Cell 1 Sediment Transport Study

Phase 2: Main Report

Scarborough Borough Council

July 2014
Draft Report
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Drafted by Nick Cooper  
Checked by Gregor Guthrie  
Date/initials check 10/07/2014  
Approved by Gregor Guthrie  
Date/initials approval 10/07/2014
SUMMARY

Royal HaskoningDHV was appointed by Scarborough Borough Council to undertake the **Cell 1 Sediment Transport Study** on behalf of all public authorities and other organisations with coastal interests within Coastal Cell 1. This frontage covers the coastline between St. Abb’s Head in Scotland and Flamborough Head in the East Riding of Yorkshire.

Management of any coastline is complex due to the dynamic nature of the processes which prevail and the range of interests that exist. In order to provide the best possible management, it is necessary to have a good understanding of the sediment transport processes, so that actions in one area of coast do not unduly affect other areas. To this end, the objective of the Cell 1 Sediment Transport Study is to improve understanding of governing sediment transport mechanisms and pathways across Coastal Cell 1 to help improve future coastal management decision-making.

The **first phase** (the previous scoping phase) of the study was reported in December 2013 and the scoping report was accompanied by a number of supporting atlases. The scoping phase involved the development of a broad-level conceptual understanding of the governing sediment transport processes and sediment-related issues. This was based upon review of existing information, consultation with relevant authorities and organisations, and characterisation of the nearshore marine environment to determine the key sediment transport processes along the Cell 1 coast.

The **second phase** (the present phase) of the study has involved use of a range of analytical and modelling techniques to provide additional levels of detail at a selected number of key locations within Coastal Cell 1:

- Historical Trends Analysis (HTA) has investigated the historical legacy of colliery spoil tipping on the foreshore at Lynemouth Bay and Cambois Bay in Northumberland and at several beaches in County Durham. It is estimated that around 30m tonnes of colliery waste from Lynemouth and Ellington Collieries was tipped at foreshore disposal sites in Lynemouth Bay between 1934 and 2005, with at its peak over 1.5m tonnes tipped in one year (1968). An unknown quantity of excavated clay (and other waste) was tipped over the cliff edge at Cambois Bay until closure of Cambois Colliery in 1968. Over 100m tonnes of colliery waste was tipped along the County Durham coastline, either at offshore disposal sites or at foreshore disposal sites. In all cases, the tipping of waste resulted in significant progradation (seaward movement) of the shoreline and at Lynemouth and in County Durham infilling of the bays to form wide spoil beaches as a ‘terrace’ on the upper beach. Since cessation of tipping, the shoreline in all former tipping areas has been eroding.

- Numerical modelling using the MIKE LITPACK software suite has investigated the **relative** alongshore (LITDRIFT) and cross-shore (LITPROF) sediment transport potential at a series of sixteen transects throughout the Cell 1 frontage. Longshore sediment transport is only low to moderate in magnitude and is strongly influenced by changes in orientation of the shore profile within bays and the angle of the shore relative to the approach directions that characterise the nearshore wave climate. Cross-shore sediment transport potential exists at all modelled transects under a 1 month timeseries of ‘winter’ wave data. Combining the outputs from both modelling approaches, it can be confirmed that during storms sediment is removed from the beaches as a cross-shore process and then transported alongshore (with a net direction to the south) in the shallow nearshore zone. After the stormier wave climate has passed, sediment then progressively returns to the beaches as a cross-shore process (either within the same bay or further south along the coast after bypassing a headland) during calmer wave conditions.
The Cell 1 Sediment Transport Study has identified that the shoreline and nearshore sea bed is predominantly controlled by its underlying solid geological structure. Through differential erosion of the different rock types a number of ‘headland and bay’ features of varying spatial extents have been formed. Littoral sediment transport is, generally, relatively well confined to within individual bays.

Whilst littoral sediment transport is predominantly to the south, the rates of drift are relatively low and temporary drift reversals can occur along frontages under short-duration storm events from different directions. The presence of numerous natural headlands, estuaries and associated control structures, such as harbour piers, can cause locally complex physical processes due to wave sheltering, tidal gyres and localised sediment accumulations or drift reversals.

Of great importance is that many beaches experience significant onshore-offshore transport during storm events, with material being drawn down the beach to the lower foreshore and nearshore zone, whereupon it can become entrained by tidal currents and advected along the coast, generally in a southerly direction. In general, beach sediment slowly and progressively returns to the upper foreshore as conditions become calmer, leading to beach recovery.

Following production of this main study report, a subsequent phase of activity will be undertaken in autumn/winter 2014, involving a field experiment using sand tracers in Scarborough South Bay. The purpose of this sand tracer experiment is twofold: (1) to confirm sand transport pathways in Scarborough South Bay; and (2) to test in a field environment the efficacy of the existing sand tracer technique, which may have wider applicability for subsequent use across other frontages within Cell and more widely across other sand-dominated coastal frontages elsewhere.
ACKNOWLEDGEMENTS

The authors would like to thank those individuals and organisations who assisted with this main phase of the Cell 1 Sediment Transport Study, in particular:

- Channel Coastal Observatory (Travis Mason)
- CEFAS (Chris Vivian, Jemma Lonsdale and Dave Pearce)
- Durham Heritage Trust (Niall Benson)
- East Riding of Yorkshire Council (Neil McLachlan)
- Scarborough Borough Council (Robin Siddle)
- HR Wallingford (Sarah Moxon)
- University of Hull – Scarborough Campus (William Mayes)
- Partrac (Kevin Black, Matt Wright)

Cover photo:

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- Saltburn Scar Headland
- Skinningrove Jetty
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UNITS

cm  centimetres
g  grams
kg  kilograms
km  kilometres
m  metres
m²  square metres
m³  cubic metres
ml  millilitres
mm  millimetres
s  seconds
µm  micrometres (more commonly known as microns)
yr  year

NOMENCLATURE

\( \alpha_0 \)  Profile orientation (in °N)
\( \Theta_1 \)  Principal direction of wave approach (in °N)
\( d_{50} \)  Mean sediment grain diameter (in mm)
\( H_s \)  Significant wave height (in m)
\( Q_s \)  Sediment transport potential (in m³/yr)
**ACRONYMS AND ABBREVIATIONS**

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<tr>
<td>a.k.a.</td>
<td>also known as</td>
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<tr>
<td>CEFAS</td>
<td>Centre for Environment, Fisheries and Aquaculture Science</td>
</tr>
<tr>
<td>CETaSS</td>
<td>Cell Eleven Tide and Sediment Study</td>
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<td>DAS</td>
<td>Disposal at Sea</td>
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<tr>
<td>DRCM</td>
<td>Direct Reading Current Meter</td>
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<tr>
<td>EGA</td>
<td>Expert Geomorphological Assessment</td>
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<td>FEPA</td>
<td>Food and Environmental Protection Act</td>
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<td>HR Wallingford</td>
<td>Hydraulics Research Wallingford</td>
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<tr>
<td>HTA</td>
<td>Historic Trends Analysis</td>
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<tr>
<td>MAFF</td>
<td>Ministry of Agriculture, Fisheries and Food</td>
</tr>
<tr>
<td>MHWN</td>
<td>Mean High Water Neaps</td>
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<td>MHWS</td>
<td>Mean High Water Springs</td>
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<td>MLWN</td>
<td>Mean Low Water Neaps</td>
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<td>MLWS</td>
<td>Mean Low Water Springs</td>
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<td>MRCM</td>
<td>Moored Reading Current Meter</td>
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<td>MSL</td>
<td>Mean Sea Level</td>
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<tr>
<td>OD</td>
<td>Ordnance Datum</td>
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<td>OS</td>
<td>Ordnance Survey</td>
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<tr>
<td>RHDHV</td>
<td>Royal Haskoning DHV</td>
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<td>SCOPAC</td>
<td>Standing Conference on Problems Associated with the Coastline</td>
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<td>UK</td>
<td>United Kingdom</td>
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## GLOSSARY

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<tr>
<td>Aeolian sediment transport</td>
<td>The transport of sand particles by wind action.</td>
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<td>Alongshore sediment transport</td>
<td>The transport of sediments along the shore by the action of waves and/or currents.</td>
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<tr>
<td>Beach recharge or beach replenishment</td>
<td>Artificial process of replenishing a beach with material from another source.</td>
</tr>
<tr>
<td>Beach management plan</td>
<td>A document which defines the management approaches for a beach, usually involving some form of sediment replenishment, sediment recycling, sediment bypassing or sediment retention using control structures such as groynes or breakwaters.</td>
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<tr>
<td>Cell 1</td>
<td>The coastal sediment cell which extends between St. Abb’s Head in Scotland and Flamborough Head in the East Riding of Yorkshire.</td>
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<td>Closure depth</td>
<td>The depth in the sub-tidal zone beyond which negligible wave-induced sediment transport occurs.</td>
</tr>
<tr>
<td>Coastal cell</td>
<td>A division of coast within which the transport of coarse-grained sediments (sands and gravels) is theoretically self-contained.</td>
</tr>
<tr>
<td>Coastal defence</td>
<td>A composite term involving the management of coastlines by means of coast protection against erosion or sea defence against flooding.</td>
</tr>
<tr>
<td>Coastal protection</td>
<td>Management of the coast to reduce risks from coastal erosion.</td>
</tr>
<tr>
<td>Coastal sub-cell</td>
<td>A sub-division of coast (within a larger coastal cell) within which the transport of coarse-grained sediments (sands and gravels) is relatively self-contained.</td>
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<tr>
<td>Cross-shore sediment transport</td>
<td>The transport of sediments across the shore into the nearshore zone by the action of waves and/or currents.</td>
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<tr>
<td>Downdrift</td>
<td>Direction of alongshore movement of beach materials.</td>
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<tr>
<td>Dune</td>
<td>An accumulation of sand at the interface between the land and sea.</td>
</tr>
<tr>
<td>Expert geomorphological assessment</td>
<td>A technique for the synthesis and interpretation of information from various sources to develop a conceptual understanding of the physical processes, sediment characteristics and morphological features of a coastal frontage.</td>
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<tr>
<td>Geomorphology</td>
<td>The branch of physical geography/geology which deals with the form of the Earth, the general configuration of its surface, and the distribution of the land, water, etc.</td>
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<td>Hard engineering</td>
<td>Traditional coastal engineering works which attempt to maintain a fixed line of defence against the sea. Examples include sea walls, revetments and embankments.</td>
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<tr>
<td>Historic trends analysis</td>
<td>A technique for analysing timeseries of data at a coastal frontage, usually involving identifying changes over time from maps and surveys.</td>
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<tr>
<td>Inter-tidal zone</td>
<td>The area of foreshore between the limits of high and low water.</td>
</tr>
<tr>
<td>Littoral sediment transport</td>
<td>The transport of sediments along the shore by the action of waves and/or currents.</td>
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<tr>
<td>Littoral zone</td>
<td>The portions of inter-tidal and sub-tidal zone within which sediment transport processes are active. It is normally defined by some offshore closure depth.</td>
</tr>
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<td>Term</td>
<td>Definition</td>
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<tr>
<td>Longshore sediment transport</td>
<td>The transport of sediments along the shore by the action of waves and/or currents.</td>
</tr>
<tr>
<td>Nearshore zone</td>
<td>The shallow sub-tidal zone.</td>
</tr>
<tr>
<td>Offshore zone</td>
<td>The deep sub-tidal zone.</td>
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<tr>
<td>Regression</td>
<td>The seaward movement of the shoreline in response to a fall in relative sea level.</td>
</tr>
<tr>
<td>Sand recycling</td>
<td>The extraction of sand from areas of unwanted accretion and re-use in areas where sediment has been depleted over time.</td>
</tr>
<tr>
<td>Sea defence</td>
<td>Management of the coast to reduce risks from sea flooding.</td>
</tr>
<tr>
<td>Shoreline management plan</td>
<td>A document which sets out management policies for long lengths of coast over the next century to manage risks from coastal erosion and sea flooding.</td>
</tr>
<tr>
<td>Soft engineering</td>
<td>Coastal management approaches which attempt to modify or work with natural processes, rather than work against them. Examples include beach replenishment and dune stabilisation.</td>
</tr>
<tr>
<td>Sub-tidal zone</td>
<td>The area of the sea bed below low water.</td>
</tr>
<tr>
<td>Shoreline Management Plan (SMP)</td>
<td>A document that provides a large-scale assessment of the risks associated with coastal processes and presents a policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner.</td>
</tr>
<tr>
<td>Topography</td>
<td>Configuration of a surface including its relief and the position of its natural and man-made features.</td>
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<tr>
<td>Transgression</td>
<td>The landward movement of the shoreline in response to a rise in relative sea level.</td>
</tr>
<tr>
<td>Updrift</td>
<td>Direction opposite to the predominant movement of longshore transport.</td>
</tr>
<tr>
<td>Wave direction</td>
<td>Direction from which a wave approaches.</td>
</tr>
<tr>
<td>Wave diffraction</td>
<td>Process by which the direction of approach and height of a wave changes as it moves around headlands or structures.</td>
</tr>
<tr>
<td>Wave refraction</td>
<td>Process by which the direction of approach and height of a wave changes as it moves into shallow water.</td>
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**SEDIMENT TYPES**

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<tr>
<td>Boulder</td>
<td>A non-cohesive sediment particle in the size range &gt; 256mm</td>
</tr>
<tr>
<td>Cobble</td>
<td>A non-cohesive sediment particle in the size range 64mm – 256mm</td>
</tr>
<tr>
<td>Gravel</td>
<td>A non-cohesive sediment particle in the size range 2mm – 64mm</td>
</tr>
<tr>
<td>Sand</td>
<td>A non-cohesive sediment particle in the size range 62.5µm – 2mm</td>
</tr>
<tr>
<td>Silt</td>
<td>A cohesive sediment particle in the size range 3.9µm – 62.5µm</td>
</tr>
<tr>
<td>Clay</td>
<td>A cohesive sediment particle in the size range &lt; 3.9µm</td>
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1 INTRODUCTION

1.1 Background

Royal HaskoningDHV was appointed by Scarborough Borough Council to undertake the **Cell 1 Sediment Transport Study** on behalf of all public authorities and other organisations with coastal interests within Coastal Cell 1. This frontage covers the coastline between St. Abb’s Head in Scotland and Flamborough Head in the East Riding of Yorkshire (Figure 1).

Within this frontage there are ten local authorities with coast protection responsibilities (one in Scotland and nine in England) and the Environment Agency with responsibilities for both sea defence and coastal erosion. Management of the coastline also involves a number of other organisations, such as marine regulators, nature conservation bodies, port and harbour authorities, fisheries committees, utilities providers and other interested parties.

Management of any coastline is complex due to the dynamic nature of the processes which prevail and the range of interests that exist. In order to provide the best possible management, it is necessary to have a good understanding of the sediment transport processes, so that actions in one area of coast do not unduly affect other areas.

To this end, a number of sediment transport studies have been undertaken around the UK on a regional basis in the past years and decades. These have included:

- SCOPAC (South Coast) Sediment Transport Study
- Cell Eleven (North West Coast) Tide and Sediment Study (CETaSS)
- Southern North Sea (East Anglia Coast) Sediment Transport Study

The north east coast is slightly different from many other areas of the English coastline in that whilst sediment transport is important, the shoreline is heavily influenced by the controls exerted by its underlying geology. This tends to create a series of typically sandy bays between harder rock headlands. Often, sediment transport remains relatively contained within these bays, moving in the prevailing direction of the residual tidal currents or predominant waves. However, during storm events, material is often drawn down the beaches to the nearshore zone, where it becomes entrained in the North Sea tidal currents and transported along the nearshore zone (sometimes along nearshore bars), before returning to the beaches when sea states become calmer.

The first and second generation Shoreline Management Plans within Coastal Cell 1 recommended monitoring studies to improve understanding of coastal behaviour in response to typical seasonal and storm events, and to longer term coastal change, such as sea level rise. As a direct result, the Cell 1 Regional Coastal Monitoring Programme was established (run in its present form since 2008) and is collecting much useful data on the changes in the beaches, cliffs, dunes and nearshore zone. Analysis of data from this programme has revealed that in some particular parts of the Cell 1 frontage there remain uncertainties regarding sediment transport processes. The purpose of the Cell 1 Sediment Transport Study is therefore to improve understanding of governing sediment transport mechanisms and pathways across Coastal Cell 1. The project involved consultation with practitioners across Coastal Cell 1 during the Scoping Phase to ensure that it has focus on pertinent management issues relating to sediment transport.
Figure 1 – Location Plan
1.2 Method

The objectives of the Cell 1 Sediment Transport Study have been delivered by means of a two-phase project.

The first (scoping) phase involved the development of a broad-level conceptual understanding of the governing sediment transport processes and sediment-related issues. This was based upon review of existing information, consultation with relevant authorities and organisations to define their needs from the study and ensure that it has focus on pertinent management issues relating to sediment transport, characterisation of the nearshore marine environment to determine the key sediment transport processes along the Cell 1 coast, and preparation of a Scoping Report (Royal HaskoningDHV, 2013) describing the key findings and recommendations for more detailed studies at selected sites during the second phase.

The Scoping Report concluded that the Cell 1 shoreline and nearshore sea bed is predominantly controlled by its underlying solid geological structure. Through differential erosion of the different rock types a number of ‘headland and bay’ features of varying spatial extents have been formed. Littoral sediment transport is, generally, relatively well confined to within individual bays.

Whilst littoral sediment transport is predominantly to the south, the rates of drift are relatively low and temporary drift reversals can occur along frontages under short-duration storm events from different directions. The presence of numerous natural headlands, estuaries and associated control structures, such as harbour piers, can cause locally complex physical processes due to wave sheltering, tidal gyres and localised sediment accumulations or drift reversals.

Of great importance is that many beaches experience significant onshore-offshore transport during storm events, with material being drawn down the beach to the lower foreshore and nearshore zone, whereupon it can become entrained by tidal currents and advected along the coast, generally in a southerly direction. In general, beach sediment slowly and progressively returns to the upper foreshore as conditions become calmer, leading to beach recovery.

Given these findings, the present second (main) phase has used a suitable range of modelling and analytical techniques to provide additional levels of detail at a selected number of key locations within Coastal Cell 1. This phase has included a combination of approaches, including:

- Historic Trends Analysis (HTA) of changes at locations that have historically been particularly affected by a long legacy of colliery spoil tipping;
- Numerical modelling of cross-shore response during storms and sediment transport potential across the littoral zone at a series of transects throughout the Cell 1 frontage; and
- Expert Geomorphological Assessment to synthesise all findings into this Main Report.
1.3 Structure of Report

This Phase 2 Main Report presents a summary of the findings from the Historical Trends Analysis (HTA) at Lynemouth Bay, Cambois Bay and along the County Durham coastline (Chapter 2) and the numerical modelling of sediment transport at selected transects across the Cell 1 frontage (Chapter 3). Further details of these activities are presented in the appendices.

The conclusions from these studies are synthesised with the findings from the Scoping Report and other recent studies in Chapter 4. The references cited throughout the report are listed in Chapter 5.

Collectively, the Phase 1 Scoping Report (Royal HaskoningDHV, 2013) and this Phase 2 Main Report provide an improved understanding of sediment transport within Cell 1 and will aid in future coastal management decisions.¹²

¹ Following production of this Phase 2 Main Report, a subsequent phase of activity will be undertaken in autumn/winter 2014, involving a field experiment using sand tracers in Scarborough South Bay. The purpose of this sand tracer experiment is twofold: (1) to confirm sand transport pathways in Scarborough South Bay; and (2) to test in a field environment the efficacy of the existing sand tracer technique. The methods and results of the sand tracer experiment will be reported separately in due course.

² At the time of writing this Phase 2 Main Report, the findings of the Cell 1 Inter-tidal Habitat Study were not available for review. However, during development of the Cell 1 Sediment Transport Study, there was correspondence with the authors of that study to share ideas about governing physical processes, sediment sources and morphological changes across Cell 1 and there was good consensus regarding these matters. When the Cell 1 Inter-tidal Habitat Study becomes available, it is recommended that its content is reviewed in detail for any further insights beyond those contained within this report.
2 HISTORICAL TRENDS ANALYSIS

2.1 Background

The Phase 1 Scoping Report (Royal HaskoningDHV, 2013) collated historic shoreline maps and sea bed charts covering the entirety of Cell 1 and compared these with contemporary Ordnance Survey maps and Admiralty charts.

At the Cell-wide, macro-scale of assessment, little significant change in the position or geomorphology of the shoreline or nearshore sea bed was identified over the timeframe of available datasets across much of the frontage. This is largely due to the controls exerted by the underling geology in terms of its general resistance to erosion.

There were, however, some local changes noted, most evident in association with the:

- historic legacy of colliery spoil tipping in Northumberland and County Durham;
- construction of coastal defences, for example at Newbiggin Bay, Littlehaven, Trow Quarry, Redcar, Skinningrove, Staithes, Whitby West Cliff, Whitby Haggerlythe; and
- alignment of the channels of some estuaries and smaller becks.

The Scoping Report recommended that the Main Report should incorporate an Historical Trends Analysis (HTA) focusing on the coastlines where greatest change has occurred over recent historic time, i.e. those frontages that historically have been subject to practices of colliery spoil tipping, namely Lynemouth Bay, Cambois Bay and the County Durham coastline.

HTA is a method for interrogating series of data to identify trends and rates of change over time (Pye and van der Wal, 2000). Often it is associated with analysis of historic maps, charts, aerial photographs, beach profiles or bathymetric surveys.

HTA at the locations of historic colliery spoil tipping was intended to help identify the past and ongoing changes associated with the erosion and transport of colliery spoil as a basis for future projections of likely re-activation of (presently dormant) backing sea cliff or coastal slope recession processes.

HTA was therefore recommended to take the form of targeted historic map analysis and beach profile analysis at all three sites, namely Lynemouth Bay, Cambois Bay and the County Durham coastline.
2.2 Main Findings

Appendix A presents the detailed findings from the Historic Trends Analysis, with a summary presented in this section.

2.2.1 Lynemouth Bay

- Lynemouth Bay was affected by colliery waste tipping from both Lynemouth Colliery and Ellington Colliery.

- Tipping commenced in 1934 at two tipping sites, one to the north of the River Lyne and one to the south along Lyne Sands.

- Tipping continued until closure of Ellington Colliery in 1994, but then recommenced (at the northern site only) when the colliery was re-opened in 1995 until its final closure in 2005.

- Tipping resulted in significant seaward movement of the beach front and infilling of Lyne Sands and the wider Lynemouth Bay (Figure 2).

- At the peak of the recorded tipping (1968) over 1.5m tonnes was deposited onto the foreshore and in each year from 1965 to 1983 around 1m tonnes was tipped. Volumes then fell substantially during the 1984 Miners’ Strike. In total, it is likely that over 30m tonnes of colliery waste was tipped at Lynemouth Bay over seven decades, with the greatest volumes occurring in the late 1950s, throughout the 1960s and 1970s and into the early 1980s.

- The progradation of the shoreline that occurred when tipping was intense facilitated the subsequent development of a coal-fired power station on the reclaimed land.

- Since cessation of tipping, the shoreline has been retreating in parts of Lynemouth Bay, most notably in the vicinity of the power station and Lyne Sands to the south. This necessitated construction of coastal defences to protect the power station in 1995 and their extension to protect a coal-stocking yard in 2005-06 (Figure 3).

- Previous monitoring and research identified that temporal changes in wave height, period and direction were the major factors influencing sediment transport of the tipped spoil, with such changes primarily affecting onshore-offshore sediment movement rather than longshore drift.

- Of the estimated 70 – 90% of spoil transported onshore-offshore, most sediment would be confined to within the 10m sea bed contour of the nearshore zone. It was considered that it would only be the very finest fractions of spoil (<180µm) that would be carried further out to sea. The net transport of any material deposited in the nearshore zone would then be governed by the residual drift of tidal currents, imposing a net southward movement in the nearshore zone.
Figure 2 – Colliery Spoil Beach at Lynemouth Bay

Figure 3 – Coastal Defences at Lynemouth Power Station
2.2.2 Cambois Bay

- Cambois Bay experienced colliery waste tipping from Cambois Colliery, which opened in 1862 and exploited under-sea reserves before closing in April 1968.

- Tipping of excavated clay (and other material, including from the nearby brickworks) occurred from the cliff top, effectively defining an artificial cliff face in a more seaward position.

- Cessation of colliery spoil tipping, combined with mining-induced subsidence of the shore and nearshore sea bed, has led to an increase in erosion in recent decades within some parts of the bay.

- A rock armour revetment was constructed around the late 1970s to prevent erosion of the Vald Birn foundry.

- Between 1966 and the present day, the high water mark has eroded by around 110m in the vicinity of Cambois House and by around 90m in the vicinity of Cambois Farm.

