Halcrow
A CH2M HILL COMPANY

Cell 1 Regional Coastal Monitoring Programme
Analytical Report 5 Full Measures Survey 2012

Scarborough Council
Final Report

A great place to live, work & play

March 2013

Contents

Appendices

List of Figures

List of Tables

Authors	
Lily Booth	Halcrow
Dr Paul Fish	Halcrow

Disclaimer

Halcrow Group Limited ('Halcrow') is a CH2M HILL company. Halcrow has prepared this report in accordance with the instructions of our client Scarborough Borough Council (SBC) for the client's sole and specific use. Any other persons who use any information contained herein do so at their own risk. This report is a review of coastal survey information made available by SBC. The objective of this report is to provide an assessment and review of the relevant background documentation and to analyse and interpret the coastal monitoring data. Halcrow has used reasonable skill, care and diligence in the interpretation of data provided to them and accepts no responsibility for the content, quality or accuracy of any Third party reports, monitoring data or further information provided either to them by SBC or, via SBC from a Third party source, for analysis under this term contract.

Raw data analysed in this report is available to download via the project's webpage: www.northeastcoastalobservatory.org.uk. The North East Coastal Observatory does not "license" the use of images or data or sign license agreements. The North East Coastal Observatory generally has no objection to the reproduction and use of these materials (aerial photography, wave data, beach surveys, bathymetric surveys), subject to the following conditions:

1. North East Coastal Observatory material may not be used to state or imply the endorsement by North East Coastal Observatory or by any North East Coastal Observatory employee of a commercial product, service, or activity, or used in any manner that might mislead.
2. North East Coastal Observatory should be acknowledged as the source of the material in any use of images and data accessed through this website, please state "Image/Data courtesy of North East Coastal Observatory". We recommend that the caption for any image and data published includes our website, so that others can locate or obtain copies when needed. We always appreciate notification of beneficial uses of images and data within your applications. This will help us continue to maintain these freely available services. Send e-mail to Robin.Siddle@scarborough.gov.uk
3. It is unlawful to falsely claim copyright or other rights in North East Coastal Observatory material.
4. North East Coastal Observatory shall in no way be liable for any costs, expenses, claims, or demands arising out of the use of North East Coastal Observatory material by a recipient or a recipient's distributees.
5. North East Coastal Observatory does not indemnify nor hold harmless users of North East Coastal Observatory material, nor release such users from copyright infringement, nor grant exclusive use rights with respect to North East Coastal Observatory material.
6. North East Coastal Observatory material is not protected by copyright unless noted (in associated metadata). If copyrighted, permission should be obtained from the copyright owner prior to use. If not copyrighted, North East Coastal Observatory material may be reproduced and distributed without further permission from North East Coastal Observatory.

Abbreviations and Acronyms

Acronym / Abbreviation	Definition
AONB	Area of Outstanding Natural Beauty
DGM	Digital Ground Model
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWS	Mean Low Water Neap
MLWS	Mean Low Water Spring
m	metres
ODN	Ordnance Datum Newlyn

Water Levels Used in Interpretation of Changes

Water Level Parameter	Water Level (m AOD) Hartlepool Headland to Saltburn Scar	Skinningrove	Hummersea Scar to Sandsend Ness	Sandsend Ness to Saltwick Nab
1 in 200 year	3.87	3.86	4.1	3.88
HAT	3.25	3.18	3.15	3.10
MHWS	2.65	2.68	2.65	2.60
MLWS	-1.95	-2.13	-2.15	-2.20
Water Level Parameter	**Water Level (m AOD) Saltwick Nab to Hundale Point**	**Hundale Point to White Nab**	**White Nab to Filey Brigg**	**Filey Brigg to Flamborough Head**
1 in 200 year	3.88	3.93	3.93	4.04
HAT	3.10	3.05	3.05	3.10
MHWS	2.60	2.45	2.45	2.50
MLWS	-2.20	-2.35	-2.35	-2.30

Source: *River Tyne to Flamborough Head Shoreline Management Plan 2*. Royal Haskoning, February 2007.

Glossary of Terms

Term	Definition
Beach nourishment	Artificial process of replenishing a beach with material from another source.
Berm crest	Ridge of sand or gravel deposited by wave action on the shore just above the normal high water mark.
Breaker zone	Area in the sea where the waves break.
Coastal squeeze	The reduction in habitat area which can arise if the natural landward migration of a habitat under sea level rise is prevented by the fixing of the high water mark, e.g. a sea wall.
Downdrift	Direction of alongshore movement of beach materials.
Ebb-tide	The falling tide, part of the tidal cycle between high water and the next low water.
Fetch	Length of water over which a given wind has blown that determines the size of the waves produced.
Flood-tide	Rising tide, part of the tidal cycle between low water and the next high water.
Foreshore	Zone between the high water and low water marks, also known as the intertidal zone.
Geomorphology	The branch of physical geography/geology which deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
Groyne	Shore protection structure built perpendicular to the shore; designed to trap sediment.
Mean High Water (MHW)	The average of all high waters observed over a sufficiently long period.
Mean Low Water (MLW)	The average of all low waters observed over a sufficiently long period.
Mean Sea Level (MSL)	Average height of the sea surface over a 19-year period.
Offshore zone	Extends from the low water mark to a water depth of about 15 m and is permanently covered with water.
Storm surge	A rise in the sea surface on an open coast, resulting from a storm.
Swell	Waves that have travelled out of the area in which they were generated.
Tidal prism	The volume of water within the estuary between the level of high and low tide, typically taken for mean spring tides.
Tide	Periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.
Topography	Configuration of a surface including its relief and the position of its natural and man-made features.
Transgression	The landward movement of the shoreline in response to a rise in relative sea level.
Updrift	Direction opposite to the predominant movement of longshore transport.
Wave direction	Direction from which a wave approaches.
Wave refraction	Process by which the direction of approach of a wave changes as it moves into shallow water.

Preamble

The Cell 1 Regional Coastal Monitoring Programme covers approximately 300km of the northeast England coastline, from the Scottish Border (just south of St. Abb's Head) to Flamborough Head in East Yorkshire. This coastline is often referred to as 'Coastal Sediment Cell 1' in England and Wales (Figure 1). Within this frontage the coastal landforms vary considerably, comprising low-lying tidal flats with fringing salt marshes, hard rock cliffs that are mantled with glacial sediment to varying thicknesses, softer rock cliffs and extensive landslide complexes.

Figure 1 Sediment Cells in England and Wales

The work commenced with a three-year monitoring programme in September 2008 that was managed by Scarborough Borough Council on behalf of the North East Coastal Group. This initial phase has been followed by a five-year programme of work, which started in October 2011. The work is funded by the Environment Agency, working in partnership with the following organisations:

Northumberland County Council
Northumberland Coast Area of Outstanding Natural Beauty
North Tyneside Council
South Tyneside Council
Sunderland City Council
Durham County Council
Redcar & Cleveland Borough Council
Hartlepool Borough Council
Borough of Scarborough
East Riding of Yorkshire Council
Environment Agency
Natural England
The National Trust

The original three year programme of work was undertaken as a partnership between Royal Haskoning, Halcrow and Academy Geomatics. For the current five year programme of work the data collection associated with beach profiles, topographic surveys and cliff top surveys is being undertaken by Academy Geomatics. The analysis and reporting for the programme is being undertaken by Halcrow.

Halcrow A CH2M HILL COMPANY academy geomatics

The main elements of the Cell 1 Regional Coastal Monitoring Programme involve:

- beach profile surveys
- topographic surveys
- cliff top recession surveys
- real-time wave data collection
- bathymetric and sea bed characterisation surveys
- aerial photography
- walk-over surveys

The beach profile surveys, topographic surveys and cliff top recession surveys are undertaken as a 'Full Measures' survey in autumn/early winter every year. Some of these surveys are then repeated the following spring as part of a Partial Measures survey.

Each year, an Analytical Report is produced for each individual authority, providing a detailed analysis and interpretation of the Full Measures surveys.

This is followed by a brief Update Report for each individual authority, providing ongoing findings from the Partial Measures surveys.

A Cell 1 Overview Report is also produced regularly to provide a region-wide summary of the main findings relating to trends and interactions along the entire Cell 1 frontage.

To date the following reports have been produced:

Table 1 Analytical, Update and Overview Reports Produced to Date

Year		Full Measures		Partial Measures		Cell 1 Overview Report
		Survey	Analytical Report	Survey	Update Report	
1	2008/09	Sep-Dec 08	May 09	Mar-May 09		-
2	2009/10	Sep-Dec 09	Mar 10	Feb-Mar 10	July 10	-
3	2010/11	Aug-Nov 10	Feb 11	Feb-April 11	August 11	Sept 11
4	2011/12	Sept 11	Aug 12	Mar-May 12	Feb 13	
5	2012/13	Sept 12	Mar 13 (*)			

(*) The present report is **Analytical Report 5** and provides an analysis of the autumn/winter 2012 Full Measures survey for Scarborough Borough Council's frontage.

In addition, separate reports are produced for other elements of the programme as and when specific components are undertaken, such as wave data collection, bathymetric and sea bed sediment data collection, aerial photography, and walk-over visual inspections.

For purposes of analysis, the Cell 1 frontage has been split into the sub-sections listed in the Table 2. Areas covered in the current report are highlighted

Table 2 Sub-divisions of the Cell 1 Coastline

Authority	Zone
Northumberland County Council	Spittal A
	Spittal B
	Goswick Sands
	Holy Island
	Bamburgh
	Beadnell Village
	Beadnell Bay
	Embelton Bay
	Boulmer
	Alnmouth Bay
	High Hauxley and Druridge Bay
	Lynemouth Bay
	Newbiggin Bay
	Cambois Bay
	Blyth South Beach
North Tyneside Council	Whitley Sands
	Cullercoats Bay
	Tynemouth Long Sands
	King Edward's Bay
South Tyneside Council	Littehaven Beach
	Herd Sands
	Trow Quarry (incl. Frenchman's Bay)
	Marsden Bay
Sunderland Council	Whitburn Bay
	Harbour and Docks
	Hendon to Ryhope (incl. Halliwell Banks)
Durham County Council	Featherbed Rocks
	Seaham
	Blast Beach
	Hawthorn Hive
	Blackhall Colliery
Hartlepool Borough Council	North Sands
	Headland
	Middleton
	Hartlepool Bay
Redcar & Cleveland Borough Council	Coatham Sands
	Redcar Sands
	Marske Sands
	Saltburn Sands
	Cattersty Sands (Skinningrove)
Scarborough Borough Council	Staithes
	Runswick Bay
	Sandsend Beach, Upgang Beach and Whitby Sands
	Robin Hood's Bay
	Scarborough North Bay
	Scarborough South Bay
	Cayton Bay
	Filey Bay

1. Introduction

1.1 Study Area

Scarborough Borough Council's frontage extends from Staithes Harbour to Speeton, in Filey Bay. For the purposes of this report, the Scarborough frontage has been sub-divided into eight areas, namely:

- Staithes
- Runswick Bay
- Sandsend Beach, Upgang Beach and Whitby Sands
- Robin Hood's Bay
- Scarborough North Bay
- Scarborough South Bay
- Cayton Bay
- Filey Bay

1.2 Methodology

Along Scarborough Borough Council's frontage, the following surveying is undertaken:

- Full Measures survey annually each autumn/early winter comprising:
    - Beach profile surveys along 20 transect lines
    - Topographic survey at Runswick Bay
    - Topographic survey along the Sandsend to Whitby frontage
    - Topographic survey at Robin Hood's Bay
    - Topographic survey at Scarborough North Bay
    - Topographic survey at Scarborough South Bay
    - Topographic survey at Cayton Bay
    - Topographic survey at Filey Bay

- Partial Measures survey annually each spring comprising:
    - Beach profile surveys along 20 transect lines
    - Topographic survey at Runswick Bay
    - Topographic survey at Robin Hood's Bay
    - Topographic survey at Filey Bay (Town coverage)

- Cliff top survey annually at:
    - Staithes
    - Robin Hood's Bay (added Spring 2010)
    - Scarborough South Bay (added Spring 2010)
    - Cayton Bay
    - Filey

The location of these surveys is shown in Figure 2. The Full Measures survey was undertaken along this frontage between 3rd and 21st September 2012. The weather for Runswick, Robin Hoods Bay, Cayton, Filey Scarborough North and Scarborough South surveys was fine and dry with a calm sea state. When Whitby was surveyed the weather was windy, bright and dry with a moderate sea state.

All data have been captured in a manner commensurate with the principles of the Environment Agency's *National Standard Contract and Specification for Surveying Services* and stored in a file format compatible with the software systems being used for the data analysis, namely SANDS and ArcGIS. This data collection approach and file format is comparable to that being used on other regional coastal monitoring programmes, such as in the South East and South West of England.

Upon receipt of the data from the survey team, they are quality assured and then uploaded onto the programme's website for storage and availability to others and also input to SANDS and GIS for subsequent analysis.

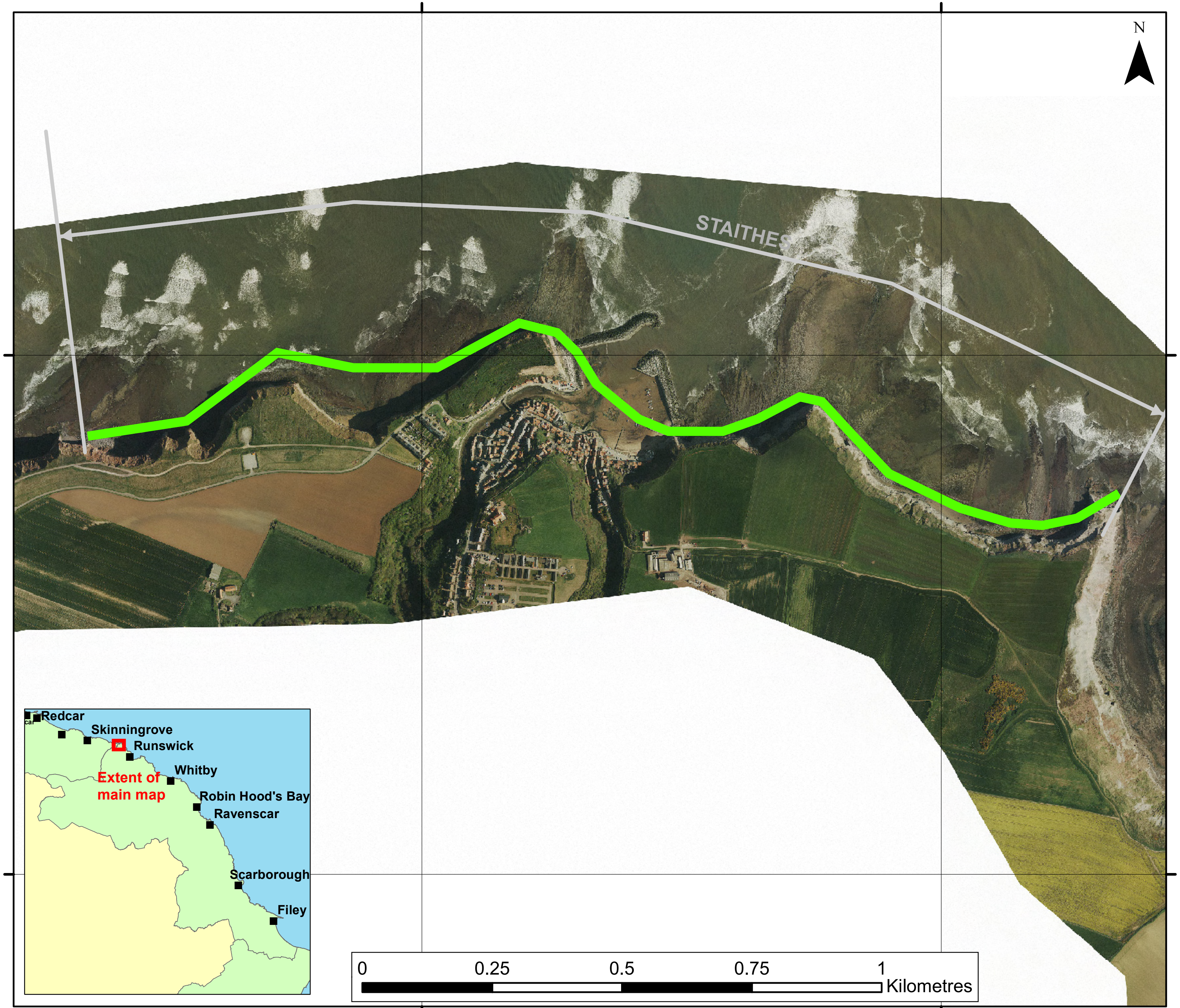
The Analytical Report is then produced following a standard structure for each authority. This involves:

- description of the changes observed since the previous survey and an interpretation of the drivers of these changes (Section 2);
- documentation of any problems encountered during surveying or uncertainties inherent in the analysis (Section 3);
- recommendations for 'fine-tuning' the programme to enhance its outputs (Section 4); and
- providing key conclusions and highlighting any areas of concern (Section 5).

