Natural England Commissioned Report NECR256

Coastal Catch-Up: How a soft rock cliff evolves when coastal defences fail

Godwin Battery, Kilnsea

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

This report was commissioned to examine how the collapse and deterioration of the Godwin Battery coastal defences and associated military structures at Kilnsea on the Holderness coast have impacted on the evolution of the adjacent shoreline. **This example is unusual in the way defences have been allowed to fail, with it is now possible to appreciate how a soft cliff coastline responds to this failure and erosion.**

Particular emphasis is given to the evolution to the shoreline as it was influenced first by (1) active coastal defence structures, then (2) redundant coastal defence structures, and currently (3) mass concrete ruins. Expert opinion is provided regarding the level of adjustment required for the frontage to reach a new equilibrium by 'catching up' with the adjacent undefended coast, and future evolution.

Historic maps and photographs were collected and analysed alongside coastal erosion monitoring data as well as contemporary evidence gathered on site, to build a detailed chronology of shore evolution since the construction of the Battery. The resulting data was used to predict the extent to which the remaining structures will continue to influence coastal evolution in the future, and the likely timescales involved. The evidence from this report will improve understanding in relation to the following designated coastal sites:

- Humber Estuary SAC, SPA and Ramsar site
- Humber Estuary SSSI
- The Lagoons SSSI
- Spurn NNR and Spurn Heritage Coast

This information will also inform Natural England's views on the management of soft cliff coasts generally, improving the advice that we give to others.

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Further information
This report can be downloaded from the Natural England Access to Evidence Catalogue: **http://publications.naturalengland.org.uk/** . For information on Natural England publications contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk**.

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Coastal Catch-Up: How a soft rock cliff evolves when coastal defences fail

Godwin Battery, Kilnsea

Report to Natural England

Dr Mark Lee

Contents

1 Introduction

This short report has been prepared in response to the request from Natural England for advice relating to the following coastal sites:

- Humber Estuary SAC, SPA and Ramsar Site.
- Humber Estuary SSSI,
- The Lagoons SSSI,
- Spurn NNR and Spurn Heritage Coast

In order to inform its own views on management and improve the advice Natural England can offer to others (EA, ABP etc) they wish to understand more about how the coast between Easington and Spurn is likely to evolve.

The casework question to be addressed relates to the impact of the collapse and deterioration of the Godwin Battery structures at Kilnsea, on the Holderness coast. The focus is on how much "catching up" the coastline plan form needs to do following the failure of the seawall built to protect naval gun emplacements, at some time in the 1960s. The old gun emplacements are currently constraining evolution of the coast by acting as a hard point and further change is to be expected once these are outflanked.

It is assumed that these blocks to coastal evolution have impacted on the coastline both northwards (the area south of the Easington Beach caravan site) and southwards as far as the Narrows (the area of the Spurn spit currently subject to regular washover). Specific questions include:

- Has the coast adjusted and 'caught up' with the plan form it would have reached if it had not been protected during World War I?
- If not how far adrift of this plan form is it now and how much longer might it take to "catch-up"?

The work has involved:

1. a desk-based review of the history of Godwin Battery. A time series of historical Ordnance Survey maps and vertical aerial photographs was purchased to catalogue the progressive loss of the site through coastal erosion[1];
2. a field inspection (April 2012) to determine the current condition and spread of the concrete ruins on the foreshore;
3. a review of erosion line and beach profile data available from East Riding of Yorkshire Council (ERYC) to determine the impact of the Battery on the adjacent shorelines[2];
4. a desk-based assessment of the historical and future impact of the Battery site on shoreline development at the Easington Lagoons and Spurn.

[1] All the vertical aerial photographs presented in this report have their own copyright restrictions. For details see the links to the company websites provided in each Photo caption.

[2] The Bluebell Visitor Centre displays a sign indicating when it was built and the distance from the sea (1847, 534 yards), together with another sign indicating when it was restored and the distance from the sea then (1994, 190 yards). This indicates a long term recession rate of 2.13 m/yr.

2 Godwin Battery

Godwin Battery was constructed in 1914-1915 as part of the outer Humber wartime defences, and was linked to Spurn Fort by a standard gauge railway (Photo 1, Figure 1). Details can be found at the English Heritage National Monuments Record website:
http://www.pastscape.org.uk/hob.aspx?hob_id=929478

The battery consisted of two 9.2 inch breech loading (BL) guns mounted in circular concrete pits, approximately 100 m apart. Between the guns were underground magazines (the roof was 5 foot thick), crew shelters and workshops. On the right and left of the battery were two battery observation posts (BOP), one housing a 30' Barr and Stroud rangefinder. Both BOP's had defensive blockhouses built into their base. The barrack accommodation was constructed of brick and concrete, these included a guard house, officers' quarters and a hospital.

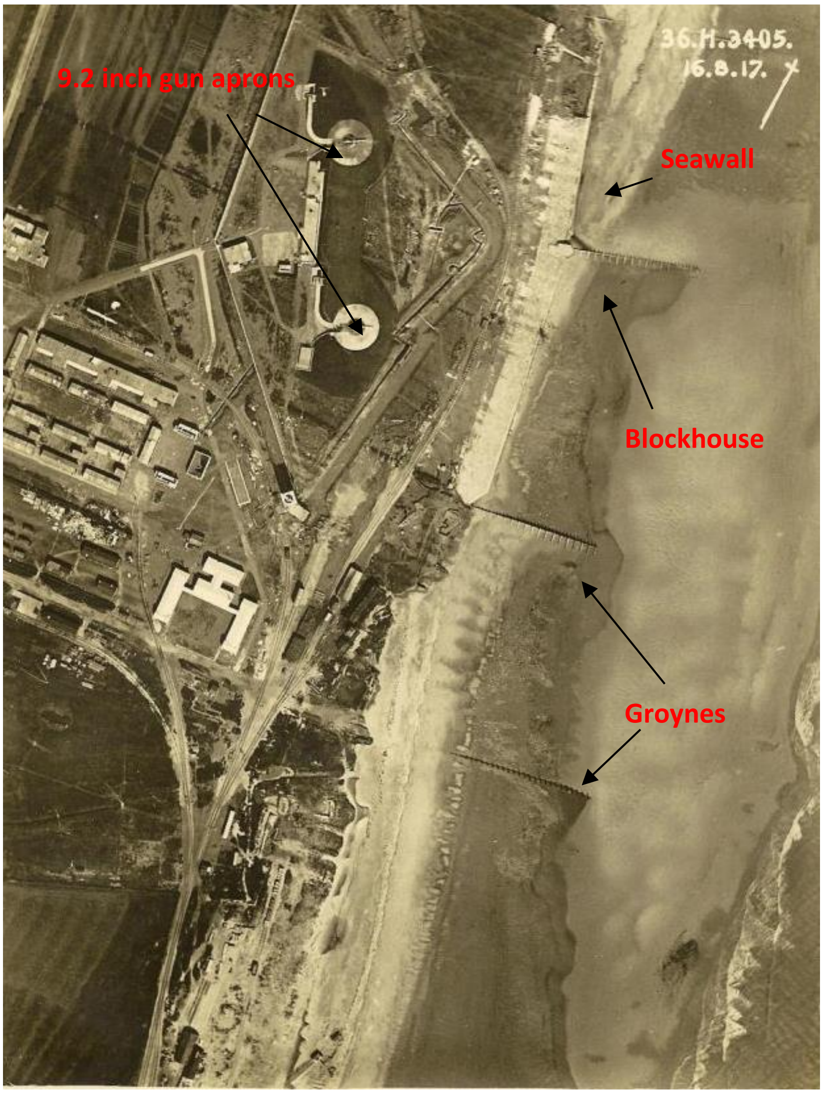


Photo 1 Godwin Battery, August 1917

The battery was protected by a 6 foot wall enclosing the landward perimeter, a network of fire trenches and a 20ft ditch filled with barbed wire. On the seaward side there was a 300 yard long seawall with a concrete blockhouse in the centre. Wooden groynes were constructed on the foreshore after a storm damaged the blockhouse; the groynes led to the rapid build-up of gravel (Crowther, 2006).

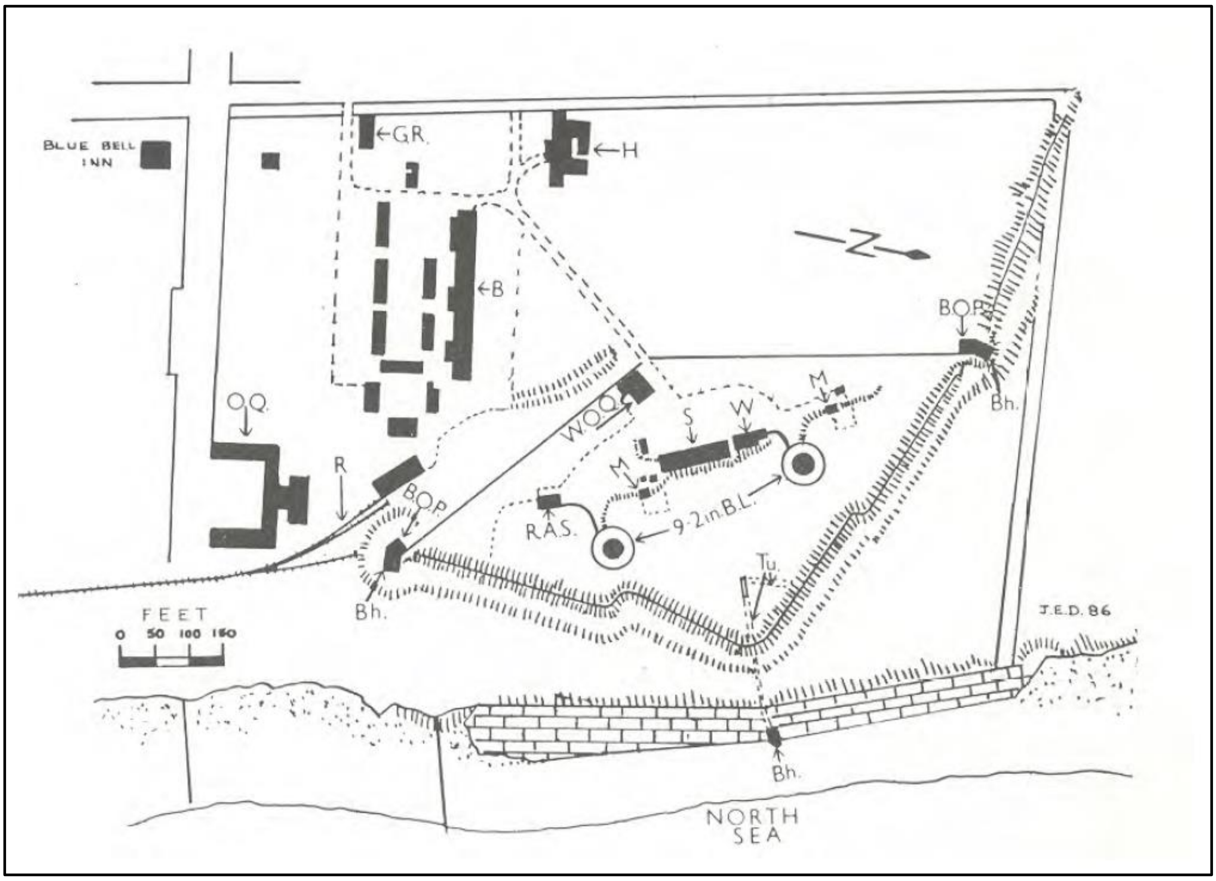


Figure 1 Godwin Battery, 1918 (from Dorman 1990). Notes: 9.2 in BL - the 9.2 inch guns; BOP – the Battery observation posts; Bh – Blockhouse; M – magazine; H – hospital; OQ – officers' quarters; R - railway

The battery was operational from early 1916 until the end of the war. Between the wars, Godwin Battery remained an active base and the guns were maintained (Photo 2).

In 1940 the Humber defences were reorganised (Photo 3). A 4" BL Mk. 9 gun was installed just to the south of the right hand Battery Observation Post, together with a single 90cm Coastal Artillery Searchlight (CASL). In August 1940 half inch thick armoured plate anti-strafing shields were built around the two 9.2 inch guns. A concrete section road was constructed in 1940/1941 along Spurn peninsula. An anti-aircraft installation was built at Warren Cottage. Three lozenge pillboxes were added to the Godwin Battery. Anti-tank blocks were placed across the neck of the peninsula and along the beach north of Kilnsea (most of these were broken up and used as sea defences in the early 1980s). Two anti-tank ditches were built in the Chalk Bank area.

The battery was manned by the 269th Coastal Battery RA. The 9.2 inch guns were removed from their mountings at the end of 1944 and finally scrapped in 1948. However, cold war tensions led to the siting of a new emplacement around 1950. The Spurn railway was closed in 1951, and during the winter of 1951/52 the rails were taken up. A new section of seawall ("the Promenade") was constructed by the MoD in 1950-52, between the Blue Bell and the Warren (i.e. south of Godwin Battery). The wall was severely damaged in the 1953 storm surge (Photo 4). Although it was repaired, it had become outflanked by 1958 and was being rapidly washed away (Crowther, 2006).

In February 1956 the MoD announced that the Coast Artillery was to be replaced by more advanced nuclear weaponry. A military presence remained at Godwin Battery until the late 1950s when the battery was put up for sale (Photo 5). It was sold in 1960 and turned into the "Sandy Beaches" caravan site. At the time of the sale, the sea defences were in good condition (Photo 6; Crowther, 2006). However, many military buildings were demolished in the 1970s because they were thought to be dangerous.

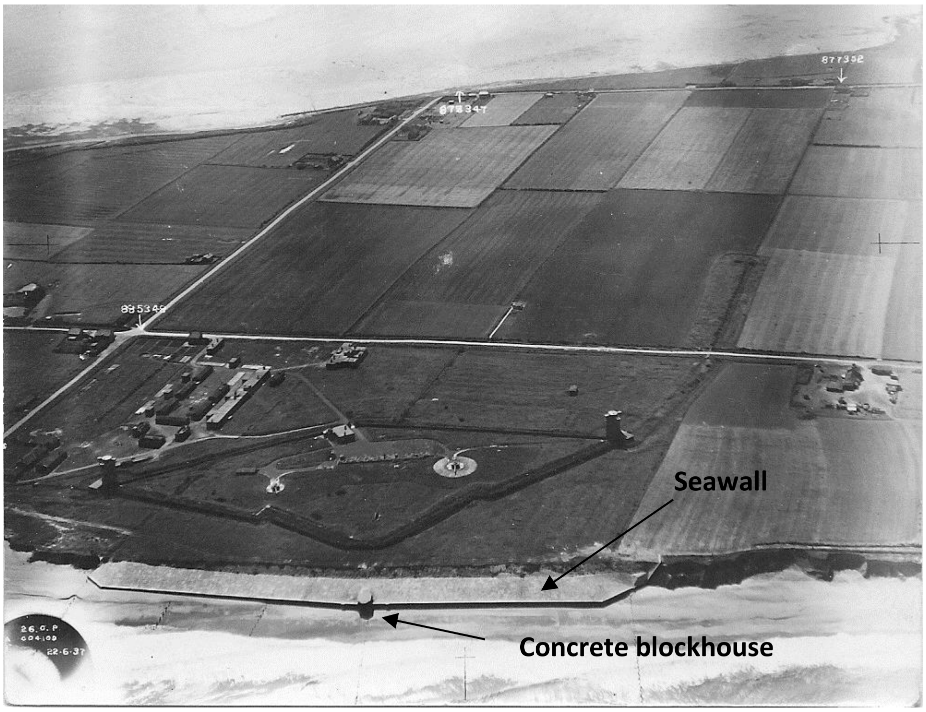


Photo 2 Godwin Battery, 22 June 1937
(source: scan from Spurn Heritage Coast Project collection supplied by Tim Collins)

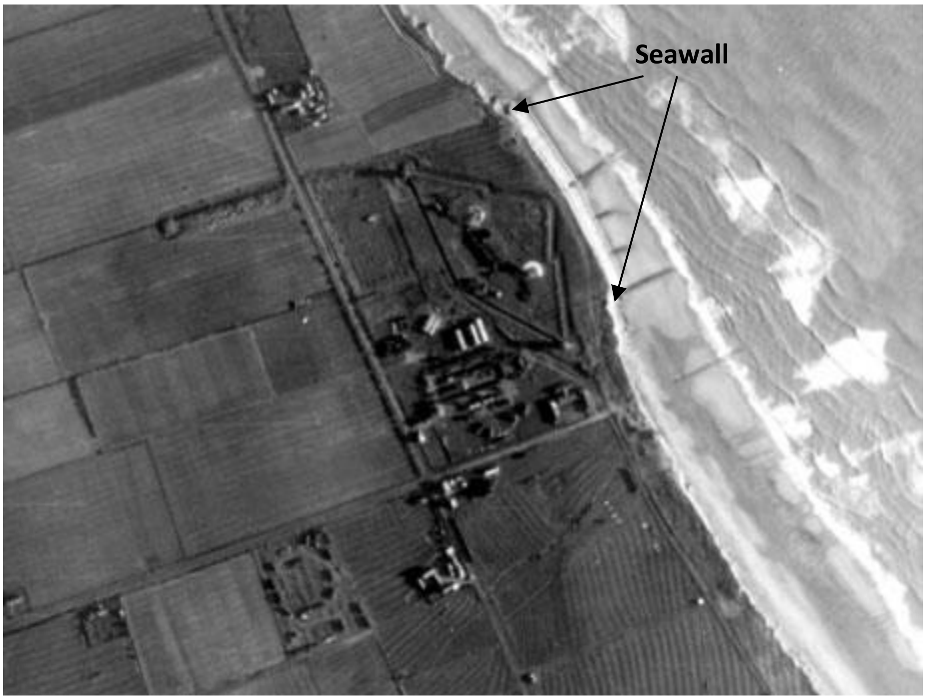


Photo 3 Godwin Battery 21 September 1946 (source: http://www.english-heritage.org.uk/content/images/maps-plans/nmp-maps-cases/yorkshire/raf-cpe-uk1748-5003-godwin-coastal-artillery-battery)