- There is little net sediment transport along the frontage, but gross transport during storms from different directions can occur.

- The main movement of sediment within Cambois Bay tends to be in an onshore-offshore direction.

Figure 4 - Spoil Cliffs at Cambois Bay
2.2.3 County Durham Coastline

- The collieries of the east County Durham coastline were opened only in the 1900s, but during the decades that followed, the beaches and sea became significantly affected by waste dumped from Dawdon, Easington, Horden and Blackhall Collieries.

- The volumes tipped on the foreshore in the recorded database (i.e. since 1976) peaked at 2.5m tonnes in one year (1983) but literature cites at least 100m tonnes of colliery waste having been dumped into the sea off County Durham, at both foreshore tipping grounds and in offshore dump sites.

- The tipping resulted in significant infilling of bays between (and in some cases beyond) headlands at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery. Although tipping did not take place directly at Hawthorne Hive or Shippersea Bay, these bays also filled with waste, generally transported southwards from Dawdon Blast Beach by longshore drift. The backing cliffs became relict features protected by a significant width of spoil beach.

- Tipping ceased in 1993 with closure of Easington as the last of the collieries and natural processes of erosion started to migrate the shoreline landwards; a process that continues to the present day (and beyond) and will ultimately result in reactivation of erosion in the backing cliffs in future decades.

- The Turning the Tide project played a significant role in cleaning up the beaches and improving the amenity and natural environment of the area between 1997 and 2002, and this work continues today under the direction of the Durham Heritage Coast.

- Previous research has identified that waves are the dominant process in influencing sediment transport and whilst the overall (bay to bay) longshore drift is intermittent and low (being controlled by the presence of the headlands), the underlying trend is for sediment to migrate (slowly) towards Crimdon.

It was also estimated that between 70% and 90% of the spoil which was dumped on the beaches was lost offshore, rather than alongshore. This was supported by the fact that coal is found in varying concentrations over large areas of the sea bed. The waste transported to the nearshore sea bed is broken down into smaller particles and then advection by tidal currents and storm wave action in a general southerly direction.
2.2.4 Overview

The Historical Trends Analysis reported in detail in Appendix A has investigated the historical legacy of colliery spoil tipping at Lynemouth Bay and Cambois Bay in Northumberland and at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery in County Durham.

Particular focus has been placed on understanding the artificial supply of sediment to the foreshores caused by spoil tipping, the associated historical effects on shoreline behaviour and the effects of subsequent cessation of that sediment supply on present day responses.

The HTA has identified that large quantities of solid wastes, from a number of sources, were dumped for many years either directly onto the shore or some miles off parts of the north-east coast of England. Wastes from some coastal collieries in Northumberland and Durham were tipped directly onto foreshore tipping sites where they have been dispersed by wave action. Wastes from other collieries, fly ash from coal-fired power stations and harbour dredgings were dumped at offshore disposal sites.

In most cases, dumping started well before statutory controls entered into force in the UK in 1974. Since that date, disposal of these wastes became regulated under license. It is estimated that:

- around 30m tonnes of colliery waste (minestone) from Lynemouth and Ellington Collieries was tipped at foreshore disposal sites in Lynemouth Bay between 1934 and 2005, with at its peak over 1.5m tonnes tipped in one year (1968);
- an unknown quantity of excavated clay (and other waste) was tipped over the cliff edge at Cambois Bay until closure of Cambois Colliery in 1968; and
- over 100m tonnes of colliery waste (minestone) was tipped along the County Durham coastline, either at offshore disposal sites or at foreshore disposal sites. The foreshore tipping of waste from Dawdon, Easington, Horden and Blackhall Collieries occurred from the early 20th Century to 1993 when the last colliery (Easington) closed, with, at its peak, over 2.5m tonnes tipped in one year (1983).

In all cases, the tipping of waste resulted in significant progradation (seaward movement) of the shoreline and infilling of the bays to form wide spoil beaches as a ‘terrace’ on the upper beach. In Lynemouth Bay this occurred to such an extent that reclaimed land was developed with construction of the Lynemouth power station and along the County Durham coastline the spoil beaches became so wide that the backing cliffs became divorced from marine action and are currently relict features.

Due to geochemical processes that occurred after extraction of the spoil and its placement on the foreshore, its composition altered from a granular state to a more consolidated clayey condition that is somewhat more resistant to erosion than the constituent sediment grains would otherwise be.
The majority of the colliery waste that was tipped became eroded and transported seawards to the nearshore zone (within the 10m sea bed contour). This 'loss' from the shoreline was more than compensated for many decades by the ongoing tipping. Material moved to the shallow nearshore zone would then become further broken up into smaller particles by marine action and, when sufficiently small in grain size, transported by tidal currents in the direction of the net southerly current residuals. Larger grain sizes would tend to remain on the beach as lag boulder, cobble or gravel deposits.

Some longshore transport of material also occurred, particularly when the spoil beaches had increased in width so much that the high water mark extended beyond the rock headlands that intersect adjacent bays. This was most notable along the County Durham frontage where both Hawthorne Hive and Shippersea Bay (both located to the south of Dawdon Blast Beach) became infilled with colliery spoil, despite not directly being tipping sites. Concerns were also raised about despoliment of the beaches at Crimdon, south of Blackball Colliery. However, the general net southerly drift was relatively small and intermittent, predominantly being storm-driven.

Since cessation of tipping, the shoreline in all former tipping areas has been retreating. This has caused retreat of the high water line to a position landward of the headlands. This means that potential for 'bay to bay' transport of remaining spoil beaches due to longshore drift has further reduced.

The ongoing retreat of the shoreline since cessation of spoil tipping on the foreshores has caused particular problems in Lynemouth Bay, where a rock revetment was constructed in 1995 in front of the power station and then was extended in 2005 around the adjacent coal-stocking yard, and in Cambois Bay where a rock revetment was constructed in the late 1970s in front of the (former) Vald Birn foundry. There are also ongoing concerns in Cambois Bay about continued cliff slumping affecting the property of Cambois House.

In County Durham it has been recorded by beach profile surveys that rapid rates (20m/year) of retreat of the colliery spoil beaches occurred initially (2 – 5 years) after cessation of tipping, but the rate then reduced significantly (to around 0.5 - 2.0m/year) as the erosion encroached into the older, consolidated spoil. Ongoing beach surveys and walk-over visual inspections that form part of the Cell 1 Regional Coastal Monitoring Programme are monitoring the ongoing retreat of the spoil beaches, which is clearly measureable.

It is envisaged that the cliffs that are currently protected by spoil could retreat at rates up to 0.3m/year when the spoil beaches have become eroded and marine processes are re-activated at the toe of the cliffs. Initially, the rate could be higher as accelerated erosion is likely to occur in the exposed rock face which, though isolated from the sea for many years, has weakened through weathering processes. Along Dawdon Bankside, the residual colliery spoil beach is now so narrow that parts of the backing cliffs have started to experience slumping in recent years.
3 SEDIMENT TRANSPORT MODELLING

3.1 Background

The Phase 1 Scoping Report (Royal HaskoningDHV, 2013) revealed that throughout much of the Cell 1 frontage, onshore-offshore sediment transport and subsequent advection of sediments by tidal currents and, potentially, wave action within the nearshore zone are considerably more important to overall understanding of the interactions between sections of the coast than the alongshore transport of beach sediments within the inter-tidal zone.

Due to this, the Scoping Report recommended that these processes are investigated further by the selection of a number of appropriately located cross-shore transects, each extending from the upper beach across the inter-tidal zone and nearshore sea bed to the 20m sea bed contour.

At each transect location, the longshore transport potential across the profile could be determined using the LITDRIFT model and the cross-shore response to wave action could be determined using the LITPROF model.

It was recommended in the Scoping Report that the modelling in Phase 2 be undertaken in a staged manner, with an initial pilot study involving modelling at transects at Newbiggin, Whitby and Scarborough North Bay and Scarborough South Bay to investigate the value of the outputs before embarking on modelling at other transects.

Subsequently, it was decided to remove the Newbiggin Bay transect and replace it with the Cambois Bay transect for the pilot study because the sediment transport processes at Newbiggin are so interrupted by the presence of the offshore breakwater in the centre of Newbiggin Bay and do not represent a natural condition.

The reason for selecting these four locations for the pilot modelling study is because suitable timeseries of nearshore wave data are directly available at, or very close to, these sites from the wave buoys deployed as part of the Cell 1 Regional Coastal Monitoring Programme at Newbiggin, Whitby and Scarborough.

3.2 Pilot Modelling Study

The pilot modelling study is described in full in Appendix B, including a short description of the LITDRIFT and LITPROF numerical models, the beach and bathymetric data and wave data sets used as input to the models, the set-up of the models, and the modelling results.

The longshore sediment transport modelling using LITDRIFT showed that, generally, longshore sediment transport potential at the four transects is relatively low in magnitude. In terms of relative ‘ranking’ of the locations, longshore transport potential is least (negligible) at Cambois Bay, increases (but remains very low) at Whitby West Beach, increases further (but remains relatively low) at Scarborough North Bay and is greatest (but remaining only modest in magnitude) at Scarborough South Bay. This is fully commensurate with the findings of the Scoping Report prepared during the first phase of the present study.
The LITDRIFT modelling has further identified that the longshore sediment transport rates are highly dependent upon the angle of shoreline orientation relative to the defined wave climate. This means that rather than replicating a large number of locations within only a single transect each (as originally recommended by the Scoping Report), it would be better to consider extending the modelling to a smaller number of locations, but exploring sensitivity to shoreline orientation more fully at each location considered, within the context of the natural alignments present.

The pilot modelling study also identified that the LITDRIFT modelling approach works best in areas where the coastal orientation is relatively uniform (e.g. Whitby West Beach) rather than in more deeply indented bays (e.g. Scarborough North Bay and South Bay). Whilst possessing subtle changes in shoreline orientation, large shallow bays (e.g. Cambois Bay) appear reasonably well suited to the approaches (including sensitivity tests relating to angle of orientation). Where bays are strongly influenced by major headlands (Scarborough North Bay and South Bay) there are limitations of the LITDRIFT approach, since its one-dimensional nature does not allow wave diffraction effects around the headland or interaction with complex residual current systems (induced by headland features) to be incorporated. Consequently, the pilot modelling study recommended that any transects that could be affected by headland-related effects (wave diffraction, tidal gyres) be omitted from future stages. Such effects can also be induced by the presence of breakwaters and harbour piers.

Whilst the influence of tidal currents was identified (through a sensitivity test at Cambois Bay) to enhance gross and net drift (in the direction of the residual current), the changes were so small as to be negligible compared to the modelling of drift with waves alone and therefore further sensitivity tests with currents were not deemed entirely necessary.

It was recommended by the pilot modelling study that LITDRIFT modelling should take the above considerations into account and omit any locations originally proposed in the Scoping Report where strong headland effects or structural effects influence local sediment transport pathways. This means that the main modelling study should focus on the following transects (locations shown in Figure 7):

Undertaken within pilot modelling study (and repeated within the main modelling study):

- Cambois Bay
- Whitby West Beach

Suitable for main modelling study:

- Bamburgh
- Druridge Bay
- Lynemouth Bay
- Blyth South Beach
- Whitley Bay
- Tynemouth Longsands
- Scarborough North Bay *
- Scarborough South Bay *
- Salterfen Rocks
- Blast Beach
- Hartlepool North Sands
- Saltburn-by-the-Sea
- Skinningrove
- Sandsend

* Note that longshore drift rates will be affected at these sites by headland-related effects (such as wave diffraction, tidal gyres) which are not incorporated in the one-dimensional LITDRIFT model.
Figure 7 - Location of Transects used in Numerical Modelling
The cross-shore sediment transport modelling using LITPROF in the pilot study showed that, generally, a rapid succession of several reasonably sized storm events causes the ‘classic’ winter beach profile response of upper beach erosion and lower beach and nearshore deposition, resulting in a temporary ‘flattening’ of the profile. This is deemed perhaps more important than a single short duration storm event of greater magnitude (until significant ‘extreme’ events are reached when more direct damage would be expected).

There clearly is connectivity in the cross-shore transport processes between the inter-tidal zone and the shallow nearshore zone, as inferred within the Scoping Report (and based on ongoing beach profile monitoring as part of the Cell 1 Regional Coastal Monitoring Programme) but never previously demonstrably proven.

In going forward with further modelling, the pilot modelling study recommended that LITPROF is used at a selected number of locations where monitoring has identified that cross-shore storm and seasonal behaviour is apparent, i.e. the same transects that will be used for the LITDRIFT modelling. The approach of ‘forcing’ the beach response with the 1-month timeseries of ‘stormy’ wave data will be used in preference to a single 12 hour storm event.

3.3 Main Modelling Study

The purpose of the main modelling study is to test relative behaviours (rates and directions of sediment movement) between transect locations within the Cell 1 frontage and explore sensitivities in the mechanisms that drive sediment transport in the inter-tidal and nearshore zones within the context of a Cell-wide study. It is not intended to precisely quantify sediment transport rates in detail at each of the transect locations considered (as may be undertaken for a site-specific study, for example).

With this in mind, the only difference between the pilot modelling study and the main modelling study is in the wave data used as input to the LITDRIFT and LITPROF models. For the pilot modelling study, timeseries of wave data recorded as part of the Cell 1 Regional Monitoring Programme from buoys deployed at Newbiggin, Whitby and Scarborough were used as input. These buoys are located in suitable water depths at the seaward limit of the extent of the beach and bathymetric survey used to define each transect.

When extending from the pilot modelling study across the wider Cell 1 frontage, there are no similar measured timeseries wave data available at other transect locations. Instead, hindcast timeseries wave data were obtained from CEFAS for the period 1980 to 2012 at six locations (in a suitable water depth) across the Cell 1 frontage (Figure 8). These hindcast data were produced by The Met Office using the WAVEWATCH III wave model (Li, 2011).
Three of the six locations (points 2, 5 and 6) were chosen close the wave buoy locations (Newbiggin, Whitby and Scarborough) so that cross-comparison of the datasets could be undertaken.

The hindcast wave data from each of the six Met Office model points have been used to create a wave rose at each location. Each hindcast dataset has been considered as being representative across a wider zone of coast, as shown in Figure 9 and Table 1. The table also shows which hindcast modelled datasets have been applied to each transect in the main modelling study.
Figure 9 – Hindcast wave roses across the Cell 1 frontage

Table 1 – Zonal application of hindcast wave datasets to transects in main modelling study

<table>
<thead>
<tr>
<th>Hindcast Model Point</th>
<th>Zone</th>
<th>Transect Location</th>
<th>Transect Orientation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Bamburgh</td>
<td>30° (38° &amp; 73° sensitivity)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Druridge Bay</td>
<td>110°(N), 80°(C), 68°(S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lynemouth Bay</td>
<td>65°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cambois Bay</td>
<td>73°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blyth South Beach</td>
<td>72°(C), 55°(S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whitley Bay</td>
<td>70°(C), 58°(S)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tynemouth Longsands</td>
<td>65°</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Salterfen Rocks</td>
<td>75°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blast Beach</td>
<td>65°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hartlepool North</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Saltburn</td>
<td>25°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skinningrove</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Sandsend</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whitby</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Scarborough North Bay</td>
<td>57°</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Scarborough South Bay</td>
<td>83°</td>
</tr>
</tbody>
</table>

Where: (N) = north of bay, (C) = centre of bay, (S) = south of bay
Figures 10, 11 and 12 show a wave rose produced using the measured wave buoy data for each of Newbiggin, Whitby and Scarborough and the modelled hindcast data from the nearest adjacent point. These figures show good general overall similarity between the datasets but some slight differences are observed when examined in detail. These differences are to be expected since: (i) the locations, whilst similar, are not co-existent; and (ii) the measured data cover a relatively short time period (~1 year) whilst the hindcast data show a much longer period (32 years) and therefore may be more representative of the longer term ‘average’ wave climate.

The implications of the subtle differences in the annual wave climate between the datasets were examined by re-running some of the pilot model study transects with the appropriate hindcast wave datasets to determine the extent of influence on sediment transport results previously calculated at those locations.

At Cambois, the wave climate input data shows a slight shift from a predominant north-east wave direction in the measured data (at Newbiggin wave buoy) to a predominant nor-north-east wave direction in the hindcast data (at point 2). There is also a slight reduction in waves from the south-east within the hindcast data when compared against the measured data. These factors combined would be expected to lead to a slight increase in the gross southerly drift, a slight decrease in the gross northerly drift and, as a consequence, a net southerly drift overall when the hindcast data are used as model input instead of the measured data that were used in the pilot study. Figures 13 and 14 confirm this finding for sediment transport at MHWS and MLWS respectively.

At Whitby, the wave climate input data shows more waves from due north in the hindcast data (at point 5) than in the measured data (at Whitby wave buoy). There is also a slight reduction in waves from the east within the hindcast data when compared against the measured data, but a component of wave activity becomes incorporated from the south-east within the hindcast data. Figures 15 and 16 show that these factors combined lead to a narrower zone within which sediment transport occurs at MHWS and at MLWS respectively. At MHWS there is a slightly lower gross drift to the east and a slightly higher gross drift to the west and whilst the overall net drift remains to the east, it is lower in magnitude than was observed from the model runs in the pilot model study using the measured wave data.

At Scarborough, the wave climate input data shows more waves from due north in the hindcast data (at point 6) than in the measured data (at Scarborough wave buoy). There is also a slight reduction in waves from both the east and the south-east within the hindcast data when compared against the measured data, and a general reduction in overall ‘storminess’ of the wave climate, with calm conditions occurring for 27.4% of the time instead of 23.5% of the time in the measured data. Figures 17 to 20 show that these factors combined lead to sediment transport of a lower magnitude at MHWS and MLWS at both Scarborough North Bay and Scarborough South Bay.

The model runs performed to investigate the effect of using the hindcast wave data on sediment transport reveal that the general patterns of behaviour observed during the pilot study using the measured wave data are reproduced, but the magnitudes of change are slightly different. For purposes of ensuring consistency of comparison throughout Cell 1 and, most likely, providing a better representation of a longer term ‘average’ annual wave climate, the hindcast data were therefore used throughout the main modelling study.
Figure 10 – Comparison of measured wave data at Newbiggin and hindcast wave data south of Newbiggin
Figure 11 – Comparison of measured wave data at Whitby and hindcast wave data near Whitby
Figure 12 – Comparison of measured wave data at Scarborough and hindcast wave data south of Scarborough
Figure 13: Cambois Bay (MHWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data.

Net Drift: m³/year
Figure 14  Cambois Bay (MLWS)  
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data  
Net Drift: $m^3/year$
Figure 15 Whitby (MHWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: $m^3$/year

Whitby West Beach (MHWS)

Whitby West Beach (MHWS, Hindcast)

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Figure 16
Whitby (MLWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: $m^3/\text{year}$

![Diagram showing Whitby West Beach (MLWS) longshore sediment transport with measured and hindcast data.](image)
Figure 17  Scarborough North Bay (MHWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: $m^3/\text{year}$
Figure 18  Scarborough North Bay (MLWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: m³/year

Scarborough North Bay (MLWS) Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift:

Scarborough Bay North (MLWS, Hindcast)
Figure 19  Scarborough South Bay (MHWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: m³/year
Figure 20: Scarborough South Bay (MLWS)
Longshore sediment transport under measured (top plot) and hindcast (bottom plot) annual wave climate data

Net Drift: $m^3/year$
### 3.4 Main Findings

#### 3.4.1 LITDRIFT Modelling Results

Appendix C presents a series of plots from the LITDRIFT modelling, showing the gross and net longshore sediment transport potential at each transect under MHWS and MLWS water levels.

On each plot:

- the yellow area shows the original shore profile and nearshore bathymetry
- the brown line shows the gross positive (southerly) sediment transport potential across the shore profile and nearshore bathymetry
- the red line shows the gross negative (northerly) sediment transport potential across the shore profile and nearshore bathymetry
- the green line shows the net sediment transport potential across the shore profile and nearshore bathymetry

**Note:** The topographic/bathymetric levels (in metres OD) are shown on the primary y-axis, the sediment drift (m$^3$ per metre run) is shown on the secondary y-axis and the transect chainage (in metres) is shown on the x-axis.

The gross and net longshore sediment transport potential at each transect under MHWS and MLWS water levels are shown in Table 2. In all cases, the gross and net drift is relatively low in magnitude and in all but one case (Bamburgh) the net drift is directed towards the south.

**Table 2 - Gross and net longshore sediment transport potential at various locations within Cell 1**

<table>
<thead>
<tr>
<th>Profile</th>
<th>Gross Drift S Drift (+ve)</th>
<th>Gross Drift N Drift (-ve)</th>
<th>Net Drift</th>
<th>Gross Drift S Drift (+ve)</th>
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Figure 21 shows that the gross southerly drift is primarily governed by transport within the inter-tidal zone (e.g. at times of high water) but that there are also important sediment transport processes in the shallow nearshore zone (e.g. at times of low water). It is noticeable that at Tynemouth, Salterfen Rocks, Blast Beach, Sandsend and Scarborough North Bay, the nearshore transport is greater than the inter-tidal transport, indicating the importance of nearshore bars or nearshore currents in these locations in transporting sediment parallel to the shore.

**Figure 21 – Gross Positive Drift at Transects within Cell 1**
Figure 22 shows that the gross northerly drift is in all but one case less than the gross southerly drift, again with transport possible in the inter-tidal and nearshore zones.

**Figure 22 – Gross Negative Drift at Transects within Cell 1**

The net effect is a general southerly net drift (Figure 23), with one exception which is discussed later. It is noticeable that the transects exhibiting the least net drift are the ones aligned normal to the predominant incoming wave direction, namely Saltburn, Sandsend, Whitby, Bamburgh, Hartlepool. Where sensitivity of shore alignment within bays was investigated, net drift rates were least at the south of bays. The greatest drift rates were noted along Skinningrove and Scarborough South Bay.

**Figure 23 – Net Drift at Transects within Cell 1**

A single exception to the net southerly drift exists at Bamburgh where (low magnitude) net drift is directed to the north along the transect that was used in the modelling. This is largely a function of the orientation of the shore with respect to the predominant wave approach direction. Shore profiles with an orientation of 20°N to 30°N along the Bamburgh frontage (Figure 24) are aligned largely normal to the predominant direction of incoming waves, which results in little net longshore drift from these sectors. However, the hindcast wave data for point 1 does have a component of wave activity from the south-east and this will tend to drive sediment to the north-west, i.e. parallel to the shore alignment.
It is noticeable, through a sensitivity test, that net drift potential reduces, but remains northerly, as the aspect changes from 30°N (the modelled transect, with results reproduced in Figure 25) to 38°N (results shown in Figure 26), which is more characteristic of the shoreline further east, around the rock outcrop of Islestone. As the aspect of the shore becomes more easterly facing (typically 73°N) with progression to the south of Islestone, so the net drift becomes southerly (results shown in Figure 27).

Figure 24 – Changes in shore alignment at Bamburgh

Figure 25 – Longshore sediment transport potential at Bamburgh (30°N profile orientation)
Figure 26 – Longshore sediment transport potential at Bamburgh (38°N profile orientation)

Figure 27 – Longshore sediment transport potential at Bamburgh (73°N profile orientation)
3.4.2 LITPROF Modelling Results

Appendix D presents a series of plots from the LITPROF modelling, showing the beach and bathymetric changes following application of a 1 month storm wave climate derived from the hindcast wave data at the appropriate point for each transect location.

On each plot:

- the yellow area shows the original shore profile and nearshore bathymetry
- the green dashed line shows the shore profile and nearshore bathymetry at the end of the 1 month simulation period

**Note:** The topographic/bathymetric levels (in metres OD) are shown on the y-axis and the transect chaining (in metres) is shown on the x-axis.

As the changes in morphology due to the 1 month wave climate are generally small in magnitude in relation to the scale of the entire plotted transect, insets diagrams have been added to many of the figures to zoom in on areas of most notable change.

Results from all transects show a ‘text book’ response of the shore profile to winter storm events, with erosion of beach sediments at the toe of the coastal defences, sand dunes, coastal slope or sea cliffs and associated deposition of these sediments further down the foreshore or in the shallow nearshore zone, resulting in a general flattening of the shore profile.

At both Bamburgh and Druridge Bay, only a small amount of sand was eroded from the dune toe, and deposited on the lower foreshore. This is in keeping with the general stability shown in the beach profiles at these locations from the Cell 1 Regional Coastal Monitoring Programme.

Changes were greater at Lynemouth Bay, where erosion occurred at two locations across the transect; one at the toe of the coastal slope comprised of colliery spoil and one at the seaward scarp of the colliery spoil beach across the foreshore. In both cases, the landward retreat was measurable (tens of metres). This is in keeping with the persistently high rates of retreat of the colliery spoil shown in the beach profiles at this location from the Cell 1 Regional Coastal Monitoring Programme.

