Natural England Commissioned Report NECR255

Spurn: Geomorphological Assessment

Humber Estuary SSSI (SAC, SPA, Ramsar)
Spurn Head Geological Conservation Review Site
Spurn National Nature Reserve
Spurn Heritage Coast

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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

Spurn Head is an outstanding example of a dynamic coastal system, very unusual if not unique that it extends across the mouth of a macro-tidal estuary, and for which there exists an exceptionally long historical record extending back to the 7th century AD.

Natural England requested that Dr Mark Lee and Professor John Pethick undertake an assessment of the geomorphological development of Spurn, in order to understand how the system is likely to evolve and how far that evolution might be. Thus appreciating how the spit could move in response to wash over events and the continuing erosion of the Holderness Coast.

The assessment has been a desk-based study and involved a critical review of the available literature, rather than “new” research or site-based investigations.

Part of this review is an exceptional chronology of historic maps, charts and diagrams displaying the evolution of Spurn from c1508 to the present day. The geological and geomorphological aspects of the system are considered before an appreciation of the past and future evolution is discussed.

A conceptual model is presented which challenges the long-standing views on the geomorphological evolution of Spurn.

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Contractor – Ebor Geoscience Limited

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Further information
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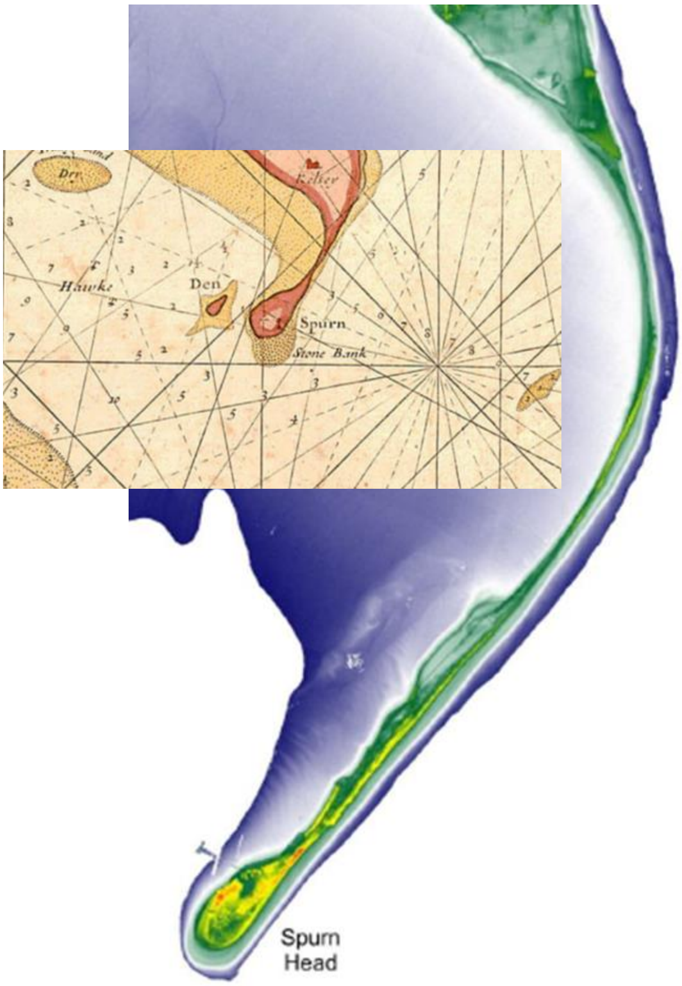
Spurn

Geomorphological Assessment



Report to Natural England

Dr Mark Lee and Professor John Pethick

June 2018

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1 Summary and Responses to Questions

1.1 Background

Natural England have requested that Dr Mark Lee and Professor John Pethick undertake an assessment of the geomorphological development of Spurn. In order to inform their future management advice Natural England would like to understand how the system is likely to evolve and how far that evolution might mean the spit could move in response to wash over events and the continuing erosion of the Holderness Coast.

The assessment has been a desk-based study and has involved a critical review of the available literature, rather than "new" research or site-based investigations.

1.2 Key Findings

Our key observations arising from the assessment are:

- the overall form of Spurn – a broad ***Head*** (Spurn Head) connected by a narrow ***Neck*** (the "High Bents") to the ***mainland*** (Kilnsea Warren and cliffs) – has been persistent over the last 300-400 years and possibly longer (see Section 3). With the exception of the well-documented events that occurred in the 1850s, the evidence for breaching, barrier breakdown and reformation is virtually non-existent and does not support the idea of cyclical behaviour, as proposed by de Boer (1964).
- it is possible to speculate that in the 12th and 13th centuries Spurn comprised a narrow Neck (around 200 yards wide) and a broader Head. Presumably Ravenser Od was a sheltered anchorage on the estuary side of the Head, located over 1 mile from the end of the mainland. The loss of Ravenser Od in the 14th century could simply have been the result of progressive rather than cyclical coastal erosion.
- John Sellers's "The English Pilot" (1673) and Greenville Collins' chart of 1684 show the tip of Spurn to the south of Easington and south-south west of Kilnsea, the same general arrangement that exists today. This suggests that westward movement of Spurn has been relatively limited over the last 500 years (when compared with de Boer's cycle of repeated formation and breakdown with kilometre-scale westward migration). If the ruins found on the Old Den are from Ravenser Od, then this would imply that parts of Spurn (the Head) has not migrated significantly westwards over the last 700-800 years (see Section 3.1).
- during the period between the late 17th and mid-19th centuries the Neck migrated westwards probably around 500m and the tip of the Head extended SW by over 2km. However, over the same period the Head had not migrated significantly westwards. These changes suggest that the spatial relationship between the Neck and the Head has been dynamically changing. The Neck is being "pulled" westwards because of the retreat of the Holderness cliffs, whereas the Head has responded to changes in the Humber estuary.
- the phase of Head lengthening broadly coincides with the pattern of land reclamation in the Humber, especially in the Axholme and Ancholme Valleys and Sunk Island. The resulting reduction in total estuary volume could have led to significant changes in the tidal flows through the estuary mouth, promoting the growth and extension of Spurn.
- the reclamation of Sunk Island between the late 17th century and the late 19th century led to the closure of the North Channel, the main flood tide channel of the Humber, and probably forced the flood flow southwards in the Humber Approaches. This was probably a key contributing factor in the lengthening of Spurn.
- the "foundations" for the present day Head were present (around 5-10m of sand and gravel/cobbles) prior to the phase of spit lengthening in the 17th to 20th centuries. As the spit lengthened after 1680 it had to build up in up to 5-10m of water before appearing above the

intertidal zone. The present day "Binks" seem to be shoals in front of the current distal end (and not a pre-existing moraine deposit).

- Spurn is probably the supra-tidal part of an extensive sedimentary structure (marginal flood rampart) that has accumulated at the mouth of the Humber, supplied by coarse sediment from the Holderness coastline. The form of this structure reflects the combined influences of wave – driven southwards coarse sediment transport and strong tidal flows from the Humber. It does not appear to be "*anchored*" by a pre-existing moraine deposit at the Binks (see Section 5). Spurn changes because the Holderness cliffs retreat and the tidal volume and flood channels in the Humber have varied over time.
- the major changes that have occurred were in response to progressive changes in boundary conditions – spit lengthening in the 18th and 19th century (due to land reclamation and changes to the tidal volume of the Humber) and breaching in the 1850s (the impact of cobble and gravel working on the sediment budget) – rather than extreme events (i.e. the Great Storm of 1703, the 1953 storm surge etc.) (see Section 3).
- the current landform has, until relatively recently, been locked in place by the extensive breach repairs and coast protection works (including dune creation) undertaken over the period between the mid-1850s and the early 20th century (see Section 3). The progressive failure of these defences since the purchase of the site by the Yorkshire Wildlife Trust in 1959 has led to a situation where Spurn has begun to respond more "*naturally*" to storm events.
- the Neck has been the most dynamic section of Spurn, through crest lowering, overwashing events and westwards migration (see Section 3). Considerable change has occurred along the Neck since the 1950s when Phillips (1962) wrote "*the dunes rise to over 30 feet O.D. with the highest point 31 feet O.D*." In 2014 the highest point along the Neck was around 3m OD. The dunes have been lost and only a low sand and gravel barrier remains.
- overwashing, rather than breaching has been the dominant process driving the changes along the Neck. The only recorded breaches, in the 1850s, occurred at a time of significant gravel extraction from both Spurn and the Holderness shoreline, and following a period of rapid extension of the Head towards the SW.
- future behaviour will be determined by the inter-play between the response of the Holderness shoreline and the Humber estuary to RSLR and a positive coarse sediment budget (see Section 4).
- the future integrity of Spurn is uncertain as the effects of the continued decay and deterioration of the coast protection works are largely unpredictable in terms of the timing and magnitude of significant erosion and overwashing events (see Section 5).
- internal structural changes have been taking place that, over time, could introduce further uncertainty about the long-term behaviour, notably Neck "stretching" and re-orientation (see Section 5) .
- the pathway from a semi-constrained to a "naturally" dynamic system is uncertain. A number of scenarios can be envisaged (see Section 5):
  - *complete breakdown and gradual re-establishment* of a shore-attached barrier further to the west. This is considered to be extremely unlikely, as there is no convincing evidence of this type of behaviour in the historical record and no obvious "tipping point";
  - *establishment of a permanent breach*, probably along the Neck, separating the Head from the mainland. This is considered to be unlikely, as the system will continue to receive coarse sediment from the Holderness cliffs whose yield is likely to increase with relative sea-level rise (RSLR). It seems more likely that future overwashing events would be "self-healing", as occurred after the December 2013 storm surge.
  - "jerky" westwards migration of the Neck, and possibly the Head, in response to RSLR, driven by the localised impacts of storm events – episodic failure of the old defences, overwashing and possibly temporary breaches along the neck, extension of the washover zone southwards, erosion of the sand dunes along the Head. Some of the local storm impacts

could be quite dramatic, especially when the protection provided by the decaying defence works suddenly declines. The Neck will remain as a low sand and gravel barrier, without dunes. This seems to be the most likely scenario and would see a return to the type of landform shown on the 1824 First Edition Ordnance Survey map.

1.3 Responses to Natural England's Questions

I. *considering the likely changes in forcing factors over the next 100 years, what is the likely evolution of the Spit? It would help Natural England if these could be framed in Shoreline Management Plan timescales (0 to 20, 20 to 50 and 50 to 100 years)*

Response: It seems likely that Spurn will remain resistant to major change, at least over the next 100 years, because RSLR will be accompanied by increased sediment yield from the Holderness shoreline and increased wave-driven sediment transport. However, future behaviour is inherently uncertain, so a number of scenarios are possible:

	Complete breakdown and gradual re-establishment	**Establishment of a permanent breach along the Neck**	**"Jerky" westwards migration: overwashing and temporary breaching of the Neck**
0-20 years	extremely unlikely	unlikely	likely
50-50 years	extremely unlikely	unlikely	likely
50-100 years	extremely unlikely	unlikely	likely

II. *It appears from early maps that Spurn's location (as a spit system), prior to the 1855 defences, had a close relationship to the Holderness coast. Simplistically this meant that as the coast eroded Spurn adjusted its position through washover to keep pace with the southern end of the Holderness boulder clay. Given that the Neck of Spurn was effectively held in place for 150 years it seems reasonable to assume that the restoration of washover processes means that the spit will want to reach a new equilibrium with the 'hard' (though actually soft) geology of the Holderness Coast. How much 'catching up' does the spit need to do in order to achieve such a point of dynamic equilibrium?*

Response: It seems likely that the distinctive curved planform is in response to "free movement" (certainly prior to the construction of the seawall/revetment in 1942) of the Neck between an almost stationary Head and the retreating Holderness cliffline; the southern end of the Neck is fixed whilst the northern end is "pulled" westwards. This has led to the Neck changing orientation from line running NNE-SSW (192°) in the early 19th century to running NNW-SSE (175°) in mid-late 20th century. In doing so, the potential longshore sediment transport (PLST) rate may have increased by 5-10% i.e. it has become more drift aligned.

The question as to whether there is an optimum alignment/orientation that represents a "dynamic equilibrium" between the cliffline, the Neck and the Head is difficult to answer. It may simply be that the rate of roll-over of the Neck barrier beach (dependent on the rate of RSLR, the barrier size and composition, and storminess) cannot be a precise match for the rate of cliff recession. Also, future changes in Neck orientation may lead to a reduction in PLST and, given a continued and increasing sediment supply from the cliffs to the north, barrier growth and reduction in the roll-over rate.

It seems likely that the Neck will continue to roll-over and retreat. Unfortunately we can offer no clear answer as to how much it needs to retreat to "catch up" with the Kilnsea cliffs or whether a "dynamic equilibrium" position will be achieved within the next 100 years.

III. *Is Spurn's former spatial stability compromising its longer term coherence? I.e. is breakdown more likely?*

Response: As outlined above and in the Report, breakdown is considered to be an extremely unlikely scenario within the next 100 years.

IV. *What is the most appropriate mechanism/ process to conserve the geomorphological interest of the SSSI? Intervention or allowing natural processes to take their course*?

Response: In our view, the processes of westwards migration, overwashing and temporary breaching should be allowed to take their course, as this would best enable the Neck to respond to future sea-level rise. Intervention (presumably involving the replacement of the 19th and 20th century coast protection works) would once again "lock-in" the position and alignment of the eastern shoreline, which may be outflanked to the north by the retreating Kilnsea shoreline.

2 Introduction

Spurn is a 5.5km long, curved, sand, gravel and cobble barrier capped with low dunes colonised by sea buckthorn and marram grass, at the mouth of the Humber[1]. It comprises a broad, >350m wide, spatulate *Head* which is connected to the mainland at Kilnsea Warren by a narrow, <50m wide, *Neck* (the "narrows"). The crest height varies from around 3m OD at the Neck to over 10m on parts of the Head (Figure 1).

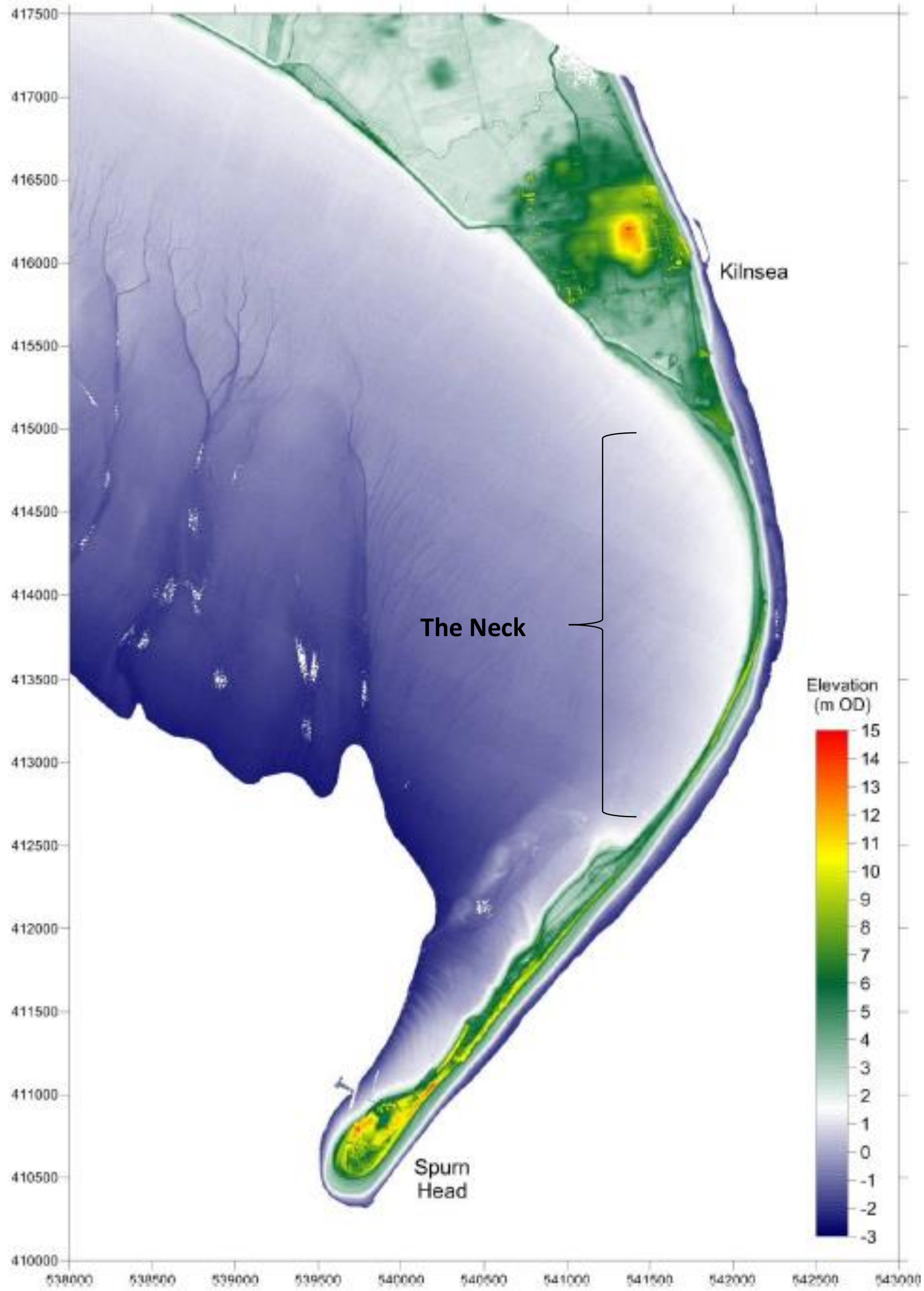


Figure 1 Spurn; elevations based on May 2000 LiDAR (from Pye and Blott, undated)

[1] Further details on the geology, geomorphology and processes operating at Spurn can be found in Phillips (1962), IECS (1992), Saye et al. (2005); ABP Mer, 2009).

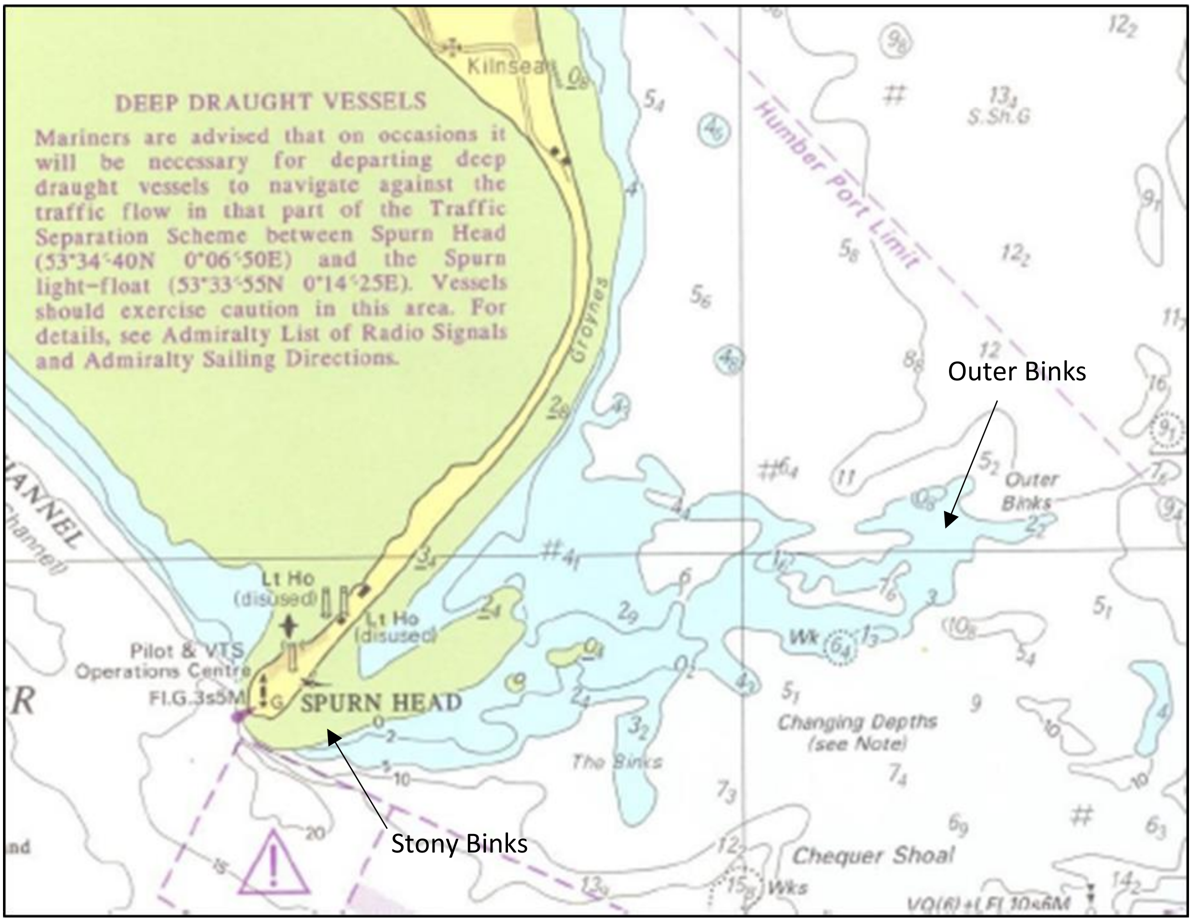


Figure 2 Hydrographic chart of the Spurn area (water depths in metres; chart datum is -3.9m OD; http://www.ntslf.org/tides/datum)

Much of Spurn lies in shallow water, although a deep water channel lies off the tip (Figure 2). Off the eastern of the Spurn Head there is a SW-NE trending bank of sand and gravel (Stony Binks). A series of mixed sand and gravel shoals (the Binks) lie to the east of the tip, and extend further offshore in a north-easterly direction towards the Outer Binks (Figure 2).

The tides are semi-diurnal, and macrotidal, with a mean spring tidal range of 5.7m. However, individual spring tidal ranges vary considerably, and in 2000, of the 24 spring tides, three spring tides had a range of 5.0m and two were as large as 6.7m (HR Wallingford et al., 2002).

	Tidal Levels Above Ordnance Datum (OD m)			
MHWS	MHWN	MSL	MLWN	MLWS
+3.0	+1.6	+0.2	-1.2	-2.7

Spring tidal currents at a point approximately 750m to the southwest of the Head have maximum surface velocities of 2.2m/s on a neap tide, approximately 3 hours after high water. The direction of the maximum ebb current is approximately west to east. Flood currents are slower, reaching a maximum of 1.95m/s on a spring tide, approximately 3 hours before high water (ABPmer 2009).

The dominant wave direction is from the NNE and NE and has a large swell component with a fetch length of approximately 900km (ABPmer 2009). The annual 10% exceedance significant wave height is 1.0 to 1.5m and the 1 in 100 year wave height for the area from Flamborough Head to Gibraltar Point has been calculated to be between 4 and 8m, decreasing in size from north to south (Halcrow, 1988).

The principal source of coarse sediment to Spurn is from erosion the glacial till cliffs, shore platform and seabed along the Holderness coastline to the north. The eroded sediment is believed to be transported southwards by wave action, along the beach and the seabed within 2km of the shore (i.e. within 5-10m of water; HR Wallingford 2003). 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).

Estimates of the transport into Spurn range from 60,000 m^3/year (Ciavola, 1997) to only 3% of the Holderness sediment yield (Valentin 1954, p126) i.e. less than the potential transport rate. It is suspected that, as the seabed zone between 5m and 10m water depth widens from around 2km at Easington to around 5km at Spurn, a significant proportion of sediment transport is southwards across this broad seabed platform rather than alongshore towards Spurn. Halcrow/GeoSea (1990) suggest that up to 60% of the sand yield may move offshore around Easington. However, it is possible that there is an onshore sediment pathway across this seabed platform to Spurn (Figure 3).

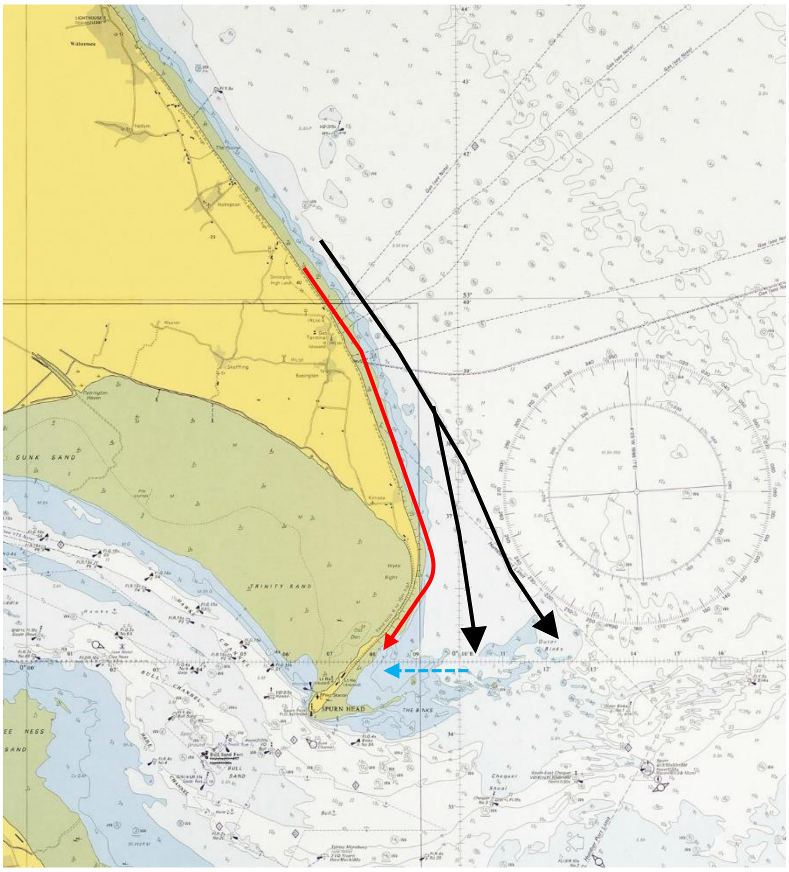


Figure 3 Coarse sediment transport pathways around Spurn: black lines indicate the transport pathway in 5-10m water depth; red line indicates the longshore transport on the beach; blue line is a conjectured onshore route.

Coarse sediment supplied to Spurn is moved southwards along the eastern shoreline towards the tip; evidence for this pathways was provided by Pickwell (1878, p192), who described how groynes constructed after the 1849/50 breach trapped sediment and led to "*the gain of land eastward along the entire length of the neck varying from 30 to 80 yards in width* …". Sediment is also transported around the tip and northwards up the western shore of the Head, mainly by refracted waves from the southeast (Phillips, 1963, 1964; Ciavola, 1997). Sand from the upper beach on the south-western side of the Head is blown onto the Head by south-westerly winds to form dunes (Pye and Blott 2010).

The curved shoreline orientation of the Neck and Head is believed to control the longshore wave power gradients generated by NE waves refracted along the seaward shoreline (Figures 4 and 5; adapted from IECS 1992). The maximum erosion for the current shoreline orientation coincides with the Neck. Accretion is predicted to occur along the Head. It follows that:

- the Neck is a net exporter of sediment, hence the low crest, narrow width and vulnerability to breaching/overwashing and the recent retreat since the seawall failed. NE waves arriving at the Neck are not significantly affected by refraction (Figure 4).
- further south, the Head is progressively more sheltered by the Binks and nearshore shallow waters, making it a more stable setting. NE waves refract towards the tip due to the nearshore zone bathymetry, but energy is dissipated because of the shallow water. N'ly waves are refracted away from Spurn (IECS 1992; Ciavola 1997).

