment transport (from SCOPAC, 2004)

D.2.2 Movement

The cliffs along this section of coast consist of hard rock types such as limestones, which erode very slowly. Very little cliff recession has occurred over the past century in most areas.

Analysis of the historic beach trends presented in Halcrow (2007) shows that the distal end of Dawlish Warren is accreting whilst the beaches along Exmouth are eroding.

Erosion of the backing cliffs has largely been prevented since the construction of the railway line in the mid-19th century. The presence of the sea wall has also led to the gradual narrowing of the beach along the northern part of this section between north Teignmouth and Holcombe.

Beach levels at Teignmouth fluctuate in response to the complex cyclical sediment transport system that operates at the mouth of the Teign Estuary.

D.2.3 Modifications

The majority of this section of coast has been affected by human intervention. The most notable of which was the construction of the Exeter to Plymouth mainline railway in 1846 which runs along the west side of the Exe Estuary, the cliff toe between Dawlish Warren and Teignmouth and the north side of the Teign Estuary. Along much of its length the railway is protected by sea walls and other defences, although in places the railway cuts through headlands via a series of tunnels. The railway artificially holds the shoreline in its present position and prevents the input of sediment from the cliffs.

The sea wall (along the open coast) was constructed on the upper part of the beach, causing the impoundment of the upper beach sediment and 'removing' it from the coastal sediment system. The construction of the sea wall, along with other groynes and breakwaters that have been built to retain beaches in front of the sea wall, prevent cliff erosion from supplying new inputs of sediment to the shoreline. The defences also interrupt the longshore sediment transport pathway which causes a reduction in beach volume of the beaches fronting the sea wall (which are also affected by beach scour) as well as the spits and banks at the mouth of the Exe Estuary.

A series of groynes have been constructed along the Teignmouth frontage to retain beach levels in front of the sea wall in order to reduce the risk of undermining of the sea wall.

In addition to the railway, other significant human interventions along this shoreline are as follows:

- The eastwards trending Exmouth spit at the mouth of the Exe Estuary has been largely impounded by the development of the town of Exmouth, with coastal defences such as sea walls having been constructed around it to protect the town. This has effectively removed the sediment that forms the spit from otherwise contributing to the complex circulation of sediment at the mouth of the Exe Estuary.
- The navigation channel at the entrance to the Exe Estuary was maintained by periodic dredging (SCOPAC, 2004), but this presently does not occur.
- At Dawlish Warren, the proximal end of the spit, where it connects to the land, has been stabilised by the construction of groynes and gabion mattresses (SCOPAC, 2004).
- In 1917 a breakwater was constructed at Langstone Rock, at the western end of Dawlish Warren spit. This has led to a realignment of the spit to its present position approximately 400 m back from the cliff line to the south-west of Langstone Rock (Halcrow, 2007).
- As a result of the development of the town of Teignmouth, the sediments that form Den Spit are now largely impounded except for at the most distal end.
- Almost daily plough dredging of the Teign approach channel occurs to maintain a navigable channel into the port of Teignmouth which is located inside the estuary. The port itself contains a number of quay walls that have been constructed along the section of estuary shoreline that forms part of the Teignmouth Port estate (ABPmer, 2006).

D.3 Local -scale understanding: Exe Estuary

D.3.1 Interactions

The full extent of the Exe Estuary is shown in Figure D-6. The outer estuary includes the spits of Dawlish Warren and Exmouth (between Langstone Rock and Orcombe Rocks), as well as sandbanks, the ebb (Pole Sands) and flood (Bull Hill Bank) deltas and the estuary mouth (refer to Figures D-3 and D-4). The historic evolution of the outer estuary (comprising Dawlish Warren and Exmouth spits, the approach channel and related sandbanks and deltas) has been a topic of significant previous study, most recently in Halcrow (2008 and 2010).

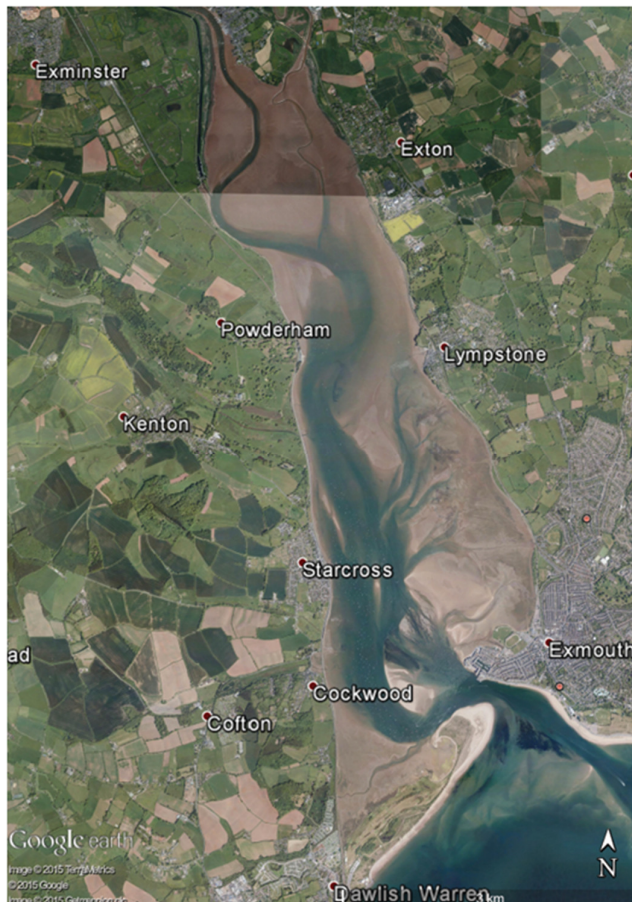


Figure D-6: Exe Estuary

Dawlish Warren and Exmouth spits have had a long history of anthropogenic influence. Dawlish Warren was increasingly managed from the early 1900s onwards. Exmouth spit was ‘reclaimed’ in the early 1800s, with the spit now rendered effectively inactive, with the town of Exmouth located on it, protected by hard defences.

Dawlish Warren is a sand spit on the western side of the Exe Estuary entrance that is about 500 m wide along much of its length at present, although it narrows towards its distal end. It is largely unique within the region as most other bars and spits are comprised of shingle and not sand. The evolution of Dawlish Warren has been complex. There were once two spit features here, the inner and outer warren, separated by Greenland Lake. It is thought that erosion of the seaward face of the outer warren supplied sediment for the development of the inner warren. This double feature is no longer present as Greenland Lake was filled in during the 1940’s (Halcrow, 2007).

Over the longer term, Dawlish Warren spit has undergone recession and re-orientation, particularly since the construction of the breakwater at Langstone Rock which has also prevented the supply of sediment to the spit from the shoreline to the south-west. This process occurs as a result of the retreat of the seaward face of the spit, with periodic breaching and destruction of the distal end (during south-easterly storms) of the spit followed by recovery and growth (Halcrow, 2002). The current trend at Dawlish Warren is accretion of the re-curved distal end of the spit whilst the rate of retreat of the seaward face of the Warren, towards the proximal end, is increasing (Halcrow, 2007). Figure C-7 shows the way in which the Warren and other features at the mouth of the Exe Estuary have evolved since the 1850s.

The beach at Exmouth is what remains of the former active second spit that was part of the double spit system at the mouth of the Exe Estuary. The beach oscillates in size and position with the Dawlish Warren spit, but is now largely removed from this system by the impoundment of the spit that has occurred as a result of the development of the town of Exmouth. The contemporary evolution of these once linked features appears to now be unrelated, with the Exmouth frontage relatively stable in comparison to the highly variable Dawlish Warren spit.

Both Dawlish Warren spit and Exmouth Beach are part of the wider complex sediment transport system at the mouth of the Exe Estuary. Dynamic sediment exchange occurs between the spit and beach with the flood and ebb tidal deltas, which presently act as sediment sinks in this regime. Accretion has occurred at both Bull Hill Bank and Pole Sands over the past century. In addition to the sandy beaches, the shorelines of both Dawlish Warren and Exmouth (extending to Maer Rocks) also have dune systems developed along them.

The inner estuary extends from Cockwood and the northern section of Exmouth, up to the tidal limits of the rivers Exe and Clyst. The inner estuary includes saltmarsh and mudflats, as well as sub-tidal estuarine channels.

The intertidal mudflats have accumulated as a result of the low energy environment that occurs within the estuary as a result of the shelter from wave action that is provided by the spit at Dawlish Warren (Halcrow, 2002). At the present time, marine sediments dominate within the Exe Estuary as human intervention upstream within the River Exe catchment has reduced the ability of fluvial sediments to reach the estuary. Fluvial sediment inputs at present are considered negligible (SCOPAC, 2004). The Exe Estuary is in a state of sedimentary equilibrium despite large areas of the estuary having been reclaimed and its present form being constrained by human activities. It also remains a strong sink for fine sediment with continued deposition occurring on most mudflats (Halcrow, 2002). This is evidenced by the fact that the relative positions of the main channels have hardly changed over the past 130 years, suggesting that deposition is slowly raising mudflat elevation. Most of this input of fine sediment is via suspension transport by tidal currents, though internally generated wind waves may have an independent role in entraining sediment in shallow water areas (SCOPAC, 2004).

The linearity and length of the estuary between the mouth and Topsham is sufficient to allow the development of wind-driven waves to occur when the wind direction is from certain directions. The development of waves within the estuary is also highly dependent upon the water level, with waves being largely depth limited over the large expanses of intertidal mudflats. Analysis undertaken for the Exe Estuary Coastal Management Study (Halcrow, 2007) included calculation of wind-driven waves within the estuary given extreme wind and water level conditions. This suggests that given the right extreme conditions, waves within the estuary of between 0.5 and 0.6 m could develop.

Transport along both Exmouth and Dawlish Warren beaches is largely driven by wave action, particularly during storm events, which Futurecoast (Halcrow, 2002) suggests may cause 20% of the total annual wave-driven transport during a single storm event.

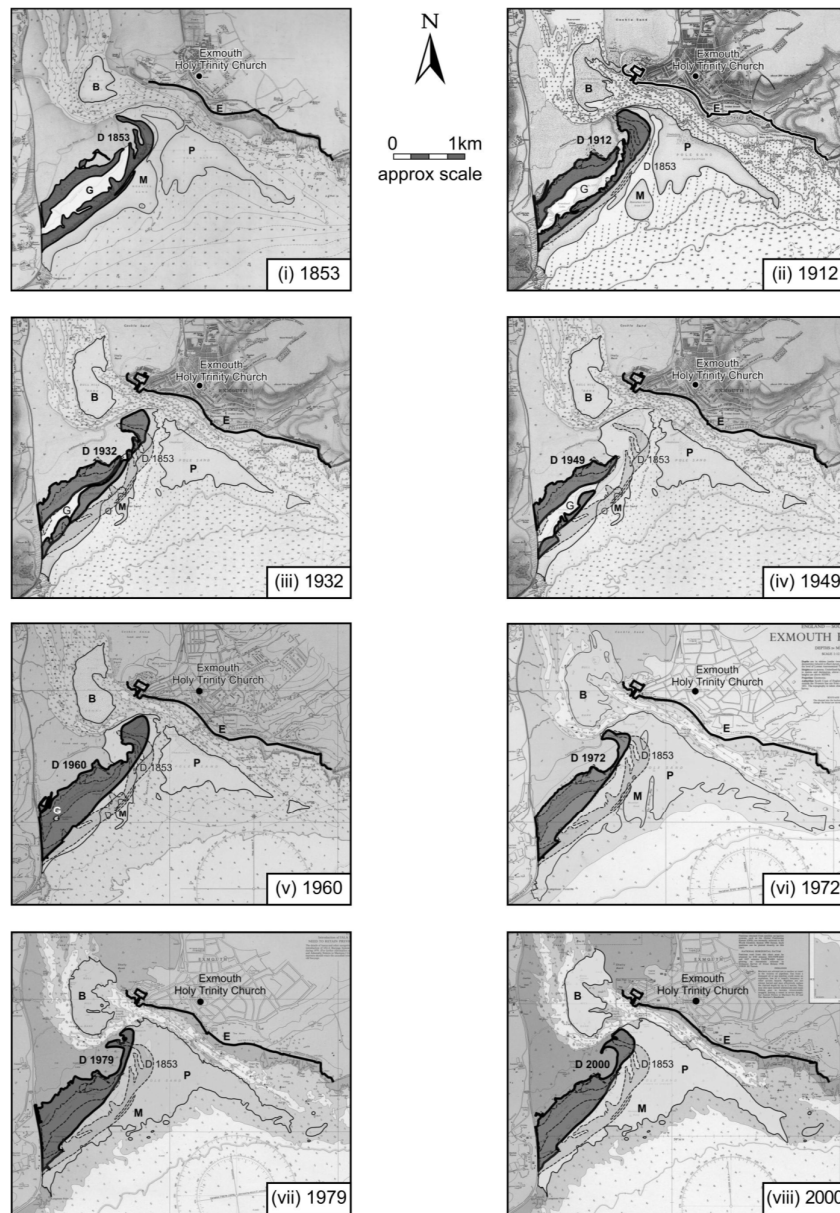


Figure D-7: Admiralty charts 1853 to 2000 (UKHO Copyright Licence 10992) (from Halcrow, 2008)

B – Bull Hill, D – Dawlish Warren, E – Exmouth Beach, G – Greenland Lake, M – Monster Bank, P – Pole Sand

D.3.2 Movement

The movement of the shoreline in this area is greatly affected by the complex sediment circulation caused by the presence of Pole Sands at the mouth of the Exe Estuary. Along the Exmouth frontage there is a westward transport of sediment due to the clockwise circulation, with material transported towards the estuary from Orcombe Rocks. The longshore transport at Dawlish Warren is from south-west to north-east, also moving sediment towards the estuary.

There has been no recorded retreat in position of the backshore at Exmouth, due to the presence of defences that prevent the natural adjustment of the beaches to storm events. However, beach volumes here have reduced over the recent past (Halcrow, 2007c). In contrast, the Dawlish Warren spit has been able to retreat and re-align over the decades and is presently about 400 m behind the line of the cliffs where the spit once extended linearly from Langstone Rock. There have also been changes in the plan form of the spit.

