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Aldbrough Gas Storage Project: Environmental Considerations for Leaching Infrastructure Protection through Erosion Control

Report to Jacobs / SSE

Institute of Estuarine and Coastal Studies
University of Hull

12 August 2010

Author(s): S. Boyes, N Cutts & M Elliott

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Institute of Estuarine & Coastal Studies (IECS)
The University of Hull
Cottingham Road
Hull
HU6 7RX
UK

Tel: +44 (0)1482 464120
Fax: +44 (0)1482 464130

E-mail: iecs@hull.ac.uk

Web site: http://www.hull.ac.uk/iecs

Jacobs / Scottish & Southern Energy (SSE)

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Reference No: ZBB758-F-2010

For and on behalf of the Institute of Estuarine and Coastal Studies

Approved by:	N Cutts
Signed:	
Position:	Deputy Director
Date:	12-08-2010

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EXECUTIVE SUMMARY

In 2004, Jacobs / Scottish and Southern Energy (SSE) installed a leaching system for their gas storage facility at Aldbrough, with construction by horizontal directional drilling (HDD) from the cliff top to the beach. At the time of installation, the initial alignment and location of the pipelines was based on a worst case erosion scenario of six years with an appropriate contingency allowance. However this section of cliff has eroded faster than initial predictions, and the leaching process has taken longer than originally anticipated due to number of sub-surface and other conditions. As such, the leaching pipeline is in danger of being exposed and lost. Jacobs believe the pipeline is likely to survive the winter of 2010 although it likely to become exposed by winter 2011.

In order to address this problem, Jacobs/SSE have proposed three options with their attendant consequences. These include:

- *Option 1 Do Nothing: this may have an unacceptable risk*
- *Option 2 Maintenance Approach: with the need to protect the pipes*
- *Option 3 Relocation: this would require the need to install new pipelines at an alternative location*

Jacobs/SSE consider Option 2 to be the currently preferred option, and this report aims to identify both the issues associated with the implementation of the management option, and the context of those issues within the wider Holderness coast, and the site of conservation importance associated with it.

Option 2 requires protection to the base of the cliff by a hard structure, as well as some remodelling of the cliff itself. The protective rock armouring would protrude out approximately 90m in length along the base of the cliff, sloping up to approximately 55m at the crest. The toe of the rock armouring would extend to 19m at its widest and have a footprint of 1517m² on the foreshore.

Given the existing sediment transport regime and erosion issues associated with the coastline, the protection structure needs to be designed to offer as little interference to the flow of sand as possible. The proposed defences should be designed to hug the cliff base with no further form of beach control. However, the whole structure will act as a small groyne and additional sand may collect at the northern limit of the structure.

As such, whilst there will undoubtedly be some disruption to sediment transport and supply, it is considered that this disruption will have only a very limited effect on down-drift locations and sites of conservation importance. Furthermore, it is suggested that project design, including the placement of sacrificial soft sediment material on the shore, would mitigate these effects further. The following points summarise conclusions on the scale of impacts in the wider context of the Holderness coast:

- Sediment volumes moving down the coast are variable on a seasonal and even annual basis, being largely driven by a small number of extreme events. This variability is seen from the suspended solids information recorded by SSE at the intake, showing intra-annual maxima and minima to vary by two orders of magnitude and for inter-annual averages (from monthly sampling values) to vary by two times.
- Associated with this are regular changes to beach and near-shore morphology, some of which occur on a regular basis following the neap-spring cycle, but with other,

more substantial changes occurring as a result of less frequent, unpredictable, storm events.

- In the context of the wider Holderness coast and associated sediment supply, the scheme is small, representing around 0.1% of the coastline length.
- The scheme will reduce sediment supply over its two year 'deployment' by perhaps:

  Sediment Transport Loss – 1,000m^3
  Sediment Supply Loss – 10,000m^3

  However, the natural volume of sediment moving down the coast over that period will be between 400,000 to 700,000m^3.

  Therefore the development would lead to a change in down-drift sediment volume by between c. 2.75 and c 1.5%.
- This volume deficit could be reduced by placing sediment from the cliff works on the shore as 'sacrificial' material. The placement of this material would certainly offset the sediment supply disruption from the project. In fact, depending on volume and placement techniques, it could even mean that the scheme approaches, or even becomes, sediment neutral in terms of supply disruption.
- Finally, the scale of the development is relatively minor in the context of other protection schemes employed down the coast. For instance it is around 17 times smaller than the protection scheme implemented at Easington, this latter scheme being semi permanent (e.g. required for the lifespan of the gas terminal it protects). This protection has already been *in situ* for a number of years without any catastrophic failure in sediment supply to Spurn or the Humber.

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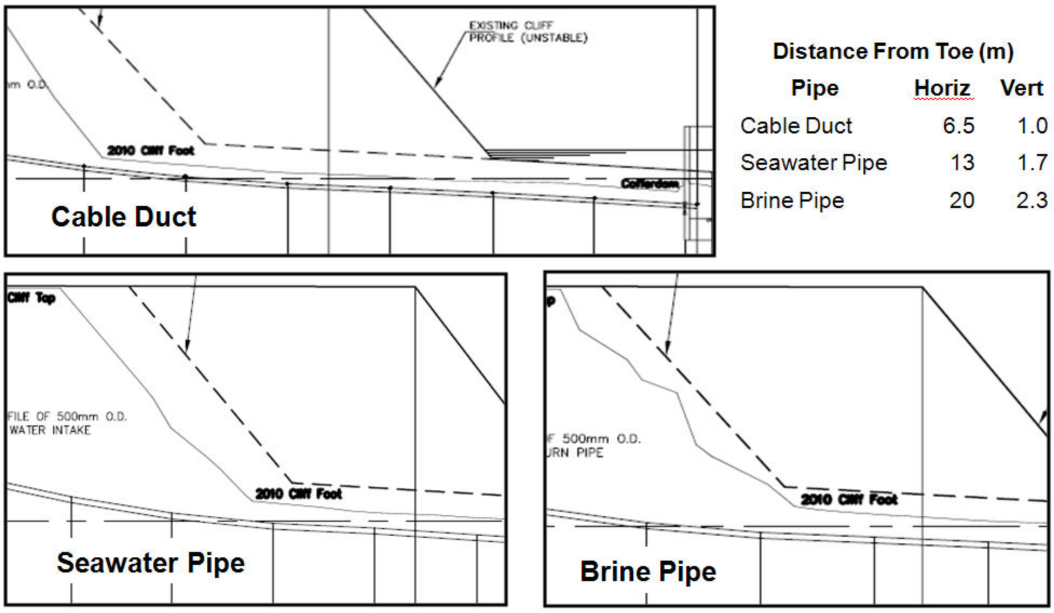
1. BACKGROUND

In 2004, Jacobs / Scottish and Southern Energy (SSE) installed a leaching system for their gas storage facility at Aldbrough. This was constructed by horizontal directional drilling (HDD) from the cliff top through the Holderness cliff at Ringbrough, just south of Aldbrough. A foreshore cofferdam was constructed to receive the pipes but once the construction had been completed, the cofferdam was removed down to beach level. The onshore and offshore work was completed in approximately six months.

At the time of installation, the initial alignment and location of the pipelines was based on a worst case erosion scenario of six years with an appropriate contingency allowance. However this section of cliff has eroded faster than initial predictions, with beach profiling results measured by the East Riding of Yorkshire Council (ERYC) showing a steepening of the beach profile, particularly at the cliff toe. In addition, the leaching process has taken longer than originally anticipated due to number of sub-surface and other conditions. A diagram of the pipelines in relation to the current cliff profile is shown in Figure 1. Continued cliff erosion at this site, both at the surface and undercutting at the cliff toe has exposed 'caves' at the location on the pipeline, accelerating the rate of erosion beyond that predicted (this will be discussed further in Chapter 2). Jacobs believe the pipeline is likely to survive the winter of 2010 although it likely to become exposed by winter 2011.