At both Cambois Bay and Blyth South Beach, erosion at the dune toe was observed, with material being deposited on the foreshore around the mark of mean low water and within the shallow nearshore zone.

This process was repeated at both Whitley Bay and Tynemouth Longsands. However, the erosion tended to affect the upper beach above MSL. Deposition tended to occur on the lower beach and, to a lesser extent, in the shallow nearshore zone. This process formed a small bar at Whitley Bay and a more pronounced bar in the shallow nearshore zone at Tynemouth Longsands.

Changes at Salterfen Rocks were minor and confined to the upper foreshore because elsewhere the cross-shore profile is dominated by hard rock and boulders.
The shore profile at Blast Beach, like the one at Lynemouth, exhibited notable (>20m) cut back in the position of the scarp of the colliery spoil beach in front of the backing cliffs. The rest of the profile exhibited little change.

At Hartlepool North there was a small amount of erosion at the toe of the dunes, but a more notable flattening of a berm present at around MSL, with deposition of the material lower down the shore profile.

At Saltburn, there was erosion (small in magnitude) across the whole upper beach, with associated deposition across the lower beach. A small berm present in the original profile just below MLWS became flattened by the 1 month wave climate, with material being spread across the sea bed within the shallow nearshore zone to a depth of around 5m below OD.

At Skinningrove, the response was generally for erosion across the foreshore, with the creation of a series of ridges and runnels in the shallow nearshore zone. Existing ridge and runnel features remained largely intact across the nearshore zone, including down to around 24m below OD.

At Sandsend and Whitby there was a classic winter beach response to the 1 month wave climate, with material removed from the upper beach and deposited on the lower inter-tidal foreshore and within the shallow nearshore zone.

This process was repeated at both Scarborough North Bay and Scarborough South Bay, with notable ridge and runnel features present in the shallow nearshore zone along both transects.

### 3.4.3 Overview

The numerical modelling approach has investigated the relative alongshore and cross-shore sediment transport potential at a series of sixteen transects throughout the Cell 1 frontage.

Modelling results presented in Appendix C show that longshore sediment transport is only modest in magnitude throughout Cell 1 and is strongly influenced by changes in orientation of the shore profile within bays and the angle of the shore relative to the approach directions that characterise the nearshore wave climate.

In this regard, there are complex physical process effects in the lee of major headlands (e.g. Hartlepool Headland, Scarborough Castle Headland) and significant shore-perpendicular structures (e.g. North and South Gare Breakwaters, Whitby Harbour Piers) which have localised effects on sediment transport directions and rates.

Results suggest that along most transects, there is strongest sediment transport potential (although only low to moderate in magnitude) along the upper inter-tidal zone, but some potential also exists in the nearshore zone. This is particularly notable at Tynemouth Longsands, Sandsend and, to a lesser extent, at Whitby. Generally, it is wave-generated forces that dominate longshore transport, with tidal currents making little effect in the mobilisation of sediments.

Modelling results presented in Appendix D show that cross-shore sediment transport potential exists at all modelled transects under a 1 month timeseries of ‘winter’ wave data. Material is typically eroded from the upper beach and deposited on the lower beach or within the nearshore zone. A rapid succession of several reasonably sized storm events causes this ‘classic’ winter
beach profile response of upper beach erosion and lower beach and nearshore deposition, resulting in a temporary ‘flattening’ of the profile. Generally, sediment volumes involved in such short-term cross-shore transport can be greater – in many cases orders of magnitude greater – than the net alongshore sediment transport potential.

Since most transects show some longshore transport potential in the nearshore zone, it is likely that during storms sediment is removed from the beaches as a cross-shore process and then transported alongshore (predominantly to the south) in the shallow nearshore zone. After the stormier wave climate has passed, the sediment then progressively returns to the beaches as a cross-shore process (either within the same bay or further south along the coast after bypassing a headland) during calmer wave conditions.
4 SYNTHESIS AND CONCLUSIONS

4.1 Datasets and Literature Sources

In preparing the Scoping Report for the Cell 1 Sediment Transport Study, a large number of published and grey literature sources, maps, charts, photographs, datasets and numerical modelling outputs were collated and reviewed to provide a synthesis of present understanding of the key sediment transport understanding issues and uncertainties within Cell 1 (Royal HaskoningDHV, 2013). Since that time, a number of additional datasets and other literature sources have been newly acquired which are of relevance to sediment transport within Cell 1. These include survey data from the Cell 1 Regional Monitoring Programme and the East Riding of Yorkshire Coastal Monitoring Programme, and reporting from the Cell 1 Inter-tidal Habitat Study.

4.1.1 East Riding of Yorkshire Bathymetry Survey

A bathymetric survey was undertaken around Flamborough Head by NetSurvey Ltd. in 2011 as part of the East Riding of Yorkshire Coastal Monitoring Programme (Figure 28). The survey actually extended along the whole East Riding of Yorkshire frontage, between Speeton and Spurn Point, but just the data from around Flamborough Head are considered here. Multi-beam echo sounder technology was used between the offshore extent of the survey and the 2m seabed contour, with single-beam echo sounder completing the survey to at least MLWS.

![Figure 28 – Bathymetric survey (2011) around Flamborough Head](image-url)
NetSurvey Ltd. (2011) report that on the northern side of Flamborough Head, between Speeton and Bempton Cliffs, the area surveyed extended to sea bed depths in excess of 20m. Examination of the bathymetry and derived contours shows that close to shore the bathymetry is characterised by rock ledges and boulders, which are evident down to 10m. The sea bed from 10m down is mostly a gently deepening sea bed with few features.

Between North Cliff on the north side of Flamborough Head and Cattlemere Hole on the south, the survey extends around the eastern extents of the headland with depths observed from the drying line to in excess of 25m. In the vicinity of Cattlemore Hole, the northeastern extents of North Smithic Shoal (sand bank) exhibit sandwave features up to 1.5m high. The area to the south and inside of the headland appears to be more sandy in origin with sandwaves and ripple features evident in the topography.

Further offshore, between North Smithic Shoal and sea bed areas eastwards off Flamborough Head, the survey extends into deeper water, reaching in excess of 40m. Sandwaves are present on the southeastern side of North Smithic Shoal which may indicate some mobility of the sea bed sediments.

On the south side of Flamborough Head, between Cattlemere Hole and Sewerby Rocks, the survey extends to depths in excess of 13m and then onto North Smithic Shoal. The sea bed in the west of North Smithic Shoal is gently sloping down to 6 - 7m, whilst to the east it is characterised by the channel that runs between the headland and North Smithic shoal. There are sandwave features up to 2.5m in height along the flank of North Smithic Shoal.
4.1.2 East Riding of Yorkshire Sediment Transport

Sutherland et al. (2002) compiled estimates of longshore sediment transport directions and rates along the East Riding of Yorkshire coastline, between Flamborough Head and Spurn Point. Whilst this frontage is outside of Cell 1, it is interesting to note that the direction of net longshore sediment transport along most of the East Riding of Yorkshire coastline is towards the south, due to the dominance of waves approaching from the northeast; this general pattern is reversed in the very north, because Flamborough Head provides protection from northeasterly waves.

Furthermore, previous studies by the Institute of Estuarine and Coastal Studies (IECS) at the University of Hull suggest that some sediment on the sea bed offshore from south of Flamborough Head is carried north around the headland by the tidal currents (IECS, 1991), as shown in Figure 29.

Figure 29 – Northward movement of sand around Flamborough Head (source: IECS, 1991)
4.2 Historical Trends Analysis

The historical legacy of colliery spoil tipping at Lynemouth Bay and Cambois Bay in Northumberland and at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery in County Durham has been investigated as part of the present study. Large quantities of colliery spoil were tipped directly onto foreshore tipping sites (as well as offshore dump sites) where they have been dispersed by wave action. In most cases, dumping started well before statutory controls entered into force in the UK in 1974. Since that date, disposal of these wastes became regulated under license. It is estimated that around 30m tonnes of colliery waste was tipped at foreshore disposal sites in Lynemouth Bay between 1934 and 2005, with at its peak over 1.5m tonnes tipped in one year (1968) and over 100m tonnes of colliery waste was tipped along the County Durham coastline, either at offshore disposal sites or at foreshore disposal sites.

In all cases, the tipping of waste resulted in significant progradation (seaward movement) of the shoreline and infilling of the bays to form wide spoil beaches as a ‘terrace’ on the upper beach. The majority of the colliery waste that was tipped became eroded and transported seawards to the nearshore zone (within the 10m sea bed contour). This ‘loss’ from the shoreline was more than compensated for many decades by the ongoing tipping. Material moved to the shallow nearshore zone would then become further broken up into smaller particles by marine action and, when sufficiently small in grain size, transported by tidal currents in the direction of the net southerly current residuals. Larger grain sizes would tend to remain on the beach as lag boulder, cobble or gravel deposits.

Some longshore transport of material also occurred, particularly when the spoil beaches had increased in width so much that the high water mark extended beyond the rock headlands that intersect adjacent bays. This was most notable along the County Durham frontage where both Hawthorne Hive and Shippersea Bay (both located to the south of Dawdon Blast Beach) became infilled with colliery spoil, despite not directly being tipping sites, and concerns were also raised about despoilment of the beaches at Crimdon, south of Blackball Colliery. However, the general net southerly drift was relatively small and intermittent, predominantly being storm-driven.

Since cessation of tipping, the shoreline in all former tipping areas has been retreating. This has caused retreat of the high water line to a position landward of the headlands, meaning that potential for ‘bay to bay’ transport of remaining spoil beaches due to longshore drift has further reduced. The ongoing retreat of the shoreline since cessation of spoil tipping on the foreshores has caused particular problems in Lynemouth Bay, where a rock revetment was constructed in 1995 in front of the power station and then was extended in 2005 around the adjacent coal-stocking yard.
4.3 Sediment Transport Modelling

The numerical modelling approach of the present study has investigated the relative alongshore and cross-shore sediment transport potential at a series of sixteen transects throughout the Cell 1 frontage.

Longshore sediment transport is only modest in magnitude and is strongly influenced by changes in orientation of the shore profile within bays and the angle of the shore relative to the approach directions that characterise the nearshore wave climate. There are complex physical process effects in the lee of major headlands (e.g. Hartlepool Headland, Scarborough Castle Headland) and significant shore-perpendicular structures (e.g. North and South Gare Breakwaters, Whitby Harbour Piers) which have localised effects on sediment transport directions and rates. Results suggest that along most transects, there is strongest sediment transport potential (although only low to moderate in magnitude) along the upper inter-tidal zone, but some potential also exists in the nearshore zone. Generally, it is wave-generated forces that dominate longshore transport, with tidal currents making little effect in the mobilisation of sediments.

Cross-shore sediment transport potential exists at all modelled transects under a 1 month timeseries of ‘winter’ wave data. Material is typically eroded from the upper beach and deposited on the lower beach or within the nearshore zone. A rapid succession of several reasonably sized storm events causes this ‘classic’ winter beach profile response of upper beach erosion and lower beach and nearshore deposition, resulting in a temporary ‘flattening’ of the profile. Generally, sediment volumes involved in such short-term cross-shore transport can be greater – in many cases orders of magnitude greater – than the net alongshore sediment transport potential. Since most transects show some longshore transport potential in the nearshore zone, it is likely that during storms sediment is removed from the beaches as a cross-shore process and then transported alongshore (predominantly to the south) in the shallow nearshore zone. After the stormier wave climate has passed, the sediment then progressively returns to the beaches as a cross-shore process (either within the same bay or further south along the coast after bypassing a headland) during calmer wave conditions.
4.4 Conclusions and Recommendations

The principal findings of Phases 1 and 2 of the Cell 1 Sediment Transport Study are:

- The Cell 1 shoreline and nearshore sea bed is predominantly controlled by its underlying solid geological structure, with the more recent glacial or post-glacial deposits of boulder clay or sand also being of significance in terms of the sea cliffs, coastal slopes and sand dunes that are present.

- Through differential erosion of the different rock types, or exploitation of faults and other structural weaknesses, a number of headland and bay features of varying spatial extents from small indentations (often known locally as ‘holes’) to expansive sandy bays have been formed.

- Littoral sediment transport is, generally, relatively well confined to movement within individual bays (or a short series of bays separated by less well defined headlands). Whilst littoral sediment transport is predominantly to the south, the rates of drift are relatively low and temporary drift reversal can occur along frontages under short-duration storm events from different directions.

- The presence of numerous natural headlands, estuaries and their associated control structures, such as harbour piers, can cause locally complex physical processes due to wave sheltering, tidal gyres and localised sediment accumulations or drift reversals.

- There are sections of high energy rock platforms backed by hard sections of cliff, where there is high drift potential, but little evidence of sediment moving through that section of the shoreline. This may be due to limited supply and limited actual drift or, in some cases, where sediment is not evidenced due to the rapid transport of sediment through the area.

- Of greater importance than alongshore sediment transport, many beaches experience significant onshore-offshore transport during storm events, particularly during autumn, winter and early spring months. In areas backed by dunes, there tends to be toe erosion of the dunes and reduction in upper beach levels, with material being drawn down the beach to the lower foreshore and nearshore zone. Liberated sediment can then become entrained by tidal currents and advected along the coast, generally in a southerly direction. Where beaches are backed by coastal defences such as sea walls, upper foreshore lowering can be notable during these events. In general, beach sediment slowly and progressively returns to the upper foreshore as conditions become calmer, leading to beach and dune recovery. However, there remains uncertainty about these processes.

- North of the River Tyne estuary, the principal issue is the genesis and evolution of the dune systems in relation to sea level history and projections. Most of the dunes, especially in Northumberland, are associated with regressive (prograding) shorelines consequent upon a fall in relative sea level from its Holocene peak. Relative sea level acted as a macro-scale control through its influence on sediment supply and accommodation space for dune development. Most dune-building occurred during the Little Ice Age. The coastal systems of Northumberland are characterised by a range of responses to the historically low rates of relative sea-level change (generally less than 1mm/yr) coupled with local variations in sediment supply. Particularly with the anticipated increased rate of sea level rise, it is possible that a change in state could occur.
• Between the River Tyne estuary and Hartlepool, the principal controls are exerted by the geology of the cliffs and legacy industrial practices, including the large-scale disposal of colliery spoil along the beaches of County Durham. Historically millions of tonnes of spoil was tipped on the beaches, resulting in the creation of artificial spoil beaches which have prograded the shoreline and stranded the backing sea cliffs. With cessation of tipping, the spoil beaches have been substantially cleared-up as part of the ‘Turning the Tide’ project and remaining spoil is now undergoing active erosion processes. In other areas, such as south of Sunderland, thick mantling of boulder clay over the cliffs has contributed sediment supply, especially pebbles, locally to the foreshore.

• In Tees Bay, the low tidal currents and set-back alignment of the shore combine to encourage the accumulation of marine-derived sediments, most notably sands, resulting in notable infilling of the River Tees estuary which necessitates an active dredging regime to maintain advertised navigation depths. The beaches between the mouth of the River Tees estuary and Saltburn exhibit measurable changes depending on prevailing conditions, but overall have accreted with significant quantities of sand in recent years, despite a recent loss of sediment from Redcar Sands in front of the recently-completed sea defences.

• Between Saltburn and Flamborough Head, the coastline is again dominated by geology, with pronounced headland and bay shorelines prevalent. Boulder clay deposits which overlay the solid geology often are subject to landslip events which can locally, but only episodically, contribute notable sediment yields to the littoral system. Several major headlands, including Castle Headland, Filey Brigg and Flamborough Head, exert significant control on shoreline form and sediment transport processes over notable lengths of frontage.

Given these findings, it is considered that the present scope and frequency of inspection, measurements and surveying that is undertaken as part of the Cell 1 Regional Coastal Monitoring Programme is, in the main, suitable for the describing the characteristic changes in morphological behaviour of the frontages within Cell 1, and furthermore is proportionate to the nature of the risks from erosion or sea flooding that are present.

However, whilst the programme routinely captures information on the condition of built defences and natural features (from visual inspections) and also records the morphological changes and principal forcing conditions of waves and tides, the measurements of sediment composition are restricted to 2-yearly characterisation surveys using swath bathymetry and (limited) grab sampling of the sea bed. These sea bed surveys are currently undertaken only along a series of shore-perpendicular transect lines and do not capture wider sea bed areas. Furthermore, the surveys are only undertaken across the sea bed between the River Tyne and Flamborough Head and not the North Tyneside or Northumberland frontages.

The above issues relating to the sea bed surveys have been reviewed on occasion during the lifespan to date of the programme and it is recommended that further consideration should be given to this topic when the programme extension beyond 2016 is being developed.

The findings from the Cell 1 Sediment Transport Study suggest that whilst it would of course be desirable to have further measurements of the sedimentological character of the sea bed and shore and measurements of the sea bed changes across the whole of Cell 1, the limited number of bed forms that exist and the somewhat limited bedload transport potential that occurs means that this is not necessarily deemed essential.
Following production of this main study report, a subsequent phase of activity will be undertaken in autumn/winter 2014, involving a field experiment using sand tracers in Scarborough South Bay. The purpose of this sand tracer experiment is twofold: (1) to confirm sand transport pathways in Scarborough South Bay; and (2) to test in a field environment the efficacy of the existing sand tracer technique, which may have wider applicability for subsequent use across other frontages within Cell and more widely across other sand-dominated coastal frontages elsewhere. The methods and results of the sand tracer experiment will be presented in a separate report in due course.

At the time of writing this report, the findings of the Cell 1 Inter-tidal Habitat Study were not available for review. However, during development of the Cell 1 Sediment Transport Study, there was correspondence with the authors of that study to share ideas about governing physical processes, sediment sources and morphological changes across Cell 1 and there was good consensus regarding these matters. When the Cell 1 Inter-tidal Habitat Study becomes available, it is recommended that its content is reviewed in detail for any further insights beyond those contained within this report.
REFERENCES


Technical Note

To: Robin Siddle (Scarborough Borough Council)
From: Nick Cooper (Royal HaskoningDHV)
Date: 05 February 2014
Our reference: PB1217/N02/303294/Newc

Subject: Cell 1 Sediment Transport Study Phase 2 – Historical Trends Analysis

Summary
This Technical Note investigates the historical legacy of colliery spoil tipping at Lynemouth Bay and Cambois Bay in Northumberland and at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery in County Durham. In order to inform the main stage of the Cell 1 Sediment Transport Study, particular focus has been placed on understanding the artificial supply of sediment to the foreshores caused by spoil tipping, the associated historical effects on shoreline behaviour and the effects of subsequent cessation of that sediment supply on present day responses.

Acknowledgements
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- Sarah Moxon from HR Wallingford for provision of a report from 1970 on colliery waste on the Durham coast by the Hydraulics Research Station.

Abbreviations
a.k.a. Also known as
Cefas Centre for Environment, Fisheries and Aquaculture Sciences
DAS Disposal at Sea
DRCM Direct Reading Current Meter
FEPA Food and Environmental Protection Act
MAFF Ministry of Agriculture, Fisheries and Food
MRCM Moored Reading Current Meter
OS Ordnance Survey

Units

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>cm</td>
<td>centimetres</td>
<td>m^3</td>
</tr>
<tr>
<td>g</td>
<td>grams</td>
<td>ml</td>
</tr>
<tr>
<td>km</td>
<td>kilometres</td>
<td>mm</td>
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<tr>
<td>m</td>
<td>metres</td>
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<tr>
<td>m^2</td>
<td>square metres</td>
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<td>m^2</td>
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1. Background

The Phase 1 Scoping Report of the Cell 1 Sediment Transport Study (Royal HaskoningDHV, 2013) collated historic shoreline maps and sea bed charts covering the entirety of Cell 1 and compared these with contemporary Ordnance Survey maps and Admiralty charts.

At the Cell-wide, macro-scale of assessment, little significant change in the position or geomorphology of the shoreline or nearshore sea bed was identified over the timeframe of available datasets across much of the frontage. This is largely due to the controls exerted by the underlying geology in terms of its general resistance to erosion.

There were, however, some local changes noted, most evident in association with the:

- historic legacy of colliery spoil tipping in Northumberland and County Durham;
- construction of coastal defences, for example at Newbiggin Bay, Littlehaven, Trow Quarry, Redcar, Skinningrove, Staithes, Whitby West Cliff, Whitby Haggerlythe; and
- alignment of the channels of some estuaries and smaller becks.

The Scoping Report recommended that the Main Report should incorporate an Historical Trends Analysis (HTA) focusing on the coastlines where greatest change has occurred over recent historic time, i.e. those frontages that historically have been subject to practices of colliery spoil tipping, namely Lynemouth Bay, Cambois Bay and the County Durham coastline.

HTA is a method for interrogating series of data to identify trends and rates of change over time (Pye and van der Wal, 2000). Often it is associated with analysis of historic maps, charts, aerial photographs, beach profiles or bathymetric surveys.

HTA at the locations of historic colliery spoil tipping would help identify the past and ongoing changes associated with the erosion and transport of colliery spoil as a basis for future projections of likely re-activation of (presently dormant) backing sea cliff or coastal slope recession processes.

HTA was therefore recommended to take the form of targeted historic map analysis and beach profile analysis at all three sites, namely Lynemouth Bay, Cambois Bay and the County Durham coastline.

This Technical Note presents the findings from the Historic Trends Analysis.
2. Previous Research

Eagle et al. (1979) undertook a comprehensive field assessment of the effects of dumping solid wastes off the north-east coast of England. This identified the following key findings:

- Large quantities of solid wastes, from a number of sources, were dumped for many years either directly onto the shore or some miles off the north-east coast of England.
- Wastes from some coastal collieries in Northumberland and Durham were tipped directly onto the foreshore where they have been dispersed by wave action.
- Wastes from other collieries, fly ash from coal-fired power stations at Newcastle (two) and Blyth and harbour dredgings from the River Blyth, Tyne and Wear estuaries were dumped offshore from dumping vessels.

The location of the sources of the solid wastes (collieries, power stations and rivers) and the dump sites of the solid wastes (foreshore tipping sites and offshore dump sites) are shown in Figure 1 (reproduced from Eagle et al., 1979).

Dumping started, in most cases, well before statutory controls, based on protection of the marine environment, entered into force in the UK in June 1974 with the enactment of the Dumping at Sea (DAS) Act 1974. Since that date, disposal of these wastes has been regulated under license.

Figure 1 – Location of sources of solid wastes and dumping sites (from: Eagle et al., 1979)
The report by Eagle et al. (1979) presents the results of five surveys carried out off the north-east coast between March 1974 and April 1977 by Fisheries Research as part of MAFF’s responsibilities under the DAS Act 1974 to protect fisheries and the marine environment.

The specific aims of these surveys were:

1. To characterise the area in physical, chemical and biological terms so as to provide a reference point or ‘bench-mark’ against which the results of future surveys can be compared;

2. To identify the sites of deposit and subsequent dispersal pathways of the dumped waste; and

3. To identify effects on the physical and chemical characteristics of the sediments attributable to dumping and to define the resulting biological effects.

At the time of the report (1979), coal mining was still a very important industry in the north east of England, with many pits located in south County Durham and near to the coastal towns of Sunderland, South Shields, Blyth and Lynemouth. As a result, large quantities of colliery waste (known locally as ‘minestone’) needed to be disposed of locally. The minestone discarded from some collieries was tipped directly off the cliff top onto adjacent beaches from as early as the start of the 20th Century. In addition, tailings from some collieries were discharged onto some of the beaches by pipes.

Minestone originates from the coal washery and is comprised mostly of an angular grey shale with some sandstone. The waste is predominantly gravel-sized (approximately 90% coarser than 2mm), with a maximum diameter of about 300mm, and contains very little material finer than 100µm. It is therefore considerably coarser than the fly ash from coal-fired power stations (2 - 200µm) which was also dumped (at offshore dumping grounds) along with a smaller proportion comprising the coarser boiler ash (60µm - 300mm).

Figure 2 – Location of sources of solid wastes and dumping sites (from: Eagle et al., 1979)

The carbon content of the minestone waste is approximately 20%; coal being present as inclusions in the shale fragments of the gravel-sized faction, with some free coal among the finer particles. The coal particles have a density of approximately 1.3g/ml compared with the density of shale of 2.65g/ml. As a result of the inclusion of coal particles, the colliery waste contains quite high concentrations of trace metals.
In the bays comprising the foreshore dump sites, the spoil changed in form over time through geochemical processes to yield a clay-like substance interspersed with sand, rock and dumping debris (e.g. rubber tubing, etc.).

Table 1 shows the quantities of colliery spoil that was reported by Eagle et al. (1979) to have been tipped onto the foreshore or taken to offshore spoil grounds in 1976 and 1977 (formal reporting of disposal quantities started in 1976 after enactment of the DAS Act in 1974).