The consensus of opinion is that the coastlines either side of the spits both act as an input of sediment to the outer estuary (SCOPAC, 2003; Halcrow, 2008 and 2010). Posford Duviver (1998) reported that the net potential drift from Orcombe Point westwards is 15,000 m³/yr, reducing to 4,500 m³/yr near the Maer.

Similarly, the eastward gross potential drift from Langstone Rock is estimated as 8,400 m³/yr reducing to 1,100 m³/yr at the distal end of Dawlish Warren (Posford Duvivier, 1998). Beach profile analysis within the Exe Estuary Strategy (Halcrow/Atkins, 2013) noted that the distal end accreted between 1998 and 2010 whilst the proximal and central section generally eroded: this tends to support the reducing drift rates. It is suggested (SCOPAC, 2003) and supported by Halcrow (2008 and 2010), that there is no direct supply of sediment from Dawlish Warren to Exmouth, although the complex sediment pathways via the sandbanks and deltas provide an indirect route. Input of sediment from the inner estuary is not considered to be significant in the present day.

Dredging around the estuary mouth has previously been quantified as removing 500 m³/yr between 1961-1986, with further intermittent removal of 40,000 m³ in both 1986 and 1996, although the disposal site for these dredging operations is not known. This represents a total removal of nearly 100,000 m³ to the present day. In contrast to this, Laming and Weir (1992) estimated that around 156,000 m³ was deposited in the estuary mouth between 1986 and 1992.

Pole Sands, whilst remaining constant in size historically is estimated to have increased in volume by around 1,800,000 m³ since 1840, which gives a broad average of 10,000 m³/yr. There is disagreement whether Pole Sands receives sediment from further offshore, or whether it is a finite resource, although the consensus appears to be moving towards the latter (as noted in SCOPAC, 2004).

Previous studies, notably SCOPAC (2004) and Halcrow (2008), have described the conceptual understanding of sediment transport around Dawlish Warren, Pole Sands, the estuary mouth, Bull Hill Bank and Exmouth. It is considered (SCOPAC, 2003; Posford Duvivier, 1998; Halcrow, 2008) that there are two main systems of sediment transport. The first is wave net onshore (and longshore) movement from Pole Sands to Dawlish Warren, and the second is dominant ebb tidal transport south-east along the estuary mouth to sandbanks flanking the Maer channel. It is also suggested (SCOPAC, 2003) that sediment can be transported from the distal end of Dawlish Warren to Bull Hill Bank under flood tides, and then passed back to Pole Sands on ebb tides.

For sands and gravel the inner estuary is considered a temporary store (SCOPAC, 2003), whereas for muddy sediment it is considered a sink, supported by qualitative observations that the Exe Estuary mudflats have accreted slowly over time. SCOPAC (2004) states that the River Exe is the main source of fluvial sediment into the inner estuary. This is estimated as 1,900 m³/yr of fine sediment, which is stored in the inner estuary intertidal area. The Rivers Kenn and Clyst are also noted as potential smaller sources of sediment, but not quantified. Erosion of the estuary banks, although not quantified, is presumably negligible as an input due to the presence of the railway line and flood defences. In contrast to this, it is suggested (SCOPAC, 2003) that 1,000 m³/yr (predominantly sand) is moved from the outer estuary (specifically Bull Hill Bank) to the inner estuary. Whilst this represents a net continuous gain to the inner estuary, it is also noted that non-storm tidal input to the inner estuary is in balance i.e. any net gain comes from storm events. If the net gain is considered to spread across the inner estuary planform, this would on average represent 0.2 mm/yr of vertical accretion; if continued over the next 100 years this would amount to 20 mm. However, it is recognised that particular locations, such as Bull Hill Bank, are a focus for accretionary processes, rather than the general estuary.

D.3.3 Existing predictions of shoreline evolution

For an 'unconstrained' scenario, Futurecoast (Halcrow, 2002) predicted that cliff erosion to the south-west of Dawlish Warren would increase as a result of the removal of the present defences and this would increase the supply of sediment to the shoreline. This increased sediment supply would drift

north-east towards Dawlish Warren and reduce, or even reverse, the present erosion at Dawlish Warren as well as providing new sediment to the ebb and flood tidal deltas. Interception of material by Langstone Rock could cause a delay between the release of sediment from cliff erosion and material actually reaching Dawlish Warren.

The removal of defences at the proximal end of the spit would assist natural ability of Dawlish Warren to roll-back in response to future sea level rise. An increase in the occurrence of temporary breaches of the spit could also be experienced as roll-back occurs. The breaches could become permanent if there is insufficient sediment to allow the breach to be re-sealed by longshore transport processes.

A similar situation would occur at Exmouth spit, where roll-back and breaching in response to future sea level rise would occur. However, sediment supplied from both cliff erosion to the east and the tidal deltas of the Exe Estuary would result in the breaches in the Exmouth spit being re-sealed.

The Futurecoast (Halcrow, 2002) prediction for a 'with present management' scenario is for there to be continued erosion and narrowing of the spit and beaches of this section of coast. The impoundment of Exmouth spit would also prevent the shoreline from adjusting to future sea level rise and storm events, leading to an increased likelihood that the defences along the Exmouth frontage would fail and breach in the future.

At Dawlish Warren it is probable that a breach towards the distal end of the spit would occur, exposing the Exe Estuary behind to increased wave attack. The continued defence of the proximal end could limit the degree of such exposure by helping to retain part of the spit.

The Exe Estuary Strategy (Halcrow/Atkins, 2013) reiterated that the future evolution of Dawlish Warren is a key issue for the wider estuary, as there is evidence it controls flood risk (i.e. extreme waves and water levels) in the inner estuary (HR Wallingford, 1965, and anecdotal records from storms in December 1945). Exmouth spit is now inactive and built-up, whilst Dawlish Warren is held in place by defences, except along its distal end, where defences are now buried by sand. The future evolution of Dawlish Warren is dependent on future changes in hydrodynamic climate, sediment supply and management of the existing defences between Langstone Rock and the distal end. Previous work by Halcrow (2008) state that in the short term (to 2030), extreme events could cause a temporary breach in Dawlish Warren (most likely at the neck or where other breach events occurred such as in 1962), and that continuation of historical trends would result in the coastal frontage of Dawlish Warren rotating anti-clockwise (in-estuary at the distal end). Between 2030 and 2060, if the complete deterioration of existing defences is allowed, it is highlighted that the anti-clockwise rotation would continue, hinged at the proximal end. By 2110, Dawlish Warren would continue this rotation, and may also partially breakdown to sand shoals or banks. These banks could still coalesce into a more coherent form into the future. However, it should be noted that predictions in the medium to long term have greater uncertainty attached to them.

Over the last 40 years, sea levels on the UK south coast have risen on average around 2 mm/yr (UK Permanent Service for Mean Sea Level). Current understanding of the estuarine system suggests that marginal accretion of the inner is occurring and would potentially continue into the future.

D.4 Local-scale understanding: Langstone Rock to Holcombe

D.4.1 Interactions

Covering the area between the isolated cliff headland at Langstone Rock and The Parson and Clerk headland at Holcombe, this section of coast consists of cliffs fronted by shingle beaches (refer to Figure D-8). From Langstone Rock to Dawlish there is one continuous mixed sand-shingle beach, after which

the shoreline is interrupted by the presence of a number of small headlands which contain small pocket beaches between them.

The key features are (moving from east to west):

- Langstone Rock
- Dawlish Beach
- Old Maid Rock
- Coryton's Cove
- Horse Rocks
- Holcombe Beach and Shell Cove
- Parson and Clerk Headland

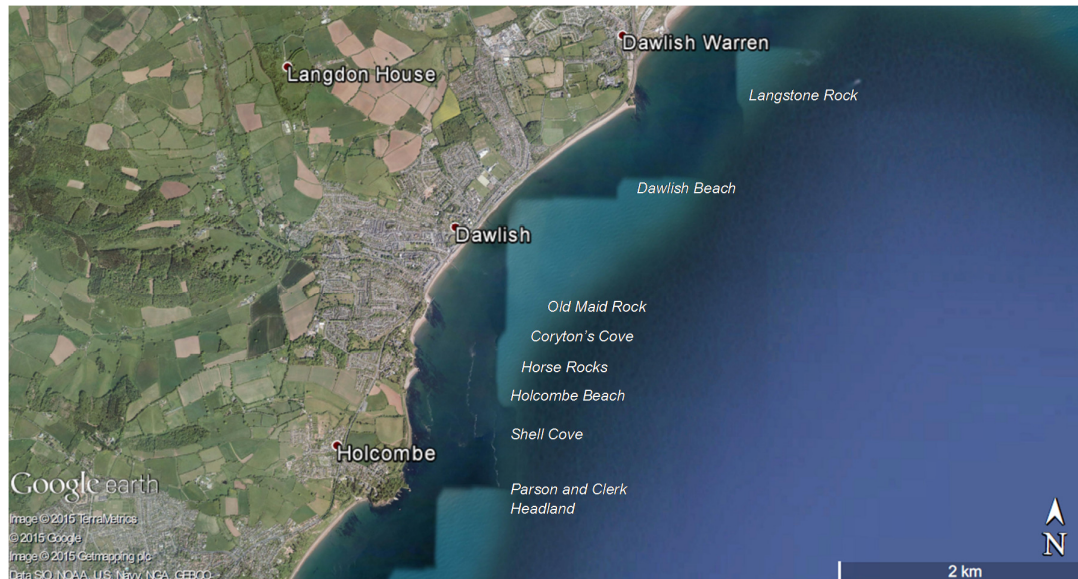


Figure D-8: Langstone Rock to Holcombe

Beach sediment along this section of coast was historically transported north-eastwards towards the mouth of the Exe Estuary, however this has largely ceased as a result of the construction of groynes and breakwaters along the shoreline that inhibit these longshore processes.

The only contemporary source of sediment input to the shoreline is from local cliff erosion, as there is no input of sediment around the headland at Holcombe from the beaches to the south-west.

D.4.2 Movement

The open coast between Holcombe and Langstone Rock has been heavily influenced by anthropogenic activities. The mainline railway was constructed in 1846, which has removed the impact of wave erosion for the majority of the coastline.

The sea wall that protects the railway line prevents erosion of the cliff and has impounded the upper beach sediments upon which it was constructed. The presence of the defences associated with the railway, has resulted in the gradual narrowing of the beach in front of the sea wall due to the effects of beach scouring by wave action. This narrowing occurs along the long section of beach between Langstone Rock and Dawlish. The small pocket beaches between the minor headlands from Dawlish to Holcombe are more stable.

Cliff erosion only occurs where the railway line runs through tunnels cut through the headlands (i.e. where there are no cliff defences); SCOPAC (2004) suggests that along this section of coast the mean annual rate of recession is about 0.5 m/year.

The construction of the railway line has prevented the erosion of the cliffs by the effects of wave action at the cliff toe, these cliffs are not completely stable and are subject to landsliding caused by weathering and high groundwater levels.

The main source of sediment supply between Holcombe and Langstone Rock is from erosion of the adjacent cliffs. However this mechanism is now predominantly inactive due to the railway construction (SCOPAC, 2003), as the railway runs along the cliff toe between Dawlish Warren and Teignmouth. The railway artificially holds the shoreline in its present position and prevents the potential input of sediment from wave action at the cliffs. For the limited lengths of cliff which are still active, Posford Duvivier (1998) indicates a recession rate of 0.5 m/yr, corroborated by Halcrow (2010). As the active cliff length is now much less than 1km, the amount of sediment supplied by this mechanism will be minimal (of the order of 1,000 m³/yr) and centred around Shell Cove and Coryton's Cove.

There is no known semi-permanent store of sediment, although it is noted (Posford Duvivier, 1998) that there is significant cross-shore exchange under summer and winter wave conditions. Whilst Langstone Rock is noted as a barrier to longshore sediment transport, under more extreme wave conditions it is thought that sediment can bypass the feature (SCOPAC, 2003).

Current understanding is that the net direction of littoral drift is south-west to north-east, with hindcast wave modelling (Posford Duvivier, 1998) indicating that drift potential is between 68,000 m³/yr (Holcombe) and 13,000 m³/yr (Langstone Rock), assuming there is no limit on available sediment. SCOPAC (2004) noted that actual transport would be much lower than this, as suggested by the above estimate of 1,000 m³/yr.

D.4.3 Existing predictions of shoreline evolution

For an 'unconstrained' scenario, Futurecoast (Halcrow, 2002) predicted that cliff erosion would be renewed, supplying sediment to the shoreline that could then be transported north-eastwards towards the Exe Estuary. This increased sediment supply would also allow the beaches along this section of coast to recover and respond to future sea level rise by retreating landwards at a rate controlled by the rate of cliff recession.

The Futurecoast (Halcrow, 2002) prediction for a 'with present management' scenario is for there to be a continued reduction in the beach fronting the sea wall and other defences along this section of coast, gradually increasing the risk of the defences failing in the future. There would also be a continued risk of landslides caused by sub-aerial processes as occurs at present.

The Exe Estuary Strategy (Halcrow/Atkins, 2013) noted that future potential change is very dependent on future management of the railway and of Langstone Groyne. Beach erosion will continue, and the difference in drift potential and available sediment would suggest that if Langstone Groyne was damaged or removed, significantly accelerated beach erosion could occur. Sea level rise and increased storminess is likely to result in either unnaturally steepened beach slopes, or beach lowering, particularly in the medium to long term.

D.5 Local-scale understanding: Holcombe to Teignmouth

D.5.1 Interactions

This section of coast extends from the headland at Holcombe to the northern end of Den Spit at Teignmouth. It consists of cliffs that have been stabilised by the construction of the railway line and

associated defences, and is fronted by several stretches of shingle beach. The extent of the section is shown in Figure D-9.

Wave driven longshore sediment transport occurs in both a northward and southward direction along this section of coast, with a drift divide at Sprey Point. There is no evidence of sediment transport around the headland at Holcombe, and material that drifts northwards towards this location from Sprey Point may actually be transported offshore from Holcombe (SCOPAC, 2004).