Distance From Toe (m)		
Pipe	Horiz	Vert
Cable Duct	6.5	1.0
Seawater Pipe	13	1.7
Brine Pipe	20	2.3

Figure 1: Survey diagrams of the pipelines in relation to the current position of the cliff toe and beach

1.1 Management Scenarios

In order to address this problem, Jacobs/SSE have proposed three options with their attendant consequences. These include:

Option 1 Do Nothing: this may have an unacceptable risk

- There will be no environmental impact but

- there could be significant project delays to this nationally important strategic asset if the supply/return system fails.

Option 2 Maintenance Approach: with the need to protect the pipes

- The resultant works would need to include:
  - Creating an access road and ramp with excavator
  - Cut back the cliff to make safe for works and profile
  - Move debris from the beach to form the base and core
  - Supplement core with imported fill / hardcore generated on beach
  - Place imported rockfill and then
  - on completion of project remove protection
- This would be needed for Phase 1 only
- Ongoing maintenance would be required
- Semi-permanent access to beach would be required

Option 3 Relocation: this would require the need to install new pipelines at an alternative location

- Works and environmental issues would include:
  - Creating an access road and ramp with excavator
  - Constructing a beach platform and cofferdam, importing protection material, sheet piling, piling rig and the excavation of the cofferdam
  - Construct a new HDD compound on cliff top near Ringbrough Farm
  - Drill down to the cofferdam using bentonite drilling mud
  - Import the pipes to the foreshore from seaward and pull them through the cliffs
  - Prepare for connection
  - Disconnect Phase 1 supply and reconnect at top and bottom
  - Backfill cofferdam and remove imported material (although not all the cofferdam can be removed)
  - There could potentially be a Phase 1 & Phase 2 activity
  - However once installed there would be no ongoing maintenance required
  - Semi-permanent access to beach would be required for removal of constructed works at the end of project

This report aims to identify the potential environmental impacts from these options, the most appropriate management strategy in terms of overall environmental effect, as well as identifying any areas of operational risk and imperative. However, it is emphasised that this report is not a *de facto* environmental statement produced as the result of an Environmental Impact Assessment with its attendant degree of scoping and consultation.

1.2 Scope of Work

Having carried out previous environmental work for Jacobs and SSE for the Aldbrough gas cavern storage facility, staff at the Institute of Estuarine and Coastal Studies (IECS) at the University of Hull have been asked to act as independent experts for this assessment. This independent assessment of the proposed works is designed to inform the relevant parties of the viable options and their associated environmental consequences and should therefore be used as an additional source of information in the consenting process. This report discusses the following issues in light of the current situation and the management options Jacobs wish to instigate for the ongoing life of the pipeline:

- The environmental consequences of armouring and sculpting the soft coastline around the Aldbrough gas cavern works in order to counter erosion during the next 2 years in the final phase of the leaching. With an extensive background knowledge of the area and of similar projects elsewhere, IECS will indicate the pros and cons of the methods to be used in tackling the problem;
- To put the changes into context of the cliff and beach erosion patterns along the Holderness coastline;
- To provide information on the environmental appraisal of the options including both near-field and far-field consequences and consequences both in the short and long term (i.e. the spatial and temporal scales operating), if any, and to indicate the consequences of:

  (i) the engineering works during construction,

  (ii) the structures being in place,

  (iii) the eventual removal after leaching has been completed.

  This study emphasises the environmental significance of the possible changes experienced with and without the works being undertaken.
- To raise the management and governance issues connected with beach protection and erosion prevention work on eroding coastlines and indicate how these can be appropriately considered.
- To highlight the societal repercussions of cliff protection, e.g. the consequences of shore protection for landowners and householders downstream (given the southerly residual currents and sediment transport).
- To indicate what information would be required if an Appropriate Assessment (related to the European Marine Site under the EU Habitats and Birds Directives) is deemed necessary by Natural England, and to indicate the relevance of concerns that might be raised by Natural England, the ERYC, Cefas (as the Governmental Advisor under the FEPA licensing conditions) and the Environment Agency and to indicate the issues associated with these.
- To provide environmental information for the Coastal Protection Act and FEPA applications as necessary.

2. GEOMORPHOLOGICAL CHANGE ALONG THE HOLDERNESS COAST

At the end of the last ice age the Holderness coast was formed from glacial till, deposited from the retreating icecap. The glacial till is comprised chiefly of boulder clay, consisting of mud (72%), sand (27%) and pebbles and boulders (1%). These less cohesive materials result in a highly eroding coastline with a long-term average rate of cliff retreat around 2m a year, although some regions of the coast occasionally experience erosion rates of up to 20m a year (IECS, 1994). Weak points and failures in the cliff, albeit on a small scale, can lead to increased erosion rates.

The erosion of the Holderness cliffs provides a major sediment source to the Humber estuary and the Lincolnshire coast. An estimated 3-4Mm^3 of sediment per year is supplied to the coastal zone by cliff recession, shore platform lowering and seabed erosion (Balson et al 1996, 1998; Balson and Philpott, 2004). The sand beaches are generally formed of a thin veneer of sand overlying a clay base layer due to the limited sand volume input from the cliff recession and the constant vertical and horizontal transport of beach material.

Classical erosion occurs through a process of undercutting at the base of the cliff through repeated landslide activity. Waves reaching the base of the cliff remove material causing the cliff face to steepen to a point at which it collapses from the weight of the material above. The rate of this direct erosion process is less than 10cm per year (IECS, 1994) and the failures, which result may not necessarily be large, but may occur frequently. Water percolating through the glacial till can also help to weaken the structure, making it saturated and more prone to erosion.

On slightly higher cliffs, translational slides are more common. Translational failures occur in predominantly dry cliffs and produce shallow surface slides, typically 3-4 metres deep and 10-20 metres wide. They occur because the cliff material is insufficiently strong to maintain the cliff face at steep angles. Wave action quickly removes fallen material from the base of the cliff, maintaining the face at a steep unstable angle and leaving it prone to further failure. As such, most coastal erosion (in terms of terrestrial land loss) is a result of translational slides rather than direct wave action, and may average between 1m and 2m of land loss per annum along the south Holderness coast.

The seabed consists of the same constituents of the soft glacial cliffs of the Holderness coast. It is characterised by relatively hard boulder clay substratum with patchy deposits of sand, shingle and pebbles together with occasional lag boulders. The location, extent and depth of the sandbanks can vary on a seasonal basis. Erosion of the nearshore seabed has not been fully calculated, although it is estimated to be *c.*2cm/yr^{-1}. Erosion of this type may provide an important sediment source for adjacent and downdrift coastlines.

The problems associated with high erosion rates along the coast have seen targeted protection, e.g. at Mappleton and Dimlington, where protection structures have been put in place to protect assets (houses and road). Methods for protection including re-profiling of the cliff, putting in toe revetment and perpendicular rock groynes to trap sand and create a beach. The increased beach then provides protection by reducing wave energy hitting the cliffs, thus showing the importance of a beach presence in reducing erosion. However, while these measures have been successful in providing site specific protection (Plate A below), it is apparent that sediment supply is restricted past the structure until a new equilibrium is established. This can lead to a reduced beach height immediately downdrift, due to sediment starvation, with less wave energy absorbed and thus relatively more hitting the cliffs (Plate B below). Although this effect is only temporary, until equilibrium (and thus downdrift sediment supply is restored, it illustrates the importance of considering the repercussions downstream of any beach/shore/cliff protection scheme.