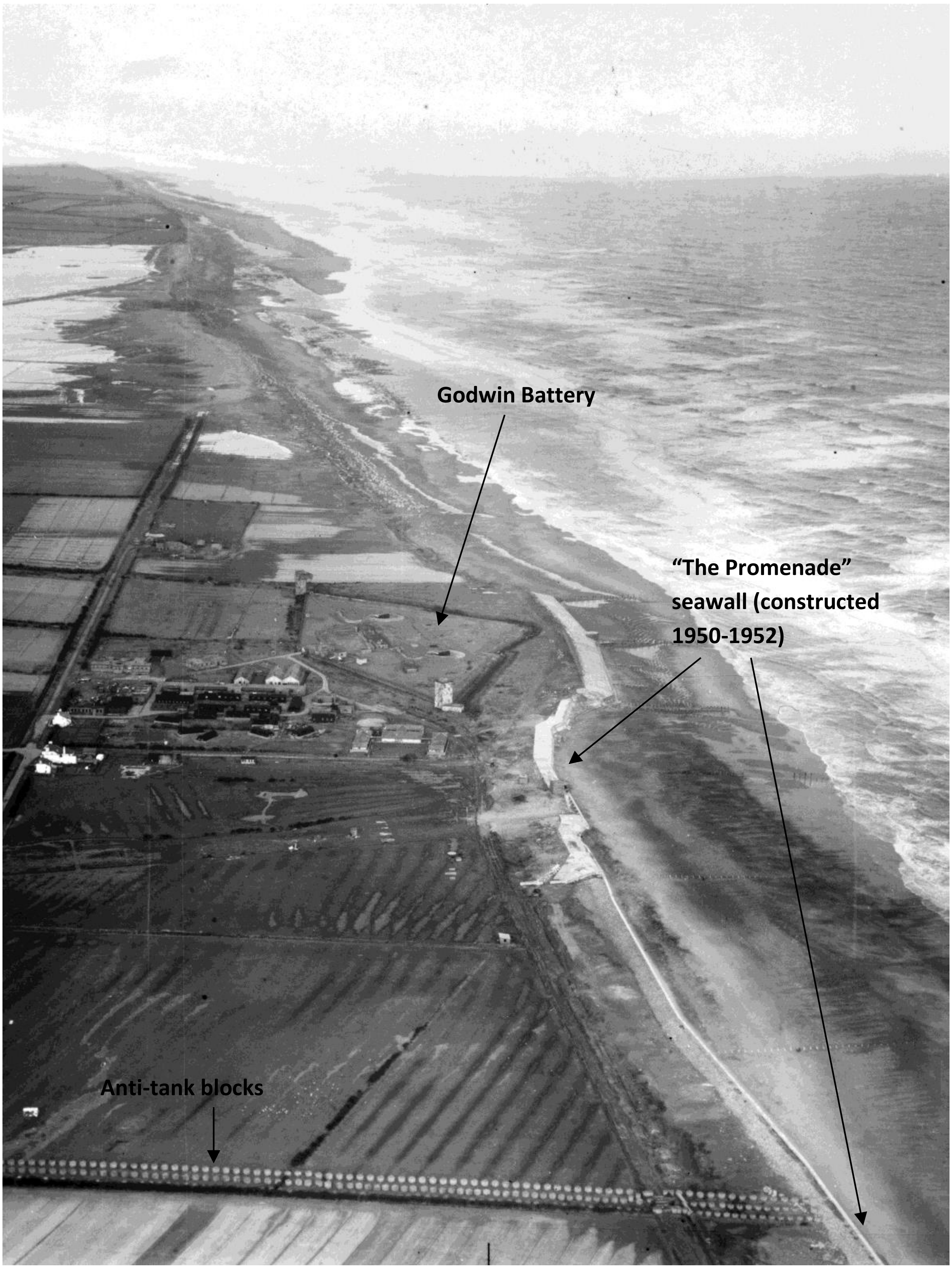


Photo 4 Godwin Battery immediately after the 1953 storm surge (photo date 3.2.1953; source Air Images Ltd.)

Photo 5 Godwin Battery southern battery observation post (the tower on the right), around 1958, showing the open ground in front of the site (source: http://www.derelictplaces.co.uk/main/showthread.php?t=20558)

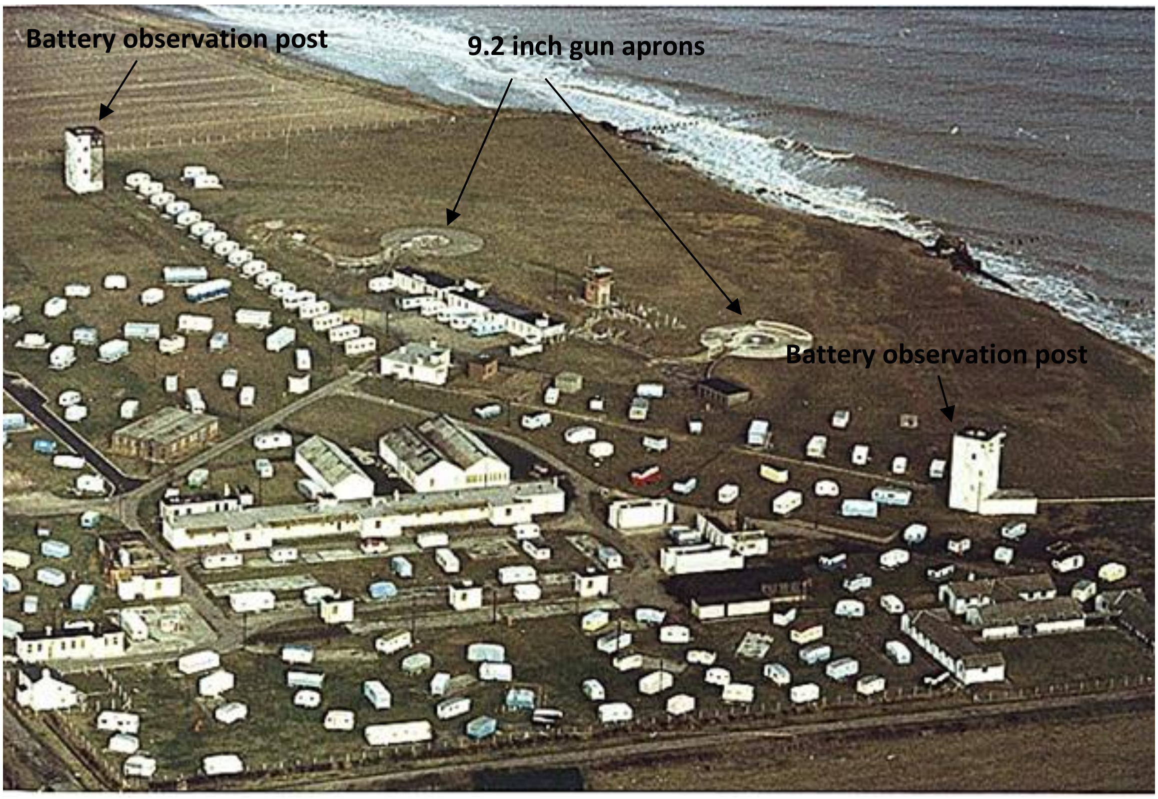


Photo 6 The Sandy Beaches caravan site, 1964 (Photo source: http://www.skeals.co.uk/)

3 The Gradual Loss of the Battery

The Battery was visited by the Fortress Studies Group (FSG) in 1992 during the Holderness Survey undertaken on behalf of the Royal Commission on the Historical Monuments of England (see: http://www.pastscape.org.uk/hob.aspx?hob_id=929478). The FSG found the site to be in generally good condition, although the hospital building has been demolished (David Clarke/12-APR-1992/FSG,RCHME: Holderness Survey). The site was visited by R. Thomas in February 1995. He found that the remnants of the seawall on the lower foreshore had been virtually destroyed by wave action, as had the strongpoint, CASL and 4" BL emplacement. The 9.2 inch gun aprons had both collapsed, half lying on the beach, half on the cliff top but highly unstable. By January 2007, the majority of the battery had either collapsed, been demolished, or rested on the beach.

Although many of the monuments were lost between 1993 and 1997 (Anderton, 2000), it is clear that this had been preceded by a period of cliff recession which removed the undeveloped strip of land between gun aprons and the cliffline. Available map evidence indicates that the seawall failed at some point between 1956 and 1972-75, triggering the renewal of cliff recession (Figures 2 and 3). The recession distance between these dates ranges from 2.5m (Point C) to 25m (Point B).

The cliff retreat and loss of the monuments between 1953 and 2008 can be observed on the sequence of vertical aerial photographs presented as Photos 7 to 13. The 1969 photograph clearly shows on-going cliff recession behind the seawall and provides evidence of seawall failure at some time prior to that date.

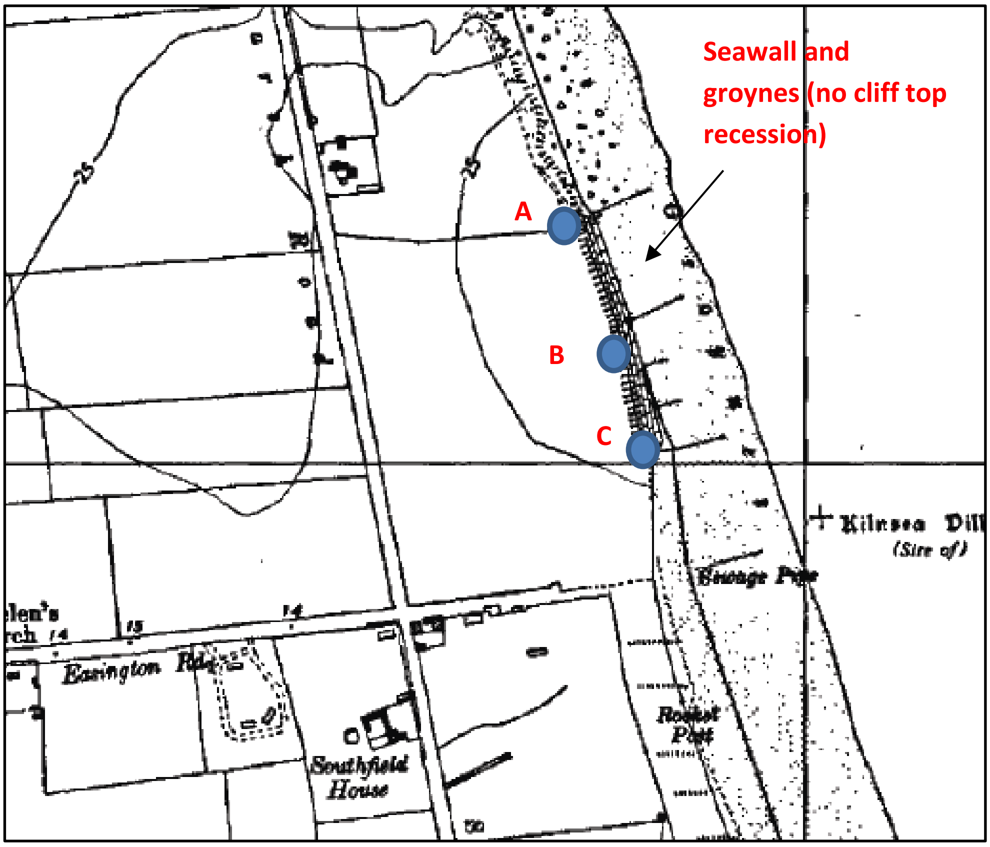


Figure 2 County Series map: 1956 (Original scale 1: 10,560). Note that the layout of the Battery is not shown for security reasons

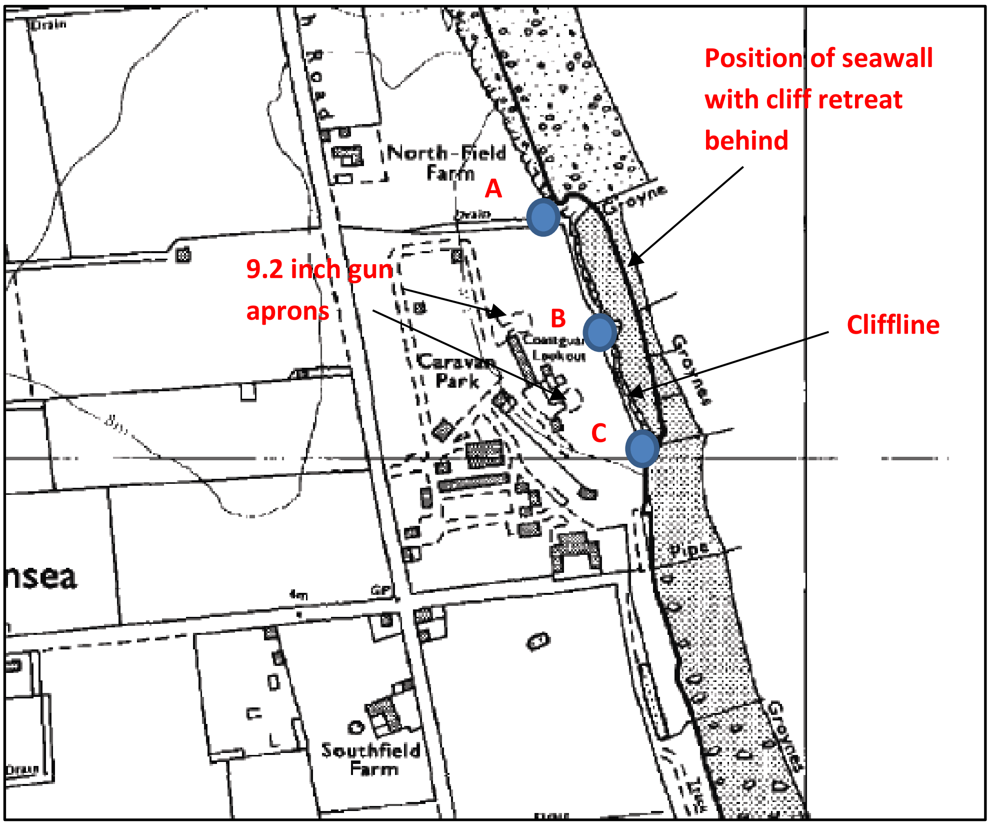


Figure 3 Yorkshire, 1972-75 series (Original scale 1: 10,000). Points A-C are cliff recession measurement point established for this study

Photo 7 Aerial photograph (3.2.1953); original scale 1:5,400 (source: Air Images Ltd.)

Photo 8 Aerial photograph (24.8.1969); original scale 1:7,500 (source: Air Images Ltd.)

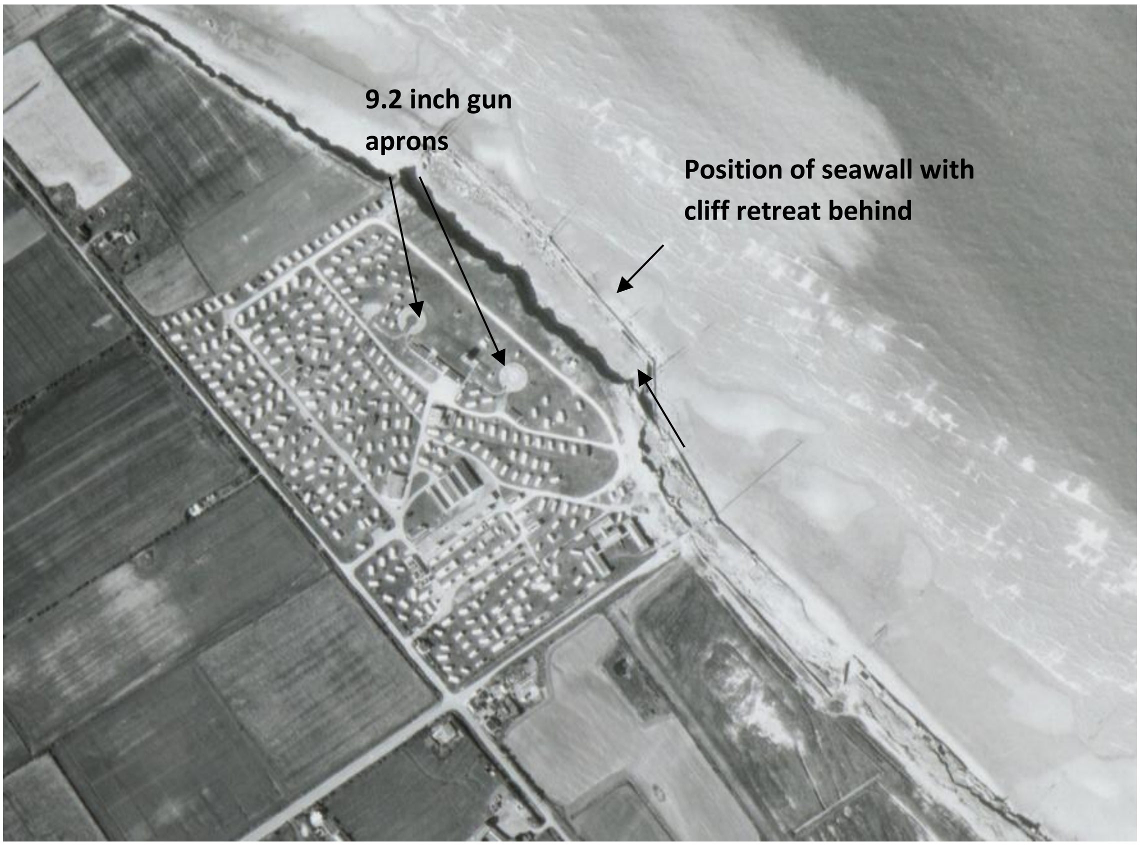


Photo 9 Aerial photograph (6.7.1977); original scale 1:10,500 (source: Air Images Ltd.)