Data from the present survey are presented in a processed form in the Appendices.

In addition to the typical analysis undertaken for a full measures survey, this report includes two additional pieces of work:

- review of high resolution cliff monitoring at Staithes that has been undertaken by Durham University using laser scanning data. Data are summarised in the report section for Staithes and provided in full in Appendix D.
- analysis of beach survey data from South Bay Scarborough undertaken in April and May 2012 immediately before and after a beach reprofiling scheme. This work comprises an assessment of different methods for deriving beach volumes and an interpretation of teh data collected. Results are summarised in the Scarborough South Bay section of this report and provided in full in Appendix E;



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

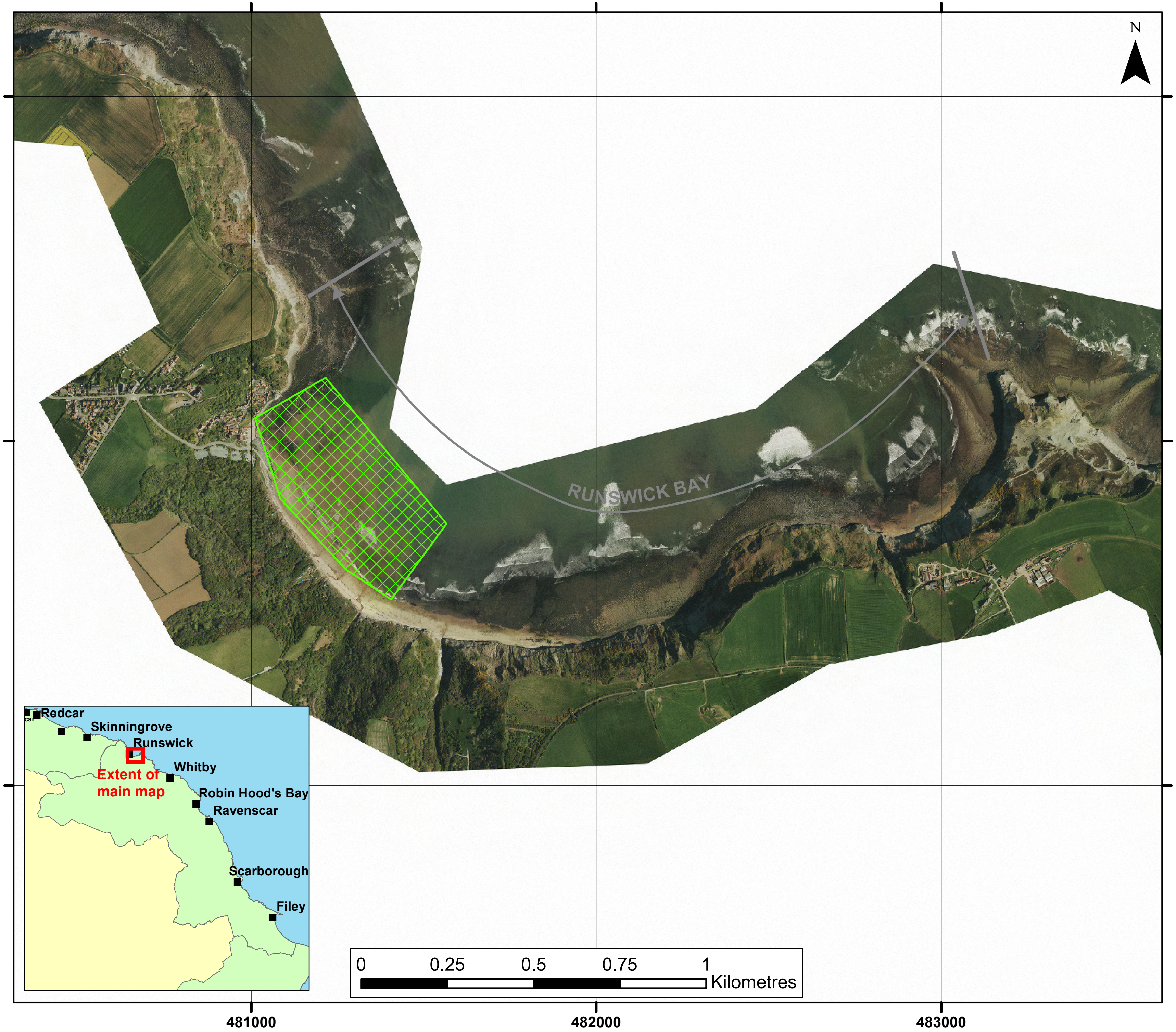
Figure 2 - Map 1
Survey Locations
Staithes
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 2
Survey Locations
Runswick Bay
Scarborough Borough Council

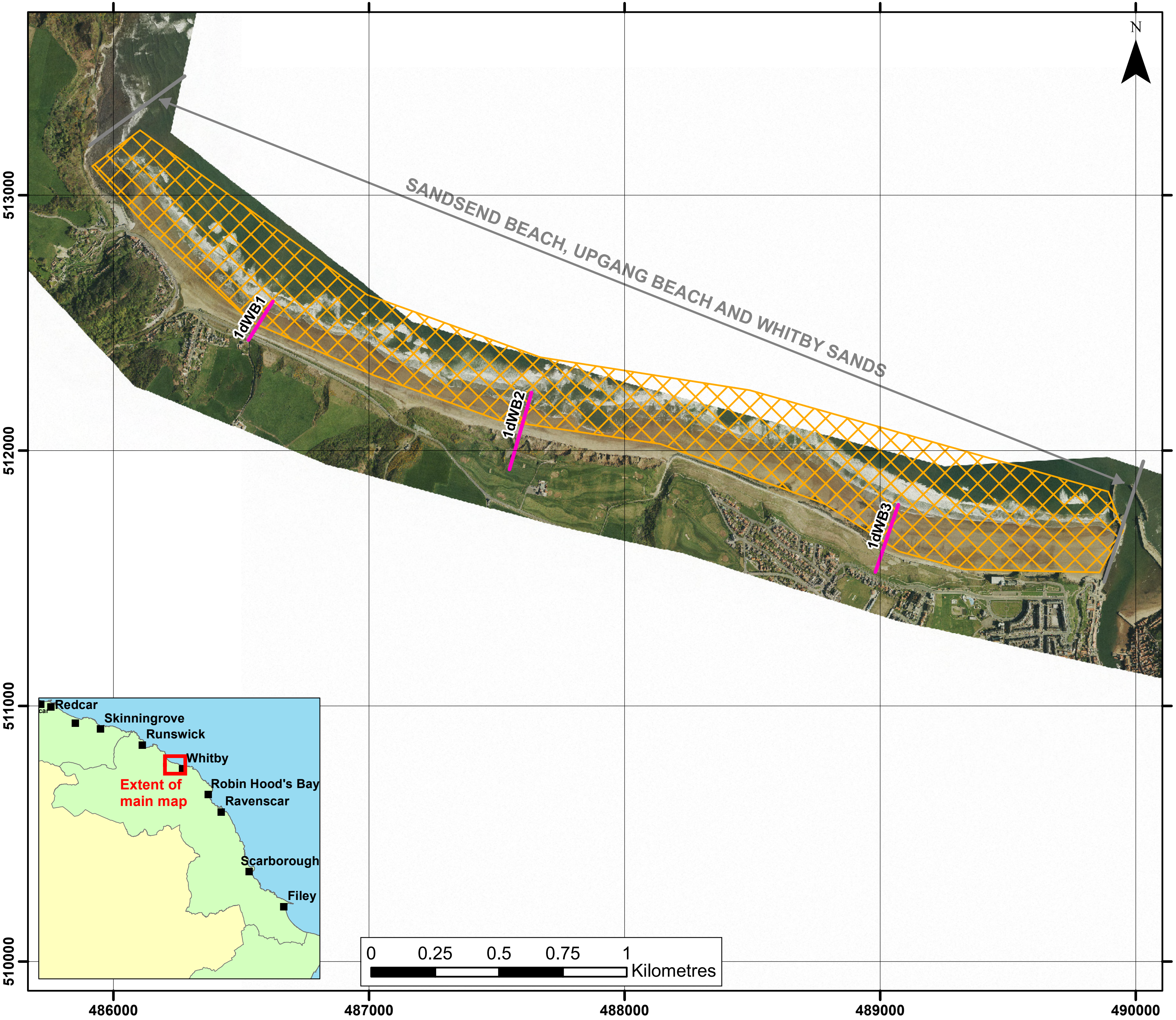
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 3
Survey Locations
Sandsend to Whitby
Scarborough
Borough Council

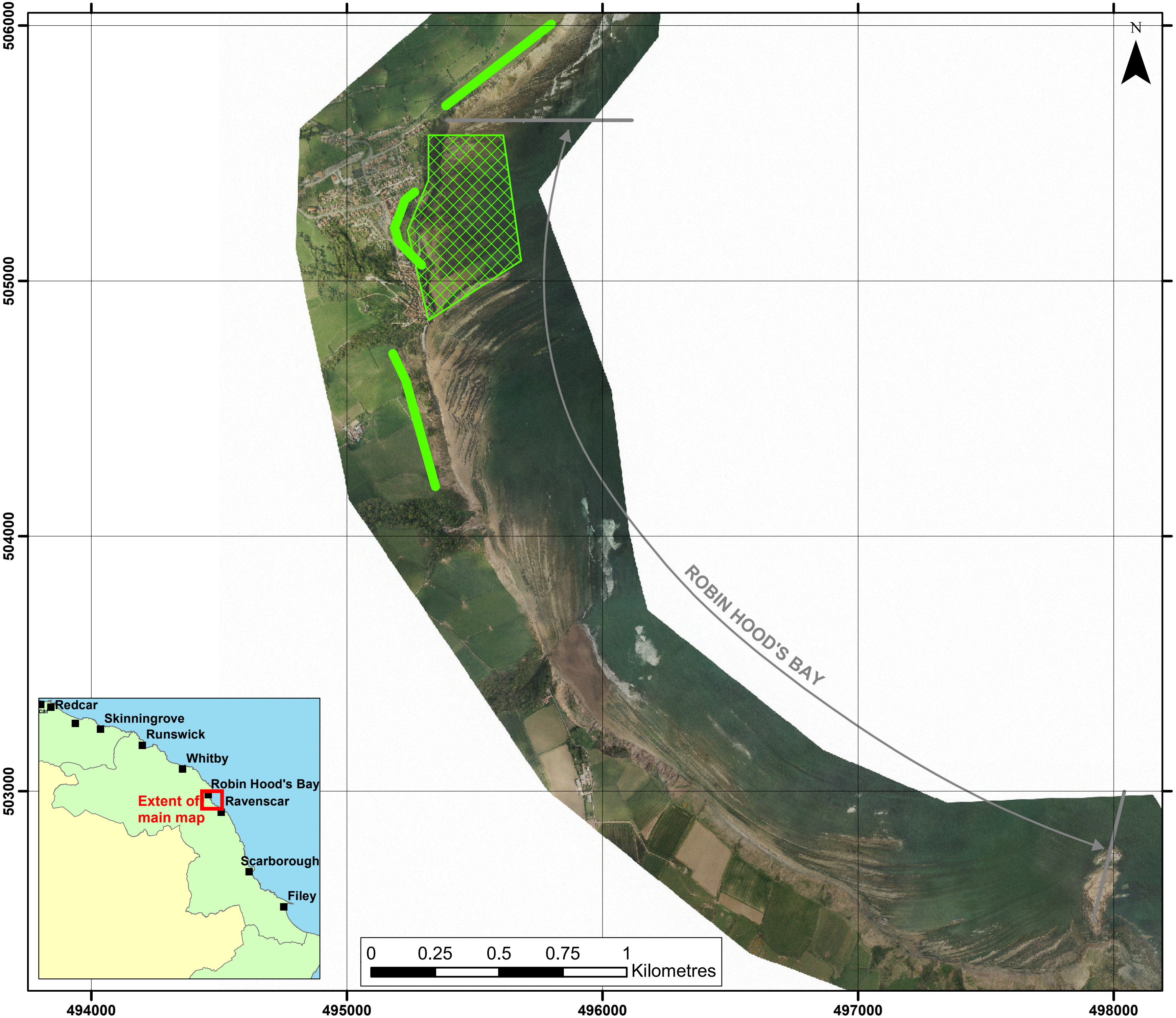
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

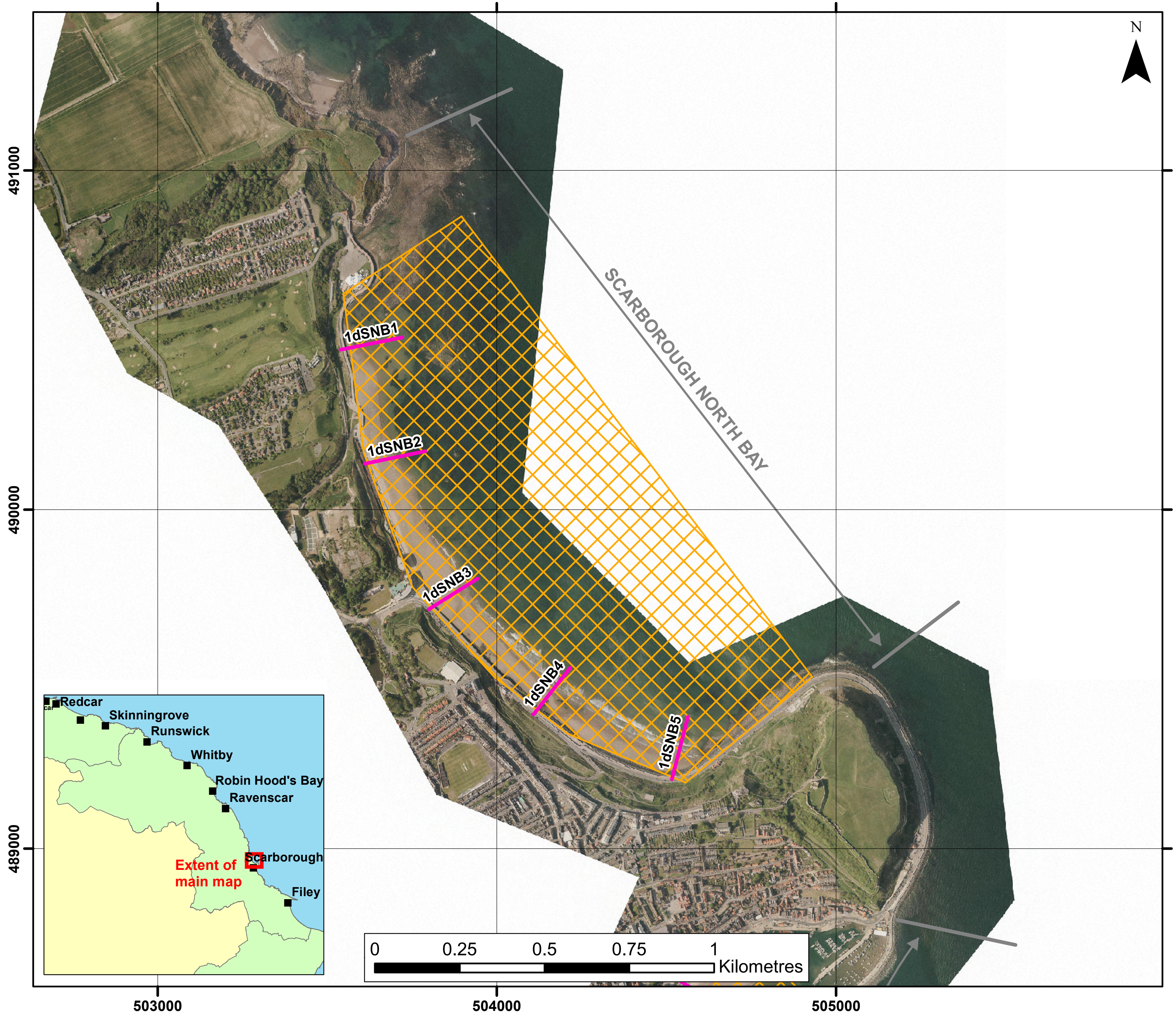
Figure 2 - Map 4
Survey Locations
Robin Hood's Bay
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