Plates A & B: Mappleton at the site and immediately downstream of the defences

2.1 Cliff Erosion Monitoring

The ERYC is responsible for the continued monitoring of coastal retreat, which was begun by Holderness Rural District Council in 1952. As ERYC is interested principally in land lost from the cliff top, measurements are made by direct reference to fixed points, which are irregularly spaced along the coast. Initially 71 marker posts were sited 50-100m from the cliff edge at intervals along the length of the coast. At various times during the past 50 years, it has been necessary to relocate posts inland when they became too close to the cliff top. Posts have also been added to the system and a new numbering system was introduced in 1994 (ERYC, 2006).

Measurements were originally made annually from each post to the cliff top, which is defined as the lip of the most recent failure scar. However, since 1997, erosion losses have been recorded in both the spring and autumn in order to determine when erosion is at its most active. The current method of monitoring uses Global Positioning Satellite (GPS), although earlier data were obtained using standard surveying techniques. The change in methodology is likely to have reduced the margin of error inherent in standard surveying techniques, so that the results have greater accuracy (ERYC, 2006).

Data recording throughout the last 50 years has not been continuous and there are gaps although, within the last decade, monitoring has been much more consistent at all posts.

The continuous monitoring programme, on temporal changes in erosion rates, has shown that erosion on the Holderness Coast is not a linear process but for the most part follows a cyclic pattern of 3-5 years. Furthermore the data indicate that it is not unusual for erosion rates to fluctuate considerably about the average annually in response to prevailing weather conditions.

2.1.1 CLIFF EROSION AT ALDBROUGH

The coastline in the area of the gas caverns is characterised by a gently undulating landscape fronted by undefended soft glacial till and clay cliffs laid down during the ice ages that typically stand between 13m to 23mOD. These are fronted by a veneer sand beach and a broad shore platform. These cliffs and the shoreward part of the seabed are continually being eroded by wave action. It is possible that the rate of erosion will increase as sea level rises unless sediment accretion on the beach keeps pace with this rise. Due to the largely unprotected nature of this coastline, the cliffs contribute significant sediment inputs to the North Sea, with a southerly nett drift of material, around 200,000-350,000m^3/year (HR Wallingford, 2002). This material feeds the beaches along the Withernsea to Easington shoreline.

In 1998, Posford Duvivier estimated a long term average erosion rate along this length of coastline as 0.94m-5.6m per year. Rates of coastal erosion can vary greatly between different locations, over successive years and in relation to particular storm events. Individual records of 6m – 9m retreat following a single event have been made. Scott Wilson (2009) reports a current trend of rapid shoreline retreat, with erosion rates of 1 to 3m per year on the undefended sections.

The Aldbrough gas cavern facility is sited in the immediate vicinity of erosion post 68 (Figure 2). The erosion post monitoring by the ERYC 2km north and south of the gas cavern site (erosion posts 64 to 72) shows the calculated erosion rates (Table 1). Erosion post 68 at the gas cavern installation shows that from September 2008 to September 2009, this length of coastline experienced 5.79m of erosion in one year. The highest recorded annual loss was 15.54m with an average erosion rate calculated at 1.11m/yr since records began in 1852. The current assumed erosion rate at post 68 is 2.10m/yr.

Two kilometres north of the gas caverns, erosion posts 64 to 67 show a similar rate of retreat, particularly at posts 66 and 67. At these two posts, the assumed erosion rate is higher than at post 68 averaging 2.33m/yr^{-1}. Two kilometres south of the gas caverns, cliff erosion rates are again higher than at post 68, particularly at posts 69 to 71, with an assumed erosion rate of 2.71m/yr^{-1} at Post 69. Figure 3 shows the cliff edges measured for the past seven years, along with the predicted cliff lines in 50 and 100 years time. At the current assumed rate of erosion of 2.10m/yr-1 at Post 68, the outermost pipeline holding the cable duct will be exposed during 2012. As erosion occurs at a non-uniform rate along this coastline, this could be sooner if a large erosion event were to occur.

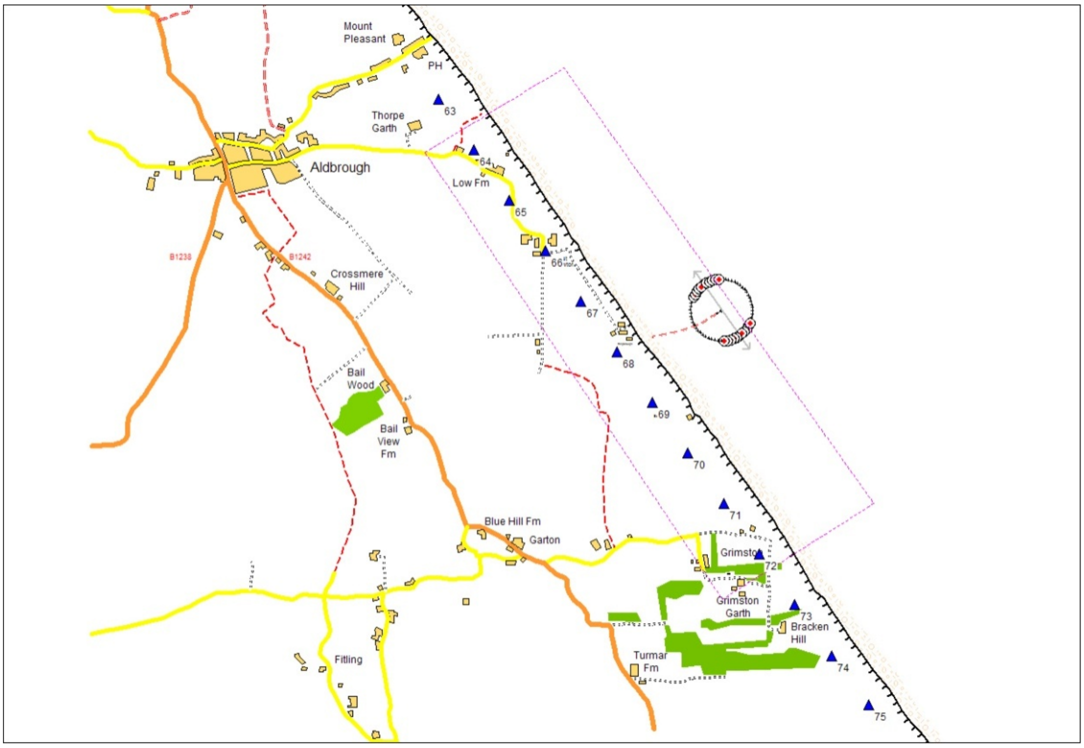


Figure 2: Location of Erosion Posts 63 to 75 along the Holderness Coast.