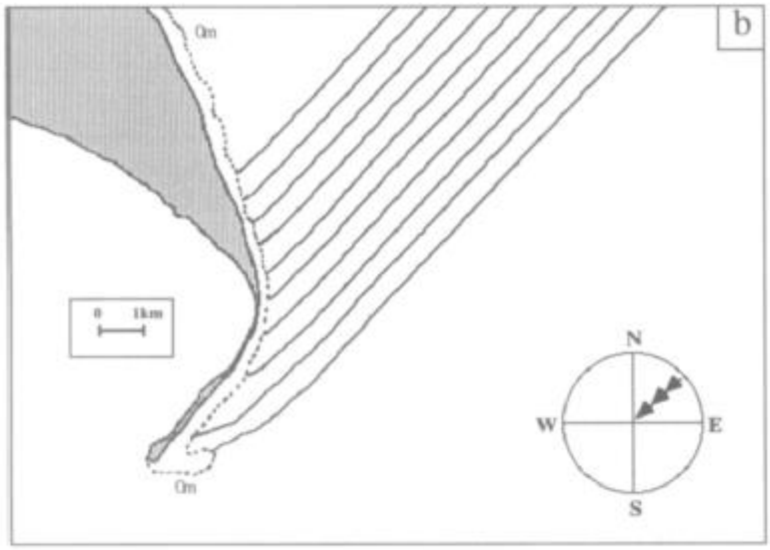


Figure 4 Wave refraction for NE waves (period 4.25s, height 0.85m). Note that there is little change in wave crest orientation for waves arriving at the Neck, but at the tip waves are refracted towards E (from Ciavola 1997)

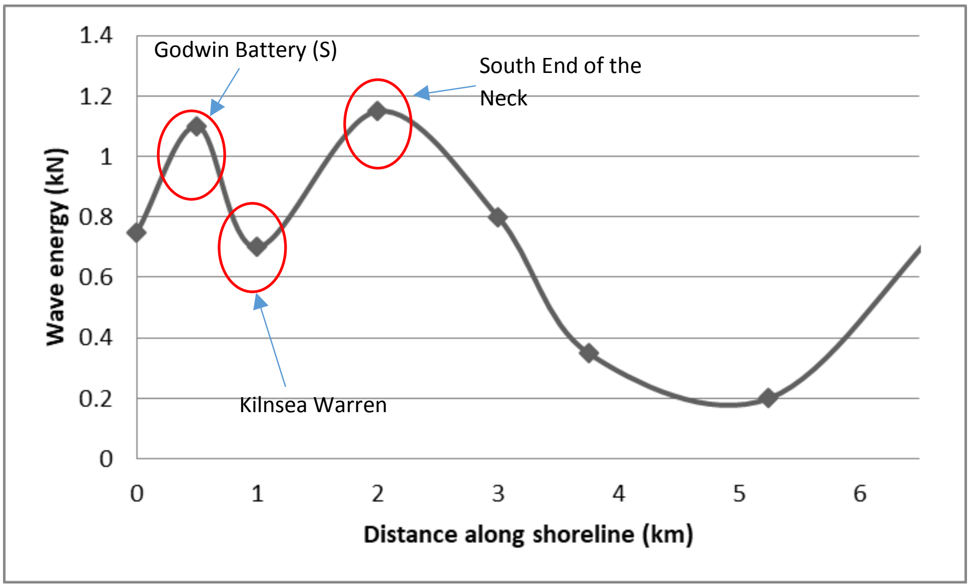


Figure 5 Longshore wave energy gradient along Spurn seaward shoreline (adapted from IECS, 1992). A positive longshore power gradient (i.e. increasing wave energy) indicates shoreline erosion, whereas a negative gradient (i.e. decreasing wave energy) indicates deposition.

The strong tidal flow in and out of the Humber Estuary interrupts the southerly transport of coarse sediment from the north, diverting the transport pathway offshore where some may be deposited on the Binks, as well as on Spurn itself or in New Sand Hole (HR Wallingford, 2003).

3 A History of Spurn

"*I had for some time considered Spurn Point as an appendage to the high cliffs of Kilnsey; and formed of the waste of the lands to the North; therefore, at whatever rate the sea encroached upon these cliffs, by taking off parallel Screeds, this whole appendage of Spurn must remove at an equal rate westwards, upon an average. It, however, might alter some years more, others less, according to the easual (sic) influence of storms*." Smeaton 1791 (p188).

3.1 Ravenser Od and the Early Charts

Ravenser Od (or Odd) was an important port during the 13th century with "*wharves, warehouses, customs sheds, a tanhouse and windmills as well as boasting a court, prison and chapel*" (Crowther, 1992). It seems to have been founded during the reign of Henry III (1216-1272) after "*the casting of the sea caused stones and sand to accumulate …*" and "*a certain small island was born, which is called Ravenserodd*" (inquisitions of 1276 and 1290, respectively, cited by Crowther 1992).

Whether Ravenser Od was actually sited on an island is unclear, because at the end of the 14th century, The Chronicle of Meaux Abbey indicates that there was access by road:

"*From the most ancient times the access to it was from Old Ravenser by a sandy road covered with round yellow stones, scarcely elevated above the sea. By the flowing of the ocean it was little affected to the east, and on the west it resisted in a wonderful manner the flux of the Humber; that part of the road leading from Ald Ravenser … is passable at this day on horseback or on foot, but the extreme part towards the south, but at its further end, for the space of half a mile is lost in the Humber*" The Chronicler of Meaux Abbey, quoted in Poulson (1840, p529).

It seems likely that Ravenser Od was on Spurn. Indeed, the general setting of a narrow Neck and a broader Head was described in The Chronicler of Meaux Abbey:

"*But that town of Ravenser Odd..., 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 one mile and more. For access to which from ancient time from Old Ravenser a sandy road extended, covered with round and yellow stones, thrown up in a little time by the height of the floods, having a breadth which an archer can scarcely shoot across* (around 200 yards) *and wonderfully maintained by the tides of the sea on its east side and the ebb and flow of the Humber on its west side*". (Chronicler of Meaux Abbey, quoted in de Boer 1964, p82)

A references in a writ and inquisition of 1290 (quoted in be Boer 1964, 1969) to the site being on an island suggests that the "*sandy road*" along the Neck was sometimes covered at high tide.

Poulson (1840 p529) suggests that Ravenser Od was four miles from Easington. Based on the discovery in the 19th century of what appeared to be ruined foundations, Poulson (1840, p540) suggested that the site of Ravenser Od (or Old Ravenser) might have been on what is now the Old Den, "*in digging some few years ago, says a gentleman perfectly competent to give an opinion, on a place within the present Spurn Point, called the Old Den, we found Ashlar Stone, chiseled and laid in lime ; seemingly the foundation of some building of note ; the heads of the piles also having been found. The old den is a singular ridge of gravel, full half a mile long, and not more than seventy or eighty yards broad, and raised about three feet above the mud banks by which it is surrounded*".

By the middle of the 14th century, the town had been severely affected by coastal erosion:

"*the chapel of Ravenser … and the majority of the buildings of the whole town of Ravenser, by the inundations of the sea and the Humber increasing more than usual, were almost completely destroyed*" (Chronicler of Meaux Abbey, quoted in Crowther 1992).

A writ from 1347 indicates that the destruction had begun in the eighth year of Edward III (1334/5) and that over 200 buildings and properties had been lost by the mid-1340s (from:

http://www.caitlingreen.org/2016/02/ravenserodd-lost-towns-yorkshire-coast.html). Ravenser Od had been completely destroyed by 1360:

> "… *yet by all its wicked deeds, and especially wrong-doing on the sea, and by its evil action and predations, it provoked the vengeance of God upon itself beyond measure*" (Chronicler of Meaux Abbey, quoted in Crowther 1992).

In 1355, the abbot of Meaux was directed to gather up the bodies of the dead which had been buried in the chapel yard of Ravenser Od, and "*which by reason of inundations were then washed up and uncovered, and bury them in the church-yard of Easington*" (Poulson 1840 p533).

de Boer (1964 p 83) indicates that the last reference to any commercial activity at Ravenser Od was in 1358, and by 1362 the port was apparently derelict, for a number of men were brought before the Easington manorial court in that year for '*throwing down and rooting up the timber of the staithes at Ravensrod*' (Easington manorial court rolls, 31 January, 36 Edward III, Documents relating to the Seigniory of Holderness).

The first Spurn lighthouse was constructed in the early 15th century by Richard Reedbarrow to provide a "*redy Bekyn, whereyn shall be light gevying by nyght to alle the Vesselx that come into the seid Ryver of Humbre*" (Patent Issues by Henry VI in 1427, quoted in de Boer 1969, p 3-4). de Boer suggested that the structure was a stone or brick tower with a wood or coal fire on the top in an iron basket (de Boer 1969 p 6). But it was not long-lived and probably had been lost by the time Edward IV landed on Spurn in 1471.

Virtually nothing is known about the development and evolution of Spurn between the mid-14th and early 16th centuries. However, the earliest chart of the Humber, from around 1540 (Table 1), shows Spurn as a bulbous Head connected to the "mainland" by a narrow curved Neck. The distal end of the feature lies to the north of a discontinuous, curved island or shoal (the Old Den?).

In 1567 Spurn was described in a survey as:

> "*a sandy hill environed and compassed about upon the sea side with sea and on the other side with the Humber containing six acres whereupon is neither arable land, meadow, nor pasture, wood, underwood nor trees neither anything else but only a few small bents and short scrubby thorns of a foot high not worth felling, which Ravensey Spurn is at ordinary spring tides almost overflown and of no value. Also there is another hill nigh adjoining the Ravensey Spurn called Conny Hill environed with the sea containing four acres whereon is neither arable land nor trees also of no value*." (Attorney General v Constable, quoted in de Boer 1964).

de Boer (1964) believed that the loss of Ravenser Od marked the termination of a cycle of spit development that had started around 1100. However, it could simply have been the result of progressive rather than cyclical coastal erosion. Indeed, the instructions for the abbot of Meaux to move bodies from Ravenser Od church yard to Easington in 1355 suggests that there was forewarning about the loss of the settlement, rather than a sudden, catastrophic event such as a breach and breakdown of the 14th century Spurn.

Bearing in mind that written evidence from over 700 years ago needs to be treated with a fair degree of caution, it is possible to speculate that in the 12th and 13th centuries Spurn comprised a narrow Neck (around 200 yards wide) and a broader Head. Presumably Ravenser Od was a sheltered anchorage on the estuary side of the Head, located over 1 mile from the end of the mainland. If the ruins found on the Old Den are from Ravenser Od, then this would imply that Spurn has not migrated significantly westwards over the last 700-800 years and that the port was located close to where Angell constructed his lighthouse in the 17th century.

3.2 Early Charts and Maps: Spurn in the 16th and 17th Centuries

de Boer (1964 p76) argued that in the early 17th century Spurn was an island, detached from the mainland. The evidence put forward in support of this view includes:

- Robert Callis (1622 p21) wrote in a course of lectures or readings on the Statute of Sewers that "…. *the Spurnhead in Yorkshire which before did adhere to the continent was torn therefrom by the sea and is now in the nature of an island*". This was a second-hand (at least) account intended to illustrate a point of law, namely that an island separated from the land is still within the realm of England (and owned by the Crown). Of note, James 1 "*very actively endeavoured to gain possession of lands cast up by the sea, and in a number of cases resorted to the expedient of making fishing grants of them*" (de Boer 1968, p8). One such fishing grant was made to the Angell family in 1609 at "Ravensey Spurn". However, as Reid (1885) noted "*it is impossible to say whether this* (Callis' statement) *refers to the shifting sand-banks, or to an overflow of the sea through the alluvial flats which cross from sea to sea near Kilnsea.*"
- The Angell's grant included 6 acres at Ravensey Spurn and 4 acres nearby at Coney Hill (Cunny Hill), surrounded on one side by the sea and on the other by the Humber (i.e. similar dimensions to those described in the 1567 survey). Evidence given in 1684 and 1695 by local people in the court actions between the Angell family (who built the early lighthouses on Spurn) and the Constable family (the landowners) stated that Ravensey Spurn had been swept into the Humber about 80 years previously (around 1600-1610?) and that the remains formed a little island. This island was distinct from the spit where Angell's lighthouse stood, which was called Kilnsea Common or Point and owned by the Constables. Poulson (1840, p526) states that other petitioners in the 1676 case of Angell's patent recorded that "*the Spurn was called … a broad long sand in the shape of a spoon*, which form it still retains." These were opposing arguments in a land dispute to determine the ownership of the lighthouse site.
- W J Blaeu's chart of 1623 shows a gap between a mainland promontory (labelled "Spurnhead") and an un-named elongate island to the SW, which could be an exposed shoal (the Den?).

However, the over-riding impression from the early maps and charts (Table 1) is the persistence of the overall form of Spurn, with an elongate or bulbous feature extending from the mainland and a series of nearshore shoals. For example, in John Sellers's "The English Pilot" (1673; Figure 6) the island was labelled The Den and Spurn was a promontory extending southwards from the mainland. Of significance is that Seller's shows the tip of Spurn to the south of Easington (Isington) and south west of Kilnsea (Kelnsey), the same general arrangement that exists today. This suggests that westward movement of Spurn has been relatively limited over the last 500 years.

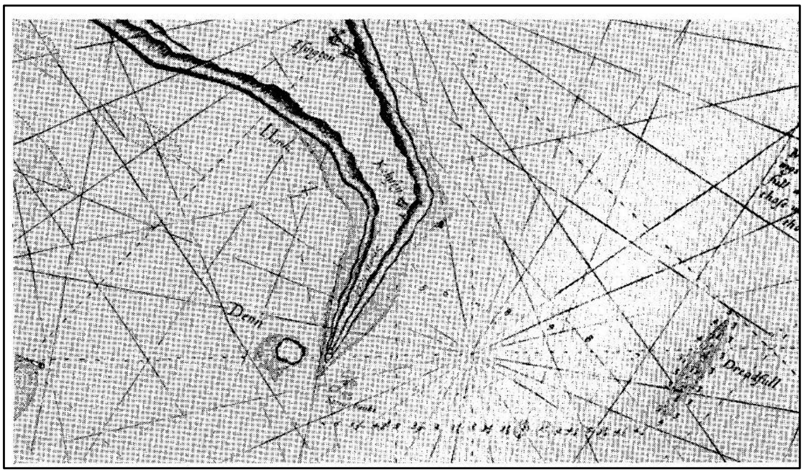
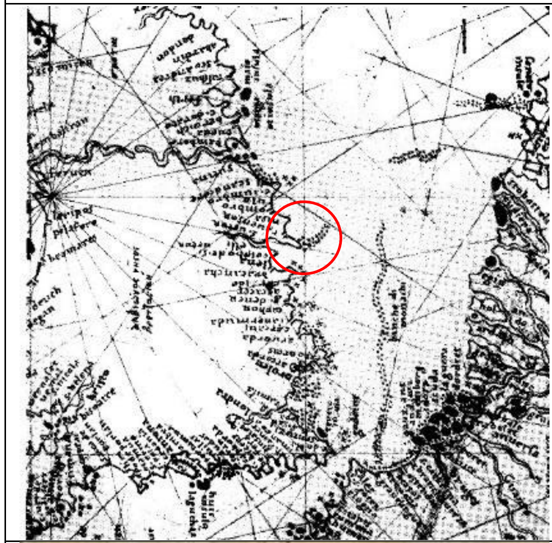
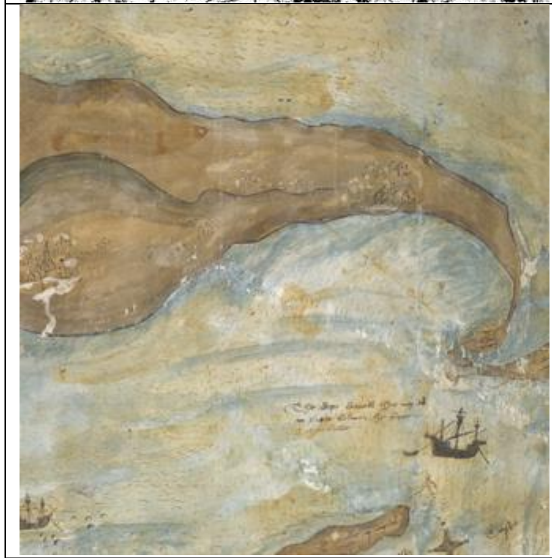
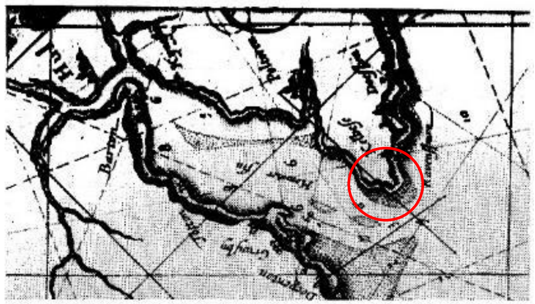
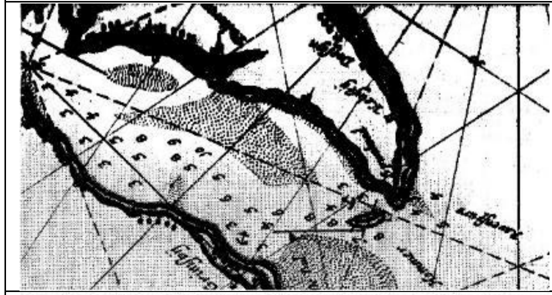
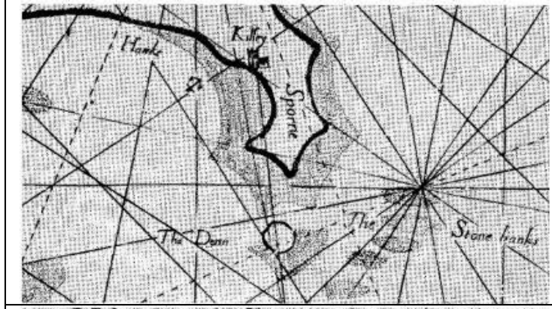
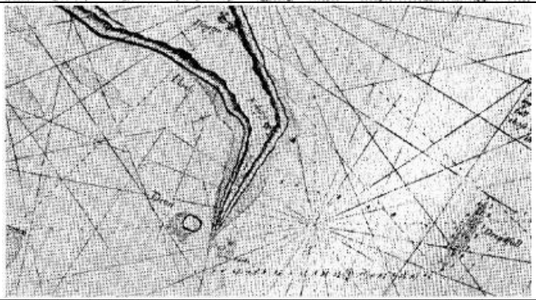


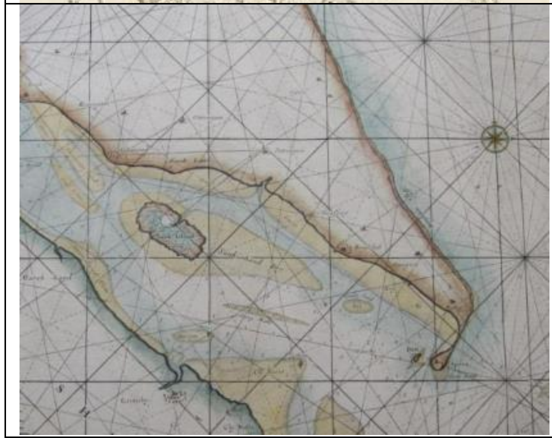
Figure 6 John Seller "The Coasting Pilot", around 1673

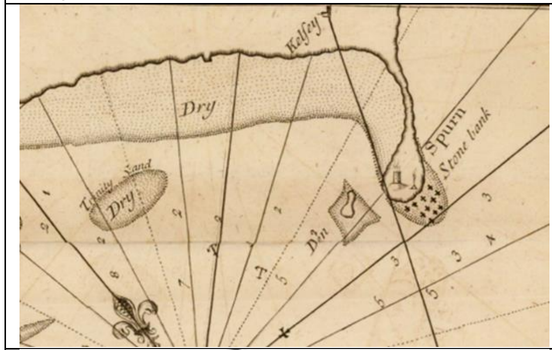
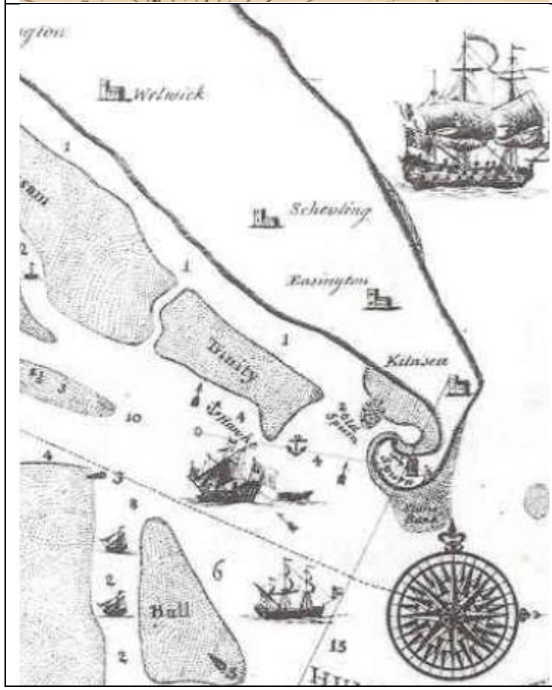
Table 1 Charts and maps of Spurn and the Humber mouth

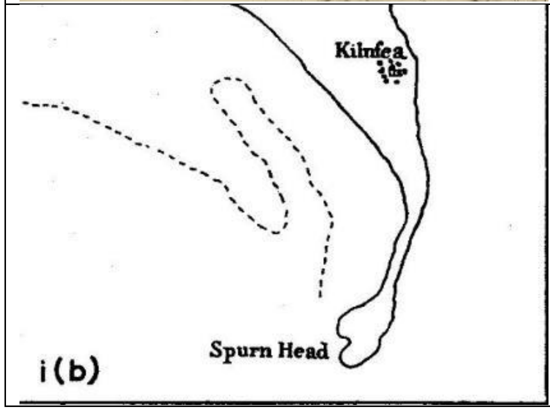
Map/Chart	Comment
	**c1508-1510 Portolan atlas, attributed to Visconti Maggiola (British Museum, Egerton MS 2803, fol. 6b)** Spurn is shown as a promontory, with a curved shoal extending NE from the distal end (the Binks?)
	**c1540 Chart of the River Humber (British Museum, Cotton MS Aug. I.i.84)** Spurn is shown comprising a bulbous head connected to the "mainland" by a narrow curved neck. The distal end of the feature lies to the north of a discontinuous, curved island or shoal (the Stony Binks). The Bull Sand is shown within the mouth of the Humber. The Holderness cliffs are shown not with a continuous, smooth plan-form, but a series of discrete segments with different orientations.

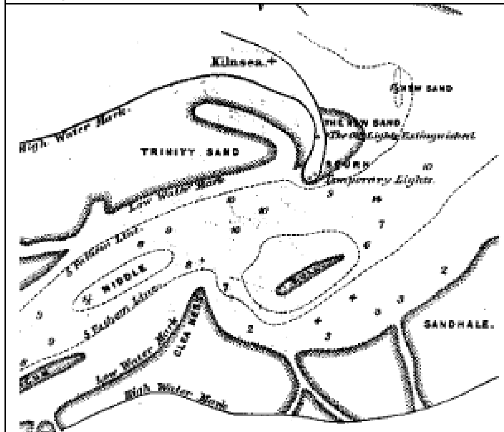
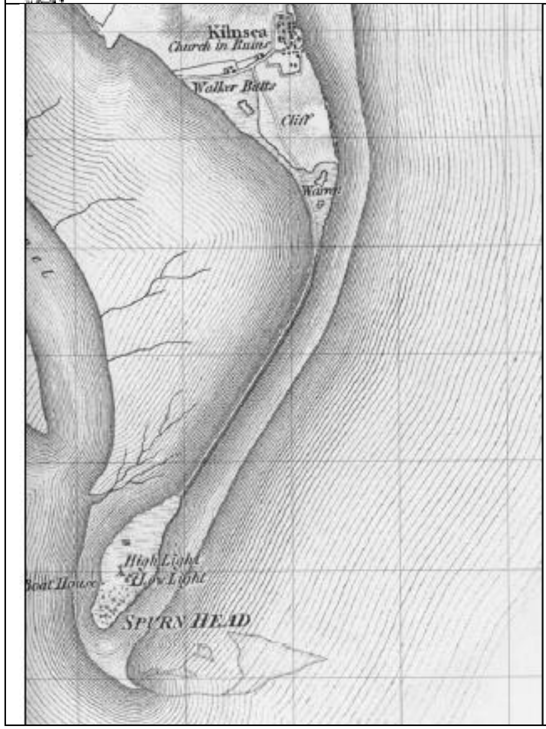
Map/Chart	Comment
	**c1560 Chart of the River Humber and Coast to Scarborough (British Museum, Royal MS 18 DIII (62))** The “Cecil map”. Spurn is shown comprising a bulbous head (labelled Ravenspurn) connected to the “mainland” by a narrow curved neck. The distal end of the feature lies adjacent to the Stony Binks. The Holderness cliffs are shown with a continuous, smooth plan-form.
	**c1584 Chart of the Thames Estuary and East Anglia Coast by Richard Polter (British Museum, Cotton MR Aug I.i.44)** The bulbous Spurn head and the narrow neck are shown, along with the Stony Binks (adjacent to the head). A marked headland is shown on the cliffline, possibly around Kilnsea (?).
	**1608 from Blaeu, “Het Licht der Zeevaert” (Dutch chart)** A “clumsy and shapeless” representation of Spurn (de Boer, 1969)

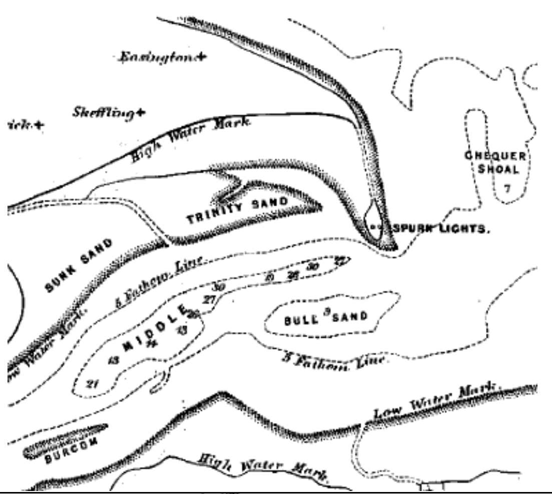
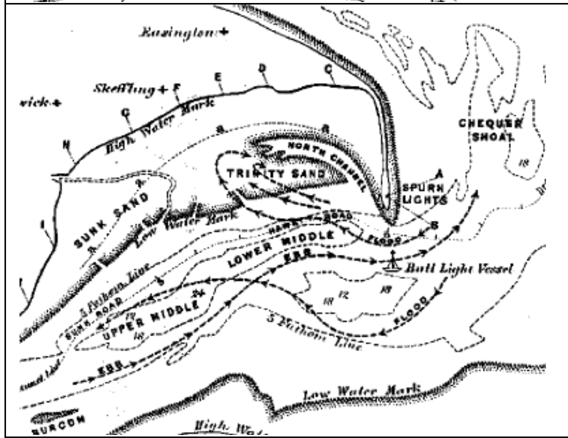
Map/Chart	Comment
	**1623 from Blaeu, “Zeespiegal” (Dutch chart)** A gap is shown between the “mainland” and what appears to be either the bulbous head of Spurn (evidence for a breach?) or a shoal (the Den?) However, the “mainland” is labelled Spurnhead at its southern end. It is possible that the “island” is an exposed shoal in the mouth of the Humber (the Den?)
	**1671, from Seller “The English Pilot”** Spurn is shown extending south from the “mainland”, with a thick neck. The shoreline head is shown as a comprising a series of arcuate bays. An exposed shoal south of Spurn head is labelled “The Den”. The Stony Binks are shown extending ENE from The Den.
	**1673 (1675?), from Seller “The Coasting Pilot”** Spurn is shown as tapering to a point immediately to the E of The Den. The Stony Binks lie immediately to the E of the tip of Spurn. Two villages are marked on the cliffline: Easington (Isington) on a NNW oriented section of cliffline; Kilnsea on a SSW oriented section, before the start of the Spurn headland.