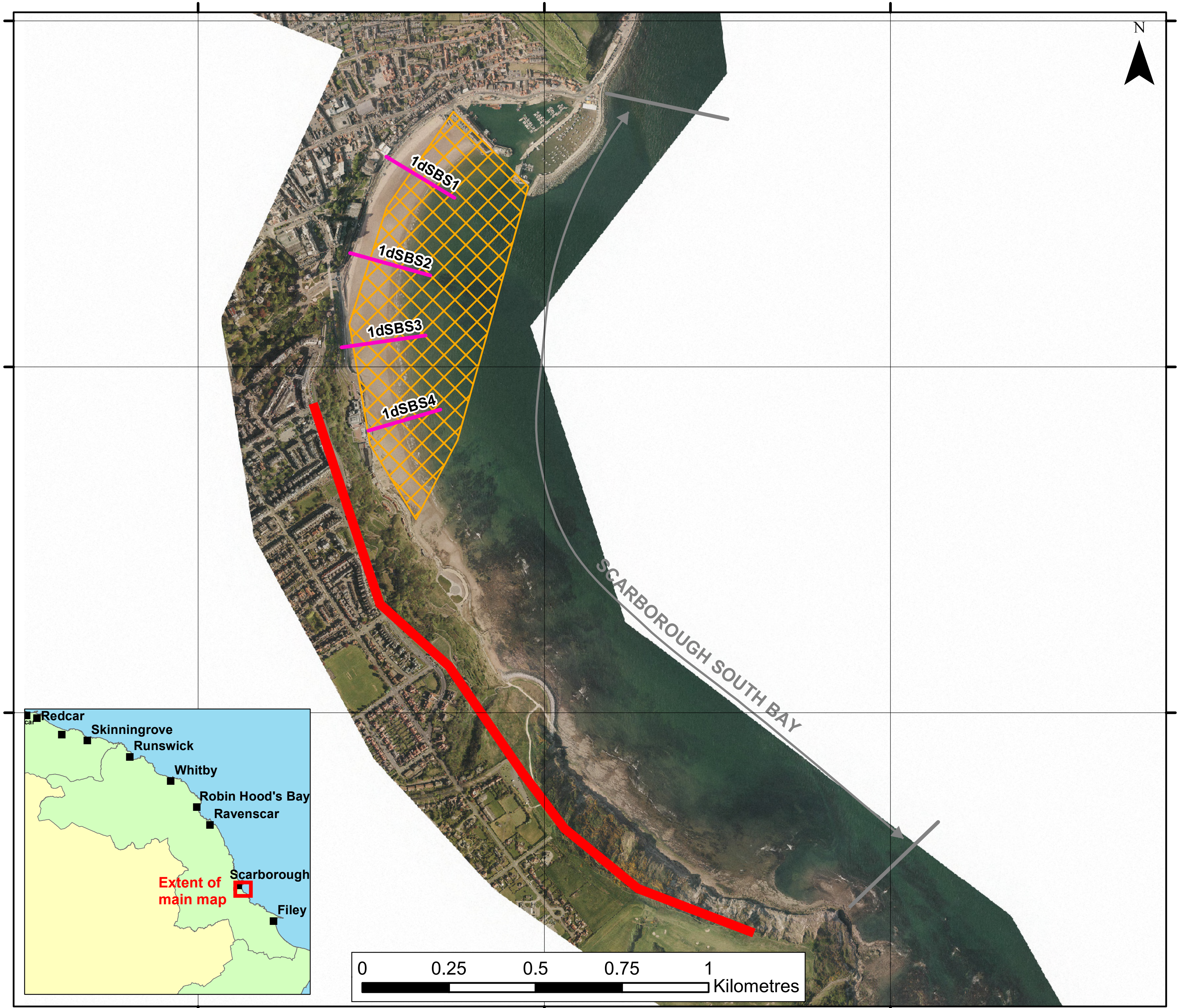
Figure 2 - Map 5
Survey Locations
Scarborough North Bay
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

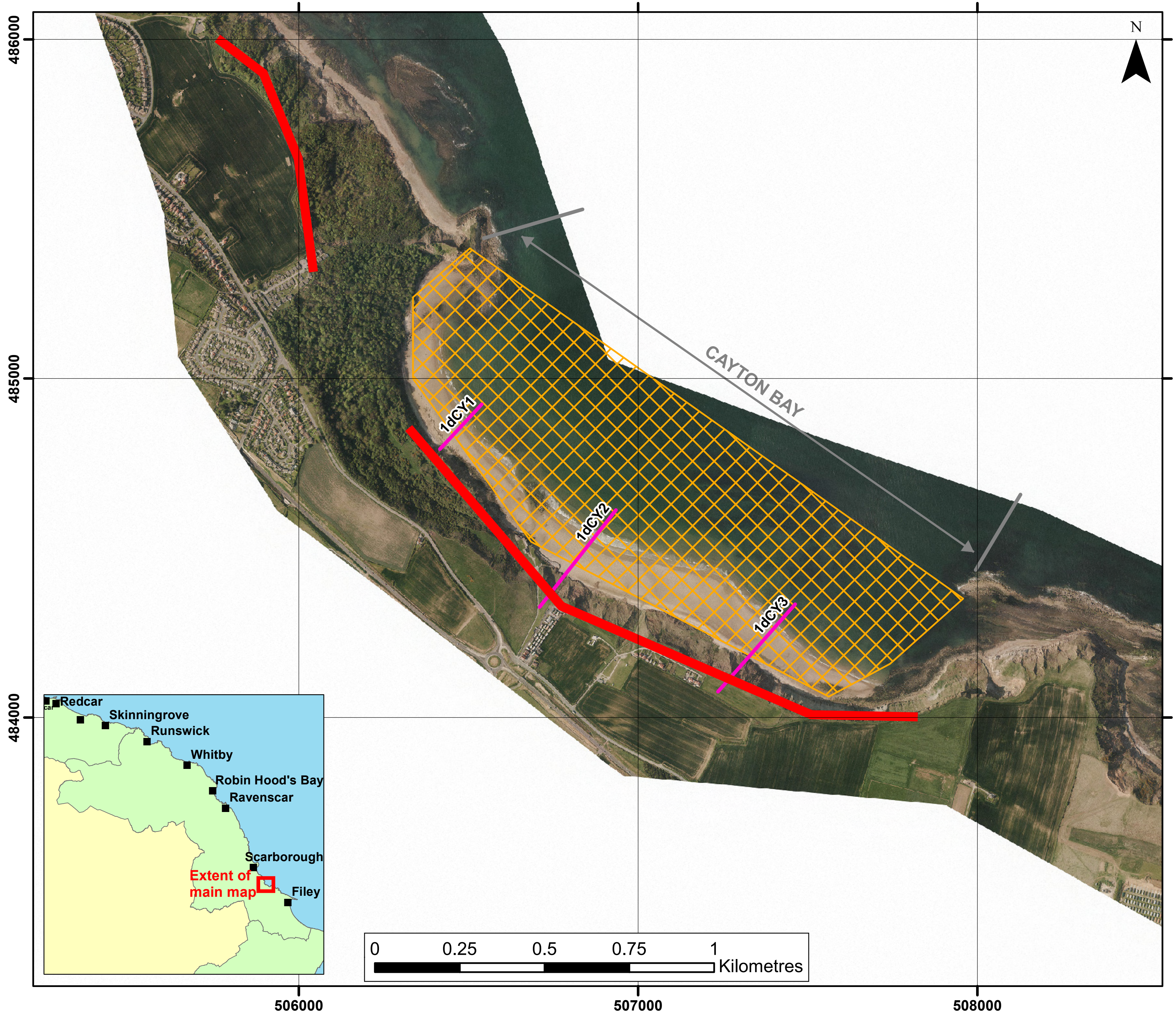
Figure 2 - Map 6
Survey Locations
Scarborough South Bay
Scarborough Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 7
Survey Locations
Cayton Bay
Scarborough
Borough Council

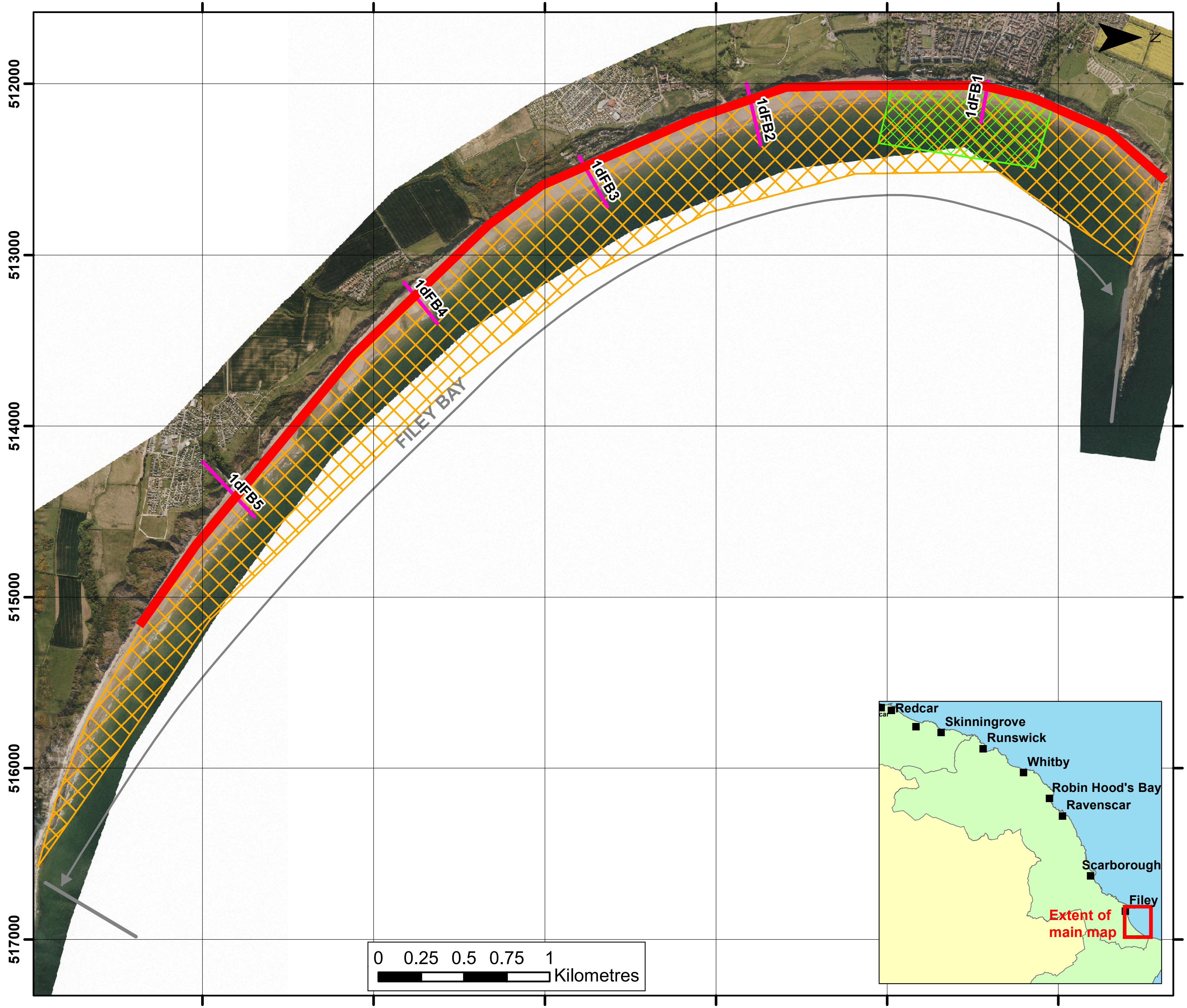
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 8
Survey Locations
Filey
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

2. Analysis of Survey Data

2.1 Staithes

Survey Date	Description of Changes Since Last Survey	Interpretation
September 2012	**Cliff-top Survey:** Twenty ground control points have been established at Staithes for biannual cliff top monitoring. The separation between any two points is around 100 m. Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing. Between March 2012 and September 2012 fifteen of the twenty posts showed change within a range of ±0.1m, which is not considered significant. Four posts showed growth of the cliff, which is likely to be error in the measurement. Post number 7 showed the largest negative change of all of the posts, with a value of -0.1m of erosion. Calculation of erosion rates based on the recorded change between 2008 and 2012 indicates that half (10 posts) of the frontage has recorded a change rate within a range of ±0.1m/yr, which is considered to be within the error of the measurement. Eight of the remaining pots have positive rates, which is due to error. Two posts show erosion, Post 4 (on the open coast near Cowbar Lane) has a rate of -0.2m/yr and Post 13 (near the eastern breakwater) has a rate of -0.6m/yr. This pattern was very similar to that observed in the 2012 Partial Measures Report. Appendix C provides results from the September 2010 survey, showing the distance from the ground control point to the edge of the cliff top along the defined bearing and changes in position since the November 2008 baseline survey. A second study of cliff failure for Cowbar Nab is being carried out by Durham University. A laser scanner is used to monitor the surface of the cliff and measure the amount of retreat experienced on the face. The area covered by the Durham study is between Points 7 and 10 of the cliff top survey. The average annual rate for Points 7 to 10 varies between-0.1 to +0.3m/yr based on the change between 2008 and 2012. A first annual report was published in February 2012 and is available in Appendix D. The method of the study was to “measure the survey area from the cliff surface in the laser scan (9,125.2 m2). The total	The majority of the Staithes frontage has remained stable over the summer of 2012. There was concern raised due to numerous cliff falls on the eastern part of the bay, close to Point 13. However, that survey location recorded minimal change (0.03m) as the cliff failure did not affect that survey line. **Longer term trends**: Table C1 shows that survey location 13 has shown the greatest total erosion with a loss of 2.3m (±0.1m) between the November 2008 baseline and September 2012, resulting in a long term average recession rate of 0.6m/yr. The other survey location showing recession is Point 4, which has a rate of 0.2m/yr. The higher rates for these points are likely to be due to one or two large failures of the cliff, rather than progressive recession. When the large loss is put into the recession rate calculation and averaged over five years it gives a comparatively high rate. The record of cliff recession should be collected over a longer term in order to provide more accurate rates. The Durham University report (Appendix D) averages the loss of material across the whole face and is noticeably higher than the erosion rate provided by the coastal monitoring. This may mean that the cliff is steepening and that the erosion of the cliff top will

Survey Date	Description of Changes Since Last Survey	Interpretation
	number of measured rockfalls during this period was 9,968, with a total volume of 318.99 m^3. This equates to a spatially averaged erosion rate of 1.99 x 10-3 myr^{-1}, over this 15-month period. The maximum monthly erosion rate was 3.7x 10^{-3} myr^{-1} (Feb, 2012), and the minimum 0.01 x 10^{-3} myr^{-1} (May, 2011)" (see Appendix D). The Durham University study is a high resolution precise pattern of change on the cliff face, which is not directly comparable with the six-monthly record of cliff top recession. In coming years the Durham study will have recorded data for a longer period, meaning that there will be more confidence in the averages.	catch-up with a period of large falls affecting the top of the cliff. Further years of high resolution of the face by Durham will give much more confidence in the erosion rates and capture any large failures which affect the cliff top.