Table 1: Erosion Profile Details and Records

Erosion Profile	Location	Height of cliff mOD	Max. recorded annual loss	**Erosion Profile Records**				
				Cliff lost over last year		**Erosion rate since 1852 m/yr**	Erosion Rate since 2003 m/yr	**Assumed erosion rate m/yr**
				Sept 08 to April 09	April 09 to Sept 09			
64	North of Hill Top Farm, south Aldbrough	19.8	13.1	0.00	0.00	1.32	1.78	**1.91**
65	South of Hill Top Farm, south Aldbrough	20.5	10.29	3.62	0.00	1.29	3.71	**2.10**
66	Opposite East Newton	16.9	10.13	5.07	2.53	1.27	4.38	**2.42**
67	Between East Newton and Ringbrough	13.3	8.3	6.23	0.00	1.17	3.31	**2.23**
68	Opposite Ringbrough (location of gas caverns)	22.0	15.54	4.15	1.64	1.11	3.12	**2.10**
69	South of Ringbrough	15.8	13.4	0.00	0.00	1.27	3.71	**2.71**
70	South of Ringbrough	22.7	12.5	0.00	0.00	1.19	2.79	**2.30**
71	North of Garton	21.1	11.27	0.00	0.00	1.36	3.62	**2.15**
72	South of Garton	23.2	15.2	9.06	0.00	1.21	3.15	**2.00**

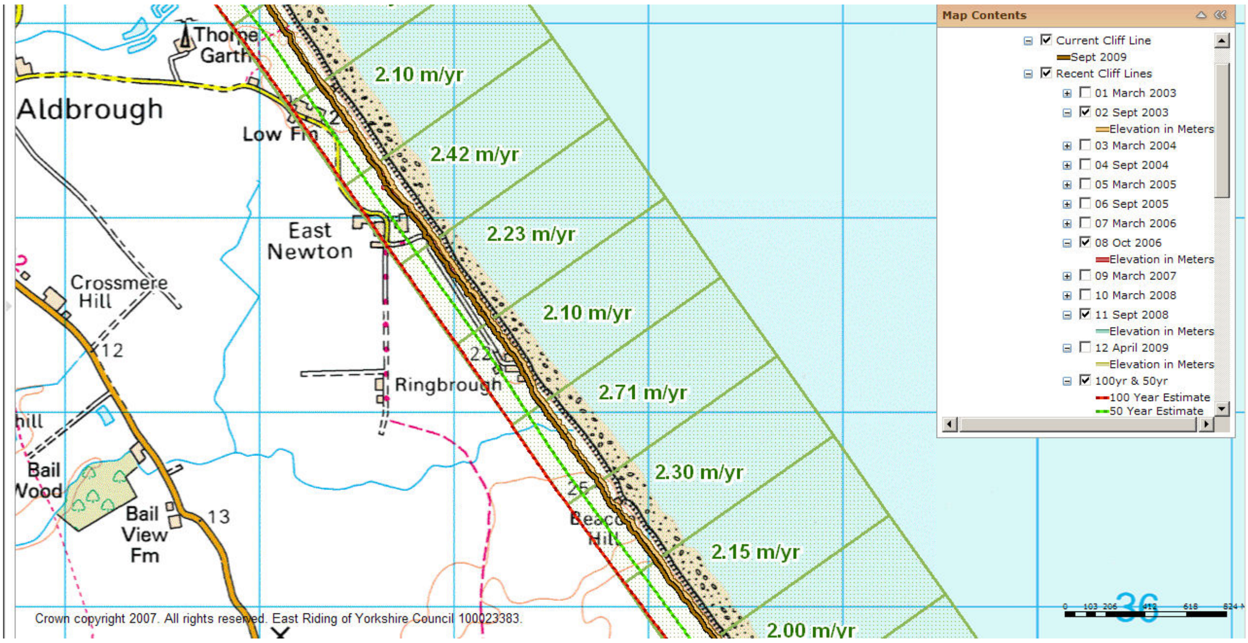


Figure 3: Cliff edges in 2003, 2006, 2008 and 2009; and estimated 50 and 100yr cliff lines from the Coastal Explorer mapping tool between Aldbrough and Grimston (ERYC, 2010).

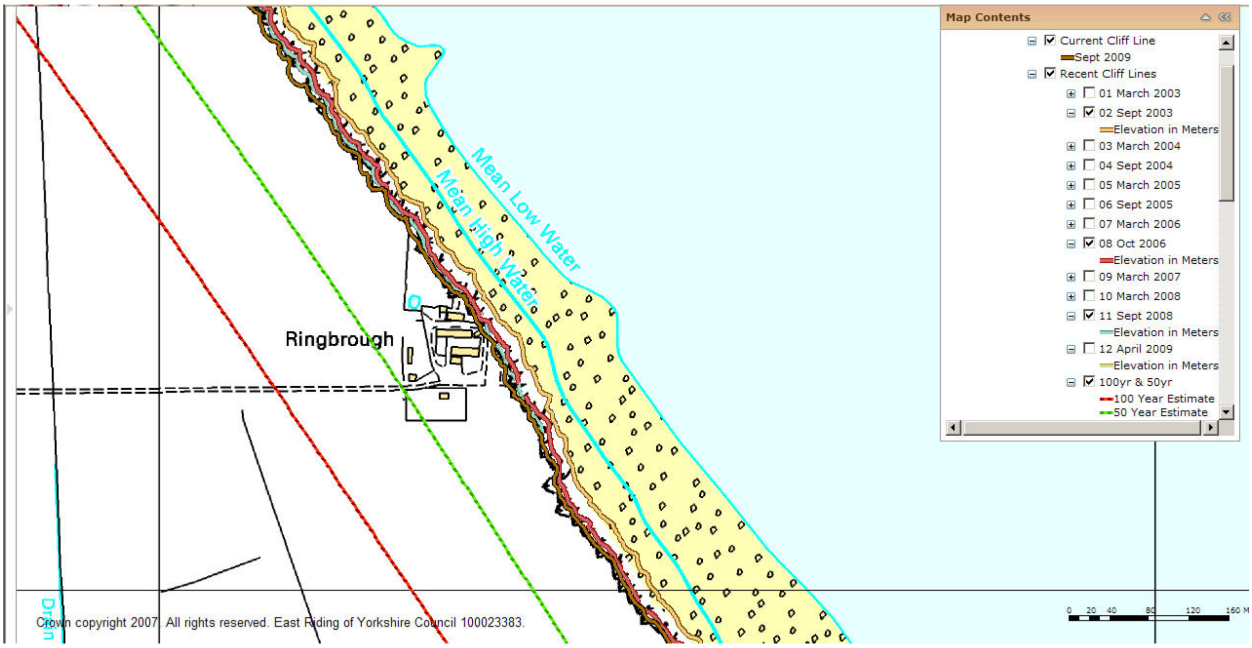


Figure 4: Cliff edges in 2003, 2006, 2008 and 2009; and estimated 50 and 100yr cliff lines from the Coastal Explorer mapping tool for Ringbrough (Erosion Post 68) (ERYC, 2010).

During routine monitoring undertaken by Jacobs/SSE to assess the integrity of the infrastructure at the site, it was noted that substantial erosion of the cliff face had occurred within the base of the cliff (see Plate C), with erosion exposing shallow 'caves' at the location of the pipeline (possibly lenses), accelerating the rate of erosion beyond that predicted. As the cliffs are composed of glacial till and boulder clay, different materials erode at different rates forming stronger or weaker zones within the cliff make-up. Water is also filtering through the cliff and will affect the structure. These undetected weak points in the cliff have had repercussions for the rate of erosion predicted and have subsequently led to an underestimated rate when the original pipelines were installed.

Plate C: 'Caves' exposed within the eroding cliff face

2.2 Beach Monitoring

Monitoring of beach profiles along the Holderness coast began in 1991 in response to the building of the coast protection scheme at Mappleton. Beach levels were important in its design and to its long-term success. Initially beach level data were used to determine construction details and then later to assess the effectiveness of the defences in controlling beach levels. The monitoring was extended by ERYC along the Holderness coast with the proposed Easington defences. These defences now protect a kilometre of coastline opposite the Easington Gas Terminals, a site bounded on both sides by Sites of Special Scientific Interest (SSSI). To aid in the design of any mitigation works if beach levels were seen to change, an extensive 25-year programme of monitoring works was initiated. This work was based upon the collection of beach profile data from cliff top to mean low water at 75 locations between Withernsea and Spurn Point every six months (ERYC, 2006).