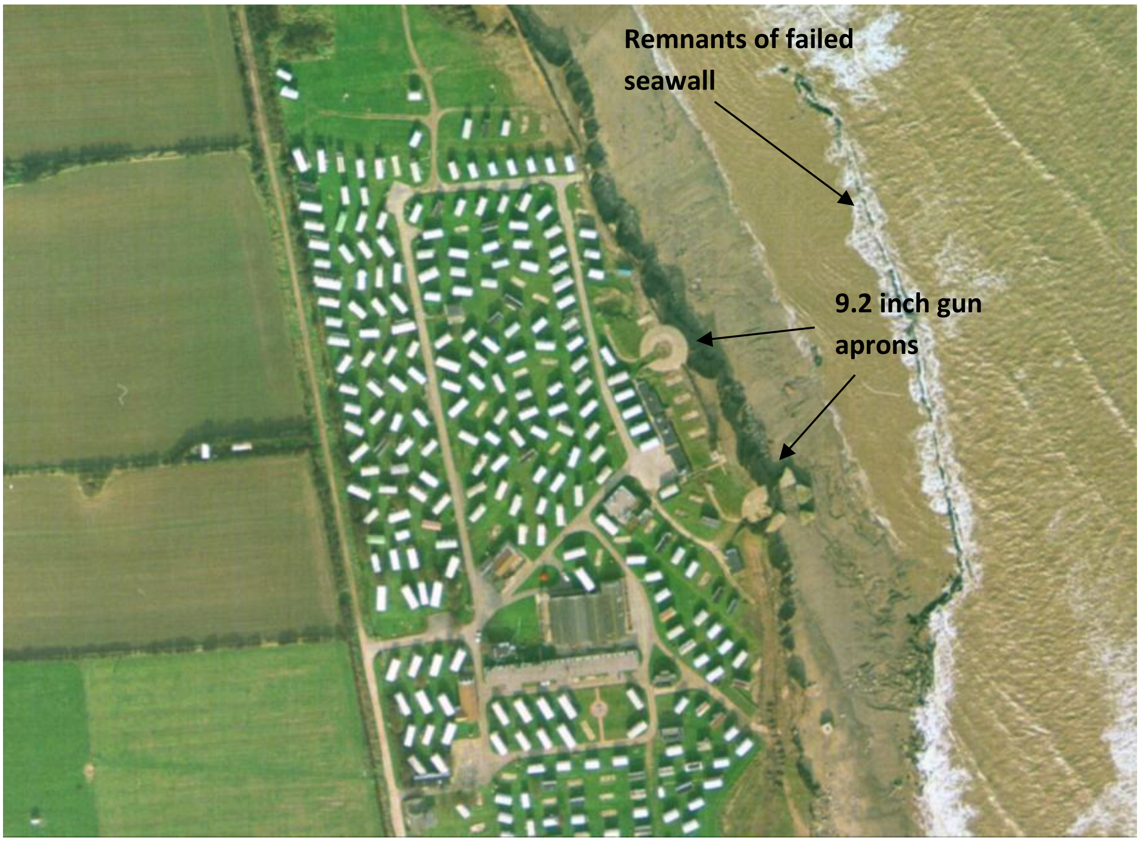


Photo 10 Aerial photograph (2.11.1994); original scale 1:10,000 (source: www,oldaerialphotos.com)

Photo 11 Aerial photograph (8.5.1999); original scale 1:10,000 (source: www.getmapping.com)

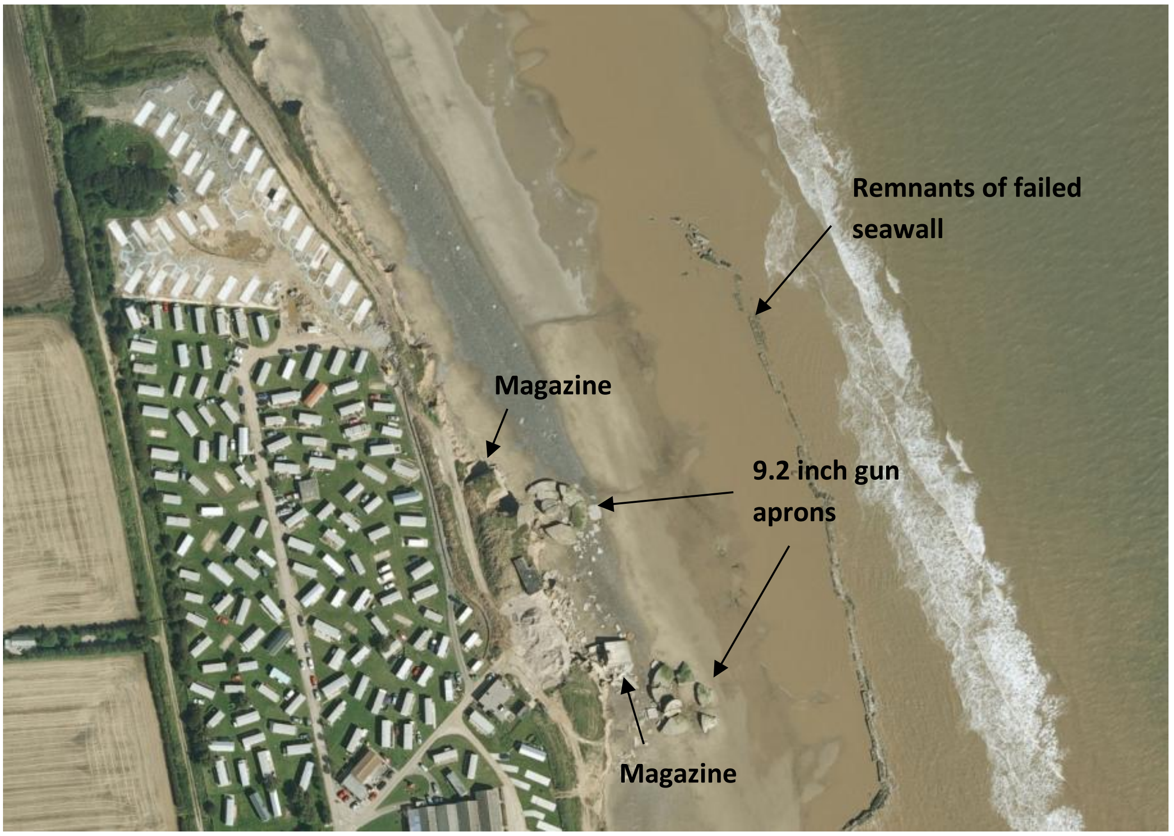


Photo 12 Aerial photograph (27.8.2007); original scale 1:10,000 (source: www.getmapping.com)

Photo 13 Aerial photograph (2.5.2008); original scale 1:10,000 (source: www.ukaerialphotos.com)

4 The Current Condition (April 2012)

As of April 2012 the foreshore is littered with large blocks of mass concrete from the Battery, including the two 9.2 inch gun mountings and aprons, the magazines, the battery observation posts (BOPs) and blockhouses, along with parts of buildings "S" and "W" on Figure 1 (see Photos 14 to 19). Much of the ruins are concentrated on a 120m long section between the two gun aprons. There are no more major concrete structures from the Battery to be lost (Figure 4).

Photo 14 The mounting for the southern 9.2 inch gun; it is surrounded by pieces of the concrete apron

Photo 17 The apron and mounting for the northern 9.2 inch gun (the magazine is on the right)

Photo 15 The magazine for the southern 9.2 inch gun

Photo 18 Remains of a concrete building (possibly the southern BOP blockhouse)

Photo 16 Sections of the old seawall and brickwork rubble, south of the southern 9.2 inch gun apron

Photo 19 Concrete and brickwork rubble on the foreshore, between the two 9.2 inch gun aprons

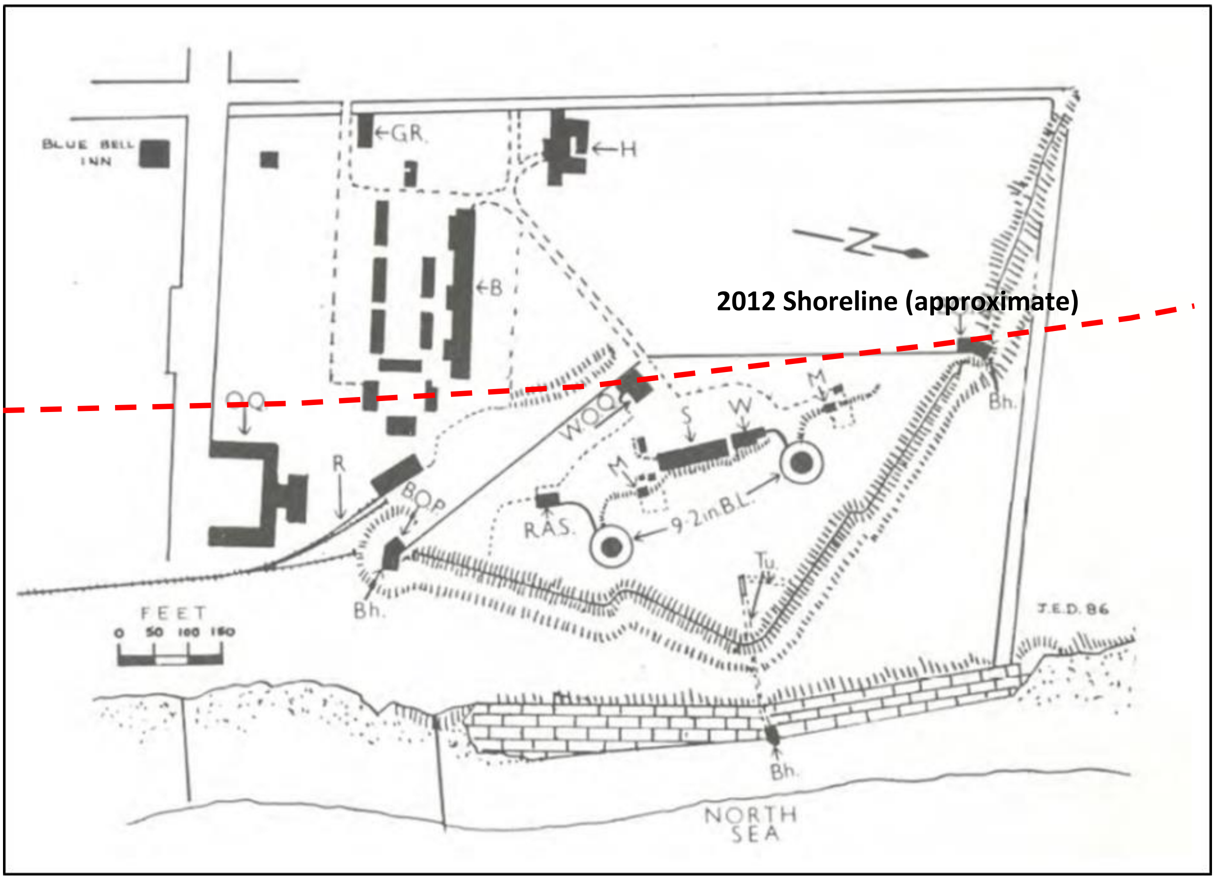


Figure 4 Approximate position of the shoreline in 2012 (red line), highlighting the loss of all of the major concrete structures. Some of the buildings shown landward of the red line have been demolished during the conversion of the site into a caravan park (base plan from Dorman 1990).

5 Cliff Recession at the Battery

The recession distances at Points A-C between the 1956 map (Figure 2) and the series of aerial photographs are presented in Table 1 (note that, the maps and photos have not been rectified and, hence, recession distances are approximate). Average annual recession rates over the time periods covered are presented in Table 2.

Table 1 Godwin Battery: approximate recession distances at Points A-C for time periods between 1956 and 2008.

Point	1956-1969	1969-1977	1977-1994	1994-1999	1999-2008
A	33m	7m	55m	26m	10m
B	10m	21m	49m	24m	4m
C	5m	12m	50m	36m	10m

Table 2 Godwin Battery: average annual recession rates (m/year) at Points A-C for time periods between the mid-1960s and 2008.

Point	Mid-1960s-1969*	1969-1977	1977-1994	1994-1999	1999-2008
A	8.3 m/year	0.9 m/year	3.2 m/year	5.2 m/year	1.1 m/year
B	2.5 m/year	2.6 m/year	2.9 m/year	4.8 m/year	0.4 m/year
C	1.3 m/year	1.5 m/year	2.9 m/year	7.2 m/year	1.1 m/year

Note: * assumes that seawall failure and renewed cliff recession occurred in the mid-1960s

From the field visit in April 2012, it was clear that the mass concrete blocks on the foreshore do not prevent wave attack at the cliff foot, and that cliff recession is on-going (Photo 20).

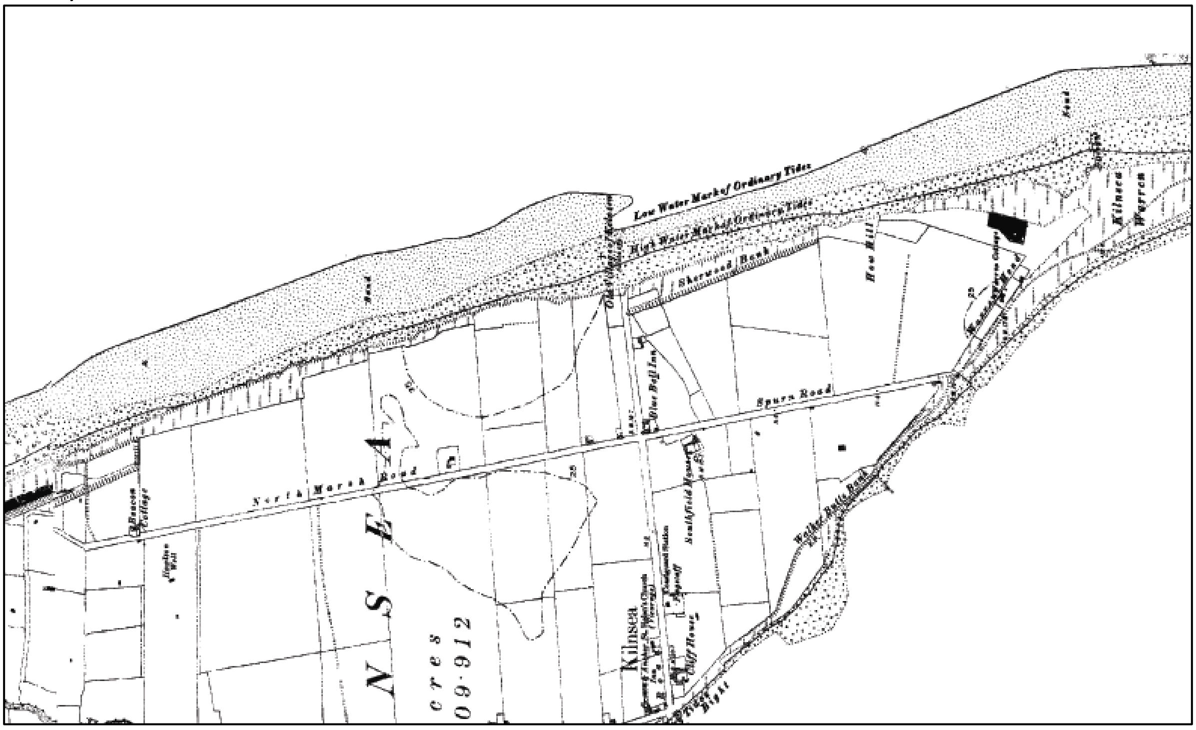
Photo 20 Exposed cliff face behind the northern 9.2 inch gun apron

From the sequence of maps and aerial photographs it is possible to define a number of phases of cliffline development along the 300 yard section in front of the Battery since WWI:

- 1915 to mid-1960s; the cliffline was protected by a seawall and groynes. No (or negligible) cliff top recession;
- mid-1960s to 1993/99; failure of the seawall leading to rapid cliff recession (between 3m and 7m/year) and loss of land in front of the 9.2 inch gun aprons;
- 1999 to present day; the mass concrete blocks on the foreshore from the gun aprons magazines and buildings provide some protection to the cliffs, resulted in lower recession rates (<1m/year).

6 The Emergence of the Battery Headland

Since 1915, the cliffline in front of the Battery (Point B on Figure 2) has retreated around 110 - 130m. The cliffline would have been expected to have retreated further if the defences had not been constructed, matching the recession of the adjacent unprotected cliffs. The result has been the formation of a small headland. If it is assumed that, if unprotected, the 2km long cliffline between the southern end of the Easington Lagoons to the Warren would have developed as a straight line (as it almost was in 1892; Figure 5), then the Battery headland currently projects in front of this cliffline by



around 60-70m at its maximum point (Photo 21).

Figure 5 County Series map: 1892 (Original scale 1: 10,560).showing the almost straight coastline between the future site of Easington lagoons and the Warren

Photo 21 The Battery headland, projecting seaward from a hypothetical 2km long straight cliffline (the red line) between the Easington Lagoons and the Warren (note that the shoreline has been rotated through 90°; image source: Google Earth, image date 2008)

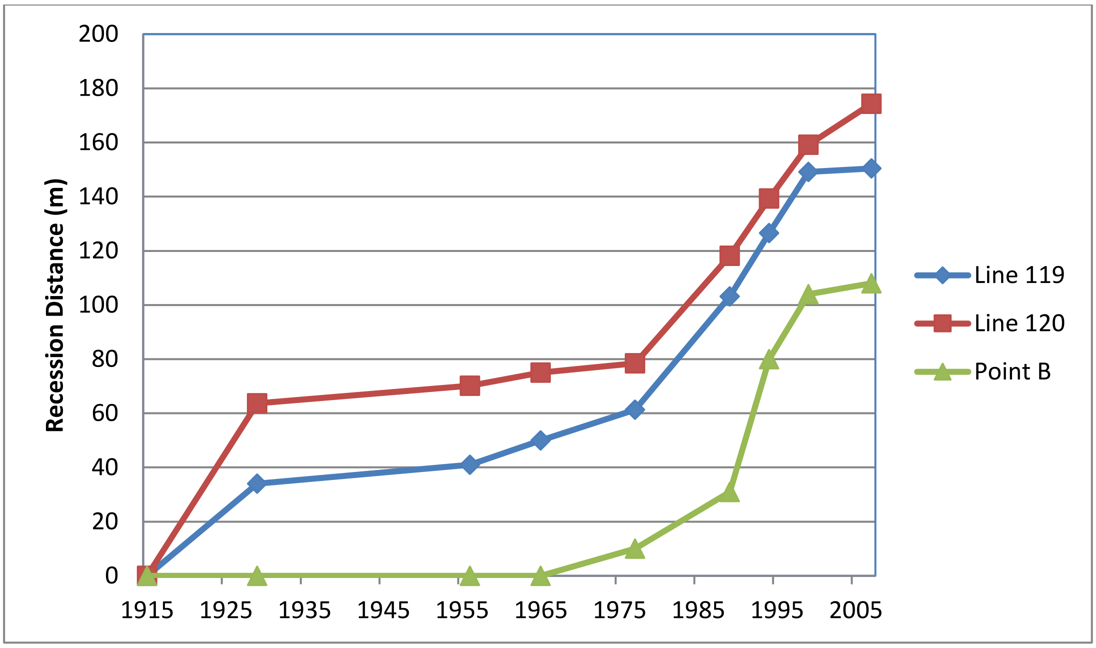


Figure 6 A comparison between the recession distance at Point B (Godwin Battery) and ERYC erosion lines immediately north and south of the Battery site (using the seawall construction date, 1915, as a baseline).