2.2 Runswick Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
6th Sept 2012	**Topographic Survey:** Runswick Bay is covered by a 6-monthly topographic survey. A consistently applied routine of GIS processing have been used to create a digital ground model (DGM) (Appendix B - Map 1a) and to calculate the differences between the current topographic survey (Autumn 2012) and the previous survey (Spring 2012). In all cases, a 5m raster grid has been used to identify areas of erosion and accretion. (Appendix B – Map 1b). Appendix B - Map 1b shows the majority of the beach at Runswick Bay eroded by between 0.25m and 0.5m over the summer of 2012. The erosion is more concentrated in some areas (such as the shingle bar), which have losses of up to 1m. Other areas with severe erosion of up to 1m are concentrated in isolated patches close to the shoreline in the south of the bay. There were parts of the bay near the shoreline which showed little change, such as close to the rocks in the north of the bay. There was up to 0.4m of accretion close to the rock in the north of the bay and on the beach in the extreme south of the difference plot. **Long Term Topographic Trends Winter 2008 to Autumn 2012:** Appendix B - Map 1c shows that the bay appears to have accreted by around 0.5m overall. However, there are two large patches of erosion are shown on the plot. The first is in the mid-beach in the centre of the bay where up to 1m of erosion was recorded. The second is in the north of the bay near the village and in front of the defended section, where around 0.75m of material was lost.	During 2012 Runswick Bay showed signs of widespread erosion, which is not expected during the summer months. Accretion was noted close to the rock outcrops in the north of the bay. The other area of accretion was in the south of the bay, where the mouth of the stream could have lead to deposition of sediment. **Longer term trends**: The erosion of the shore was also noted in the 2011 Full Measures Report. It may be that there is a lag between material being deposited on the beach from the eroding cliffs and the fines being washed offshore. In the centre of the bay there is a large bar, which persisted but experienced loss of sediment over the summer of 2011 and 2012. There are also areas of erosion close to the shore along the defended sections of the bay **Autumn 2008 to Autumn 2012 trends:** The long term difference plots show that the upper and lower extents of the survey have been accreting. The observed erosion is centred on specific areas, rather than being scattered throughout the bay. The patch of erosion in the north of the bay appears to be related to the veneer of sediment over the rocks which outcrop on the foreshore here. Overall the bay appears to be stable but the erosion in the mid-bay could be a precursor to erosion at the back of the bay.

2.3 Sandsend Beach, Upgang Beach and Whitby Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
20 and 21st Sept 2012	**Beach Profiles:** The frontage spanning Sandsend Beach, Upgang Beach, and Whitby Sands is covered by three beach profile lines, spaced between Sandsend and Whitby West Cliff (Appendix A). At profile **1dWB1** the beach level has eroded by around 0.5m between HAT and 85m chainage. Beyond 85m chainage the profile is relatively high and very similar to the September 2011 profile. At **1dWB2** the profile above the HAT level has not changed significantly. Academy Geomatics reported that the middle of section 2 was not accessible due to "soft grass, sand and deep fissures present in the slumping mud". The beach has accreted by around 0.25m to 0.75m since March 2011. The beach profiles were very similar in September 2011 and September 2012. At profile **1dWB3** the stabilised face of Whitby West Cliff demonstrates negligible change. When compared to the other profiles the beach surface is similar to that previously existing, The beach below MHWS has been variable over the years but shows no real trend in behaviour. Close to the seawall a mound of material which had developed in March 2012 had been eroded by September 2012. On the beach below that level the September 2012 profile is around 0.3m higher than the March 2012 profile. **Topographic Survey:** The Sandsend to Whitby frontage is covered by an annual topographic survey, providing continuous survey of Sandsend Beach, Upgang Beach, and Whitby Sands. Data have been used to create a DGM (Appendix B – Maps 2a and 3a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Autumn 2012) and the earlier topographic survey DGM (Autumn 2011), with 5m raster grids (as shown in Appendix B – Maps 2b and 3b), to identify areas of erosion and accretion. Appendix B – Maps 2b and 3b show a reasonably equal distribution of accretion and erosion. The accretion tended to be concentrated in the south and erosion in the north, although there was no clear pattern. The changes in 2011 and 2012 can be divided into three main areas. At Sandsend (Appendix B - Map 2b) from the western edge of the topographic survey to East Row beck there are patches of	The profile at WB1 was the only profile which had developed a concave cross-section since March 2012. Profiles WB2 and WB3 have flattened over the summer. The volume of each of the profiles appears to be similar between March 2012 and September 2012. The upper beach has eroded and the lower beach has accreted but flattened overall. The topographic difference plots do not show a straightforward pattern to the distribution of erosion and accretion. However, the losses and gains in the centre of the Bay are much more pronounced than at the distal ends of the Bay where the changes tend to be smaller. This distinction between the large changes in the middle of the bay with modest change at each end of the bay was also noted in 2010 and 2011. The central area of this frontage near Upgang runs from the Eat Row Beck to the eastern end of Whitby Golf Course. The cliffs on this part of the bay are undefended and erode to provide a source of material to the beach. It is considered likely that during the winter months the cliffs erode depositing material on the beaches which is redistributed through the spring and summer. **Longer term trends**: the beach profiles show seasonal variation but no linear trend of accretion or erosion.

Survey Date	Description of Changes Since Last Survey	Interpretation
	around ±0.5m erosion or accretion in adjacent areas. There is no obvious pattern of where the erosion or accretion occurs in front of Sandsend, although there has been up to 1m of material lost along the whole of the defended frontage in a thin strip. The central area of this frontage (Appendix B – Maps 2b and 3b) near Upgang runs from the East Row Beck to the eastern end of Whitby Golf Course. This area has been subject to significant erosion and accretion during the summer of 2012. This central part of the frontage is much more dominated by shore-parallel strips of change. There is severe erosion of up to 1.5m in the middle of this frontage close to the high water line in a wide strip. There is also 1m loss of material at the toe of the cliff in front of the Golf Course. Accretion of up to 1m was recoded directly in front of the golf course and at the seaward extent of the survey with up to 1m of erosion recorded in-between. The lower beach in the central area tended to be dominated by accretion of around 0.75m to 1m. The southern third of the shoreline is Whitby, between the golf course and harbour walls (Appendix B – Map 3b). The Whitby frontage has not been subject to large scale erosion or accretion, the changes have been more patchy and subdued (±0.25m) than in the central third of the bay. Overall this part of the bay is dominated by accretion of up to 0.5m. There is an area of over 1m of accretion which runs parallel to the shore in the middle of foreshore. There are adjacent areas of slight (<0.5m) erosion also running parallel to the shore. There has been moderate accretion of up to 0.5m on the part of the Whitby Beach in front of West Cliff for the second year. Beach profiles and the topographic survey data were collected at the same time. However, interpretations of beach change are different for each data series; this reflects the use of different baseline data, i.e. beach profiles (March 2010, partial measures data), and topographic survey (October 2009, full measures data) in the respective comparisons. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term difference in surface elevation between 2008 and 2012 is shown in Appendix B Maps 2c and 3c.The Sandsend to Whitby frontage (Appendix B Map 2c) can be divided into three different areas based on the long term difference plot. The Sandsend frontage has accreted by around 0.75m overall but there are patches of erosion at the northern extent of the frontage where up to 0.75m has been lost. The centre of the bay, around Whitby Golf Club, has the most pronounced erosion and accretion (Maps 2c and 2c). There are patches or bands of erosion up to 0.75m on the mid beach in the centre of the bay which are separated by a swath of accretion of up to 0.5m. There is a strip of accretion of up to 1m	The topographic difference plots show very similar trends of accretion and erosion in the 2011 and 2012 difference plots. The patchy distribution of the areas of accretion and erosion show that sediment from the cliffs or alongshore appears to be redistributed within the bay with minimal offshore movement. **Autumn 2008 to Autumn 2012 trends:** The difference plot for the changes between 2008 and 2012 shows that the changes in the centre of the bay are more pronounced than at the ends. There are strips of accretion and erosion on the long term plot. The erosion in front of the cliffs had been assumed to be due to fluctuations in beach level due to the feeding of the beach from cliff erosion and then the material being moved offshore. It was considered that the beach had been reasonably stable. The plot shows that between 2008 and 2012 the beach close to the toe of the cliff has eroded in a thin strip. So the erosion may be progressive. However, it is also possible that the sediment is being redistributed in the bay due to the patchy nature of the accretion and erosion. Longer term plots would help to delineate the behaviour of the beach.

Survey Date	Description of Changes Since Last Survey	Interpretation
	in the centre of the bay at the seaward extent of the survey. The southern third of the frontage in front of Whitby has changed less than the frontage to the north (see Appendix B Map 3c). The observed changes tend to be within the 0.5m band. The frontage has accreted overall. There is a strip of erosion close to the defences in Whitby where around 0.5m of material has been lost.	

2.4 Robin Hood's Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
19th Sept 2012	**Topographic Survey:** Robin Hood's Bay is covered by a six-monthly topographic survey. Data have been used to create a DGM (Appendix B - Map 4a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Autumn 2012) and the earlier topographic survey DGM (Spring 2012), with 5m raster grids (as shown in Appendix B – Map 4b), to identify areas of erosion and accretion. Appendix B - Map 4b shows a very patchy distribution of areas of accretion and erosion. Overall the bay has eroded by around 0.1m-0.2m over the summer of 2012, although there are parches of accretion in the bay. Areas showing the greatest deposition were concentrated over the rocks in the north of the Bay. There was an isolated area of around 1m of erosion close to the shore in the centre of the Bay. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The plot of difference between 2008 and 2012 (Appendix B - Map 4c) shows a very patchy distribution of accretion and erosion. There is no pattern to the changes but the orientation of some of the erosive patches is affected by the outcropping rocks on the foreshore. Much of the centre and seaward extent of the bay has eroded by 0.5m since 2008. However, there has been accretion of around 0.75m close to the top of the beach and the upper extent of the survey.	The topographic change plots show that the Bay as a whole appears to have been subject to slight erosion. Although the changes on the difference plot are generally small, the pattern was observed in the 2010 and 2011 Full Measures Reports. The cliff survey data shows that 3 of the 13 survey points showed erosion of around 0.1m over the summer. The locations which recorded erosion were posts 1, 3, and 7. The rest of the posts were stable between March and September 2012. Overall the cliffs at Robin Hoods Bay have been stable with minimal change since cliff-top monitoring began in 2010. Marker 1 has had consistent recession and currently has a high rate. The annual rates show that four of the 13 points had been subject to erosion through the duration of the data collection. However,

Survey Date	Description of Changes Since Last Survey	Interpretation
	Cliff-top Survey: Thirteen ground control points have been established at Robin Hood's Bay (since March 2010) to monitor the cliff top The separation between any two points is around 200m Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing. The results are unlikely to be representative of the long-term trends because the data has only been collected over a short amount of time. Table C2 shows that, taking into account the survey accuracy of +/-0.1m, seven of the 13 markers had no change in cliff top position between March 2012 and September 2012. Of the other remaining markers three show advance of the cliff, which suggests survey error. Three of the markers had recession of 0.1m between March 2012 and September 2012. The erosion rates based on the data recorded between March 2010 and September 2012 illustrate little change in eight markers. One marker shows growth of 0.2m/yr, although this is due to errors. The remaining four posts (locations 1, 5, 7 and 10) had erosion of between -0.1 and -1.4m/yr.	this is the second year of this type of monitoring it is difficult to tell the long term trends from the natural variability and any errors in the measurements. **Longer term trends:** The limited change in Robin Hoods Bay is likely to be due to the relative erosional resistance of the rock platforms and the limited sediment supply to the bay. In contrast, the erosional hotspots are likely to correspond to local pockets of more mobile sand adjacent to the shore. **Autumn 2008 to Autumn 2012 trends** Although the long term plot shows accretion and erosion much of the bay has been subject to little change due to the shallow nature of the veneer beach. Accretion was recorded on the upper beach close at the landward extent of the survey.

2.5 Scarborough North Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
19th Sept 2012	**Beach Profiles:** Scarborough North Bay is covered by five beach profile lines, spaced between the Sealife Centre at Scalby Mills to Clarence Gardens (Appendix A). Profile **1dSBN1** remains stable for the defended, upper part of the profile. From 10m to 60m chainage the beach has accreted by up to 0.1m since March 2012. Below 60m chainage the profile has remained stable over the previous six months of summer. . At **1dSBN2** the beach is characterised by a shifting berm in the profile, which can form on the upper or lower beach. In September 2012 the berm is on the upper beach and is very large, it has accreted by 0.8m since March 2012. From the edge of the berm at 50m chainage to the rocks the level of the beach has dropped by 0.2m. When compared to the profiles dating back to November 2008 the upper beach is high and the lower beach is close to the middle of the range of results. The beach at profile **1dSBN3** is well within the limits of variability observed at this location. The beach profile has flattened in the upper beach, so the upper beach has eroded by 0.5m and the mid beach has accreted by 0.4m since March 2012. From 70m chainage to the end of the profile the beach level has dropped by 0.2m over the summer of 2012. The beach at profile **1dSBN4** is around 0.5m higher than the other recorded profiles. Between chainage c. 30-60 m the uneven topography includes rock platform and boulder deposits. The rocky part of the beach from 40m to 60m chainage is buried in September 2012 by up to 1m of material compared to the rocks being exposed in September 2011. The large accumulation of material on the upper beach gradually reduces down the profile so that by the end of the profile the beach level is comparable with the March 2012 profile. On profile **1dSBN5** the gradient of the beach is similar to the March 2012 survey, but the beach has accreted by 0.2-0.4m throughout the profile.	The beach levels for profiles SBN1, SBN2, SBN4 and SBN5 in North Bay were relatively high in September 2012. The September 2012 profile SBN3 was closer to the middle of the range of results. The accretion observed in North Bay could be due to the beach forming processes which dominate the shore over the summer months. However, it is considered more likely that the beach has been renourished or managed to provide amenity value. The plot of change between topographic surveys shows very little change in beach topography over the summer of 2012. Erosion persisted over the rocks in the northern part of the bay but it was not as severe as over the summer of 2011. The lack of erosion or accretion observed at Scarborough North Bay may be due to beach management methods, rather than natural processes. **Longer term trends:** The beach over the longer term looks at through it will be stable. Although this could be due to ongoing management. **Autumn 2008 to Autumn 2012 trends:** There has been little overall change in North Bay, with the

Survey Date	Description of Changes Since Last Survey	Interpretation
	Topographic Survey: Scarborough North Bay is covered by an annual topographic survey. Data have been used to create a DGM (Appendix B - Map 5a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Winter 2011) and the earlier topographic survey DGM (Spring 2011), with 5m raster grids (as shown in Appendix B – Map 5b), to identify areas of erosion and accretion. Appendix B - Map 5b shows that the centre of the Bay has changed very little over the summer of 2012. The majority of changes shown in the difference plot are ±0.25m, but the bay was dominated by slight accretion overall. The erosion and accretion is patchy, but there was more erosion recorded in the north than in the south. The nearshore has accreted by around 0.5m along much of the frontage. In the 2011 Full Measures Report a band of erosion was observed in the northern third of the bay and described as a zone of erosion running oblique to the shore for c. 700m. The erosion was severe in some places with up to 2m of material lost since the winter of 2010. A zone of accretion was observed in the same part of the bay as the erosion band in the 2010 Full Measures Report. However, the erosion which was described in the 2011 Full Measures Report was not present in the summer of 2012. Erosion continued around the rock outcrops in the north of the bay through the summer of 2012. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term topographic plots in Appendix B – Map 5c show that the north of the bay has been dominated by accretion while the south of the bay has been subject to erosion. The accretion in the north of the bay is concentrated close to the defended section where up to 1m of material has been deposited further down the beach the accretion is around 0.5m over the four-year period. The southern half of the bay has also been subject to accretion of around 0.5m but erosion of up to 0.75m has occurred on the upper and lower extents of the beach.	majority of the frontage experiencing erosion or accretion within a range of ±0.25. The erosion and accretion which has occurred points to a northward transport of material within the bay but this is the comparison between two 'snap-shots' so it may be misleading.