Table 1 – Quantity of Colliery Spoil Disposal off the North East Coast in 1976 and 1977 (source: Eagle et al., 1979)

<table>
<thead>
<tr>
<th>Dumping Site</th>
<th>Quantity dumped in 1976 (tonnes x 10⁶)</th>
<th>Quantity dumped in 1977 (tonnes x 10⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynemouth (foreshore)</td>
<td>1.18</td>
<td>1.20</td>
</tr>
<tr>
<td>Blyth (spoil ground)</td>
<td>0.21</td>
<td>0.30</td>
</tr>
<tr>
<td>Souter Point (spoil ground)</td>
<td>0.57</td>
<td>0.85</td>
</tr>
<tr>
<td>Wear (spoil ground)</td>
<td>0.63</td>
<td>0.85</td>
</tr>
<tr>
<td>County Durham (foreshore)</td>
<td>1.21</td>
<td>2.50</td>
</tr>
</tbody>
</table>

Note: The spoil grounds also received additional quantities of harbour dredgings and fly ash

In order to investigate the fate and environmental effects of the foreshore and offshore dumping activities, Eagle et al. (1979) undertook and analysed a large number of sediment grab samples covering an extensive area of the sea bed off the south Northumberland, Tyne & Wear and County Durham coasts. The locations of the grab sample sites are shown in the earlier Figure 1, with surveys undertaken between March 1974 and April 1977.

At each sampling station, three sea bed sediment samples were taken using a 0.1m² Day grab. From one of these hauls samples of the upper 1cm of sediment were analysed for particle size distribution, carbon content and the presence of heavy metals (the other two samples were used for macrobenthos analysis).

In addition, a number of observations were made from Direct Reading Current Metres (DRCMs) and Moored Reading Current Meters (MRCM) at positions shown in Figure 3, to supplement information available from tidal diamonds on Admiralty charts.

Table 2 – Current meters (source: Eagle et al., 1979)

<table>
<thead>
<tr>
<th>Current Meter Station</th>
<th>Dates</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Several months of records</td>
<td>MRCM: 5m above bed</td>
</tr>
<tr>
<td>B &amp; C</td>
<td>7–11 March 1975</td>
<td>DRCM: 8m above bed and 8m below surface</td>
</tr>
<tr>
<td>D</td>
<td>28-29 April 1976</td>
<td>DRCM: 1m above bed</td>
</tr>
<tr>
<td>E</td>
<td>26 April 1976</td>
<td>DRCM: 1m above bed</td>
</tr>
<tr>
<td>F, G, H, I</td>
<td>3 August – 5 September 1976</td>
<td>MRCM: 1m above bed</td>
</tr>
<tr>
<td>J</td>
<td>30 June 1968</td>
<td>DRCM: 0.7m above bed (Hydraulics Research Station)</td>
</tr>
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Also, sea bed drifters were released from two stations: from Station A by MAFF in 1975 and from Station K off Sunderland in 1971 (Watson and Watson, 1971).
Figure 3 – Current meter locations and water movements (from: Eagle et al., 1979)
From the current meter and sea bed drifter information, it was apparent to Eagle et al. (1979) that tidal streams are aligned parallel to the coast during the periods of strongest flow. Inshore, the tidal ellipse was noted to be very narrow, with little flow normal to the main axis, whilst offshore the ellipse had a greater east-west component.

On the north-going (ebbing) tide the fastest currents were recorded off Souter Point and Tynemouth, attaining values of 0.5m/s. This pattern is repeated on the south-going (flooding) tide, with the development of stronger currents offshore (south of Station B), where flows of 0.6m/s were recorded.

Factors influencing the dispersal of the solid wastes dumped offshore:

- All the solid wastes dumped at offshore dumping sites were released from large vessels via bottom-opening doors while the vessel was stationary or slowly underway. The bulk of the material fell through the water column to the sea bed as one mass, settling within a few minutes of discharge. Only a small fraction of the waste was dispersed more widely into the surrounding water during the settling. Due to this, density variations within the water column and tidal currents during the period immediately following dumping did not significantly affect the site of the initial settlement of these wastes.

- Over the longer term, considerable fractions of the wastes dumped offshore were dispersed by tidal or wave-induced currents along pathways away from the dump sites, running parallel to the shore in predominantly a southwards direction. This process was particularly influenced by the fine-grained nature of the ash and the low density of the minestone; both of which contribute to remobilisation of the deposited wastes. It was notable that very little transport occurred normal to the shore (offshore to onshore transport of dumped solid wastes).

Factors influencing the dispersal of the solid wastes dumped on the foreshore:

- The distribution percentages of sand-sized coal coarser than 0.5mm in the samples indicated to Eagle et al. (1979) that very little transport of material occurred away from the shore tipping sites beyond the surf zone (despite considerable transport of material occurring away from offshore spoil grounds).

- Coal particles coarser than 0.5mm were considered to be transported as bedload, rather than as near bed suspended load, accounting for their more restricted distribution.

In addition to this research, Hyslop et al (1997) assessed the ecological effects of colliery waste disposal on littoral communities in the north-east of England based on a large number of core sediment samples (in soft sediments) or quadrat samples (on rocky platforms) and associated laboratory analysis in winter 1993-94, summer 1994, summer 1995 and winter 1995-96. It was identified that a maximum of two species of macroinvertebrates per shore level (low shore, mid shore and high shore levels) were found at sites characterised by soft sediments that were heavily contaminated by colliery waste, compared to typical background values on uncontaminated shores of about eight species. The principal reasons were stated as:

- The physical presence of large quantities of solid material;
- The release of inorganics such as trace metals;
- The release or organic substances such as coal-derived hydrocarbons; and
- The attenuation of light in the water column by waste particles.
3. Lynemouth Bay, Northumberland

3.1 Background

Lynemouth Bay was affected by colliery waste tipping initially from nearby Lynemouth Colliery and, later, from Ellington Colliery. Lynemouth Colliery commenced production in 1934 and immediately began tipping waste onto the foreshore. It was later, in 1994, adjoined underground to the older Ellington Colliery, which opened in 1909 and began production in 1911.

Ellington Colliery exclusively exploited a number of coal seams which run under the North Sea. By the time the collieries were nationalised in 1947 there were 1,381 men employed. By 1986 the number had grown to around 2,170 men producing approximately 45,000 tonnes of coal per week.

Although the colliery was closed by British Coal in February 1994, it was maintained until acquired by RJB Mining and re-opened in 1995. It remained the last deep mine in the UK to extract coal from right under the sea until its closure on 26th January 2005. The colliery was used as the fictional 'Everington' mine in the year 2000 film *Billy Elliot*.

Waste from both Lynemouth and Ellington Collieries was tipped onto the foreshore at Lynemouth Bay. The action of the sea separated the lighter coal contained within the waste from the coarser rock and deposited it back onto the beaches from where it was mined using hand-made wire mesh pans and transported away by horse and cart by so-called ‘seacoalers’ (Figure 4).

A film called *Seacoal* was released by Amber Films in 1985 about the harsh industrialised beach of Lynemouth and the ‘seacoalers’ who were residents of the Lynemouth traveller camp. The film stared many of the local travellers as themselves.

A photographic exhibition by Chris Killip was shown at Side Gallery in Newcastle in 1984 of the Lynemouth seacoalers, documenting their life, work and struggle to survive on the beach between 1982 and 1984. A book containing one hundred and twenty four of his images was later published in 1988.

In addition, in 2006, a short television documentary was made about one of the last remaining seacoalers. This notes that the volumes of coal were diminishing even then (in 2006) following closure of the colliery and cessation of tipping in 2005. The documentary is available to watch on YouTube via: [http://www.youtube.com/watch?v=8xV33jatcmA](http://www.youtube.com/watch?v=8xV33jatcmA).
3.2 Historic Records of Colliery Spoil Tipping

Colliery spoil (minestone) was placed on the beaches at Lynemouth for several decades from 1934, resulting in an artificially advanced beach front that facilitated the subsequent development of Alcan’s (now part of Rio Tinto Alcan) coal-fired power station on the reclaimed land. The power station initially provided electricity to the nearby Lynemouth aluminium smelter but, following closure of the smelter in May 2012, it is currently planned to be converted into a biomass power plant.

The advanced beach front was maintained by tipping, which remained ongoing initially until 1995, but was sensitive to tipping volumes. For example, in 1994 minestone placement was temporarily stopped and rapid erosion of around 40m of the beach front occurred during storms in the 1994-95 winter. This led to sea flooding of the Alcan power station and a subsequent construction of rock armour revetment scheme in front of the power station in 1995.

This revetment was subsequently extended between October 2005 and March 2006 around the adjacent coal-stocking yard of the power station (Figure 5). This was needed due to greater reliance being placed on on-site coal stocking around this time because Ellington Colliery (which directly provided coal for the power station) was closed in 2005. Until closure of the colliery, ongoing tipping of waste directly in front of the coal-stocking yard provided some protection, but following cessation of tipping the shore began to erode.
During the later works to the coal-stocking yard, the contractor built a temporary bund of colliery waste to allow the revetment to be built 'in the dry' (this bund is seen being attended to by two excavators in Figure 5; it can also be noted from the colour of the sea local to the works that the colliery waste was readily erodible).

Figure 5 - Coal stocking yard rock revetment under construction at Lynemouth

The tipping that occurred onto the Lynemouth shore between 1934 and 1972 was reported by Nunny (1978). Two tipping sites were used, one to the north of the original route of the River Lyne and one to the south (Lyne Sands). Initially, waste was transported by an aerial ropeway, rail wagons and conveyor systems, but when coal production (and associated waste production) intensified lorries were used to carry minestone to dump sites along the high water mark.

There is then a data gap between 1973 and 1975, but Cefas has kept records of the volumes tipped between 1976 and initial closure of Ellington Colliery in 1994 and has kindly made them available for the present study. Data from 1976 to 1985 were transcribed from paper records, while data from 1986 to 1994 were available in a spreadsheet.

Posford Duvivier (2000) reports that tipping then recommenced in front of the coal-stocking yard after the colliery re-opened in 1995 until its final closure in 2005. The quantities tipped between these dates are not available from Cefas but are available between 1995 and (August) 2001 from Royal Haskoning (2001). Quantities tipped between 2002 and 2005 remain unknown but are likely to be of a similar (or smaller, declining) order as the early 2000s.
It is noted that a FEPA licence was issued to RJB Mining, the then owners of the re-opened colliery, in 1998 to allow beach tipping at the site to the north (only) of the power station until the originally planned closure date of 31st December 2000. However, earlier in 2000 the closure date for the colliery was set back (by between 1 and 4 years) due to receipt of additional government grants. Consequently, efforts were made at that time to secure a 5 year extension of the FEPA licence. This was supported by an investigation into alternative spoil disposal options by Estelle Warren which concluded that continued minestone placement on the foreshore was not only more viable than land-based disposal, but also continued to provide a coastal protection function and would have little or no ‘additional’ impact on the already adversely affected coastal and marine biological communities.

The Cefas database identifies both the ‘total volume’ deposited and ‘volume of solids’ deposited at the beach tipping sites, so the latter data are used alongside the Nunny (1978) and Royal Haskoning (2001) data in Figure 6 to show the trends over the length of the data record. It can be seen that, at the peak of the recorded tipping, over 1.5m tonnes was tipped and in each year from 1965 to 1983 around 1m tonnes was tipped. In total, it is likely that over 30m tonnes of colliery waste was tipped at Lynemouth over seven decades. Note how production fell in 1984 during the Miners’ Strike.

Figure 6 – Colliery Waste Disposal on the Foreshore at Lynemouth (1934 – 2005)
Figure 7 – Lynemouth Bay - spoil beach looking south towards power station

Figure 8 – Lynemouth Bay - spoil beach to north of power station
Figure 9 – Lynemouth Bay - embankment of colliery spoil to north of power station

Figure 10 – Lynemouth Bay – rock revetment protecting the power station
Figure 11 – Lynemouth Bay - spoil beach in Lyne Sands (south of power station)
3.3 Historic Trends Analysis

3.3.1 Historic Maps
For the purposes of the present study, digital historic maps were purchased at 1:10k scale from Landmark covering the dates 1865, 1966 and the period 1980-89. These have been orthorectified and compiled as ArcReader files for viewing and the historic mapping (shown in Figure 12) has been compared with the present day OS maps to depict areas of change along the frontage.

In the 1865 map, the Snab Point headland at the northern end of Lynemouth Bay was in the same position and form as in the present day, with the foreshore rock outcrops of Broad Skear, Headagee, The Quay and Lyne Skear all well-defined in front of Cresswell Links which extended southwards along the frontage to the mouth of the River Lyne. Between these foreshore rock outcrops are Headagee Hole, Fairn Leiches and Lishey Hole. The River Lyne flowed to sea to the immediate south of Lyne Hill and immediately offshore from the mouth a small gravel bank was apparent. South of the mouth, the shoreline was characterised by Lynfield [sic] Links, Holy Brae Hill and Broad Hill, which extended southwards to meet the Beacon Point headland.

By 1966, the shape of the coastline south of Broad Skear had changed dramatically, with sediment infilling the foreshore hollows and covering much of the foreshore rocky outcrops to the north of the River Lyne. The line of mean high water prograded seawards markedly through the whole bay, most especially in the vicinity of the mouth of the River Lyne and in Lyne Sands to the south, due to tipping of considerable quantities of colliery spoil. Two conveyors were marked as being present north of Lyne Hill. At Lyne Hill, the high water mark moved 125m seaward. At Lynemouth Cottage, at the northern end of Lyne Sands, just south of the mouth, the progradation was in excess of 400m. Further south along Lyne Sands, the high water marked moved seaward, leaving Lynefield Links, Holy Brae Hill and Broad Hill stranded.

By the 1980-89 mapping, the shoreline had prograded further through the whole bay, but again most markedly between Lyne Hill and the Beacon Point headland. At the point of greatest change, in the immediate vicinity of the mouth of the River Lyne, the high water mark moved seawards by around a further 115m compared to the 1966 mapping, marking a progradation of just under 500m at this point since 1865. By this time, Lynemouth power station had been constructed on reclaimed land at the northern end of Lyne Sands, coving part of Lynefield Links and part of the spoil beach.

By the time of the present day OS mapping, the high water line had retreated landward by around 25m at the point of discharge of the River Lyne and by a similar distance immediately in front of the power station.

It is noted from a review of aerial photographs available from 2002, 2006, 2007 and 2012 that the travellers camp present in 2002 was largely gone by July 2006 following closure of the colliery and cessation of tipping in 2005.
Figure 12 – Historic and Present-day Mapping of Lynemouth
3.3.2 *Cell 1 Regional Coastal Monitoring Programme*

The Cell 1 Regional Coastal Monitoring Programme incorporates collection of beach profile survey data along six transects within Lynemouth Bay (Figure 13), and 2-yearly walkover inspections of the whole frontage. Four transects are surveyed annually and two (namely 1aCMBC03a and 1aCMBC03b) are surveyed 6-monthly. Available data have been analysed and key findings are reported below, with plots from the beach profiles presented in Appendix A.

Profile 1aCMBC03 at the very northern end of Lynemouth Bay has remained highly stable over the length of the survey record, with no change in cliff or rocky foreshore position.

Profile 1aCMBC03a was introduced to the monitoring programme in 2007 and has shown a progressive landward movement of the spoil beach, with erosion at the high water mark of around 10m.

Profile 1aCMBC03b was also introduced to the monitoring programme in 2007 and is located in the area of most recent colliery spoil tipping. The profile has shown a progressive landward retreat since 2007 of almost 30m.

Profile 1aWDC01 is located just to the north of the power station, in the area now protected by the extension of the rock revetment around the coal stocking yard. The profile has shown a progressive landward retreat since 2003 in excess of 70m.

Profiles 1aWDC02 and 1aWDC03 are located to the south of Lynemouth power station along Lyne Sands. The spoil slag heaps have continuously experienced processes of wash-over, leading to landward migration of the seaward face and deposition of liberated material on the crest and landward slope of the bank.

Along 1aWDC02 the high water line moved around 20m landwards between 2002 and 2010 and along 1aWDC03 the migration was around 10m landwards.
3.4 Other Literature Sources

Eagle et al. (1979) reported that the absence of coal in the sediments sampled north of Lynemouth indicated that dispersion from the shore tipping sites in Lynemouth Bay is predominantly southwards. Limpenny et al (1992) reported that coal was recovered in relatively large quantities in core sediment samples taken at Newbiggin in 1993-1996, inferring some bypassing of the headlands and southwards transport. However, Nunny (1978) had earlier reported that sea coal was naturally occurring at Newbiggin and it was impossible to differentiate this source from residual coal particles transported from the colliery waste at Lynemouth. Nonetheless, southward transport under severe storm action was acknowledged as a possibility.

Nunny (1978) reported on a field survey that was undertaken in October and November 1976 to:

- Identify transport pathways carrying colliery waste offshore and alongshore from the tipping zone;
- Locate and map any extensive nearshore reservoir of colliery waste which may exist; and
- Ascertain the likelihood that the coal content of any such reservoirs might eventually be returned to the inter-tidal zone anywhere along the Northumberland, Tyne & Wear or County Durham coasts.

The field survey involved a series of sea bed grab samples, sea bed core samples and beach sediment samples taken between Druridge Bay and Whitley Bay and an analysis of the physical processes and sediment transport dynamics. In relation to those sediments within Lynemouth Bay, the key findings were:

- The freshly dumped waste is very coarse, with the largest cobbles being around 10cm in diameter and only around 6% of the sample being finer than 1mm. Approximately 20% of the material is coal, either as loose particles or, more commonly, bound up within the larger sandstone pieces.

- The cobbles near the high water mark are lag deposits from the waste, left behind as finer particles are winnowed away. All material finer than about 4mm is transported away, while most material greater than 20cm remains as lag. Thus around 40% of the minestone tipped can be immediately redistributed during periods of high wave activity. At such times the remaining cobbles will undergo some movement, being edged landwards to the extreme high water mark, where they accumulate as storm deposits. The extremely rounded nature of the cobbles indicates that they are easily abraded and that progressive destruction to finer particle sizes will be an active process.

- The lower beach comprises finer gravel and coarse sand which is capable of being moved by surf action and can be subject to modest longshore drift in a net southerly direction. Attrition must be active because particle size reduces with increasing distance away from the tipping sites.

- The natural sized sand population of the bay appears as thin veneers at isolated localities in the bay and are likely to be quite extensive in the immediate sub-tidal nearshore environment. In summer months, constructive wave action is likely to bring these sands onshore, depositing them as temporary veneers on the gravel beach, to be combed seawards again during winter storms.
• In the vicinity of Snab Point, the headland at the northern end of the bay, the shelter afforded by the headland and offshore ledges has prevented the movement northwards of the coarser colliery waste and the beach is comprised of natural-sized medium sands, although there are deposits of finer coal particles along the high water mark.

• Towards the southern end of Lyne Sands, the beach is covered by a plateau of consolidated waste protecting the backing cliffs and dunes. This meets high water with a distinct ‘cliffed’ notch of about 0.5m in height. The back beach is composed of ridges of waste-derived gravels and cobbles up to several centimetres in diameter. The lower beach is composed of the finer waste material, fine gravel and coarse sands.

It was also found by Nunny (1978) that the nature of this coastline, with a narrow range of (the natural) beach sediment sizes, a uniform sub-marine slope, and a degree of indentation (which causes diffracted waves to approach normal to the shore in many bays), produces a considerable simplification of the movement of beach sediment, such that:

• Temporal changes in wave height, period and direction remain the major factors influencing sediment transport, with such changes primarily affecting onshore-offshore sediment movement rather than longshore drift. It was suggested that sediment moved offshore from the beaches never passes seaward of around the 10m sea bed contour, remaining in much shallower nearshore areas.

• Wave-driven longshore drift to the south had previously been reported (Steers, 1964) but it was considered that this is not a major process affecting sediment movements along this coastline. Whilst isolated storms could produce some movement, it would seem more probable that each bay encloses its own cell of beach sediment transport, with very little exchange between adjoining bays. Material coarser than 180µm will be rapidly transported to and fro along the beaches, and periodically moved offshore during storms to be returned to the beach during calmer weather. Sediment finer than 180µm will be rapidly carried out to sea. The net transport of any material put into suspension from the sea bed by wave activity will accordingly be affected by the residual drift of tidal currents, imposing a southward and offshore movement.

Nunny (1978) also undertook Historical Trends Analysis, comparing the first Ordnance Survey map of 1859 to the (then) present maps of the 1970s (Figure 14). This showed that the form of the coastline at Druridge Bay, Cresswell, Black Dyke and Newbiggin had altered very little in over more than a century, but that differences were very notable in Lynemouth Bay due to the tipping activities, namely:

• In the earliest map, the north of the bay comprised rock ledges with the high water line reaching the toe of the low backing cliffs whilst to the south of the bay Lyne Sands was an extensive area of inter-tidal sands backed by eroding sand dunes;

• By 1940, the high water mark had translated seawards and the cliffs in the north of the bay had become stabilised and well vegetated, whilst the embayment of Lyne Sands had become infilled; and

• Between 1940 and 1955 there was a steady overall further advancement and steepening along the whole length of the beach.
Posford Duvivier (2000) reported on longshore sediment transport modelling studies which identified:

- There is a net drift of sediment to the south in the northern part of Lynemouth Bay.
- Due to the orientation of the bay, its southwards drift potential reduces towards the south of the bay.
- Between 70 – 90% of sediment is moved offshore, so much of the tipped material is removed from the bay into the nearshore sea bed.

Royal Haskoning (2001) undertook beach surveying and visual condition assessments in 1998, 1999 and 2000 in the vicinity of Lynemouth power station. Minestone placement remained ongoing at that time at a location just north of the power station, forming a bund which acted as a (sacrificial) sea defence. Results identified that the MHW line had retreated to the north of the rock revetment fronting the power station since 1999, but remained relatively stable to the south. Table 3 presents the rate of change in the MHW line, with reference to an earlier baseline survey from 1993.
Table 3 – Change in MHW line at Lynemouth from beach survey data

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<tbody>
<tr>
<td>Minestone disposal area in front of the coal stocking yard</td>
<td>12 – 25m erosion, 10 – 17m accretion, 15 – 25m erosion</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Power station</td>
<td>20m erosion, 4m erosion</td>
<td></td>
<td></td>
<td>Position fixed by toe of rock revetment</td>
</tr>
<tr>
<td>Lyne Sands</td>
<td>No 1993 survey, 9m erosion</td>
<td></td>
<td></td>
<td>7m accretion</td>
</tr>
</tbody>
</table>

Observations from the Lynemouth rock revetment and revetment extension projects in 1995 and 2005-06 indicate that the colliery spoil is essentially a fine-grained clayey material. When extracted it appears initially like a granular material and, as it has spent many millions of years compressed under heavy overburden, has almost zero water content. When first excavated it fragments into gravel like pieces, and initially it behaves as a granular material when handled and placed. However, when exposed to the sea, water is absorbed and the material expands and softens. If it has been placed in any significant thickness, it re-combines to become a medium soft clay. As such, it eroded relatively quickly in its raw granular state, but stabilised when it transformed into a more consolidated form (Newman, personal communication).

3.5 Summary of Findings

- Lynemouth Bay was affected by colliery waste tipping from both Lynemouth Colliery and Ellington Colliery.

- Tipping commenced in 1934 at two tipping sites, one to the north of the River Lyne and one to the south along Lyne Sands.

- Tipping continued until closure of Ellington Colliery in 1994, but then recommenced (at the northern site only) when the colliery was re-opened in 1995 until its final closure in 2005.

- Tipping resulted in significant seaward movement of the beach front and infilling of Lyne Sands and the wider Lynemouth Bay.

- At the peak of the recorded tipping (1968) over 1.5m tonnes was deposited onto the foreshore and in each year from 1965 to 1983 around 1m tonnes was tipped. Volumes then fell substantially during the 1984 Miners’ Strike. In total, it is likely that over 30m tonnes of colliery waste was tipped at Lynemouth Bay over seven decades, with the greatest volumes occurring in the late 1950s, throughout the 1960s and 1970s and into the early 1980s.

- The progradation of the shoreline that occurred when tipping was intense facilitated the subsequent development of a coal-fired power station on the reclaimed land.

- Since cessation of tipping, the shoreline has been retreating in parts of Lynemouth Bay, most notably in the vicinity of the power station and Lyne Sands to the south.
• Previous monitoring and research identified that temporal changes in wave height, period and direction were the major factors influencing sediment transport of the tipped spoil, with such changes primarily affecting onshore-offshore sediment movement rather than longshore drift.