An indication of the recession distance since WWI immediately north and south (Lines 119 and 120, respectively[3]) of Point B at the Battery (see Figures 1 and 2) is shown in Figure 6. This suggests that prior to seawall failure (around 1965) Point B (on the headland) was around 50m seaward of Line 119 and 75m seaward of Point 120. By around 1994, Point B was 47m seaward of Line 119 and 59m seaward Line 120, indicating that there had been only minor "catch-up" since seawall failure. Since the concrete structures collapsed onto the foreshore in the early-mid 1990s the position of Point B seaward of these 2 profile lines has remained broadly similar (Table 3). This clearly indicates that since seawall failure there have been relatively consistent recession rates along the entire frontage and that the section in front of the Battery has remained as a headland.

It is expected that the existing mass concrete ruins will remain largely intact on the foreshore for the next 50 years or so. They will almost certainly influence wave attack and cliff recession over the 120m section within which the debris is concentrated. However, as the cliffs continue to retreat, the ruins will be left lower and lower down the beach relative to the cliff foot (the seawall was at HWM in the 1960s and is now close to LWM). As a result, the influence on wave attack will progressively decline to a point where the impact on the recession rates will be insignificant, probably within 20-25 years. Over time, perhaps 50-100 years, the headland will be gradually removed, leaving a straight cliffline between the Easington Lagoons and the Warren.

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[3] This analysis uses the East Riding of Yorkshire Council (ERYC) data set of long-term cliff recession measurements at 123 profile line locations along the Holderness coast (note that profile locations are different from the ERYC Erosion Post locations). This data set has been compiled by the Council using a combination of historical maps and, since 2000, GPS survey measurements. Godwin Battery lies between lines 119 and 120 (see Photo 18). The data set is available from:
http://www.eastriding.gov.uk/coastalexplorer/pdf/cliff_erosion_results.pdf

Table 3 Position of Point B since seawall failure, relative to the adjacent shoreline.

Date	Point B position seaward of Profile Line	
	119	120
1965	50	75
1989	72	87
1994	47	59
1999/2000	46	55
2007	49	66

7 Historical Impact of Godwin Battery Sea Defences on the Adjacent Shoreline

The impact of the Battery on the at-site (i.e. along the Battery frontage) shoreline processes can be summarised as follows:

- pre 1914/15 the Kilnsea frontage was unprotected with unrestricted southwards sediment transport towards Spurn;
- 1914/15 to the mid-1960s a concrete seawall and groynes protected the Battery (300 yard section); sediment transport southwards restricted by groynes. Cessation of sediment supply from the cliffline in front of the Battery (300 yard section);
- mid-1960s to the early 1990s, failure and collapse of the sea defences; removal of restrictions on southwards sediment transport. Increased sediment yield from rapidly eroding cliffs in front of the Battery site;
- early 1990s to present day, concrete ruins on the foreshore providing some protection to the cliffs over a 120m section. Reduced cliff recession rates and sediment supply from this short section. No significant restriction on southwards sediment transport (the ruins do not present a complete cross-shore barrier to sediment transport).

The impact of the Battery on the regional sediment budget is likely to be trivial. An estimated 3-4Mm^3/year of sediment is supplied to the coastal zone by Holderness cliff recession, shore platform lowering and seabed erosion (Balson et al 1996, 1998; Balson and Philpott, 2004). The contribution from the 300m long cliffline in front of the Battery is probably <5,000m^3/year (<0.1% of the sediment budget).

The impact on longshore sediment transport could be more significant. Based on experience elsewhere on the Holderness coast, coast protection works can be expected to influence shoreline development in two related ways (e.g. IECS 1991, 1994; Figure 7):

- trapping sediment within and immediately updrift of the groyne field. This results in increased beach volume on the northern side of the works, enhanced “natural” cliff toe protection and reduced cliff recession rates. The reverse occurs on the downdrift side of the works, with the groynes disrupting longshore sediment transport, leading to accelerated cliff recession.

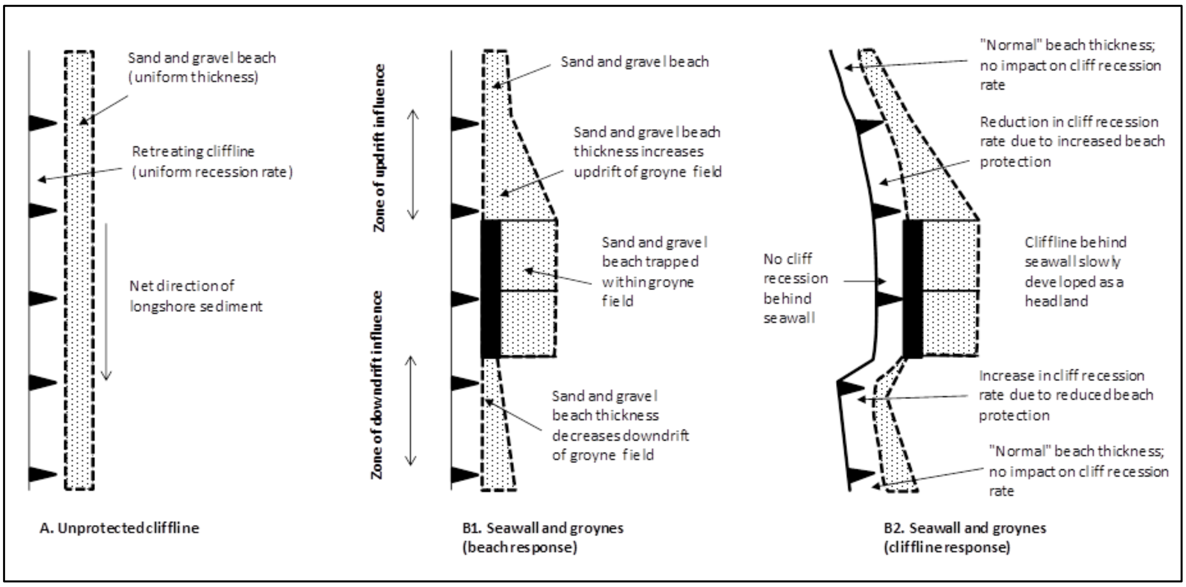


Figure 7 Schematic model highlighting the impact of coast protection works (seawall and groynes) on shoreline development

- modification of local sediment transport rates. The contrast between no cliff recession behind the seawall and continued cliff recession on the adjacent unprotected cliffline eventually results in the emergence of a hard-point (headland). On the updrift side of this hard-point, the shoreline orientation slowly rotates anti-clockwise, resulting in a decrease in longshore sediment transport rate and beach accretion (see Pethick, 1996). On the downdrift side, the shoreline rotates clockwise, sediment transport rates increase and beach volumes decline. The updrift and downdrift shoreline orientation changes lead to a local decreases and increases in cliff recession rate, respectively.

Along the Holderness coast, zones of reduced cliff recession occur immediately north of hard-points (due to sand accumulation and beach growth), with zones of accelerated erosion developing to the south. For example, differences in recession rates of between 1.9 - 2.4m/year have been recorded between the cliffs at similar distances to the north and south of the Hornsea defences (Posford Duvivier 1993). IECS (1991, 1994) analysed historical records and erosion post data, and concluded that the Hornsea and Withernsea defences had led to the development of a zone of accelerated erosion which extended at least 10km south of the groynes from both of these locations[4].

It would be expected that the Battery seawall and groynes (1914/15 to the mid-1960s), and concrete ruins (1993/97 onwards) might have trapped sediment and acted as hard-points, influencing the local shoreline orientation and processes to the north and south (Figure 8). One test of the impact of the Battery would be determine whether there are significant differences in recession rate to the north and south of the frontage. A model of the possible impact is presented in Figure 9, with recession rates shown for hypothetical erosion lines, spaced 1km apart, to the north (N) and south (S) of the battery:

- to the north, the zone of reduced cliff recession occurs between lines 1N and 3N, after which the rate returns to a nominal 2m/year;
- to the south, the zone of increased cliff recession occurs between lines 1S and 3S, after which the rate returns to a nominal 2m/year.

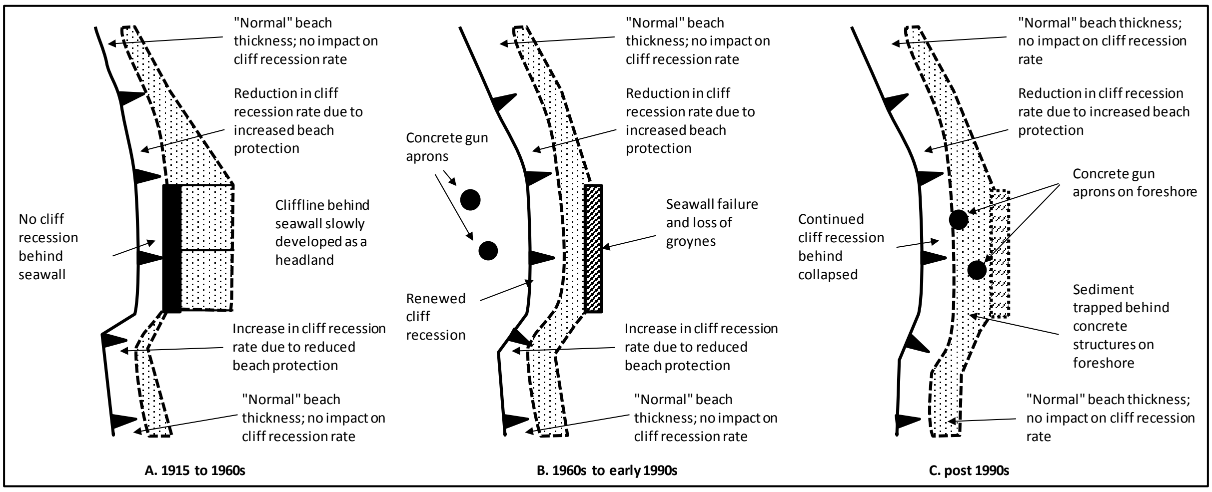


Figure 8 Schematic model highlighting the impact of Godwin Battery on shoreline development

The recession distance and average annual rates (1854-2007) for lines south of Easington (113 to 123) are shown in Figure 10:

- the largest recession distance (434m) occurs immediately N of the Battery site (line 118);

[4] At Easington Gas Terminal, Royal Haskoning (2004) concluded that there were no indications of any significant effect of the defence works on shoreline development at that time. It was also concluded that a build up of sediment is expected to the north of the defences as the structure, in time, will stand forward of the adjacent cliff.

- recession distances between lines 119 and 122 appear broadly similar, in the range 300-360m, and are higher than the rates measured south of Easington (lines 113 and 114).
- long-term (1854-2007) recession rates are typically in the range 1.8-2.8m/year, with a lower rate around 1m/year at Spurn neck (line 123).

This model has been tested using the East Riding of Yorkshire Council (ERYC) data set of long-term cliff recession measurements at 123 profile line locations (note that profile locations are different from the ERYC Erosion Post locations). Godwin Battery lies between lines 119 and 120 (see Photo 18).

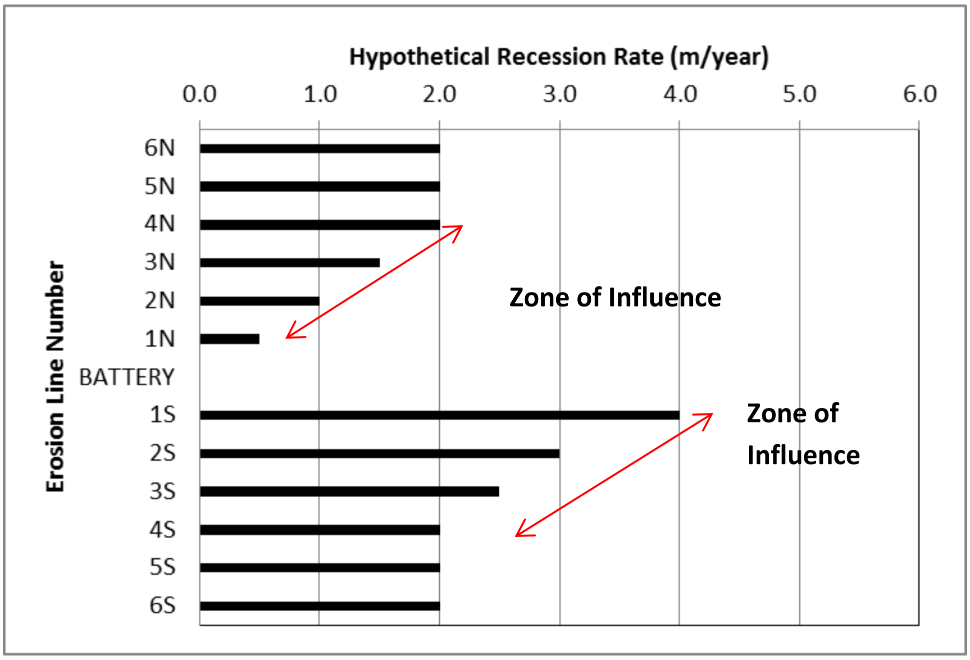
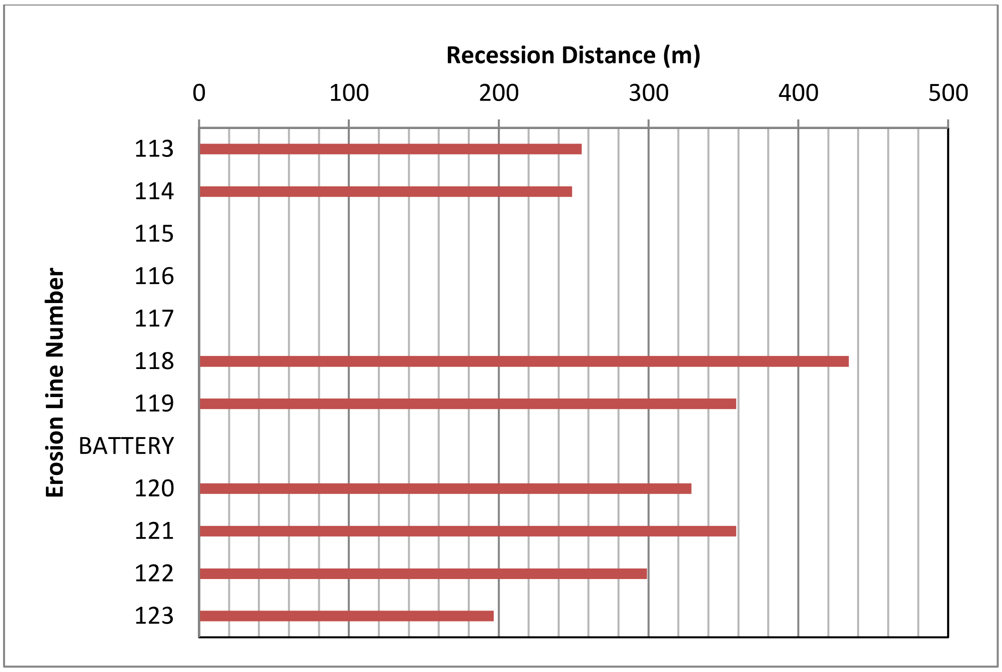


Figure 9 Hypothetical recession rates at erosion lines along the shoreline to the north and south of the Battery. This has been compiled to illustrate the expected effects of the hard-point on shoreline development.