2.6 Scarborough South Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
18th Sept 2012	**Beach Profiles:** Scarborough South Bay is covered by four beach profile lines, spaced between the Harbour in the north and The Spa Complex in the south (Appendix A). At profile **1dSBS1** the mound of material which was near to the seawall has been eroded by 0.8m since March 2012 and the face of the seawall exposed. Between HAT and MHWS the beach has eroded by 0.8m over the summer of 2012. Between 55m and 120m there has been accretion and erosion, but little overall change. From 120m chainage to the end of the survey the beach has become much steeper since March 2012. In previous surveys the beach at profile **1dSBS2** has been flat. In the September 2012 survey there are three mounds of material recorded on the profile. The beach does not appear to have accreted or eroded since March 2012 because the undulating gains and losses on the profile has been centred around the flat March 2012 profile. The September 2012 profile **1dSBS3** is high compared to previous profiles. The beach between 5m and 105m chainage has accreted by 0.4m over the summer of 2012. Beyond 105m chainage the beach has changed very little since March 2012. At profile **1dSBS4** the defended part of the shore remains stable though the profiles. The beach between chainage 20 and 90 has accreted by 0.2m and is the highest that part of the beach has been. Between 100 and 170m the beach has eroded by 0.2m since March 2012. Beyond 170m the beach was stable over the summer of 2012. **Topographic Survey:** Scarborough South Bay is covered by an annual topographic survey. Data have been used to create a DGM (Appendix B - Map 6a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Autumn 2012) and the earlier topographic survey DGM (Spring 2012), with 5m raster grids (as shown in Appendix B – Map 6b), to identify areas of erosion and accretion.	Over the summer of 2012 the beach at Scarborough remained stable at SBS 2 and 4. SBS1 had eroded and SBS3 had accreted. The beach behaviour is considered to be due to re-profiling, rather than marine processes. Along SBS 3 and 4 as well as parts of SBS2 the beach level was higher than in previous surveys. The topographic survey change plots show bands of shore parallel changes in accretion and erosion. The plots in the 2010 and 2011 Full Measures Report showed a very similar pattern, but with erosion at the upper beach close to the shore. The pattern of shore parallel bands in the bay is likely to be due to the refraction of the incoming waves within the bay points to the stability of the bay form. The beach itself is showing signs of accretion on the upper beach, which broadly agrees with the profile data. The beach management activities carried out by Scarborough Council are the likely cause of some of the changes seen in South Bay. As a result, the accretion of material seen in these profiles may be due to human action rather than coastal processes. Table C3 shows that since March 2010 the majority of the profiles have shown minimal recession rates. Of the significant rates the highest is 0.2m/year at

Survey Date	Description of Changes Since Last Survey	Interpretation
	Appendix B - Map 6b shows that the northern part of the survey is characterised by a sequence of shore parallel changes including deposition at the rear of the beach with erosion further seaward, and then deposition at the beach toe and erosion on the foreshore. All of the changes are less than 0.5m in magnitude. This is the third consecutive year where this pattern has been observed. The shore-parallel trend weakens as you move south so that at the southerly end of the beach the pattern becomes patchy although the magnitude of change remains the same (±0.5m of difference). Overall there has been little change in topography in Scarborough South Bay. The current beach profiles and the topographic survey were collected on the same day. However, interpretations of beach change are in large part different between these data series; this reflects the use of different baseline data, i.e. beach profiles (March 2010, partial measures data), and topographic survey (October 2009, full measures data) in the respective comparisons. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term plot of change (Appendix B Map 6c) shows that Scarborough South Bay has eroded overall. There is a swath of erosion running north to south down the middle of the beach. In the north there are a number of shore parallel bands which make up the whole feature. The erosion tends to be around -0.75m the swath of erosion gets thinner and less severe towards the south. The southern part of the bay has seen modest accretion of up to 0.5m.	locations 6 and 11. The data collection will need to continue for a number of years before an accurate picture of the behaviour of these cliffs is established. **Longer term trends**: The beach profiles appear to show that beach levels are high and have been accreting. The extent to which this is due to marine processes or active management is unknown. **Autumn 2008 to Autumn 2012 trends:** The bay has been subject to erosion throughout most of the bay. The most severe erosion was observed in the north of the bay. However it is known that beach re-nourishment schemes in this area take material from the north and deposits it on the south of the bay. As a result it is considered that the changes shown on the plot are not likely to be natural, because the prevailing long-shore drift direction is northwards.
	Cliff-top Survey: Thirteen ground control points have been established at Scarborough South Bay, extending from South Bay to Cayton Bay for the purposes of cliff top monitoring. The separation between any two points is around 300 m. The cliff top surveys at Scarborough South Bay are undertaken bi-annually. Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing. Between March 2012 and September 2012 seven of the thirteen locations showed little or no change. One marker recorded growth, showing a larger error in the data set. The remaining five markers had been subject to erosion of 0.1m to 0.2m during the summer of 2012. The recession rates calculated for the period from March 2012 to September 2012 give a picture of the change over the longer term. Nine of the markers have a recession rate within the range of 0.1m/yr.	

Survey Date	Description of Changes Since Last Survey	Interpretation
	Four profiles show a rate of change of 0.1-0.2m/yr. These rates are based on a very limited dataset, many more years of monitoring are necessary before the rate can be calculated with any confidence. Appendix C provides results from the September 2012 survey, showing the distance from the ground control point to the edge of the cliff top along the defined bearing and changes in position since the March 2010 baseline survey.	
April 2012 to May 2012	**Volume Analysis of the Beach Reprofiling works for April/May 2012** GIS analysis of 3D topographic survey data and analysis of four 2D beach profiles data collected before and after the beach re-profiling scheme in April and May 2012 have been used to calculate changes in the volume of sediment in the beach. Two additional surveys collected in the Septembers before and after the reprofiling have also been assessed to put these changes in context. The GIS analysis indicates the volume gained on the southern part of the bay was c. 8,869m^3, while 8,511m^3 was lost from the northern section. The SANDS analysis indicates loss of 3,153m^3 in the north with a gain of 8,496m^3 in the south. The small imbalance in gains and losses in the GIS assessment reflects uncertainty about offshore sediment movements in the area beyond mean low water, where no survey data are available. The imbalance in the SANDS volume data is significantly greater and principally reflects the limited number of survey profiles and error introduced by interpolation between them.	Taken as a whole, the data (in Appendix E) suggest that a volume of c. 8,000m^3 was moved from the north of the bay to the south. The data also indicate that by September 2012, four months after the reprofiling work, the redistributed sediment had been transported back north as the frontage moved back to its equilibrium profile. The comparison of approaches indicates that the wide spacing of profiles limits the accuracy of any beach volume analysis undertaken in SANDS. This problem is eliminated in the GIS analysis of topographic data that provides a map of the spatial pattern of change and data on the volume of change. Both approaches are limited by the coverage of data that does not extend beyond mean low water and which therefore cannot determine the volumes of sediment transferred to the nearshore zone.

2.7 Cayton Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
5th Sept 2012	**Beach Profiles:** Cayton Bay is covered by three beach profile lines, spaced between Tenants' Cliff and the south of Cayton Sands (Appendix A). The cliff face at profile **1dCY1** is largely vegetated and was difficult for the surveyors to access. So there is low confidence in that part of the profile. The remainder of the survey shows little change since March 2012. There was 0.2m of accretion recorded between 100m and 110m chainage and around 0.3m of erosion between 110m and 125m chainage. The centre of cliff profile **1dCY2** could not be accessed for the survey, so there is low confidence in the centre of the profile. Overall the beach has remained stable since 2008 and was very similar to the September 2011 profile. Over the summer of 2012 the berm which had been present in the upper beach had eroded. The lower part of the beach from 210m chainage to the end of the profile has accreted by around 0.5m since March 2012. At profile **1dCY 3** The centre of this cliff profile could not be accessed for the survey, so there is low confidence in the centre of the profile. The profile above MHWS is very similar to that of March 2012. Below MHWS the beach has accreted by 0.5m overall although there is one area of slight (0.2m) erosion at around 190m to 200m chainage. **Topographic Survey:** Cayton Bay is covered by an annual topographic survey. Data have been used to create a DGM (Appendix B - Map 7a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Autumn 2012) and the earlier topographic survey DGM (Autumn 2011), with 5m raster grids (as shown in Appendix B – Map 6b), to identify areas of erosion and accretion. Appendix B - Map 7b shows that there has been up to 1m of erosion at the base of the cliff for the northern two thirds of the Cayton Bay frontage. The southern third has had up to 0.5m of accretion close to the high tide line. Further seaward on the foreshore there is a shore parallel bank of accretion of	The September 2012 profiles tend to be close to the middle of the range of previous profiles dating back to November 2011. Profile CY1 had flattened while the middle of both CY2 and 3 had eroded. Little overall change in beach volumes was observed through the profiles. The change plot of the differences between the March 2012 and September 2012 surveys shows variability in the erosion and accretion in the bay. The majority of the change in Cayton Bay was not significant. The difference plots from the 2010 and 2011 Full Measures Reports show a similar pattern of shore parallel bands of accretion and erosion. However the positioning of these bands of coastal change move over the years. The cliff top survey data shows that there was stability overall during the summer of 2012. The exceptions were markers 4 and 6 where 0.2m and 0.8m of erosion was recorded respectively. **Longer term trends:** The shore parallel band system in Cayton Bay has remained stable through 2010, 2011 and the summer of 2012. The patchy redistribution of sediment within the bay means that the changes to volume are likely to have been minimal.

Survey Date	Description of Changes Since Last Survey	Interpretation
	around 0.75m across much of the bay. This band was closer to the slope during the summer of 2011. The extent of the survey is dominated by two areas of significant erosion of around 0.5m, one in the middle of the northern half of the bay and the second in the centre of the bay. Both areas of erosion appear to be centred on sandbanks or rock out crops. These two areas of erosion are separated by an accreting area. The current beach profiles and the topographic survey were collected on the same day. However; interpretations of beach change are in large part different between these data series, this reflects the use of different baseline data, i.e. beach profiles (March 2010, partial measures data), and topographic survey (October 2009, full measures data) in the respective comparisons. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term difference plots in Appendix B – Map 7c show that the overall trend in Cayton Bay between 2008 and 2012 has been stability. The difference plot shows accretion and erosion but most of the changes are within a range of ±0.25m. The large changes observed are in localised patches throughout the bay. There are a number of patches in the north of the bay and close to the high tide line where erosion of around 0.75m has occurred. There is also a patch of up to 1m of erosion at the southern extent of the survey.	The cliff top survey results show little change or positive growth. There are three profile locations which show recession since November 2008. Points 1 and 6 have eroded by 0.2m/yr. The largest erosion rate has been recorded at Marker 2 which has a rate of 1.3m/yr. The overall pattern of change observed is similar to that in the 2011 Full Measures Report. **Autumn 2008 to Autumn 2012 trends:** The bay has stayed stable overall between 2008 and 2012. The most notable accretion has been in the mid beach but it has been moderate. A strip of erosion was noted at the base of the cliffs on the upper beach where 0.75m of erosion has occurred. The erosion at the base of the cliff may mean that there will be a knock-on effect on the cliff which may retreat. The remainder of the erosion has been limited to isolated patches.
	Cliff-top Survey: Eight ground control points have been established within Cayton Bay for the purposes of cliff top monitoring. The separation between any two points is typically around 200 m. The cliff top surveys at Cayton Bay are undertaken bi-annually. Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing. The results of the cliff top survey are varied, as shown in Table C4. Between March 2012 and September 2012 five of the eight profiles show very little change (within the ±0.1m accuracy of the survey). One point has shown growth – which points to larger errors in the data set. The remaining two profile locations, markers 4 and 6, show significant recession of 0.2m and 0.8m respectively. The rates calculated using the data collected since November 2008 show growth in four of the eight locations, which is likely to be due to errors in the data. Of the remaining markers, one shows stability and three show erosion. The data has only been collected over a few years so a better understanding of	

Survey Date	Description of Changes Since Last Survey	Interpretation
	the average trends will be gained through further years of monitoring. Appendix C provides results from the September 2012 survey showing the distance from the ground control point to the edge of the cliff top along the defined bearing and changes in position since the November 2008 baseline survey.	

2.8 Filey Bay

Survey Date	Description of Changes Since Last Survey	Interpretation
3rd and 4th Sept 2012	**Beach Profiles:** Filey Bay is covered by five beach profile lines, spaced between Filey Sands and Speeton Sands (Appendix A). At profile **1dFB1**, which is at Filey seawall, the overall the beach profile has fluctuated but shows no long term trend of accretion or erosion. The profile appears to have stayed static since March 2012 with very little change observed. The only parts of the profile that changed over the summer was between 17m and 25m change where there was 0.2m of erosion From 190m chainage to the end of the profile there was up to 0.1m of erosion recorded between March 2012 and September 2012. Overall there has been little change at profile **1dFB2** since March 2012. A berm on the upper beach has eroded by 0.5m. The middle section of the beach has accreted by around 0.4m. From 250m to the end of the survey the beach has eroded by around 0.3m over the summer of 2012. At profile **1dFB3**, near Flat Cliff, the cliff face remains unchanged, although the surveyor noted the presence of mudflows. The beach profile shows greatest change on the upper beach where a large sand berm had eroded so that the beach level has dropped by 0.5m since March 2012. The middle and lower parts of the beach, from 100m to 260m chainage, has accreted by 0.2-0.5m over the summer months. . Profile **1dFB4,** Hunmanby Gap, has changed very little between March 2012 and September 2012. The changes have been negligible (±0.1m) and the only clear behaviour is the flattening out of the lower beach to a less pronounced mound of material. The September 2012 profile for **1dFB5** is high compared with the range of profiles recorded since 2009. Above MHWS the profile has changed very little since March 2012. Below MHWS there has been accretion of 0.5-1m throughout much of the beach. The only area of erosion is between 340m and 360m chainage when the beach eroded by 0.2m.	Profiles FB1, FB2 and FB3 have remained stable with the exception of the very top of the beach, where a berm has been eroded. FB 4 and FB5 have been characterised by stability with little change occurring between the March 2012 and September 2012 surveys. The topographic change assessment shows that the whole of Filey Bay is dominated by shore parallel successive bands of accretion and erosion. The beach sediment appears to be being redistributed within the bay. This is a continuation of the trend observed in the 2010 and 2011 Full Measures Reports. The topographic change plot of Filey town shows that the losses and gains occurred in shore-parallel bands. Overall there has been accretion in a band close to the upper beach and erosion near the low water The cliff top survey data provided in Table C5 shows that of the 27 profiles recorded 21 had no data or a measurement too small to be significant. Four profiles recorded significant change, one of those showed growth. As a result only three profiles showed recession. The maximum total erosion seen since the baseline survey is at location 5, just south of Filey seawall where there has been 5.7m of erosion, equivalent to an annual rate of 1.5m/yr. Location 7 was 0.5m/yr, Location 14 was 0.2m/yr and Location 24
	Topographic Survey (Filey Bay): Filey Bay is covered by an annual topographic survey. Data have been used to create a DGM (Appendix	

Survey Date	Description of Changes Since Last Survey	Interpretation
	B - Maps 8a and 9a) using a GIS computer software package. The GIS has also been used to calculate the differences between the current topographic survey DGM (Autumn 2012) and the earlier topographic survey DGM (Autumn 2011), with 5m raster grids (as shown in Appendix B – Maps 8b, 9b and 10a) to identify areas of erosion and accretion. Appendix B - Map 8b shows shore parallel change between Filey Brigg and Hunmanby Gap, with alternating bands of erosion and accretion, which are more prominent in the centre of the bay. The erosion has occurred at the high water mark and the low water mark while the accretion is concentrated in the centre of the beach. The northern half of the bay had been subject to erosion and accretion in the order of ±0.25m. Appendix B – Map 9b shows the continuation of the shore parallel trend on the Filey frontage but the magnitude of change observed in the centre of the bay is greater than in the north. In the southern half of the bay the plots show areas of accretion of around 1m and erosion of 0.75m in the same bands of change, but further south. At the very southern extent of the survey the beach is dominated by a modest accretionary trend, with a gain of 0.5m of material. **Topographic Survey (Filey Town):** Further to the more extensive annual survey of Filey Bay, a smaller (selected) area within this extent (i.e. fronting Filey Town) is also surveyed in the partial measures programme, enabling further analysis of change, but specifically for the shorter spring to early autumn period fronting this asset. The GIS has been used to calculate the differences between the current (full measures) topographic survey DGM (Autumn 2012) and the earlier (partial measures) topographic survey DGM (Spring 2012), with 5m raster grids (as shown in Appendix B – Map 10a), to identify areas of erosion and accretion during the defined time period. Appendix B - Map 10a shows very little change has occurred over the summer with the majority of the frontage having experienced minimal losses and gains (less than ±0.25m). There is a zone of accretion on the mid and upper beach where up to 0.5m of material was gained. Close to the defences 0.25m was lost in two strips of erosion in the north and the south. Overall the changes in topography are minimal. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term trends of change in Filey Bay are shown in Appendix B – Maps 8c and 9c. The plots show that overall the bay has accreted by 0.5 to 0.75m. In some parts of the south of the bay there has been	was 0.1m/yr. The pattern of overall stability and erosion at these locations was also observed in the 2011 Full Measures Report. **Longer term trends**: the topographic difference plots were very similar to the 2011 Full Measures Report. The erosion and accretion was more significant in the south, which is largely undefended. Filey Town was subject to little change. The defences mean that there is little input of sediment from the cliffs and thus no large fluctuations in beach level. **Autumn 2008 to Autumn 2012 trends:** The overall trend in Filey Bay over the last four years has been accretion throughout much of the bay. The erosion has been limited to the north of the bay and a thin strip on the upper beach. The erosion in the north of the bay may be a precursor to the erosion of the nearby cliffs and Filey Brigg. At Filey Bay the changes observed are so small for a time period of 4 years that it shows that the frontage is reasonably stable overall.