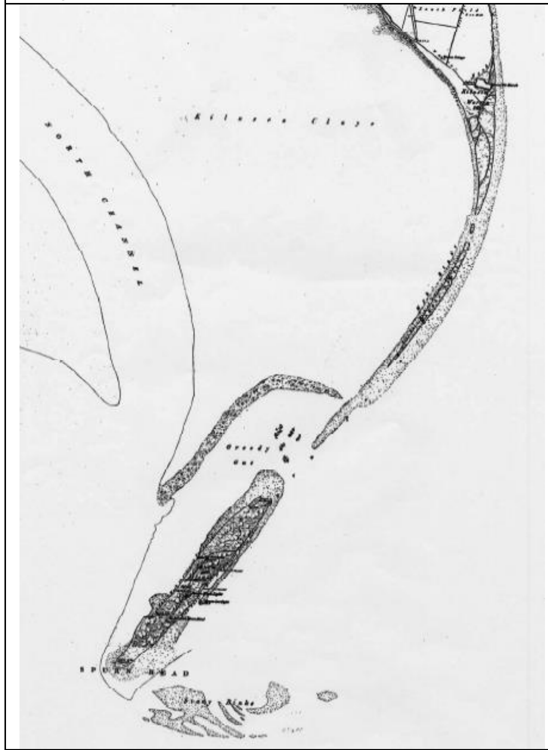
Map/Chart	Comment
	**1682? Sea chart of the east coast of England, with the mouth of the Humber, Jan Luyken, Johannes van Keulen** Spurn is shown as a promontory extending S from the mainland. The Stoney Binks and the Dreadful are shown as shoals extending E from the tip of Spurn. The Den is shown as an exposed island/shoal W of Spurn.
	**1684 Greenville Collins Chart of the River Humber** Spurn is shown as a bulbous head connected to the “mainland” by a narrow, straight neck. The Den is shown as an exposed island/shoal W of Spurn. The Binks are shown as shoals S and SE of the tip of Spurn. The chart shows Angell’s Lights at Spurn.

Map/Chart	Comment
	**1728 John Sennex/Edmund Halley/Nathaniel Cutler A Draught of the River Humber** Spurn is shown as a bulbous head connected to the “mainland” by a narrow, straight neck. The Den is shown as an exposed island/shoal W of Spurn. The Sone bank is shown as shoals S and SE of the tip of Spurn. The chart shows Angell’s Lights at Spurn.
	**1734 John Scott’s Draught of the River Humber** Spurn is shown as a curved and bulbous head connected to the “mainland” by a narrow, straight neck. The Den is shown as an exposed island/shoal W of Spurn, and labelled as “Old Spurn”. The Binks are shown as shoals S and SE of the tip of Spurn. The chart shows Angell’s Lights at Spurn.

Map/Chart	Comment
	**1786 Smeaton's map from "Appendix to A Narrative of the Building of Edystone Lighthouse"** Spurn is shown as a bulbous head connected to the "mainland" by a narrow neck. A small shoal or island is shown immediately south of the distal end. What appears to be a curved bank of shoals to the SE of the bulbous head is an inset map of changes to the tip between 1766 and 1786 (over 300 yards of shoreline advance).
	**1787 Tuke's map of Yorkshire (outline drawn by De Boer and Carr, 1969)** Spurn is shown as a bulbous head connected to the "mainland" by a narrow, straight neck.

Map/Chart	Comment
	**1778 Robert Mitchell's chart** Spurn is shown as a bulbous head connected to the "mainland" by a curved, narrow neck. Extensive shoals are shown to the E of Spurn (the "New Sand", part of the Binks?). The Den is not shown. Temporary lights are shown at the distal end of Spurn. The Old Lighthouse is shown close to the distal end of the neck.
	**1824, First Edition Ordnance Survey map (1 inch to 1 mile)** Spurn is shown as a bulbous head connected to the "mainland" by a straight, narrow neck. The Binks are shown immediately to the ESE of the distal end of the head.

<table>
<tr><th>Map/Chart</th><th>Comment</th></tr>
<tr><td>
</td><td>1828 Hewett’s Chart
Spurn is shown as a bulbous head connected to the “mainland” by a straight, narrow neck.
There is a note that the southern part of the Neck overflows at high spring tides.
The Binks are shown immediately to the ESE of the distal end of the head, extending NE to the “Chequer Shoal”.</td></tr>
<tr><td>
</td><td>1852 Calver’s Chart
Spurn is shown as a relatively narrow head connected to the “mainland” by a straight, narrow neck.
The Binks are shown immediately to the ESE of the distal end of the head, extending NE to the “Chequer Shoal”.</td></tr>
</table>

Map/Chart	Comment
	**1852 Ordnance Survey 6” to 1 mile.** Spurn is shown as an elongate SSW oriented head with a discontinuous connection to the mainland (the breached neck). The Stoney Binks and Den are shown.

3.3 Angell's Lighthouse

In 1673-74, Justinian Angell erected a 75 foot high lighthouse and a low lighthouses (210 yards E of the high light; de Boer 1968, p25) on what was then the tip of Spurn (de Boer 1964, p 77; shown as tapering to a point E of The Den on Sellers chart of 1673 or 1675). The high lighthouse was a strong octagonal tower of brick about 60 feet high on the top of which the light was exhibited-a coal fire in an iron basket hanging from a wooden lever or "*swape*" with which the fire could be raised another 14 feet (de Boer 1968, p24).

The lights burned coal from Newcastle and Sunderland which was landed on the beach and carried by oxen "*over sand and shingle so rough that they were sometimes lamed*" (de Boer 1968, p29). The low light was rebuilt and re-sited a number of times between 1735 and 1765 as the seaward side of Spurn eroded, and in January 1776 the high lighthouse was also lost (de Boer, 1968, p57).

Over a century later, John Smeaton wrote:

> "*In the year 1676 a patent was granted by King Charles II to Justinian Angell … enabling him to continue, renew and maintain certain lights that he had erected upon the Spurn Point. Which lights were erected at the request of the masters of ships using the northern Trade; who in their petition to his Majesty, represented that a very broad long Sand, about six or seven months before, had been discovered to have been thrown up near the mouth of the river Humber, upon which they had great losses* ….". Smeaton 1791 (p185).

However, it seems unlikely that Spurn had made a dramatic appearance in 1675-1676. The site for the Angell's high lighthouse had been selected in 1673, and when the surveyor John Osborne mapped Spurn for Angell around 1675, it covered 35 acres. It is possible that Smeaton was referring, mistakenly, to the emergence in 1673-1674 of a new sand bank, two miles long and half a mile wide, about four miles south-east of Spurnhead (the Dread of Humber; see de Boer 1968) or shoals emerging in front of the spit (i.e. precursors of the Binks). Indeed, on 21 February, 1674, the Hull Trinity House reported the appearance of a new sandbank (the Dread of the Humber or Dreadful) to the London House:

> "*we have had notice of a new sand as it is now called which is growne neere humber mouth about four miles east and by south from the Spurnhead upon which divers shippes have been endangered and some lost. Whether it be really a new sand or whether it be one of the old overfalls which hath gathered of late we cannot certainly tell, having an intent to view it …. however we perceive on all hands that the lighthouse now in erecting will be a thing of soe little use that it will be rather as it is placed a snare to draw shippes upon that sand*". (de Boer 1968, p24).

The position of the Dreadful is shown on both John Seller's and Greenville Collins chart which were produced around this time (Figures 6 and 7). Angell's high and low lighthouses were initially arranged to provide a safe route into the Humber, avoiding the Dreadful; ship keeping the low light in line with the high lighthouse would come in well south of the sandbank (de Boer 1968 p 25).

Angell's lights soon proved to be "*so far inland as to deceive masters of vessels* …" (Poulson 1840, p524). As a result, an application was made to Parliament in 1766 by the corporations of the trinity houses of Deptford, Stroud, London and Hull to remove the lights. This led to another dispute about the ownership of Spurn:

> "*Mr Constable and his ancestors … were entitled to the soil of several waste grounds …, particularly to a certain piece of ground called Kilnsea Common, or Spurn Point, part of which had been, in the memory of man, left by the river Humber, and over which he had constantly used every act of ownership without dispute or molestation. That, in the reign of Charles the Second, Justinian Angell had a spot of ground granted to him by King James the First* (in 1609)*, situated in an Island, or Islands, called Ravensey Spurn, and Coney Hills, and containing ten*

acres, about a mile west of the said Kilnsea Common, and supposed to be the remains of Ravenspurn, esteemed a convenient situation to erect light-houses upon; but on further inspection of the situation, it appearing to be at too great a distance from the sea and incapable of affording the necessary advantages, he abandoned the first intended situation and, without entering into any treaty, or having licence or permission … took upon himself to erect two light-houses on Kilnsea Common …" Poulson (1840, p524-525)

The available evidence does point to either significant changes to Spurn over the period between the 1580s (Richard Polter's chart) and around 1670, or simply obfuscation and confusion about whether Ravensey Spurn and Spurnhead were actually different pieces of land. It is possible that the bulbous Head mapped on 16th century charts was separated from the mainland by a breach around 1600-1610, but it seems more likely that island was The Den. However, it is also possible that the land dispute was centred around the fact that the land in Angell's grant in 1609 was 10 acres, but by the 1670's it had expanded to 35 acres – and the Constable's argument may have been that the Angell's grant must have been for somewhere else or not on my 35 acre plot!

By the 1670s a long, broad spit was present, extending southwards from the mainland towards, but separate from, The Den. In Smeaton's view, the "new Spurn" was "… *a sand thrown up by the sea, in the course of less than a century* …" (Smeaton 1791, p186). However, by the time Greenville Collins produced his chart of the Humber in 1684 (Figure 7), all the main features of the present-day assemblage of landforms on the north side of the river mouth were in place. Angell's lighthouse is shown SSW of Kilnsea, suggesting that the current position of Spurn's main elements has remained reasonably consistent over the last 400 years.

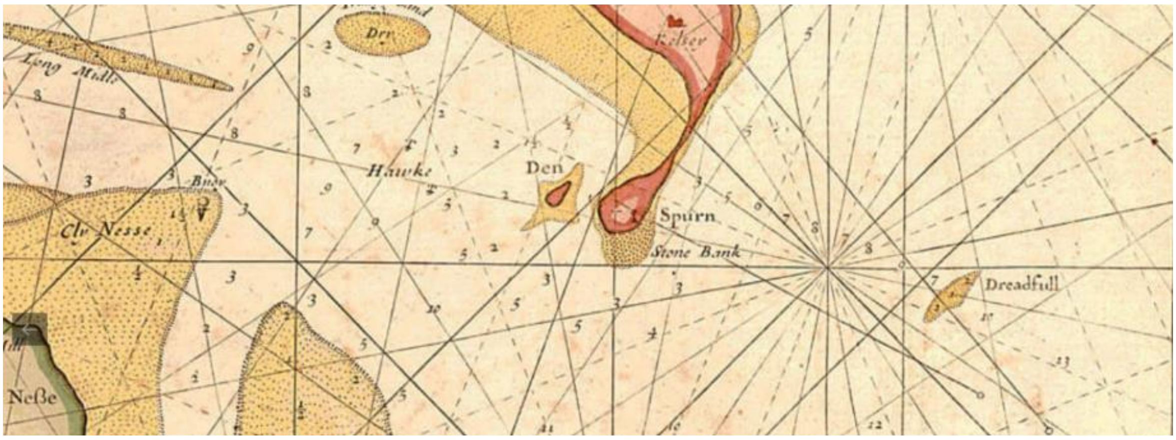


Figure 7 Section of Greenville Collin's 1684 Chart of the River Humber (note that the Chart Datum is not stated, depths are in fathoms)

3.4 Late 17th Century to Mid-19th Century: Spit Growth and Shoreline Erosion

Angell's lighthouses were replaced by Smeaton's high and low lighthouses, built between 1771 and 1776. The site on which the high lighthouse was constructed was 80 yards (73m) further inland from a site chosen in 1766 (indicating the rate of shoreline erosion of Spurn at this time), and 1840 yards (1680m) to the south-west of Angell's lighthouses (de Boer 1968 p54; Figure 8).

In 1791, Smeaton wrote that "*as the Spurn Point was a piece of ground that was rapidly increasing, there would be no danger of the ground being washed away*" Smeaton 1791 (p186). Between 1676 and 1851, Spurn extended southwards by around 2.3km (Figures 8 and 9):

- an indenture of 1685 indicated that the tip had extended at least 300 yards (275m) beyond the site of Angell's high lighthouse (de Boer 1964, p77).
- by 1764 the tip of Spurn had extended 1 mile 2 chains (1.64 km) SW of Angell's high lighthouse (de Boer 1968, p44)

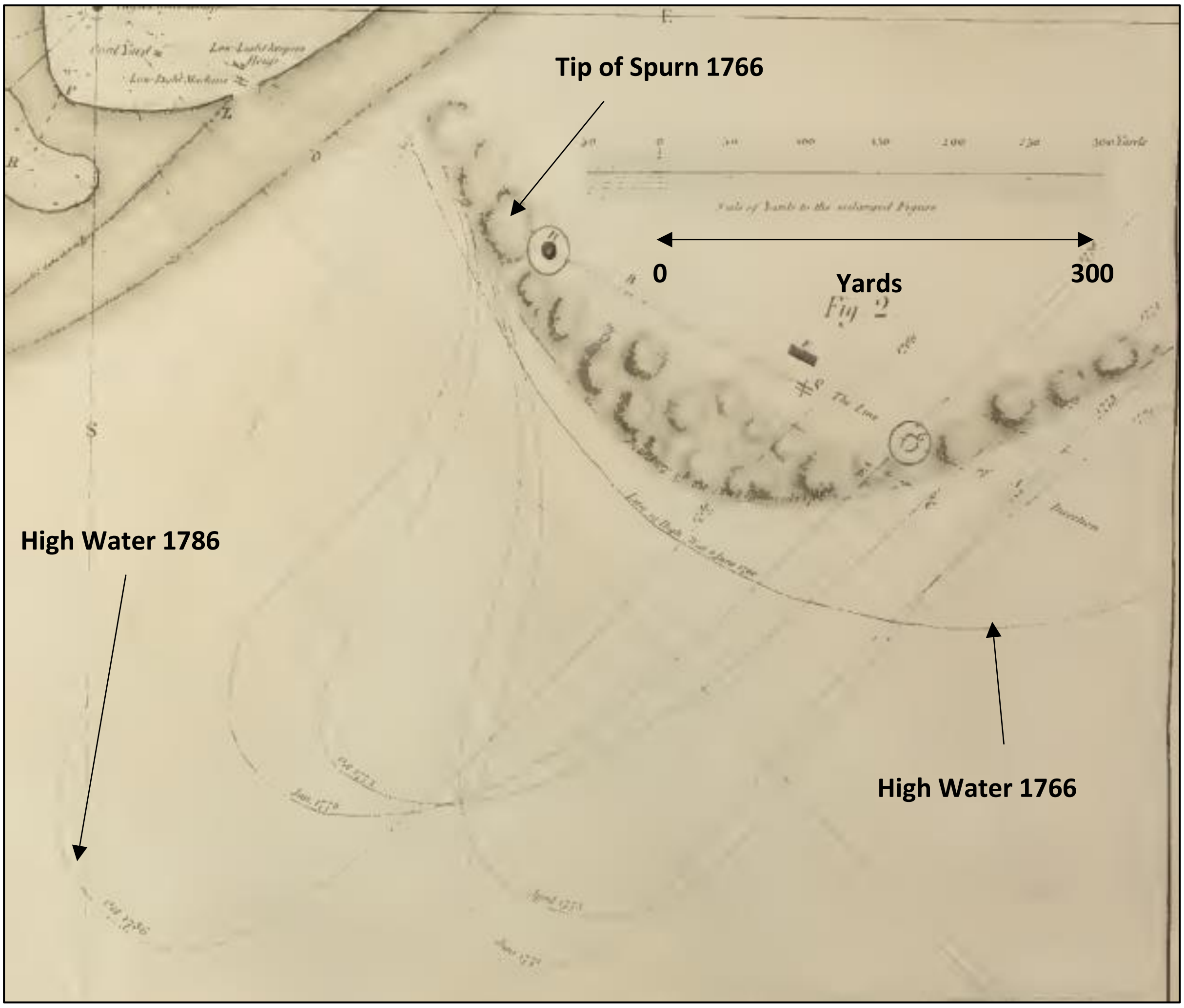


Figure 8 Changes in the tip of Spurn between 1766 and 1786 (from Smeaton 1791, with additional labels)

- between 1766 and 1786 there had been around 500 yards (c.450m) of shoreline advance at the site of Smeaton's high lighthouse (Smeaton 1791; Plan of Spurn Point as in 1786; Figure 8).
- between 1766 and 1851 the tip extended 730 yards (670m; Shelford 1869, p480).

Over the same time period, there was significant erosion of the eastern shoreline, as indicated by the changes observed at the lighthouses (Figures 9 and 10):

- by 1763 Angell's low lighthouse had been washed away and the sea was within 24 feet of the high lighthouse (de Boer 1968, p43), suggesting the shoreline had retreated by around 210 yards since 1771 (190m).
- between 1766 and 1771 there had been around 110 yards (100m) of shoreline retreat at the site of Smeaton's low light (Reid 1885, p 102).
- Smeaton's low light was destroyed in about 1778 and further low lights were brought into use in 1816, 1830, 1831 and 1851. The shoreline retreat over this period was around 150 yards (Shelford 1869, p481).

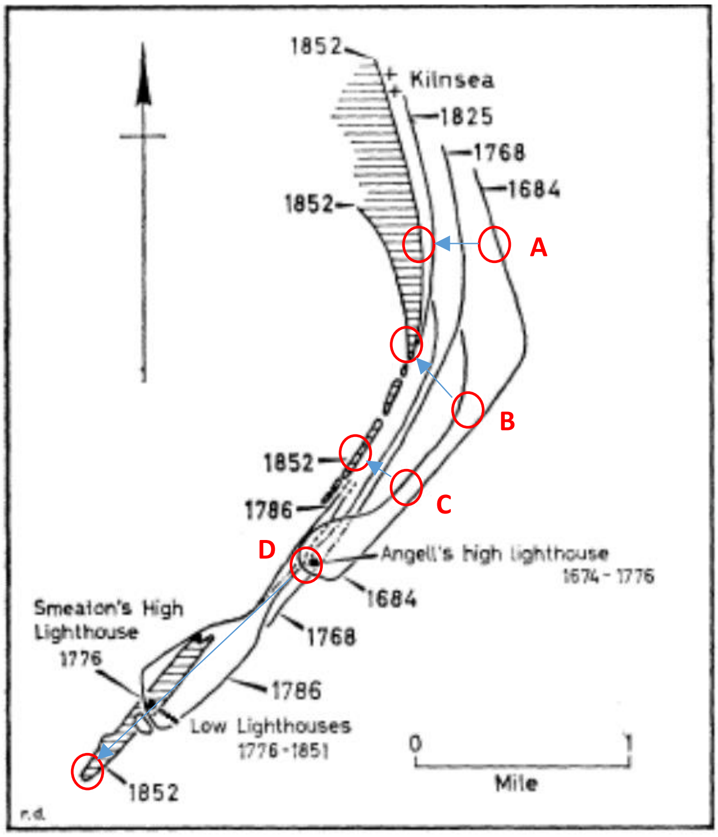


Figure 9 Spurn Point 1684-1852 (de Boer 1964). The outlines were based on Collin's chart of 1684, a Plan of Spurn from a 1768 survey (possibly for Smeaton), Smeaton's map of 1786 and the 1852 OS 6" to 1 mile map.

Figure 10 Smeaton's high lighthouse in 1829 (foreground) and one of the low lighthouses built in 1816

- in 1776 the original site for Smeaton's high lighthouse was swept away by a storm (Smeaton 1791, p188).
- by 1863 the shoreline had retreated to Smeaton's high lighthouse, a distance of 280 yards (256m; Shelford 1869, p481) in the 92 years since 1771 (2.8m/year, on average).

It is likely that the material removed by shoreline erosion around the sites of Angell's and Smeaton's lighthouses was re-deposited on the lengthening Head and in the near shore shoals.

Shelford (1869) indicated that the erosion of the eastern shoreline was accompanied by the westward movement of Spurn; this movement "*has been nearly uniform throughout the length of the Point*" (p480).

Smeaton's high lighthouse remained in use until 1895, but there were problems with maintaining the low light. A series of more-or-less temporary replacements were used in the years that followed, until a more solid lighthouse was constructed in 1852, 158 yards from the high lighthouse (de Boer 1968, p64). In 1895 both this low light and Smeaton's high light were replaced by a single lighthouse which still stands on Spurn Head. The 1852 low light also still stands on the sandy shore of the island, though its lantern has been replaced by a large water tank. Only the foundations of the old Smeaton high light remain (de Boer 1968).

During the period between the late 17th and mid-19th centuries, the various charts and maps show Spurn connected to the mainland by the Neck which was probably low-lying beach ridge, prone to being overwashed:

- Smeaton (1791) noted that the Neck was "*a narrow isthmus which extending about a quarter of a mile to the north east becomes a naked beach or ridge over which the sea breaks into the Humber at high water in rough weather with easterly winds at spring tides*."
- a note on Hewett's 1823 chart states that the southern part of the Neck overflows at high spring tides.
- de Boer (1964) cited the deposition of a Samuel Hodgson, made in 1850, who stated that about February 1789 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.

The main changes to Spurn and the adjacent shoreline over this period are summarised in Figure 9 and include:

- retreat of the Kilnsea cliffline (line A on Figure 9), probably around a third of a mile in 170 years (500m; 3m/year).
- northward migration of the point where the Neck is attached to the cliffline (line B on Figure 9).
- westward migration of the Neck (line C), probably around a third of a mile in 170 years (500m; 3m/year).
- south-westwards extension of the Head, as described earlier in this section (line D).

3.5 19th Century Cobble and Gravel Working

During the 18th and 19th centuries there was extensive cobble and gravel extraction from Spurn and the Holderness coast (Pickwell 1878; Mathison 2008); the first evidence of extraction coming from 1737 (the granting of rights to the Constable family who owned the land). The material was used for:

- building construction (to counter the 1783 Brick Tax, which was abolished in 1849).
- road building in Lincolnshire and East Riding (e.g. Sunk Island and Stone Creek roads).
- cement (concrete?) manufacture, e.g. at Immingham docks.
- ballast for ships sailing from the Humber (e.g. whaling ships).

Gravel and cobbles was collected on Spurn by:

- the landowner (the Constable family) and tenants.
- Spurn lifeboatmen; the men were poorly paid but were permitted to supplement their income by gravel and ballast extraction south of Smeaton's lighthouse (an agreement between the Constable's and Trinity House in 1810).

Over time, the focus of cobble trade operations centred around the Neck and Kilnsea Warren, possibly because the Head became overworked and starved of suitable material. Cobbles were loaded onto carts on the seaward side, taken over to the estuary-side and piled in heaps ready for loading onto boats. IECS (1992) make reference to a map of 1850 which contains the note "*heaps of cobbles or bolder stones carted over the Bents from the Sea Shore for lighters to fetch away*". Gravel was collected by shovels and baskets and loaded directly into the holds of sloops.

Prior to the 1849 breach (see below), cobble and gravel removal from Spurn may have been around 40,000-45,000 tons/year (20,000-25,000m^3; around 10,000-15,000 tons per mile/year). The tonnage probably increased 4 times between 1811 and 1850 (from 5,000 to 20,000m^3/year?). In 1868, 30,000 tons (around 18,000m^3) were removed (24,000 tons of gravel; 6,000 tons of cobbles; Mathison 2008); around 1% of the total supratidal volume per year.

Pickwell (1878, p204) observed that there was also widespread extraction along the Holderness shoreline:

> "*for many years it had been the practice to remove the shingle for sale for the repairs of the parish roads. This custom grew to such an extent that it was not uncommon to see from twenty to thirty vessels beached between Withernsea and the Spurn, taking from 50 to 80 tons each, in a single tide. On the opening of the Hull and Holderness railway the gravel trade received a great impetus*."

Pickwell (1878, p204) reported evidence from a resident of Withernsea that "*from 200,000 tons to 250,000 tons had been removed along a length of 2 miles opposite Withernsea between the years 1854 and 1869, equal to 8,000 tons per mile per annum*" (between 1951 and 2016 the coarse sand and gravel yield from the Holderness cliffline ranged from 500-2500m^3/km/year, roughly equivalent to 2,000-10,000 tons per mile/year; see Figure 36).

In 1850 the Admiralty imposed an order "*prohibiting the taking of ballast or shingle from the shore or banks at Spurn Point from the low lighthouse, southward to the extreme point at low water, and northwards, two and a half statute miles on both sides of Spurn Point*." In 1854 the Lord High Admiral imposed a total ban on the removal of materials at Spurn; the ban was eased to allow lifeboat crews to take material from the Binks.

In 1868 the Board of Trade issued an order under the Harbour Transfer Act of 1862 prohibiting the removal of shingle from any portion of the shore at Spurn for a distance of 2 $^{1/2}$ miles northward from the point (Pickwell 1878 p205). In 1869 the Board of Trade prohibited all shingle and ballast removal from the Holderness beaches up to Hornsea; in 1869 and 1870 a number of people were prosecuted for violating the law (Pickwell 1878 p205). However, gravel extraction by sloops continued at the Binks until the 1920s.

3.6 Land Reclamation in the Humber

Around the beginning of the last Millennium there would have been around 250 square miles (over 65,000ha, 65km^2) of wetlands adjacent to the Humber and the lower reaches of its tributaries, notably in the Axholme (160 square miles) and Ancholme (50 square miles) valleys (e.g. Shelford 1869). Much of this wetland has been progressively transformed into reclaimed farmland by artificial drainage works and river improvements. The main stages of this transformation can be summarised as follows:

- the Hull valley, where 60 square miles that had been "*open to the flow of the tide*" *Shelford p473) was embanked and reclaimed by the early 14th century when a Royal Commission was appointed to oversee repairs (Dugdale 1772).
- the Isle of Axholme was drained by Cornelius Vermuyden around 1630, for Charles I in return for one third of the newly drained land (60,000 acres, around 95 square miles). When work started on the drainage of Haxey Carr in 1628, riots broke out during which materials were destroyed, workmen abused or assaulted, and construction work damaged (Fleet 2002). Shelford (1869 p 474) stated that "*the land near the Humber is 2 feet below high-water spring tides at sea, and 6 feet below it at some points farther inland*".
- the drainage of the Ancholme Valley (3 to 9 feet below HWST; Shelford 1869 p 473) under the direction of a local landowner, Sir John Monson, in 1638-40 (Smith 2012). In the 1630s, the Court of Sewers gave the drainage contract to Monson and in return he was promised 5,827 acres of the drained land. Work began in 1638 and included a sluice gate at South Ferriby which would stop the Humber tides from regularly inundating the low-lying lands of the parishes

either side of the newly straightened river (Smith 2012 p 194). The works stopped tidal flooding for 20 miles south of the sluice.

However, the "*works and sluices went to decay*" (Rennie 1845 p189) and the "*level relapsed to its former waste and unprofitable state*" (Rennie 1845 p190). In 1767 it was reported that the Ancholme had been under water for several years (Smith 2012, p197).