Photo 22 East Riding of Yorkshire Council erosion profile line locations (note that the shoreline has been rotated through 90°; image source: Google Earth)



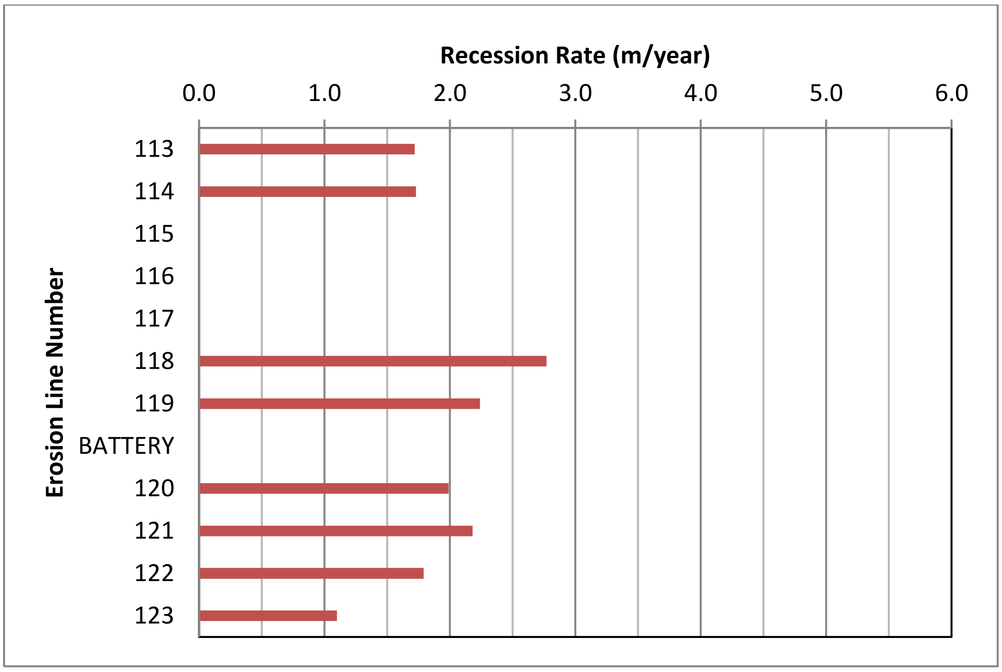


Figure 10 Long-term recession distances and rates south of Easington (1854-2007; adapted from ERYC data)

113 To south of Easington defences (540501 419058); Cliff Height 7.9m
114 Opposite Seaside Rd to south of Easington (540711 418604); Cliff Height 6.8m
115 to 117 Easington/Kilnsea Dunes;
118 South end of Lagoon/Dune SSSI, Kilnsea (541375 416719); Cliff Height 4.5m
119 North of old MOD site, Kilnsea (541569 416258); Cliff Height 7.8m
120 South of Blue Bell, Kilnsea (541714 415785); Cliff Height 4.3m
121 Between Kilnsea and Spurn (541855 415324); Cliff Height 6.1m
122 North end of Spurn (542001 414846); Cliff Height 5.4m
123 At neck point on Spurn peninsular

Figure 11 presents the average recession rates (m/year) at each of the lines over 3 approximately 50-year periods covered by the data series: 1854-1909; 1909-1956; 1956-2007. These periods broadly correspond with the unprotected, protected and deteriorating phases along the Battery frontage. The results indicate:

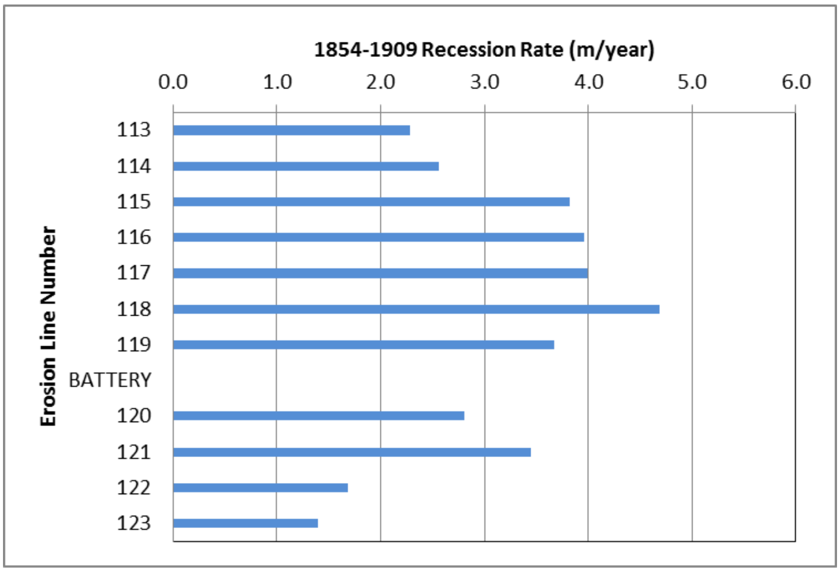
- recession rates are highest (typically 2-4+m/year) in the period 1854-1909. This is so for lines both N and S of the Battery frontage. The exceptions are at the Spurn neck, where the highest rates occur in the period 1956-2007 (probably concentrated in the early 1990s).
- recession rates are lowest (typically 1-1.5m/year) in the period 1909-1956. During this period, the recession rate immediately south of the Battery defences (line 120, 0.9m/year) is higher than immediately to the north (line 120, 1.5m/year), as might have been expected if the seawall section was acting as a hard-point.
- during the period 1909-1956, the rate at line 121 (around 1km south of the seawall) is significantly lower than at line 119 (0.25m/year compared with 0.9m/year). This suggest that the zone of accelerated erosion south of the seawall and groynes was <1km long;
- over the same period, the rate at line 118 (around 0.6km north of the seawall) is higher than at line 119 (1.16m/year compared with 0.9m/year), suggesting that the influence of the hard point decreased between these two lines;
- since 1956 there appears to have been a doubling in the recession rates for lines south of Easington lagoons (118-123). Rates immediately to the north and south of the Battery frontage are similar, with 2.27m/year at line 119 and 2.04m/year at line 120. This suggests that shoreline development was no longer being influenced by the seawall hard-point.

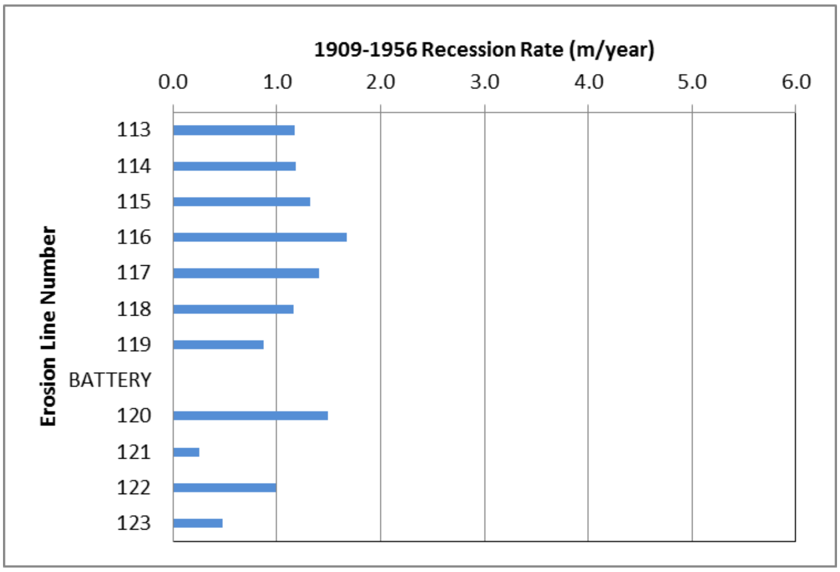
A more detailed breakdown of recession rates at the line sites for the period 1956-2007 is presented in Figure 12. This reveals a more complex picture:

- rates are highly variable between the different time periods, highlighting episodes of accelerated erosion (e.g. 1994-1997) and relatively low erosion (e.g. 1997-2000, 2000-2007).
- over the periods 1997-2000 and 2000-2007, the contrast between the lower rates at line 119 (0.4m/year and 0.9m/year, respectively) than those at line 120 (3.31m/ear and 2.15m/year) probably reflects the influence of the mass concrete ruins acting as a hard point.
- over the same periods, the rates at line 121 (2.23m/year and 0.76m/year, respectively) are significantly lower than those at line 120, suggesting that the zone of accelerated erosion south of the concrete ruins is limited in length. The combination of seawall and groynes is likely to have had a larger zone of influence than the concrete ruins.

In summary, there is evidence that the seawall (1914/15 to the mid-1960s) and then the concrete ruins (1993/97 to present day) have acted as hard points on the shoreline. However, their zone of direct influence on cliff recession rates is likely to have been <1km to the north and the south.

Further evidence of the limited extent of the hard point influence at the Battery comes from the recent Environment Agency study of long-term erosion rates along the Easington lagoon frontage (Beach, 2006; Black and Veatch Ltd 2008). The long-term trends (Table 4) indicate a progressive increase in recession rates between the northern end of the lagoons (1.5m/year) and the Battery (2.1m/year), with the highest rates recorded in the middle of the southern lagoon (2.9m/year). It is possible that the decrease in erosion rates between the middle of the Southern Lagoon (2.9m/year) and the Battery (2.1m/year) might be related to the influence of the seawall and, latterly, the concrete ruins. If this was the case, then the northern limit to the zone of influence would be between 0.5-1km.





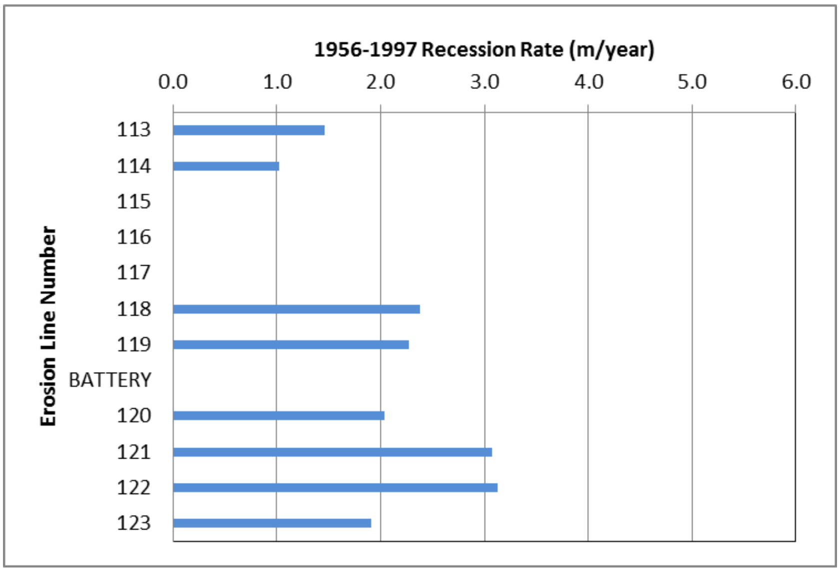


Figure 11 Cliff recession rates over approximately 50-year time periods (1854-1909, 1909-1956, 1956-2007; adapted from ERYC data)

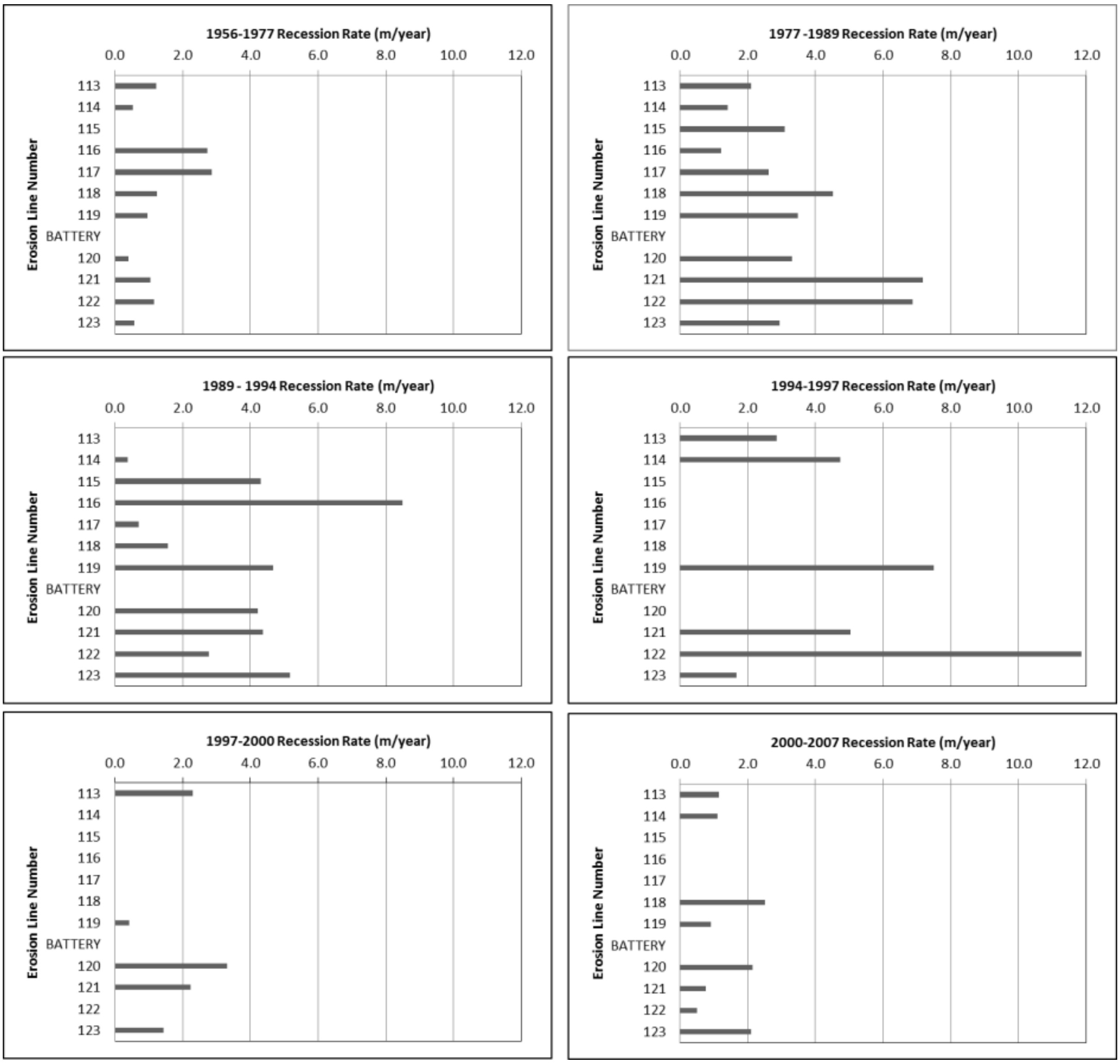


Figure 12 Cliff recession rates over various time periods between 1956 and 2007 (adapted from HDC data)

Table 4 Long-term erosion trends between Easington Lagoons and the Godwin Battery site (from Black and Veatch Ltd., 2008)

Location	Long-term rate (m/year)
At WWII lookout north of the Northern Lagoon	1.5
North of Northern Lagoon	1.5
At separating break in Northern Lagoon	2.35
At the end of relic Long Bank	2.35
Between Northern and Southern Lagoons	2.36
Middle of Southern Lagoon	2.9
South of Southern Lagoon	2.01
Godwin Battery ruins	2.1

8 Future Impact of Godwin Battery on Easington Lagoons

The Easington Lagoons lie 0.8km to the north of the Battery site. The mosaic of saline shallow and deep water areas, bare sand and shingle, sand dune and transitional saltmarsh support a diverse flora and fauna. As a result, the lagoons form part of the proposed extension to the Humber Flats, Marshes and Coast Special Protection Area (SPA) and Ramsar site (the Humber Estuary SPA and Ramsar) and are also designated as a Site of Special Scientific Interest for their national importance (Black and Veatch Ltd. 2008).

The Northern Lagoon is thought to occupy a borrow pit that was used to win material for the construction of the New Bank sea defence in 1954 (Sheader and Sheader 1998). The previous defence line, the Long Bank, had been breached during the 1953 floods. The Southern Lagoon borrow pit was created in 1977/8 to win material for subsequent raising of the maintained section of Long Bank and the New Bank. It is separated from the Northern Lagoon by an old section of the Long Bank.

The lagoons are fronted by a low sand and gravel barrier beach. Sections of the barrier beach in front of the Southern Lagoon can be overtopped by waves on an annual basis (Black and Veatch Ltd 2008). Most of the barrier is vulnerable to crest scour subject to 1 in 1 year storm conditions. In March 2007 the Southern Lagoon breached (a 1 in 5 year return period combination of wave height and water level).

As discussed in the previous section, zones of reduced erosion can occur north of hard-points on the Holderness coast. As the hard point projects further out from the coast, so there is a gradual anticlockwise re-orientation of the shoreline on the northern side. This leads to a reduction in the southwards longshore sediment transport at that location, and beach growth updrift of the northern end of the hard point (e.g. Pethick 1996). This zone of higher than "normal" beach levels extends as a tapering wedge for >5km north of the defences (seawalls and groynes) at both Hornsea and Withernsea (e.g. HECAG SMP2).

At the Battery, there are no groynes to actively trap sand and shingle along the frontage and any beach growth is dependent on the slow change in shoreline orientation updrift of the ruins. An indication of the beach trends between Easington (line 113) and the Battery ruins (line 119) is presented in Figure 13. This has been derived from ERYC beach monitoring data for a single date, September 2011 (available from: http://www.eastriding.gov.uk/coastalexplorer/lines.html). The beach area has been calculated as the cross-sectional line area of beach material above MHW neap tides (+1.55m). The results indicate that the beach cross sectional area (a measure of beach volume for a 1m wide profile) declines from line 119 (north of the Battery ruins) to line 117 (in front of the middle of the Southern Lagoon). This suggests that, in September 2011, the tapering wedge updrift of the concrete ruins only reached the southern end of the lagoons.

The hard point at the Battery is expected to be present for another 20-25 years, until the concrete deteriorates or lies too far down the beach line to have a significant effect on recession rates. During this time it will probably influence beach volumes to the north. However, it is unlikely that this influence will extend to providing enhanced levels of protection along the lagoons frontage.

The lagoons will have been lost by erosion before the hard point has been removed and the battery frontage "catches-up" with the adjacent cliflines. As reported by Black and Veatch Ltd (2008) continuing coastal erosion is likely to lead to the lagoon-barrier beach system impinging on the line of flood defences (New Bank and remaining parts of the Long Bank), with the loss of all supporting habitat attributes by 2037. The Environment Agency has recently been addressing this issue through the provision of compensatory habitat in Kilnsea. The presence of the concrete ruins on the Battery foreshore is unlikely to change the timing this prediction.

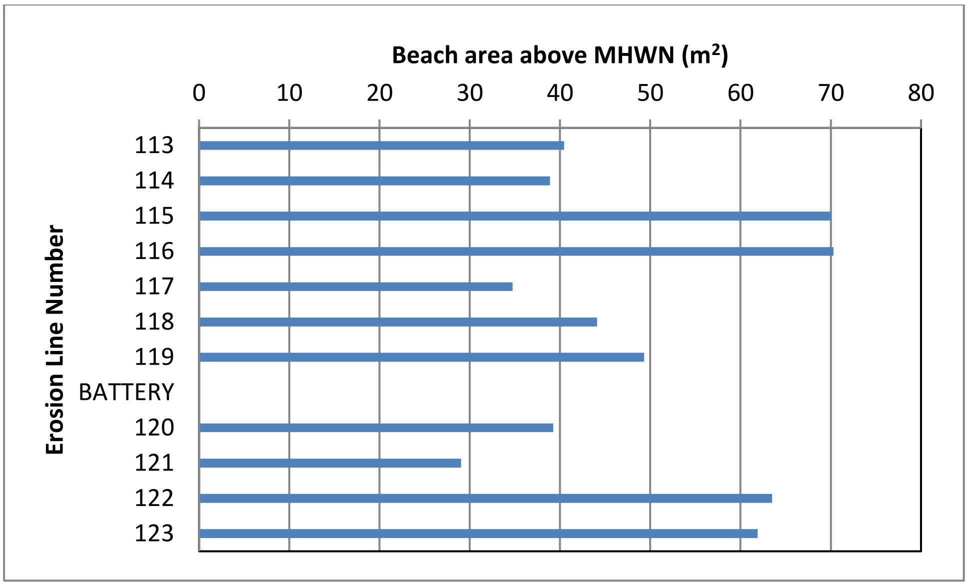


Figure 13 Beach area (September 2011) at profiles between Easington and Spurn (data from ERYC)

9 Future Impact of Godwin Battery Sea Defences on Spurn

Spurn is a curved, sand and gravel barrier capped with low dunes, at the mouth of the Humber[5]. It comprises a broad, >350m wide, head (IECS 1992 suggest a series of islands) which is connected to the mainland at Kilnsea Warren by a narrow, <50m wide, neck (the "narrows"). The crest height varies from around 4m OD at the neck to over 10m on parts of the head (Figure 14).