Survey Date	Description of Changes Since Last Survey	Interpretation
	over 1m of accretion but these are isolated patches. The largest area of erosion over the last four years is shown on Map 8c and occurred in the north of the bay close to Filey Brigg. The recorded erosion was up to 0.75m over four years. There is also a thin strip of erosion at the toe of the cliffs which is not continuous but is up to 0.5m of change in places. The remainder of the erosion occurred in isolated patches **Filey Town Long Term Trends:** The long term difference plot for the Filey town frontage is in Appendix B Map 10b. The plot shows that over the previous four years there has been a clear trend in coastal change. The upper beach has accreted by up to 0.75m at the very top of the beach. The lower beach has been subject to erosion and has lost up to 0.25m.	
	Cliff-top Survey: Twenty-seven ground control points have been established within Filey Bay for the purposes of cliff top monitoring. This includes the installation of three new locations in September 2010, these being points 12A (as a replacement for point 13 which can no longer be accessed due to vegetation growth), 24 & 25 (to the north of Filey Bay at Filey Brigg). The maximum separation between any two points is nominally 300 m. The cliff top surveys at Filey Bay are undertaken bi-annually. Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing. Between March 2012 and September 2012 twenty-one of the twenty-seven ground control points showed change within the region of ±0.1m. One marker showed growth of 0.5m, which means that there was an error at some point. The remaining five points had shown erosion of -0.1 to -0.5m The rates which have been calculated since the baseline survey, which is November 2008 in most cases. However, the baseline for 12A and 24-27 is March 2011. Twenty-three of the markers show an erosion rate of ±0.1m/yr since the baseline was established. Four of the markers show erosion rates of between -0.1m/yr and 1.5m/yr. Appendix C provides results from the September 2012 survey showing the distance from the ground control point to the edge of the cliff top along the defined bearing and changes in position since the November 2008 baseline survey (where applicable).	

3. Problems Encountered and Uncertainty in Analysis

Survey accuracy of beach/ cliff profiles
The aim of cliff monitoring data is to gain a reliable record of the frequency and magnitude of cliff top failures. Data are collected every six months, but previous surveys have had a low accuracy, meaning that survey error is typically greater than any measured short term change. It is possible that a more reliable pattern of change will be determined over the longer term. However, in the short term, more reliable assessments of cliff recession will be derived from analysis of time-series remote sensing data. A high quality baseline survey, comprising LiDAR and aerial photography, was collected in 2010, a repeat survey was completed in Sept/Oct 2012 and a second repeat survey is planned for 2014. These data will be analysed to give more accurate information on the behaviour of the cliffs in a separate report.

Cliff top erosion errors & data capture techniques
The cliff top surveys are in general assumed to have a limit of accuracy of ± 0.1m due to the techniques used. At a number of locations apparent cliff advance is calculated, which is highly unlikely excepting if a toppling mechanism of failure is being recorded, so the accuracy may actually be worse than this. It is more likely that this is due to a different point being identified as the edge of the cliff, especially with different seasonal vegetation cover. This problem remains marked at all locations. Over a longer monitoring period, it is anticipated that any underlying patterns of cliff recession will become clear. However, in the short term, analysis of high quality aerial photography will allow detailed assessment of short term cliff recession rates.

Repeat terrestrial laser scan surveys of cliff faces and tops could be undertaken at key locations within the cliff survey areas if a very detailed understanding of changing conditions was required for risk management.

4. Recommendations for 'Fine-tuning' the Monitoring Programme

The following recommendations are suggested:

- Consider and implement measures to improve the accuracy of cliff top and cliff face survey data capture. This may include a site visit by a geomorphologist with knowledge of cliffs, and a programme of targeted laser scanning.
- More consideration needs to be given to the analysis and reporting of longer-term beach behaviours demonstrated by the topographic survey data. This may include the calculation of volumetric sediment budgets (as best possible) for each successive time period.

5. Conclusions and Areas of Concern

The following points have been observed:

- The Staithes cliff face shows stability overall. However, the monitoring has only been being carried out for three years so a trend is unlikely to be clear from such a limited data set. There is one point which has eroded by 2.3m since November 2008, which is the maximum erosion observed for this frontage. The continuing Durham University study will also give an accurate picture of the changes occurring on the cliff face of Cowbar Nab.
- Runswick Bay showed slight erosion on the topographic survey comparison. Erosion was also noted in the 2011 Full Measures Report. Although erosion is not considered a common feature of summer beach profiles the trend may be due to the movement of material offshore which has been sourced from cliff erosion over the winter. The long term plot of elevation difference showed that overall the bay was stable but the erosion in the mid-bay could be a precursor to erosion at the back of the bay.
- At Sandsend Beach, Upgang Beach and Whitby Sands the volumes of the beaches appear to have remained stable. The changes in level on both the one year and four year

topographic differences plot are greater in the centre of the bay that at each end of the frontage. The beach profiles show some flattening over the summer, but stability overall.

- At Robin Hoods Bay the majority of change in the beach during 2012 was due to the erosion and accretion of the veneer of mobile sand on top of the rock platform. The cliff top survey shows minimal change since cliff top monitoring began in 2010. The maximum observed change was at a rate of 1.4m/yr, although monitoring will need to be carried out over a longer period to assess the long term behavioural trends.
- Scarborough North Bay has shown stability overall but accretion in some places. The topographic change plot shows shore parallel bands of accretion and erosion, similar to those observed in the 2011 Full Measures Report.
- Scarborough South Bay is similar to the North Bay because it shows some accretion although overall the beach profiles were similar to previous years. The topographic change plots show successive shore-parallel bands of accretion and erosion, which probably means that sediment, is being redistributed within the Bay. The cliff top survey points have shown recession rates of between 0.1 and 0.2m/yr. However, the cliff was stable overall. An overview of the volume of material moved as part of reprofiling works in the early summer of 2012 found that 8800m^3 of material had been transported from north to south.
- The Cayton Bay beach profiles show stability overall. The beach profiles are well within the range of previous profiles and have not changed significantly since March 2012. The long term difference plots show that the overall trend in Cayton Bay between 2008 and 2012 has been stability. The difference plot shows accretion and erosion but most of the changes are within a range of ±0.25m. The cliff top profiles show stability of the cliff overall, with the largest calculated rate in a single profile being 1.3m/yr. More data is needed to gain confidence in these calculated rates.
- The beach profiles at Filey Bay show stability, although the northern profiles showed that a berm which was present in March 2012 had eroded by September 2012. The overall trend in Filey Bay over the last four years has been accretion throughout much of the bay. The erosion has been limited to the north of the bay and a thin strip on the upper beach. The smaller Filey town area shows a similar pattern to the Bay as a whole, although the erosion and accretion recorded is modest. The cliff profiles show stability overall with localised erosion in places of up to 1.5m/year.