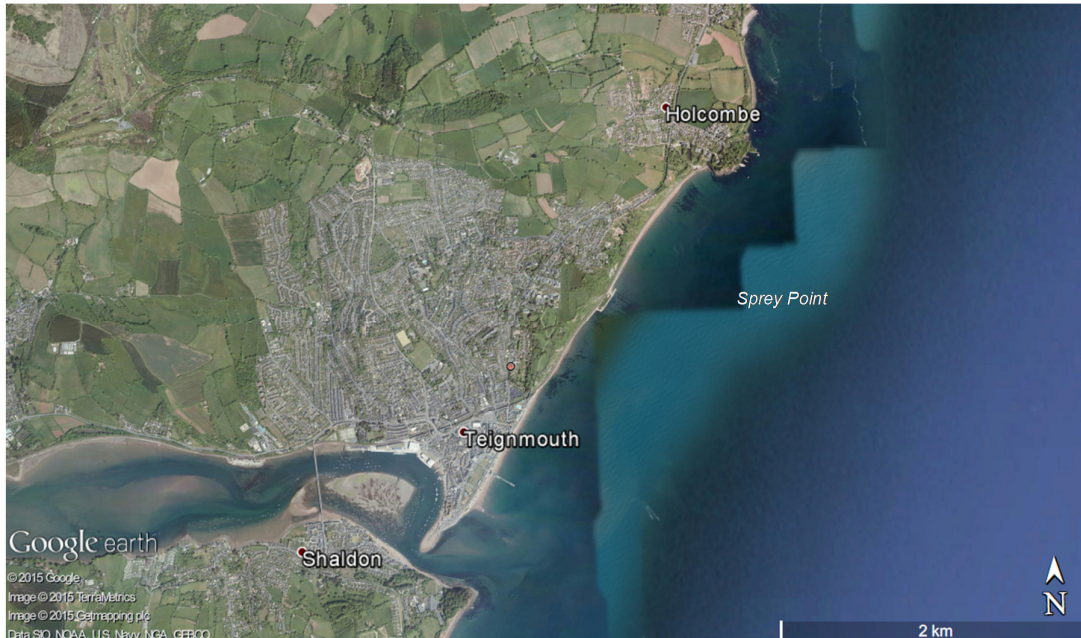


Figure D-9: Holcombe to Teignmouth

D.5.2 Movement

The stabilisation of the cliff by the construction of the sea wall and railway along the cliff toe has resulted in very little if any cliff recession since the mid-19th century. Despite the stabilisation of the cliffs by the reduction of wave action at the toe, the cliffs are still susceptible to landsliding due to weathering and high groundwater levels.

The presence of the sea wall has led to the gradual narrowing of the beach width as sediment is not replaced along the shoreline by the erosion of the cliffs as would have occurred historically.

D.5.3 Existing predictions of shoreline evolution

For an 'unconstrained' scenario, Futurecoast (Halcrow, 2002) predicted that cliff erosion would be renewed, supplying sediment to the shoreline that could then be transported along the shoreline by littoral drift processes. This increased sediment supply would also allow the beaches along this section of coast to recover and respond to future sea level rise by retreating landwards at a rate controlled by the rate of cliff recession.

The Futurecoast (Halcrow, 2002) prediction for a 'with present management' scenario is for there to be a continued reduction in the beach fronting the sea wall and other defences along this section of coast, gradually increasing the risk of the defences failing in the future. There would also be a continued risk of landslides caused by sub-aerial processes as occurs at present.

D.6 Local-scale understanding: Teign Estuary

D.6.1 Interactions

This section of coast extends from the northern end of Den Spit at Teignmouth, across the mouth of the Teign Estuary where the River Teign discharges to the sea, to The Ness headland at Shaldon on the south side of the Teign Estuary mouth. Also present on the south side of the entrance is Shaldon Beach. This section is shown in Figure D-10.



Figure D-10: Teign Estuary

Den Spit is a sand spit that extends across the mouth of the Teign Estuary from the northern shoreline and serves to both shelter the estuary from exposure to wave action and to divert the channel of the Teign towards the south, constricting its flow through the mouth between the end of the spit and the headland on its southern side. The spit has been largely impounded by the development of the town of Teignmouth, and is fringed by a sand beach. The southern tip of Den Spit is, however, unprotected and extends into the mouth of the estuary where it exhibits large changes in form over short time-scales (ABPmer, 2006).

In addition to the spit across the mouth of the estuary, there is also a very mobile ebb tidal delta seaward of the mouth that is in a cyclic sediment transport relationship with nearshore sand bars and the beach to the north of the mouth up to Sprey Point (SCOPAC, 2004). This cyclical sediment transport occurs with a periodicity of between 3 and 7 years and involves the growth and recession of the spit, ebb tidal delta, and beach. This latter relationship between the cyclical sediment transport pattern and the beach fronting Teignmouth between Sprey Point and Den Spit is also (in part) responsible for the fluctuation of beach levels along this part of the shoreline (Halcrow, 2002).

The presence of this complex sediment transport regime at the mouth of the Teign Estuary is due to the effect of tide and waves and forms an interruption to net northwards drift of material derived from the erosion of cliffs to the south of the estuary. Despite this, the overall impact of this system upon coastal processes remains relatively localised to the area from Sprey Point to The Ness.

Within the estuary there is a well-defined pattern of sediment sorting over the intertidal flats, from coarse sand and fine shingle near the entrance to finer silt and clay towards the head of the estuary.

The coarser material at the mouth of the estuary is contained in a well-defined sand and shingle bank known as The Salty as well as a number of minor sandbanks that occur immediately upstream of the entrance. The Salty is most likely a flood tide delta that owes its form to the clockwise tidal circulation inside the estuary mouth (SCOPAC, 2004).

The Teign Estuary itself has evolved from a ria-type estuary and retains many of the ria-type characteristics, being fairly linear in form with steep hills on either side (Halcrow, 2002). However, this original form has been largely infilled with sediment over the Holocene (ABPmer, 2006). A process that has been accelerated by the growth of Den Spit across the mouth that has provided more sheltered conditions allowing settling of sediment to occur (SCOPAC, 2004). Over recent times the estuary has eroded, providing sediment back to the wider local sediment system in response to a combination of sea level rise and long-term natural tidal variations (ABPmer, 2006).

ABPmer (2002) suggests that there are two superimposed regimes at work within the Teign Estuary. The outer estuary (up to about 2km landwards from the mouth) is approximately linear and may be dominated by the presence of Den Spit across the mouth that imposes a geomorphological constraint, whilst the inner estuary tends towards a more idealised estuary form.

Despite the limited fetch and shallow depth of the estuary, the linearity of the estuary allows small wind-driven waves to develop when the wind speed and directions are conducive to this. Under ideal storm conditions, a westerly gale at high water, waves of between 0.6 to 1.0 m can form (ABPmer, 2006).

D.6.2 Movement

The stabilisation of the cliff to the north of Den Spit by the construction of the sea wall and railway along the cliff toe has resulted in very little if any cliff recession since the mid-19th century. Despite the stabilisation of the cliffs by the reduction of wave action at the toe, the cliffs are still susceptible to landsliding due to weathering and high groundwater levels.

Limited analysis carried out by ABPmer (2007) suggests that Shaldon Beach on the south side of the entrance to the Teign estuary has remained relatively stable between 1998 and 2006, although erosion was observed between 2005 and 2006.

At the mouth of the Teign Estuary (seaward), it is well documented that a cyclical sediment transport relationship occurs between the nearshore sand bars and the beach to the north of the mouth up to Sprey Point. This is summarised by ABPmer (ABPmer, 2002):

- Captain Sprat initially studied the dynamic nature of these features in 1856 (Sprat, 1856) identifying cyclic movements in their positions.
- Further studies in the 1970s, such as Robinson (1975; see Figure C-11), monitored the movements and suggested that the sandbanks follow a distinct cyclic pattern with a period of approximately 5 – 7 years.
- More recently, video observations made within the CoastView Project (2001) (described in more detail below) indicate that this cycle may even take less than 2 years (12-18 months) (Medina et al., 2007).

This cyclical movement of material occurs when sediment is transported between the sandbanks in the mouth of the estuary. CoastView (2001) summarises the findings of Robinson (1975) who proposed the linkages described below and shown in Figure D-11 below:

- Stage I: A projected spit or more usually a bar known as the Ness Pole takes a north-easterly route seawards.

- Stage II: Development of the offshore banks, including the inner and outer poles, which are created as a result of the disintegration of the Ness Pole or independently from a supply of sediment brought down the ebb channel from the harbours mouth.
- Stage III: The final stage occurs when these banks move onshore and a build-up of sediment takes place on the Denn beach (the seaward facing beach on The Point. This sediment ultimately travels south-westwards towards Denn Point (located on the distal end of The Point) where it contributes to the accretion of Sprat Sand.

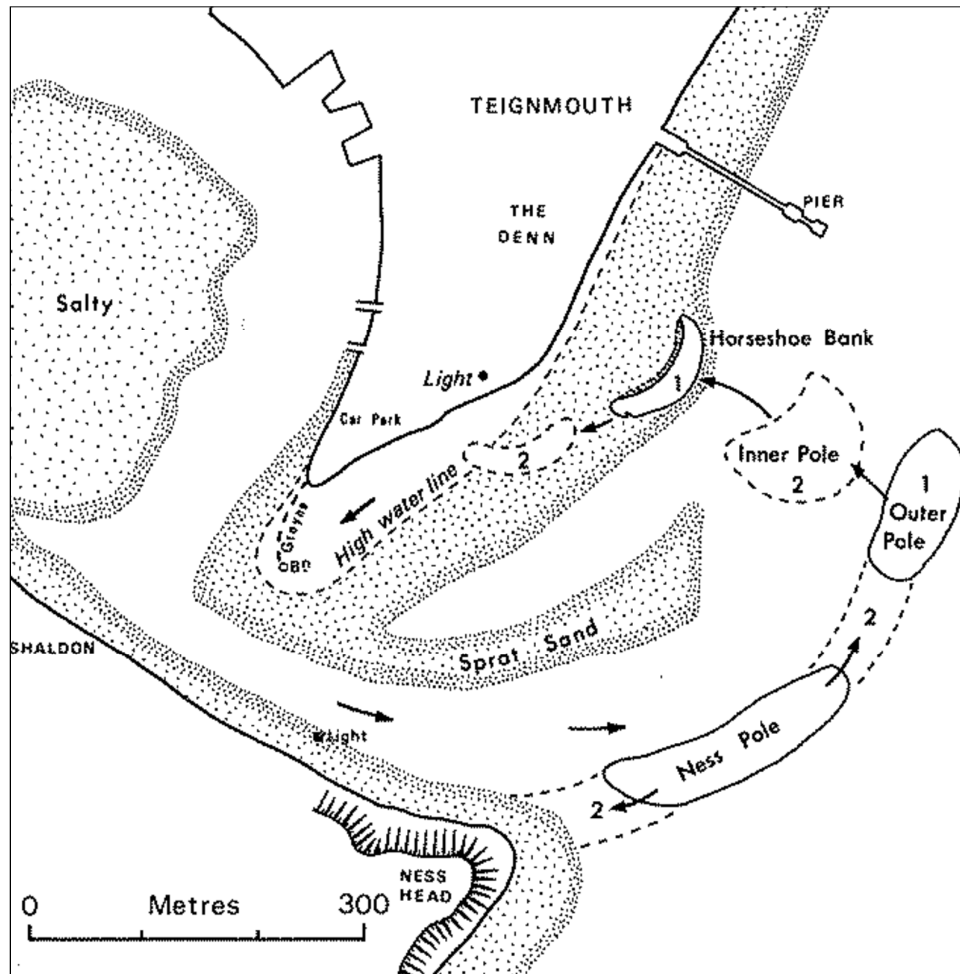


Figure D-11: Diagrammatic representation of movement of sediment in the estuary mouth (Robinson, 1975).

More recently, analysis of a 6-year time-series of video images of the mouth of Teign Estuary was undertaken for the CoastView Project (2001). The results of the project show that sediment transport in the estuary mouth is dominated by the movements of four sand bodies (Jiminez et al., 2007). These are shown diagrammatically in Figure D-12 and listed below:

- Ness Pole – an offshore ‘ebb-shoal sandbank’, which periodically migrates towards the Ness headland especially during storms.
- An offshore sandbank – forms the ‘outer ebb delta’ and migrates consistently onshore until it attaches to the beach;
- A solitary shore-attached sandbank – generated from the attachment of the offshore sandbank. Over a period of months, the sandbank moves shoreward, eventually dissipating and becoming part of the upper beach.
- Sprat Sand – generally remains stable, but is subject to changes in volume.

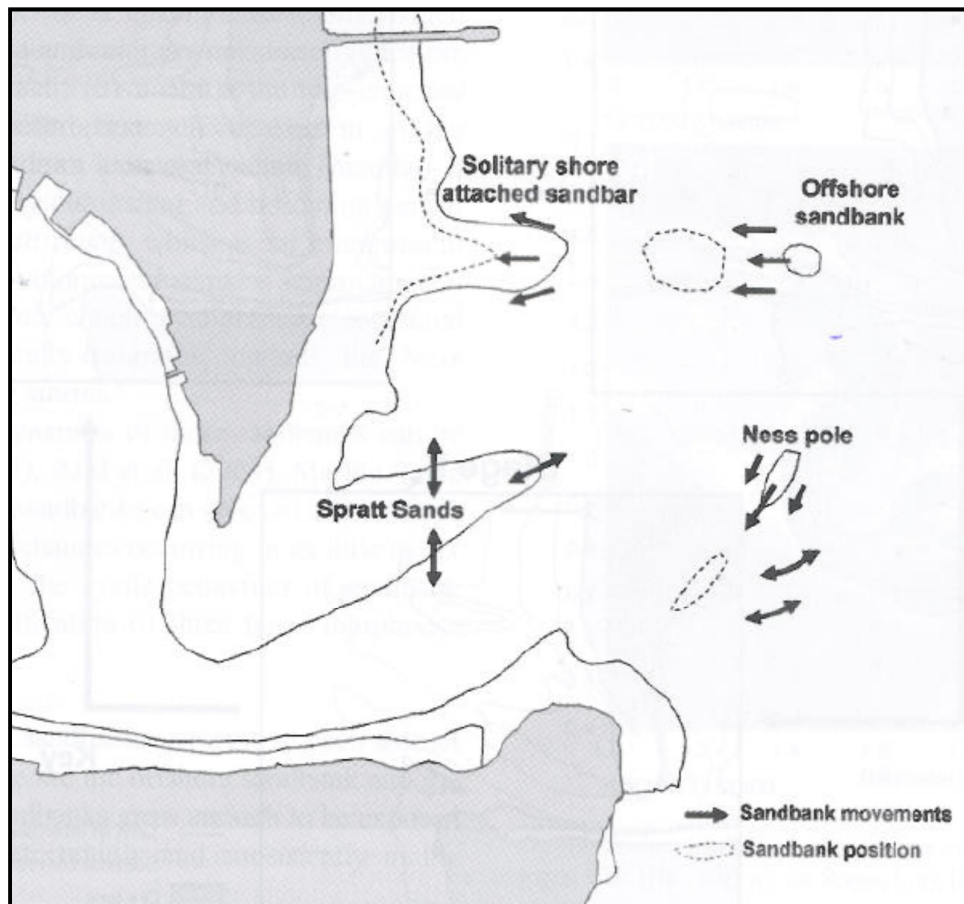


Figure D-12: Sandbanks at Teignmouth (South Devon, UK) and their dominant dynamics (Jiminez et al., 2007).