The barrier is underlain by estuarine intertidal deposits and a platform of glacial till which slopes in a southerly direction from -1.0m OD near Kilnsea to -20m OD near the head (Balson, 2008). The volume of supratidal sediment in the barrier has been estimated at 5M m^3, while the total volume of sediment above the till platform could be as much as 50-100M m^3 (Balson and Philpott, 2004).

IECS (1992) suggested that 2 till ridges are superimposed on the general trend of the till platform: beneath the head (the Outer Ridge, linking to the Stony Binks) and on a line between the Old Den and the Binks (the Inner Ridge). These ridges "anchor" the barrier in place (IECS, 1992). This would imply that Spurn comprises 2 distinct sections; a series of connected "islands" formed by the accumulation of coarse sediment behind and protected by the ridges, and a barrier (the neck) connecting this feature to the Holderness cliffline. An important difference between these two sections is that the barrier is free to erode and retreat, whereas the "islands" are anchored. However, the presence of the till ridges has not been supported by more recent borehole evidence (Balson, 2008).

Spurn acts as a barrier which impedes the progression of storm surges and waves into the Humber estuary and is a base for the Humber Pilots, the Associated British Ports Vessel Traffic Services centre and the RNLI lifeboat station. Access to these facilities is by means of a single track road. The barrier has been identified as a geomorphological feature of national importance in the JNCC Geological Conservation Review (May, 2003), and has numerous other nature conservation and environmental designations, including NNR, SSSI and Heritage Coast. In a review of the threats to its Humber assets, ABP (2011) state that the EA is confident that the barrier will not breach in the short to medium term, and consider that it will continue to provide protection to the Humber mouth for at least 40 years without any active intervention.

The classic model of the evolution of Spurn was presented by de Boer (1964, 1969). He suggested Spurn went through of regular phases of growth (spit lengthening and narrowing), breaching and redevelopment further westwards on a 250 year cycle, with major breach events occurring around 1360, 1600 and 1849. The trigger for the breakdown was the instability caused by progressive spit lengthening and narrowing. This model is still widely cited in text books, but has not stood the test of time (e.g. IECS, 1992).

A re-appraisal of the evidence undertaken as part of this study demonstrates that Spurn does not appear to have had a history of repeated breaching and reformation (see Table A.1):

- Ravenser Odd seems to have been lost during a long period (50 years) of sustained erosion between around 1300 and 1350 rather than in a sudden breach event;

[5] Further details on the geology, geomorphology and processes operating at Spurn can be found in IECS (1992), Saye et al. (2005); Pye et al. (2007), ABPMer, 2008).

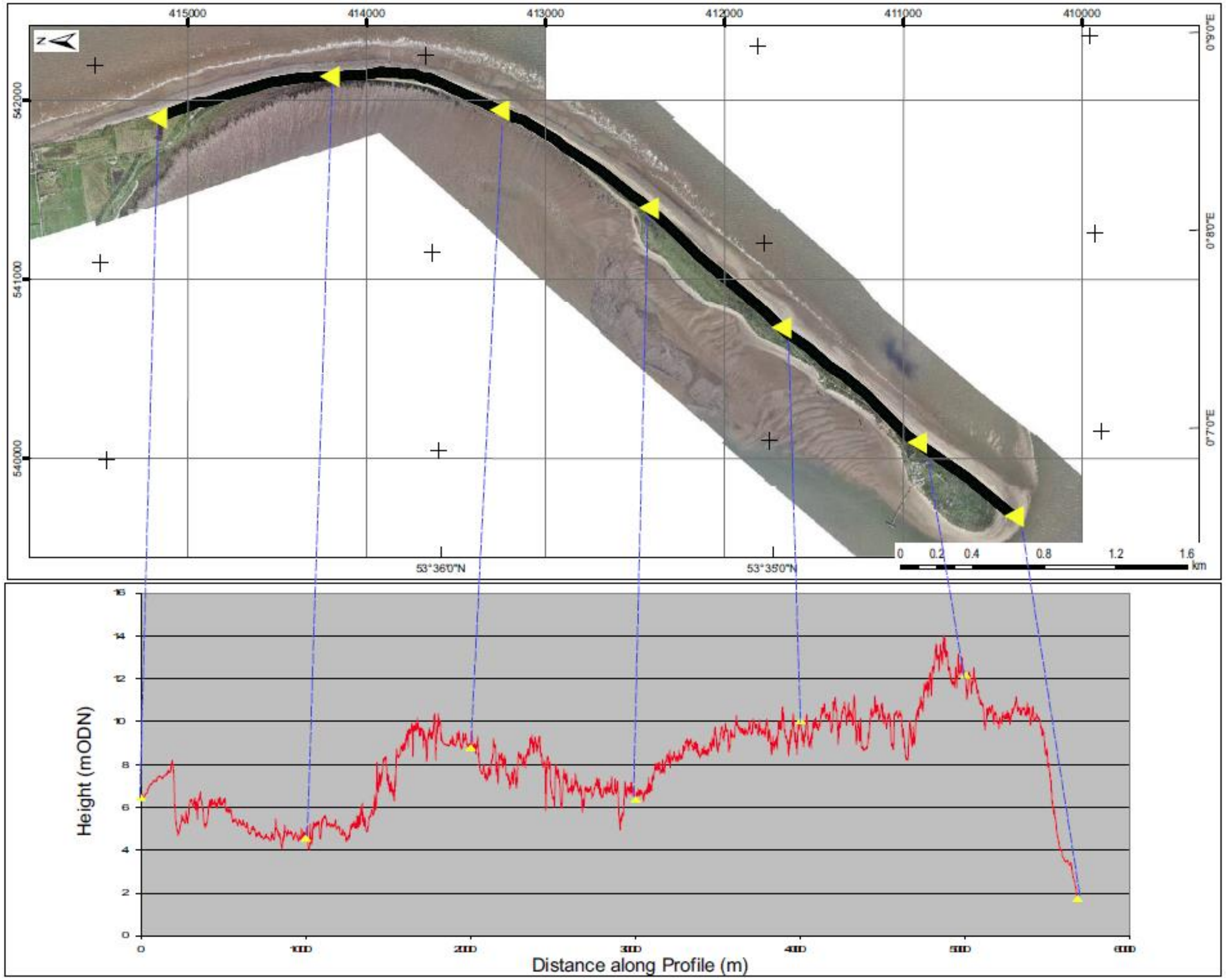


Figure 14 2007 LiDAR profile along Spurn (from ABPMer 2008)

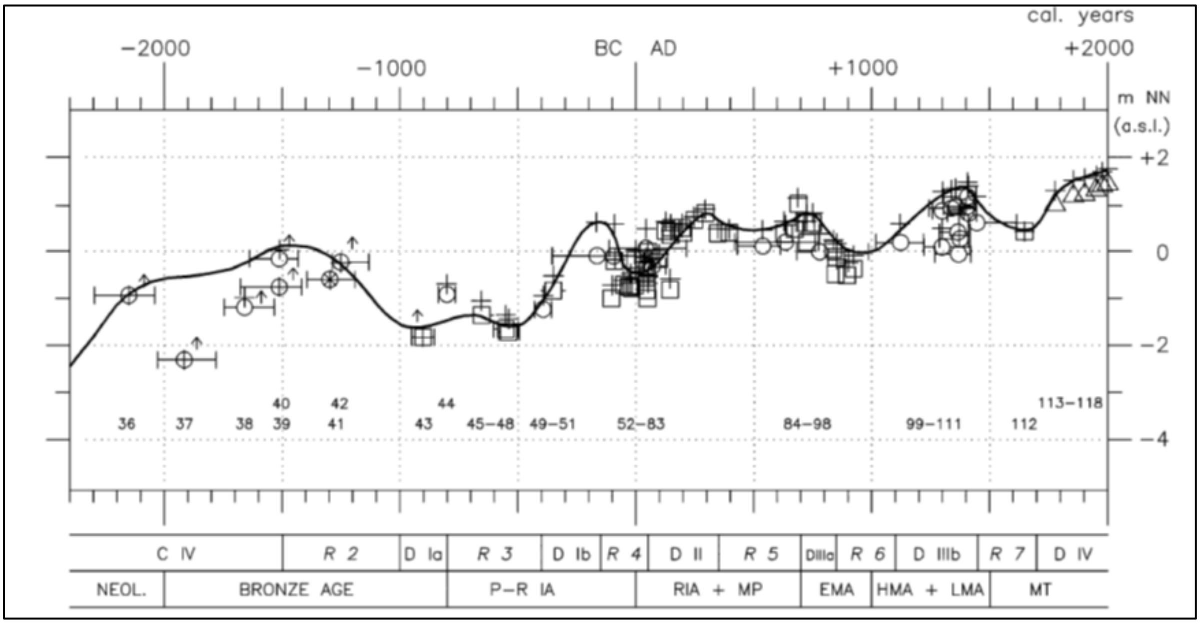


Figure 15 A Holocene sea-level curve for the southern North Sea (from Behre, 2007). The 14C dates the end of transgression D IIIb was at c. AD 1450, and was followed by Regression R7 The MHW decreased rapidly and reached a minimum at AD 1644. The final rise of the MHW, the Dunkirk IV transgression began around AD 1700.

- the evidence of breaching around 1600-1620 is limited to Callis' 1622 comment (at second hand, at least) and local testimony (80 years later) that an island was torn from land. However, the main features of the Spurn complex: the continuous spit, head, the Den and Stony Binks are present around 1540 and remain on all maps and charts until the 1849 breach. The island referred to is probably the Den (first labelled in 1671). The emergence of Den during the early 17th century may be related to a general 1m fall in sea-level during the Little Ice Age, between around 1450 and 1640 (Figure 15; Behre, 2007). The late 17th to 18th century decline in size of the Den may have been related to the subsequent rise in sea-level;
- Vetch (1850) records that there had been a breach in 1789/90, possibly near Kilnsea, through which a vessel had sailed. The breach healed naturally. However, de Boer (1964) cites evidence that "*the sea broke over the spit in a storm all the way from Kilnsea Warren to Spurn and swept the bents over to the Humber shore where they collected sand and became bent hills*". This description suggests that this might have been a major overwashing event rather than a breach.

There is no dispute that a major breach did occur on 28 December 1849, during a north-westerly gale and high tide that had followed nine calm days. It occurred around half to three-quarters of a mile to the north of the Smeaton lighthouse and resulted in the formation of a channel through which vessels were able to pass at high water (Vetch, 1850; de Boer, 1981). Other breaches occurred further north in 1851 and 1856 (de Boer, 1981).

It seems likely that the breaches (see Table A.3) occurred in response to 18th and 19th century gravel extraction, mainly for road and building construction, the cement industry and also for ships' ballast (20-30,000 m^3/year, around 10Mm^3 in total; see Table A.4). Barrier extension (around 2km between 1674 and the 1850s) may have also caused local sediment budget deficits, promoting neck narrowing (see Table A.5) and shoreline erosion (see Table A.6). This rapid extension may have been initiated by the Little ice Age sea-level fall exposing spreads of inter-tidal gravels which then provided the "foundations" for dune growth (IECS, 1992).

Contrary to the de Boer model, Spurn actually appears to have been a very resilient feature over the last Millennium. The barrier breached in 1849 during a Severity Class IV/V storm[6] (i.e. relatively low severity), having survived many previous major storm events and storm surges[7] (Figures 16 and 17). The period 1920 to the 1960s appears to have been particularly high frequency of major storms and surges. However, there are no reports of breaches. In contrast, the 1840s appears to have occurred within a "calm" period and yet a relatively minor storm initiated a breach in 1849. It seems likely, therefore, that Spurn is more vulnerable to the prolonged effect of sediment budget deficits (caused by gravel extraction) rather than short-term very high energy wave loadings.

The 1849 breach was eventually closed with the construction of two chalk banks. However, the breaches led to increasing concern for the future of the barrier, resulting in further intervention. A series of groynes were constructed in front of the high lighthouse in 1853 and on the eastern shore in 1864 (3 at the breach site and 2 to the north). This resulted in around 36m of beach accretion on the eastern shore between 1964 and 1878. Further groynes were added, so that by 1926 there were groynes at 250m intervals along the entire shoreline of the barrier. Dunes were artificially created along the neck by trapping sand behind brushwood fences inserted into chalk compartments.

Spurn Fort was constructed at the head in 1915 and connected to Godwin Battery by a single-track, narrow gauge railway. The narrow neck was artificially altered into a railway embankment. The railway was dismantled in 1951-52.

A single track access road to the head was constructed in 1942 and protected by a seawall along the neck. In the early 1980s, anti-tank blocks were moved from Kilnsea and placed on the seaward side of the neck. Due to escalating maintenance costs, the decision was taken in 1961 to abandon the defences and allow the natural processes to fashion the shoreline. As these structures, and others, have deteriorated they have become localised hard-points focusing wave erosion and scour events on the adjacent unprotected sections of the barrier. Areas of "damage" can be the focus of future overwashing events and, ultimately, become vulnerable to breach events. Seawall failure occurred progressively between 1989 and 2002/03 and was followed by a period of rapid erosion (40m by late 2007; ABPMer, 2008).

It is widely accepted that Spurn is maintained by sediment supplied from the erosion of the Holderness shoreline. The *potential* longshore sand transport rate southwards, between Hornsea and Easington, is estimated to be between 200,000m^3/year and 350,000m^3/year (HR Wallingford et al., 2002; Posford Duvivier, 1992; IECS 1994a). The highest drift rates are within about 2km of the coast (HR Wallingford 2003).

Estimates of the transport rate into Spurn Point range from 60,000 m^3/year (Ciavola, 1997) to 125,000m^3/year (Valentin 1954) i.e. less than the potential transport rate. It is suspected, therefore, that a significant proportion of the sediment is deflected offshore, south of Withernsea. Halcrow/GeoSea (1990) suggest that up to 60% of the sand may move offshore around Easington, associated with a change in overall shoreline orientation. Large volumes of gravel are stored in the Binks, an area of sand and gravel banks off the head. The volume of gravel and coarse sand in the Binks and New Sand Hole is sufficient to hold about 6000 years supply from Holderness at present day rates of erosion (Balson, 2008).

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[6] In his review of "Historic Storms of the North Sea, British Isles and Northwest Europe" Hubert Lamb (1991) developed a storm severity index, ranging from Class 1 to Class VI. The index was based on the greatest recorded wind speed, the area affected and duration. The most severe storm was 10/12 December 1792, with a severity index score of 10000-20000 (Class I). In contrast the December 1849 storm index score was around 200-300 (Class IV/V).

[7] In a review of the 11 January 1978 storm surge, Steers et al. (1979) presented a list of major North Sea surge events, including the 1953 event. Zong and Tooley (2003) have compiled an inventory of coastal flood events around Britain, including the East Coast sector.

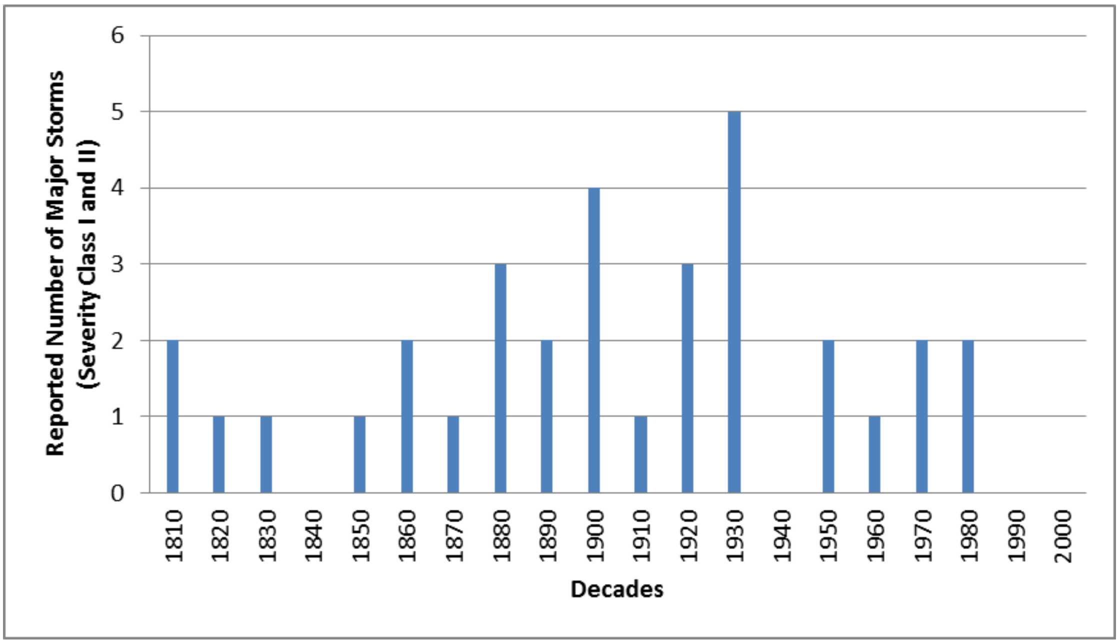

Figure 16 Major North Sea storms (Lamb's Severity Classes I and II) between 1810 and 1990)

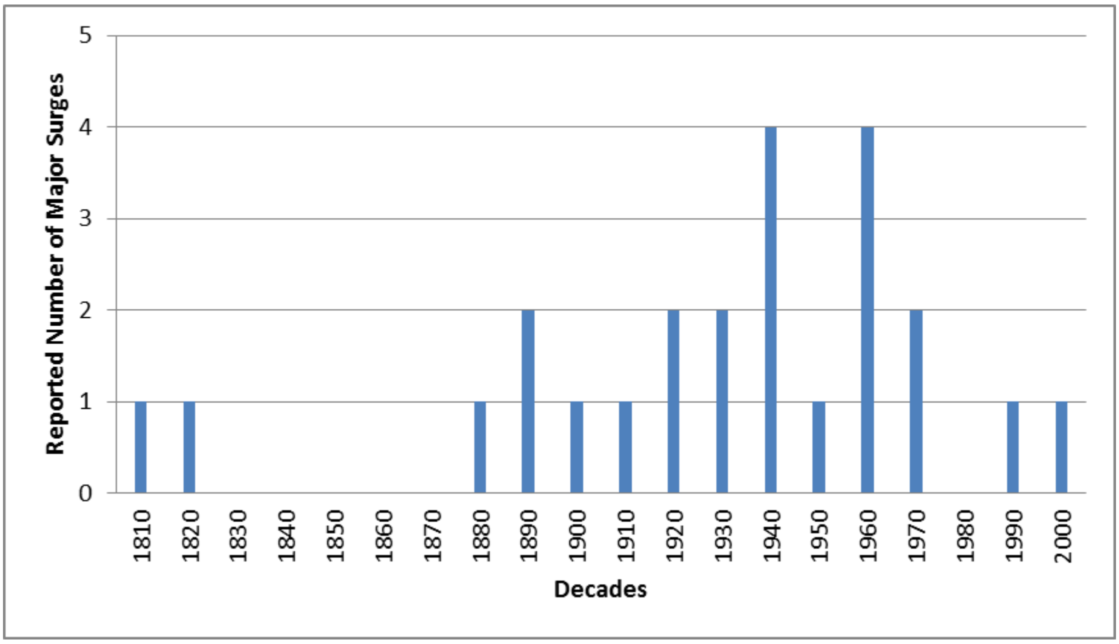

Figure 17 Major North Sea storm surges (mainly from Steers et al, 1979)

Sediment transport onto the west shore (i.e. the Humber side) of Spurn is an integral part of the barrier development and involves:

- longshore sand transport southwards around the tip and then northwards on the estuarine shore, driven by wave action. A low gravel and clay bank on the Humber shore, the Old Den, may restrict sediment transport northwards to the landward side of the neck (IECS, 1992);
- sand transfer from the seaward to Humber shores during overwashing events at the neck. The construction of coastal defences and dunes along the neck is believed to have led to have reduced wash-over frequency from the 1850s to the 1990s (IECS, 1992).