Plate D shows the location of the profile section at Post 68, with Figure 5 showing the beach profiles taken from 2003 to 2009 using the data collected by the ERYC. Over this six year period the beach has progressively retreated approximately 20m as the high water mark has moved upshore with cliff erosion. The foreshore fronting the cliff face in 2009 has attained a shorter steeper profile, with the gradient on the lower shore becoming much steeper beyond low water than in 2003.

Plate D: L Orientation of beach profile transect at EP68, Ringbrough Farm

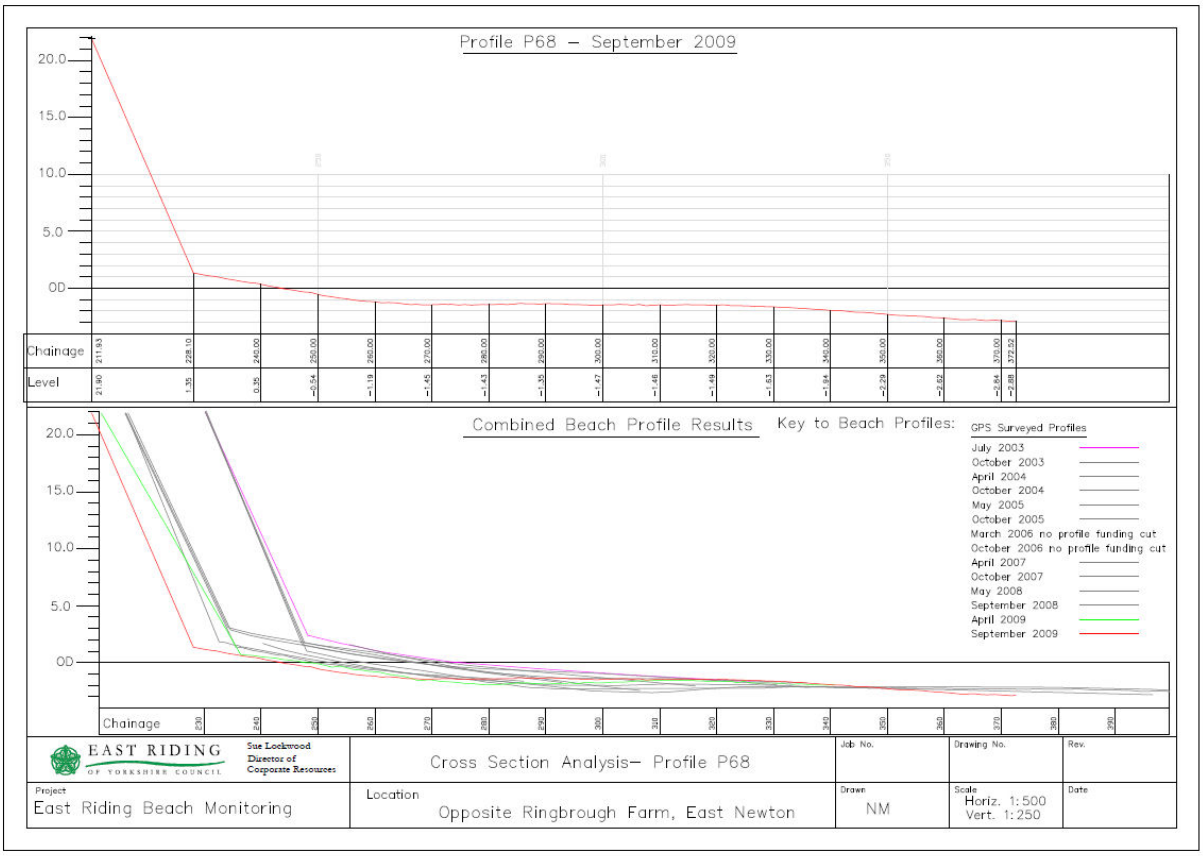


Figure 5: Cross section of the cliff face at Erosion Post 68, Ringbrough Farm in the vicinity of the pipelines.

2.3 Sea Level Rise

Although this current assessment is only immediately concerned with the state of the coastline over the next 2 to 5 years, it is still of relevance to assess future predictions for the erosion rates related to sea level rise. Using the present guidance by Defra (2006) which takes account of the IPCC (2001) high emissions scenario and regional tectonic/isostatic changes (Shennan and Horton, 2002), Scott Wilson (2009) reported the following guidance:

Table 2: Defra Predictions for the East of England: Net sea-level rise (mm/year) relative to 1990 mean level (from Defra, October 2006)

Assumed Vertical Land Movement (mm/ year)	High Emissions: Net sea-level rise (mm/year)			
	1990-2025	2026-2055	2055-2085	2085-2115
-0.8	4.0	8.5	12.0	15.0

The H++ scenario is an additional climate scenario described in UKCP09 which presents increased sea level rise as a result of accelerated ice sheet dynamics and storm surges. This provides an additional amount of change above the likely range of current models and in addition includes a low-probability high-impact SLR scenario range to enable vulnerability testing. The H++ scenario range is intended to provide an extreme but physically plausible range of change for users wishing to investigate contingency planning and the limits of adaptation.

As there is uncertainty over the nature and scale of future climate and relative sea level change, and no established relationship between the scale of these changes and the resulting modifications to the behaviour of cliffs, beaches and barriers, it is not possible to make precise predictions about future shoreline positions. However, estimates have been made, using best available methods within the revised SMP (Scott Wilson, 2009). Using the ERYC's cliff erosion monitoring data up to and including the survey carried out in April 2009, Scott Wilson (2009) calculated the mean recession rates for unprotected sections of the Holderness coast (see Figure 6).

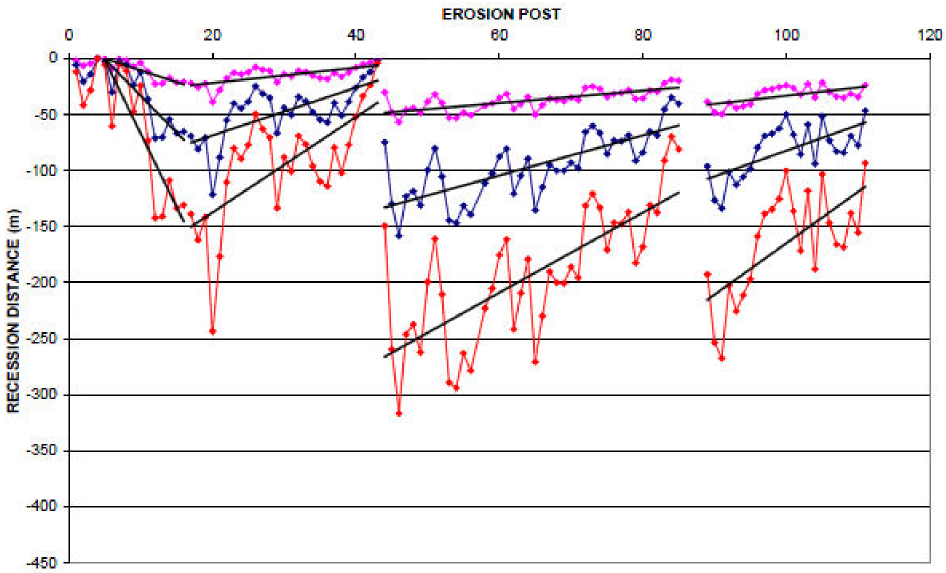


Figure 6: Extrapolation of past cliff recession rates: the predicted 20, 50 and 100 year recession distances for erosion posts within each cliff segment. (Top line (magenta) >2025, middle line (blue) >2055, bottom line (red) >2105, with linear trend lines shown).

The erosion posts of direct interest to this study fall within the middle section (posts 64 to 72) predicting some of the highest rates of erosion.