• Of the estimated 70 – 90% of spoil transported onshore-offshore, most sediment would be confined to within the 10m sea bed contour of the nearshore zone. It was considered that it would only be the very finest fractions of spoil (<180µm) that would be carried further out to sea. The net transport of any material deposited in the nearshore zone would then be governed by the residual drift of tidal currents, imposing a net southward movement in the nearshore zone.
4. Cambois Bay, Northumberland

4.1 Background

Cambois Bay experienced colliery waste tipping from Cambois Colliery, which opened in 1862 and exploited under-sea reserves before closing in April 1968. It is believed that cessation of colliery spoil tipping, combined with mining-induced subsidence of the shore and nearshore seabed, has led to an increase in erosion in recent decades within some parts of the bay.

There are also changes to coastal processes locally adjacent to the mouth of the River Wansbeck estuary, caused by the construction of a weir in 1974 – 1975. The purpose of the weir was to retain freshwater and create an amenity lake which covered the inter-tidal areas which had become so blackened by coal dust within the mud deposits.

Tipping of excavated clay (and other material, including from the nearby brickworks) occurred from the cliff top, effectively defining an artificial cliff face in a more seaward position.

4.2 Historic Records of Colliery Spoil Tipping

All of the tipping pre-dates environmental regulation and no records are known to exist of tipped quantities before its cessation in 1968. Royal Haskoning (2001) state that the position of the cliff line immediately south of the mouth of the River Wansbeck estuary is artificial, having been formed by the deposition of excavated clay (and other waste material) placed during the 1960s. This has resulted in advancement of the cliff line by some 40m.

4.3 Historic Trends Analysis

4.3.1 Historic Maps

For the purposes of the present study, digital historic maps have been purchased at 1:10k scale from Landmark covering the dates 1865, 1966 and the period 1980-89. These have been orthorectified and compiled as ArcReader files for viewing and the historic mapping (shown in Figure 15) has been compared with the present day OS maps to depict areas of change along the frontage.

The 1865 map shows that a chain ferry operated between Camboise [sic] and the north side of the River Wansbeck estuary. The village comprised only a small number of properties at this time and the rest of the bay was undeveloped, with Camboise [sic] Links extending southwards to the azimuth of land that comprised North Blyth, to the north of the River Blyth estuary.

By the time of the 1966 map, the high water mark had prograded seaward due to the tipping of waste from the nearby colliery and brickworks, which had been built since the time of the original map. A length of around 2km of the bay was affected as a consequence of this tipping, with the high water mark prograding seawards, but by far the greatest effect was in the vicinity of Cambois House and Cambois Farm where the high water mark moved around 130m seaward.

Following closure of the colliery in 1968, the former colliery and brickworks areas were redeveloped to attract new industry. The Vald Birn foundry was constructed shortly after this time and although it was originally protected by a sea wall this suffered damage in the late 1970s and erosion of the tipped cliffline occurred as a consequence. A rock armour revetment was constructed around this time to prevent further erosion.
As the tipping of excavated clay and spoil ceased with closure of the colliery in 1968, the high water mark has retreated landwards since. Between 1966 and the present day, the high water mark has eroded by around 110m in the vicinity of Cambois House and by around 90m in the vicinity of Cambois Farm. As a consequence of this, there have been concerns about the slumping that is occurring in the cliffs adjacent to Cambois House.

Figure 15 – Historic and Present-day Mapping of Cambois Bay
Figure 16 - Rock armour revetment fronting the former Vald Birn foundry

Figure 17 – Slumping in the spoil cliffs near Cambois House
4.3.2 Cell 1 Regional Coastal Monitoring Programme

The Cell 1 Regional Coastal Monitoring Programme incorporates collection of beach profile survey data at various points within Cambois Bay (Figure 18), and 2-yearly walkover inspections of the whole frontage. Available data have been analysed and key findings are reported below, with plots from the beach profiles surveyed between the mouth of the River Wansbeck estuary and North Blyth presented in Appendix B.

Profile 1aWDC10 is the location where greatest changes occurred in the position of the coastline due to historic spoil tipping. It is also presently the most actively eroding section of the bay. Between 2002 and 2010 the mark of the mean high water spring tide moved landward by around 28m as a consequence of this erosion.

Profile 1aWDC11 is relatively stabilised in cliff position due to the presence of the rock revetment, but the fronting foreshore exhibits natural changes in level.

Further towards the centre of the bay, profile 1aWDC12 also exhibits measureable changes in foreshore level, as do profiles 1aWDC13 and 1aWDC14 to the south. However, other than at profile 1aWDC10, the backing cliffs are relatively stable over time.

In addition to beach profiles, cliff top surveys are undertaken throughout Cambois Bat at 36 ground control points that are located to the south of the River Wansbeck estuary.

Since these surveys began in May 2009, erosion or an amount of movement greater than the survey error has occurred most notably at the clifftop points located close to the mouth of the River Wansbeck.

Figure 18 - Beach Profile Survey Transects along Cambois Bay
4.4 Other Literature Sources

Royal Haskoning, 2001 stated that:

- Historically the coastline remained relatively stable between 1850 and 1950 until human intervention occurred, especially during the 1960s, involving mining coal from under-sea reserves and placing colliery spoil onto the beaches nearby.
- There is overall equilibrium in terms of longshore sediment movement, although the foreshore can still be quite dynamic under different wave conditions.
- The Wansbeck Estuary appears to interrupt or even interact with the longshore sediment processes.
- Sediment generally is retained within crenulated beaches formed between rocky hard points.
- The main movement tends to be in an onshore-offshore direction.

4.5 Summary of Findings

- Cambois Bay experienced colliery waste tipping from Cambois Colliery, which opened in 1862 and exploited under-sea reserves before closing in April 1968.
- Tipping of excavated clay (and other material, including from the nearby brickworks) occurred from the cliff top, effectively defining an artificial cliff face in a more seaward position.
- Cessation of colliery spoil tipping, combined with mining-induced subsidence of the shore and nearshore sea bed, has led to an increase in erosion in recent decades within some parts of the bay.
- A rock armour revetment was constructed around the late 1970s to prevent erosion of the Vald Birn foundry.
- Between 1966 and the present day, the high water mark has eroded by around 110m in the vicinity of Cambois House and by around 90m in the vicinity of Cambois Farm.
- There is little net sediment transport along the frontage, but gross transport during storms from different directions can occur.
- The main movement of sediment within Cambois Bay tends to be in an onshore-offshore direction.
5. County Durham Coastline

5.1 Background

The collieries of the east County Durham coastline were opened only in the 1900s, but during the few decades that followed, the beaches and sea became indescribably fouled with waste dumped from the mines, and with raw sewage deposited by the pit villages (Somerville, 2006).

At the coastal collieries of Dawdon, Easington, Horden and Blackhall, deep mines were sunk to penetrate the overlying rock and overburden and reach the Coal Measures. Massive underground working extended the excavations out beneath the sea. Dumping of mining waste from these coastal pits directly onto the beaches of County Durham began in around 1900, particularly focused between Seaham and Hartlepool (Beech & Paterson, 1994).

- **Dawdon Colliery** – Sinking work in the rocky coastal area around Noses Point began in March 1900 and the colliery opened for production in October 1907. At its peak (in 1925) Dawdon Colliery employed 3,862 men and produced over 1 million tonnes of coal annually. In its lifetime, the pit broke national and European production records. Colliery waste was dumped at both ‘Seaham Foreshore’ (a.k.a. Dawdon Blast Beach) and ‘Bankside Spoil Tip’ (a.k.a. Dawdon bankside). The accumulation of spoil formed an artificial beach in both tipping locations. At Seaham Foreshore the resulting Blast Beach comprised colliery spoil some 140m in width. This material effectively arrested coastal erosion of the cliffs at both tipping sites, but also had undesired aesthetic effects and other environmental impacts. Dawdon Colliery closed in July 1991. The artificial Blast Beach was used for the opening scenes in the 1992 film *Alien 3*.

- **Easington Colliery** – The colliery was sunk in 1899 and its associated pit village was purpose built at the beginning of 20th century to house workers from the newly-opened mine. Although the colliery opened in 1899 it did not start producing coal until 1910. It is infamous for the Easington Colliery Disaster which occurred on 29th May 1951 when an explosion resulted in the deaths of 81 miners and 2 rescuers. A Garden of Remembrance in Easington Colliery Cemetery commemorates this tragic event. The pit was the last one to work the County Durham seams and closed in May 1993. The Who’s cover for their 1971 album *Who’s Next* was shot at a concrete pillar protruding from a spoil tip at Easington Colliery.
• **Horden Colliery** – Sinking commenced in 1900 and created one of the largest mines in the country, mainly focused on working under-sea coal reserves. At its peak, in 1935, it employed 4,342 men and produced over 1.5 million tonnes of coal a year. In May 1930, the pit broke national and European production records for the most coal mined by a single colliery in a day (6,758 tonnes); a record that stood for over thirty years. The colliery closed in February 1987. In 1986 the historian Tony Parker wrote a book about Horden and the people of the Horden Colliery and anonymised it as *Red Hill: A Mining Community*. The book became the inspiration for the track *Red Hill Mining Town* on the album *The Joshua Tree* by U2.

• **Blackhall Colliery** – In 1971, Blackhall Beach, was used for the climactic ‘death scene’ in the brutalist gangster thriller *Get Carter*. The film shows the lead actor, Michael Caine, chasing, and being chased by, gangsters through the beach blackened with colliery waste. It uses the mine’s sinister-looking conveyor system and iron waste buckets, known locally as ‘The Flight’, to dispose of a body. The colliery was closed in 1981.

After suffering from around a century of waste tipping from these collieries, the coastline of County Durham had a run-down and neglected image. For many years people campaigned for the cessation of tipping and the restoration of the beaches. In 1974, it was decided that colliery waste tipping would stop as soon as alternative means of disposal were found.

Durham County Council and Easington District Council produced a management plan in 1982 which advocated policies for cleaning-up the beaches. Some policies were implemented but beach tipping continued. Finally, in 1990, it was confirmed that the authorities would not renew licences for dumping waste and colliery tailings after 1995. After this decision was taken, tipping on the County Durham coastline actually stopped in 1993 as a result of closure of the pits.

When the end of tipping was in sight, a management plan was developed in order to enable return of the shoreline to its natural character. To inform this, a study was initiated to identify the management issues and potential impacts (both beneficial and adverse) of the cessation of tipping colliery waste on the beaches (Posford Duvivier Environment, 1993). A crucial part of this work was to develop a comprehensive understanding of the shoreline processes and related characteristics of cliff erosion (Posford Duvivier, 1993).
Following cessation of tipping, marine erosion began the process of naturally removing spoil from the beaches, to bring them back to their natural position over future decades. Then, as part of the drive towards giving East Durham a more attractive environment and making it into a location in which new industry will wish to invest and people will chose to live and visit, the Turning the Tide project accelerated efforts to restore the coastline to its former glory, including re-creation of a grandeur landscape and rich and diverse wildlife.

Turning the Tide was a partnership of 14 organisations that commenced in July 1997 and ran until March 2002. It received £10.5m of funding from various sources (£4.5m from Millennium Commission and contributions from English Partnerships, Countryside Agency, Durham County Council, District of Easington Council, Northumbrian Water, and European Regional Development fund grant).

The aims of the project were to:

- restore, enhance and conserve the environmental quality of the Durham Coast.
- encourage sustainable use and enjoyment of the Durham Coast.
- rekindle social pride and a sense of ownership of the Durham Coast.

These aims were delivered through a co-ordinated programme comprising four inter-linked elements spread along the 18km length coastline of County Durham. In total over one hundred projects were delivered, within the following themes:

1. Improving the Beaches – based on the removal of derelict structures (conveyors and the concrete towers), debris and rubbish from the beaches, to enable their rejuvenation as attractive destinations for visitors.

2. Removal of Colliery Spoil – involving the removal of remaining spoil heaps at Easington and Horden, with over 1.3m tonnes of spoil material spread over the sites, capped and covered with top soil to create public open space at Easington and for habitat creation at Horden.

3. Nature Conservation Landscape Enhancement – with tree and shrub planting, the creation of limestone grassland on cliff tops to restore the area to the conditions that existed before the coal mines were developed.

4. Coastal Recreation and Access – including provision of new cliff top pathways and cycle tracks and artworks to encourage greater enjoyment of the coast by the local community and visitors, and accompanied by an extensive marketing campaign to inform the public of the attractiveness of the coast, and to provide information in the history and heritage.

The work of the Turning the Tide project is now being continued by the Durham Heritage Coast Partnership. For example, in 2006 a grant of £340k from the Heritage Lottery Fund was used at Nose’s Point to improve access, seating, signs and information panels.
Figure 19 - Dawdon Bankside (Seaham Fleet Rock sea stack)

Figure 20 - Dawdon Blast Beach (from Nose’s Point looking south)
Figure 21 - Hawthorne Hive

Figure 22 - Shippersea Bay
5.2 Historic Records of Colliery Spoil Tipping

Colliery waste has been dumped on the beaches and sea bed off County Durham’s coastline since as early as Victorian times. The number of dumping sites increased up to the 1920s and subsequently, after the Second World War, increased mechanisation led to substantial increases in production of coal and associated colliery waste.

The progression of tipping at beach dump sites is believed to be (although reports do vary):

<table>
<thead>
<tr>
<th>Site</th>
<th>Commencement</th>
<th>Cessation</th>
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<tbody>
<tr>
<td>Dawdon Blast Beach</td>
<td>Pre 1900</td>
<td>1987</td>
</tr>
<tr>
<td>Dawdon Bankside</td>
<td>1910</td>
<td>1991</td>
</tr>
<tr>
<td>Easington</td>
<td>1920</td>
<td>1993</td>
</tr>
<tr>
<td>Horden</td>
<td>1922</td>
<td>1984</td>
</tr>
<tr>
<td>Blackhall</td>
<td>1924</td>
<td>1974</td>
</tr>
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The disposal at Dawdon contained waste from Dawdon, Hawthorn, South Hetton, Seaham and Vane Tempest Collieries. Material was taken by rail to Nose’s Point where it was tipped over the cliff and then spread by bulldozer. Waste at Easington, Horden and Blackhall was tipped directly on the beach from aerial flights.

Much of the tipping occurred prior to the introduction of environmental regulation and therefore went undocumented. It has previously been estimated that by 1970, around 40m tonnes of colliery waste was tipped in total on the County Durham beaches (HR Wallingford, 1970). At the peak of tipping, over 2.5m tonnes of waste was tipped in one year.

Other literature cites at least 100m tonnes of colliery waste having been dumped into the sea off County Durham, at both foreshore tipping grounds (covered in this section) and in offshore dump sites (Durham Heritage Coast, 2002).

Records of colliery spoil volumes being tipped at locations along the County Durham coastline (and also volumes being tipped at the offshore dump sites) began in 1976, following enactment of the DAS Act in 1974.

For the purposes of the present study, Cefas has kindly provided its records of volumes tipped onto the shore between 1976 and 1995. Data from 1976 to 1985 were transcribed from paper records, while data from 1986 to 1995 were available in a spreadsheet.

This database identifies both the ‘total volume’ deposited and the ‘volume of solids’ deposited at the beach tipping sites, so the latter data are used in Figure 25 to show the trends over the length of the data record. Note how production fell in 1984 during the Miners’ Strike.

It should be noted that all of the tipping at Blackhall went unrecorded before its cessation in 1974. Also, prior to 1985, only the cumulative volume of solids tipped along the Durham coastline was recorded, but after this date the tipping at individual sites was recorded. By this time tipping had ceased at Horden, so it is only at Seaham Foreshore (a.k.a. Dawdon Blast Beach), Bankside Spoil Tip and Easington Foreshore that deposits are shown as individual quantities, post-1985, in Figure 25.
5.3 Historical Trends Analysis

6.3.1 Historic Maps

For the purposes of the present study, digital historic maps have been purchased at 1:10k scale from Landmark covering the dates 1861, 1967 and 1985. These have been orthorectified and compiled as ArcReader files for viewing and the historic mapping (shown in Figures 26 - 31) has been compared with the present day OS maps to depict areas of change along the frontage.

In addition, reference has been made to a larger sequence of historic maps and aerial photographs from 1940, 2001 and 2010 that are available to view on Durham County Council’s GIS-enabled website.

**Dawdon Bankside (Figure 26)**

In the 1861 mapping, Dawdon Bankside comprises a relatively undeveloped cliffline with the high water mark at its toe. It extended southwards from Seaham Harbour, which had a different configuration of harbour arms to the present day, through to Noses [sic] Point. Liddle Stack and Seaham Fleet Rock were notable sea stacks on the foreshore and the cliff top was occupied by a number of bottle works just south of Seaham.

By the time of the 1967 mapping, Dawdon Colliery had been opened and Seaham Harbour had been considerably expanded and defences extended down the coastline past Liddle Stack. Colliery tipping from the cliff top had advanced the line of high water seawards by around 40m from the toe of the cliffs.

By 1985, continued tipping had massively advanced the line of high water through the whole frontage between Seaham Harbour and Nose’s Point, covering the inter-tidal rocky foreshore immediately south of the harbour and extending a spoil beach out as far as Seaham Flat Rocks and beyond the headland at Nose’s Point itself.
By the present day, the high water mark has retreated by around 25m, making Nose’s Point a more pronounced headland once again.

Figure 26 – Historic and Present-day Mapping of Dawdon Bankside
**Dawdon Blast Beach (Figure 27)**

In 1861, the mapping shows that other than an 'old quarry' there was no development along the cliff top between Noses [sic] Point and Chourdon Point. However, by the time of the 1967 mapping (which only has a tile covering the central and southern parts of Blast Beach) colliery spoil tipping had advanced the mean high water line from the toe of the cliffs to a position around 150m seaward. By 1985 a further 115m of progradation had occurred in the centre of Blast Beach, and in the northern section the high water line was almost 300m seaward of the toe of the cliffs. This resulted in Nose's Point becoming 'stranded' as a headland. However, by the present day mapping the high water line has migrated landwards by over 75m in the north of the bay, and around 40m in the centre.

*Figure 27 – Historic and Present-day Mapping of Dawdon Blast Beach*
**Hawthorne Hive and Shippersea Bay (Figure 28)**

The 1861 mapping shows that Hawthorne Hive was a small natural bay between Chourdon Point and Hythe Point and Shippersea Bay was similar between Beacon Point and Shippersea Point. In between the two bays was a short length of straight undeveloped cliff between Hythe Point and Beacon Point. By 1967, Hawthorne Hive had become infilled with colliery waste transported from Blast Beach around Chourdon Point. This moved the line of high water seaward by over 100m. The effect was slightly less pronounced in Shippersea Bay, due to its greater distance from the source of the colliery spoil, but nonetheless the high water mark was pushed seaward by over 50m. In addition, a small colliery spoil beach developed in front of the straight section of cliffs between Hythe Point and Beacon Point and, to a small extent, around Shippersea Point. Progradation of the high water mark continued to 1985, most notably in Hawthorne Hive where a width of waste beach of over 180m was present in the centre of the bay. Whilst the beach growth was more modest in Shippersea Bay, to a maximum width of just under 100m, the continued growth in these bays, along the cliffs between them and around Shippersea Point headland indicated continued feed from the colliery spoil that was deposited in Blast Beach.

*Figure 28 – Historic and Present-day Mapping of Hawthorne Hive and Shippersea Bay*
**Easington (Figure 29)**

The Easington foreshore, between Shippersea Point and Fox Holes, was undeveloped at the time of the 1861 mapping and comprised a series of shallow bays between hard rock headlands such as Shot Rock, Loom and Busiers Holes. By the time of the 1967 mapping, Easington Colliery had been constructed and the tipping of spoil on the foreshore was occurring by a marked aerial ropeway. This had the effect of pushing the high water mark seawards from the cliff toe by up to 100m, especially in the vicinity of Busiers Holes, which became infilled. Further progradation of the high water mark by between 25 and 35m occurred to 1985.

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*Figure 29 – Historic and Present-day Mapping of Easington*
Horden (Figure 30)
The Horden frontage, defined nominally between Horden Point and Dene Mouth, experienced progradation of the high water mark by around 90m along the length of frontage of over 2km. This continued to 1985 with a further 70m of seaward migration of the high water mark.

Figure 30 – Historic and Present-day Mapping of Horden
Blackhall Colliery (Figure 31)
The Blackhall Colliery frontage, defined nominally between Dene Mouth and Blackhall Rocks, experienced progradation of the high water mark by around 100m along the length of frontage of over 1.5km to 1985. The high water mark along the Crimdon Park frontage also prograded, although not by such great quantities as at Blackhall Colliery, indicating some movement of colliery spoil from the disposal sites further north past Blackhall Rocks.

Figure 31 – Historic and Present-day Mapping of Blackhall
5.3.2 Cell 1 Regional Coastal Monitoring Programme

The Cell 1 Regional Coastal Monitoring Programme incorporates collection of beach profile survey data (Figure 32) and cliff top survey data at various points along the County Durham coast, and 2-yearly walkover inspections of the whole frontage. Available data have been analysed and key findings are reported below, with plots from the beach profiles surveyed within County Durham presented in Appendix C.

Figure 32 – Beach surveying at the colliery spoil beach at County Durham foreshore

Dawdon Bankside

Three ground control points have been established along the cliff top at Dawdon Bankside (Figure 33). The separation between any two points is nominally 300m. These cliff top surveys are intended to inform on erosion rates of the undefended sea cliffs extending south of the rock armour revetment that has been placed to the south of Seaham Harbour. The cliff top surveys at Dawdon are undertaken bi-annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top. Points 1 and 3 have shown an average recession rate of 0.2m/year since monitoring began in 2008, whilst Point 2 has shown no erosion.

The 2012 walkover inspections identified that there was very little colliery spoil left on the foreshore and, associated with this, there are an increasing number of local slumps in the backing cliffs.

Dawdon Blast Beach

Blast Beach is covered by three beach profile lines which are surveyed 6-monthly (Figure 34). Two of these commenced in November 2008, with SH1a being added in October 2009. Profile 1bSH1a has shown a consistent position and form in the backing (now relict) cliffs, the 60m width of fronting spoil beach and the cliffed edge at the seaward margin of the spoil between 2008 and 2013. The beach levels seaward of the spoil show natural fluctuations in level and form. Profile 1bSH1 has shown some modest landward migration of the edge of the colliery spoil and the toe of the cliffs between 2008 and 2013, with natural changes on the beach seaward of the edge of the spoil. Profile 1bSH2 has shown measurable change in the width of colliery spoil, retreating by around 16m between 2008 and 2013. The trend has been of persistent retreat over a number of years, rather than due to any single storm event. There is a remaining width of around only 25m in front of the (presently) relict cliffs. It is likely that this remaining width of spoil will be removed over several years (rather than several decades) and the cliff erosion due to marine processes will become reactivated.
Figure 33 – Clifftop Survey Points along Dawdon Bankside

Figure 34 – Beach Profile Survey Transects along Dawdon Blast Beach
Hawthorne Hive and Shippersea Bay
Hawthorne Hive is covered by one beach profile line which is surveyed 6-monthly (Figure 35). Both bays are covered by 2-yearly walkover inspections. Profile 1cEA2 has shown measurable change in the width of colliery spoil, with the mean high water line retreating by around 17m between 2008 and 2013. The trend has been of persistent retreat over a number of years, rather than due to any single storm event. It is likely that the remaining width of spoil will be removed over several years (rather than several decades) and the cliff erosion due to marine processes will become reactivated.

The 2012 walkover inspections identified that the colliery spoil continues to erode on the foreshore within the bays.

Easington
The 2012 walkover inspections (Figure 36) identified that the colliery spoil continues to erode on the foreshore between Shippersea Point and Fox Holes.
**Horden**
This frontage is covered by two beach profiles that are surveyed annually (Figure 37). Profile 1cBH1 has shown measurable change in the width of colliery spoil, retreating by around 3m between 2009 and 2013. There is a remaining width of spoil of around 27m at this point along the frontage. Profile 1cBH2 has also shown measurable change in the width of colliery spoil, persistently retreating between successive surveys. In total, the edge of the spoil has retreated by around 17m between 2009 and 2013. There is a remaining width of spoil of around 50m at this point along the frontage. Once the remaining spoil along the Horden frontage has been removed by marine processes, erosion of the (presently stable) backing cliffs will become reactivated.

**Blackhall Colliery**
This frontage is covered by one beach profile that is surveyed annually (Figure 38). Profile 1cBH3 has shown measurable change in the width of colliery spoil, persistently retreating between successive surveys. In total, the high water mark has retreated by around 10m between 2009 and 2013.
5.4 Other Literature Sources

Colliery waste tipping has undeniably had a major impact on the environmental aspects of the shoreline and sea bed off County Durham, but has also provided some protection to the backing cliffs against coastal erosion. Since cessation of tipping, the spoil beaches are now retreating.