An Act of Parliament in 1767 would have the effect of draining 18,669 acres of carrs and low ground (Smith 2012 p198). The scheme involve constructing a new sluice near Ferriby sluice (Mr. Yeoman's Gate), "*of sufficient height … to shut out the Flow of the Tides*." (Smith 2012 p199). However, the drainage remained "very inefficient" (Rennie 1845 p193), and further improvements were made in 1802, 1825 and 1844, by John Rennie and his son, Sir John, to lower the bed of the New Ancholme and to replace Yeoman's Gate.

- the reclamation of Sunk Island (around 15 square miles; "*at a level of 2 feet below high-water spring tides*" Shelford 1869 p 474) occurred between the later parts of the 17th century until the late 19th century (Bulmer 1892). In 1688 the area was described as containing 3,500 acres of "drowned land," of which only about 7 acres were embanked from the water (Bulmer 1892). By 1744 there were 1500 acres of embanked land, with a further 2700 acres of new ground fit for embankment. In 1833 a survey indicated 5929 acres of cultivation (Bulmer 1892), with the reclamation possibly occurring in the early 19th century. At some point between the later 17th and late 18th centuries the reclamation had closed off the North Channel (the main flood tide channel in the Humber; Figure 11). A further embankment took place in 1850, when nearly 700 acres of land was added to the estate (Oldham 1862).

  The closure of the North Channel appears to have forced the flood tide system southward along the line of what is now the Sunk/Hawke Channels.

The cumulative area of reclamation over time (Figure 12) highlights the step-changes in wetland loss in the early-mid 17th century and then in the mid-18th century. This reclamation will have had a significant impact on the total estuary volume of the Humber. Townend et al (2007) modelled the post 1850 decline in total estuary HW volume using historical chart data; the results (Figure 13). This indicates a 1.3×10^8 m^3 (5%) reduction between around 1850 and the 1870s, probably coinciding, at least in part, with the reclamation of Sunk Island (5000 acres of early-mid 19th century reclamation, or around 2000ha x 5.7m tidal range = 1.14×10^8 m^3 tidal volume decrease). The earlier reclamation would have had a greater impact, with a post 1630 decline in estuary volume of possibly 6.8×10^8 m^3, potentially a 20% reduction in tidal volume[2].

[2] It has been assumed here that the Axholme and Ancholme levels would have been, on average, around MSL (i.e. 2m below MHWS). The possible contribution to the total estuary volume would have been 34,000 ha (3.4×10^8 m^2) x 2m = 6.8×10^8 m^3, suggesting a pre-reclamation estuary volume of 3.4×10^9 m^3, and a decline of around 20% by the 1850 value of 2.71×10^9 m^3).

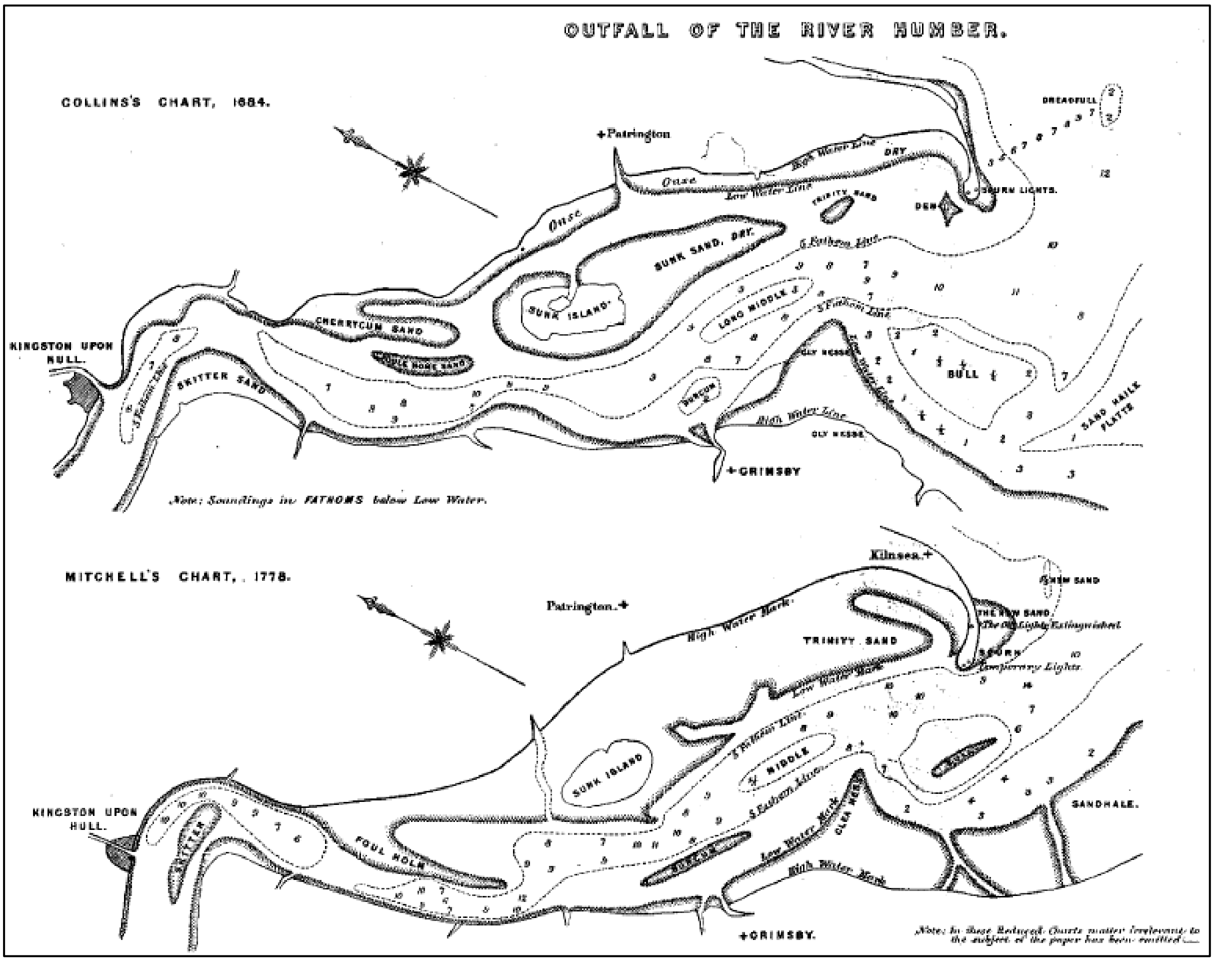


Figure 11 The impact of land reclamation at Sunk Island on the North Channel, between 1684 (top) and 1778 (bottom chart).

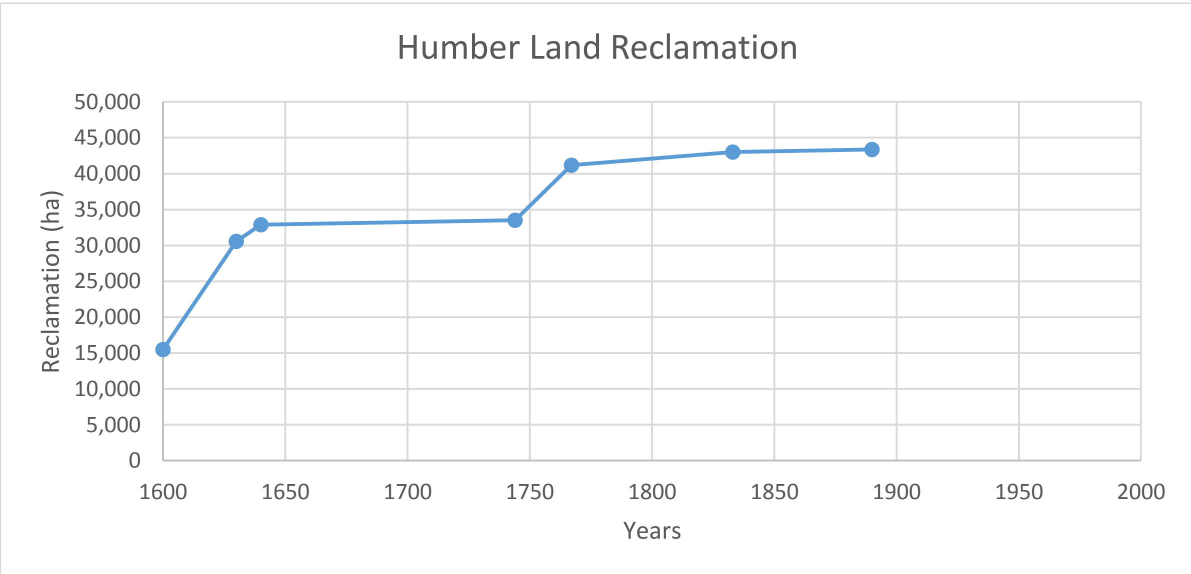


Figure 12 The post 1600 cumulative history of land reclamation in the Humber (the value at 1600 is for the Hull valley, believed to have been reclaimed earlier in the Millennium).

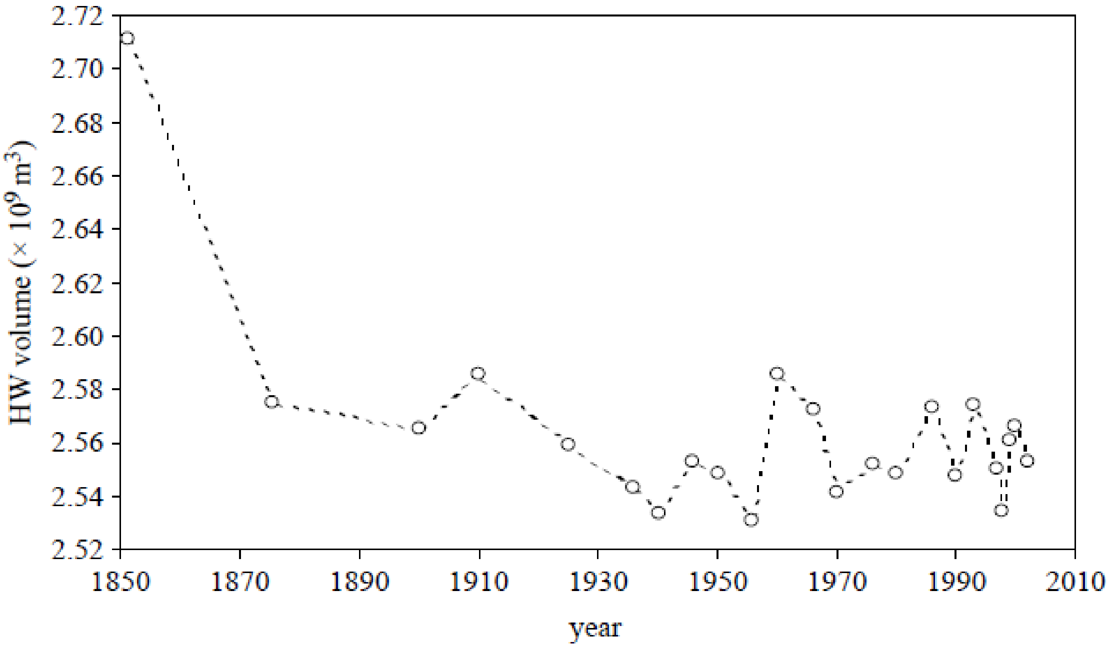


Figure 13 Historic changes in total estuary volume since 1850 (from Townend et al 2007)

3.7 The 1849 Breach

On 28 December 1849, Spurn was breached during the course of a NNW gale which occurred at the time of an exceptionally high tide (Vetch 1850; Figure 14). The breach occurred close to the Old Den, around half and three-quarters of a mile north of Smeaton's high lighthouse, in the area worked for cobbles. Mathison (2008) has suggested that horse and cart traffic to remove the material would also have damaged the dunes.

de Boer (1981) reported that the Spurn lifeboat sailed through the breach on 29 February 1850 and on 29 June 1850 six or seven sloops drawing at least six feet of water passed through from the Humber side on a single tide. By July 1850 when Captain Vetch made his visit to Spurn, the breach was 293 metres wide at "ordinary high water" and 10-12 feet (3-3.66m) deep with currents up to 6-7 knots (Vetch, 1850; Figure 15). Long stretches of dunes either side of the breach were eroded away, leaving over 1100m of the Neck under water at extreme high tides (de Boer 1981 p207).

Vetch (1850) made a number of recommendations: a prohibition of cobble and gravel workings, the closure of the breach, the erection of groynes and reclamation between Spurn and Sunk Island.

The breach continued to expand and by the end of 1851 was around 1250m wide, and around 4.88m deep at high spring tides. A smaller breach had also occurred 500 yards north of the 1849/1850 breach. On February 28th 1851, the lighthouse keeper reported:

> "*… the breach is very much wider and deeper than last August, but not much deeper in the centre as it is on clay. The beach is gone away very much on the sea side to the north of the breach and there is another place where the sea crosses the bank five hundred yards north of the breach, but that place has been open some four or five months, but as the beach has come along it has partly stopped it again, but now I see it getting deeper*." (quoted by de Boer 1981 p207).

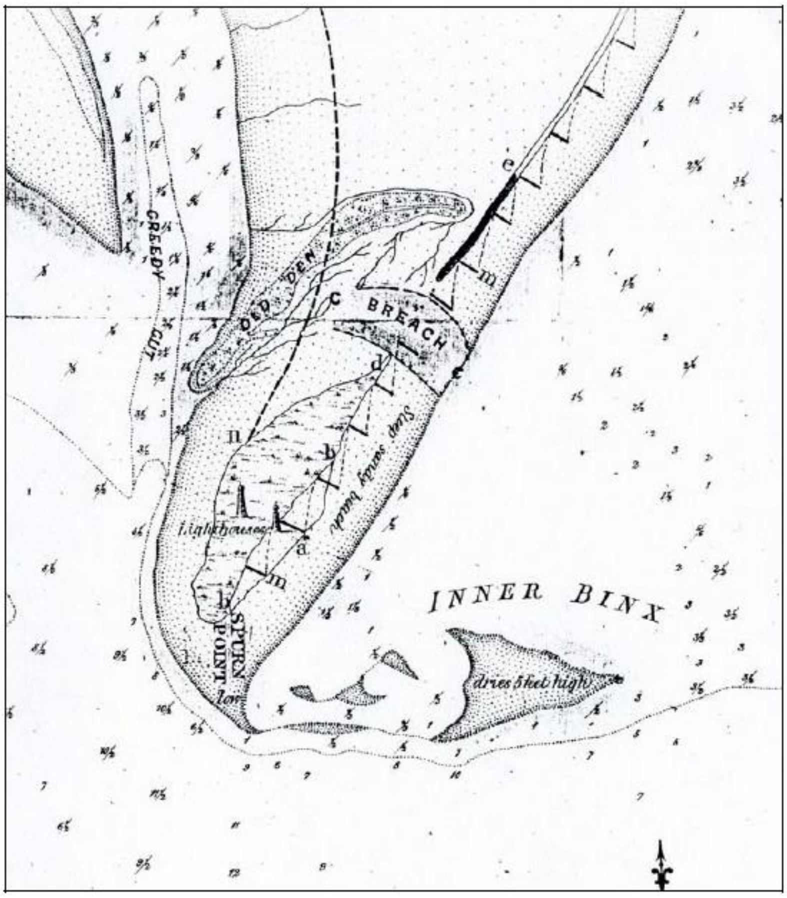


Figure 14 Map of Spurn Point in 1850 showing location of main breach; (Vetch, 1850)

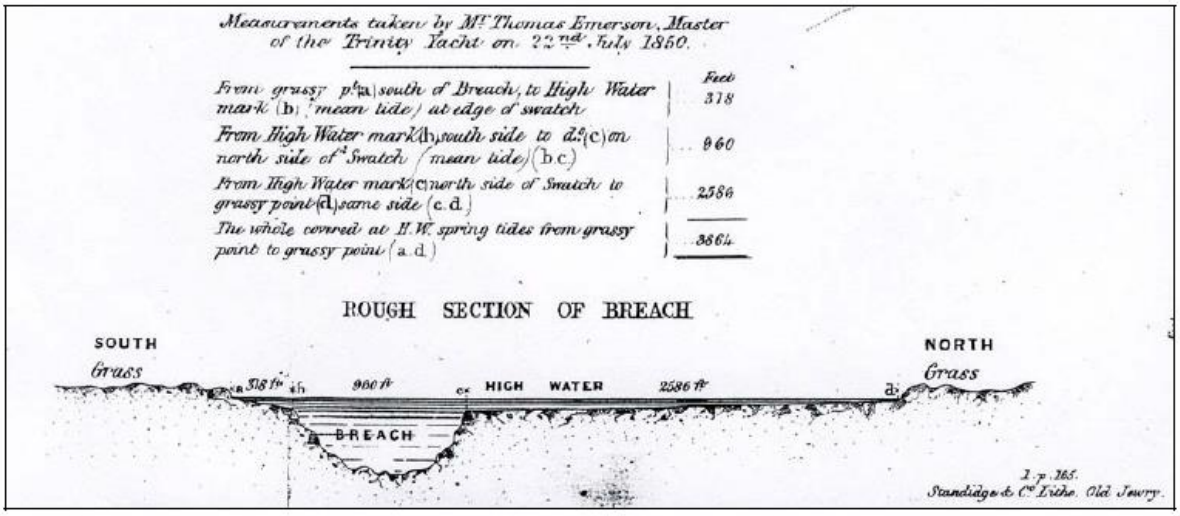


Figure 15 Section across 1849/50 breach (Vetch 1850)

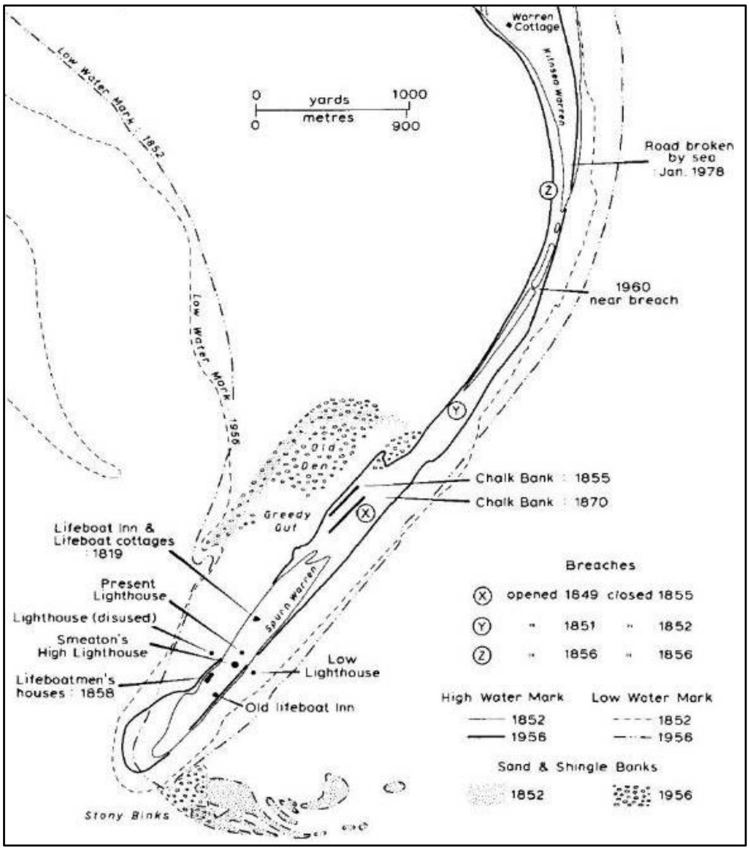


Figure 16 Location of the Chalk Banks and breach events (de Boer 1981)

By May 1852, the northern breach was successfully closed by the engineer James Walker using chalk blocks set behind stakes and wattling (de Boer, 1981 p 209). However, the main breach could not be closed using the stakes and wattling method and it remained open until 1855 when an embankment of chalk blocks was constructed on the estuary side of the breach. However this embankment was curved and protruded significantly into the Humber where it was believed to be restricting the northward movement of sediment along this flank of the peninsula causing a weakening of the northern Neck of the spit. By 1870 a second chalk embankment had been built across the breach location a little to the east of the first embankment (Figure 16).

A series of groynes were constructed in 1853 to control the erosion in front of Smeaton's high lighthouse, and by Coode on the eastern shore in 1864 (3 at the breach site and 2 to the north). Further groynes were added, so that by 1926 there were groynes at 250m intervals along the entire shoreline. A timber revetment (the Wyke Revetment) was constructed along the Neck in 1883-1884 (de Boer 1981, p212; Crowther 2006, p84).

The spit was breached again in 1856, close to the mainland end of the Neck (80 yards wide and 13 feet deep at high water; de Boer 1981 p210); it was sealed in 1857 (Crowther 1997).

Dunes were artificially created along the Neck by trapping sand behind wattle fences inserted into chalk compartments and sowing marram grass. Pickwell (1878, p206) estimated that there had been an accumulation of vegetated dune 60 yards wide for two miles along the Neck, and recorded that the groynes had led to the build-up of a beach 100 yards wide and 7 feet deep. Pickwells's measurements in 1875 showed that there had been a "*further southward extension of 60 yards since 1864, or 5.4 yards per annum, while the westward movement had been arrested*" (Pickwell 1878, p192).

3.8 20th Century War-time Defences

Spurn was fortified during the Great War. Spurn Fort was constructed at the point in 1915 and connected to Godwin Battery (Kilnsea) by a single-track, narrow gauge railway (Hartley and Frost 1981). The Wyke Revetment along the Neck was raised and modified into a railway embankment (the railway was dismantled in 1951-52). Near Smeaton's lighthouse, the Port War Signal Station was built and from here all vessels using the area were monitored; they used pennants, lights and sound to indicate that they were friendly vessels. Two groynes were constructed on the eastern shoreline, one at the southern end of the Neck, the other at the northern end.

After the War the defences were maintained by the Board of Trade, several groynes were renewed and extended, and five groynes were added opposite the site of the 1858 lifeboat cottages towards the Head (de Boer 1981 p212). Planting of *Spartina anglica* between 1938 and 1964 led to the establishment of a salt marsh on the western side of the Neck (IECS 1992, p43).

During WWII, a concrete single track access road to the Head was constructed in 1941 (Crowther 2006). In 1942, a storm surge caused severe erosion on the eastern shoreline and left around 30m of railway hanging in the air across a gap (de Boer 1981). The damage was repaired by a wall of concrete-filled bags along the Neck. In 1950-52 a concrete seawall was constructed by the Ministry of Defence (MoD) between Kilnsea and Kilnsea Warren; it was badly damaged during the 1953 storm surge and had completely failed by the 1960's (Crowther 2006, p 160-161).

Surveys undertaken by Dossor showed that the point extended southwards by 260 feet (c80m) from 1930 to 1959 (de Boer 1964, p86).

In the 1950s, during the Cold War, anti-aircraft artillery was placed in the Warren area (see: http://www.wilgilsland.co.uk). However, in 1956 the MoD had decided that Spurn no longer had any useful military role, and negotiations began with interested parties concerning its future. However, none of the parties were "*prepared to take over the financial burden of maintaining the sea defences*" (Richard Wood, MP for Holderness, quoted in Crowther 2006, p187). Due to the high costs involved, the responsibility of maintaining the sea defences appears to have been waived (Crowther 2006, p188).

The Yorkshire Naturalists' Trust (now the Yorkshire Wildlife Trust) bought Spurn in 1959 for £1500 (Crowther 2006 p189). The valuers, Messrs Todd & Thorpe of Hull, estimated that without maintenance of the sea defences the probable life of the Spurn promontory would be five years (Crowther 2006, p189). The Trust adopted a policy of "*letting nature take its course*" (Crowther 2006 p 215).

At the time of her research into the geomorphology of Spurn in the late 1950's and early 1960's, Ada Phillips (Pringle) described the defences (Figures 17 to 22):

> "*Along the whole length of the seaward side of Spurn Head groynes have been built …. In addition concrete revetments were built along the east side of High Bents* (i.e. the Neck), *near the lighthouse, and at Kilnsea. Except for a new section at the narrowest part of High Bents, built in 1958, most of the revetments were in poor condition in 1959*." Phillips 1962

Figure 17 January 1960: Broken groyne and collapsed revetment along the Neck (from Phillips 1962)

Figure 18 January 1960: Collapsed revetment along the Neck (from Phillips 1962)

Figure 19 January 1960: Dune erosion behind collapsed revetment along the Neck (from Phillips 1962)

Figure 20 January 1960: collapsed revetment along the Neck – it appears to be fronted by a timber framework and topped with thin concrete slabs (from Phillips 1962)

Figure 21 March 1961: Storm waves along the seaward shore of the Neck (from Phillips 1962)

Figure 22 March 1961: Waves along the estuary shore of the Neck (from Phillips 1962)

Figure 23 1997: Concrete block seawall/revetment along the southern part of the Neck (from Nicholas 2003)

In 1981, the triple row of anti-tank blocks were moved from Kilnsea and placed on the seaward side of the Neck to act as a sea defence (Figure 23; Crowther 2006, p208). This work was funded by ABP in order to protect access to the pilotage operation at the Point.

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 (Table 2).

In 1982 over 700,000 tons of clay from BP's Easington Gas Terminal were dumped, graded and consolidated between the Neck and Easington. However, a storm surge on 1st February 1983 removed much of this material: "*In places, at Narrow Neck, ripping half its height away, hurling clay over the top onto the roadway. At the northern end of the peninsula, behind the warden's house and information centre the damage was more serious. The sea had come within two feet of severing the bank; over 30 feet of coast disappeared in one night*" (Yorkshire Wildlife Trust, quoted in Crowther 2018). As a result of this storm, the Trust Council "*accepted there is no way it can prevent the sea from ultimately breaking through the neck of the peninsula*" (Yorkshire Wildlife Trust, quoted in Crowther 2018).

3.9 The Temporary Breach of December 2013

On the 5-6 December 2013, the Neck "breached" between beach profiles 123 and 124 (around the site of the 1856 breach). The area affected was 280m wide and scoured to a depth of 2.3m OD, but had closed naturally by May 2014 (Figures 24 and 25):

> "*The damage at the northern end of the peninsula was quite amazing, and has changed both the landscape and access by road to the Point … The tarmac road, which goes from the Warren area over an old gun emplacement and along the Humber side down to post 19 remained intact, though at its southern end it was covered with sand. From there, as far as post 31 the peninsula was unrecognisable. A large area, where the road had been, was rendered a virtually featureless*

beach. The sand dunes had entirely disappeared … It was (and is) very difficult to orientate oneself, as the points of reference, like the electricity poles, the road, and the wooden posts which edged the Armorflex road along the Humber foreshore were all either gone or covered with sand. The narrow dunes on the seaward side had been washed away. The length of road which has been lost is estimated to be about a third of a mile or 500 metres." Crowther 2014

This temporary breach (a major overwashing event) coincided with a large positive surge event associated with storm Xaver, which raised the high water levels by 1.7m at Spurn to 8.95 m CD (5.05 m OD). The surge was approximately equivalent to a 1:1,000 year event (ABPMer 2014). By the time of the succeeding high water (at approximately 08:00 on 6 December 2013), the surge influence had reduced to around 0.5 m although peak water levels remained high (3.55 m OD), above MHWST (3.0 m OD). However, the largest waves occurred around 06:00 on 6 December.

Table 2 Notable storm damage events since the 1950s.