3. POTENTIAL OPTIONS

3.1 Less Preferred Options

As identified in Section 1, there are several potential management options available. However some of these, whilst feasible are currently less preferred. These are:

Option 1 - Do Nothing: This may have an unacceptable risk

- There will be no environmental impact but
- there could be significant project delays to this nationally important strategic asset if the supply/return system fails.

Option 3 - Relocation: This would require the need to install new pipelines at an alternative location

- Works and environmental issues would include:
  - Creating an access road and ramp with excavator
  - Constructing a beach platform and cofferdam, importing protection material, sheet piling, piling rig and the excavation of the cofferdam
  - Construct a new HDD compound on cliff top near Ringbrough Farm
  - Drill down to the cofferdam using bentonite drilling mud
  - Import the pipes to the foreshore from seaward and pull them through the cliffs
  - Prepare for connection
  - Disconnect Phase 1 supply and reconnect at top and bottom
  - Backfill cofferdam and remove imported material (not all cofferdam can be removed)
  - There could potentially be a Phase 1 & Phase 2 activity
  - However once installed there would be no ongoing maintenance required
  - Semi-permanent access to beach would be required for removal of constructed works at end of project

3.2 Jacobs/SSE Proposed Solution

As indicated above when discussing the erosion-prevention response at Mappleton, new structures which protrude from the cliffs will trap sand and create a beach while at the same time, and until an equilibrium is reached, preventing sediment from migrating longshore (southwards in the case of the current coastline). Therefore the new defences proposed for the protection of the pipelines should be designed to offer as little interference to the flow of sand as possible. The proposed defences should be designed to hug the cliff base with no further form of beach control. The whole structure would act as a small groyne and additional sand may collect at the northern limit of the structure but within a short time sediment will continue to bypass the structure. In this way sand should continue to move past, thus maintain the beach either side and allowing the cliffs to erode on either side as before. Figure 7 shows the intended works. The protective rock armouring would protrude out approximately 90m in length along the base of the cliff, sloping up to approximately 55m at the crest. The toe of the rock armouring would extend to 19m at its widest and have a footprint of 1517m² on the foreshore.

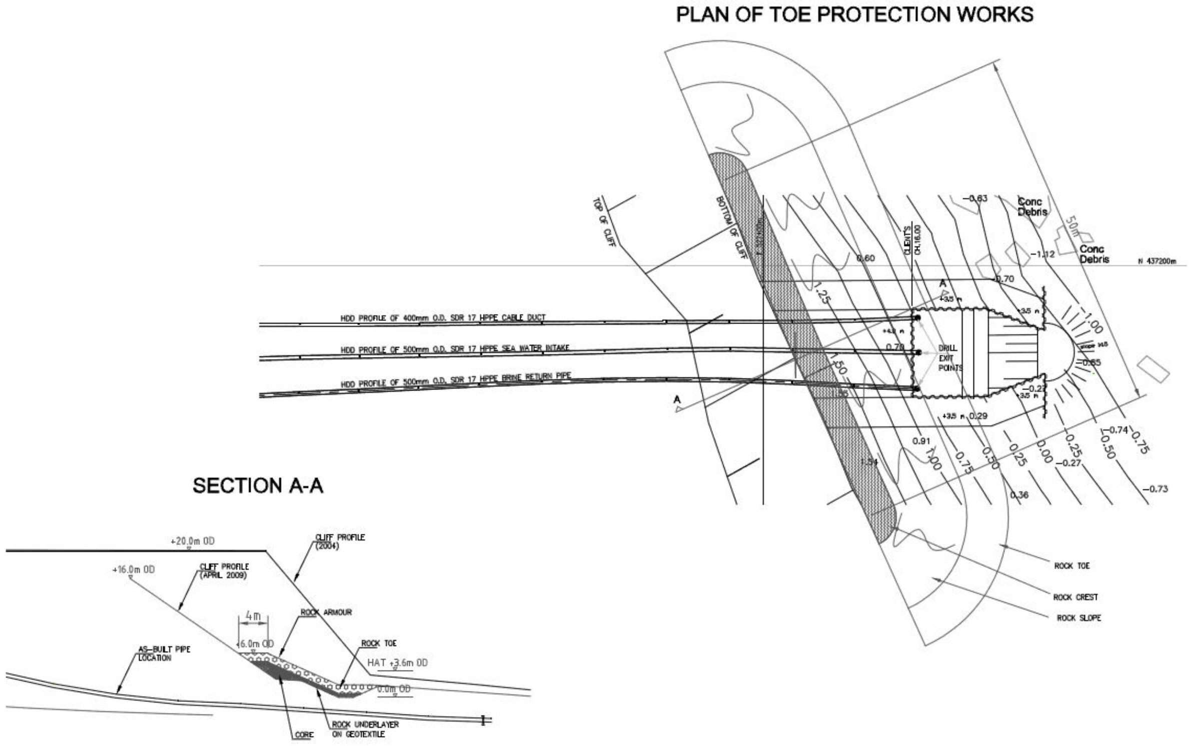


Figure 7: Proposed rock armouring at base of cliff

Jacobs/SSE intend to create the rock armouring by creating an access road and ramp with an excavator extending the Aldbrough phase 2 access road to the cliff edge. At the edge of the cliff, an access ramp will be created by progressively lowering the cliff top with an excavator. The lowering of the cliff top would start about 50m from the cliff edge to create about a 1:5 slope west-east and gently turn north (about 30m from the cliff edge) toward the intake pipeworks. Excavated material will be temporarily piled on the cliff top and when possible against the cliff base on the foreshore. Due to the orientation of the cliff, the area south of the temporary cliff protection can be prone to wave attack. Therefore a bund will be created by piling the excavated material south of the cliff protection to dissipate the wave energy and place imported material as temporary protection of the ramp. The cliff face will then be cut back to make safe for works and profile. For safety reasons and to provide a stable slope (profile), the cliff face will be sculpted to minimise slumping using an excavator starting from the cliff top side, again stockpiling material on the cliff top. Cliff stabilisation will be completed from the base of the cliff, stockpiling material to the south against cliff base on the foreshore. Depending on consultee responses, this material could be placed at the base of the cliff around the development, to form a 'sacrificial' area of sediment, compensating to some degree for the disruption to and restriction of sediment supply.

3.2 Potential Issues Related to this Proposal

If the existing pipelines are protected, the following environmental issues require addressing:

3.2.1 PHYSICAL IMPACTS TO FORESHORE

The footprint of the rock armouring would cover approximately 1517m² of the foreshore removing this from further erosion and biological productivity. Alterations to the physical environment through work being undertaken on the beach could include some small scale impacts to erosion and beach transport from the protection of the cliff.

It is expected that small scale alterations to the beach profile and sediment transport will occur from the works. In defending a coastline, any structure will to some extent impact upon the natural flow or supply of sediment and so affect the local coastal processes in some way. These changes tend to be greatest immediately following the construction of the defences, particularly if they contain an element of beach control. In the longer term there will be a gradual reorientation in the coastline as raised beach levels progress northwards, and a slight decrease in sand supply south as the protection given to the cliffs will reduce the amount of sediment released through erosion. Ultimately the degree to which this becomes a problem will depend upon the magnitude of the impact and the sensitivity of the area particularly down drift to short-term changes in sediment supply.