In anticipation of potential changes to the coastal environment and backing cliffs, studies were commissioned leading to the preparation of a Durham Coast Management Plan. As part of the coastal processes studies (Posford Duvivier, 1993; Beech & Paterson, 1994) that informed the Plan, Historical Trend Analysis (HTA) was undertaken, utilising the following data sources:

- Beach profiles (eleven sites between Horden and Crimdon shown in Figure 39)
  1974 – 1986 (HR Wallingford)
- Beach profiles (Horden) 1991 – 1993 (Sunderland University)
- Beach profiles (eight locations) 1993 (Blom (UK) Ltd. For Posford Duvivier)

The HTA performed showed that the spoil deposited on the foreshore encroaches beyond the former MLWM, surrounding rock stacks and covering other shallow features (Figure 40). In places, the spoil extended the low water line beyond the headlands and due to this the bays between Dawdon and Easington (namely Hawthorne Hive and Shippersea Bay) filled with spoil between 1939 and 1994, despite there being no tipping sites there.

By comparing the position of the Dawdon Bankside shoreline in 1991 (the year that tipping ceased) with the 1993 survey, it was indicated that erosion of 20m/year had occurred over that time. Similar beach profile data following cessation of tipping at Blackhall and Horden also demonstrated an initial rapid retreat of up to 20m/year. However, after some 2 - 5 years, the rate of retreat reduced significantly to around 0.5 - 2.0m/year as the erosion encroached into the older, consolidated spoil. It was therefore estimated that the spoil would take decades to, in places, a century to erode.

It was further considered that the cliffs that are currently protected by spoil could retreat at rates up to 0.3m/year when the spoil beaches have become eroded. However, there are no long term records available from pre-tipping against which these predictions can be compared and therefore some uncertainty exists. Initially, the rate could be higher as accelerated erosion is likely to occur in the exposed rock face which, though isolated from the sea for many years, has weakened through weathering processes.
Figure 39 – Location of eleven historic beach profiles (1974 – 1986)
Figure 40 – Historic changes in shoreline (high water) and cliffline between 1897 and 1939 (Posford Duvivier, 1993)
Longshore sediment transport potential was computed by Posford Duvivier (1993) along transects at eight locations along the County Durham frontage (Figure 41), using the average annual wave climate. This was established by first hindcasting an offshore wave climate, using HINDWAVE, based on measured wind records from South Shields. This offshore wave climate was then transformed inshore to the 10mCD contour using HISWA. The transformation of waves from the 10mCD contour to the shore was incorporated in the sediment transport modelling.

The transect profile at each location was defined by specially commissioned beach profile survey supplemented with an extension of the profile to the 10mCD contour using Admiralty charts. Local variations in sediment transport potential within each bay were examined by varying the modelled shoreline orientation within the limits of the bay.

To inform the modelling, the physical and chemical properties of the colliery waste were investigated by Sunderland University (Humphries, 1993). It was reported that prior to extraction, the minestone was geochemically stable with high confining pressure producing conditions of low free oxygen and moisture. However, excavation and disposal of the minestone onto the beaches exposed the fragmented spoil to mechanical and chemical weathering processes, promoting oxidation and breakdown of the spoil. Over time, free minerals in the spoil’s water content precipitated onto the grains to form a more cohesive material.

The affected beaches thus comprise two components:

1. A wide terrace of consolidated waste, some 5-6m above mean sea level, extending from the cliffs.
2. A lower, steeply inclined mobile beach in the inter-tidal zone.

The upper terrace level is between 5m and 6m above ODN and is up to 150m wide in places. Chemical degradation of this material has changed its character into a cohesive bank of clay, pebbles and sand together with mining debris. This alteration of loose sediments to clay slows down the rate of erosion of the material compared to its non-cohesive counterpart.

Sediment grab samples were taken from about mean tide level at the eight beaches used in the modelling (both clean and contaminated beaches) between Hendon and Hartlepool. An additional sediment grab sample was taken from the spoil beach at Dawdon Bankside Tip.

Particle size analysis on these samples showed that the sediments from the spoil beaches (Dawdon, Easington and Horden) were the coarsest, being typically medium gravel, whereas beaches to the north (Hendon, Ryhope, Seaham) were fine gravel and those to the south (Crimdon, Hartlepool) were medium sand (Table 4).
Figure 41 - Location of longshore transport modelling studies by Posford Duvivier (1993)
Table 4 – Beach Sediment Samples (Posford Duvivier, 1993)

<table>
<thead>
<tr>
<th>Location</th>
<th>( D_{50} ) (mm)</th>
<th>( D_{90} ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Hendon</td>
<td>3.21</td>
<td>5.74</td>
</tr>
<tr>
<td>(B) Ryhope</td>
<td>3.28</td>
<td>15.96</td>
</tr>
<tr>
<td>(C) Seaham</td>
<td>6.66</td>
<td>33.39</td>
</tr>
<tr>
<td>(D) Dawdon Blast Beach</td>
<td>9.58</td>
<td>17.72</td>
</tr>
<tr>
<td>(E) Easington</td>
<td>8.84</td>
<td>19.75</td>
</tr>
<tr>
<td>(F) Horden</td>
<td>10.29</td>
<td>20.00</td>
</tr>
<tr>
<td>(G) Crimdon</td>
<td>0.48</td>
<td>23.30</td>
</tr>
<tr>
<td>(H) Hartlepool</td>
<td>0.28</td>
<td>0.38</td>
</tr>
<tr>
<td>Dawdon Bankside Tip *</td>
<td>21.82</td>
<td>&gt;63.00</td>
</tr>
</tbody>
</table>

* Sample was taken directly from the spoil
Locations (D), (E) and (F) are beaches where tipping occurred

Key findings from the modelling by Posford Duvivier (1993) are shown in Figure 42 and are summarised below:

- Zero longshore sediment transport occurs at some point within each bay.
- On either side of this point, the longshore sediment transport is directed towards the centre of the bay.
- This implies zero net longshore sediment transport from one bay to another.
- In reality, certain (storm) wave conditions are sufficient in magnitude and direction to cause sediment to bypass at the headlands, where these penetrate the spoil beach.
- North of Crimdon, all of the modelled profiles showed a bias in favour of net southwards drift, whereas along the Hartlepool profile net northwards drift was identified.
- Thus, whilst the overall (bay to bay) longshore drift is believed to be intermittent, the underlying trend is for sediment to migrate (slowly) towards Crimdon. This finding is consistent with the observed wider beaches in the Crimdon area.
- The longshore sediment transport rates increase for coastal orientations which depart by only a few degrees from the angle of zero transport.
- This shows that whilst the bays are relatively stable in the long term, short term weather conditions can impart significant longshore movements.

Modelling of the longshore sediment transport due to currents in combination with waves showed an increase of only 15% in terms if a net southerly drift. This demonstrates that waves are the dominant process and reinforces the concept of an overall southerly drift in the area of the contaminated beaches.

Sensitivity tests incorporating a sea level rise of 300mm were performed at Horden. This identified an intensified southerly drift rate by 6%.

Beech & Paterson (1994) estimated that between 70% and 90% of the spoil which was dumped on the beaches was lost offshore. This was supported by the fact that coal is found in varying concentrations over large areas of the sea bed.

Overall, it was concluded by Posford Duvivier (1993) that the headlands have a containing effect on the longshore sediment movements. Nevertheless, there is a general (weak) drift along the shore from the area of the spoil beaches between Seaham and Blackhall Rock towards Crimdon. However, there is also a considerable loss offshore of sediment from the spoil beaches.
Figure 42 – Longshore sediment transport potential (Posford Duvivier, 1993)
Limpenny et al. (1992) reported on fieldwork that was undertaken in 1989 to investigate the (then ongoing) discharge of colliery waste onto the beach tipping sites from Dawdon Colliery and Easington Colliery. By this time tipping had stopped at both Horden and Blackhall.

The fieldwork involved divers’ surveys that collected:

- Visual descriptions of the physical nature of the sea bed, the thickness of sediment deposits, evidence of any sediment transport features (ripples, sand waves, etc.), the presence or absence of coal particles and details of any flora and fauna present;
- Surface sediment samples from the sea bed;
- Still photographs or video recordings of the sea bed; and
- Sediment cores (three sites only).

In addition, samples of the colliery tailings and minestone were taken prior to the survey for purposes of comparison with the sea bed data.

Results from the fieldwork are reproduced in Figure 43 and show that coal content in the sediment samples (measured by means of the percentage loss on ignition) was greatest in the inshore region south of Seaham, adjacent to the beach tipping sites at Dawdon and Easington (note: another area of high concentration was identified further offshore, where dredged material from Seaham Harbour was dumped). Little coal-containing sediment was recorded north of Seaham and a rapid decline in the coal content was noted towards the south of the surveyed area. These results confirm the earlier spatial distribution of coal-content in the sediment samples described by Eagle et al. (1979; Figure 44).

![Figure 43 – Percentage loss on ignition of the sand fraction in 1989 (from Limpenny et al., 1992)](image-url)
Figure 44 – Percentage loss on ignition of the sand fraction in 1975-77
(from Eagle et al (1979)

Observations by divers of ripple marks on the sea bed indicated that there is sediment transport occurring across the area. Limpenny et al (1992) concluded that much of the large quantities of colliery spoil deposited on the beach at Dawdon is transported by wave action, particularly during storms, into the nearby areas of the sea bed. Despite this, there is no evidence of significant accumulation of waste on the nearshore sea bed, which indicates a breakdown of the waste into smaller particles and then advection by tidal currents and storm wave action in a general southerly direction.

The above conclusion was also reached by Hydraulics Research Station (1970) who investigated the potential for despoliation of beaches at Crimdon due to southerly transport of the waste. Their work involved measurements of tidal currents and beach levels and vessel-based coring and sampling of surface sediments and collection of water samples for analysis of suspended sediment concentrations. The results confirmed that colliery waste would be transported in a generally southerly direction by wave action on the beach until it has broken down to a small size (<0.5mm), after which it is transported to the offshore sea bed where its further movement is dominated by tidal currents, with a general trend for movement towards the south.
5.5 Summary of Findings

- The collieries of the east County Durham coastline were opened only in the 1900s, but during the decades that followed, the beaches and sea became significantly affected by waste dumped from Dawdon, Easington, Horden and Blackhall Collieries.

- The volumes tipped on the foreshore in the recorded database (i.e. since 1976) peaked at 2.5m tonnes in one year (1983) but literature cites at least 100m tonnes of colliery waste having been dumped into the sea off County Durham, at both foreshore tipping grounds and in offshore dump sites.

- The tipping resulted in significant infilling of bays between (and in some cases beyond) headlands at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery. Although tipping did not take place directly at Hawthorne Hive or Shippersea Bay, these bays also filled with waste, generally transported southwards from Dawdon Blast Beach by longshore drift. The backing cliffs became relict features protected by a significant width of spoil beach.

- Tipping ceased in 1993 with closure of Easington as the last of the collieries and natural processes of erosion started to migrate the shoreline landwards; a process that continues to the present day (and beyond) and will ultimately result in re-activation of erosion in the backing cliffs in future decades.

- The Turning the Tide project played a significant role in cleaning up the beaches and improving the amenity and natural environment of the area between 1997 and 2002, and this work continues today under the direction of the Durham Heritage Coast.

- Previous research has identified that waves are the dominant process in influencing sediment transport and whilst the overall (bay to bay) longshore drift is intermittent and low (being controlled by the presence of the headlands), the underlying trend is for sediment to migrate (slowly) towards Crimdon.

- It was also estimated that between 70% and 90% of the spoil which was dumped on the beaches was lost offshore, rather than alongshore. This was supported by the fact that coal is found in varying concentrations over large areas of the sea bed. The waste transported to the nearshore sea bed is broken down into smaller particles and then advection by tidal currents and storm wave action in a general southerly direction.
6. Conclusions

This Technical Note has investigated the historical legacy of colliery spoil tipping at Lynemouth Bay and Cambois Bay in Northumberland and at Dawdon Bankside, Dawdon Blast Beach, Easington, Horden and Blackhall Colliery in County Durham.

In order to inform the main stage of the Cell 1 Sediment Transport Study, particular focus has been placed on understanding the artificial supply of sediment to the foreshores caused by spoil tipping, the associated historical effects on shoreline behaviour and the effects of subsequent cessation of that sediment supply on present day responses.

This has been achieved by means of Historical Trends Analysis (HTA). This is a method for interrogating series of data to identify trends and rates of change in a shoreline over time based upon analysis of historic maps, charts, aerial photographs and beach profile surveys and review of available literature sources.

The HTA has identified that large quantities of solid wastes, from a number of sources, were dumped for many years either directly onto the shore or some miles off parts of the north-east coast of England. Wastes from some coastal collieries in Northumberland and Durham were tipped directly onto foreshore tipping sites where they have been dispersed by wave action. Wastes from other collieries, fly ash from coal-fired power stations and harbour dredgings were dumped at offshore disposal sites.

In most cases, dumping started well before statutory controls entered into force in the UK in 1974. Since that date, disposal of these wastes became regulated under license. It is estimated that:

- around 30m tonnes of colliery waste (minestone) from Lynemouth and Ellington Collieries was tipped at foreshore disposal sites in Lynemouth Bay between 1934 and 2005, with at its peak over 1.5m tonnes tipped in one year (1968);
- an unknown quantity of excavated clay (and other waste) was tipped over the cliff edge at Cambois Bay until closure of Cambois Colliery in 1968; and
- over 100m tonnes of colliery waste (minestone) was tipped along the County Durham coastline, either at offshore disposal sites or at foreshore disposal sites. The foreshore tipping of waste from Dawdon, Easington, Horden and Blackhall Collieries occurred from the early 20th Century to 1993 when the last colliery (Easington) closed, with at its peak over 2.5m tonnes tipped in one year (1983);

In all cases, the tipping of waste resulted in significant progradation (seaward movement) of the shoreline and infilling of the bays to form wide spoil beaches as a ‘terrace’ on the upper beach. In Lynemouth Bay this occurred to such an extent that reclaimed land was developed with construction of the Lynemouth power station and along the County Durham coastline the spoil beaches became so wide that the backing cliffs became divorced from marine action and are currently relict features.

Due to geochemical processes that occurred after extraction of the spoil and its placement on the foreshore, its composition altered from a granular state to a more consolidated clayey condition that is somewhat more resistant to erosion than the constituent sediment grains would otherwise be.
The majority of the colliery waste that was tipped became eroded and transported seawards to the nearshore zone (within the 10m sea bed contour). This 'loss' from the shoreline was more than compensated for many decades by the ongoing tipping. Material moved to the shallow nearshore zone would then become further broken up into smaller particles by marine action and, when sufficiently small in grain size, transported by tidal currents in the direction of the net southerly current residuals. Larger grain sizes would tend to remain on the beach as lag boulder, cobble or gravel deposits.

Some longshore transport of material also occurred, particularly when the spoil beaches had increased in width so much that the high water mark extended beyond the rock headlands that intersect adjacent bays. This was most notable along the County Durham frontage where both Hawthorne Hive and Shippersea Bay (both located to the south of Dawdon Blast Beach) became infilled with colliery spoil, despite not directly being tipping sites, and concerns were also raised about despoilment of the beaches at Crimdon, south of Blackball Colliery. However, the general net southerly drift was relatively small and intermittent, predominantly being storm-driven.

Since cessation of tipping, the shoreline in all former tipping areas has been retreating. This has caused retreat of the high water line to a position landward of the headlands, meaning that potential for 'bay to bay' transport of remaining spoil beaches due to longshore drift has further reduced.

The ongoing retreat of the shoreline since cessation of spoil tipping on the foreshores has caused particular problems in Lynemouth Bay, where a rock revetment was constructed in 1995 in front of the power station and then was extended in 2005 around the adjacent coal-stocking yard, and in Cambois Bay where a rock revetment was constructed in the late 1970s in front of the (former) Vald Birn foundry. There are also ongoing concerns in Cambois Bay about continued cliff slumping affecting the property of Cambois House.

In County Durham it has been recorded by beach profile surveys that rapid rates (20m/year) of retreat of the colliery spoil beaches occurred initially (2 – 5 years) after cessation of tipping, but the rate then reduced significantly (to around 0.5 - 2.0m/year) as the erosion encroached into the older, consolidated spoil. Ongoing beach surveys and walk-over visual inspections that form part of the Cell 1 Regional Coastal Monitoring Programme are monitoring the ongoing retreat of the spoil beaches, which is clearly measureable.

It is envisaged that the cliffs that are currently protected by spoil could retreat at rates up to 0.3m/year when the spoil beaches have become eroded and marine processes are re-activated at the toe of the cliffs. Initially, the rate could be higher as accelerated erosion is likely to occur in the exposed rock face which, though isolated from the sea for many years, has weakened through weathering processes. Along Dawdon Bankside, the residual colliery spoil beach is now so narrow that parts of the backing cliffs have started to experience slumping in recent years.
7. References


Newman, M, 2013. Personal Communication, Royal HaskoningDHV.


Appendix A

Cell 1 Regional Coastal Monitoring Programme

Lynemouth Bay Beach Profiles
Lynemouth Bay – 1aWDC02
Appendix B

Cell 1 Regional Coastal Monitoring Programme

Cambois Bay Beach Profiles
Appendix C

Cell 1 Regional Coastal Monitoring Programme

County Durham Beach Profiles
Technical Note

To : Robin Siddle (Scarborough Borough Council)
From : Nick Cooper and Tanja Cooper (Royal HaskoningDHV)
Date : 31 January 2014
Copy : Keming Hu, Greg Guthrie
Our reference : PB1217/N01/303294/Newc

Subject : Cell 1 Sediment Transport Study Phase 2 – Pilot Modelling Study

1. Background

The Phase 1 Scoping Report of the Cell 1 Sediment Transport Study revealed that throughout much of the Cell 1 frontage, onshore-offshore sediment transport and subsequent advection of sediments by tidal currents and, potentially, wave action within the nearshore zone are considerably more important to overall understanding of the interactions between sections of the coast than the alongshore transport of beach sediments within the inter-tidal zone.

Due to this, the Scoping Report recommended that these processes are investigated further by the selection of a number of appropriately located cross-shore transects, each extending from the upper beach across the inter-tidal zone and nearshore sea bed to the 20m sea bed contour.

At each transect location, the longshore transport potential across the profile could be determined using a model such as LITDRIFT and the cross-shore response to wave action was proposed to be determined using a model such as LITPROF.

This approach would help define the ‘closure depth’ of each profile and assess the relative importance of longshore and cross-shore processes to the overall transport of sediment.

It was recommended in the Scoping Report that the modelling could be undertaken at all, or some, of the following cross-shore transects within the Cell 1 frontage:

- Spittal
- Bamburgh *
- Beadnell Bay
- Embleton Bay
- Boulmer
- Alnmouth Bay
- Druridge Bay
- Lynemouth Bay
- Newbiggin Bay
- Cambois Bay
- Blyth South Beach
- Whitley Bay
- Tynemouth Longsands
- Herd Sands
- Whitburn Bay
- Salterfen Rocks
- Blast Beach
- Hartlepool North Sands
- Satburn-by-the-Sea
- Skinningrove
- Runswick Bay
- Sandsend
- Whitby West Beach
- Robin Hood’s Bay
- Scarborough North Bay
- Scarborough South Bay
- Cayton Bay
- Filey Bay

* Added subsequent to the Scoping Report.

1 The limit of influence on sediment transport by the nearshore or longshore currents and wave-induced currents
It was suggested, however, that the modelling in Phase 2 is taken forward in a staged manner, with an initial Pilot Study involving modelling at transects at Newbiggin, Whitby and Scarborough to investigate the value of the outputs before embarking on modelling at all, or some, of the other transects listed.

Subsequently, it was decided to remove the Newbiggin Bay transect and replace it with the Cambois Bay transect for this Pilot Study because the sediment transport processes at Newbiggin are so interrupted by the presence of the offshore breakwater in the centre of Newbiggin Bay and do not represent a natural condition.

The reason for selecting the named locations for the pilot study is because suitable timeseries of nearshore wave data are directly available at, or very close to, these sites from the wave buoys deployed as part of the Cell 1 Regional Coastal Monitoring Programme at Newbiggin, Whitby and Scarborough.

This Technical Note presents the findings from the Pilot Modelling Study.

2. Short Model Descriptions

**Longshore Sediment Transport Model (LITDRIFT)**

LITDRIFT is a module of the LITPACK software package developed by DHI. For a given coastal profile with corresponding wave climate, tidal conditions and coastline orientation, LITDRIFT computes the sediment transport capacity across the profile in an alongshore direction.

LITDRIFT is a deterministic numerical model which consists of two major parts:

(i) a hydrodynamic model, which includes a description of propagation, shoaling and breaking of waves, calculation of the driving forces due to radiation stress gradients, momentum balance for the cross-shore and longshore direction given the wave setup and the longshore current velocities.

(ii) a sediment transport model for non-cohesive sediment transport.

The annual longshore sediment drift is computed to provide:

- gross longshore sediment transport rates at each profile;
- net longshore sediment transport rates at each profile;
- net direction of longshore transport along the coast at each profile.

LITDRIFT is widely used across the coastal engineering sector as it provides a relatively straightforward, robust and accepted method for calculating longshore sediment transport rates.
Longshore Sediment Transport Model (LITPROF)

LITDPROF is a module of the LITPACK software package developed by DHI. For a given coastal profile with corresponding wave climate, tidal conditions and coastline orientation, LITDRIFT computes the sediment transport capacity along the profile in a cross-shore direction.

LITPROF describes the cross-shore profile changes based on a timeseries of wave events. The model is based on the assumption that longshore gradients in hydrodynamic and sediment conditions are negligible and that the depth contours are parallel to the coastline. Thus the coastal morphology is solely described by the cross-shore profile response.

3. Beach Transects

For the pilot study, four transect locations were chosen for the modelling (Figure 1), namely:

- Cambois Bay
- Whitby West Beach
- Scarborough North Bay
- Scarborough South Bay

![Figure 1: Location of Pilot Study Transects](image-url)
Topographic profile data for each transect location were combined with bathymetric survey data to reach the depth contour of the offshore wave buoy location that was used to provide the wave climate data that drives the sediment transport models. Table 1 provides details of the beach and bathymetric data used at each transect location.

Table 1: Beach and bathymetric survey input data at each transect

<table>
<thead>
<tr>
<th>Transect Location</th>
<th>Topographic Survey Data</th>
<th>Bathymetric Survey Data</th>
<th>Angle of transect (°N)</th>
<th>Length of transect (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambois Bay</td>
<td>Cell 1 Topo Profile WDC12 Nov 2012</td>
<td>Admiralty Chart (no bathy survey available)</td>
<td>73</td>
<td>3,040</td>
</tr>
<tr>
<td>Whitby West Beach</td>
<td>Cell 1 Topo Profile WDC3 April 2013</td>
<td>Cell 1 Bathy 2010 (P10)</td>
<td>30</td>
<td>1,980</td>
</tr>
<tr>
<td>Scarborough North Bay</td>
<td>Cell 1 Topo Profile SB3 April 2013</td>
<td>Cell 1 Bathy 2010 (P12)</td>
<td>57</td>
<td>2,690</td>
</tr>
<tr>
<td>Scarborough South Bay</td>
<td>Cell 1 Topo Profile SBS3 April 2013</td>
<td>Cell 1 Bathy 2010 (P13)</td>
<td>83</td>
<td>4,400</td>
</tr>
</tbody>
</table>

4. Wave Climate Data

The wave climate applied at the seaward limit of each transect location was based on measured timeseries wave data collected at, or near, the chosen transect sites by Cell 1 waverider buoys at Newbiggin, Whitby and Scarborough. Table 2 shows details for these wave buoys and Figures 2 to 4 present the corresponding wave roses based on the measured wave climate.

Table 2: Measured timeseries wave buoy data

<table>
<thead>
<tr>
<th>Location</th>
<th>Dates</th>
<th>Water Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitby Buoy</td>
<td>• 20th May 2010 - 31st December 2010; • 1st January 2011 - 4th February 2011; • 17th January 2013 - October 2013</td>
<td>17</td>
</tr>
<tr>
<td>Scarborough Buoy</td>
<td>• 28th October 2003 - 10th December 2004; • 17th January 2013 - 31st October 2013</td>
<td>19</td>
</tr>
</tbody>
</table>

Note that the wave roses at Whitby and Scarborough are similar, both with a north-north-east prominence, but they differ slightly from the wave climate at Newbiggin, which has a greater north-easterly prominence.
Figure 2: Wave Rose for Newbiggin buoy

Figure 3: Wave Rose for Whitby buoy

Figure 4: Wave Rose for Scarborough buoy
5. LITDRIFT Modelling

Purpose

The purpose of the LITDRIFT modelling is to simulate the annual longshore drift of sediment along the shoreline, in the inter-tidal and nearshore zones.