The CoastView Project provides more detail on the sediment movements between the sand bodies. These movements are described below:

- Stage I: two sandbanks (Ness Pole and the offshore sandbank) grow at each side of the entrance channel. When the sandbanks grow enough to be exposed at low-tide, they migrate in an onshore direction.
- Stage II: an intermediate stage where the Ness Pole and offshore sandbank move closer to shore.
- Stage III: (i) an elongated, shore-normal orientated sandbank is attached to the pier and estuary mouth (although not documented, it is assumed that this is referring the solitary shore attached sandbar on the figure below); and (ii) the Ness Pole can be shore attached.

With regard to transport into the estuary, sand and fine material is potentially supplied to the lower estuary via transport through the mouth. Based on the available information, the routes by which sediment is transported into the mouth are thought to include:

- Fine sediment is supplied in suspension from offshore. It is assumed that this occurs during the flood tide. SCOPAC (2004) suggest that although the flood currents are weaker than the ebb, they are of longer duration and it therefore likely that there is a net input of fine sediments.
- The offshore area has the ability to supply a source of sand to the estuary, particularly during periods of easterly winds and waves; this corresponds with the sediment samples taken in 2012, which shows a greater proportion of sand within the offshore sediments than those within the estuary channel and approaches (ABPmer, 2012).

- Sand is reported to be transferred from the distal area of The Point into the channels at the estuary entrance (SCOPAC, 2004). ABPmer (2006) suggests that material is carried from the spit by flood flows across the channel to flow into the estuary along Shaldon Beach.
- Flood currents operate in conjunction with wave action at the entrance to transport sandy sediments into the estuary (SCOPAC, 2004). SCOPAC suggests that this action lead to the creation of the extensive flood tidal delta of The Salty. ABPmer (2006) suggests that the main movement of sediment is a fan-like flow on and off The Salty. Otherwise, sediment transported into the estuary on the flood tide may be deposited on The Salty or at the western end of Shaldon beach.
- Alongshore transport along the southern bank of the estuary. During the Sediment Dynamics Meeting (2006), it was reported that people have observed a change in the particle size with areas of fine sand becoming rock (this may be that sand is eroded to expose the rock beneath). Sediment at Shaldon Beach contains sediment that can be traced back to Ness Cove. The pathway taken is unknown, but it could be possible that the material moved to Shaldon beach along the southern bank of the mouth of the Teign.

Sand and fine grained has the potential to be stored in the lower estuary, however, due to the strong tidal currents a large amount is exported:

- ABPmer (2002) suggests that there is little potential for the deposition of sediment in the estuary due to both the high current speeds and relatively short high water slack period. Fine sediments may undergo some short-term deposition but this is unlikely to accrete over the long-term in all but the most sheltered locations.
- On the ebb tide, material in suspension or entrained from The Salty is transported along the south side of the channel and out towards the Ness (or Pole Sand). ABPmer (2006) suggests that from here it is joined by northerly transport from the coast to the south and progressive extension of Pole Sand.
- SCOPAC (2004) suggests that there is a net seawards transport of sand and fine gravel in the Teign estuary entrance channel. This takes place via the ebb tidal channel, and occurs as both suspended and bedload transport.
- SCOPAC also reports that some of the sediment that is discharged into the Teign Estuary from the Lemon, Teign and Bovey drainage systems is stored in upper and mid marsh mudflats, whilst other proportions are flushed through the estuary and discharged at its mouth during high river flows (SCOPAC, 2004).

Due to the strong ebb current combined with the river flow, residual circulations from the mouth of the estuary are directed offshore, and high bed shear stresses are experienced in this area (ABPmer, 2002).

Potential sediment transport pathways in the middle and upper estuary have been identified by ABPmer (2002):

- The channels of the upper estuary could act as a pathway for the transport of coarser bedload material. These pathways are inferred from the residual circulations observed from numerical modelling, and could be enhanced during periods of high river discharge.
- Under normal hydrological and meteorological conditions, some material is deposited on the middle/upper estuary mudflats resulting in a slight accretional trend.
- Under more extreme conditions (i.e. periods of high riverine discharge and wave action), material is eroded from the middle/upper estuary mudflats and channels.
- Material eroded from the lower intertidal, together with riverine sediment loads, has the ability to be deposited on the upper intertidal areas around the estuary but can also be transported downstream and exported from the estuarine system.

D.6.3 Existing predictions of shoreline evolution

For an ‘unconstrained’ scenario, Futurecoast (Halcrow, 2002) predicted that cliff erosion to the north of this section of coast would provide sediment to feed and possibly increase the size of the spit and foreshore along the northern shoreline of Teignmouth. The seaward face of Den Spit would retreat in response to future sea level rise and could possibly breach in the future. Due to the presence of the river channel that flows behind the spit, there is a possibility that a breach could become permanent.

The cyclic sediment transport regime at the mouth of the Teign Estuary would continue to occur, and may involve an increased volume of sediment as a result of an increased supply of sediment from erosion of the cliffs along the shorelines to both the north and south.

The Futurecoast (Halcrow, 2002) prediction for a ‘with present management’ scenario is for the continued presence of the defences along the seaward coast of Teignmouth. The management would lead to the gradual narrowing of the beach and foreshore as a result of future sea level rise and in turn increase the risk of failure of these defences over time.

D.7 Impacts on Network Rail infrastructure and operation

D.7.1 Exe Estuary

The banks of the Exe Estuary are highly managed and evolution of the western bank’s alignment is not anticipated. Changes in the shape and size of the spit at Dawlish Warren could impact on the rail embankment from Powderham Banks to Dawlish Warren. In particular, if the Warren decreases in size, larger waves could be generated within the estuary and larger waves from beyond the open coast could travel upstream into the estuary.

D.7.2 Langstone Rock to Holcombe

This section of the frontage is likely to be subject to continued beach narrowing and eventual scour at the toe of the sea wall. The cliffs around each headland, which are unprotected, will continue to be eroded by wave action. As beach levels lower, the water depth at the toe of the sea wall will increase and the volume of water overtopping the defences in storm events will rise. Coryton’s Cove and Shell Cove are considerably more sheltered than the Dawlish frontage and are likely to be less affected by these trends.

D.7.3 Holcombe to Teignmouth

This section of the frontage is likely to be subject to continued beach narrowing and eventual scour at the toe of the sea wall. The cliffs around each headland, which are again unprotected, will continue to be eroded by wave action. As beach levels lower, the water depth at the toe of the sea wall will increase and the volume of water overtopping the defences in storm events will rise.

D.7.4 Teign Estuary

The coastal processes at the mouth of the Teign Estuary are unlikely to have a direct impact on Network Rail assets. The inner estuary is well sheltered from prevailing storm directions.

Annex D-1: Shoreline Evolution Modelling

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DATE: 8 July 2016 **DATE:** 13 July 2016
PROJECT NUMBER: 657257
REVISION NO.: 1
APPROVED BY: Peter Barter

1.0 Introduction

As part of the Exeter to Newton Abbot Geo-environmental Resilience Study, CH2M HILL has undertaken shoreline evolution modelling of the coastline between Dawlish Warren and Teignmouth. To carry out this modelling, the LITDRIFT and LITLINE modules of DHI’s LITPACK suite were used. This DHI model is an industry standard model and was used for a previous Feasibility Study carried out for Network Rail by Halcrow in 2009 (Halcrow, 2009). The model was updated with the latest data regarding sediment size of both the existing beach and nearshore area available through Halcrow’s modelling work of 2012 (Halcrow, 2012). The beach profiles were also updated with the representative beach profiles established for the study.

An extensive time series of surveyed data beach profiles along the coast between Langstone Rock and Teignmouth were analysed to generate the representative beach profiles. The locations of the surveyed beach profiles are shown in Figure 1-1 based on the data stored in CH2M’s in-house software SANDS.



Figure 1-1 Locations of surveyed beach profiles.

1.1 Document overview

The technical note is structured as follows:

Section 2: Methodology and Model - this section presents descriptions of the LITPACK modules used.

Section 3: Data - this section describes the data used for the modelling.

Section 4: LITDRIFT Model - the results of the LITDRIFT modelling are presented in this section

Section 5: LITLINE Model - the results from the LITLINE modelling are presented in this section.

Section 6: Conclusions - this section presents the key conclusions from the analysis.

1.2 Coordinates and reference datum

The following are to be noted:

- All horizontal co-ordinates are not referenced to the geographical grid because horizontal transformation of co-ordinates was conducted for the representative beach profiles, and the input beach profiles required for the DHI LITLINE model are not referenced to the geographical grid.
- All vertical levels are given relative to Ordnance Datum Newlyn (hereafter referred to as mOD).

2.0 Methodology and model

DHI's model LITPACK includes the tools to simulate the dominant physical processes so as to be able to evaluate observed shoreline evolution and assess the effect of proposed shoreline control structures. A short description of the LITPACK modules used for the shoreline evolution modeling is provided below.

The LITDRIFT module simulates the cross-shore distribution of wave height, set-up and longshore current for the given boundary conditions of waves, tide, sediment properties and the coastal profile shape. Based on the local hydrodynamics across the profile, the cross-shore distribution of the local longshore sediment transport rates are found and the annual drift rates can be derived from the summation of the contribution from the single wave events.

LITLINE is a so-called one-line model which calculates the shoreline evolution along a quasi-uniform coastline by solving a continuity equation for the sediment in the littoral zone. The coastal response to gradients in the longshore sediment transport capacity resulting from natural features and coastal structures are simulated.

3.0 Data

Various data sources were used to provide input and background data for the LITDRIFT and LITLINE modelling. The data used for this study is summarised in the following section.

3.1 Model area

The area modelled stretches from Langstone Rock (just south of the Dawlish Warren) to the estuary mouth at Teignmouth in the south. The area consists of two main open shorelines, one in front of Dawlish and the other extending south from the Parson's Tunnel to the beaches of Teignmouth. They are separated by the large headland at Holcombe. The Holcombe headland is considered to be a barrier to longshore transport and acts as a sediment cell boundary /Halcrow 2008/. Between the two main open shorelines, at the Holcombe, there are isolated pocket beaches. Shoreline evolution has been constrained by the construction of the railway (in the 19th century) that runs along the cliff toe and by the seawall that was constructed to protect the railway line. The study area is shown in Figure 3-1.

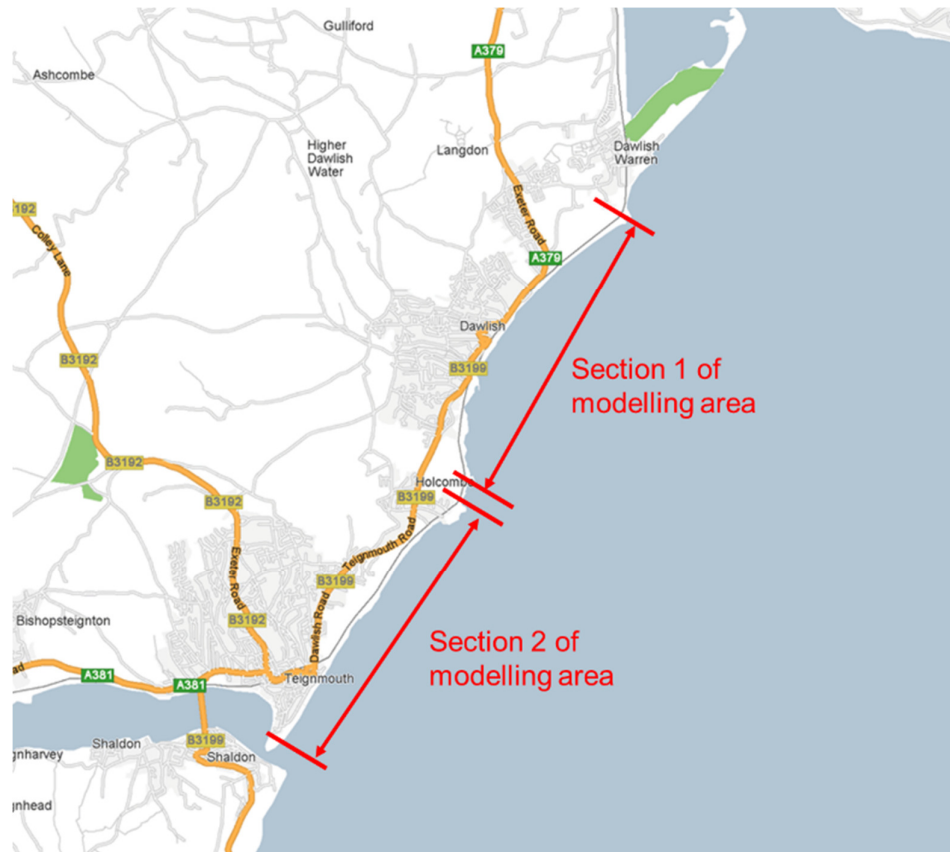


Figure 3-1. Dawlish Warren to Teignmouth model area.