It is expected that the rock armouring will take a maximum of 3 months to complete, with all surficial plant and head-works removed on completion of the instatement activity. Vehicular access will be along the beach, with personnel accessing via the existing cliff path. Heavy plant machinery may cause compacting of the sediments in the zone of the construction area. Some disturbance will occur to the intertidal sediment of the fronting beach and along the vehicular access route. However, the intertidal sediments along the Ringbrough reach are generally characterised by a thin soft sediment veneer, overlaying bounder clay and cobbles. A survey in 2007 found that the sediment types around the discharge ranged from medium sand or slightly gravelly sand to coarser mixed gravels and sandy gravels with some areas of cobble and pebble evident (particularly to the south of the discharge and further offshore) (Allen, 2008).

3.2.2 USING LOCALLY SOURCED MATERIALS

It is the intention of the developer to use debris found on the beach within the rock armouring and also material from the re-profiling of the cliff face, including the potential use of this material as ‘sacrificial’ sediment to offset some of the disruption to sediment supply.

Considerable ‘foreign’ debris exists along this stretch of coastline from eroded cliff material, collapsed buildings and foreshore structures. However, removing some of the larger structures and material from the foreshore could have a negative impact on that specific area of cliff line where the object was providing some degree of protection from the sea.

Although Jacobs/SSE intend to limit the amount of material imported into the area, bringing in any additional materials by boat would provide the best option for minimum disturbance within the area.

3.2.3 BIOLOGICAL IMPACTS TO FORESHORE

As with most mixed shore and highly eroding areas, the shore here is biologically not productive hence the impact of the works on the ecology of the area is of little concern. IECS staff have undertaken a series of intertidal surveys in the intertidal areas fronting the Aldbrough gas caverns (Proctor & Mazik, 2005; Allen, 2008). They found that the animal communities in the intertidal area was extremely sparse with no infaunal (sediment-dwelling) organisms recorded from sites above the low water mark, with a total of five species recorded for the whole survey area, although a maximum of only three was recorded from any one site. Diversity was low both at individual sites and across the whole survey area although evenness (the relationship between the number of species and the number of individuals) was quite high, this is due to the combined low number of species and low abundance of organisms recorded. The amphipod crustaceans *Pontocrates arenarius* and *Bathyporeia pelagica* were the dominant species at all sites with the amphipod crustaceans *Bathyporeia elegans, Eurydice pulchra* and *Haustorius arenarius* also being recorded occasionally. As in the subtidal area, the intertidal species found and their abundances were considered to be characteristic of sediments composed of mobile and often eroded coarse material with very little organic matter.

The high mobility of the sediment and the relatively high wave energy of the area means that the faunal assemblage associated with the intertidal area is impoverished, often with the greatest abundance of organisms occurring in the mobile strandline where there may be some organic matter such as degrading deposited seaweed. Those species able to withstand the environmental rigours of the area are naturally able to tolerate and recolonise areas following any change in sediment either through natural or anthropogenic impact. As such, it is not expected that the disturbance to the sediment through direct construction activity, or secondary effects via alterations to hydrodynamic conditions would have any significant long term impact on the faunal community of the intertidal area, with short-term impacts during construction being of only very small scale.

3.2.4 ACCESS

For health and safety reasons, it will be necessary to restrict public access to the works area. However a safe pathway around the works will be maintained, in order that public access along the beach is not restricted. This will be short-term.

3.2.5 EFFECTS FOCUS

Based on the above, it would appear that the greatest potential environmental impacts from the proposed management option (Option 2), relate to the disruption of sediment supply and the issues of downdrift beach starvation and coastal erosion.

These issues are discussed in greater detail in Section 4, which attempts to define the severity of impacts in the context of natural processes, as well as broadly characterising the potential impacts to downstream sites of nature conservation importance.

4. ENVIRONMENTAL CONSIDERATIONS FOR OPTION 2

It is emphasised that this discussion does not constitute an Environmental Statement following an Environmental Impact Assessment. Instead, it is an exploration of the likely key aspects of the proposed management option in the context of natural processes along the coast and issues associated with the maintenance of integrity to the Interest Features of the Humber Estuary European Marine Site.

4.1 Context

The coastline in the area of the gas caverns is characterised by a gently undulating landscape fronted by undefended soft glacial till and clay cliffs laid down during the ice ages that typically stand between 13m to 23mOD. These are fronted by a veneer sand beach and a broad shore platform. These cliffs and the shoreward part of the seabed are continually being eroded by wave action.

Due to the largely unprotected nature of this coastline, the cliffs contribute significant sediment inputs to the North Sea with a southerly net drift of material, around 200,000-350,000m^3/year (HR Wallingford, 2002). This material feeds the beaches on the Withernsea to Easington shoreline. Some of this material moves along the Spurn Peninsula and will enter the Humber Estuary, with habitats and species contained within these sites included in the Humber Estuary European Marine Site (EMS) designation. In addition to this, there is some debate that some of the material moves offshore into the open North Sea basin although this has not been conclusively proven.

As part of the EMS designation, it is necessary to maintain the site and its components in Favourable Condition including the supply and type of sediment. There is the potential, were the supply of soft sediment via long-shore drift down the Holderness coast to be substantially disrupted, for this Favourable Condition to be threatened. It is therefore necessary for those charged with the management of the Humber Estuary EMS to be sure that the proposed works as described above have no Likely Significant Effect on the integrity or Favourable Condition of the estuary and its constituent qualifying conservation features. This constitutes what may be regarded as an Appropriate Assessment as defined under the EU Habitats & Species Directive.

4.2 Assessment of Likely Effects and Context

Clearly any structure extending out from the base of the cliff onto the shore in this region will potentially affect the sediment transport pathways, in essence trapping longshore-moving sediment until an equilibrium is reached. In addition, protection of a cliff base will slow erosion and the associated supply of sediment. However the extent of these effects will be influenced by the scale and duration of the development.

4.2.1 DISRUPTION TO SEDIMENT TRANSPORT

In terms of disruption to sediment transport, these changes tend to be greatest immediately following the construction of the structure, particularly if they contain an element of beach control, as sediment will be ‘trapped’ and thus not able to move downstream along the coast. However, ultimately, a degree of stability in sediment transport will be regained, as the ability of the structure to ‘trap’ sediment will reach capacity and a new equilibrium and then any additional sediment will move around the structure and continue downstream. The degree and duration of the disruption period will depend on the design the structure, especially the extent to which is projects from the cliffs.

In this instance, it is understood that the protection will extend out from cliff base to toe by a maximum of 19m and be of *c.*50m in length. Either end of the structure will be rounded and thus slightly 'faired' into the cliff in order to minimise the potential for disruption to the sediment transport pathway down the Holderness coast by long-shore drift.

Given the 'faired' shape, it is likely that, simplistically, this would potentially 'trap' an area equivalent to around 1,000m^2. Assuming a tidal range of 3.5m (a very much worst case given the way the beach profile would react), this would lead to a volume of around 3,500m^3 of 'trapped' material. However, although used for these calculations, in practice this would not occur, and even a 45^o slope on this area would reduce the trapped volume and associated predictions by 50%.

Even so, assuming an unrealistic worst case potential for the volume of trapped material and an annual movement of between 200,000m^3 and 350,000m^3 pa, this would equate to perhaps 1% or 2% of the annual transport of material. This is considered to be very much a worst case, and would effectively mean that the trapping potential of the structure would be back to zero within a week, assuming no sediment were to move past the structure at this time. This is very much a worst case volume as it assumes that the entire area of the trapped sediment would fill to the top of the highest astronomical tide. However this is highly unlikely, as the active area of sediment transport extends across the beach and out into the shallow subtidal, usually to a distance of around 400m. As such, the likely impact of the structure on sediment transport would be much reduced, equating perhaps to around 10% of the active transport zone, initially trapping perhaps 50 to 100m^3 per day. On this basis, it is possible that the 'trapping' potential of the structure would last for several months but, at worst, involve only 10% of the sediment transport volume over that period. As discussed above, it is however considered that less than half the volume of sediment would actually be trapped and thus the levels given above are considered considerably precautionary.