Input Data

The following input data have been compiled to run LITDRFIT:

- Beach profile data
  - Beach profile survey data at the defined transect locations from the Cell 1 Regional Coastal Monitoring Programme have been used to define the inter-tidal beach profile.

- Bathymetric data
  - For areas north of the River Tyne, depth contours from published Admiralty Charts have been used to produce the nearshore profile between low water and the 20m depth contour.
  - For areas south of the River Tyne, bathymetric survey data at the defined transect locations from the Cell 1 Regional Coastal Monitoring Programme have been used to produce the nearshore profile between low water and the 20m depth contour.

- Sedimentological data
  - For areas north of the River Tyne, sediment grain size and sorting characteristics across the profile have been defined based on local knowledge of site, photographic records from the visual inspections undertaken as part of the Cell 1 Regional Coastal Monitoring Programme and surveyors' photographs and survey notes undertaken as part of the same programme.
  - For areas south of the River Tyne, particle size analysis (grain size, sorting, skewness, kurtosis) of grab samples collected at the defined transect locations from the Cell 1 Regional Coastal Monitoring Programme have been used to define the grain size and sorting characteristics across the profile.

- Water level data
  - MHWS and MLWS tide levels were defined at each of the transect locations using the Admiralty Tide Tables and timeseries data records from the class A tide gauges at North Shields and Whitby.

- Wave data
  - Measured timeseries wave data were available from buoys deployed at Newbiggin, Whitby and Scarborough as part of the Cell 1 Regional Coastal Monitoring Programme.

- Current data (for sensitivity runs only)
  - Current data for sensitivity runs were obtained from pre-existing hydrodynamic models covering the study area. These models had been built, calibrated and run by RHDHV previously.
LITDRIFT Model Set-up

Coastal profile
The LITDRIFT model requires definition of a “coastal profile” in its set up. This is described by the following items:

- bathymetry (bed level)
- orientation
- bed roughness
- sediment properties (density, porosity, mean grain diameter ($d_{50}$), geometric spreading parameter defined as $\sqrt{d_{84}/d_{16}}$, and fall velocity).

Bathymetry (bed level) - As described previously, the bathymetry of the coastal profile was defined based upon measured beach profile survey data and measured bathymetric survey data or charted sea bed contours.

Coastline orientation - The orientation of the coastline is defined relative to north (see Figure 5) and varies for each site. Details of the orientation for each transect can be found in Table 1.

Figure 5: Definition of profile orientation
The convention adopted for transport direction is shown in Figure 6 and is defined as follows:

- positive values indicate that sediment transport ($Q_s$) is to the south (or to the east if the shoreline north-facing, like at Whtiby)
- negative values indicate that sediment transport ($Q_s$) is to the north (or to the west if the shoreline north-facing, like at Whtiby)

**Figure 6: Definition of sediment transport direction**

*Bed Roughness* - The bed roughness was defined as based on $20 \times d_{50}$ sediment grain size.

*Sediment Properties* - As described previously, the grain size and spreading properties of sediments at points along the coastal profile were defined based upon available information, photographs and grab sample data from the Cell 1 Regional Coastal Monitoring Programme.
Wave climate
The wave climate data used in LITDRIFT is represented by a number of “events”, each described by their duration and frequency of occurrence over the period of one year.

Wave climate data that was input to the model includes a series of ‘frequency distribution’ tables which define the combinations of:

- Wave height
- Wave direction
- Peak wave period
- Wave spreading

In addition, water level data is input. A constant water level was used for all “events”. To test the sensitivity of varying water levels, two runs were carried out with an identical wave climate at each transect location; one using MHWS as the constant water level and the other using MLWS as the constant water level. These water levels were defined using the Admiralty Tide Tables and were converted from metres Chart Datum to metres Ordnance Datum to tie in with the datum used by the beach profile and bathymetric surveys data used at each transect location.

Tidal currents (sensitivity run)
A sensitivity run was carried out at the Cambois Bay transect using tidal currents to investigate the contribution they make (in addition to wave climate) in influencing longshore sediment transport.

Default settings
In addition to these ‘user-defined’ set-up parameters, a number of numerical model ‘default’ settings were also used (Table 3).

### Table 3: LITDRIFT model default settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach Transect Grid resolution</td>
<td>1m</td>
</tr>
<tr>
<td>Spectral description</td>
<td>Rayleigh waves</td>
</tr>
<tr>
<td>Wave theory</td>
<td>Stokes’ 5th order</td>
</tr>
<tr>
<td>Description of bed concentration</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Maximum number of iterations</td>
<td>1000</td>
</tr>
<tr>
<td>Number of steps per period</td>
<td>140</td>
</tr>
<tr>
<td>Iteration tolerance</td>
<td>0.001m</td>
</tr>
<tr>
<td>Graded sediment description</td>
<td>10 fractions</td>
</tr>
<tr>
<td>Water Temperature</td>
<td>12° C</td>
</tr>
<tr>
<td>Ripples</td>
<td>Included</td>
</tr>
</tbody>
</table>
Rayleigh waves - The waves were described as a series of regular wave trains, each characterised by the wave height and frequency of occurrence. The wave heights were Rayleigh distributed and the wave period is fixed. Each wave train was tracked across the coastal profile similar to the regular waves.

Ripples - The effect of ripples on the bed shear stresses was included. This decision was taken after consulting with an expert from DHI.

Physical processes and sedimentological settings
The model settings for physical processes and sedimentological parameters are presented in Tables 4 and 5.

The wave directional spreading factor was defined after consultation with an expert from DHI, and the value of 0.7 was chosen as being typical for a coast open to ocean waves.

Table 4: LITDRIFT model settings relating to physical processes and sedimentology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave directional spreading factor</td>
<td>0.7</td>
</tr>
<tr>
<td>Currents</td>
<td>Included as a sensitivity run</td>
</tr>
<tr>
<td>Wind</td>
<td>Excluded</td>
</tr>
<tr>
<td>Bed roughness</td>
<td>Included specific data for each transect (see Table 5)</td>
</tr>
<tr>
<td>Sediment density</td>
<td>2,650 kg/m³</td>
</tr>
<tr>
<td>Sediment geometrical spreading (σ)</td>
<td>Included specific data for each transect (see Table 5)</td>
</tr>
<tr>
<td>Sediment porosity</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Table 5 shows the location-dependant set-up parameters used in the LITDRIFT model.

### Table 5: LITDRIFT model set-up for each transect set-up

<table>
<thead>
<tr>
<th>Location</th>
<th>Angle of transect (°N)</th>
<th>Sediment Grain Size (m)</th>
<th>Bottom Friction(#)</th>
<th>Geometrical Spreading</th>
<th>MHWS (mOD)</th>
<th>MLWS (mOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambois Bay (*)</td>
<td>73</td>
<td>0.25</td>
<td>0.005</td>
<td>1.5</td>
<td>2.48</td>
<td>-1.86</td>
</tr>
<tr>
<td>Whitby West Beach (**)</td>
<td>30</td>
<td>0.24/1.93/0.28</td>
<td>0.0048/0.0386/0.0056</td>
<td>1.16/0.59/1.59</td>
<td>2.56</td>
<td>-1.87</td>
</tr>
<tr>
<td>Scarborough North Bay (Avg)</td>
<td>57</td>
<td>0.22</td>
<td>0.0044</td>
<td>1.95</td>
<td>2.51</td>
<td>-2.06</td>
</tr>
<tr>
<td>Scarborough South Bay (Avg)</td>
<td>83</td>
<td>0.18</td>
<td>0.0036</td>
<td>1.52</td>
<td>2.51</td>
<td>-2.06</td>
</tr>
</tbody>
</table>

(##) 20*Grain Size/1000  
(*) grain size and spreading estimated  
(**) grain size and spreading based on sediment grab sample survey 2010 (varies across profile)  
(Avg) grain size and spreading based on average of sediment grab sample values, 2010 Survey (similar values across profile)

**Wave diffraction**

LITDRIFT is a 1-dimensional model and whilst it does take account of cross-shore breaking and shoaling of waves due to varying bathymetry, it does not take account of wave diffraction around headlands. For this reason, LITDRIFT is best applied to longer stretches of 'open' coast unaffected by major headlands.

In order to investigate whether the LITDRIFT model remained suitable for use at Scarborough North Bay and Scarborough South Bay, where the wave climate within each bay is notably affected by diffraction and sheltering by Scarborough’s Castle Headland, an initial wave transformation was first applied to the measured wave buoy data.

This approach was based on the Goda² method, illustrated in Figure 7. In the figure the point of interest at the shore is defined as Point O and the headland is defined as Point P. The angle between the geometric shadow line caused by the headland, Line O-P, and the principal direction of wave approach is shown on the figure as $\Theta_1$.

The value of $\Theta_1$ helps determine whether waves from a particular approach direction are unblocked, partially blocked or fully blocked by the headland before reaching a defined point at the shoreline.

The Goda method introduces suite of a ‘reduction factors’ to the incoming wave climate, depending on the proportion of waves in the wave climate that approach from certain directions, including those waves from directions that are partially or fully blocked by the headland.

---

This approach was applied to the Scarborough wavebouy data before the LITDRIFT modelling at Scarborough North Bay (where Scarborough’s Castle Headland influences the proportion of waves in the annual climate that approach from the south-east and southern sectors) and at Scarborough South Bay (where Scarborough’s Castle Headland influences the proportion of waves in the annual climate that approach from the northern and north-east sectors).

Figure 7: Schematic representation of the Goda method
LITDRIFT Model Results

Cambois Bay

Figures 8 and 9 show the LITDRIFT model results under a constant water level of MHWS and a constant water level of MLWS, respectively, for Cambois Bay (defined by the Cell 1 Regional Coastal Monitoring Programme’s transect WDC12).

There is broadly equal, modest, gross drift to both the north and the south of this transect when driven by a typical annual wave climate. This indicates that the net annual drift is so low as to be negligible.

Furthermore, the longshore drift is confined to within a very narrow zone of the inter-tidal shore when modelled under a constant water level of MHWS and extends to only a shallow section of the nearshore zone when modelled under a constant water level of MLWS. In total, longshore drift is confined to a band of the inter-tidal and nearshore zone covering a width of only around 375m.

These findings are in keeping with the conceptual understanding of longshore sediment transport processes in Cambois Bay that were presented in the Scoping Report (Royal HaskoningDHV, 2013), which state:

- The main sediment movement is onshore to offshore under storm wave action and vice versa during calmer conditions.

- The bay is relatively self-contained as a sediment system, with little input from updrift or throughput to downdrift frontages.

The principal reason for this is that the bay is relatively swash-aligned in its plan form (i.e. the contours are normal to the incoming wave trains) and in such systems net longshore drift is minimal, although gross drift can vary depending on incidences of storm waves from differing directions.

One surprising finding from the LITDRIFT modelling, however, was that the (albeit insignificantly small) net drift was directed to the north, whereas a very small net southward drift may have been expected from the conceptual understanding. Consequently, this issue was further examined through a series of sensitivity tests that examined different angles of shoreline orientation and the effects of nearshore tidal currents.
Figure 8
Cambois Bay
MHWS with profile orientation of 73deg

Net Drift: m³/year
Top plot = whole profile
Bottom plot = zoomed-in section
Figure 9
Cambois Bay
MLWS with profile orientation of 73deg

Net Drift: $m^3$/year
Top plot = whole profile
Bottom plot = zoomed-in section
Cambois Bay sensitivity tests

Considering first shoreline orientation, it is evident when viewed in plan form that different sections of the Cambois Bay frontage present different angles of shoreline orientation. The initial angle of 73°N was defined based upon the Cell 1 Regional Coastal Monitoring Programme’s survey data from transect WDC12 and is therefore representative at that location. However, other sections of the frontage present different orientations as the bay adopts its shallow curve between Spital Point and North Blyth.

To capture the full range of potential orientations, runs were also made with an angle of 68°N (less oblique frontages, similar to those further south of transect WDC12) and 82°N (more oblique frontages, typical of those further north).

Figures 10 and 11 show the LITDRIFT model results under a constant water level of MHWS and a constant water level of MLWS, respectively, for the less oblique (68°N) shoreline orientation in Cambois Bay. There is very little difference between these results and the results for the original orientation of 73°N indicating that towards the southern end of the bay the longshore sediment transport is negligible in magnitude.

Figures 12 and 13 show the LITDRIFT model results for the more oblique (82°N) shoreline orientation in Cambois Bay. Longshore drift rates along the more oblique shores remain negligible in magnitude, but show a slight (insignificant) tendency for net southwards drift.

These results demonstrate how shoreline orientation within a bay can affect the direction of net sediment transport, indicating that it may not be feasible to represent more pronounced bays within the Cell 1 frontage by means of a single transect only, as originally intended as a recommendation from the Scoping Study.

Figure 14 shows that when peak tidal current velocities are added to the LITDRIFT model (undertaken for the constant water level of MHWS only), the magnitude of gross southerly longshore sediment transport increases and gross northerly longshore transport reduces, and the net drift increases with the direction becoming more clearly to the south. This suggests that wave-driven longshore sediment transport is low, but wave-stirring of bed sediments enables sediments to become entrained in tidal currents for a short distance before they settle once again. However, the magnitude of the drift rates remains very low.

Cambois Bay summary

Table 6 summarises the gross and net drift rates under the initial runs and the further sensitivity tests in Cambois Bay. In all cases, annual gross longshore sediment transport is low and annual net longshore sediment transport are negligible in Cambois Bay, indicating its relatively self-contained nature as a (broadly) swash-aligned bay.

Table 6: Gross and net longshore drift rates in Cambois Bay

<table>
<thead>
<tr>
<th>Cambois Bay</th>
<th>Initial runs</th>
<th>Sensitivity runs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MHWS 73°N</td>
<td>MLWS 73°N</td>
</tr>
<tr>
<td>Net Drift (m³/year)</td>
<td>-116</td>
<td>-80</td>
</tr>
<tr>
<td>Gross Drift +ve (m³/year)</td>
<td>822</td>
<td>637</td>
</tr>
<tr>
<td>Gross Drift -ve (m³/year)</td>
<td>-938</td>
<td>-717</td>
</tr>
</tbody>
</table>
| Figure 10 | Cambois Bay MHWS with profile orientation of 68deg | Net Drift: \( m^3/\text{year} \)  
Top plot = whole profile  
Bottom plot = zoomed-in section |
Figure 11  Cambois Bay
MLWS with profile orientation of 68deg

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
| Figure 12 | Cambois Bay MHWS with profile orientation of 82deg | Net Drift: $\text{m}^3/\text{year}$
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top plot = whole profile</td>
<td>Top plot = whole profile</td>
</tr>
<tr>
<td></td>
<td>Bottom plot = zoomed-in section</td>
<td>Bottom plot = zoomed-in section</td>
</tr>
</tbody>
</table>
Figure 13: Cambois Bay MLWS with profile orientation of 82deg

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section

31 January 2014
PB1217/N01/303294/Newc
Figure 14
Cambois Bay
MHWS with profile orientation of 73deg and with peak flood current speed of 0.2m/sec and a direction from north to south

Net Drift: m³/year
Top plot = whole profile
Bottom plot = zoomed-in section
Whitby West Beach

Figures 15 and 16 show the LITDRIFT model results under a constant water level of MHWS and a constant water level of MLWS, respectively, for Whitby West Beach (defined by the Cell 1 Regional Coastal Monitoring Programme’s transect WB3).

There is a notable peak in the longshore drift potential at times of MHWS, but this is highly localised to the very uppermost section of beach. Gross drift at this point can be directed to the west, but is more pronounced to the east and the net drift is certainly directed towards the east.

Under the MHWS water level condition, drift is confined to a narrow section (150m) of inter-tidal foreshore, but from examination of the longshore drift rates under the MLWS water level conditions, it can be seen that there is a further zone of around 250m in width, extending seawards from around MLWS into the nearshore zone, where transport remains active.

These findings are in keeping with the conceptual understanding of longshore sediment transport processes at Whitby West Beach that were presented in the Scoping Report (Royal HaskoningDHV, 2013), which state:

• Beach movement is dominated by onshore-offshore transport, while littoral transport serves to redistribute sediment within the bay.

• Net longshore transport is to the east, with the magnitude of potential movement reducing progressively eastwards. The bay is relatively self-contained as a sediment system, with little input from updrift or throughput to downdrift frontages.

• It has been estimated that over half of the potential transport takes place outside of the inter-tidal zone.

Whitby West Beach sensitivity tests

With the subtle changes in shoreline orientation along the Sandsend to Whitby frontage, and based on the LITPACK results from the Cambois Bay sensitivity runs, it would be expected that towards the west (near Sandsend) net longshore drift rates would be slightly higher than those modelled at transect WB3 and further towards the east (near Whitby Harbour) net drift rates would be slightly lower.

Whitby West Beach summary

Table 7 summarises the gross and net drift rates under the runs in Whitby West Beach. The magnitude of both gross and net drift remains relatively modest, but is greater than at Cambois Bay (as is to be expected from the conceptual understanding). The direction of net longshore drift is to the east, with a zone at the uppermost section of the beach (directly at the toe of the cliffs or defences) being particularly active.

A further zone in the nearshore sea bed also provides active longshore sediment transport, indicating that storm waves may erode sediment from the beach to the nearshore, where it becomes transported eastwards, parallel to the shore, by tidal currents before being returned to the beach at a location further to the east of its origin.
Table 7: Gross and net longshore drift rates in Whitby West Beach

<table>
<thead>
<tr>
<th>Whitby West Beach</th>
<th>MHWS (30deg)</th>
<th>MLWS (30deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Drift +ve (m$^3$/year)</td>
<td>1060</td>
<td>765</td>
</tr>
<tr>
<td>Gross Drift -ve (m$^3$/year)</td>
<td>2117</td>
<td>1640</td>
</tr>
<tr>
<td>Gross Drift +ve (m$^3$/year)</td>
<td>-1056</td>
<td>-876</td>
</tr>
</tbody>
</table>
Figure 15: Whitby West Beach: MHWS with profile orientation of 30deg

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
Figure 16: Whitby West Beach: MLWS with profile orientation of 30deg

Net Drift: m³/year

Top plot = whole profile
Bottom plot = zoomed-in section
Scarborough North Bay

Figures 17 and 18 show the LITDRIFT model results under a constant water level of MHWS and a constant water level of MLWS, respectively, for Scarborough North Bay (defined by the Cell 1 Regional Coastal Monitoring Programme’s transect SB3).

Findings show that under a constant MHWS water level there is a modest gross and net drift to the south, with little gross drift to the north, across a width of around 200m of inter-tidal zone. Under a constant MLWS water level the zone of potential drift extends seawards from MLWS by a distance of around a further 350m, still with a net southward bias. This indicates that there is potential for both inter-tidal and nearshore longshore transport within Scarborough North Bay, but the magnitudes are relatively low.

These findings are in keeping with the conceptual understanding of longshore sediment transport processes at Scarborough North Bay that were presented in the Scoping Report (Royal HaskoningDHV, 2013), which state:

- The beach is ‘self-contained’, being constrained by control points to the north (Scalby Ness) and south (Castle Cliff).
- The beaches are likely to be dependent on supply from offshore sand stores.

Scarborough North Bay sensitivity tests

As described in Section 5, the one-dimensional nature of the LITDRIFT model means that it does not represent longshore sediment transport potential entirely accurately in areas where wave diffraction effects are important. In Scarborough North Bay, the annual wave climate is affected by the sheltering and diffraction effects of Scarborough’s Castle Headland. This process affects waves approaching Scarborough North Bay from the south and south-east. Figure 4 presented a wave rose based on the measured wave data from the Scarborough waverider buoy. This shows that a (relatively small) proportion of waves approaching Scarborough are from the south-west and therefore the wave climate in Scarborough North Bay will be (to a small extent) affected by headland-induced wave diffraction.

To assess the sensitivity of gross and net longshore drift potential to this process, the Goda method (described in Section 5) was applied to modify the wave climate available to drive longshore sediment transport and account for these diffraction effects. Figure 19 presents the results from the LITDRIFT sensitivity run (performed at a constant water level of MHWS). Results show that taking account of the headland effects does marginally reduce the (already very low) gross drift to the north and therefore leads to a slight increase in the net drift to the south.

In addition to wave-driven longshore sediment transport, tidal current effects may also exert an influence (as they did to a limited degree during the sensitivity tests at Cambois Bay). However, in Scarborough North Bay, the residual tidal circulation patterns are highly complex, showing areas where both northwards (close to shore and deeper offshore in the north of North Bay) and southwards (deeper offshore, especially in the centre and south of North Bay) tidal current residuals are present. This complexity is caused by the gyre effect induced by the presence of Scarborough’s Castle Headland, which has previously been modelled (HR Wallingford, 2001) to inform coastal strategies. Such complex currents cannot be fully represented in the one-dimensional LITDRIFT model.
**Scarborough North Bay summary**

Table 8 summarises the gross and net drift rates under the runs in Scarborough North Bay. The magnitude of both gross and net drift remains relatively modest. The direction of net longshore drift is to the south, with transport potentially possible across the inter-tidal zone and in the shallow nearshore zone.

The drift rates presented are useful indications of drift potential, but actual drift will be influenced by both the sheltering effect of Scarborough’s Castle Headland and the complex residual tidal current gyres induced by the headland which cannot fully be represented using by the one-dimensional LITDRIFT model.

**Table 8: Gross and net longshore drift rates in Scarborough North Bay**

<table>
<thead>
<tr>
<th>Scarborough North Bay</th>
<th>Initial runs MHWS (57deg)</th>
<th>Initial runs MLWS (57deg)</th>
<th>Sensitivity run MHWS (Goda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Drift (m$^3$/year)</td>
<td>2040</td>
<td>3110</td>
<td>2106</td>
</tr>
<tr>
<td>Gross Drift +ve (m$^3$/year)</td>
<td>2359</td>
<td>3727</td>
<td>2359</td>
</tr>
<tr>
<td>Gross Drift -ve (m$^3$/year)</td>
<td>-319</td>
<td>-617</td>
<td>-253</td>
</tr>
</tbody>
</table>
Figure 17
Scarborough North Bay: MHWS

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
Figure 18: Scarborough North Bay: MLWS

Net Drift: m³/year
- Top plot = whole profile
- Bottom plot = zoomed-in section
Figure 19
Scarborough North Bay: MHWS with modified wave climate using Goda method to account for headland diffraction effects

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
Scarborough South Bay

Figures 20 and 21 show the LITDRIFT model results under a constant water level of MHWS and a constant water level of MLWS, respectively, for Scarborough South Bay (defined by the Cell 1 Regional Coastal Monitoring Programme’s transect SBS3).

Findings show that under a constant MHWS water level there is a notable gross and net drift to the south locally at the very uppermost section of the beach, with modest gross and net drift to the south, with little gross drift to the north, across a width of around 150m of inter-tidal zone. Under a constant MLWS water level the zone of potential drift extends seawards from MLWS by a distance of around a further 350m, still with a net southward bias. This indicates that, like in Scarborough North Bay, there is potential for both inter-tidal and nearshore longshore transport within Scarborough South Bay, but the magnitudes are relatively modest.

These findings are in keeping with the conceptual understanding of longshore sediment transport processes at Scarborough North Bay that were presented in the Scoping Report (Royal HaskoningDHV, 2013), which state:

- The beach is ‘self-contained’ between Castle Cliff to the north and White Nab to the south.
- Sediment is not actively ‘lost’ out of South Bay suggesting that the volume transported beyond Black Rocks is negligible.
- The local longshore transport of sand in the north of South Bay is to the north. A clockwise tidal gyre is evident in the lee of the Castle Cliff headland and supports northwards re-distribution.
- Further south of the Spa, the longshore transport of sand is to the south, although the now-defended talus slope of the Holbeck Hall landslip presents a partial barrier.
- The accretion in the north of South Bay (Foreshore Road beach plus harbour) is around two orders of magnitude greater than the erosion in the south indicating a relatively large supply of sediment from offshore. The accumulation of sand along the northern part of the bay is because of the shelter afforded by Castle Cliff and the harbour.

Scarborough South Bay sensitivity tests

As for Scarborough North Bay, the annual wave climate in Scarborough South Bay is affected by the sheltering and diffraction effects of Scarborough’s Castle Headland; however in South bay it is waves from the north and north-east sectors that are most affected. Figure 4 presented a wave rose based on the measured wave data from the Scarborough waverider buoy. This shows that a high proportion of waves approaching Scarborough are from between the north and north-east sectors and therefore the wave climate in Scarborough South Bay will be (to a quite significant extent) affected by headland-induced wave diffraction.

To assess the sensitivity of gross and net longshore drift potential to this process, the Goda method (described in Section 5) was applied to modify the wave climate available to drive longshore sediment transport and account for these diffraction effects. Figure 22 presents the results from the LITDRIFT sensitivity run (performed at a constant water level of MHWS).