3.2 Beach profiles

Recorded beach profile data brought together within CH2M's SANDS database were used for the analysis. Beach profiles exist for a number of locations at intervals along the shoreline of the study area of approximately 50 metres. Profiles were measured in April 2007, in September 2007, March 2008, September 2008 and in 2014. The profiles extend from inland at about +5 mOD out to a depth of -2 mOD¹. A high resolution bathymetry survey covers the depths from about 0 mOD to the -10 mOD contour line. The location of the beach profiles for the Dawlish frontage is illustrated in Figure 3-2.

The latest survey data of beach profiles for 2014 were presented in the beach profile modelling report for this project (CH2M, 2015), and the representative beach profiles were obtained by calculations of temporal mean beach profiles over time and spatial mean beach profiles related to different assets. Those mean beach profiles were used for updating eight representative beach profiles for Dawlish (4) and Teignmouth (4) which are shown in Figure 3-3 and Figure 3-4. The beach profiles are shown in Figure 3-5 and Figure 3-6. The profiles have a relative gentle slope (about 1:100) until reaching the surf zone. The four profiles at Dawlish are very similar while at Teignmouth the profile closest to the jetty (profile 198) has a slightly gentler slope, probably due to the accumulation of sediments at the mouth of the River Teign. In some of the profiles, erosion at the toe of the seawall can be observed.

¹ OD = Ordnance Datum



Figure 3-2. Measured beach profile locations from SANDS, the numbers are for beach profile sections

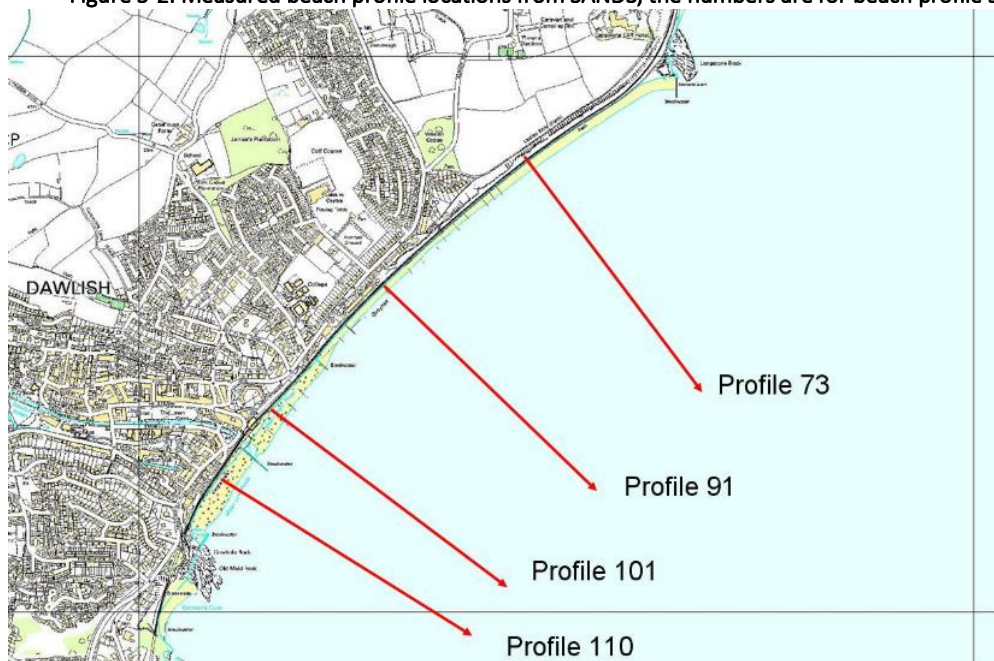


Figure 3-3. Location of representative beach profiles at Dawlish

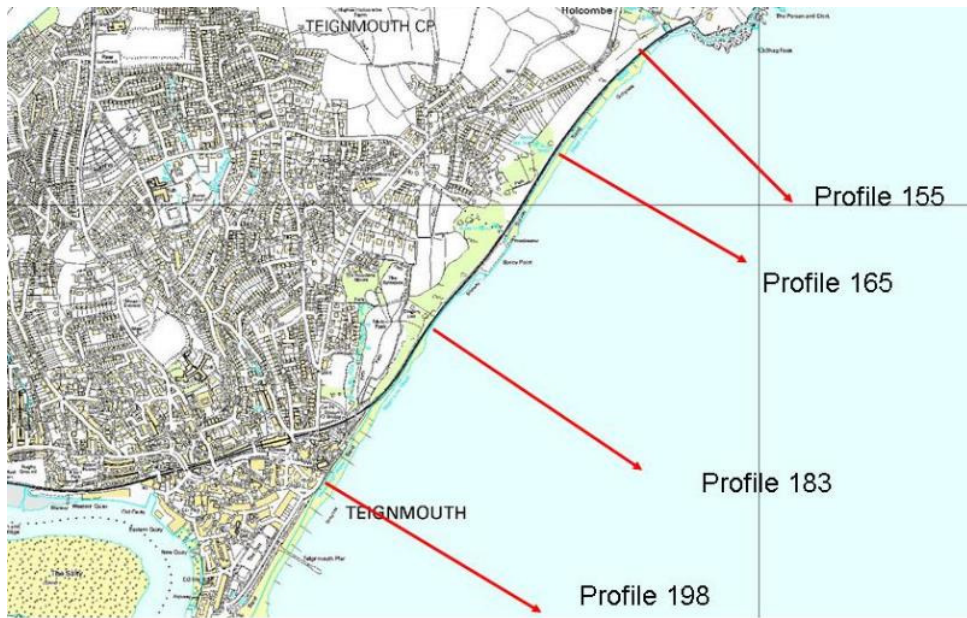


Figure 3-4 Location of representative beach profiles at Teignmouth

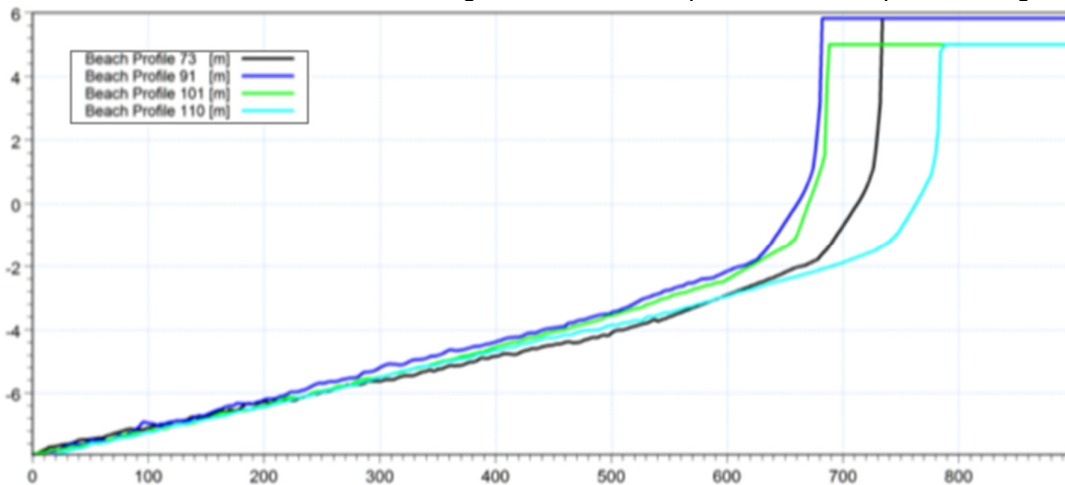


Figure 3-5 Representative Dawlish beach profiles

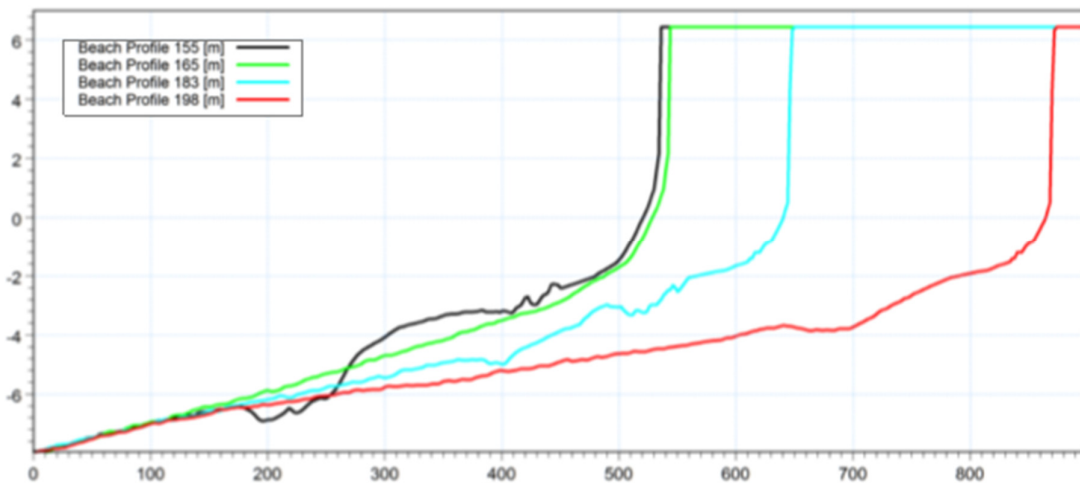


Figure 3-6. Representative beach profiles for Parson's Tunnel to Teignmouth

3.3 Sediment sizes

In 2009 Halcrow carried out shoreline modelling work for the Dawlish coast. At that time very little information on sediment characteristics were available. Based on sediment data of CIRIA 1990 (Figure 3-1), the sediment size D_{50} at Dawlish Warren was around 0.5- 1 mm. For the modelling work of 2009 a uniform sediment size D_{50} of 1.0 mm was used with a spreading of 1.5 ($\sqrt{D_{84}/D_{16}}$).

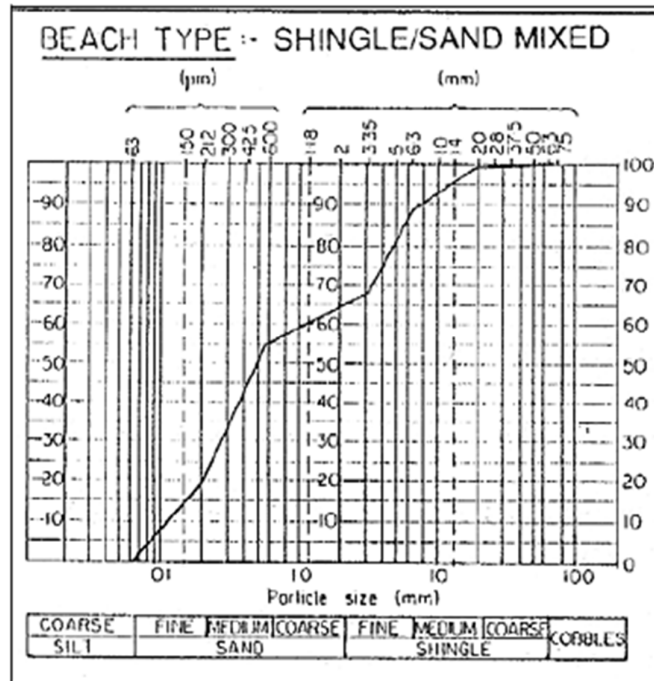


Figure 3-7 Sediment sizes at Dawlish Warren /CIRIA 1990

However, for modelling study of 2012 (Halcrow, 2012), the measured sediment sizes were available for the different beach profiles at Dawlish Warren. Table 3-1 shows the sediment sizes for different locations along these profiles (see Figure 1-1). An averaged D_{50} of 3.72 mm was obtained from the analysis of the D_{50} along the coast. Thus for the present modelling study the sediment size D_{50} of 3.72 mm was used as updated data.

Table 3-1 Sediment sizes from Dawlish Warren to Kennaway Tunnel

Location	Nearest sample location	D_{50} (mm)
6b00007	DW10	4.1
6b00009	average of DW 9 and DW10	1.15
6b00011	DW9	0.9
6b00014	average of DW 9 and DWA	2.4
6b00017	DWA	3.9
6b00019	DW8	3
6b00021	average of DW 7 and DW8	4.4
6b00024	DW7	5.8
6b00026	average of DW 6 and DW7	4.4
6b00030	average of DW 5 and DW6	2.3
6b00034	average of DW 3 and DW 5	3.3
6b00038	average of DW 2 and DW 3	5.5

Table 3-1 Sediment sizes from Dawlish Warren to Kennaway Tunnel

Location	Nearest sample location	D50 (mm)
6b00042	average of DW 2 and DW 1	5.6
6b00047	DW1	5.2
6b00051	DW1	5.2

3.4 Wave and water level data

For the 2009 modelling, wave data at offshore point was acquired from Met Office for the Dawlish to Teignmouth Seawall Feasibility Study and used to further calibrate the wave model (M21 SW) for the area. The wave model has been updated with new wave data from an offshore Met Office wave data point and expanded to cover the whole of Lyme Bay. The model resolution has been increased along the focus area of the modelling namely; Teignmouth to Dawlish and the Exmouth shoreline. The data from the new offshore Met Office wave point has been applied along the boundary of the wave model and a recalibration of the wave model has successfully been carried out. The calibration of wave heights is improved significantly at the two monitoring stations; station 6 and 5 with the general RMS value² reduced to less than half of the RMS value obtained from the previous calibration. The calibrated wave model was used to transform a 20 year offshore wave climate to discrete inshore wave points. (Halcrow, 2012).

The dominant offshore wave approach to Lyme Bay is from the south-west, originating from the Atlantic, however, sheltering and wave refraction alters the incoming waves towards a more southern dominant wave direction for the nearshore. Waves are the primary cause for sediment transport in the nearshore zone. Although the dominant (most frequent) wave approach to the estuary is from the south, it should be noted that most storm waves are from the east/south-east. These waves have larger amounts of energy and may therefore dominate annual littoral transport.

Two typical nearshore (-8 mOD) wave roses from Dawlish (profile 91) and Teignmouth (profile 183) are shown in Figure 3-8. The majority of the waves originate from the south-west to south east direction. However the largest waves are typically coming from a more easterly direction.