Date	Observations
31 January – 1 February 1953	Spurn withstood the effects of the storm surge without serious damage. de Boer 1981.
January 1960	During a storm and surge conditions the road was damaged near the groyne at High Bent, the dunes were washed away until the road was only inches from the edge of a cliff of loose sand. de Boer 1981.
1962-1965	Continued erosion of the beach opposite the Chalk Bank, eventually removed the dunes sheltering the road. Laying of hawthorn hedge prunings encouraged re-growth of lyme and marram grass and re-establishment of the dunes. de Boer 1981
1976 onwards	Erosion on the Humber-side from High Bents southwards; placement of building rubble controlled the problem. de Boer 1981.
11 January 1978	Storm surge and NE gale undermined the road south of Warren Cottage. Sections of the road collapsed and a by-pass was made. de Boer 1981
31 December 1978	By-pass road was inundated and sections of the old road suffered further damage and was buried beneath the beach. de Boer 1981
1 February 1981	Gales seriously damaged the spit, concern that it might breach. HRS 1983.
February 1983	Severe conditions led to loss of the clay bank near Warden Cottage. HRS 1983.
April 1991	The Warren compound was flooded and the concrete road between the "loop" roads was undermined, leading to its collapse. A new road was later built on the west side of the Peninsula. Crowther 2006.
February 1996	The road at the northern end of the Peninsula and just north of the Chalk Bank was lost. Two bypasses were later constructed. Crowther 2006.
2002-2003	Collapse and erosion of the seawall, leading to around 40m of retreat by 2007 ABP Mer 2008
February 2005	Significant damage to the road over a 140m section as a result of N'ly storms and high spring tides. The road over this section was re-aligned to the W. A temporary 4x4 route was established. ABP Mer 2009.
March 2007	Storm damage (less severe than 2005) over a distance of 400m; between 150m and 200m of road needed realigning and a further 200m of concrete mats needed lifting, repairing and rebidding. ABP Mer 2009.
5-6 December 2013	Storm surge led to a temporary breach at approximately 280 m from north to south at the MHWST mark, with the spit to the south becoming cut off during spring tides. However, by May 2014 the spit had showed signs of recovery with the crest of the spit almost entirely above the MHWST mark. ABP Mer 2014

It unclear whether the event occurred at around high water in the evening on 5 December 2013 (the time of the largest surge) or whether it occurred the next morning, at the time of the largest waves. However, previous significant narrowing of the spit and lowering of the crest was also a significant factor (ABPMer 2014).

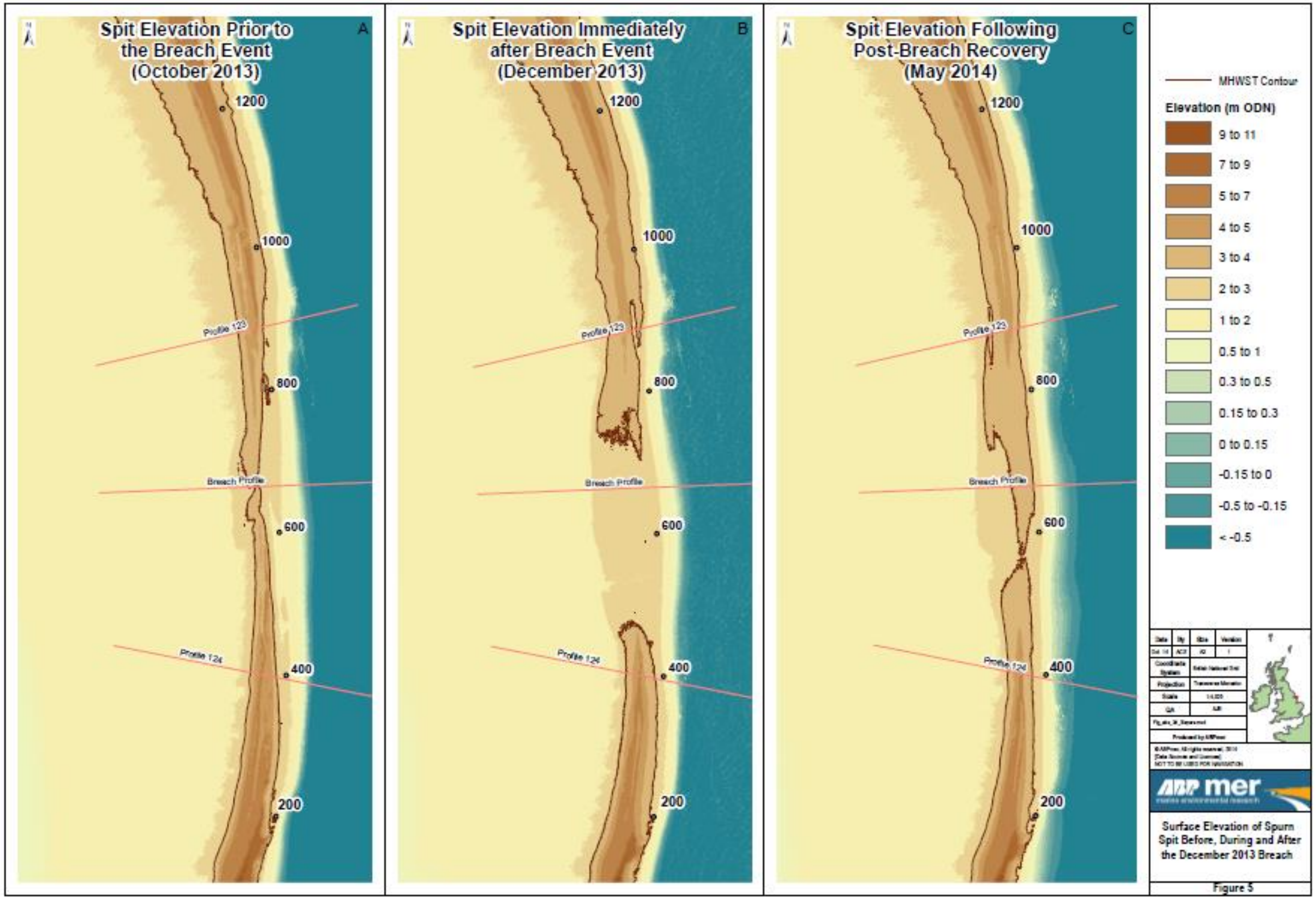


Figure 24 Surface elevation of Spurn prior to and after the 2013 temporary breach (from ABP mer 2014)

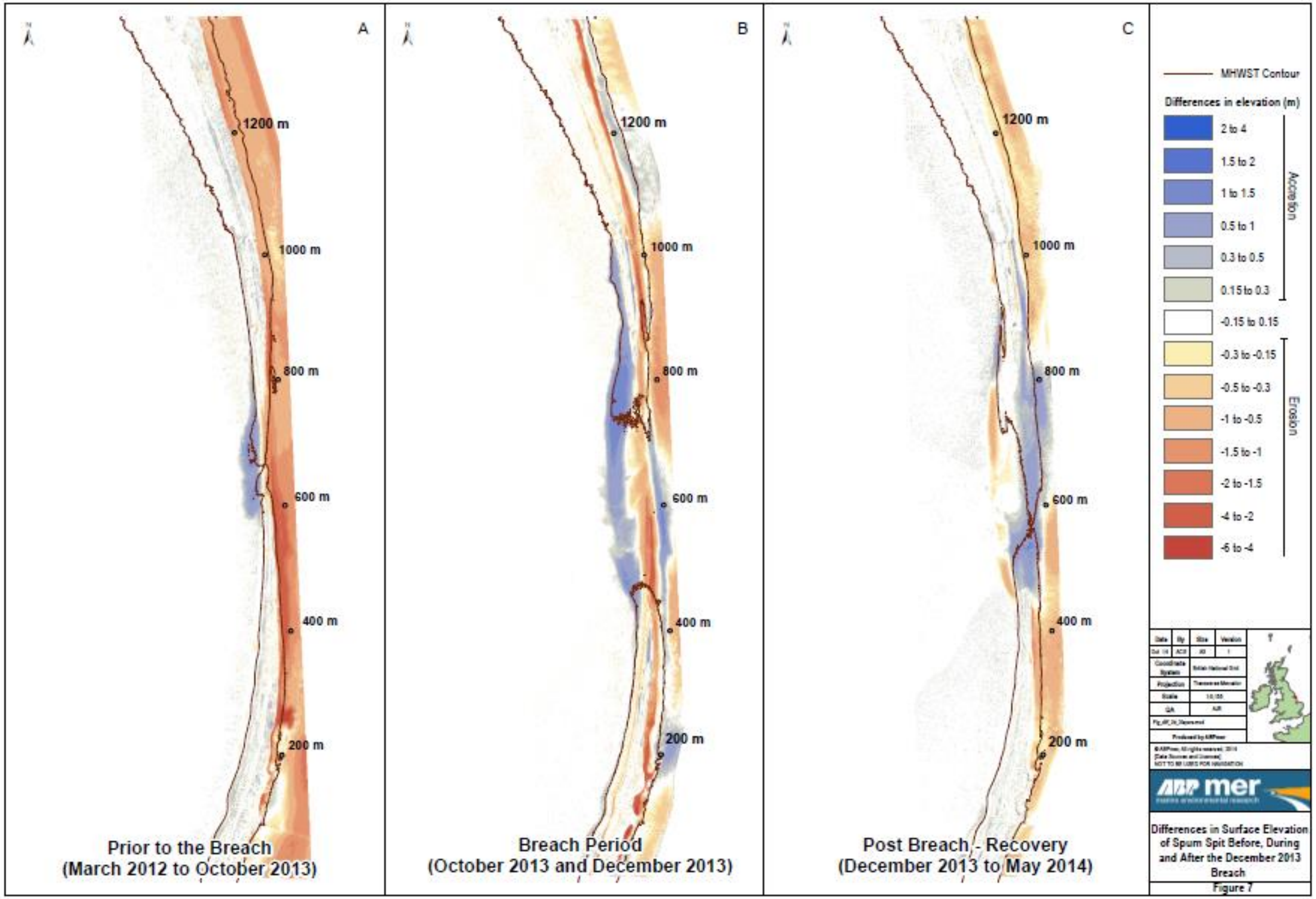


Figure 25 Differences in surface elevation before and after the 2014 temporary breach (from ABP mer 2014)

ABPMer (2014) undertook an assessment of the impact of the event and concluded that:

- the Neck is backed by extensive mudflats which restrict the potential volume of tidal flow that would be required to sustain the breach, given the supply of sediment from the Holderness cliffs. The "breach" would probably recover naturally and there is no potential for channel development across the mudflats (Wyke Bight).
- the beach and dune deposits were stripped off, but the underlying estuarine deposits proved resistant to erosion and limited the scour depth (as occurred in 1850).
- the risk of a future "breach" was considered to be high, because (in 2014) the crest of the Neck was very low-lying.
- even if the 2013 had remained open and expanded, the potential impact on the Humber tidal prism and navigation would not be significant.

3.10 Concluding Remarks

de Boer (1964) proposed that, since the 14th Century there have been a series of breaches of varying size and differing locations, notably in 1360, 1600, 1789/90, 1810, 1849/50, and 1856. He also proposed that Spurn has evolved in a cyclic manner on a timescale of c.250 years, with periods of spit growth followed by breaching of the Neck and subsequent re-growth along new alignments further to the west. With the exception of the well-documented events that occurred in the 1850s, the evidence for breaching, barrier breakdown and reformation is virtually non-existent and does not support the idea of cyclical behaviour. This model is still widely cited in text books, but in our view has not stood the test of time.

It seems that the idea of a cyclic model of spit growth and breakdown had its origins with Reid (1885). He observed that Camden had written in his Britannia (1586) that "*on the very tip of this Promontory, where it draws most towards a Point, and is call'd Spurnhead, stands the little village Kilnsey* …" (Camden 1586, p899). Assuming that the observed spit lengthening during 17th to 19th centuries was part of a continuous process operating at an average rate of 13.5 yards/year, Reid proposed that:

> "*the whole spit would be formed in 400 years. If, however, we accept the more rapid increase during the 17th century, and carry it back for about 100 years, till the date when Camden wrote, the result is that the long spit of sand which now forms Spurn Point had then no existence, but commenced to form a few years later, and has gone on increasing ever since …. But this naturally leads to the inquiry, if the bank only commenced forming about 300 years ago, what became of the southward travelling beach before that date?*" (Reid, 1885, p104).

However, as shown on Saxton's map of Yorkshire, Spurn was present in 1577, before Camden made his description of Kilnsea (Figure 26); in this instance Camden's promontory is probably the much larger triangle of land that forms Holderness: "*From Hull, a large promontory shoots out into the Sea, call'd by Ptolemy Ocellum, and by us at this day Holderness*." (Camden 1586, p898).

The key points arising from this review of the history of Spurn are:

- the overall form of Spurn – a broad bulbous or spatulate Head connected by a narrow Neck to the mainland – has been persistent over the last 300-400 years and possibly longer.
- major changes have occurred in response to progressive changes in boundary conditions – spit lengthening in the 18th and early 20th century (due to land reclamation and changes to the tidal prism of the Humber; see IECS 1992) and breaching in the 1850s (the impact of cobble and gravel working on the sediment budget) – rather than extreme events (i.e. the Great Storm of 1703, the 1953 storm surge etc.).

Figure 26 Part of Saxton's Map of Yorkshire 1577

- during the period between the late 17th and mid-19th centuries the Neck migrated westwards probably around a third of a mile in 170 years (500m; 3m/year) and the tip of the Head extended SW by over 2km. However, over the same period the Head has not migrated significantly westwards. These changes suggest that whilst the position of the Neck responds to erosion of the Holderness shoreline, the position of the Head is probably a reflection of the Humber tidal regime. The spatial relationship between the Neck and the Head has been dynamically changing.
- the significance of the link between Spurn and the Humber reclamation and tidal volume change is illustrated in Figure 27, where the late 17th to mid-19th century phase of Head lengthening broadly coincides with the pattern of land reclamation in the Humber. The resulting reduction in total estuary volume and changes along the North Channel (Figure 11) could have led to significant changes in the tidal flows through the estuary mouth, promoting the growth and extension of Spurn.

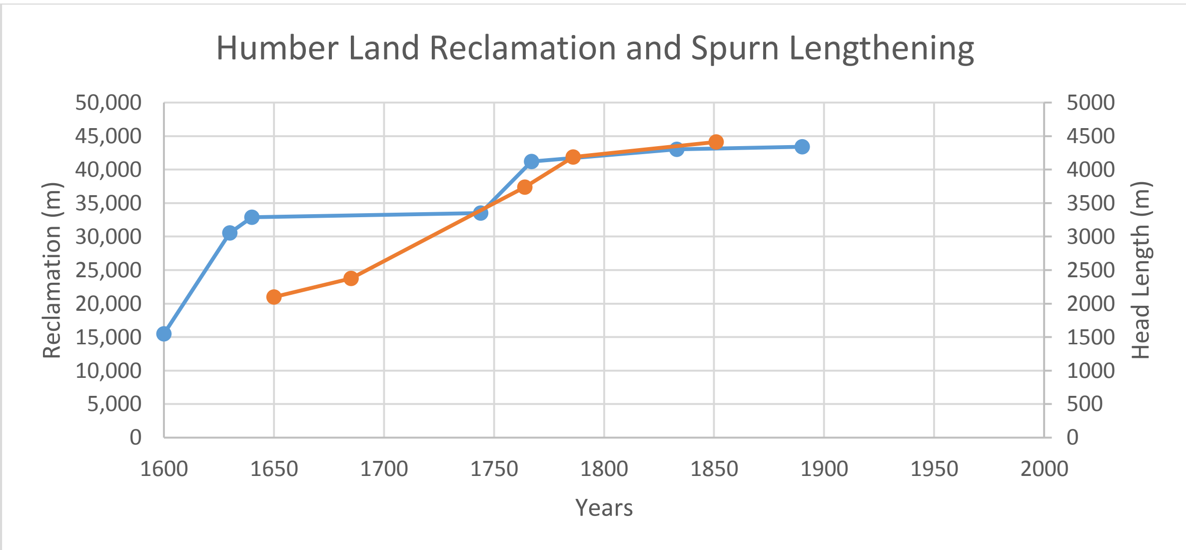


Figure 27 The relationship between the lengthening of the Head (orange line) and the pattern of land reclamation in the Humber (blue line)

- the reclamation of Sunk Island between the late 17th century and the late 19th century led to the closure of the North Channel, the main flood tide channel of the Humber, and probably forced the flood flow southwards in the Humber Approaches. This was probably a key contributing factor in the lengthening of Spurn.
- the present day Spurn has been locked in place by the extensive breach repairs and coast protection works (including dune creation) undertaken over the period between the mid-1850s and the mid-20th century. These works are decaying and deteriorating, and have become localised hard-points focusing wave erosion and scour events on the adjacent unprotected sections of the barrier. IECS (1992) indicated that the WWII seawall prevented westward movement of the Neck, whilst the cliff recession at Kilnsea continued. Since the defences failed, around 2002-2003, the Neck has been affected by erosion and westwards migration through overwashing and, in 2013, breaching.
- as the Kilnsea cliffs have eroded they have both retreated westwards and shortened northwards as the narrow promontory of Kinlsea Warren has been lost (Figure 28). This has led to northwards lengthening of the Neck, possibly in the order of 400-500m between 1855 and 2009 (see Figure 29; it is difficult to be precise about the northern end of the Neck on the 1855 map).
- considerable change has occurred along the Neck since the 1950s when Phillips (1962) wrote "*the dunes rise to over 30 feet O.D. with the highest point 31 feet O.D*." In 2014 the highest point along the Neck was around 3m OD (ABP Mer 2014). The dunes have been lost and only a low sand and gravel barrier remains (Figure 30).

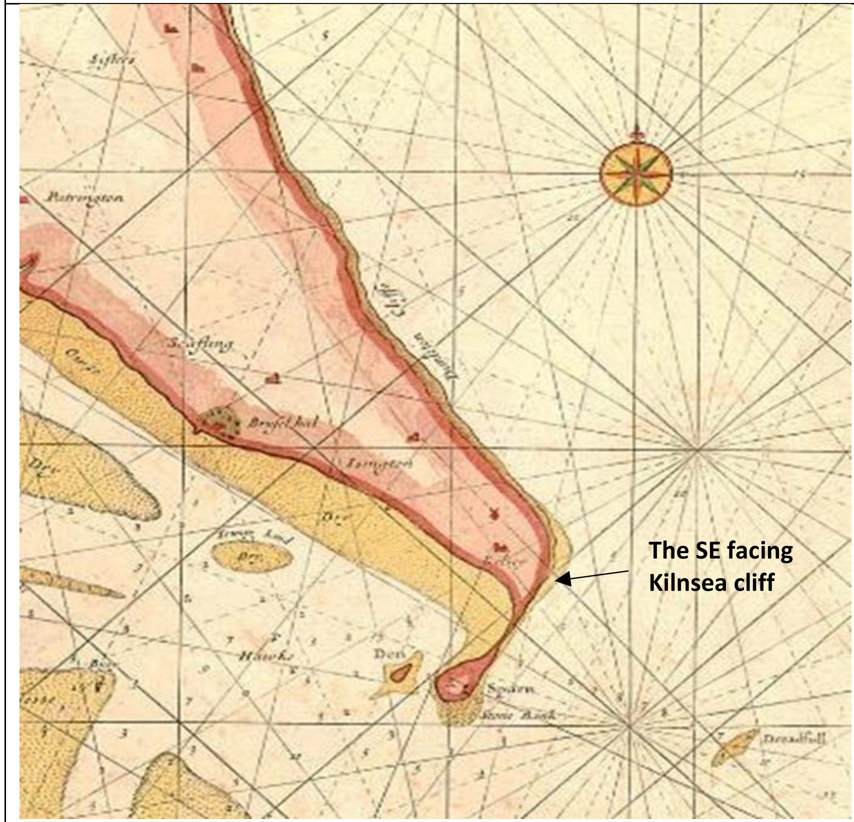
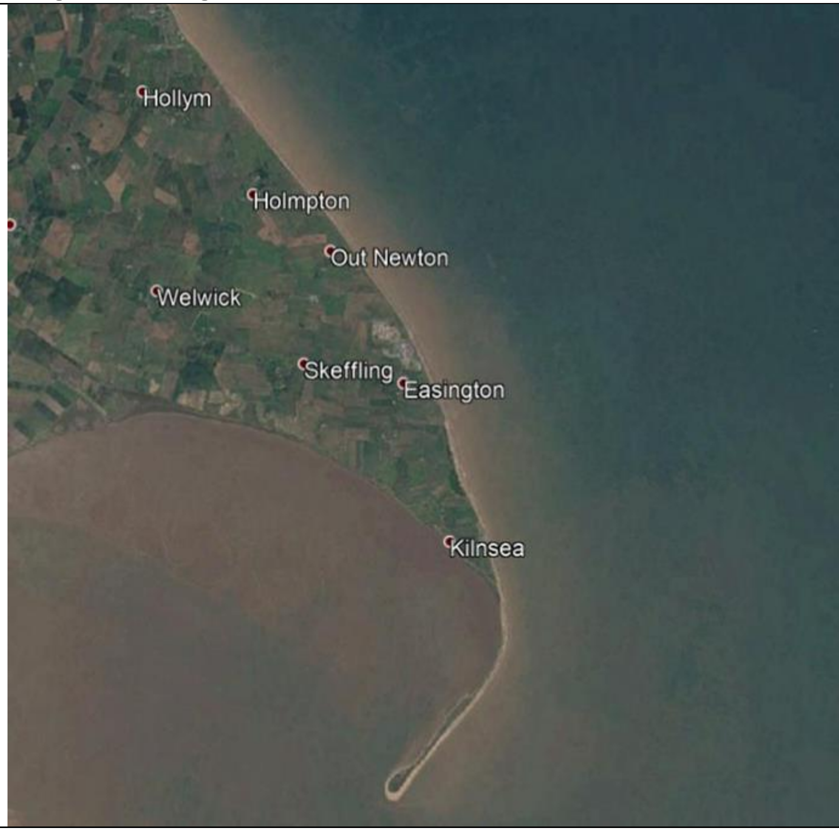
Greenville Collin’s 1684 Chart of the River Humber	Google Earth Image December 2016
 	
The shoreline S of Kilnsea comprises: • the SE facing Kilnsea cliff • a short, narrow straight Neck • a bulbous Head with Angell’s lighthouse on the tip	The shoreline S of Kilnsea comprises: • the loss of the SE facing Kilnsea cliff • a longer, curved narrow Neck • an elongate Head

Figure 28 A comparison of the main features of Spurn in 1684 and 2016 (note that the scaling and registration of the 2 images is approximate)

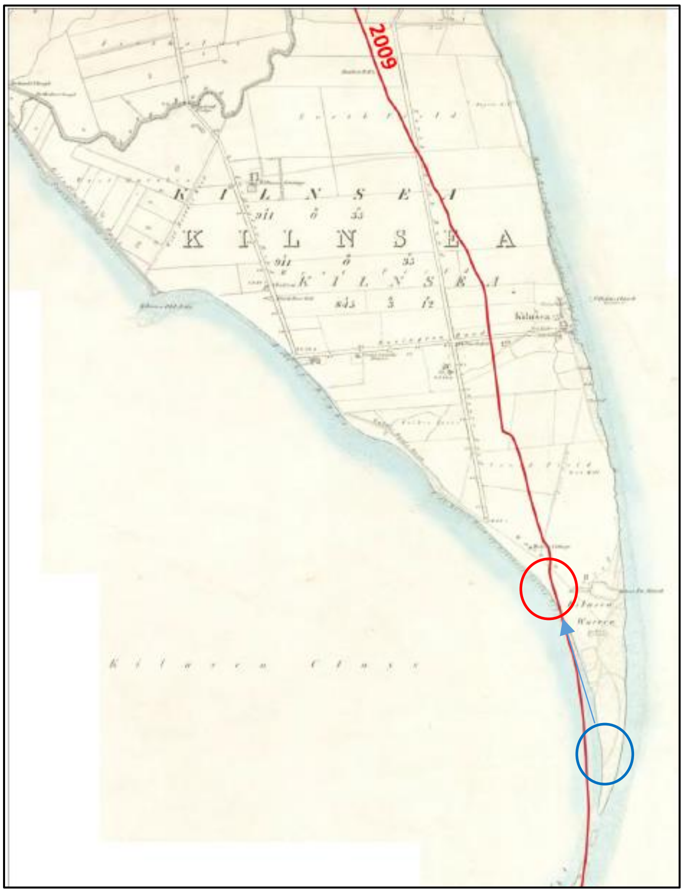


Figure 29 Northwards migration (approximate) of the junction between the end of the Kilnsea cliffs and the Neck of Spurn between 1855 (blue circle) and 2009 (red circle) (adapted from Pye and Blott, undated)

Figure 30 March 2018: the Neck, looking N

4 Spurn: Geology and Geomorphology

4.1 Geological Framework

Spurn is underlain by glacial till deposited during the most recent (Devensian) glaciation, around 18-20,000 years ago. Balson (2008) states that the till is exposed on the foreshore in the intertidal zone on the seaward side of the northern part of the Neck, where the uppermost surface lies at approximately -1.5m OD. This upper till surface dips southwards towards the centre of the palaeovalley in which the modern Humber estuary lies:

- A series of shallow cores taken by IECS (1992) on the central part of the Neck (TA 420140), 1.5km from the 1849/50 breach site, identified the till surface at around -6mOD.
- A BGS borehole drilled on the Old Den in 1995 reached the till surface at around -10m OD.
- A borehole drilled in 1860 on the site of Smeaton's lighthouse failed to reach the surface of the till at a depth of around -13m OD.
- A BGS borehole, drilled in the 1990s, just to the E of the RNLI station, reached the till at -17.37m OD, encountering only "rough gravel" and "sand and gravel" above the till (Berridge and Pattison 1994).

It has been speculated that the till surface rises to around -3m OD at the tip of Spurn, due to the presence of a morainic ridge (IECS 1992). However, Balson (2008) states that "*no corroborating evidence has been found to substantiate the presence of a till ridge under Spurn Point*. *All of the available borehole evidence plus evidence from offshore seismic records show that the glacial till surface dips gently southwards from -17 to -20 metres OD beneath the Point and is overlain by a substantial thickness of gravels, probably of marine origin*".

Balson (2008) described the BGS borehole investigation carried out across the 1849-1850 breach site to examine the underlying geology and sediments (Figure 31). In Borehole 408 the floor of a buried channel was identified at -1.88m OD, coinciding with the reported depth of the breach (4.88m deep at high water, +3mOD i.e. -1.88m OD). The channel floor was underlain by estuarine intertidal deposits and spit deposits (sands and gravels) with the glacial till lying 5-10+ m lower at between -6.87 and -14.33 m OD (Figure 31). The investigation revealed:

- the breach channel was cut in estuarine silts and clays, not glacial till as previously speculated (i.e. the "inner ridge" of IECS 1992 and May 2003).
- the channel has been subsequently infilled with sands and, between the chalk banks, estuarine silts and clays.

At the same time as the breach investigation, 3 boreholes were drilled along the Neck which revealed a sequence of <1-2m of sands over estuarine silts and clays, with the till upper surface at around 5-6m OD. The sequence is probably the product of westwards migration of the Neck across the Humber mudflats.

Balson and Philpott (2004) state that Spurn contains 5Mm^3 of supratidal sediments (based on that LIDAR data); the total volume would be significantly more.

Sidescan sonar and shallow seismic data collected in 2001 has revealed that the seabed offshore of Spurn and southern Holderness is dominated by gravel and sand sheets and exposed till (Balson and Phipott 2004; Figure 32). However, around 85Mm3 of mobile sands are present, extending through the Humber mouth and NE to the elongate trough of the New Sand Hole. Sand wave are present in these areas, typically 2-7m high, with wavelengths of between 100m and 800m. The wave asymmetry indicates movement towards the NE i.e. towards the New Sand Hole.