Results show that taking account of the headland effects in this manner does reduce the gross drift to the south by around 24%. As expected, the gross drift to the north is unaffected because waves from the east and south-east are unaffected by the Goda modification and this empirical approach does not fully account for the enhanced contribution of diffracted waves to northwards-
driven drift in the northern part of the bay. Indeed, to fully account for such process would require a two-dimensional wave diffraction model. However, the Goda modification does nonetheless indicate that headland effects are important on longshore sediment transport potential in Scarborough South Bay, with the net southward drift at transect SBS3 reducing by around 26% due to this simple modification of the wave climate in the bay.

In addition to wave-driven longshore sediment transport, tidal current effects may also exert an influence (as they did to a limited degree during the sensitivity tests at Cambois Bay). However, in Scarborough South Bay, like in Scarborough North Bay, the residual tidal circulation patterns are highly complex, showing areas where both northwards (close to shore north of the Spa) and southwards (close to shore south of the Holbeck Hall landslip) tidal current residuals are present. This complexity is caused by the gyre effect induced by the presence of Scarborough’s Castle Headland, which has previously been modelled (HR Wallingford, 2001) to inform coastal strategies. Such complex currents cannot be fully represented in the one-dimensional LITDRIFT model.

Scarborough South Bay summary
Table 9 summarises the gross and net drift rates under the runs in Scarborough South Bay. The magnitude of both gross and net drift remains relatively modest. The direction of net longshore drift is to the south, with transport potentially possible across the inter-tidal zone and in the shallow nearshore zone.

The drift rates presented are useful indications of drift potential, but actual drift will be influenced by both the (significant) wave diffraction effect of Scarborough’s Castle Headland and the complex residual tidal current gyres induced by the headland which cannot fully be represented using by the one-dimensional LITDRIFT model.

Table 9: Gross and net longshore drift rates in Scarborough South Bay

<table>
<thead>
<tr>
<th>Scarborough South Bay</th>
<th>Initial runs</th>
<th>Sensitivity run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MHWS (83deg)</td>
<td>MLWS (83deg)</td>
</tr>
<tr>
<td>Net Drift (m³/year)</td>
<td>8816</td>
<td>5111</td>
</tr>
<tr>
<td>Gross Drift +ve (m³/year)</td>
<td>9567</td>
<td>5567</td>
</tr>
<tr>
<td>Gross Drift -ve (m³/year)</td>
<td>-751</td>
<td>-456</td>
</tr>
</tbody>
</table>
Figure 20  Scarborough South Bay: MHWS

Net Drift: m$^3$/year
Top plot = whole profile
Bottom plot = zoomed-in section
Figure 21
Scarborough South Bay: MLWS
Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
Figure 22
Scarborough South Bay: MHWS with modified wave climate using Goda method to account for headland diffraction effects

Net Drift: m^3/year
Top plot = whole profile
Bottom plot = zoomed-in section
6. **LITPROF**

**Purpose**

The purpose of the LITPROF modelling is to simulate the storm-driven cross-shore sediment transport between the inter-tidal and nearshore zones.

**Input Data**

The input data for the LITPROF modelling is largely as was used for the LITDRIFT modelling, with the differences in model set-up as described below.

**LITPROF Model Set-up**

The LITPROF model requires definition of a “coastal profile” and a forcing wave climate.

The coastal profile is described by the following items:

- bathymetry (bed level)
- orientation
- dominant sediment characteristics; the main parameter is the mean grain diameter, $d_{50}$, which is considered uniform across the profile.

The wave data is specified by wave height, wave angle and wave period at the most seaward point of the profile.

Three storm wave climate scenarios were simulated for each of the four transects used in the Pilot Study:

(a) 12 hour storm (highest wave height of time series), run with a fixed water level  
(b) 12 hour storm (highest wave height of time series), run with a time-varying water level  
(c) 1 month timeseries of measured wave data containing several storms, run with a time-varying water level

Table 10 shows input parameters for events (a) and (b) for each transect. These were defined as the highest wave height recorded to date within each of the timeseries wave data records.
Table 10: LITPROF model input settings for 12 hours storm simulations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transect Location</th>
<th>Wave Buoy</th>
<th>Duration (hours)</th>
<th>Wave Height (Hrms)</th>
<th>Direction (degree)</th>
<th>Wave Period (Tz)</th>
<th>Water Level (mOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Cambois Bay</td>
<td>Newbiggin</td>
<td>12</td>
<td>3.85</td>
<td>91</td>
<td>7.84</td>
<td>2.45</td>
</tr>
<tr>
<td>(b)</td>
<td>Cambois Bay</td>
<td>Newbiggin</td>
<td>12</td>
<td>3.85</td>
<td>91</td>
<td>7.84</td>
<td>Min: -1.4 Max: 2.68</td>
</tr>
<tr>
<td>(a)</td>
<td>Whitby West Beach</td>
<td>Whitby</td>
<td>12</td>
<td>4.24</td>
<td>27</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>(b)</td>
<td>Whitby West Beach</td>
<td>Whitby</td>
<td>12</td>
<td>4.24</td>
<td>27</td>
<td>8</td>
<td>Min: -0.5 Max: 2.1</td>
</tr>
<tr>
<td>(a)</td>
<td>Scarborough North and South Bays</td>
<td>Scarborough</td>
<td>12</td>
<td>4.11</td>
<td>31</td>
<td>8</td>
<td>2.32</td>
</tr>
<tr>
<td>(b)</td>
<td>Scarborough North and South Bays</td>
<td>Scarborough</td>
<td>12</td>
<td>4.11</td>
<td>31</td>
<td>8</td>
<td>Min: -0.84 Max: 2.51</td>
</tr>
</tbody>
</table>

Figures 23 to 25 show the one-month timeseries of measured wave data from Newbiggin, Whitby and Scarborough wave buoys that were used in the simulations for scenario (c). Each timeseries contained several notable storm events.

Figure 23: Newbiggin measured 1-month timeseries of wave data containing storm events
Figure 24: Whitby measured 1-month timeseries of wave data containing storm events

Figure 25: Scarborough measured 1-month timeseries of wave data containing storm events
LITPROF Model Results

Cambois Bay

Figures 26 to 28 show the results of the LITPROF cross-shore sediment transport simulations under storm conditions for modelling scenarios (a), (b) and (c) respectively at Cambois Bay.

Figure 26 shows that the 12 hour storm with a fixed water level causes a small extent of erosion centred around the high water mark, but the changes are barely noticeable when simulated with a varying water level (Figure 27) since the wave action is occurring at any particular point on the inter-tidal section of the profile for only a relatively short duration.

However, when a 1 month timeseries of measured wave data from Newbiggin is applied (Figure 28), containing three notable storm events, material is shown to have eroded from the upper beach (just below MHWS) and becomes deposited lower down the profile, between around -1mOD and -4mOD. This indicates that a sequence of storm events in rapid succession can cause more damage than a shorter duration but larger single event at this location.
Figure 27  
Cambois Bay:  
12 hour storm with varied water level  
Net Drift: m$^3$/year  
Whole profile
Figure 28
Cambois Bay:
1 month of real-time data with several storms
Net Drift: m^3/year
Whole profile
Whitby West Beach

Figures 29 to 31 show the results of the LITPROF cross-shore sediment transport simulations under storm conditions for modelling scenarios (a), (b) and (c) respectively at Whitby West Beach.

Figure 29 shows that the 12 hour storm (with a fixed water level) causes flattening of a berm that was present on the beach profile at around the mark of high water. This process is replicated in Figure 30 for the 12 hour storm with a variable water level.

The 1 month timeseries of measured wave data from Whitby, containing three notable storm events, not only replicates the flattening of this berm near the high water mark, but also – more significantly - causes further lowering of the original profile around the mark of the mean sea level, with deposition of the liberated sediment occurring lower down the profile, between levels or around -4mOD and -6mOD.

<table>
<thead>
<tr>
<th>Figure 29</th>
<th>Whitby West Beach: 12 hour storm with fixed water level</th>
<th>Net Drift: m^3/year</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image_url" alt="Figure 29" /></td>
<td>Whitby West Beach: 12 hour storm with fixed water level</td>
<td>Zoomed-in section</td>
</tr>
</tbody>
</table>
Figure 30  White West Beach:  12 hour storm with varied water level

Net Drift:  m^3/year
Zoomed-in section
Figure 31  Whitby West Beach: 1 month of real-time data with several storms

Net Drift: m³/3/year
Top plot = zoomed-in section
Bottom plot = whole profile
Scarborough North Bay

Figures 32 to 34 show the results of the LITPROF cross-shore sediment transport simulations under storm conditions for modelling scenarios (a), (b) and (c) respectively at Scarborough North Bay.

Figures 32 and 33 show that the 12 hour storm causes no measureable change in the original pre-storm profile. However, the 1-month timeseries of measured wave data from Scarborough, containing three notable storm events, does cause some erosion of a berm around just above the mark of mean sea level. Material liberated from this erosion becomes deposited lower down the profile as a series of ridge and runnel features around and just below the mark of mean low water.

<table>
<thead>
<tr>
<th>Figure 32</th>
<th>Scarborough North Bay: 12 hour storm with fixed water level</th>
<th>Net Drift: m^3/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole profile</td>
<td></td>
</tr>
</tbody>
</table>

Net Drift: m^3/year

Whole profile
Figure 33  
Scarborough North Bay:  
12 hour storm with varied water level  
Net Drift: \( m^3/\text{year} \)  
Whole profile
Figure 34

Scarborough North Bay: 1 month of real-time data with several storms

Net Drift: m^3/year Whole profile
Figures 35 to 37 show the results of the LITPROF cross-shore sediment transport simulations under storm conditions for modelling scenarios (a), (b) and (c) respectively at Scarborough South Bay.

In keeping with the findings in Scarborough North Bay, Figures 35 and 36 both show that the 12 hour storm causes no measureable change in the original pre-storm profile. However, the 1-month timeseries of measured wave data from Scarborough, containing three notable storm events, does cause some erosion of a berm around just above the mark of mean sea level. Material liberated from this erosion becomes deposited lower down the profile just below the mark of mean low water.

<table>
<thead>
<tr>
<th>Figure 35</th>
<th>Scarborough South Bay: 12 hour storm with fixed water level</th>
<th>Net Drift: m^3/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Whole profile</td>
</tr>
</tbody>
</table>
Figure 36
Scarborough South Bay: 12 hour storm with varied water level
Net Drift: m^3/year
Whole profile
Figure 37

Scarborough South Bay:
1 month of real-time data with several storms

Net Drift: m³/year
Whole profile
7. Conclusions and Recommendations

This Pilot Study has applied two modules from the LIPACK modelling suite to beach and bathymetric transects at four locations within the Cell 1 coastal frontage.

The LITDRIFT model has been used to investigate longshore sediment transport potential and the LITPROF model has been used to investigate cross-shore sediment transport potential at transects in Cambois Bay, Whitby West Beach, Scarborough North Bay and Scarborough South Bay.

The purpose of the modelling has been to test relative behaviours (rates and directions of drift) between transect locations and explore sensitivities in the mechanisms that drive sediment transport in the inter-tidal and nearshore zones within the context of a Cell-wide study. It has not been intended to precisely quantify sediment transport rates in detail at each of these locations (as may be undertaken for a site-specific study, for example).

The longshore sediment transport modelling using LITDRIFT has shown that, generally, longshore sediment transport potential at the four transects is relatively low in magnitude. In terms of relative ‘ranking’ of the locations, longshore transport potential is least (negligible) at Cambois Bay, increases (but remains very low) at Whitby West Beach, increases further (but remains relatively low) at Scarborough North Bay and is greatest (but remaining only modest in magnitude) at Scarborough South Bay. This is fully commensurate with the findings of the Scoping Report prepared during the first phase of the present study.

The LITPACK modelling has further identified that the longshore sediment transport rates are highly dependent upon the angle of shoreline orientation relative to the defined wave climate. This means that rather than replication a large number of locations within only a single transect each (as originally recommended by the Scoping Report), it would be better to consider extending the modelling to a smaller number of locations, but exploring sensitivity to shoreline orientation more fully at each location considered.

The LITDRIFT modelling approach works best in areas where the coastal orientation is relatively uniform (e.g. Whitby West Beach) rather than in more deeply indented bays (e.g. Scarborough North Bay and South Bay). Whilst possessing subtle changes in shoreline orientation, large shallow bays (e.g. Cambois Bay) appear reasonably well suited to the approaches (including sensitivity tests relating to angle of orientation). Where bays are strongly influenced by major headlands (Scarborough North Bay and South Bay) there are limitations of the LITDRIFT approach, since its one-dimensional nature does not allow wave diffraction effects around the headland or interaction with complex residual current systems (induced by headland features) to be incorporated. Consequently, it is recommended that any transects that could be affected by headland-related effects (wave diffraction, tidal gyres) are omitted from future stages. Such effects can also be induced by the presence of breakwaters and harbour piers.

Whilst the influence of tidal currents has been identified (through a sensitivity test at Cambois Bay) to enhance gross and net drift (in the direction of the residual current), the changes are so small as to be negligible compared to the modelling of drift with waves alone and therefore further sensitivity tests with currents are not deemed entirely necessary.
Further LITDRIFT modelling should take the above considerations into account and omit any locations where strong headland effects or structural effects influence local sediment transport pathways.

The cross-shore sediment transport modelling using LITPROF has shown that, generally, a rapid succession of several reasonably sized storm events causes the ‘classic’ winter beach profile response of upper beach erosion and lower beach and nearshore deposition, resulting in a temporary ‘flattening’ of the profile. This is deemed more perhaps important than a single short duration storm event of greater magnitude (until significant ‘extreme’ events are reached when more direct damage would be expected).

There clearly is connectivity in the cross-shore transport processes between the inter-tidal zone and the shallow nearshore zone, as inferred within the Scoping Report (and based on ongoing beach profile monitoring as part of the Cell 1 Regional Coastal Monitoring Programme) but never previously demonstrably proven.

In going forward with further modelling, it is recommend that LITPROF is continued to be used at a selected number of locations where monitoring has identified that cross-shore storm and seasonal behaviour is apparent. The approach of ‘forcing’ the beach response with the 1-month timeseries of wave data should be used.

8. References


Figure C1
Bamburgh (MHWS) Profile Orientation: 30° Net Drift: m³/year

Profile Orientation: 30° Net Drift: m³/year

Bamburgh (MHWS)

Bathymetry [m]

Net drift [m³/3m]
Drift +ve [m³/3m]
Drift -ve [m³/3m]

Elevation (mOD)

Sediment Drift (m³/3m)

01/02/00 16:00:00:000
Figure C2 | Bamburgh (MLWS) | Profile Orientation: 30° | Net Drift: m³/year

Net Drift: m³/year

Bathymetry [m]
Figure C3  Druridge Bay – North (MHWS)  
Profile Orientation: 110°  
Net Drift: m³/year

Druridge Bay (MHWS, 110N)

Bathymetry [m]  
Net drift [m³/3m]  
Drift +ve [m³/3m]  
Drift -ve [m³/3m]  

01/02/00 07:30:00:000
Figure C4  Druridge Bay – Centre (MHWS)

Profile Orientation: 80°  Net Drift: m³/year

Bathymetry [m]  Net drift [m³/3m]

Druridge Bay (MHWS, 80C)  Drift +ve [m³/3m]

Chainage (m)  Drift -ve [m³/3m]

Elevation (mO.D.)  Sediment Drift [m³/3m]

01/02/00 07:30:00:000
Figure C5

Druridge Bay – South (MHWS)

Bathymetry [m]

Druridge Bay (MHWS, 68S)

Profile Orientation: 68°

Net Drift: m³/year

01/02/00 07:30:00.000
Figure C6 | Druridge Bay – North (MLWS) | Profile Orientation: 110° | Net Drift: m³/year

Druridge Bay (MLWS, 110N)

- Bathymetry [m] (yellow)
- Net drift [m³/year] (red)
- Drift +ve [m³/year] (green)
- Drift -ve [m³/year] (blue)

Profile Orientation: 110°

Net Drift: m³/year

01/02/00 07:30:00:000
Figure C7: Druridge Bay - Centre (MLWS) Profile Orientation: 80° Net Drift: m³/year
Figure C8  Druridge Bay – South (MLWS)

Profile Orientation: 68°  Net Drift: m³/year

Druridge Bay (MLWS, 68S)
Profile Orientation: 65°

Net Drift: m³/year
Figure C10 | Lynemouth (MLWS) | Profile Orientation: 65° | Net Drift: m³/year

Lynemouth Bay (MLWS)
Figure C11: Cambois Bay – North (MHWS)

Profile Orientation: 82°

Net Drift: m³/year

Cambois Bay (MHWS, Hindcast)

01/02/00 07:30:00:000
Figure C12  Cambois Bay – North (MLWS)

Profile Orientation: 82°

Net Drift: m³/year

Cambois Bay (MLWS, Hindcast)

Bathymetry [m]

Chainage (m)

Elevation (mO.D.)

Sediment Drift (m³/m³)

01/02/00 07:30:00:000
Figure C13 | Blyth South Beach - Centre (MHWS) | Profile Orientation: 72° | Net Drift: m³/year

Blyth South Beach (MHWS, 72C)
Figure C14: Blyth South Beach - South (MHWS)

Profile Orientation: 55°

Net Drift: m³/year

Bathymetry [m]

Blyth South Beach (MHWS, 55S)

Elevation (mO.D.)

0  200  400  600  800  1000  1200  1400  1600  1800  2000  2200  2400  2600  2800  3000

Chainage (m)

0  10  20  30  40  50  60  70  80  90  100  110  120  130  140  150

Sediment Drift [m³/3m]
Figure C15  Blyth South Beach - Centre (MLWS)

Profile Orientation: 72°  Net Drift: m³/year

Blyth South Beach (MLWS, 72C)

Bathymetry [m]

Net drift [m³/3y]  Drift: +ve [m³/3y]  Drift: -ve [m³/3y]

01/02/00 07:30:00.000
Figure C16 | Blyth South Beach - South (MLWS) | Profile Orientation: 55° | Net Drift: m³/year

Net drift [m³/year] | Drift +ve [m³/year] | Drift -ve [m³/year]
Figure C17

Whitley Bay - Centre (MHWS)

Profile Orientation: 70°

Net Drift: m³/year

Bathymetry [m] (MHWS, 70C)

Elevation (mOD)

Chainage (m)

01/02/02 07:30:00.000
Profile Orientation: 58°
Net Drift: m³/year

Whitley Bay - South (MHWS)

Figure C18
Figure C19  Whitley Bay - Centre (MLWS)  
Profile Orientation: 70°  
Net Drift: m³/year

Whitley Bay (MLWS, 70C)

Bathymetry [m]  
Net drift [m³/3m]  
Drift +ve [m³/3m]  
Drift -ve [m³/3m]
Figure C20 | Whitley Bay - South (MHWS) | Profile Orientation: 58° | Net Drift: m³/year

- Bathymetry [m] (Yellow)
- Net Drift [m³/year] (Green)
Figure C22  Tynemouth Longsands (MLWS)  Profile Orientation: 65°  Net Drift: m³/year

Bathymetry [m]  Net drill [m³/3m²]  Drift +ve [m³/3m²]  Drift -ve [m³/3m²]

Tynemouth Longsands (MLWS, 65)

0 200 400 600 800 1000 1200 1400 1600 1800 2000
0 2 4 6 8 10 12 14 16 18 20

0 50 100 150 200 250 300
-50 -100 -150 -200 -250 -300

Elevation (m OD)  Sediment Drift (m³/3m²)  Chainage (m)

01/02/00 07:30:00.000
Salterfen Rocks (MHWS)

Profile Orientation: 75°  
Net Drift: m³/year

Bathymetry [m]

Salterfen Rocks (MHWS)

Elevation (mOD)

Sediment Drift (m³/3m)

Chainage (m)

01/02/03 09:00:00:000
Figure C24
Salterfen Rocks (MLWS)

Profile Orientation: 75°
Net Drift: m³/year

Salterfen Rocks (MLWS)

Bathymetry [m]  

Net drift [m³/3m³]  
Drift +ve [m³/3m³]  
Drift -ve [m³/3m³]  

Elevation (m O.D.)  

Sediment Drift (m³/3m³)  

Chainage (m)
Figure C25  Blast Beach (MHWS)  
Profile Orientation: 65°  
Net Drift: m³/year
Figure C26

Blast Beach (MLWS)

Profile Orientation: 65°

Net Drift: $m^3$/year
Figure C27 | Hartlepool North (MHWS)  

Profile Orientation: 45°  

Net Drift: m³/year  

Bathymetry [m]  

Hartlepool North (MHWS)  

Elevation (mOCD)  

Charnage (m)  

01/02/00 00:00:00:000
Figure C28

Hartlepool North (MLWS)

Profile Orientation: 45°

Net Drift: m³/year
Figure C29  Saltburn (MHWS)  
Profile Orientation: 25°  
Net Drift: m³/year
Figure C30

Saltburn (MLWS)

Profile Orientation: 25°

Net Drift: m³/year

Net drift [m³/3m]
Drift +ve [m³/3m]
Drift -ve [m³/3m]
Figure C31
Skinningrove (MHWS)

Profile Orientation: 45°
Net Drift: m³/year
Figure C32

Skinningrove (MHWS)

Profile Orientation: 45°

Net Drift: m³/year
Figure C33 | Sandsend (MHWS) | Profile Orientation: 30° | Net Drift: m³/year

- Bathymetry [m] (yellow)
- Net drift [m³/year] (red)

Sandsend (MHWS)

Chainage (m)

Elevation (mOHD)

01/02/00 12:00:00:000
Figure C34: Sandsend (MLWS) Profile Orientation: 30° Net Drift: m³/year
Figure C35  Whitby West Beach (MHWS)  Profile Orientation: 30°  Net Drift: m$^3$/year

Bathymetry [m]

Whitby West Beach (MHWS, Hindcast)

Chaining (m)

Elevation (mOCD)

Sediment Drift (m$^3$/yr)

01/02/00 12:00:00:000
Figure C36 | Whitby West Beach (MLWS) | Profile Orientation: 30° | Net Drift: m³/year

Whitby West Beach (MLWS, Hindcast)
Figure C37: Scarborough North Bay (MHWS)

Profile Orientation: 57°

Net Drift: m³/year

[Diagram of Scarborough Bay North (MHWS, Hindcast) showing bathymetry and net drift]
Figure C38  Scarborough North Bay (MLWS)

Profile Orientation: 57°  Net Drift: m³/year

![Graph of Scarborough Bay North (MLWS, Hindcast) showing bathymetry and sediment drift.]
Figure C39 | Scarborough South Bay (MHWS)

Profile Orientation: 83°

Net Drift: m³/year

Bathymetry [m]

Scarborough South Bay (MHWS)
Figure C40 | Scarborough South Bay (MLWS)  | Profile Orientation: 83° | Net Drift: $m^3/\text{year}$

Scarborough South Bay (MLWS)

Profile Orientation: 83°

Net Drift: $m^3/\text{year}$

Bathymetry [m]

Drift: $+$ [m$^3$/m$^3$]

Drift: $-$ [m$^3$/m$^3$]

Sediment Drift [m$^3$/m$^3$]

Elevation (mOD)

Chainage (m)

01/01/00 00:12:30:000
Figure D1  Bamburgh  1 month storm wave climate  Profile Response

Bamburgh (1 month of storms)
Figure D2 | Druridge Bay

1 month storm wave climate | Profile Response

Druridge (1 month of storms)

Elevation (mO.D.)

Chainage (m)

01/01/90 00:00:00:0000
Figure D3 | Lynemouth Bay | 1 month storm wave climate | Profile Response

Lynemouth (1 month of storms)

Elevation (mO.D.) vs Chainage (m)

-22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12
0 200 400 600 800 1000 1200 1400 1600 1800

Bathymetry
Simulated 1 month storm profile [m]
Figure D4 | Cambois Bay | 1 month storm wave climate | Profile Response

Cambois Bay (1 month of storms)

Chainage (m) | Elevation (m ODN)

2200 | -10
2300 | -9
2400 | -8
2500 | -7
2600 | -6
2700 | -5
2800 | -4
2900 | -3
3000 | -2

01/01/90 00:00:00:000
Figure D5 | Blyth South Beach

1 month storm wave climate | Profile Response

Blyth South Beach (1 month of storms)

[Graph showing bathymetry and simulated 1 month storm profile]
Figure D6

Whitley Bay

1 month storm wave climate | Profile Response

Whitley Bay (1 month of storms)
Figure D9

Blast Beach

1 month storm wave climate

Profile Response
Figure D14

Whitby

1 month storm wave climate | Profile Response

Whitby (1 month of storms)

Elevation (mOC)

Chainage (m)


Bathymetry
Simulated 1 month storm profile [m]

10/04/11 03:00:00.000