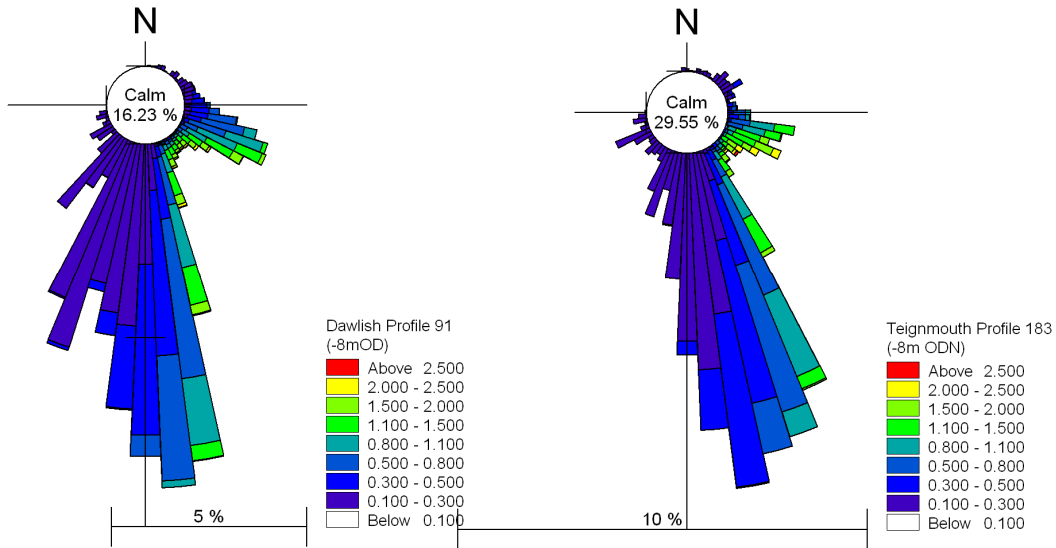


Figure 3-8 Representative wave roses from Dawlish (profile 91) and Teignmouth (profile 183)

$$2 \quad RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N dif_i^2}$$

Tidal levels at Exmouth Docks were obtained from the 2015 Admiralty Tide Tables (UKHO, 2015) and converted from Chart Datum (mCD) to Ordnance Datum (mOD); these are listed below:

- Mean High Water Springs = 2.17 mOD
- Mean High Water Neaps = 0.97 mOD
- Mean Sea Level = 0.27 mOD
- Mean Low Water Neaps = -0.53 mOD
- Mean Low Water Springs = -1.63 mOD

In order to get a general idea of the zone of active sediment transport capacity, the depth of closure was estimated for the area. The depth of closure (depth at which there is minimal or no longshore sediment transport) was calculated using the approximation: $D_c = 2 * H_{s12hr/yr}$. The depth of closure is relative to Mean Low Water and is two times the significant wave height exceeded approximately 12hr per year. This corresponds to an exceedance percentage of 0.137%. The depth of closure is estimated to be $2 * 2.38 \text{ m} = 5.76 \text{ m}$ relative to MLW or 6.84 mOD (about 7 mOD).

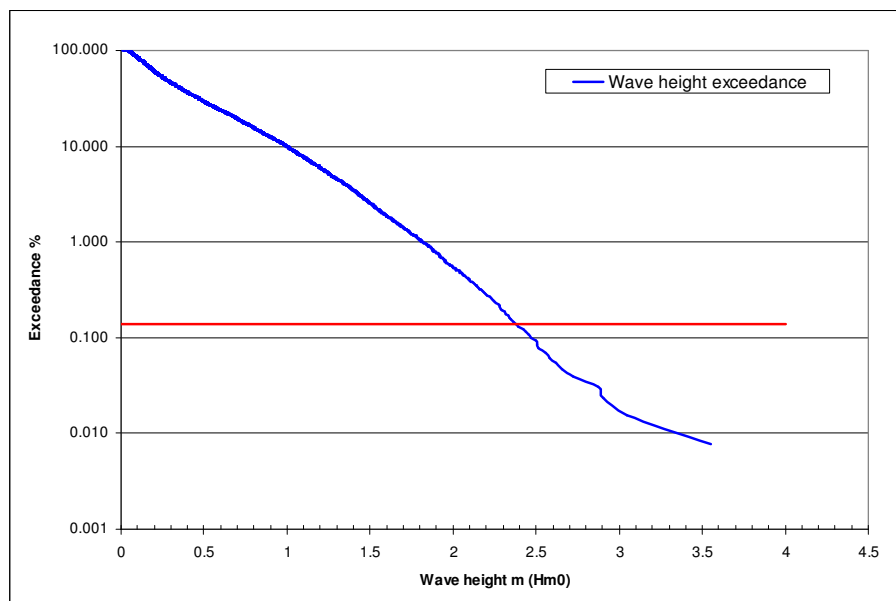


Figure 3-9 Wave height exceedance. Exceedance for $H_{12hr/yr}$ is shown in red.

4.0 LITDRIFT Model

LITDRIFT calculates the potential longshore transport rate across a shore normal profile by transforming a wave condition at its offshore end (depth app. 8 m) to the beach and calculating the transport rate at intervals along its length. It calculates the transport rate across this profile for each wave data point (every 3 hours for Met Office data). The LITDRIFT model was used to calculate the annual net and gross transport rates and sediment directions along the coast. Sensitivity analysis was carried out for varying sediment sizes (D_{50}) as only very limited sediment data was available. The model was furthermore used to estimate the equilibrium shore normals (designing beaches/ structures) and identifying areas at risk of erosion.

4.1 LITDRIFT modelling results

The LITDRIFT model was used to study beach responses due to extreme wave and water level conditions. Eight representative beach profiles for Dawlish (4) and Teignmouth (4) were selected for the LITDRIFT model (Figure 3-3-3 to Figure 3-6).

A uniform sediment size of 1.0 mm was used for D_{50} with a spreading of 1.5 ($\sqrt{D_{84}/D_{16}}$). A sensitivity analysis was carried out with sediment sizes of $D_{50}=2.0 \text{ mm}$, $D_{50}=1.0 \text{ mm}$, $D_{50}=0.5 \text{ mm}$, and $D_{50}=0.25 \text{ mm}$.

Potential annual sediment transport rates were estimated using a 20 year inshore transformed wave data. The modelling results for the 8 profiles are summarised in Table 4-1 and **Error! Reference source not found.** and Figure 4-2. Potential annual sediment rates for a grainsize D_{50} of 1.0 mm varies from - 20,000 $m^3/year$ (towards north) to 13,000 $m^3/year$ (towards south). The estimated potential southward transport at Teignmouth profile 155 is probably overestimated and in reality restricted by the Holcombe headland. Historic information also indicates that it is likely an accretion area over long timespans.

Table 4-1 Estimated yearly sediment transport rates ($m^3/year$)

Transport rates	Profile 73	Profile 91	Profile 101	Profile 110	Profile 155	Profile 165	Profile 183	Profile 198
Location	Dawlish				Teignmouth			
D_{50} 3.72 mm	-8,600	-18,000	-17,000	-18,600	13,100	-14,100	-3,300	-4,100
Beach Angle	143°	134°	127°	120°	140°	120°	124°	121°

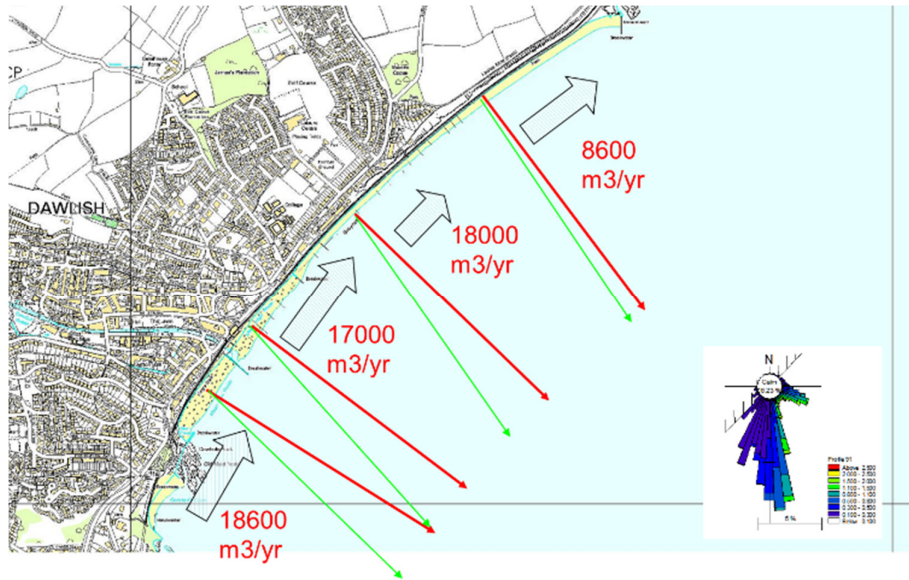


Figure 4-1 Dawlish: estimation of longshore sediment transport rates (m^3/yr). Shore normal profile (red) and equilibrium (green) profiles are indicated.

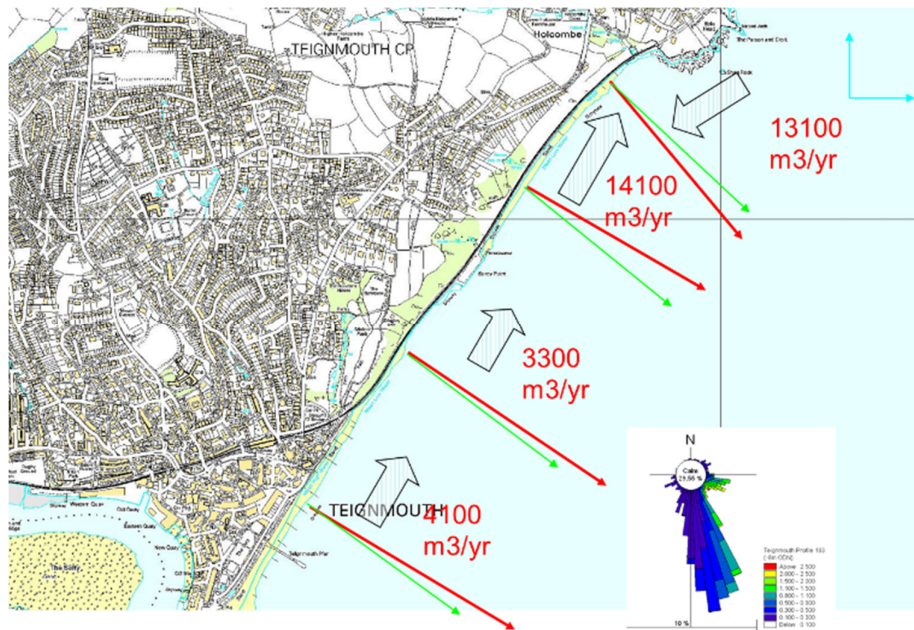


Figure 4-2 Teignmouth: estimation of longshore sediment transport rates (m^3/yr). Shore normal profile (red) and equilibrium (green) profiles are indicated.

4.1.1 Equilibrium angle, Q- α relationship

The Q- α relationship represents the net littoral drift (Q) for various orientations of the coastline (α), here defined as the orientation of the shore normal with respect to true North. In the following, net littoral drift is defined positive in the southward direction.

An illustration of how to interpret the Q- α relationship is shown in Figure . For any given orientation of the coastline, the net transport (black) is obtained as the sum of the negative northward (blue) and positive southward (red) transport components. Figure 4-3 shows that a clockwise rotation of the coastline gives an increase in the net transport. The equilibrium coastline orientation (i.e. the orientation resulting in zero net transport) is found to be 66° in this example. For this coastline orientation, the northward and southward components of the sediment transport are equal and the residual sediment transport is 0 m^3/yr

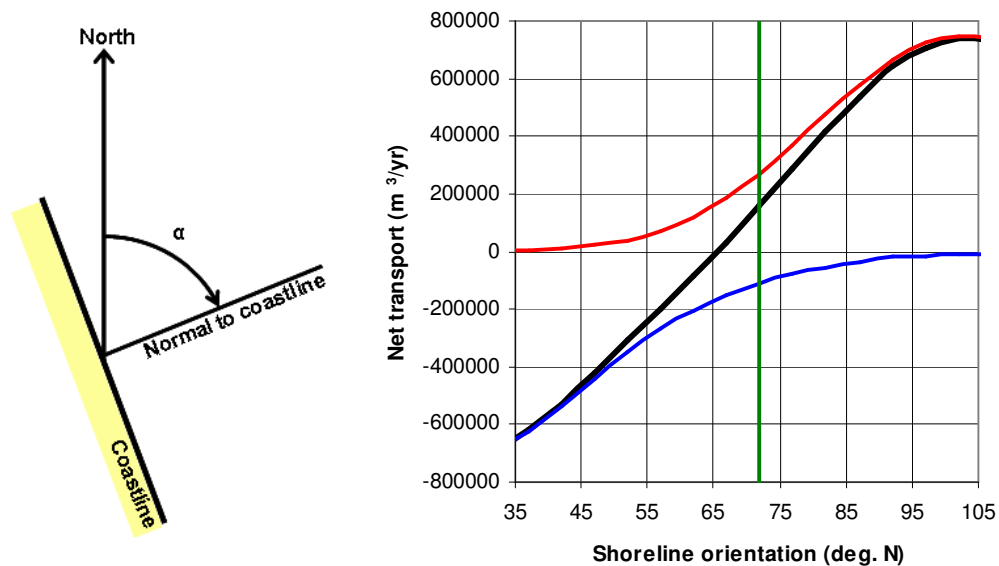


Figure 4-3 Left: Definition of coastline orientation α with respect to true North. Right: Annual net littoral drift as function of the shoreline orientation: total (black), southward (red) and northward (blue) transport. Positive (negative) values indicate southward (northward) transport direction. The green line indicates the actual orientation of the coastline.

Equilibrium angles were estimated for all profiles used in the modelling and compared to the shore normal angles. The results are shown below. The difference between the shore normal angle and the equilibrium angles are between -9 and +15 deg with most profiles having a shore normal angle slightly smaller than the equilibrium angle.