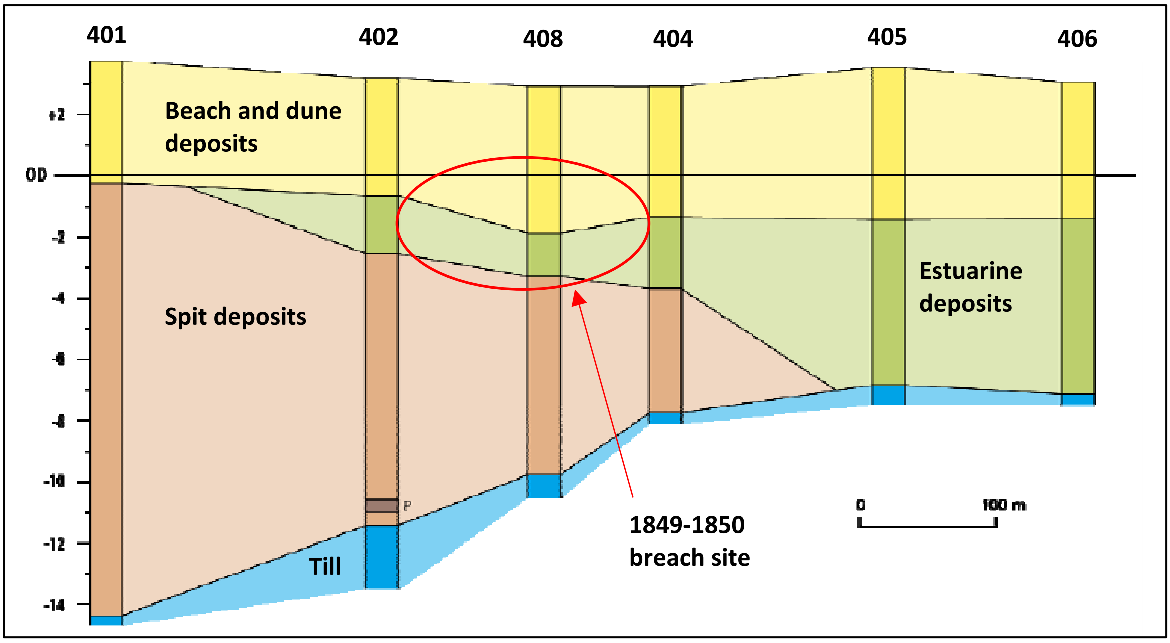


Figure 31 BGS borehole investigation at the 1849/1850 breach site (from Balson 2008).

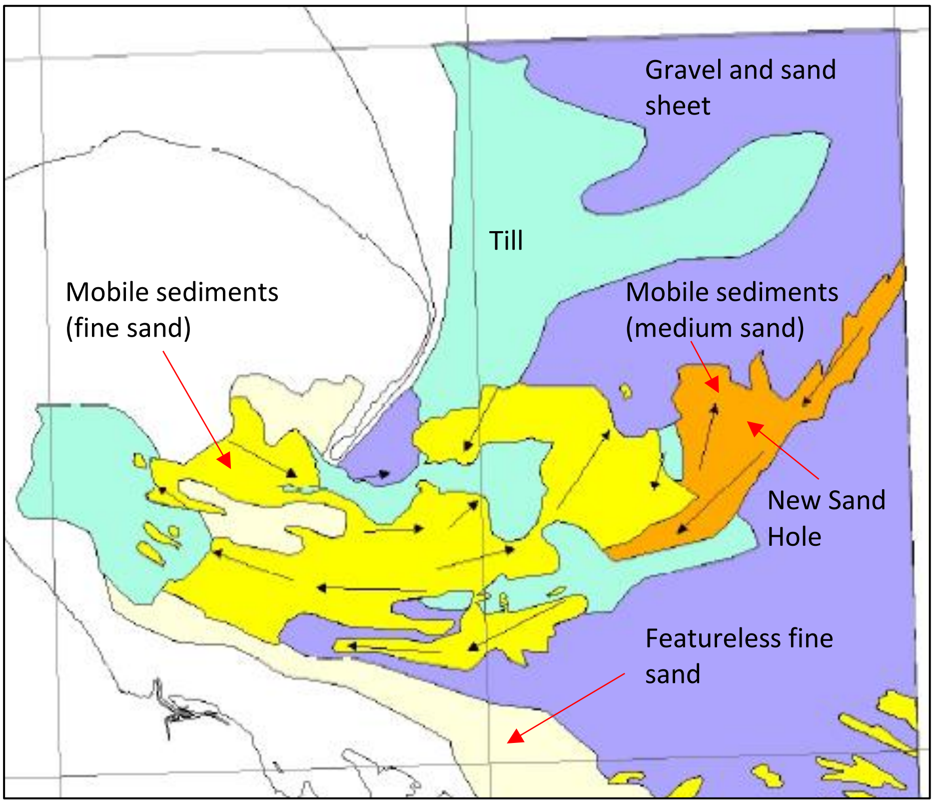


Figure 32 Seabed sediments map of the Humber mouth, black arrows indicate sediment transport directions (after Balson and Philpott 2004)

Sand waves (up to 7m high, wavelengths 100-200m) were also identified between The Binks and The Outer Binks, possibly moving towards the NNE. Across the Binks, sediment has prograded from the N and has probably derived from Holderness.

Balson and Philpott (2004) estimated that the New Sand Hole contained around 3.5Mm^3 of sand and gravel. This may have accumulated over the 5000 years since sea-levels were close to present day levels, suggesting an average deposition rate of 700m^3/year which would be considerably less than the current gravel yield from the Holderness cliff erosion. Balson and Philpott (2004) suggest that much of this gravel yield, however, may simply be stranded on the seabed as the cliffs retreat and not transported southwards towards Spurn and the Humber mouth; this remains unproven.

4.2 Historical Relative Sea-Level Changes

Recent studies of tide gauge records have established the eustatic (global) sea level change trends during the 20th century (e.g. Jevrejeva, et al., 2006; Holgate 2007, Woodworth et al., 2009). Over the period 1904-2003 global sea level has risen by 174mm, with an average rate of 1.74mm/year (Figure 33). Holgate (2007) reports that the highest decadal rate of rise occurred in the 10 years centred on 1980 (5.31 mm/yr) with the sea level fall occurring in the 10 year periods centred on 1964 (-1.49 mm/yr) and 1987 (-1.33mm/year).

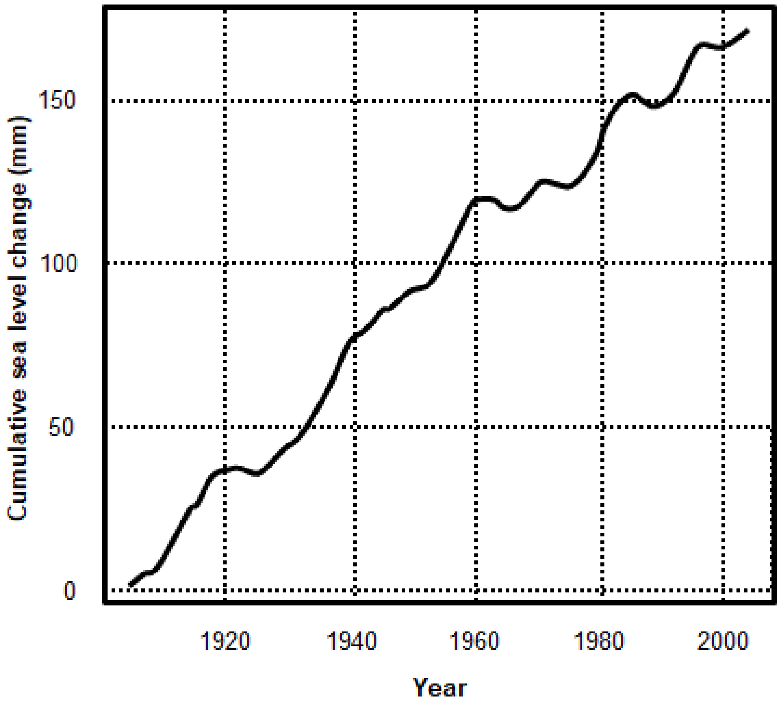


Figure 33 The mean global sea level record over the period 1904-2003 (from Holgate, 2007)

Around the UK the rate of land level change due to tectonic activity or isostatic adjustment is unlikely to vary significantly over the decadal scale. As a result, the UK trends in relative sea-level rise (RSLR) can probably be directly matched to the global sea level trends. Woodworth et al (2008) have reported that the tide gauge mean sea level trends for 1901 onwards are estimated to be 1.4 ± 0.2 mm/year.

Relative sea level rise in the Humber was investigated by ABPmer (2003) who concluded that mean water level at Spurn showed a long term rise of 1.8mm/year at Immingham. Recent analysis of sea-level data by Woodworth et al (2008) has suggested that the sea level trend at Immingham between 1960 and 2006 has been a rise of 0.64 ± 0.38 mm/year.

The nature and scale of sea-level changes on this coast between the 14th century (the first descriptions of Ravenser Od) and the early 20th century are uncertain. Whilst it is generally accepted that sea level has risen progressively by around 5m since the mid-Holocene (5/5000 years = c.1mm/year; Shennan and Horton 2002), little is known about the century or decadal scale variation in this trend. However, research on the German North Sea coast raises the possibility of a general 1m fall in sea-level during the Little Ice Age, between around the 15th and mid-17th century, followed by a progressive rise to present day levels (Figure 34; Behre, 2007).

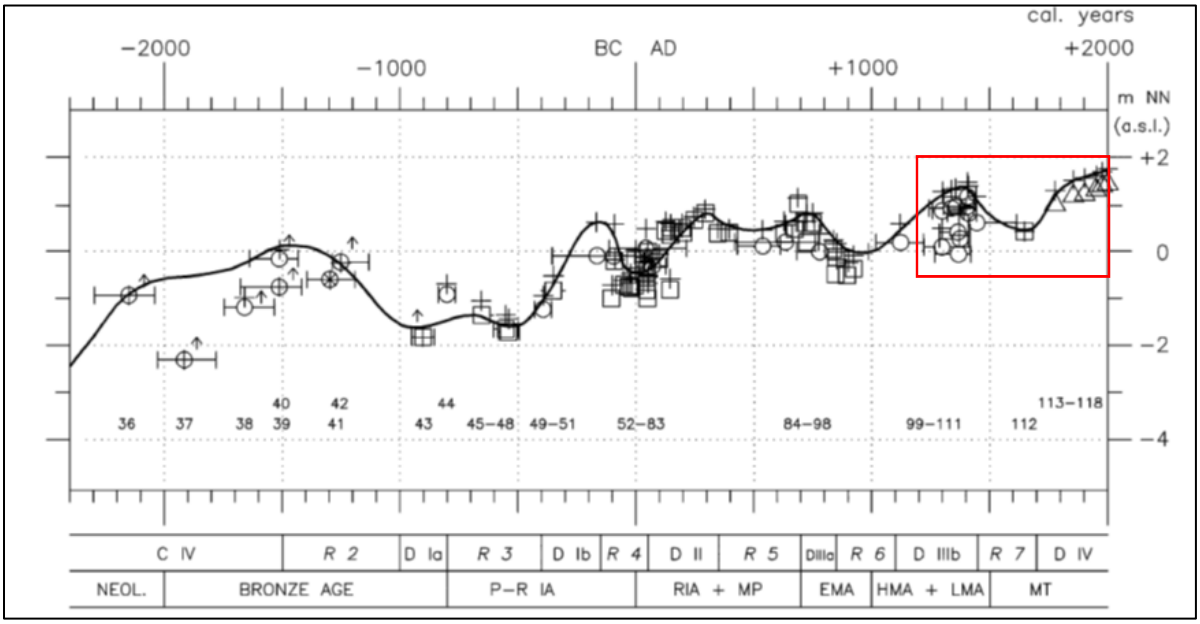


Figure 34 A Holocene sea-level curve for the southern North Sea (from Behre, 2007). The 14C dates the end of transgression D IIIb was at c. AD 1450, and was followed by Regression R7 The MHW decreased rapidly and reached a minimum at AD 1644. The final rise of the MHW, the Dunkirk IV transgression began around AD 1700.

Note, however, that other researchers believe that such century-scale fluctuations are highly unlikely to be real features of the sea-level history of the southern North Sea (e.g. Baetman et al 2011).

The current Environment Agency guidance (February 2017) on sea level change allowance for NE England is: 1990-2025; 2.5mm/year, 2026-2055; 7mm/year. Flood risk assessments: climate change allowances https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances.

4.3 Sediment Sources: the Holderness Cliffs

It is widely accepted that Spurn has evolved and is maintained by coarse sediment supplied from the erosion of the Holderness shoreline.

Using the Erosion Post (EP) data series (1951-2016; see Appendix A) it can be shown that the average annual recession rate for the Holderness coast has increased since 1951 (Figure 35 i.e. the total recorded recession per year for all EPs divided by the number of EPs). This suggests a progressive rise in the average recession rate, by around 1cm/year.

It is possible that this trend reflects the response of the whole cliffline to RSLR and is a trend that is superimposed on the effect of bay development and changing shoreline orientation (Lee, 2011). Relating these changes to the recorded trends of RSLR from nearby Immingham (0.64 ± 0.38mm/year rise 1960-2006) suggests a “retreat efficiency” of the cliffline of around 1.5cm per mm of RSL rise.

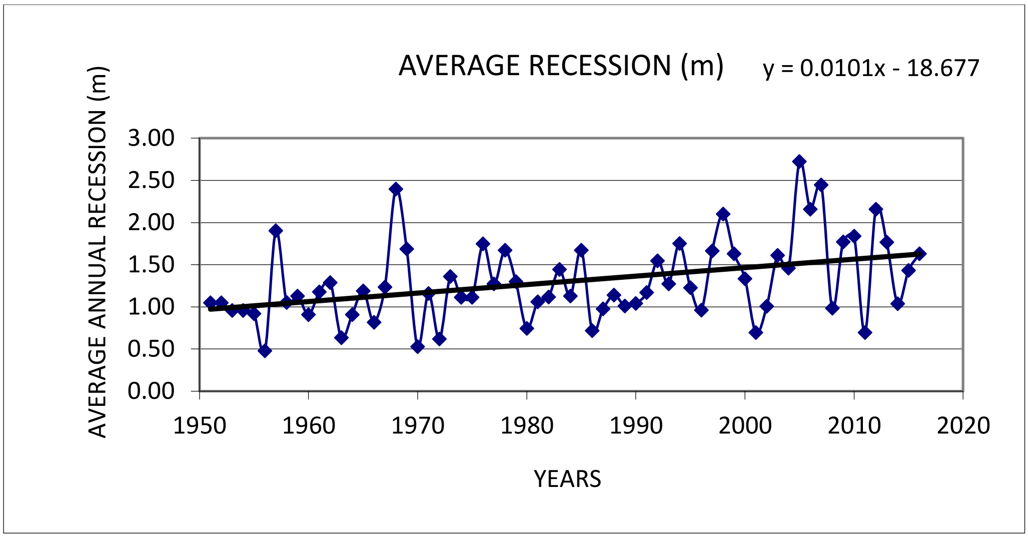


Figure 35 Holderness cliffs: overall annual recession rates 1951-2016

The total sediment yield per year from the eroding cliffs is shown in Figure 36. For each erosion post, the volume is calculated as the recession rate *x* cliff height *x* distance to/from adjacent posts (half the distance one way plus half the other). The sediment yield from the cliffs has increased by around 10,000m^3/year over the time period 1951-2016.

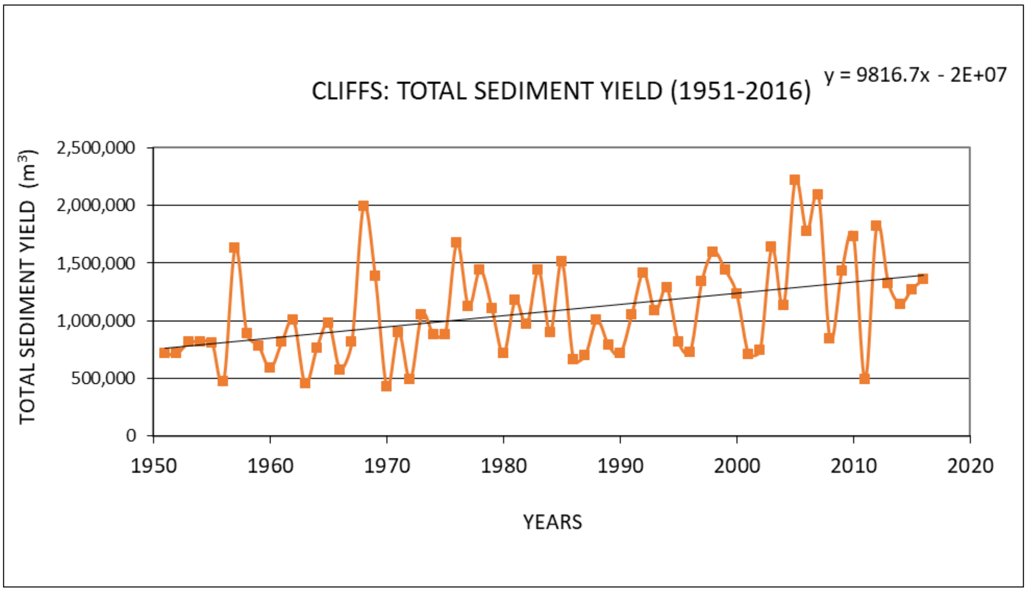


Figure 36 Holderness cliffs: total sediment yield 1951-2016

The composition of the Holderness till cliffs is known to be highly variable. Balson and Philpott (2004) suggest that only 7% is coarse sand and larger (assumed to be potential beach building material); this implies that the annual coarse sand and gravel yield has increased from around 50,000m^3/year in the early 1950s to over 100,000m^3/year (Figure 37). However, the annual yield can be highly variable (over 150,000m^3 in 2005; 35,000m^3 in 2011).

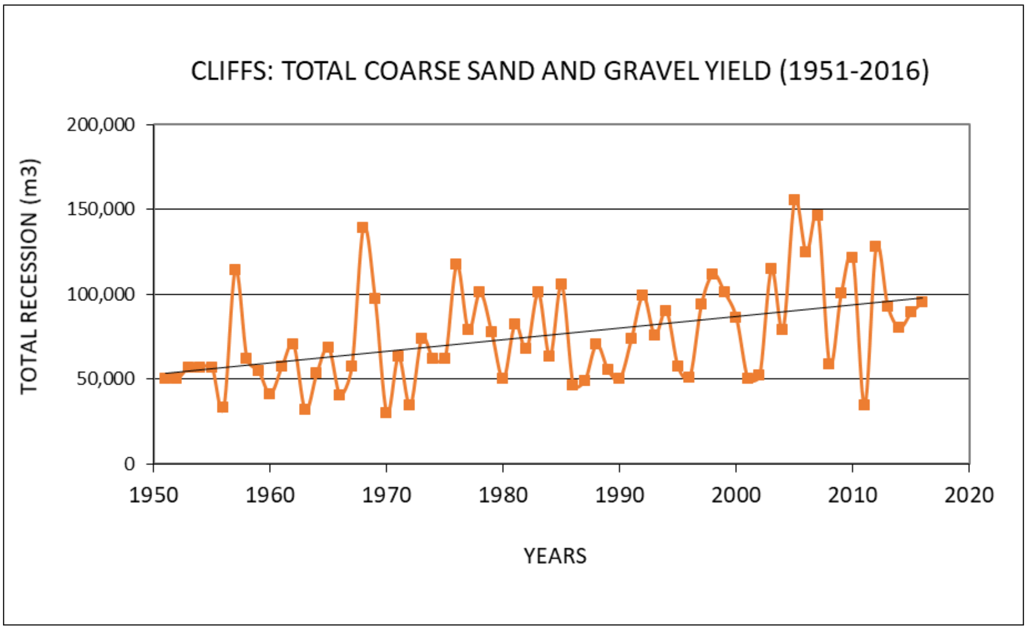


Figure 37 Holderness cliffs: total coarse sand and gravel yield 1951-2016

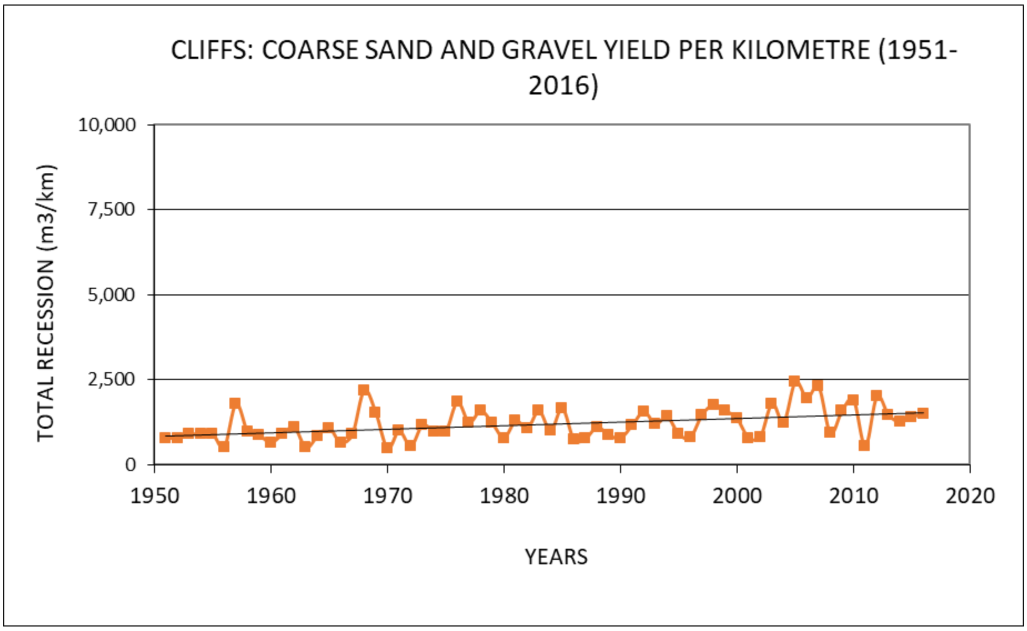


Figure 38 Holderness cliffs: total coarse sand and gravel yield per km, 1951-2016

Wingfield and Evans (1998) suggested that the sediment yield from the eroding cliffs is only 23% of the total sediment yield from the Holderness coast; a further 33% comes from the shore platforms and 44% from the sea bed. Together, these three sources could generate, on average around 400,000m^3/year of coarse sand and gravel.

4.4 The Curved Planform

One of the more intriguing aspects of Spurn is the "convex-eastwards" curvature and orientation of the Neck as it connects the mainland at Kilnsea to the Head (south of the 1849/1850 breach). This general arrangement is the product of the effects of progressive retreat of the Holderness coast and the loss of the SE facing Kilnsea cliffs that were present in the 17th century (see Figure 28). The curvature reflects the "free movement" (certainly prior to the construction of the seawall/revetment in 1942) of the Neck between an almost stationary Head and the retreating Holderness cliffline; the southern end of the Neck is fixed whilst the northern end is "pulled" westwards.

Over time the curve along the northern part of the Neck has changed orientation from line running approximately NE-SW (around 220°) in the late 17th century (Collins' chart of 1684; Figure 28), NNE-SSW (192°) in the early 19th century (1824; OS 1" to 1 mile map) to running NNW (175°) in mid-late 20th century (IECS, 1992). Given that the Neck was "locked" in place by the construction of the seawall/revetment to protect the road and railway in 1941/42, this represents an anticlockwise shift by 17° over 120 years or so. The impact was modelled by IECS (1992) who concluded that the change in orientation would have led to an increase in the energy gradient and, hence, sediment transport rate along the Neck under NE waves.

An indication of the scale of change along the Neck can be shown by using Dalrymple's online sediment transport calculator: http://coastal.udel.edu/faculty/rad/sand.html For 0.5m high waves from the NE the change in orientation results in a 5-10% increase in the potential transport rate (note that the rates shown in Figure 39 should be seen as relative rather than absolute values).

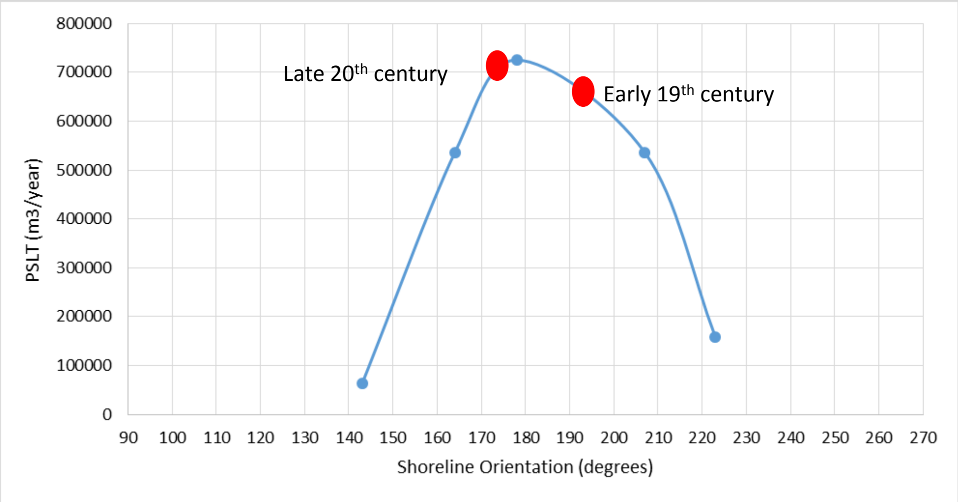


Figure 39 An indication of the effect of changing shoreline orientation on potential longshore sediment transport (PLST) along the Neck (note that the rates should be seen as relative rather than absolute values). Based on Dalrymple's sediment transport calculator, using 0.5m high NE waves.

4.5 Concluding Remarks

The presence of estuarine sediments beneath the beach deposits at the 1849/50 breach site indicates that the Neck had, prior to this date, retreated westwards across pre-existing mudflats. However, the absence of similar deposits in the BGS borehole at the tip of Spurn suggests a different story for the Head. Indeed, it seems likely that much of Spurn is founded on up to 17m of sand and gravels (and cobbles?) above a gently sloping glacial till platform. This material has probably been derived from the erosion of the Holderness coast – the cliffs, platform and seabed.

Over the last century or more, Spurn has been developing within an environment controlled by slow relative sea-level rise (probably around 1mm/year) and abundant and increasing coarse sediment yield from the Holderness coast. These conditions are expected to continue in the future; the rate of sea-level rise is expected to increase, and this will probably result in a continued increase in the coarse sediment yield.

There are significant uncertainties attached to the current understanding of how continued planform changes will impact Spurn, notably:

- whether continued anticlockwise re-orientation and lengthening of the Neck in response to Kilnsea cliff retreat will lead to a situation whereby sediment transport along the Neck to the Head is significantly reduced.

- whether continued northwards lengthening of the Neck would lead to further crest lowering because sediment inputs are spread over a larger area whilst outputs remain the same (i.e. “stretching”).
- whether counter clockwise reorientation in Kilnsea creates more exposure at the neck/narrows and leads to overwashing which more than balances out recession rates in Kilnsea.

5 Evolution and Trends

5.1 Post 1680s Evolution

Figure 40 presents a model of the development of Spurn since the late 17th century, based on:

- the known positions of Angell's and Smeaton's high lighthouses;
- the water depths and shoals shown on Greenville Collin's 1684 chart of the Humber[3]. Note that Collin's soundings were not to a stated datum. In this assessment, the soundings have been plotted to Om OD for convenience. However, if the actual datum was closer to the current chart datum -3.9m, then the plotted depths would be lower than shown[4].
- BGS boreholes have been used to define the surface of the glacial till (relative to 0m OD).
- Greenville Collin's soundings and shoals are shallower than the depth of the till platform (even if a lower chart datum was used). This implies that the till surface in the late 17th century was mantled by superficial deposits. The borehole records (including the 1860 borehole close to Smeaton's lighthouse) show that this material is typically sand and gravel, with no recorded estuarine sediments.
- the extent and height of Spurn in the 2000's is based on EA LiDAR data (see Figure 1) and the current distance between Smeaton's high lighthouse and the tip (as measured on Google Earth). The offshore extension of sand and gravel/cobbles beyond the tip is conjectured.