Table 3 below summarises data from the suspended sediment monitoring programme undertaken by SSE at Aldbrough since 2005, the data being presented on a monthly basis using values generally sampled from a once per month frequency. This suggests that there is a substantial variability in the concentration of suspended sediment material present in the vicinity of the works both on an inter- and intra-annual basis, with monthly annual averages varying by around 100% and monthly values showing considerable variation between maxima and minima.

Table 3: Sediment Loadings (mg l^{-1}), Aldbrough SP4 Intake (Data Source Jacobs/SSE)

	2005	2006	2007	2008	2009
Monthly Average	73	120	51	71	120
Monthly Maxima	283	233	406	424	180
Monthly Minima	3	<2	<2	10	35

Given this, it is considered that the potential 10% variation in sediment volume moving down the coast (using the worst case calculations detailed above), would not be of particular significance in general, again given the inherent variability in suspended material present in the area on a monthly basis.

It is also of note that possibly only 50% of the available material moving down the Holderness coast is actually delivered to the Spurn area, the rest moving offshore of this, with the volume of material entering the estuary being further reduced. As such, any upstream effects would be further buffered.

As such, whilst it is accepted that the proposed works will lead to a short-term modification to the transport of sediment down the coast, it is considered that in the context of the wider sediment volume, this disruption would be minor in extent, and occur for only a limited period.

Furthermore, given the variability in the naturally occurring levels of sediment, it is considered unlikely that the disruption would have any measurable effects on the supply of sediment necessary to maintain the structure of Spurn *c.*28km downstream, nor the supply of sediment necessary to maintain the status of habitats present within the Humber estuary at a minimum, 30km downstream from the works.

4.2.2 Disruption to Sediment Supply

In addition to the disruption to sediment transport, the proposed remedial works have the potential to directly disrupt sediment supply, through stopping erosion along the protected reach, this process normally providing a supply of sediment and other larger material to the marine environment, with this material then being transported downstream.

Assuming a cliff height of *c.*20m, a protected reach of 50m and an erosion rate (worst case observed) of around 5m per annum, the cliff protection works would remove 5,000m^3 of material from the Holderness sediment supply each year, and therefore 10,000m^3 over the duration of the ‘deployment’. Whilst this figure represents a substantial amount of material, in the context of sediment transport volume down the coast, it represents perhaps 0.15% of the material moving downstream each year. Alternatively, the loss of supply could be considered in the context of the wider Holderness supply length. The Holderness coast is approximately 50km in length, and as such the 50m development will reduce available sediment volume by around 0.1% for the two years of the works duration.

Of the sediment material moving down the Holderness coast, approximately only half will actually move around Spurn Point, and an even smaller percentage will enter the Humber, reducing the level of effect further.

It is also of note that the release of sediment into the system from the Holderness cliffs does not occur on a uniform basis. In fact, the release will occur primarily via a series of individual events, relating to storms, rainfall and large tides etc, over a year. As such, there is a degree of inherent variability in annual sediment supply. Although it is acknowledged that this would be of little direct relevance in this instance, as the deployment of the proposed works is over a two year period, there may be a few ecosystems, habitats or species present within the Humber and associated areas, that require the Holderness coast to provide a steady supply of material at a relatively stable concentration.

It is emphasised here that these conclusions rest on highly variable data and generalisations of sediment transport patterns along this coast. Despite this, it is suggested that previous, larger scale, protection schemes can act as an indicator of likely effect. Whilst it is acknowledged that this approach does not address the cumulative or in combination effects of a suite of such protection schemes, it is considered that there is value in their consideration, given their significantly larger area than the current proposed development. The coastal protection schemes at Mappleton and Easington are considered of note. The toe-and-revetment scheme and rock groynes at Mappleton illustrate the effects of structures which trap sediment and which may temporarily exacerbate erosion immediately downstream. With regard to the latter, the Holderness coastline shows several examples of notable erosion at the downstream end of erosion prevention works in which that exacerbated erosion continues at least until the sediment transport interrupted by the new structure is then restored.

The Easington scheme is of particular relevance given its proximity to Spurn and the Humber (and thus potentially less likely than the Aldbrough-Mappleton schemes to have its effects on the Humber system buffered by distance). The Easington scheme involved the protection of *c.*850m of cliff, a substantially longer reach than that proposed here, with the works only *c.*5km upstream from the neck of Spurn, and thus with the potential to have a significantly greater level of impact than the proposed works on the morphology of the peninsula.

As such, whilst it is acknowledged that the works on their own will lead to a reduction in the sediment supply entering the system, it is considered that this reduction will be relatively minor in its extent, given the length of reach to be protected in the context of the wider Holderness sediment source. Given the large-scale inherent variability in these features and the difficulty of measuring such small amounts, it is acknowledged that the changes may not be detectable.

Furthermore, the distance of the proposed works from the Humber system (e.g. Spurn and estuarine habitats) and the temporal variability in supply, means that the effects of any nett reduction in sediment supply will be buffered by natural environmental processes, with the morphological structures, habitats and species of Spurn and the Humber having developed under an inherently variable regime. In essence, estuarine communities are adapted to tolerate the erosion-deposition cycles common to estuaries and so it is likely that any changes occurring as the result of the proposed works will be accommodated.

4.3 Mitigation

Both main effects identified above will be reversible especially as the protection will be removed at the end of life of the pipe works. It is anticipated that no long-term impacts to the local area will occur, and nor will there be any legacy effects to wider sediment processes from materials left on the shore. Indeed, it is proposed to use non-natural material from the shore in this area as part of the protection structure (e.g. concrete). This material, which to a small extent, currently modifies sediment transport and supply, will be removed from the beach system on completion of the works.

Furthermore, as already described above, it is anticipated that the protection structure will be designed in such a way that it will not cause substantial disruption to sediment transport, with the armouring being somewhat ‘faired’ into the existing cliff alignment. Although there will remain some potential for sediment to be trapped immediately upstream of the structure (as discussed above in detail), this will allow some of the sediment to ‘drift’ around and down the structure, thus maintaining sediment transport pathways.

Based on the above, the impacts of the proposed works are considered to be minor, short-term and reversible. Their extent might be considered to be at a ‘system’ level, e.g. within the sediment cell, but in practice it is considered that any impacts at this level would not be measurable except at a local scale. Given the current understanding of the system, it is considered unlikely that there will be any significant (or even detectable) effect on the morphology of the Spurn peninsula or on the habitats and species present within the Humber estuary.

Despite this likely absence of wider scale impacts, there is the potential for additional mitigation to be applied during the project in order to minimise the impacts of the minor disruption to sediment transport and supply. As part of the works, it may be possible to place cliff spoil from the access track construction and upper cliff profile sculpting immediately off and downstream from the protection works. The volume of this material would probably be less than that which would be excluded from the combined transport and supply processes during the duration of the works deployment. It would, however, be sufficient to provide a degree of offset to the volume of material ‘trapped’ upstream during the initial disruption to the sediment transport, as well as providing a supply of additional material during the operational phase, or at least part of it.

Part of the sediment could be placed away from the works, thus acting as an initial sediment source feeding around to the south of the site, and in turn addressing in part any short-term localised beach starvation effects. A further amount could be placed downshore of the works to both provide protection to the access area from increased wave attack (beach starvation) and provide a source of sediment for onward transport downstream.

If considered necessary as a further mitigation measure, the design of such a strategy can be considered in greater detail, although whilst there are several potential benefits from the scheme in terms of mitigation measures, there may also be constraints to its application, not the least that it is likely to require FEPA and other licensing in its own right.

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