Table 4-2 Estimated equilibrium shoreline angle

Transport rates	Profile 73	Profile 91	Profile 101	Profile 110	Profile 155	Profile 165	Profile 183	Profile 198
Location	Dawlish				Teignmouth			
Shore normal Angle	143°	134°	127°	120°	140°	120°	124°	121°
Equilibrium angle	149°	145°	139°	135°	131°	129°	127°	125°
Difference	6°	11°	12°	15°	-9°	9°	3°	4°

5.0 LITLINE Model

To study the coastline changes along the Dawlish and Teignmouth coast, DHI model LITLINE was used. LITLINE is a coastline evolution model which assess the changes in the coastline due to the varying wave climate. The model was used in 2009 for investigation of the shoreline evolution was generally calibrated against historic measured changes to the coastline. For the present study further measured sediment data were available for 2012 (see Section 3.3), and the beach profiles surveyed in 2014 were added to the data held in SANDS. Thus the latest surveyed beach profile data and the shoreline of 2014 were used for the present modelling study. The modelling results provide a general indication of how the shoreline in front of the seawall will be responding to the incoming wave climate.

5.1 Beach Profiles for LITLINE Model

Using these latest data, as presented in the beach profile modelling report for this project (CH2M, 2015), representative beach profiles were established by calculation of temporal mean beach profiles over time and spatial mean beach profiles related to different assets. Those mean beach profiles were used for updating the representative beach profiles for Dawlish and Teignmouth. The beach profiles are shown in Figure 3-5-1 for Dawlish and Teignmouth. Those two representative profiles were used for the LITLINE model as input data.

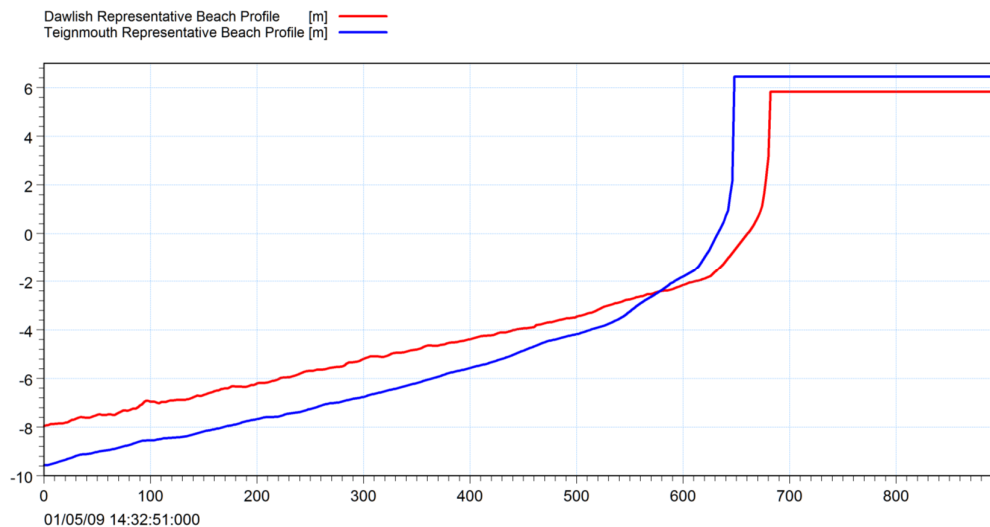


Figure 5-1 Representative Dawlish and Teignmouth beach profiles

5.2 Shorelines for LITLINE Model

In order to apply the LITLINE model, the model area is subdivided into two main sections where shoreline and seawall are exposed to the waves and assessment of erosion and accretion patterns is required.

Section 1 Dawlish; covers from Langstone Rock (Dawlish Warren) to Cowhole and Old Maid Rocks. This section stretches approximately 2500 m (see Figure 5-2).

Section 2 Teignmouth; covers from the Holcombe headland to Teignmouth. This section stretches approximately 3300 m (see Figure 5-3).



Figure 5-2 Dawlish LITLINE model set-up. The model extends from Langstone Rock (northern end) 0 m to Cowhole Rock (southern end) 2500 m.



Figure 5-3 Teignmouth LITLINE model set-up. The model extends from Holcombe (northern end) 0 m to the Teign River mouth (southern end) 3300 m.

The DHI LITLINE model requires input data of the initial coastline. The initial coastline was obtained by analysing the measured beach profiles of 2014 from Dawlish to Teignmouth stored in SANDS. Figure 5-4 shows the shoreline of Dawlish in 2014 but also the shoreline of 2007. Figure 5-5 shows the shoreline of Teignmouth also in 2014 and 2007. The shorelines of 2014 were used as the initial shorelines for LITLINE modelling of coastline evolution at Dawlish and Teignmouth.

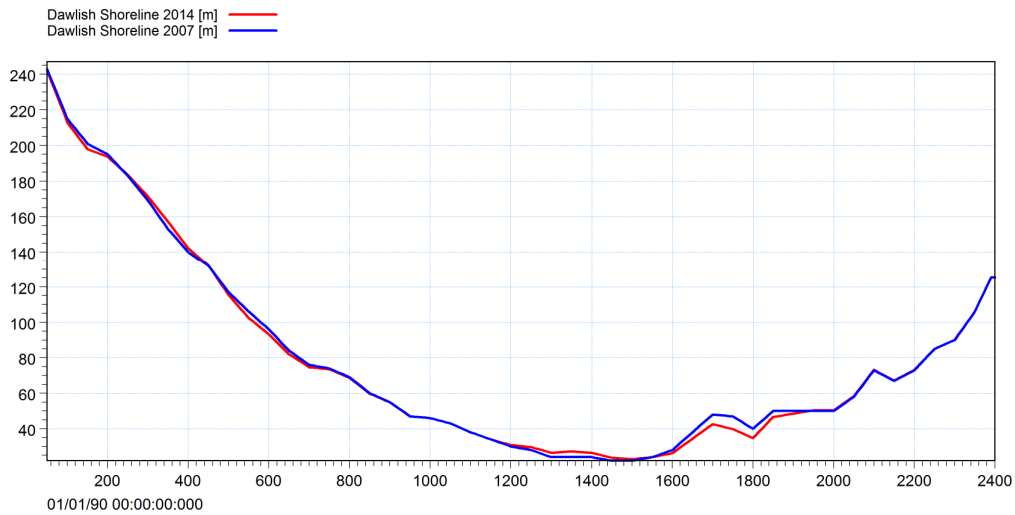


Figure 5-4 Dawlish shoreline of 2014 and 2007(from Langstone Rock 0 m to Cowhole Rock 2500 m)

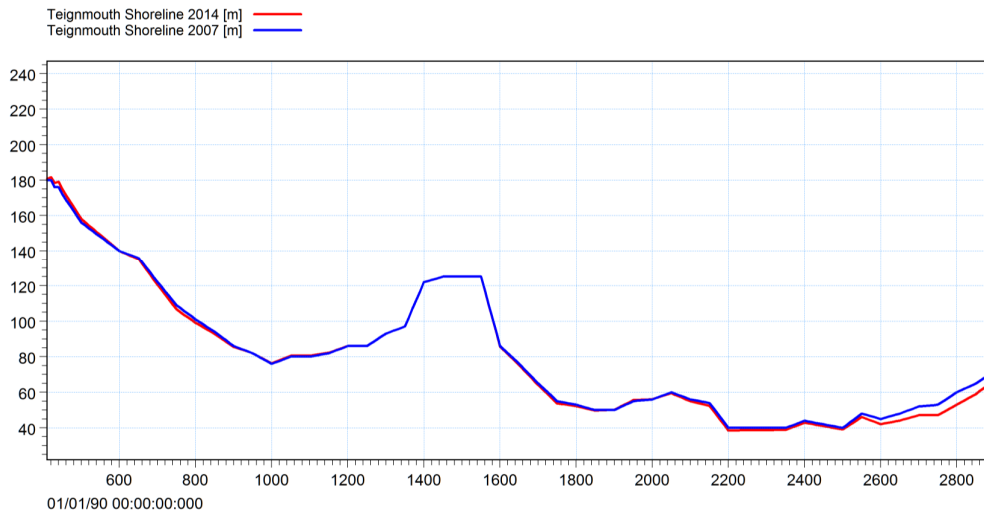


Figure 5-5 Teignmouth shoreline of 2014 and 2007 (from Holcombe 0 m to Teign River mouth 3300 m)

5.3 Dawlish LITLINE modelling results

Figure 5-2 show the main LITLINE model set-up for the Dawlish seawall. Two main jetties are located along the shoreline at 1650 m and 2050 m as shown in Figure 5-6. The lengths of these two jetties extending from the seawall are 50 m and 140 m respectively.

The initial shoreline for the simulations is the measured shoreline from the 2014 survey. The evaluation of the beach width is based on the width at high water. The high water mark is typically very close to or in some instances above the toe of the seawall.

Modelling results are presented as the shoreline evolution after 20 years in Figure 5-6. The left side is the northern boundary (Langstone Rock) and the right is the southern boundary (Cowhole Rock). The two main jetties at 1650 m and 2050 m are shown as grey structures. The initial shoreline is shown as a black line for comparison purposes. The existing seawall is shown as a solid green line. Estimated yearly longshore transport rates are shown on the right axis (m^3/yr).

As shown in in Figure 5-6, the shoreline evolution for the existing shoreline show only minor changes at most sections after 20 years simulation. The section in the centre of the Dawlish stretch (1000 m-1400 m) already suffering from erosion will continue to erode and probably worsen the existing situation. The area to the north close to Langstone Rock (50-300 m) will see some erosion and the section from 400-800 m additional accretion however only very slowly and after 20 years approximately 15 metres of beach has been added. The LITLINE model only takes longshore transport into account and cross shore transport could potentially reduce the width of the beach. The area in between the two main jetties shows little change. To the south of the 2nd jetty there is a tendency for erosion.

In order to investigate the impact of sea level rise to the shoreline changes, two cases were studied. The first case is to model the shoreline evolution after 50 years, and the second case is to assess the impact of climate change on the shore line evolution including the sea level rise. A sea level rise coefficient to 2065 of 0.301 m has been used as discussed in Section 3 of the Phase 1 Baseline Report.

The results are presented as the shoreline evolution after 50 years in Figure 5-7 for the case without and with the sea level rise. Estimated impact of the climate change is shown on the right axis (m) by comparison of the shoreline positions in 50 years with and without sea level rise, i.e. impact = shoreline position with SLR - shoreline position without SLR.

As shown in Figure 5-7, the shoreline evolution for the existing shoreline show the changes at most sections after 50 years simulation. The section to the south of the model (1100 m-2400 m) which is already suffering from erosion will continue to erode to the seawall position. The area to the north close to Langstone Rock (50-400 m) will see some accretion and the section from 400-800 m some additional accretion after 50 years approximately 20 metre of beach has been added. The area in between the two main jetties shows the beach in front of the seawall will also erode away.

By comparing the shoreline positions after 50 years with and without sea level rise, the results indicate that there is no difference of shoreline positions to the south area (1160 m to 2400 m) due to the shoreline retreating to the seawall position. To the north area (50 m to 1160 m) the effect of sea level rise will slow down beach accretion after 50 years reaching a maximum value of 2.9 m, i.e. the shoreline accretion with SLR will be less than the shoreline accretion without SLR.

Figure 5-8 shows the impact of the sea level rise on the shoreline evolution after years of 10, 20, 30, 40 and 50, by comparison between the modelled shoreline positions with and without the sea level rise. The maximum shoreline changes due to the climate change are from -2.9 m to +2 m.

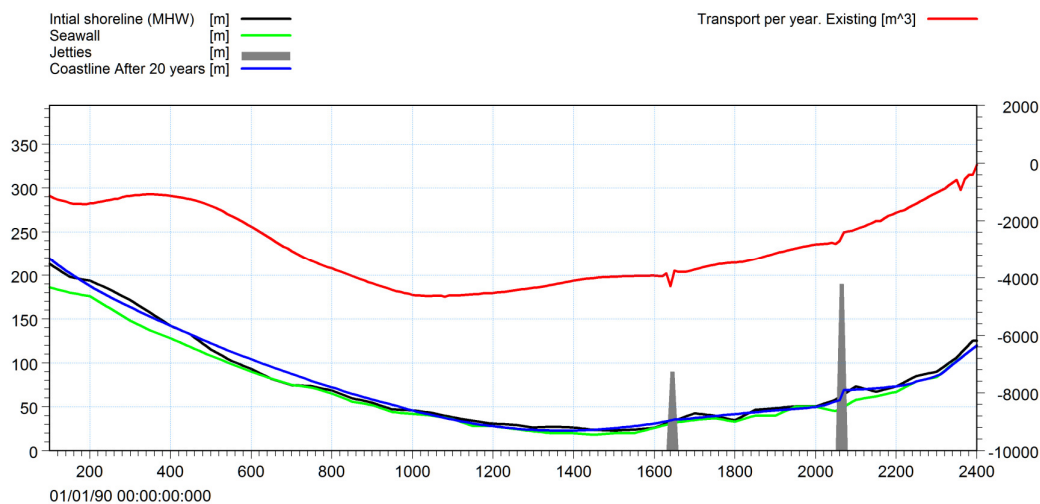


Figure 5-6 Shoreline evolution: modelled coastline after 20 years (from Langstone Rock 0 m to Cowhole Rock 2500 m)

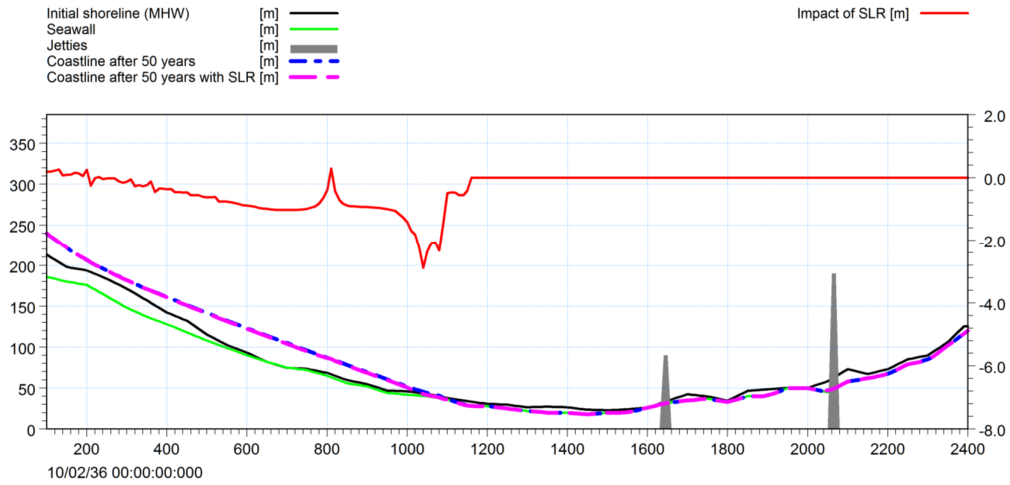


Figure 5-7 Shoreline evolution: modelled coastline after 50 years (from Langstone Rock 0 m to Cowhole Rock 2500 m)