This model, although not precise because of the assumptions about the datum, raises some interesting points, including:

- the "foundations" for the present day Spurn were present (around 5-10m of sand and gravel/cobbles) prior to the phase of spit lengthening in the 17th to 20th centuries.
- as the spit lengthened after 1680 it had to build up in up to 5-10m of water before appearing above the intertidal zone.
- on Greenville Collins' chart, the Old Den-Stony Banks seem to be shoals in front of the distal end of the "spit". Over time, these seem to have been largely subsumed within the lengthening spit.
- the present day "Binks" also seem to be shoals in front of the current distal end (and not a pre-existing moraine deposit).
- along the section line in Figure 40, in the order of 30-40,000m^3 coarse sediment accumulated since the late 17th century, (assuming a 1m wide strip). As it is not known how wide the lengthening spit would have been underwater, it is not possible to make a realistic judgement on the total volume of accumulation since that date.

5.2 Post 1680s Bathymetric Changes

Significant bathymetric changes have occurred between Spurn and the Outer Binks since Greenville Collins compiled his 1864 chart. Figure 41 shows the approximate locations of Collin's soundings and an indication of the change in water depth at each of these locations (as stated earlier, Collin's soundings were not to a stated datum, making precise comparisons not possible, although it is likely that the datum was around MLWS i.e. -2.7m OD). Across the entire nearshore area there has been in the order of 5+m of accretion, presumably of coarse sediment from the Holderness coast. The volume of accreted material since the 1680s could have been around 50Mm^3.

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[3] Similar soundings were recorded on John Seller's chart of around 1673/75 and John Sennex/Edmund Halley/Nathaniel Cutler's A Draught of the River Humber published in 1728 (Table 1)

[4] Admiralty surveys since 1968 have used LAT (Lowest Astronomical Tide) as chart datum. Prior to this the levels at or close to MWLS (Mean Low Water Springs) were commonly used (Burningham and French 2008). Shelford 1869 reproduced part of Collin's chart and stated that the soundings were in "Fathoms below Low Water".

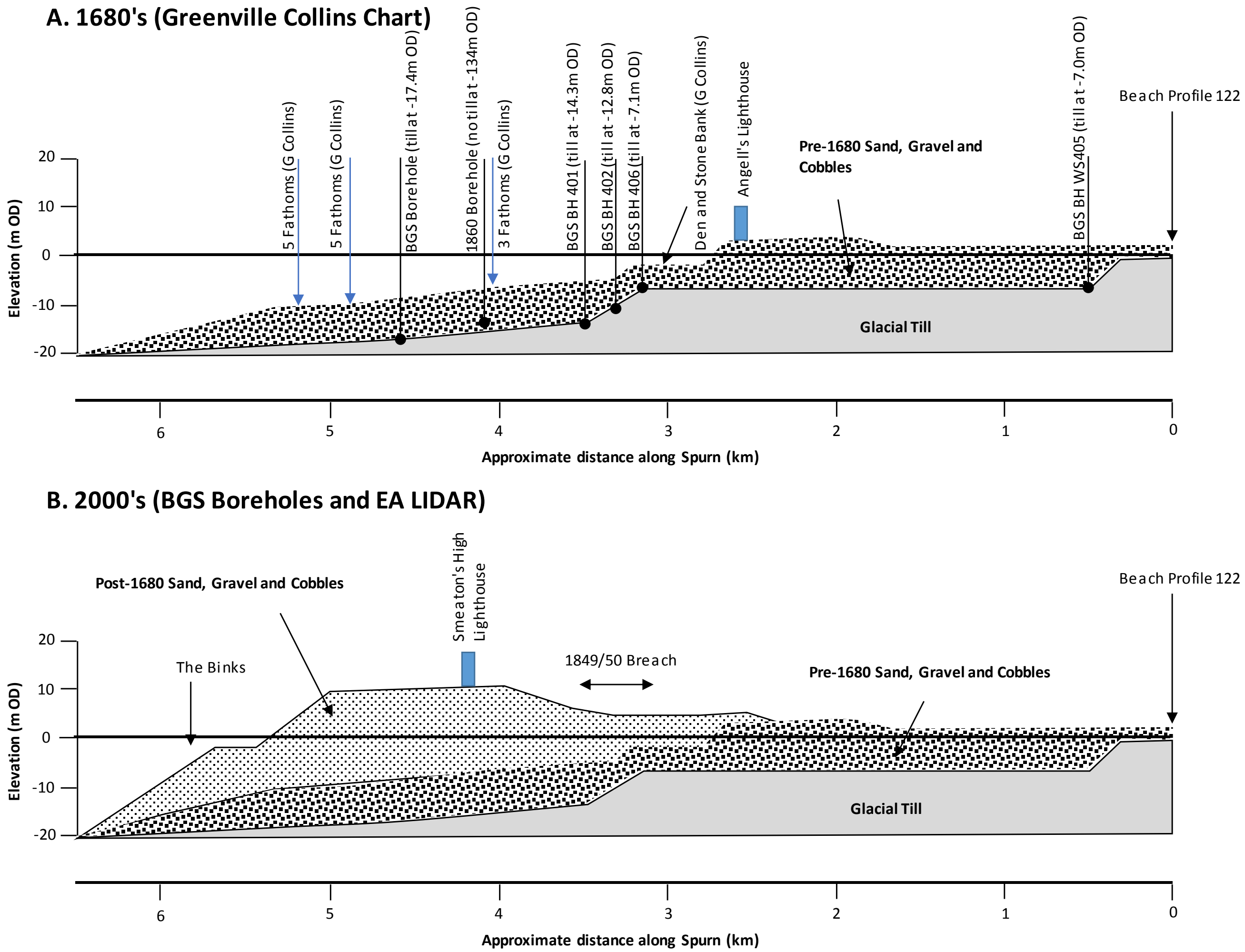

Figure 40 A schematic model showing how Spurn has changed since the late 17th Century (the section follows a line down the centre of the present day Spurn. Note the vertical exaggeration)

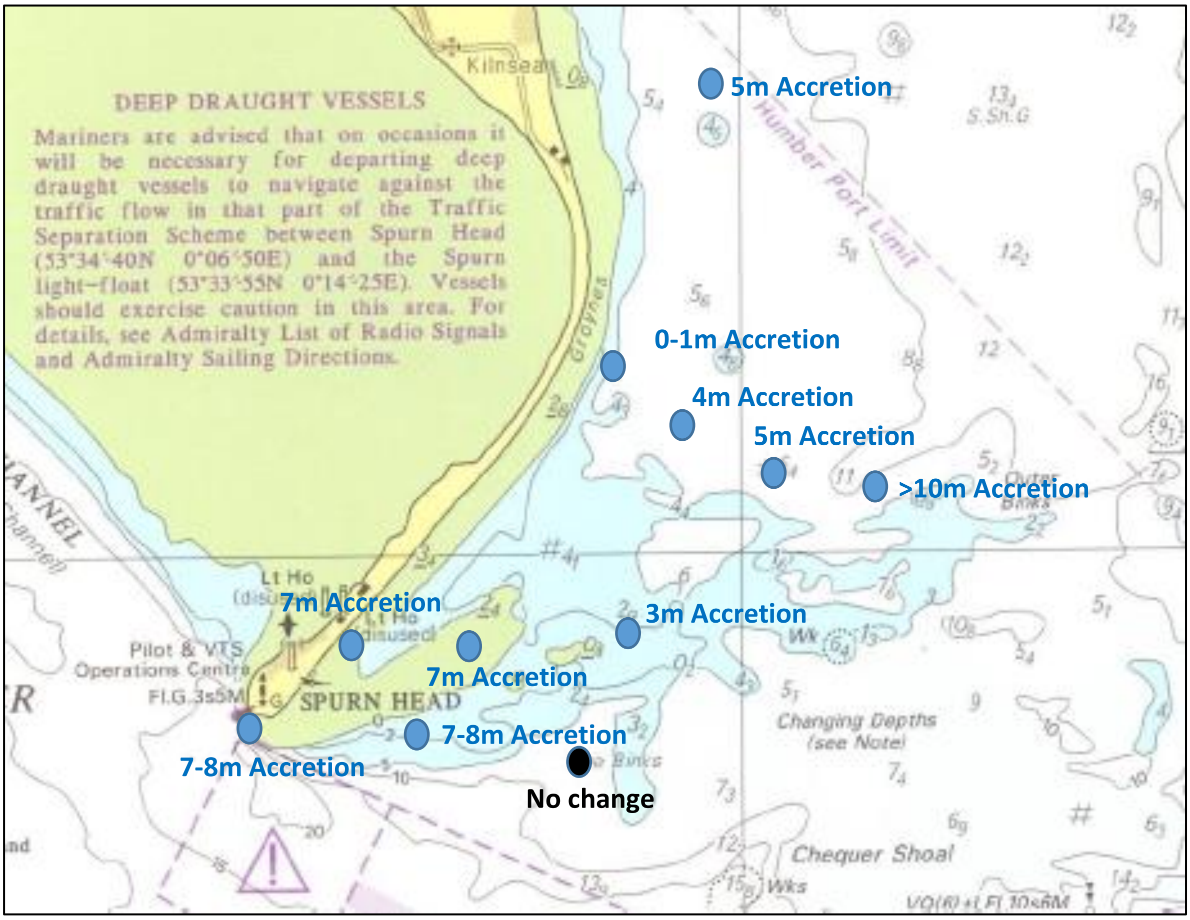

Figure 41 Comparison of the present day water depths with depths records by Greenville Collins on his chart of 1684. Blue dots are the approximate locations of Collin's soundings; the labels indicate the amount of accretion since the 1680's. (note that the Chart Datum is not stated and are assumed here to be to -2.7mOD, rather than the modern chart datum of -3.9m)

5.3 Current Trends

- the eastern side of the Head has remained relatively stationary since the mid-19th century (Figure 42), although some retreat of the eastern shoreline has occurred around the site of Smeaton's lighthouse.
- beach profile analysis reported in ABP Mer (2014) indicates that the western side of the Head (south of the 1849/50 breach) has remained relatively stable since 2000, whereas the eastern side has shown pronounced beach variation. Pronounced accretion has occurred at the tip, in the lee of the Binks.
- the Neck has been the most dynamic section of Spurn, through crest lowering, overwashing events and westwards migration.
- as the Kilnsea cliffs have eroded they have both retreated westwards and shortened northwards as the narrow promontory of Kinlsea Warren has been lost. This has led to northwards lengthening of the Neck, possibly in the order of 300-400m between 1855 and 2009.
- prior to 2002-2003, the main body of the Neck was locked in place by the WWII seawall whilst the low cliffs at Kilnsea continued to retreat at around 1-3m/year (Figure 43; see Appendix A; EPs 114-120) This has resulted in a re-orientation of the narrow barrier beach, from a line running NNE-SSW (192°) in the early 19th century (1824; OS 1" to 1 mile map) to running NNW-SSE (175°) in 1990 (IECS, 1992).

Figure 42 Comparison of the 1852 (blue line; this shows the spit following the 1849/50 breach) and 2000 (red line) shoreline positions along Spurn (from Pye and Blott, undated)

- the collapse and erosion of the seawall in 2002-2003 has resulted in an increase in the rate of retreat of the Neck, approximately 40m by late 2007, through a combination of overwashing events and temporary breaching in 2013.
- since the late 1950's the "*man-made*" dunes along the Neck (the result of the late 19th and early 20th century protection and stabilisation works) have been lost, to be replaced by a "*more natural*" low sand and gravel barrier beach.
- crest levels along the Neck lowered by around 1-2.5m between 2000 and 2014 (see Table 3). Over the same period the Neck narrowed from 100m to 50m (measured at MHWS; ABP Mer 2014).
- prior to the December 2013 breach, the Neck was almost completely below MHWS (3m OD). However, crest levels on the Neck do recover through sediment accumulation.

Table 3 Recent variations in the crest level at beach profiles on the Neck (after ABP Mer 2009)

Date	**Profile 123**		**Profile 124**	
	Max Crest Height (m OD)	**Difference from 2000 (m OD)**	**Max Crest Height (m OD)**	**Difference from 2000 (m OD)**
2000	5.7		8.07	
2001	5.39	-0.31	7.72	-0.35
2002	5.77	0.07	8.17	0.1
2003	5.92	0.21	8.03	-0.04
2004	5.86	0.16	8.03	-0.04
2005	4.79	-0.91	5.69	-2.38
2007	4.8	-0.9	7.27	-0.8

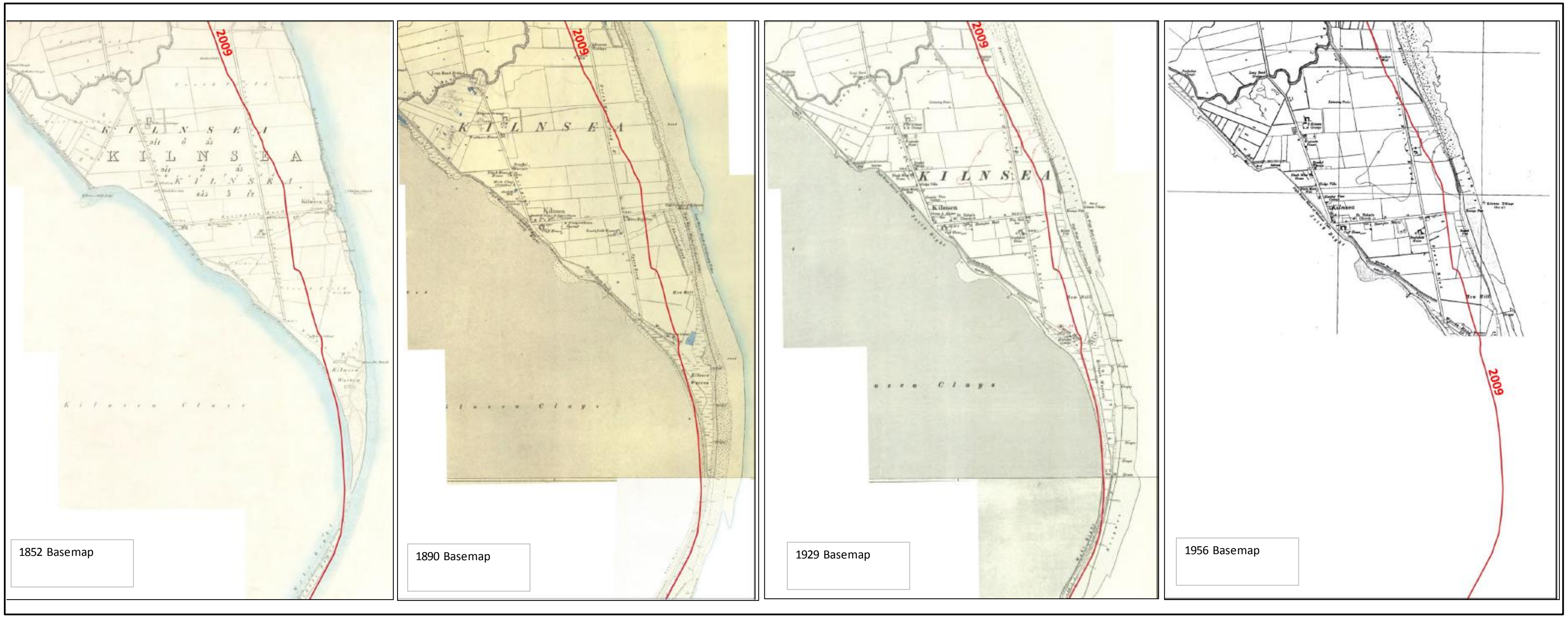

Figure 43 Comparison of the 2009 Kilnsea-Easington cliffline and Spurn Neck with the positions on earlier Ordnance Survey maps (from L-R: 1852, 1890, 1929, 1956). From Pye and Blott (undated)

5.4 Future Trends: Continuity or Tipping Points?

The overall form of Spurn – a broad bulbous or spatulate Head connected by a narrow Neck to the mainland – has been persistent over the last 300-400 years and possibly longer. It is probably the supra-tidal part of an extensive sedimentary structure (flood rampart) that has accumulated at the mouth of the Humber.

The long-term westwards migration, "stretching" and reorientation of the Neck has been in response to progressive retreat of the Holderness cliffs, especially the loss of the SE facing Kilnsea cliffs that were shown on Collin's chart of 1684 (Figure 28). In contrast, the SW extension of the Head (over 2km between the 1680s and 1850s) was probably a response to changes in the Humber tidal volume associated with land reclamation, especially in the Axholme and Ancholme Valleys, and the southwards diversion of the main flood tide channel due to the closure of the North Channel during the Sunk Island reclamations.

Overwashing, rather than breaching has been the dominant process driving the changes along the Neck. The only recorded breaches, in the 1850s, occurred at a time of significant gravel extraction from both Spurn and the Holderness shoreline, and following a period of rapid extension towards the SW.

The current trends, especially erosion and retreat of the Neck, are shoreline readjustments to the decay and deterioration of the 19^{th} and 20^{th} century coastal engineering works.

It seems likely that Spurn will remain resistant to major change, at least over the next 100 years, because RSLR will probably be accompanied by increased sediment yield from the Holderness shoreline and increased wave-driven sediment transport within the nearshore zone and alongshore (deeper water will reduce wave refraction, thus increasing southerly transport rates).

The current landform has been locked in place by the extensive breach repairs and coast protection works (including dune creation) undertaken over the period between the mid-1850s and the mid-20th century. The effects of the continued decay and deterioration of these works are largely unpredictable in terms of the timing and magnitude of significant erosion events. As a result, the pathway from a semi-constrained to a "naturally" dynamic system is uncertain.

In addition, internal structural changes have been taking place that, over time, could introduce further uncertainty about the long-term behaviour:

- Neck "stretching" as the southern end of the Kilnsea cliffs have been lost, possibly in the order of 300-400m between 1855 and 2009.
- re-orientation of the Neck, continuing the anti-clockwise movement from a NNE-SSW alignment in the early 19th century to the current NNW-SSE alignment. Should it occur, this could have a significant impact on longshore sediment transport along the Neck. However, it is unlikely that a "tipping point" would be reached after which sediment transport along the Neck declines to zero or reverses.

A number of scenarios can be envisaged for the next 100 years or so:

- *complete breakdown and gradual re-establishment* of a shore-attached barrier further to the west. This is considered to be extremely unlikely, as there is no convincing evidence of this type of behaviour in the historical record and it is not clear what would be the "tipping point" to trigger this behaviour;
- *establishment of a permanent breach*, probably along the Neck, separating the Head from the mainland. This is considered to be unlikely, as the system will continue to receive coarse sediment from the Holderness cliffs (longshore and possibly from offshore) whose yield is likely to increase with RSLR. It seems more likely that future "breaches" would be temporary and "self-healing", as occurred after the December 2013 breach.

- "jerky" westwards migration of the Neck, and possibly the Head, in response to RSLR, driven by the localised impacts of storm events – episodic failure of the old defences, overwashing and possibly temporary breaches along the neck, extension of the washover zone southwards, erosion of the sand dunes along the Head. Some of the local storm impacts could be quite dramatic, especially when the protection provided by the decaying defence works suddenly declines. The Neck will remain as a low sand and gravel barrier, without dunes. This seems to be the most likely scenario and would see a return to the type of landform shown on the 1824 First Edition Ordnance Survey map (Figure 44).

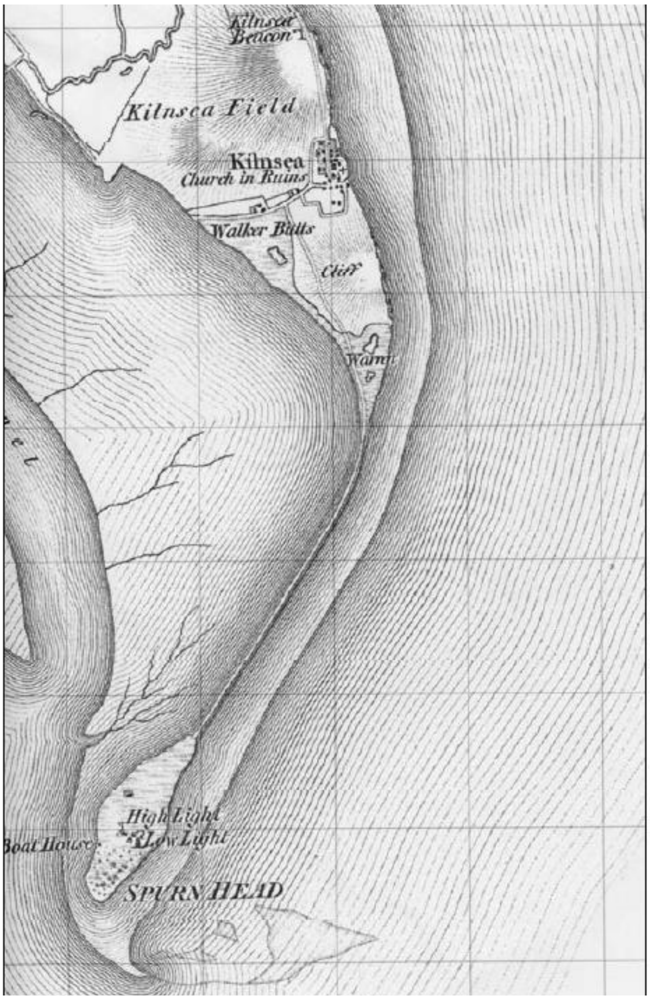

Figure 44 Spurn as shown on the 1824 Ordnance Survey map (1" to 1 mile); an analogy for the future Spurn after the defences have finally broken down?

6 A Conceptual Model for Spurn

6.1 A Proposed Tidal Delta Model

Since the 1680's, the dominant trends have been the SW lengthening of the Head into relatively deep water, westward migration and re-orientation of the Neck, and the progressive accretion across the nearshore zone (the Binks). These changes are connected; as Balson and Philpott (2004 p 14) noted: "*It is difficult to separate the spit from the offshore accumulations represented by the Binks*."

This suggests that rather than Spurn being simply a stand-alone spit and barrier beach attached the Holderness coastline (as suggested by de Boer 1964, 1969), it is part of an extensive sub-tidal and supra-tidal sedimentary structure that has accumulated at the mouth of the Humber. The form of this structure reflects the combined influences of wave –driven southwards coarse sediment transport and strong ebb-dominated tidal flows from the Humber.

Tidal delta structures have been described in many coastal inlets and estuaries (e.g. Hayes 1980; Fitzgerald et al. 2000). In these systems, longshore coarse sediment movement along an open coast is initially interrupted at an inlet by tidal flows within the estuary mouth and, in response, a series of sedimentary landforms develop that allow the sediment to move across the opening. In micro-and meso-tidal areas, *flood tide* and *ebb tide deltas* form inside and outside the inlet mouth, respectively. Longshore sediment movement along the open coast is retarded by the inlet tidal flow and sediment accumulates, forming sediment waves that move intermittently, mainly during storm events, across the inlet mouth and weld first onto the ebb delta and then onto the downstream coast where it disperses along the interrupted longshore sediment transport pathway. In macro-tidal areas, such as the Humber or Thames, the flood and ebb delta features are large and are elongated normal to the coast. Flood and ebb currents in these estuarine delta systems take mutually evasive pathways (van Veen et al., 2005). Since the ebb tide continues to flow seawards from an estuary while the flood tide in the open sea has already begun, the ebb flow occupies the middle ground of the inlet while flood currents enter on either side (see Figure 45).

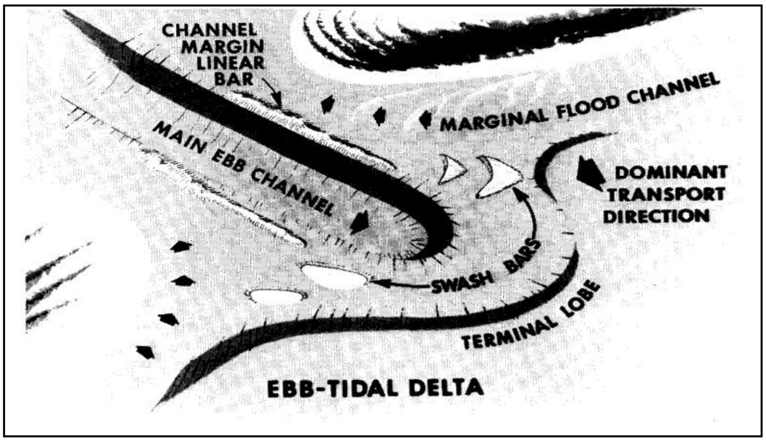

Figure 45 Schematic morphology of ebb-tidal deltas (from Hayes, 1980)

It seems likely that Spurn is a supra-tidal element of an estuary mouth structure, receiving inputs of coarse sediment from both longshore transport and, probably, the onshore migration of material. In the Humber the ebb delta appears to have formed within the palaeo-valley known as the New Sand Hole, where approximately 3.5 x10^6 m^3 of coarse sand and gravel is reported to have accumulated over the past 5000 years (Balson and Philpott, 2004). The flood tide delta of the Humber is represented by the Middle Shoal, although dredging of the Sunk Channel bordering the Middle Shoal has almost certainly reduced its dimensions. In the Humber mouth the ebb flow occupies the Bull Channel and thence flows seaward along the line of the New Sand Hole (Figures 46 and 47).