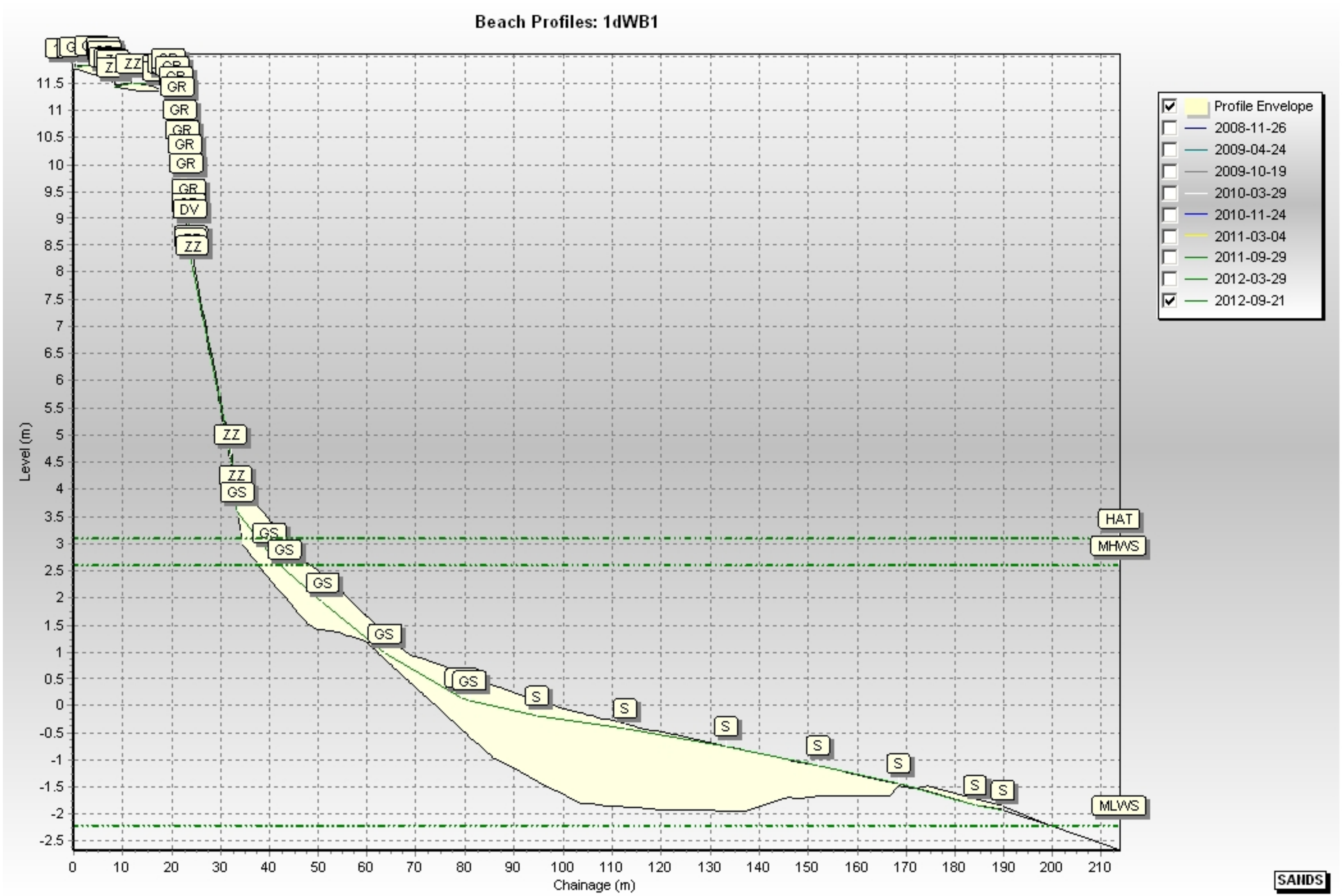
Appendices

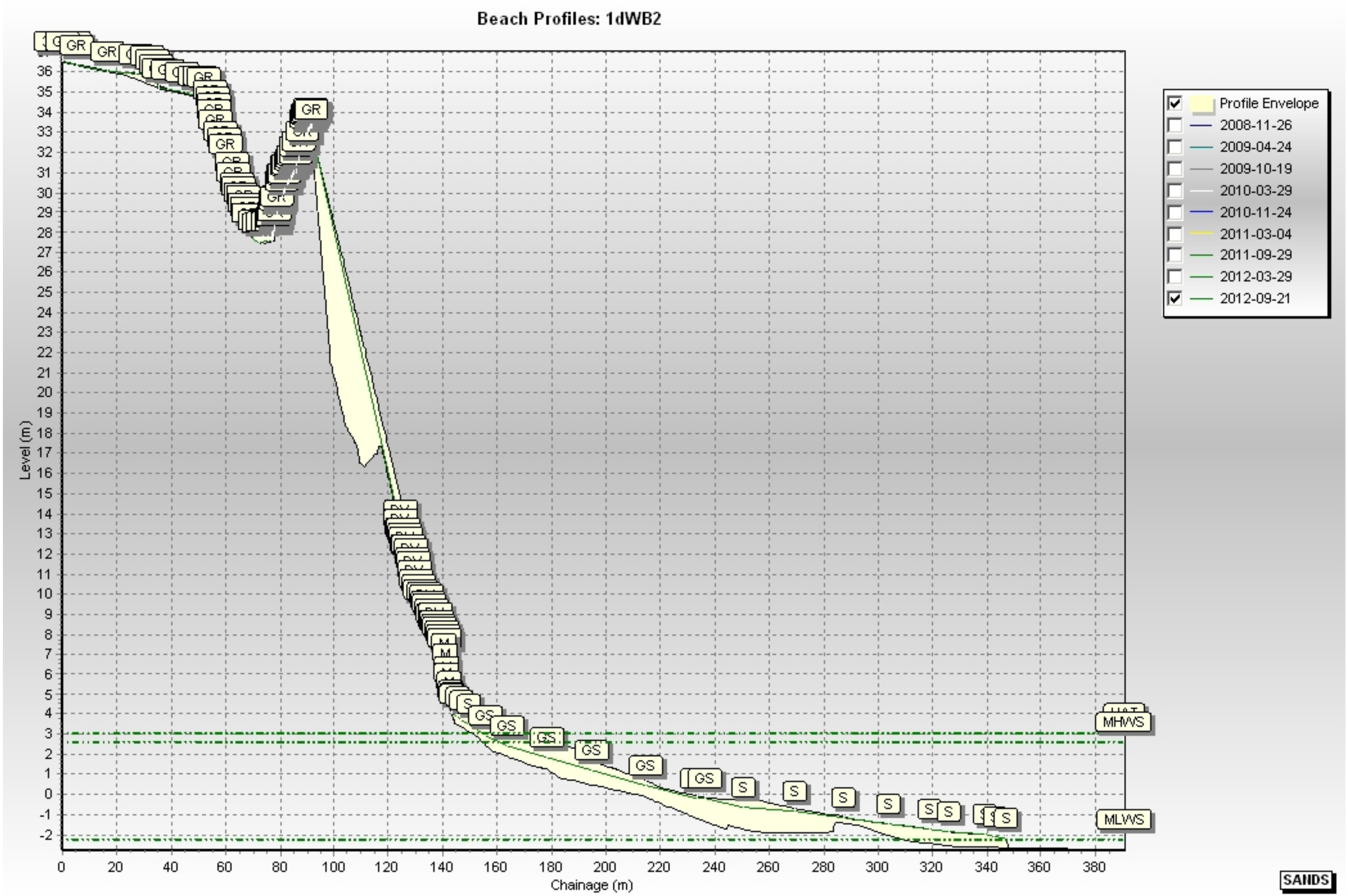
Appendix A

Beach Profiles

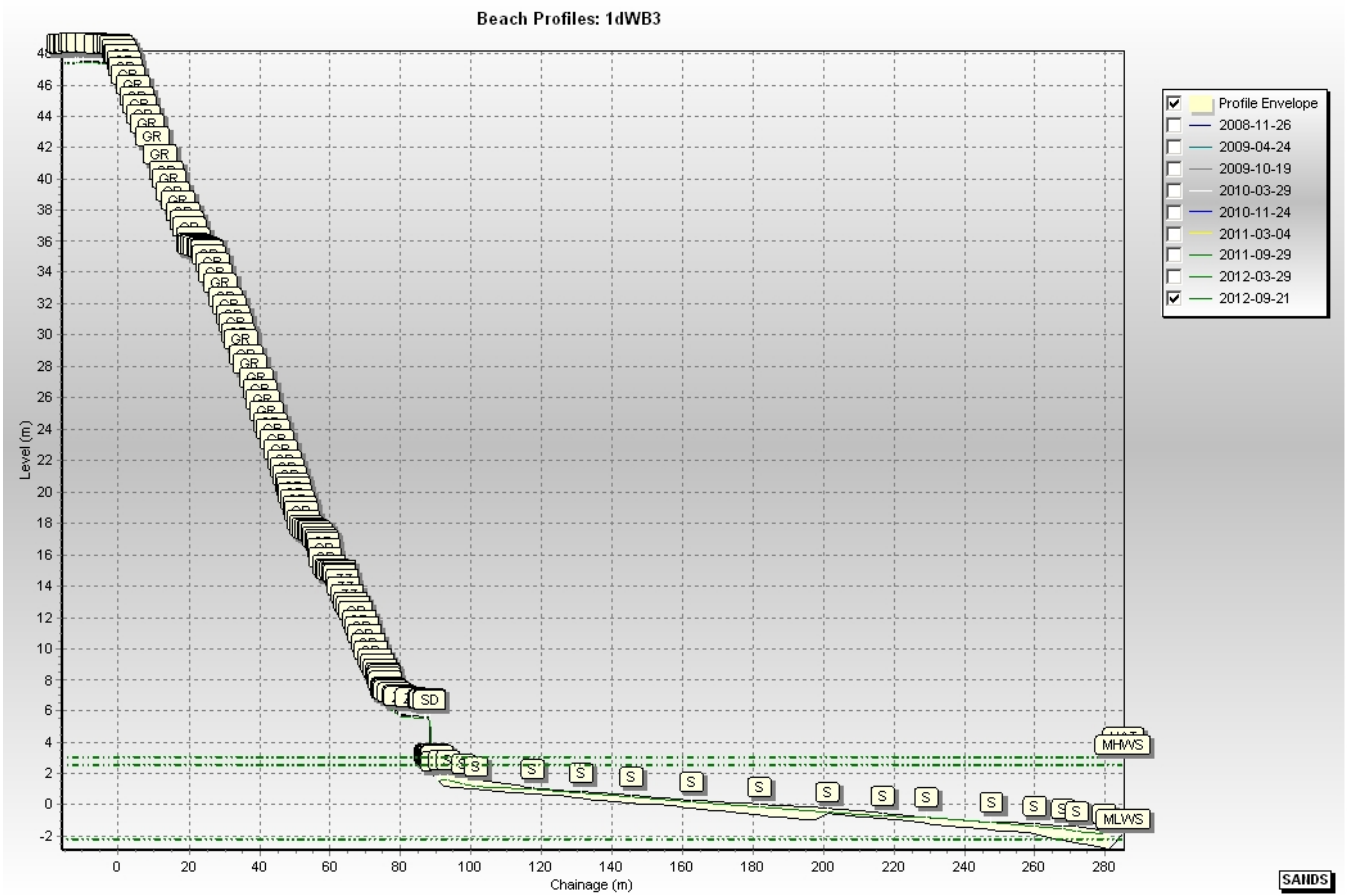
The following sediment feature codes are used on some profile plots:

Code	Description
S	Sand
M	Mud
G	Gravel
GS	Gravel & Sand
MS	Mud & Sand
B	Boulders
R	Rock
SD	Sea Defence
SM	Saltmarsh
W	Water Body
GM	Gravel & Mud
GR	Grass
D	Dune (non-vegetated)
DV	Dune (vegetated)
F	Forested
X	Mixture
FB	Obstruction
CT	Cliff Top
CE	Cliff Edge
CF	Cliff Face
SH	Shell
ZZ	Unknown

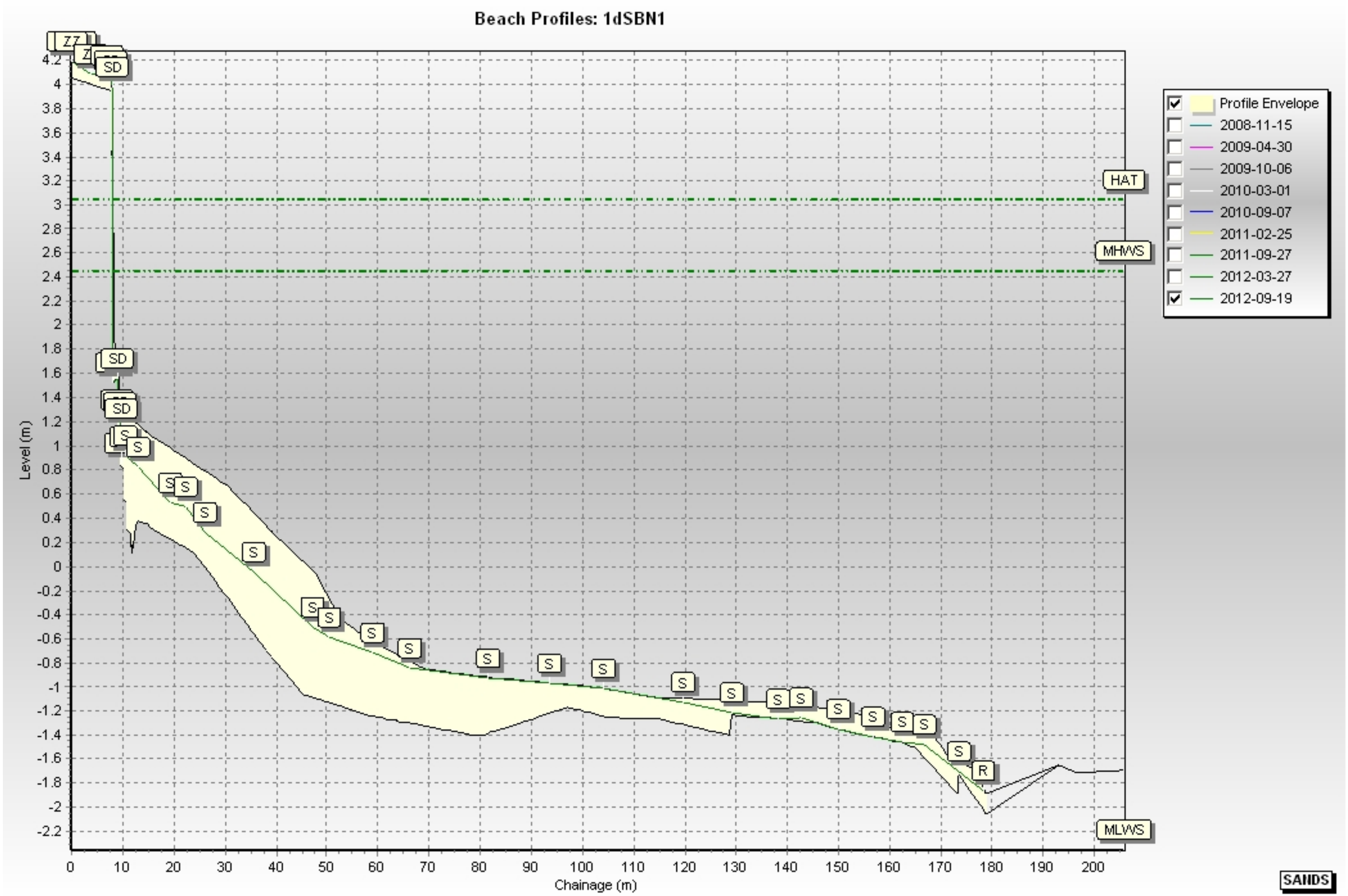

Beach Profiles: 1dWB1
Level (m)
Chainage (m)
Profile Envelope
2008-11-26
2009-04-24
2009-10-19
2010-03-29
2010-11-24
2011-03-04
2011-09-29
2012-03-29
2012-09-21
HAT
MHWS
MLWS
SANDS



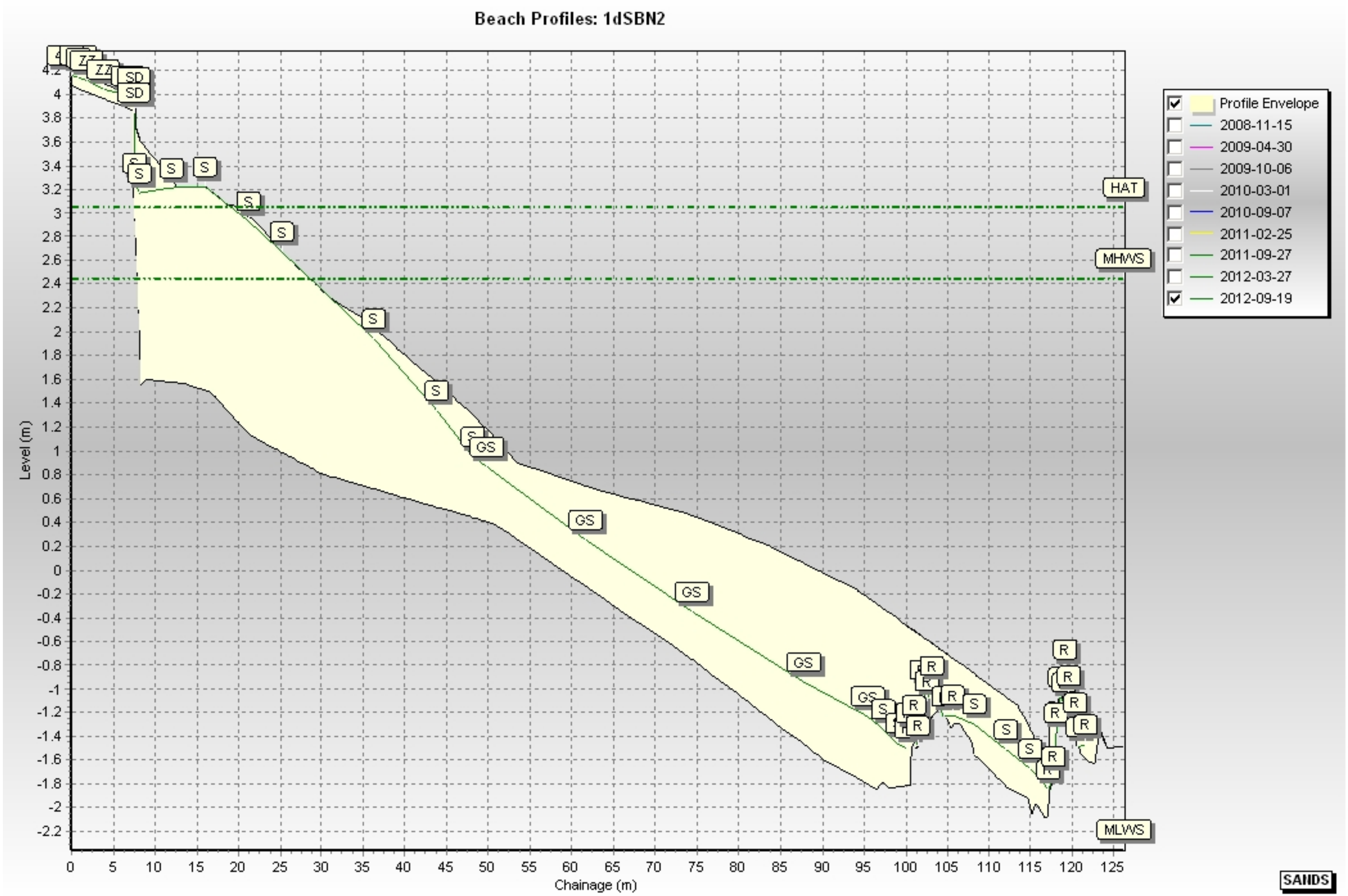
Beach Profiles: 1dWB2
Level (m)
Chainage (m)
Profile Envelope
2008-11-26
2009-04-24
2009-10-19
2010-03-29
2010-11-24
2011-03-04
2011-09-29
2012-03-29
2012-09-21
GR
GS
S
M
MHWS
MLWS
SANDS



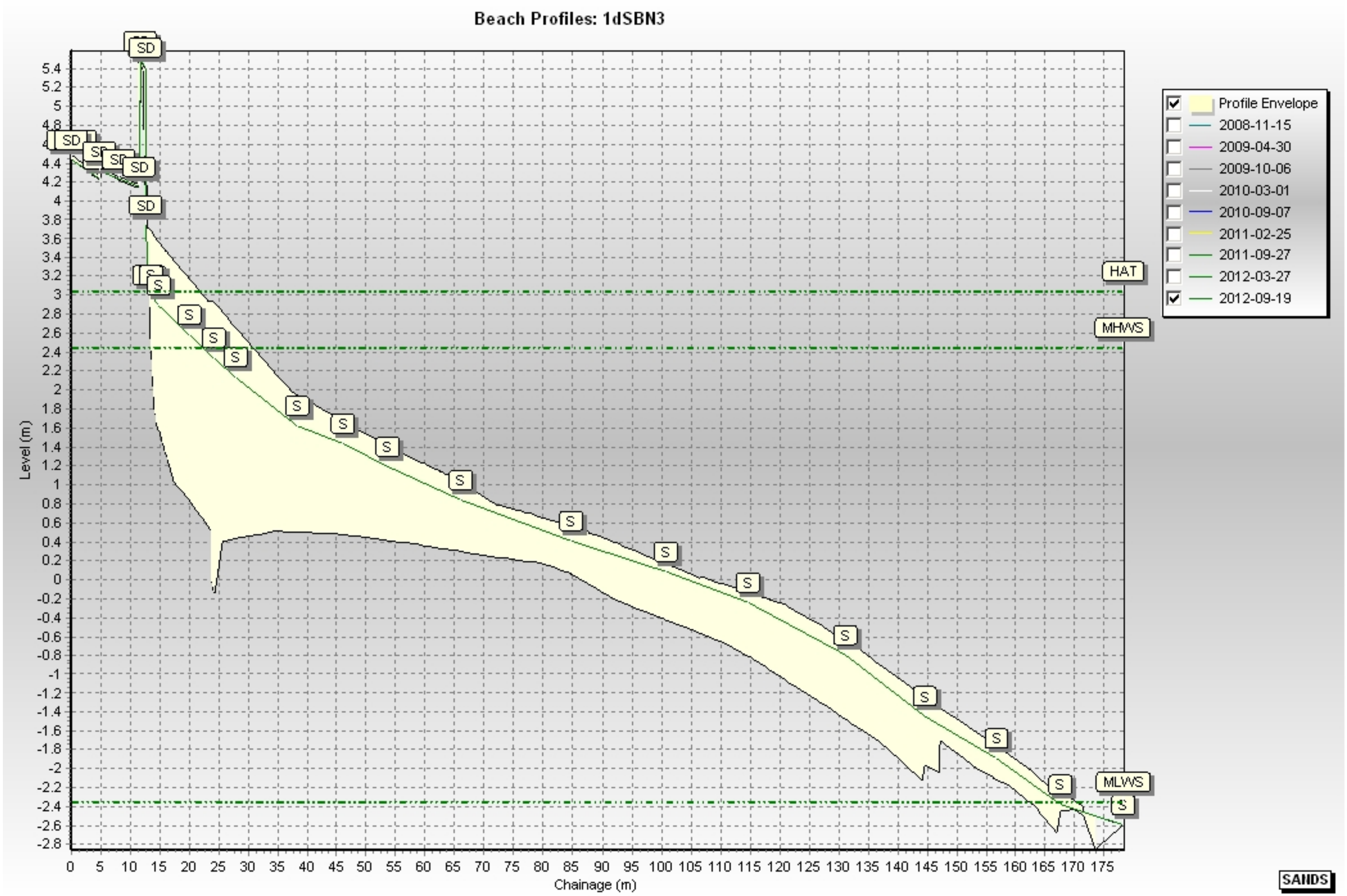
Beach Profiles: 1dWB3
Level (m)
Chainage (m)
Profile Envelope
2008-11-26
2009-04-24
2009-10-19
2010-03-29
2010-11-24
2011-03-04
2011-09-29
2012-03-29
2012-09-21
GR
SD
S
MHWS
MLWS
SANDS