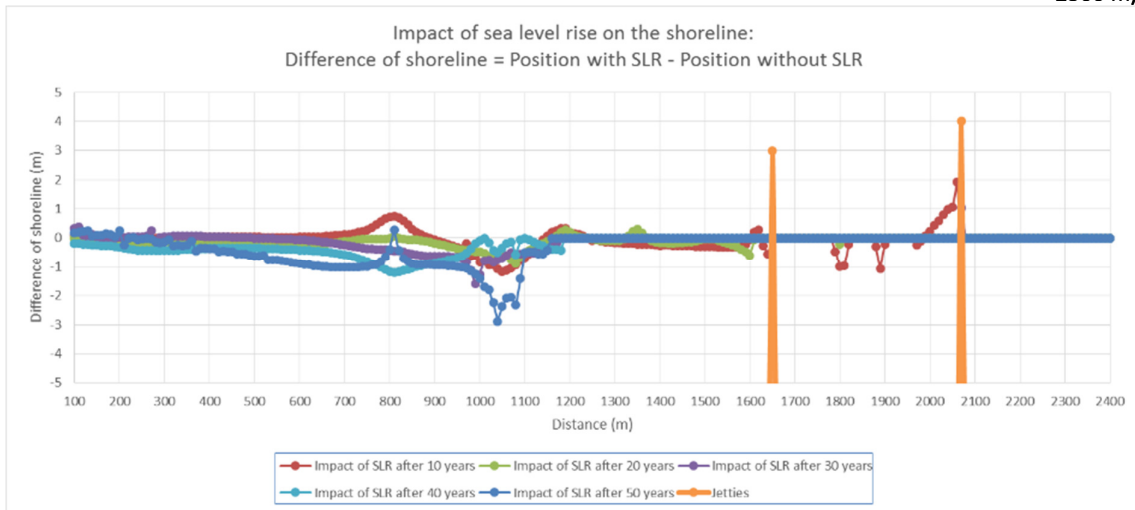


Figure 5-8 Impact of sea level rise on the shoreline evolution.

5.4 Teignmouth LITLINE modelling results

Figure show the main LITLINE model set-up for the Teignmouth seawall.

One main jetty is located along the shoreline at 2800 m. The length of this jetty extending from the seawall is about 170 m (see Figure 5-9).

The initial shoreline for the simulations is the measured shoreline from the 2014 survey. The evaluation of the beach width is based on the width at high water.

Results are shown as the shoreline evolution after 20 years. The left side is the northern boundary (Holcombe headland) and the right is the southern boundary (Teignmouth). The main jetty at 2800 m is shown as a grey structure. The initial shoreline is shown as a black line for comparison purposes. The existing seawall is shown as a solid dark blue line. Estimated yearly longshore transport rates are shown on the right axis (m^3/yr).

Figure 5-9 show the results of the existing shoreline evolution after 20 years. The shoreline evolution for the existing shoreline show small changes at most sections after 20 years simulation. The section just north of Sprey Point is showing some erosion and a little accretion of shoreline from 500-1100 m. The shoreline seems to have adjusted to a configuration close to equilibrium in this section and a little accretion/erosion is observed. South of Sprey Point the shoreline is more or less preserved with a large section of accretion. It has been suggested (SCOPAC, 2004) that Sprey Point is a transport divider with northward transport north of Sprey Point and southward south of Sprey Point. The alternating

erosion/accretion is not unlike what has been observed from maps, shoreline surveys and the Railway data of beach levels at the toe. The area south of the Jetty is not addressed as it will be highly influenced by the complex transport patterns in the area of the Teign river mouth.

In order to investigate the impact of sea level rise to the shoreline changes, two cases were studied. The first case is to model the shoreline evolution after 50 years, and the second case is to assess the impact of climate change on the shore line evolution including the sea level rise. A sea level rise coefficient to 2065 of 0.301 m has been used as discussed in Section 3 of the Phase 1 Baseline Report.

Results are shown in Figure 5-10 as the shoreline evolution after 50 years. Estimated impact of the climate change is shown on the right axis (m) by comparison of the shoreline positions in 50 years with and without sea level rise.

The shoreline evolution show significant changes at entire section after 50 years simulation. The modelling results indicate that the shoreline will retreat to the seawall in the modelling area. This is consistent with the modelling results of the south Dawlish coast (1100 m-2400 m) as shown in Figure 5-7, where the shoreline will also retreat to the seawall after 50 years.

By comparing the shoreline positions after 50 years with and without the sea level rise, the results indicate that there is no difference of shoreline position along the modelling section due to the shoreline retreating to the seawall position. However, there will be impacts due to climate change on the shorelines up to 40 years. Figure 5-11 shows the impact of the sea level rise on the shoreline evolution after years of 10, 20, 30, 40 and 50 by comparison between the modelled shoreline positions with and without the sea level rise. The maximum shoreline changes due to the climate change are from -0.4 m to +2.1 m, which will happen in 30 years according to the modelling results. However, both modelling results with and without the sea level rise indicate the shoreline retreating to the seawall after 50 years.

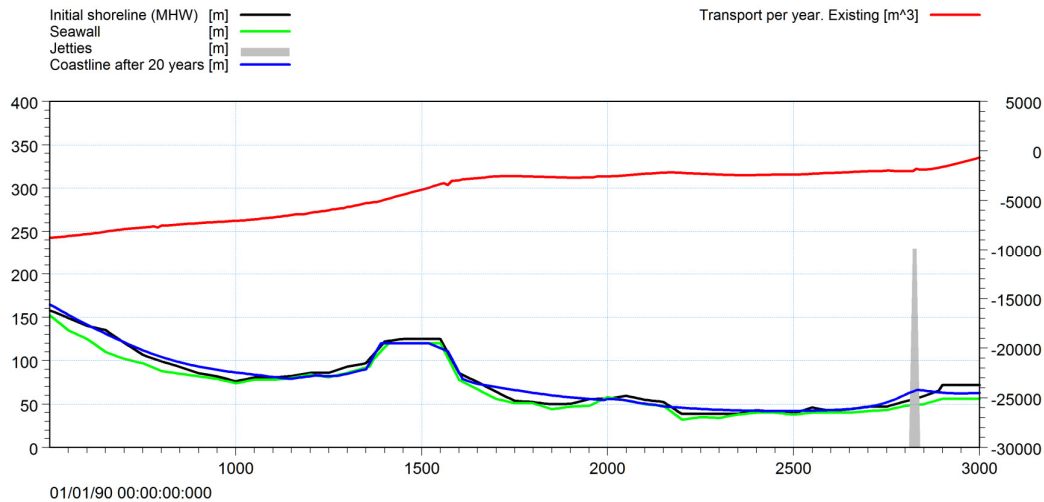


Figure 5-9 Shoreline evolution: modelled coastline after 20 years (from Holcombe 0 m to Teign River mouth 3300 m)

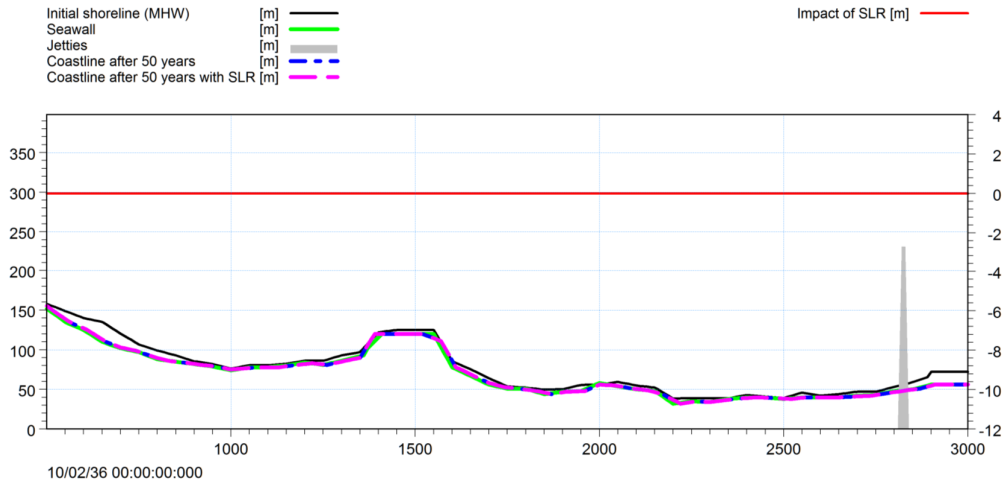


Figure 5-10 Shoreline evolution: modelled coastline after 50 years (from Holcombe 0 m to Teign River mouth 3300 m)

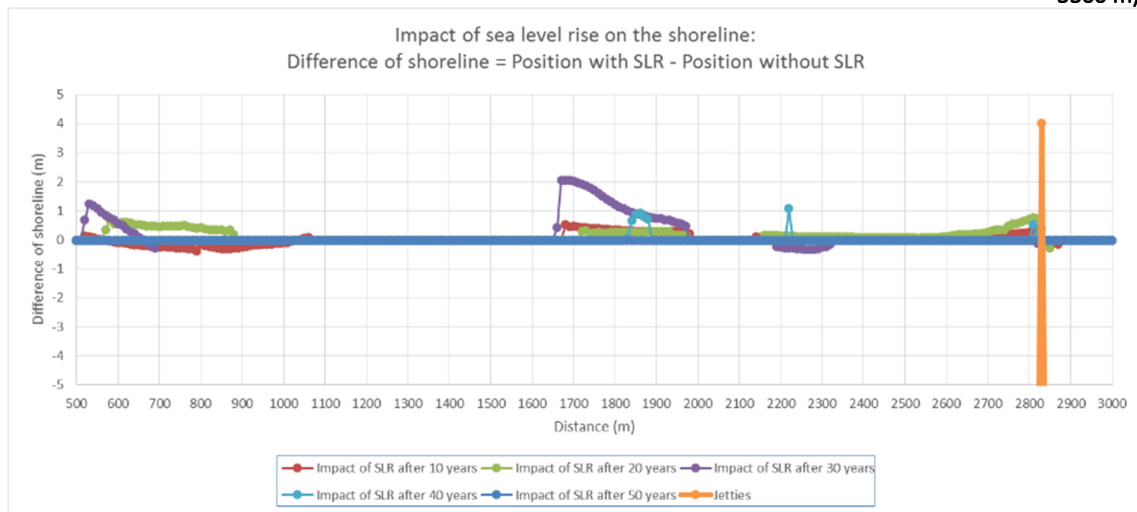


Figure 5-11 Impact of sea level rise on the shoreline evolution.

6.0 Conclusions

The conclusions from this study are summarised below.

DHI’s LITLINE model has been applied to the Dawlish coast covering from Langstone Rock (Dawlish Warren) to Cowhole and Old Maid Rocks, and to Teignmouth coast covering from the Holcombe headland to Teignmouth.

The shoreline evolution modelling of the Dawlish coast for 50 years show that the section to the south of the Dawlish coast (1100 m-2400 m) which is already suffering from erosion will continue to erode to the seawall position. This is the same as indicated in the SCOPAC report (SCOPAC, 2004) for the coast of Holcombe to Dawlish Warren that “Over the last 140 years, railway engineers have experienced persistent problems with the exposure of the footings of the seawall, due to beach drawdown. The longer-term trend would appear to be one of beach erosion, probably influenced by wave reflection from the seawall”.

The area to the north close to Langstone Rock (50-400 m) will see some accretion and the section from 400-800 m some additional accretion after 50 years approximately 20 metre of beach has been added. This is because the Langstone Rock is acting as the large groyne as indicated in the SCOPAC report (SCOPAC, 2004). This states that “From the evidence of beach setback immediately north of Langstone Rock, it is effective in trapping sediment drifting north-eastwards, thus functioning as a large terminal groyne”.

By comparing the shoreline positions after 50 years with and without the sea level rise, the results indicate that there is no difference of shoreline positions to the south Dawlish coast (1160 m to 2400 m) due to the shoreline retreating to the seawall position. To the north Dawlish coast (50 m to 1160 m) the effect of the sea level rise will slow down beach accretion after 50 years with the maximum value of 2.9 m. The impact of sea level rise on the shoreline evolution after years of 10, 20, 30, 40 and 50 is assessed by comparison between the modelled shoreline positions with and without the sea level rise. The maximum shoreline changes due to the climate change are from -2.9 m to +2 m.

Shoreline evolution modelling of the Teignmouth coast shows small changes at most sections after 20 years simulation. The section just north of Sprey Point is showing some erosion and a little accretion of the shoreline from 500-1100 m. The shoreline seems to have adjusted to a configuration close to equilibrium in this section and little accretion/erosion is observed. South of Sprey Point the shoreline is more or less preserved with a large section of accretion. It has been suggested (SCOPAC, 2004) that Sprey Point is a transport divide with northward transport north of Sprey Point and southward south of Sprey Point. The modelling results with small changes at most sections support the conclusion in that report (SCOPAC, 2004), namely that "In summary, the longshore transport system for the open coast is a set of closed or partially closed sub-cells, though onshore and offshore exchanges are probable, especially in the vicinity of the Teign estuary entrance".

However, the shoreline evolution shows significant changes over the entire section after 50 years simulation. The modelling results indicate that the shoreline will retreat to the seawall in the modelling area.

The impact of the sea level rise on the shoreline evolution is assessed by comparison modelling results for years of 10, 20, 30, 40 and 50 with and without the sea level rise. The maximum shoreline changes due to the climate change are from -0.4 m to +2.1 m, which will happen in 30 years according to the modelling results.

It should be noted that cross shore transport is not directly accounted for in the LITLINE model which may impact the overall shoreline changes.

7.0 References

CH2M 2015. Phase 1 Baseline Report.

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