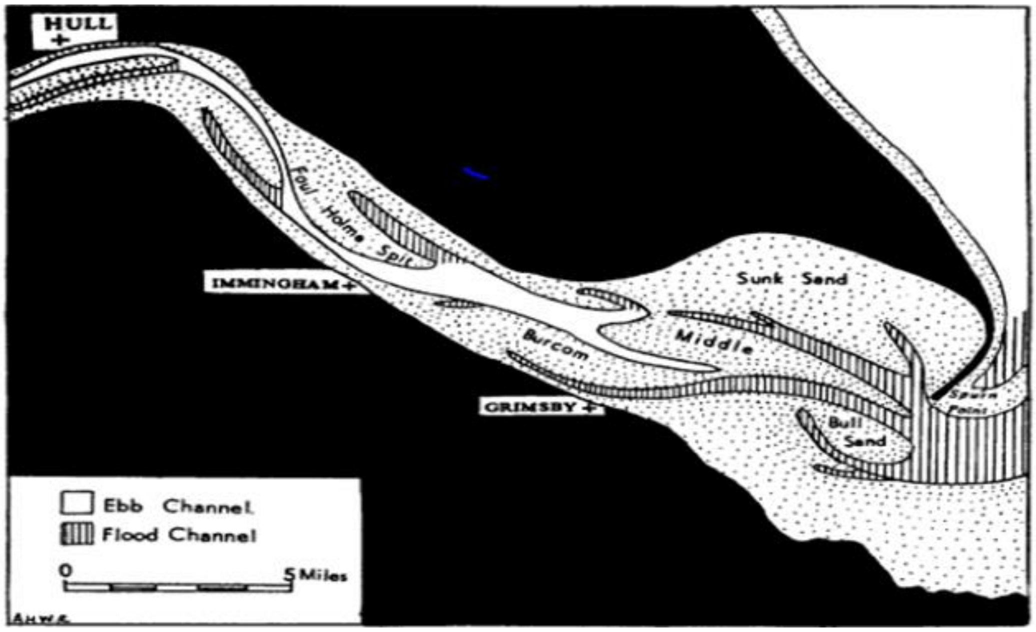

Figure 46 Ebb and flood channels in the outer Humber Estuary from Robinson (1960)

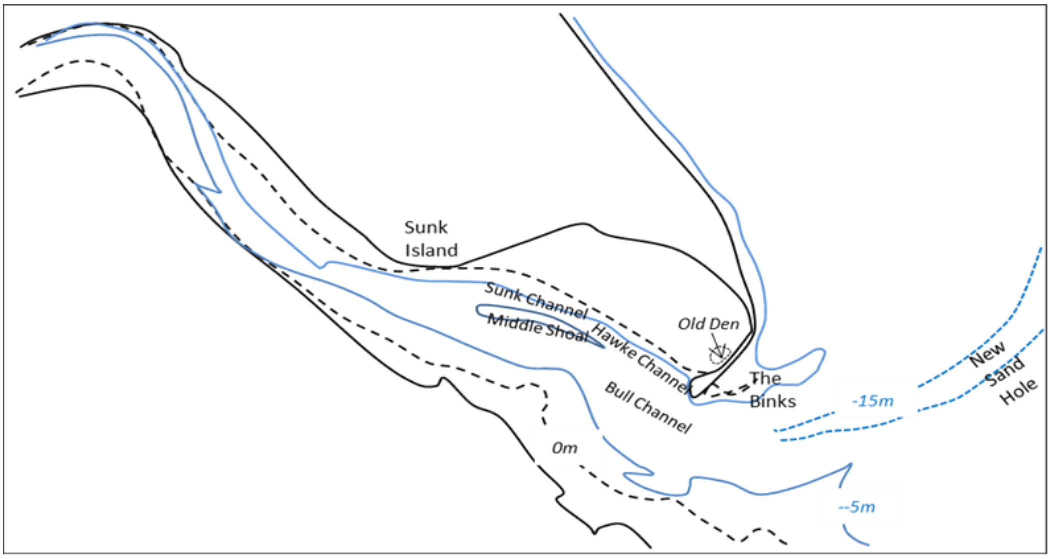

Figure 47 The Outer Humber and its approaches, showing features mentioned in the text. Isobaths depths refer to Admiralty Chart Datum at -3.9mOD

The ebb tide in the Humber estuary continues to flow seaward for up to 5 hours after the flood tide commences in the open sea. To avoid the ebb, the southward moving flood flow in the open sea initially takes a curving pathway along the southern edge of the Binks, around Spurn Point and along the Hawke/Sunk Channels (Robinson, 1960). As the flood tide progresses and ebb flows from the estuary decreases this initial curved pathway becomes broader and eventually the flood occupies the entire mouth.

Sediment derived from the Holderness coast (cliffs, platform and seabed) is moved south, by nearshore currents driven by the dominant north to north-easterly waves, towards the flood channel where the strong tidal current prevents its further progress. The sediment, arriving from the north, therefore accumulates along the northern edge of the flood channel forming the curved southern ridge of the Binks, while further sediment probably accretes behind it. The Binks might be best described as a *marginal flood rampart* of the complex ebb tide delta of the Humber (Figure 45). The intertidal and supratidal gravels and sands that form the Spurn spit would, therefore, represent the landward margin of this flood rampart. Field measurements on Spurn by Foote (1994) demonstrated that strong cross shore currents can winnow the finer grained sediment from this subtidal sediment and deposit it as an intertidal beach, from which intertidal source aeolian processes have formed the supratidal sand dunes that formerly characterised much of Spurn.

We suggest that Spurn is a sub-component of a much larger geomorphological feature: the flood rampart of the Humber ebb delta. This model differs from the conventional account of the formation of Spurn in several respects but perhaps the most important of these are, first the recognition that the form of the intertidal spit (at least the Head) depends largely on the morphology of the flood and ebb channels in the Humber mouth and, second, that the sediments forming the intertidal spit may not be wholly dependent on longshore transport from the Holderness cliffs, but depend also on an intervening store in the flood rampart of the estuarine delta.

It follows that the form and function of the outer Humber are as important to the understanding of Spurn as much as the sediment supply from the Holderness coastline. Historical changes in the morphology of the Humber approaches have been reflected in the morphology of the Binks and therefore in the form of Spurn itself. This is clearly demonstrated by the analysis of historic charts discussed above (Section 5.2). The major depositional phase in the late 18th and early 19th century during which 50 x 10^6 m^3 of gravels and sands accumulated in the nearshore approaches and Spurn Point advanced by 2km, is contemporaneous with major changes in the outer Humber brought about by the reclamation of the Axholme and Ancholme Valleys and Sunk Island (especially the closure of the North Channel).

The closure of the North Channel (the main flood channel) in the outer estuary probably initiated a series of important morphological changes. Prior to the late 17th century, the flood tide would have entered the estuary around Spurn Point immediately south of the Old Den, and then along the North Channel, with the pre-reclamation Sunk Island acting as the flood tide delta (Figure 48A). Closure of the North Channel forced the entire flood system southward along the line of what is now the Sunk/Hawke Channels and a new flood tide delta was formed, the Middle Shoal. The southward shift of the flood channel in the Humber Approaches, to the east of Spurn, meant that the southern limit of the sand and gravel accumulation was also shifted south. (Figure 48B). Thus, the Binks accumulated 5-10m of gravels and sands, as shown by the chart analysis, and Spurn Point advanced by 2km.

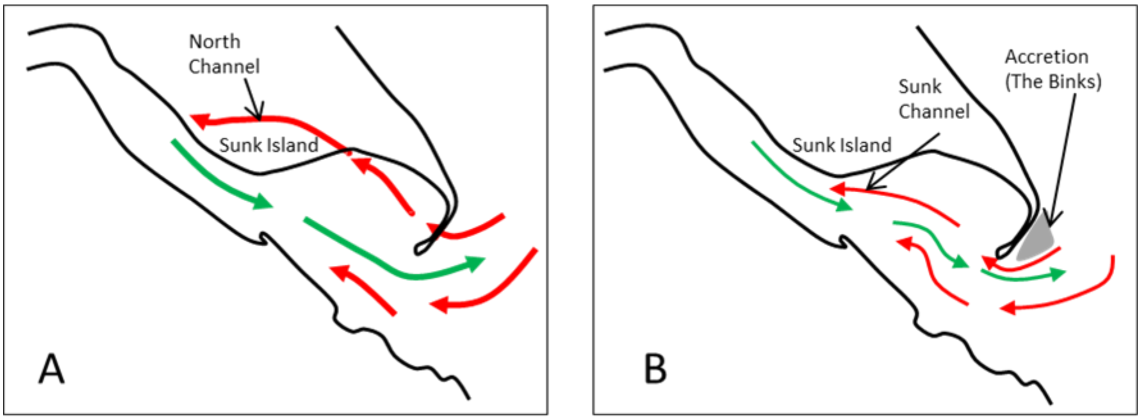

Figure 48 Flood and ebb channels in the outer Humber (A) Pre-reclamation - early flood enters at Old Den, thence through North Channel (B) Post-reclamation- early flood migrates south allowing accretion of the Binks and elongation of the spit

6.2 The Classic Model Revisited

The "classic" geomorphological model of Spurn was proposed by de Boer in the 1960s (de Boer 1964, 1969) and has been repeated in numerous text books since that time. We would challenge many of the key components of this model:

"*Material derived from the erosion of the coast of Holderness is moved by wave action along the beach to the tip where some is swept by the ebb tide on to the Binks, some is carried to the wide sand flats inside the tip, and the rest contributes to the still continuing growth of Spurn southwards*." (de Boer 1964, p71). The bulk of the around 0.4M m^3 of coarse material derived from the erosion of the Holderness coast (the cliffs, shore platform and seabed; see Section 4.3) is probably transported southwards across the broad seabed platform rather than along the beach towards Spurn. Halcrow/GeoSea (1990) suggest that up to 60% of the sand yield may move offshore around Easington. As we have discussed above, the tidal currents have a major controlling influence on the nature and extent of Spurn and the broader flood tide rampart (including the Binks), rather than simply sweeping material onto the Binks. Indeed, it is likely that changes in tidal volume and channel locations have been a key factor in causing the well-documented historical changes along Spurn, especially the lengthening of the Head, and the accretion and southwards growth of the tidal rampart.

"(Spurn) *follows an evolutionary pattern consisting of fairly regularly repeated phases of destruction and regrowth.... the neck of Spurn is extended in this direction (northwards) also and so becomes progressively more exposed to the effects of northerly gales. Eventually this reaches a stage in which the neck is breached. The breach then becomes a swatchway branching off the flood barb inside the Stony Binks and material which formerly travelled to the end of the spit is swept through by the flood tide and deposited inside the spit as a shoal. The bulbous end, starved of its supply of fresh material, dwindles and ultimately disappears. The now very much shortened peninsula is presumably driven back until it has reached a sufficiently sheltered position in relation to the coast of Holderness for construction to become the dominant process again. Then the spit will begin to lengthen once more, and will grow out past the shoal inside the breach, and so another cycle of development will have begun its course. The last time such a cycle ran its full course was from about 1600 or 1610 to about 1850 when artificial intervention checked further developments*." (de Boer 1969, p19).

With the exception of the well-documented events that occurred in the 1850s, the evidence for repeated breaching, barrier breakdown and reformation is virtually non-existent and does not support the idea of cyclical behaviour. For example, the loss of Ravenser Od in the 14th century could simply have been the result of progressive rather than cyclical coastal erosion. The overall form of Spurn – a broad bulbous or spatulate Head connected by a narrow Neck to the mainland – has been persistent over the last 300-400 years and possibly longer. John Sellers's "The English Pilot" (1673) and Greenville Collins' chart of 1684 show the tip of Spurn to the south of Easington and south-south west of Kilnsea, the same general arrangement that exists today. This suggests that westward movement of Spurn has been relatively limited over the last 500 years (when compared with de Boer's cycle of repeated formation and breakdown with kilometre-scale westward migration).

Whilst the Neck migrated westwards probably around 500m during the period between the late 17th and mid-19th centuries, the Head did not migrate significantly westwards. These changes suggest that the spatial relationship between the Neck and the Head has been dynamically changing. The Neck is being "pulled" westwards because of the retreat of the Kilnsea cliffs, whereas the Head has responded to changes in the Humber estuary. We would argue that the key controls on the behaviour of Spurn over this period have been the effects of land reclamation in the Humber and the progressive erosion of the Kilnsea cliffline, rather than any tendency for step-wise westward migration westwards through repeated phases of breakdown and reformation.

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Appendix A: Holderness Erosion Monitoring Data and Analysis

For an excellent summary of the cliff monitoring programmes along Holderness and the erosion data up to 2016, see Brian Williams's website: http://urbanrim.org.uk/data-in-detail.htm#posts

A.1 Erosion Posts and Profiles

- ***Erosion posts*** (1-120, plus R1-R3 and 58a); East Riding County Council established a network of monitoring stations along the cliffline, at an average interval of around 520m. Measurement from the post to the cliff top was by tape until 2003 after which coordinates of posts were coupled to GPS readings, and from 2009 to LiDAR equipment.

  Surveys were conducted annually before 1991, then twice a year, though there are spaces and gaps in the data. Posts 1 to 31, Sewerby to Skirlington, went unchecked for twelve years, apart from five readings, before a major repositioning in November 1983.

  Posts at times needed to be repositioned (193 occasions, including posts repositioned more than once) or re-established (5 occasions).

  In 1998, when RAF operations ceased at Cowden, three erosion posts were installed on roadways within the site. The new posts were labelled R1 to R3, with a fourth installed to the south of the site as 58a.

  In this analysis, a year is taken to be that in which the erosion occurred, not the year of measurement. Readings from periods of twice-yearly monitoring are added together to make the year.

Dates	Posts Established	Posts Abandoned
1951	1-28, 31-56, 58-85, 87, 89-114 (109)	
1958	29-30 (2)	
1976	86	
1978	115	
1979		112
1980		113 (restarted March 2007)
October 1993	57	
March 1995	116	
March 1997	88	
September 1997	117-120 (4)	
March 1999		106-108
September 1999	R1-R3 (3)	87
September 2000	58a	
October 2010		1-86, 88-105
April 2013		119
October 2013		109-111, 113-118, 120

- ***Beach Profiles*** (1-123); 123 profiles were established from 1999 by East Riding Yorkshire Council for monitoring with GPS technology. Each profile line extends about one-and-one-third kilometres from a coordinate inland of the coast to another out to sea, crossing the cliff line at right-angles. They are close to, but do not correspond directly with the erosion post locations, and the numbering systems do not exactly match (e.g. erosion post 119 is close to profile 123). Intervals between profile intersects along the cliff top are approximately 500 metres. In 2008-2009, LiDAR replaced GPS. There was a 15 year overlap between the erosion post and profile monitoring.

Dates	Profiles Recorded	Locations
1999 Spring	94-99, 102, 106-114, 119-122	south of Withernsea to Neck of Spurn
1999 Autumn	94-98, 102, 107-110 + 113-114, 119-123	south of Withernsea to Neck of Spurn
2000 Spring	94-110 + 113-114, 119-123	south of Withernsea to Neck of Spurn
2000 Autumn	40-41	north of Hornsea
	49-58	north and south of Mappleton
	62-63	(Aldbrough)
	88-89 + 94-99	north and south of Withernsea
	106-109 + 113-114, 119, 121-123	north of Easington to Neck of Spurn
2001 Spring	39-41	north of Hornsea
	49-55	north and south of Mappleton
	89	north of Withernsea
2001 Autumn	19-22	Barmston to north of Ulrome
	39-41 + 45-46	north and south of Hornsea
	82-85	Sand-le-Mere
	88-89 + 94-100	north and south of Withernsea
	107-109 + 113-114, 119-123	north of Easington to Neck of Spurn
2002 February	19-22	Barmston to north of Ulrome
	39-41 + 45-55	north of Hornsea to south of Mappleton
	82-84	Sand-le-Mere
	87-89 + 94-99	north and south of Withernsea
	107-109 + 113-114, 119, 121-123	north of Easington to Neck of Spurn
2002 August	18-22	north of Barmston to north of Ulrome
	39-41 + 45-55 exc. 51	north of Hornsea to south of Mappleton
	82-84	Sand-le-Mere
	86-89 + 94-109 + 113-114, 119-123	north of Withernsea to Neck of Spurn
to 1999 Spring	111-112	(Easington defences constructed)
to 2000 Spring	110	(Easington defences constructed)

Although GPS profile started in 1999, a complete data series for all the profiles only became established in 2003.

Any determinable cliff line for profile 123 at Neck of Spurn was lost in the storm surge of December 2013. Recently, profiles (124-136) were introduced to monitor the Spurn peninsula.

A.2 The Ordnance Survey Map Data Series (1853-1954)

East Riding of Yorkshire Council has compiled a data series for recession at the 123 erosion profile locations, comparing the cliff top position on OS maps of different dates between 1852 and 1995.

In this analysis, a data series for the period 1853-1954 has been compiled for the 120 erosion post locations by using the nearest erosion profile data (Figure 49).

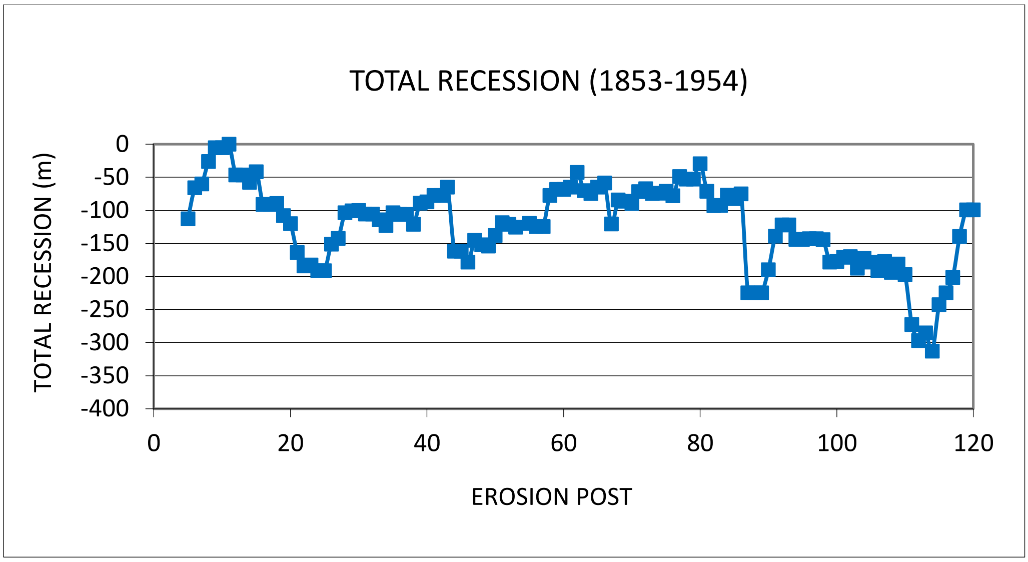

Figure 49 Holderness cliffs: total cliff recession at Erosion Post (EP) locations, 1853-1954 (data for the EPs are from the nearest beach profile site, generally within 100-200m)

A.3 The Erosion Post Data Series (1951-2016)

Unfortunately the Holderness Erosion Post data series is not complete. For example, measurements were not generally made in 1952, 1954, 1956, 1958, 1965, 1972 and 1975. At some posts there are gaps of several years or more in the data series that end with a new post being established.

The gaps in the data set have been treated as follows:

1. Situations where there are missing dates between measurements (e.g. measurement in Year 1 and Year 4, but no measurements for Years 2 and 3); the recession for Years 2, 3 and 4 was assumed to be identical and calculated as the measured recession distance between Years 1 and 4 divided by 3 years. If 0m recession was measured in Year 4, then the values assigned for Years 2 and 3 would be 0m.
2. Situations where there are missing dates prior to the post being abandoned (e.g. measurement in Year 1, but no measurements for Years 2 and 3 with the post abandoned in Year 4); the data is considered to be missing from the series and no attempt has been made to fill the gaps.

   Around 12% of the data set is affected in this way. Posts 1-31 appear to have been abandoned around 1970, and then re-established in 1983. The minimum number of measurements for a site is 27, at EP50 (Mappleton). The average number of measurements is 46 out of a possible 53.

   For EPs affected by this issue, the average annual recession rate is calculated as the total cumulative recession divided by the number of years with measurements and infilled measurements (Point 1 above).

   For Years affected by this issue, the overall average recession for that year is calculated as the total recession recorded at EPs divided by the number of EPs with measurements and infilled measurements (Point 1 above).

The monitoring of the erosion posts ended in 2010, and was replaced by erosion profile data (which started in 1993). In this analysis, a “composite” data series has been constructed that extends the erosion post data to 2016 by using the 2010-2016 recession data from the nearest erosion profile (typically they are only 100-200 apart; Figure 50).

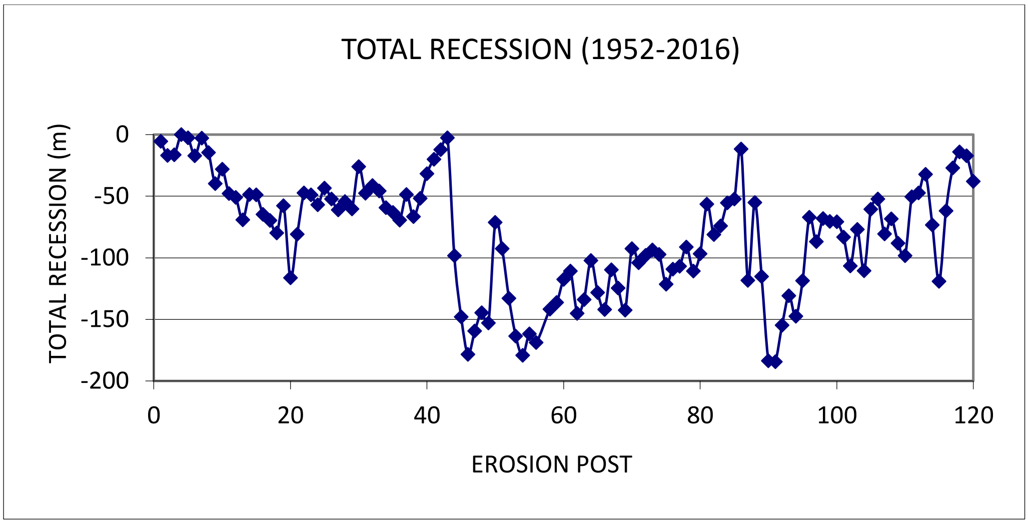

Figure 50 Holderness cliffs: total cliff recession at Erosion Post (EP) locations, 1952-2016 (data for the period 2010-2016 are from the nearest beach profile location)

A.4 Combined "Erosion Post" Data Series (1853-2016)

Combining the OS data and erosion post data series yields a composite series for the period 1853-2016 (albeit with possible overlap between 1951 and 1954). The data series is shown in Figure 51.

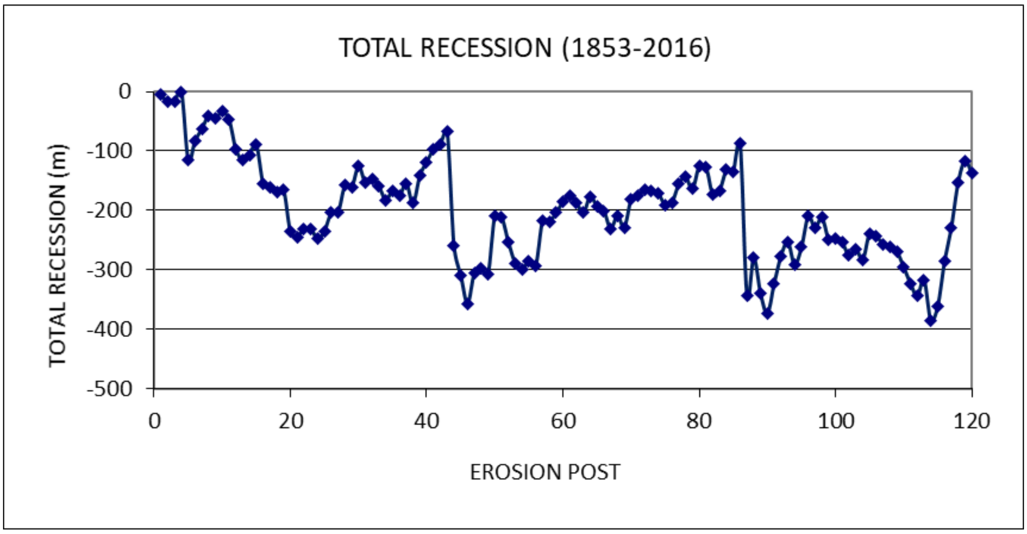

Figure 51 Holderness cliffs: total cliff recession at Erosion Post (EP) locations, 1853-2016 (combined data series)

The data series highlights the gradual segmentation of the coast into a series of broad, shallow embayments (Segment 1, Sewerby to Bridlington (EP1-4); Segment 2, Bridlington to Barmston (EP9-15); Segment 3, Barmston to Atwick, north of Hornsea(EP16-36); Segment 4, Hornsea (south) to Waxholme, north of Withernsea (EP44-85); Segment 5, Withernsea to Kilnsea, north of Spurn (EP90-120). The data also reveal a trend of decreasing erosion rates towards the southern limit of Segments 3, 4 and 5.

A.5 South of Easington Combined "Erosion Post" Data Series (1853-2016)

The recession distances for Erosion Posts south of Easington (Eps 110-120) are presented in Figure 52 and Table 4, respectively.

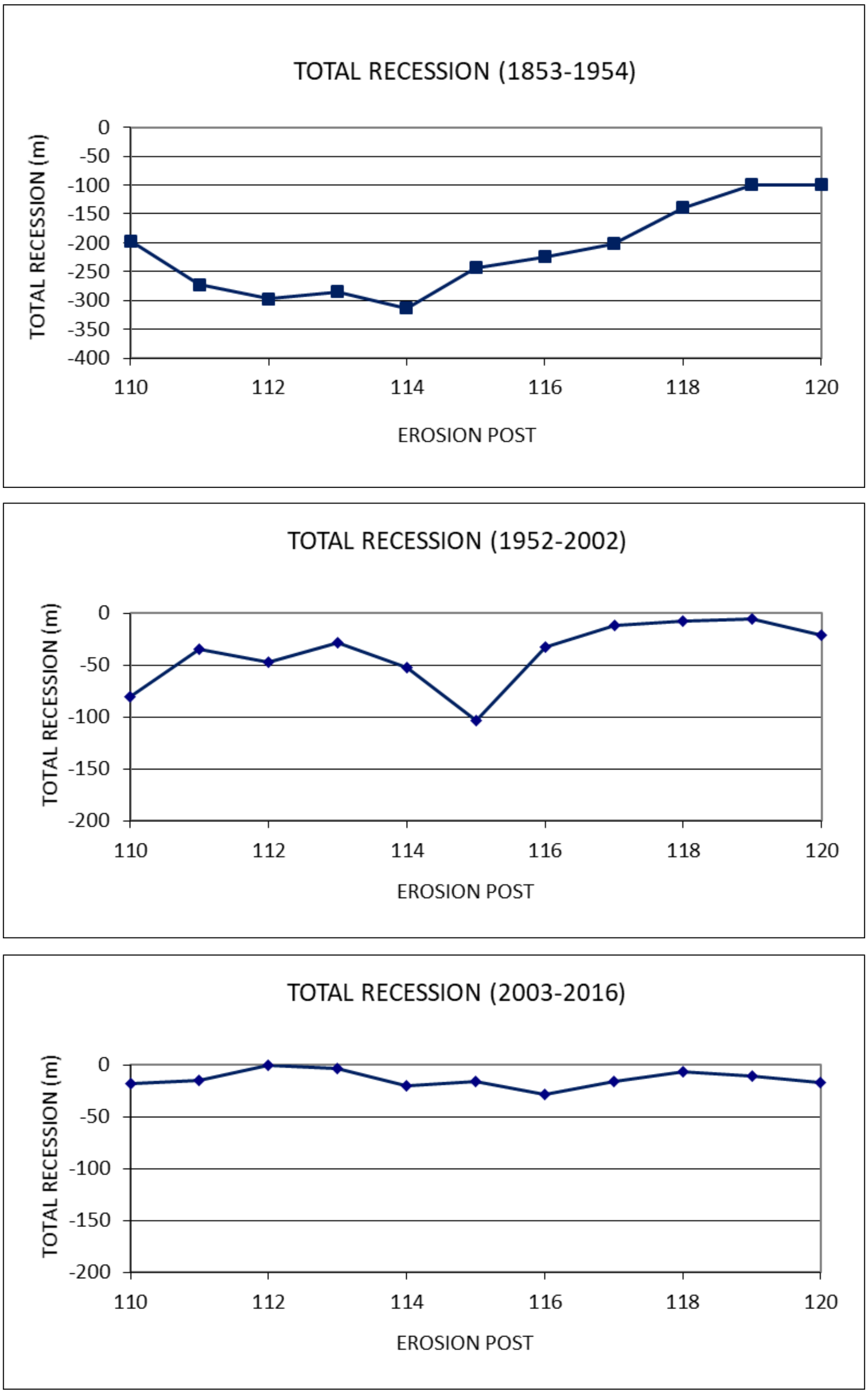

Figure 52 Holderness cliffs: recession south of Easington (top – 1853-1954; middle – 1952-2002; bottom – 2002-2016)

Table 4 Holderness cliffs: average annual recession rates south of Easington

Period	Erosion Posts/Average Annual Recession Rate (m/year)										
	110	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**	**120**
1853-1954	1.9	2.7	2.9	2.8	3.1	2.4	2.2	2.0	1.4	1.0	1.0
1951-2003	1.6	0.7	0.9	0.6	1.0	2.0	0.6	0.2	0.2	0.1	0.4
2003-2016	1.4	1.2	0.0	0.3	1.6	1.2	2.2	1.2	0.5	0.9	1.3