IECS (1992) state that there has been a sediment budget deficit between erosion of the seaward shore and accretion on the west shore (i.e. the Humber side). This had led to neck narrowing and an increase in breach potential.

A key feature of Spurn is that it is connected at the northern end to a retreating cliffline. A critical factor in the long-term integrity of the barrier is, therefore, believed to be the ability for the neck to maintain its position relative to the rapidly retreating cliffline to the north. Historically, this would be achieved by overwashing events transferring material onto the west shore, allowing the neck to "roll-over" itself. However, the construction of defences along the shoreline in the 19th and 20th centuries had the effect of holding the shoreline in place, promoting dune growth and reducing the effectiveness of the wash-over process. IECS (1992) indicate that, since the 19th century, the seaward shore of barrier has retreated at around 0.2-0.5m/year whereas the Kilnsea cliffs have retreated at around 2m/year over the same period. As a result, the connection between the barrier and the cliffline has become increasingly curved over time, making the neck more vulnerable to erosion and, possibly, breaching (IECS 1992). The orientation of the neck changed from NNE (12°) in the early 19th century to NNW (335°) in 1990 (IECS 1992).

The longshore wave power gradients generated by NE waves along the seaward shoreline of Spurn are controlled by the shoreline orientation (Figure 18; adapted from IECS 1992). A positive longshore power gradient (i.e. increasing wave energy) indicates shoreline erosion, whereas a negative gradient (i.e. decreasing wave energy) indicates deposition. On Spurn, maximum erosion for the current shoreline orientation coincides with the northern end of the neck (with a second peak at km 2 close to the southern end of the neck). Maximum accretion is predicted to occur in the centre of the neck (km 1) and on the head (km 4, north of the lighthouse). These energy gradients are believed to have strengthened as a result of the orientation change since the early 19th century (IECS 1992).

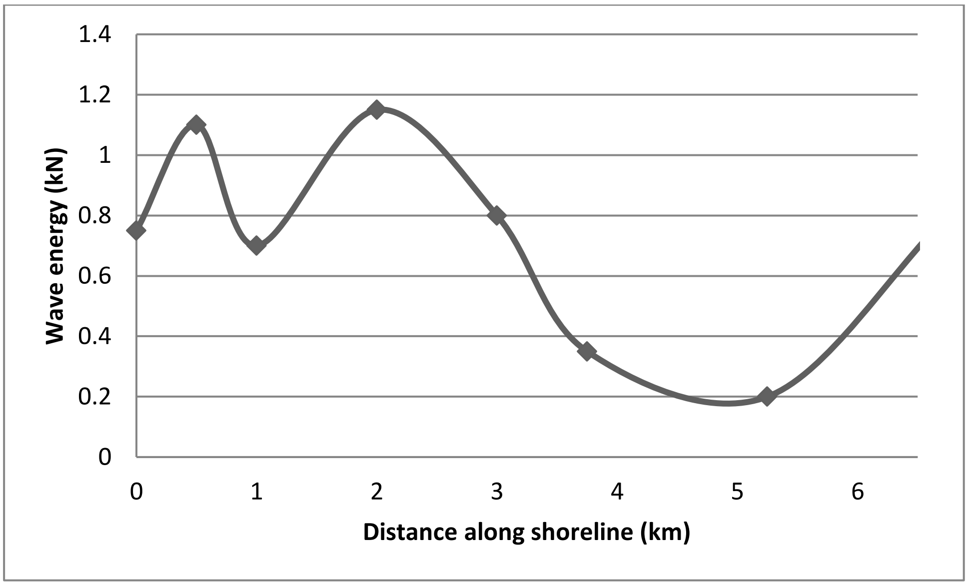

Figure 18 Longshore wave energy gradient along Spurn seaward shoreline (adapted from IECS, 1992)

Following the failure of the 1942 seawall between 1989 and 2002/03, the neck has been frequently overwashed during storm events. This may allow a realignment of this section of Spurn, thereby reducing the angle of Spurn in relation to the Holderness coastline (ABPMer 2008, 2009), and reducing the erosion potential.

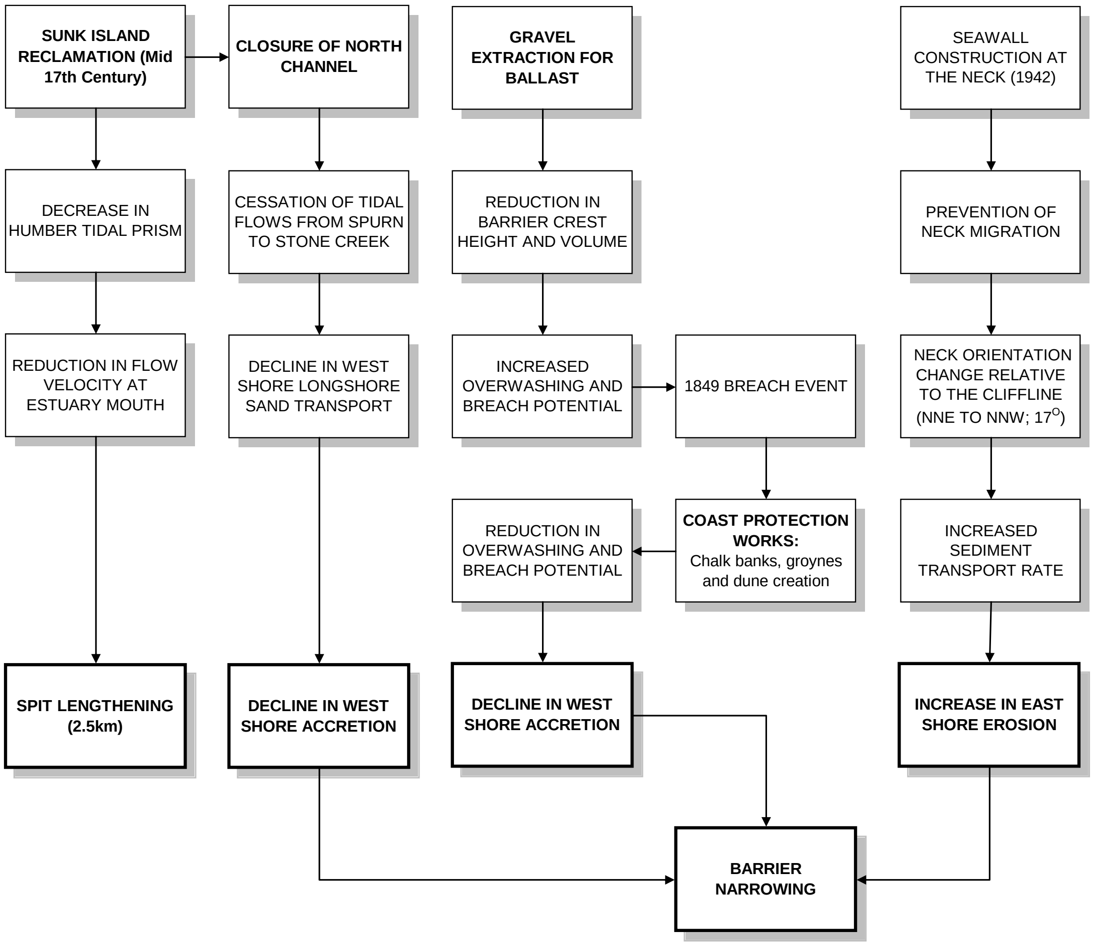

Figure 19 A summary of the man-made causes of contemporary change to Spurn (from Lee, 2009; developed from IECS 1992)

Given the experience elsewhere on the Holderness coast, it might be expected that the Godwin Battery seawall and groynes (1914/15 to the mid-1960s), and concrete ruins (1993/97 onwards) would have trapped sediment and disrupted sediment transport toward Spurn. This may have been the case, but it is does not appear to have been as significant as other factors influencing the development of Spurn over this time period. Indeed, the main controls on the development of Spurn over the last few centuries have been (Figure 19):

- the decline in west shore accretion, resulting from reduced overwashing potential caused by dune creation and coastal defence works, and the long-term changes in sediment transport on the west shore associated with 19th century land reclamation in the Humber[8];
- an increase in the seaward shore erosion that can be linked to the construction of coastal defences and the resulting changing orientation of the neck relative to the cliffline.

Following the failure of the Battery seawall in the mid 1960s there was a period of increased cliff recession rates between the Battery and the Warren (see Section 6). This probably contributed significantly to the long-term change in the orientation of the neck relative to the cliffline. However, other factors have been important in causing this change, most notably the construction of the seawall along the neck in 1942, which prevented shoreline retreat. Indeed, it was the collapse of the

[8] The reclamation of Sunk Island (40km^2) resulted in a major reduction in the hydraulic cross section of the Humber (28% of the inter-tidal area). The reclamation also closed off the North Channel, changing the tidal circulation at Spurn Bight. Within the 20 years the channel in Spurn Bight had silted up.

neck seawall from 1989 onwards that initiated a major period of shoreline erosion along the neck (40m between 2002/03 and late 2007; ABPMer, 2008, 2009).

The concrete ruins of the gun aprons and other structures are expected to remain on the foreshore for another 50 years or more, causing some disruption to longshore sediment transport and modification of local cliff recession rates. However, this will probably be a far less significant influence on Spurn than the predicted impact of relative sea-level rise and climate change (e.g. ABPMer 2008).

In summary, the neck is considered to be vulnerable to breaching that would sever Spurn from the mainland (e.g. IECS 1992, ABPMer 2008). This vulnerability is largely the legacy of the way in which Spurn was managed after the breaches between 1849 and 1856:

- the artificial creation of dunes along the neck raised the crest height and prevented the overwashing transfer of sediment to the Humber shoreline;
- northwards longshore sediment transport on the Humber shoreline was constrained by the construction of chalk banks to heal the breaches, preventing sediment build up on the western side of the neck;
- the construction of a groyne field and, in 1942, a seawall at the neck prevented seaward shore retreat. This led to a marked change in the orientation of the neck relative to the cliffline to the north and accelerated shoreline erosion on this section.

Changes in the sediment supply to Spurn from the Holderness cliffs do not appear to have been a significant driver of shoreline change over the last century. Spurn is more sensitive to how the neck has been managed rather than relatively minor changes in the local sediment transport regime associated with the construction of Godwin Battery and its subsequent collapse onto the foreshore. It seems unlikely that the loss of Godwin Battery will have any noticeable effect on the potential for breaching at Spurn. In the future, the effectiveness of the management approach of promoting overwashing at the neck will be critical, especially if relative sea-level rise matches the predictions.

10 Summary and Conclusions

10.1 Historical Development

Godwin Battery was constructed in 1914-1915 as part of the outer Humber wartime defences. The battery included two 9.2 inch breech loading (BL) guns mounted in circular concrete pits, approximately 100 m apart. Between the guns were underground magazines (the roof was 5 foot thick), crew shelters and workshops. On the right and left of the battery were two battery observation posts (BOP), one housing a 30' Barr and Stroud rangefinder. Both BOP's had defensive blockhouses built into their base. The barrack accommodation was constructed of brick and concrete, these included a guard house, officers' quarters and a hospital. The battery was protected by a 300 yard long seawall with a concrete blockhouse in the centre. Wooden groynes were constructed on the foreshore.

The 9.2 inch guns were removed from their mountings at the end of 1944 and finally scrapped in 1948. A military presence remained at Godwin Battery until the late 1950s when the battery was put up for sale (Photo 5). It was sold in 1960 and turned into the "Sandy Beaches" caravan site. At the time of the sale, the sea defences were in good condition.

The seawall in front of the Battery failed at some time between 1960 and 1969, triggering the renewal of cliff recession. In the early 1990s, the southern 9.2 inch gun apron had collapsed onto the foreshore. By 1999 the northern gun apron was on the foreshore. As of April 2012 the foreshore is littered with large blocks of mass concrete from the Battery, including the two 9.2 inch gun mountings and aprons, the magazines, the battery observation posts (BOPs) and blockhouses, along with parts of other buildings. Much of the ruins are concentrated on a 120m long section between the two gun aprons. There are no more major concrete structures from the Battery to be lost. The mass concrete blocks on the foreshore do not prevent wave attack at the cliff foot, and that cliff recession is on-going.

10.2 The Battery Headland

Along the Battery frontage there has been between 110m and 130m of cliff top recession since the failure of the seawall in the mid 1960s. The cliffline would have been expected to have retreated further if the defences had not been constructed, matching the recession of the adjacent unprotected cliffs. The result has been the formation of a small headland. If it is assumed that, if unprotected, the 2km long cliffline between the southern end of the Easington Lagoons to the Warren would have developed as a straight line (as it almost was in 1892), then the Battery headland (i.e. a "hard point") currently projects in front of this cliffline by around 60-70m at its maximum point.

A comparison of the recession distances at Point B at the Battery with ERYC erosion lines on the adjacent shoreline indicates that since seawall failure in the mid 1960s there have been relatively consistent recession rates along the entire frontage and that the section in front of the Battery has remained as a headland i.e. there has been no significant "catch-up".

It is expected that the existing mass concrete ruins will remain largely intact on the foreshore for the next 50 years or so. They will almost certainly influence wave attack and cliff recession over the 120m section within which the debris is concentrated. However, as the cliffs continue to retreat, the ruins will be left lower and lower down the beach relative to the cliff foot (the seawall was at HWM in the 1960s and is now close to LWM). As a result, the influence on wave attack will progressively decline to a point where the impact on the recession rates will be insignificant, probably within 20-25 years. Over time, perhaps 50-100 years, the headland will be removed, leaving a straight cliffline between the Easington Lagoons and the Warren.

10.3 Impact on the Adjacent Shoreline

Based on experience elsewhere on the Holderness coast, coast protection works can be expected to influence shoreline development in two related ways:

- trapping sediment within and immediately updrift of the groyne field. This results in increased beach volume on the northern side of the works, enhanced “natural” cliff toe protection and reduced cliff recession rates. The reverse occurs on the downdrift side of the works, with the groynes disrupting longshore sediment transport, leading to accelerated cliff recession.
- modification of local sediment transport rates. The contrast between no cliff recession behind the seawall and continued cliff recession on the adjacent unprotected cliffline eventually results in the emergence of a hard-point (headland). On the updrift side of this hard-point, the shoreline orientation slowly rotates anti-clockwise, resulting in a decrease in longshore sediment transport rate and beach accretion. On the downdrift side, the shoreline rotates clockwise, sediment transport rates increase and beach volumes decline. The updrift and downdrift shoreline orientation changes lead to a local decreases and increases in cliff recession rate, respectively.

It would be expected that the Battery seawall and groynes (1914/15 to the mid-1960s), and concrete ruins (early 1990s onwards) might have trapped sediment and acted as hard-points, influencing the local shoreline orientation and processes to the north and south. There is evidence that the seawall (1914/15 to the mid-1960s) and then the concrete ruins (early 1990s to present day) have acted as hard points on the shoreline. However, their zone of direct influence on cliff recession rates is likely to have been <1km to the north and the south.

The Easington Lagoons lie 0.8km to the north of the Battery site. ERYC beach monitoring data indicate that the beach cross sectional area (a measure of beach volume for a 1m wide profile) declines from north of the Battery ruins (line 119) to in front of the middle of the Southern Lagoon (line 117). This suggests that although the Battery ruins has probably influenced beach levels, this tapering wedge updrift of the concrete ruins only reaches the southern end of the lagoons.

The lagoons will have been lost by erosion before the headland has been removed and the battery frontage “catches-up” with the adjacent clifflines. As reported by Black and Veatch Ltd (2008) continuing coastal erosion is likely to lead to the lagoon-barrier beach system impinging on the line of flood defences (New Bank and remaining parts of the Long Bank), with the loss of all supporting habitat attributes by 2037. The presence of the concrete ruins on the Battery foreshore is unlikely to change the timing this prediction.

To the south of the Battery, the Spurn is considered to be vulnerable to breaching at the narrow neck (e.g. IECS 1992, ABPMer 2008, 2009). This vulnerability is largely the legacy of the way in which Spurn was managed after the breaches between 1849 and 1856:

- the artificial creation of dunes along the neck raised the crest height and prevented the overwashing transfer of sediment to the Humber shoreline;
- northwards longshore sediment transport on the Humber shoreline was constrained by the construction of chalk banks to heal the breaches, preventing sediment build up on the western side of the neck;
- the construction of a groyne field and, in 1942, a seawall at the neck prevented seaward shore retreat. This led to a marked change in the orientation of the neck relative to the cliffline to the north and accelerated shoreline erosion on this section.

Changes in the sediment supply to Spurn from the Holderness cliffs do not appear to have been a significant driver of shoreline change over the last century. Spurn is more sensitive to how the neck has been managed rather than relatively minor changes in the local sediment transport regime associated with the construction of Godwin Battery and its subsequent collapse onto the foreshore.

It seems unlikely that the loss of Godwin Battery will have any noticeable effect on the potential for breaching at Spurn. In the future, the effectiveness of the management approach of promoting overwashing at the neck will be critical, especially if relative sea-level rise matches the predictions.

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Table A.1 Evidence for the early breaches (1360 and 1620)

Date	Notes	Comment/Interpretation	Source
1235-1290	Ravenser Odd: "by the casting up of the sea, a certain small island was born" (1290 inquisition) "occupying a position in the utmost limits of Holderness, between the waters of the sea and those of the Humber, was distant from the main land a space of 1 mile and more. … having a breadth which an archer can scarcely shoot across" (Chronicle of Meaux)	Chronicle of Meaux suggests Ravenser Odd was at the end of a continuous spit (1.5 miles long, 250 yards wide*). These are similar dimensions to those shown on Collins' chart of 1684.	de Boer 1964 (p82)
1310-1362	Erosion of Ravenser Odd: by 1346 2 thirds of the town had been destroyed. Further erosion in 1350-1355 exposed the graves in St Mary's chapel. Exceptionally high tides led to the evacuation of the town (Chronicle of Meaux) Henry IV lands in 1399 and was met by a single hermit.	De Boer uses this to indicate a breach, but appears more likely to be a period of sustained erosion, similar to that experienced between the 1660s and 1850s.	de Boer 1964 (p82-83)
c.1540	Chart of the Humber shows a continuous elongate spit with a lobate head (Ravens Spurn), an island/bank to the SW (the Den?) and an island/bank to the S (the Stony Binks)	The main features appear to be present at this time.	de Boer 1969 (Plate II)
1608	J W Bleau's Chart shows a lobate spit (Spurn), extensive banks around the head, but no island.		de Boer 1969 (Plate III)
1612	J W Bleau's The Light of Navigation: pilot book for sailing into the Humber makes reference to Ravenspurre, the north point of the Humber (i.e. Spurn Point), but no islands.	Spurn Point is present and is a clear navigation feature.	de Boer 1964 (p77)
1622	Robert Callis "as of late years did parcels of the Spurnhead Yorkshire which before did adhere to the continent was torn therefrom by	Implies that an island was cut off from the mainland (possibly a breach). But this is a	Shelford 1869 (p476)

	the sea and is now in the nature of an island”	secondary reference and may be an unreliable source of local knowledge. The island is probably the Den.	de Boer 1964 (p76)
1623	J W Bleau’s The Sea Mirror: “you must saile alongst the shore to the north point, but coming by the point you must keepe somewhat off from the shore in 4 or 5 fathom, for to avoyde a little taile which lyeth off the point, being about it, runne to the little island which lyeth a little by west that foresaid north point”	It is likely that: North Point = Spurn Point Little taile = the Stony Binks Little island = the Den	de Boer 1964 (p77)
1623	J W Bleau’s Chart shows a lobate spit (Spurn) and an island to the SW (probably the Den)		de Boer 1969 (Plate III)
1671	J Seller’s Chart shows a lobate spit (Spurn) and a circular island to the SW (labelled as The Denn)		de Boer 1969 (Plate III)
1673	J Seller’s Chart shows an elongate tapering spit (Spurn) and a circular island close to the distal end (labelled as The Denn)	The Chart implies a period of rapid spit lengthening since the 1623 Chart (and the 1671 Chart).	de Boer 1969 (Plate III)
1684	Greenvile Collins Chart shows a “spoon-like” head to Spurn connected to the mainland by a very narrow neck. An island is shown W of the point (the Den) with the Stony Binks to the S and SE. Angell’s lighthouses are shown on the head.		Greenvile Collins 1683
1684/1695	Local testimony (recalled from 80 years previously): “Ravensey Spurn had been swept into the Humber about 80 years previously”, leaving a little island. Contradicted by testimony that stated that the island was the Den.	The testimony was part of a land dispute.	De Boer 1964 (p76-77)

Notes: * The old English mile was around 1.5 miles; an archer’s range was between 180 and 250 yards.

- Ravenser Odd seems to have been lost during a long period (50 years) of sustained erosion rather than in a sudden breach event;
- the main features of the Spurn complex: the continuous spit, head, the Den and Stony Binks are present around 1540 and remain on all maps and charts until the 1849 breach;
- evidence of breaching around 1610-1620 is limited to Callis' 1622 comment (at second hand, at least) and local testimony (80 years later) that an island was torn from land;
- the island in navigation charts and pilot books is probably the Den (first labelled 1671). Whether it was a remnant caused by breaching or an emerging feature associated with RSL fall is not clear.

Table A.2 Changes at the Den (1650-1786)

Date	Note	Source
c. 1650	The Den was 7-8 acres at HW, with 60 acres exposed at LW and had "scoggs and bushes".	de Boer 1964 (p78)
c. 1675	The Den was 5-6 acres at HW, covered with sea bent.	de Boer 1964 (p78)
1695	The Den was 0.5 acre in size, overwashed at HWS or high seas,	de Boer 1964 (p78)
1786	The Den only dried out at LWS.	de Boer 1964 (p78)

Notes:

- the Den emergence and submergence may be related to Little Ice Age RSL fall

Table A.3 The 1849 breach major erosion events and coastal defences (1703 to present day)

Date	Note	Source	North Sea Storm
1703	November 1703: the lighthouse keeper believed the tower would be blown down. No record of breaching or major overwashing.	de Boer 1968 (p37)	Severity Class I event "The Great Storm"
1789	February 1789: the sea broke over the neck and carried sand and bent grass over onto the Humber shore where new dunes ("bent hills") were formed (event recalled around 1850)	de Boer 1964 (p79)	No major storm listed in Lamb's catalogue.
1849-1855	28 December 1849: a significant breach was formed in the barrier just to the south of the Inner Ridge of glacial till. The 1849 breach developed into a 60m wide channel with a maximum depth of 5 m at low water. This breach was eventually sealed by placing of timber piles and Chalk rubble in 1855 and 1870. A smaller and shallower breach was formed about 1 km to the north in 1850 and a further breach formed on the neck in 1855.	de Boer, 1981	Severity Class IV/V in Lamb's catalogue
1869/70 – 1875	Shoreline accretion post installation of groynes by Coode in 1864 : "the gain of land eastward along the entire length of the neck varying from 30-80 yards in width, or an average of 6 yards per annum". The Chalk Bank was built across the site of the major breach inside the curved line of the previous chalk rubble.	Pickwell 1878 (p192)	N/A
1883/84	Timber revetment was added to the seaward side of High Bents	ABPMer 2008	
1942	Construction of a concrete road and seawall along part of the neck. Storm surge undermined the railway. 30 yards of track suspended in the air.	Hartley and Frost, 1981 Pringle 2003	No major storm listed in Lamb's catalogue.

1953	January 1953: lifeboatmens's cottages damaged by water from the Humber side. No reported breach of Spurn. No serious damage to seaward side.	Pringle 2003 Crowther 2006	Severity Class I event: the "East Coast floods"
1960	January 1960: "an ord centred at the neck enable2 periods of N storm waves with storm surges at high spring tides to breach the landward end of a groyne, undermine and breach 9.3m of the nearby revetment wall and remove 8.4m of sand dunes behind it. This left the concrete road only 4m from the edge of a high dune cliff".	Pringle 2003	No major storm listed in Lamb's catalogue.
1978	11 January 1978: major storm at the peak of spring tides. The Point was cut off when the military road was damaged. At Chalk Bank the tide was level with the top of the bank. Anti-tank blocks were moved and placed on the seaward side of the Narrow Neck. A new tarmac road was alid to the west of the earlier road.	Pringle 2003 Crowther 2006	Severity Class III event
1983	February 1983: gales seriously damaged the spit, causing concern it might breach. Questions raised in Parliament (Hansard HC Deb 21 December 1983 vol 51 cc260-1W).	Hydraulics Research Station Ltd March 1983	Severity Class III event
1988	Road damage led to the construction of a new bypass section.	ABPMer 2008	
1996	February 1996: Nly storm produced a storm surge on high spring tides, leading to marked erosion. At the S end of the neck, 200m of the concrete road was left broken on the beach after the seaward dunes were removed.	Pringle 2003	Not listed in Lamb's catalogue.
2002/03	Collapse of the 1942 seawall.	ABPMer 2008	

Notes:

- Spurn 1849 breach occurred in response to a Severity Class IV/V storm (i.e. relatively low severity), having survived many previous major storm events.
- Spurn has survived subsequent major storms without breaching.

Table A.4 Shingle extraction from Spurn

Date	Note	Interpretation	Source
1693	Earliest reference to cobble extraction at the Binks, for ballast.		ABPMer 2008 (p17)
1800 (?)-1862	Harbour Transfer Act 1862 prohibited the removal of shingle from any portion of the shore at Spurn for a distance of 2.5 miles north from the point. An estimated 25,000 tons/year had been removed from near Kilnsea over the period around 1850. The practice had gone on prior to that period. 20-30 vessels per tide taking 50-80 tons for parish roads. In 1836 the landowner collected charges on 480 loads (around 30,000 tons) 1840-1850 around 40,000 tons/year removed from between north of Withernsea and Spurn.	In the order of 20,000-30,000 m^3/year of shingle removed from south Holderness and Spurn in the early-mid 19th century. Likely to be >1Mm^3 in total (the equivalent to 10 years supply from the entire cliffline to Flamborough).	Pickwell 1878 (p205)
1864-1876	Coode's groynes had trapped an estimated 1.25M tons of shingle (0.9Mm^3).	Shingle supply to Spurn around 1M3/year.	Pickwell 1878 (p207)
1907	A licence was required to remove gravel for any purpose.		ABPMer 2008 (p17)

Table A.5 Spit lengthening: 1674 to 1892 and during the 20th century

Period	Note	Comment	Source
1674-1685	Indenture in 1685 indicates: "Spurn had extended at least 300 yards farther south"	Spit lengthening (0.275m)	de Boer 1964 (p77)
1680-1693	"the utmost point .. has gained ground … within the last 10-12 years considerably"	Spit lengthening (unknown distance)	de Boer 1968 (p37)
1680 (?)-1752	April 1752 survey by Hull Trinity House revealed that "a tract of land about 1 mile long and more than 0.5 mile in breath had grown up at the southern end of Spurn"	Spit lengthening (1.6km) Head widening (0.8km)	de Boer 1968 (p40)
1674-1764	February 1764 report to the Wardens that the point "extended 1 mile 2 chains southwest of the old (Angell) lighthouse"	Spit lengthening (1.65km)	de Boer 1968 (p44)
1674-1766	1766: Smeaton sites new lighthouse 1840 yards south-west of Angell's lighthouse. Considered that Spurn was growing rapidly.	Spit lengthening (1.68km)	de Boer 1968 (p54)
1776-1892	"accretion since then (the construction of the Smeaton lighthouse in 1776) had extended the point half a mile beyond its former position"	Spit lengthening (0.8km)	de Boer 1968 (p66)
1864-1875	"southward extension of 60 yards … or 5.4 yards per annum"	Spite lengthening (0.055km)	Pickwell 1878
1930-1959	Point extended southwards by 260 feet.	Spit lengthening (0.08km)	Dosser quoted in de Boer 1964 (p86)
1900-2000 (?)	Over the last 100 years the peninsula has lengthened by over 200 m (FutureCoast) at up to 7m/year.	Spit lengthening (0.2km)	Halcrow 2002 HR Wallingford 2003

Notes:

- 1674-1766; spit lengthening 1.68km
- 1776-1892; spit lengthening 0.8km
- 1930-1959; spit lengthening 0.08km

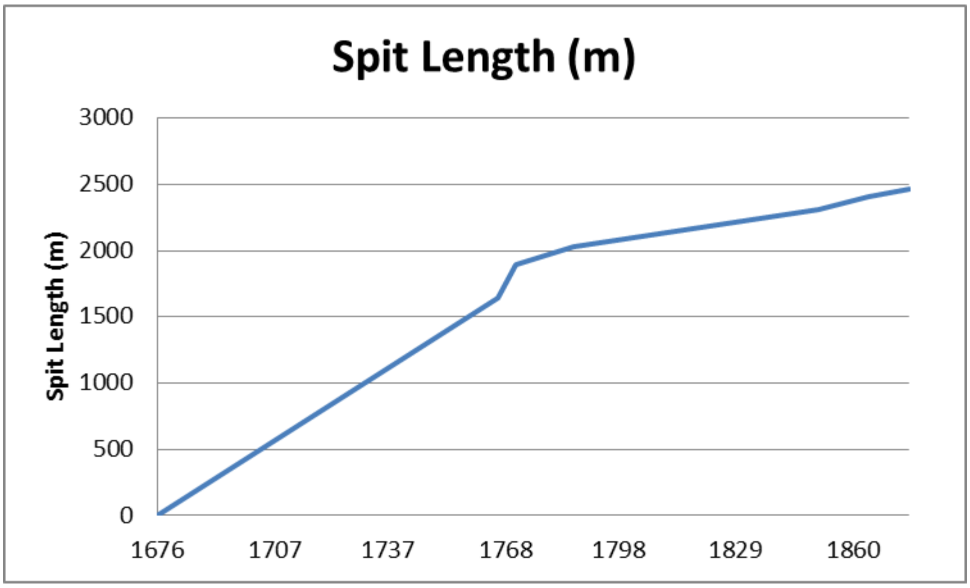
Spit Length (m)
3000
2500
2000
1500
1000
500
0
Spit Length (m)
1676
1707
1737
1768
1798
1829
1860

Table A.6 Shoreline changes around the sites of Angell's and Smeaton's lighthouses (1674-1851)

Period	Note	Comment	Source
1674	Angell's high lighthouse constructed. Low lighthouse sited 210 yds to south-east		de Boer 1968 (p25)
1715	Hull Trinity House noted "the sea have taken away the lower light"	Shoreline retreat (unknown distance)	de Boer 1968 (p37)
1674-1735	By 1735, the lower light had been moved inland to about 135 yards from the high lighthouse	Shoreline retreat (around 70m)	de Boer 1968 (p38)
1735-1752	January 1752; "the low light was washed down and so much ground carried away that it is doubtful whether it could be set up again in the same place"	Shoreline retreat (around 45m)	de Boer 1968 (p39)
1752-1753	"a temporary accretion at Spurn … made it possible in the early part of 1753 for the low light to be moved further out to a distance of 55 yards from the high light"	Shoreline advance (around 25m)	de Boer 1968 (p41)
1763	February 1763 "the low light washed down wholly all together and can no more ever be set upon that place"	Shoreline retreat (unknown distance)	de Boer 1968 (p43)
1763	December 1763: "the low light … was washed down and the sea hath taken all the ground away within 24 feet of the foundation of the (High) House"	Shoreline retreat (around 45m)	de Boer 1968 (p43)
1763-1765	Hull Trinity House: "the ground … to the eastwards of the High Lighthouse to about 3 or 4 yards is washed away"	Shoreline retreat (around 5m)	de Boer 1968 (p48)
1766	Sites selected for Smeaton's high and low lighthouses around 1840 yards south-west of Angell's lighthouse.		de Boer 1968 (p54)
1766-1771	June 1771 Smeaton found "the seaside of Spurn had been so much eroded … that the site of the low lighthouse, which before was 116 yards inland, now lay on high water mark" The site was moved back 80 yards	Shoreline retreat (around 105m)	de Boer 1968 (p55)
1774-1776	1774: HWM "had advanced to within 40 yards of the (Smeaton) low lighthouse"	Shoreline retreat (around 35m)	de Boer 1968 (p57)

1776	"a great storm washed down half of the compound wall round it (the Smeaton low lighthouse) … and took entirely away all that was left of Justinian Angell's lighthouse"	Smeaton's lighthouse Shoreline retreat (unknown distance) Angell's lighthouse: Shoreline retreat 1674-1776 around 190m.	de Boer 1968 (p57)
1778/79(?)	Smeaton low lighthouse swept away	Shoreline retreat (unknown distance)	de Boer 1968 (p58)
1776-1786	Smeaton visited Spurn "Angell's lighthouse … was by this time 50 yards below high water mark"	Shoreline retreat (around 45m)	de Boer 1968 (p58)
1786	Smeaton's replacement low lighthouse was 80 yards from the original site and 200 yards from the high lighthouse.	1776-1786 Shoreline retreat (around 75m)	de Boer 1968 (p58)
1776-1808	"since the destruction of Smeaton's low lighthouse there had been so much accretion that the swape was 110 yards from high water mark"	Shoreline advance (around 100m)	de Boer 1968 (p61)
1816	New low lighthouse 210 yards from the Smeaton high light and 70 yards back from the original low lighthouse		de Boer 1968 (p62)
1816-1829	November 1829 " a storm undermined the (low lighthouse) tower"	Shoreline retreat (unknown distance)	de Boer 1968 (p62)
1830	New low lighthouse sited 30 yards back from 1816 lighthouse. Site abandoned May 1831. 1831: New low lighthouse constructed 50 yards nearer the high lighthouse.	1816-1831 shoreline retreat (30m)	de Boer 1968 (p62)
1849-1851	Low lighthouse damage in December 1849 storm and March 1851 gales. Swept away in December 1851.	Shoreline retreat (unknown distance)	de Boer 1968 (p64)
1852	Site of proposed new low lighthouse would be 90 yards from high lighthouse. New lighthouse built on Humber shore 158 yards from the high lighthouse.	1776-1851 shoreline retreat (around 175m)	de Boer 1968 (p64)

Notes:

- Angell lighthouse: around 250m shoreline retreat 1674-1786, with brief periods of shoreline advance (25m in a single year)
- Smeaton lighthouse: around 175m shoreline retreat 1776-1851, with brief periods of shoreline advance (100m in 3 decades).