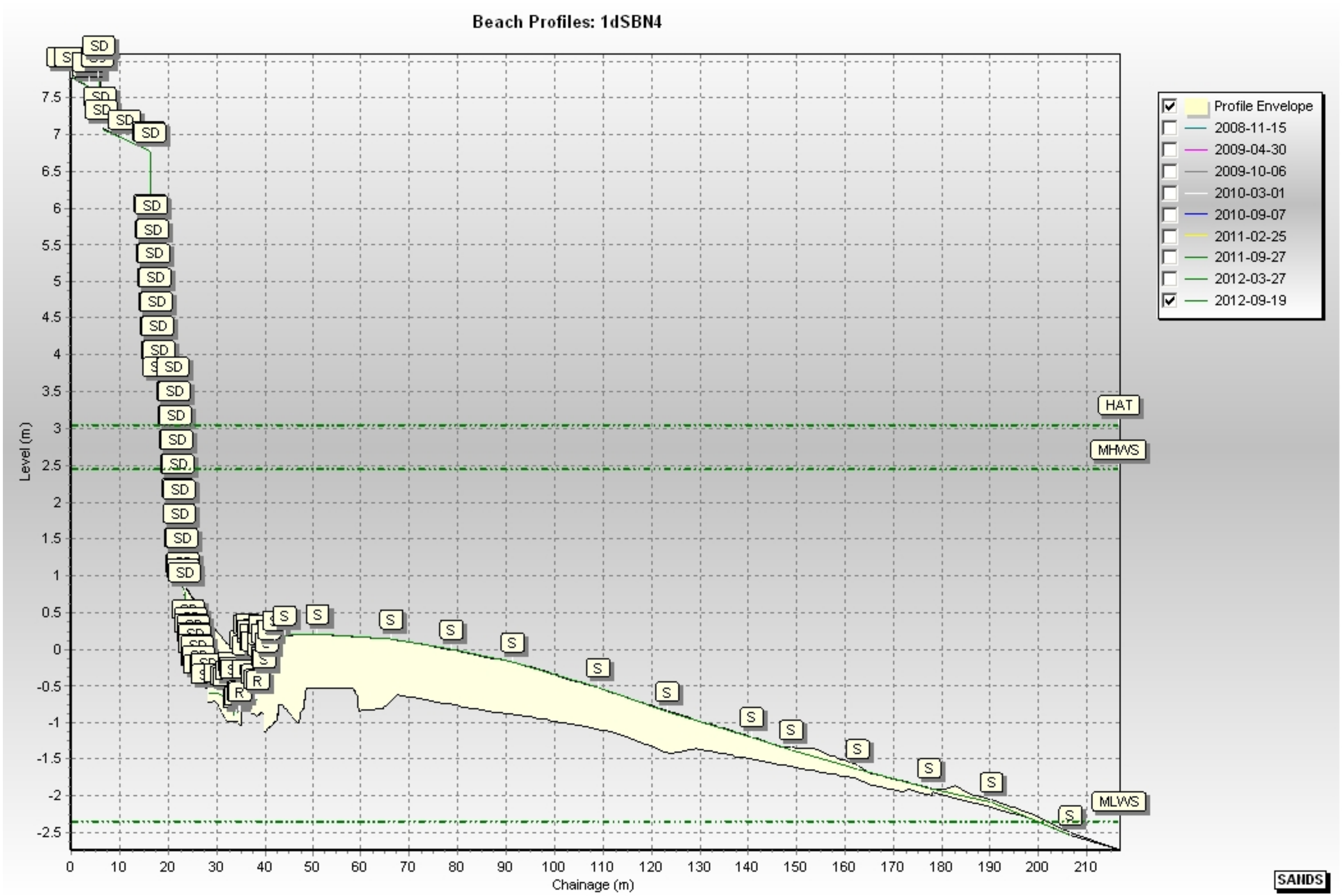
Beach Profiles: 1dSBN1
Level (m)
Chainage (m)
Profile Envelope
2008-11-15
2009-04-30
2009-10-06
2010-03-01
2010-09-07
2011-02-25
2011-09-27
2012-03-27
2012-09-19
HAT
MHWS
MLWS
SANDS



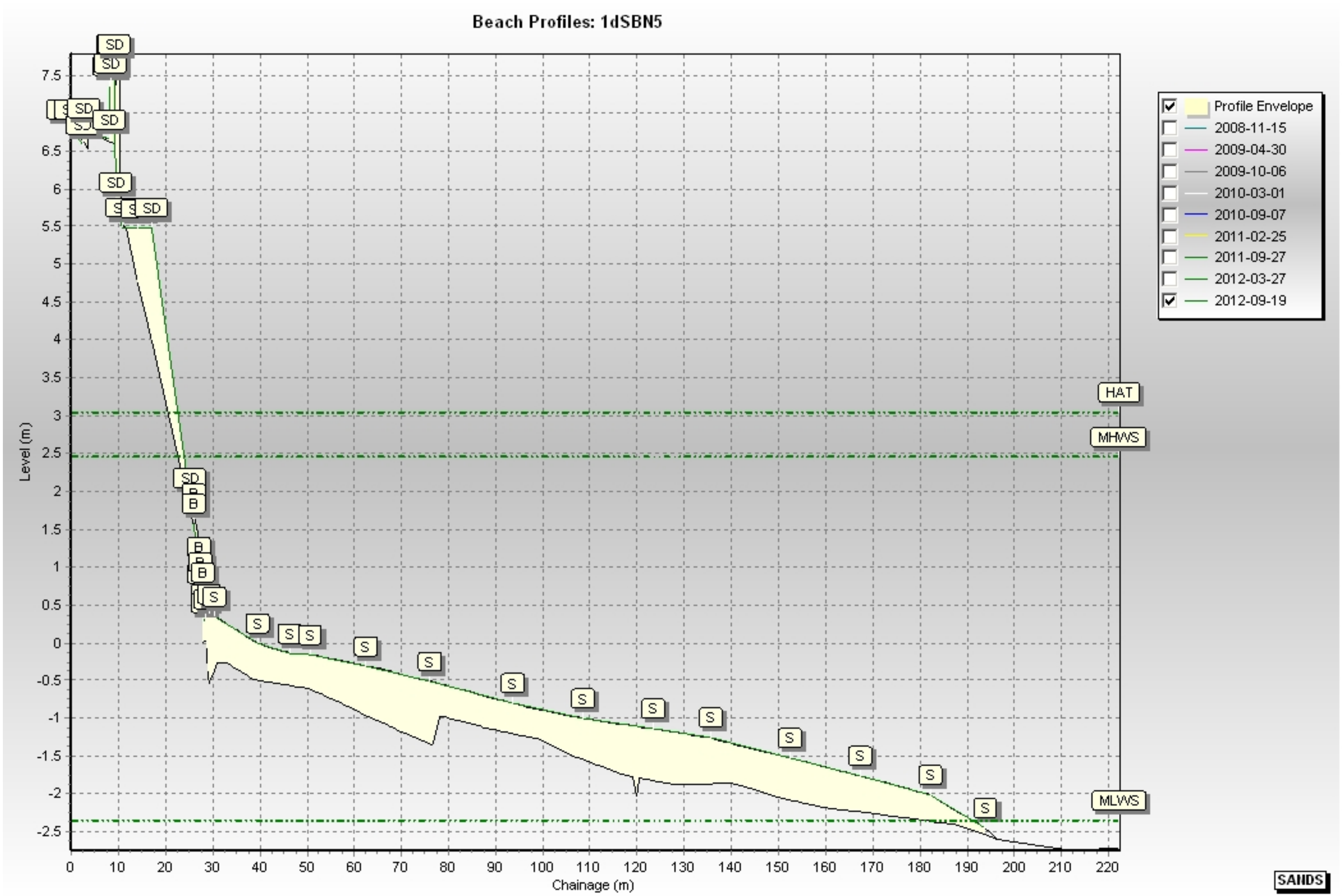
Beach Profiles: 1dSBN2
Level (m)
Chainage (m)
Profile Envelope
2008-11-15
2009-04-30
2009-10-06
2010-03-01
2010-09-07
2011-02-25
2011-09-27
2012-03-27
2012-09-19
HAT
MHWS
MLWS
SANDS



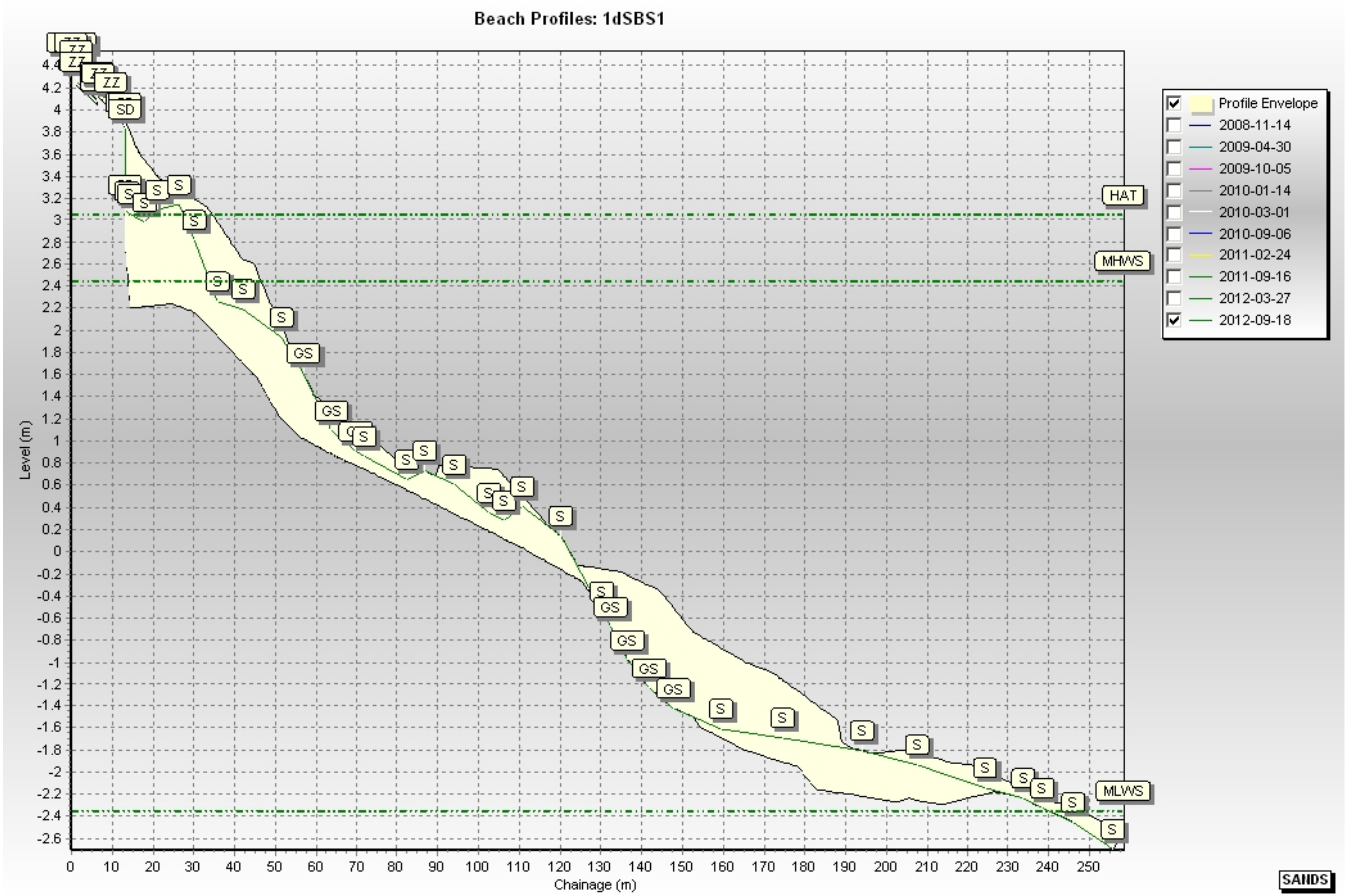
Beach Profiles: 1dSBN3
Level (m)
Chainage (m)
Profile Envelope
2008-11-15
2009-04-30
2009-10-06
2010-03-01
2010-09-07
2011-02-25
2011-09-27
2012-03-27
2012-09-19
HAT
MHWS
MLWS
SD
S
SANDS



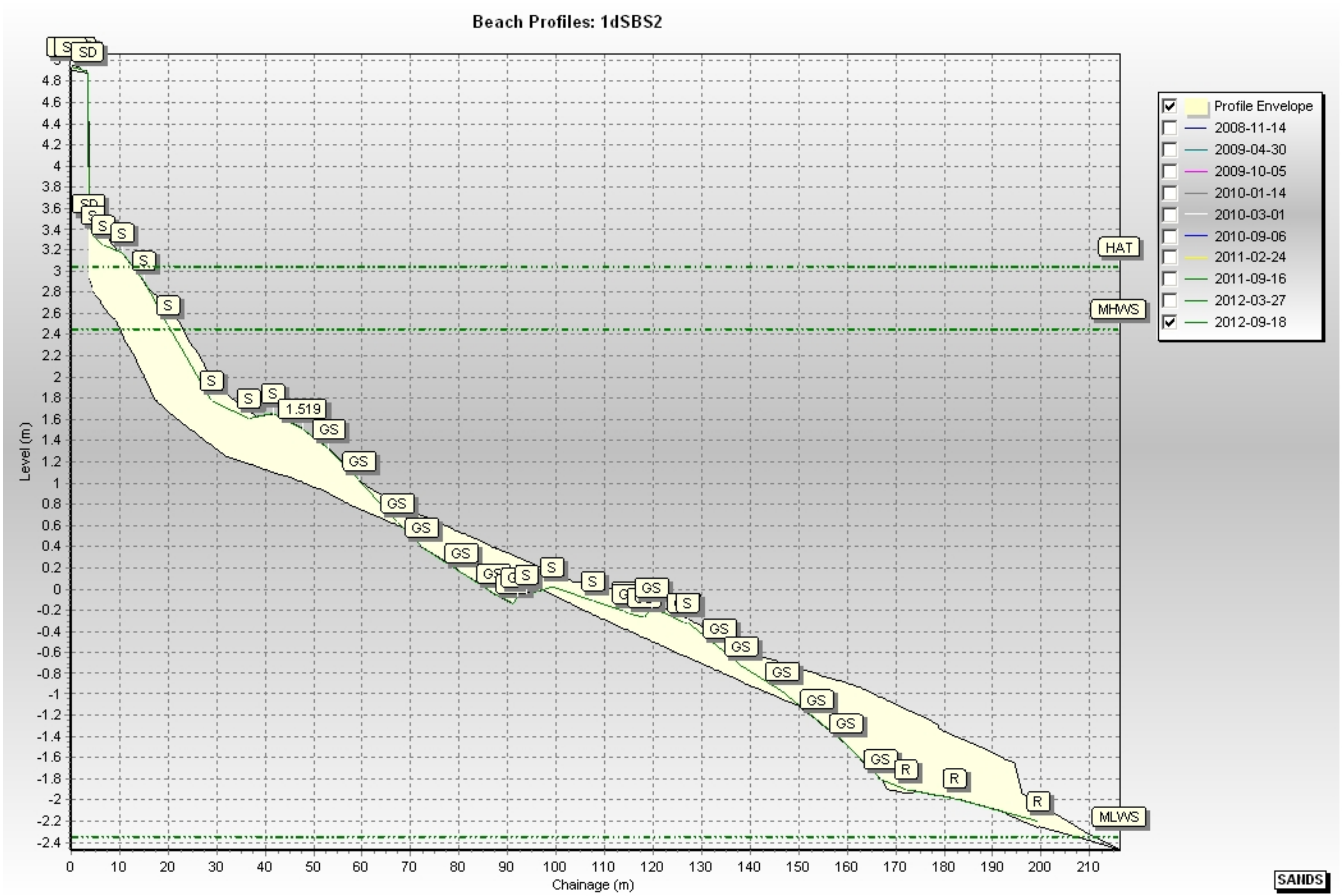
Beach Profiles: 1dSBN4
Level (m)
Chainage (m)
Profile Envelope
2008-11-15
2009-04-30
2009-10-06
2010-03-01
2010-09-07
2011-02-25
2011-09-27
2012-03-27
2012-09-19
HAT
MHWS
MLWS
SANDS

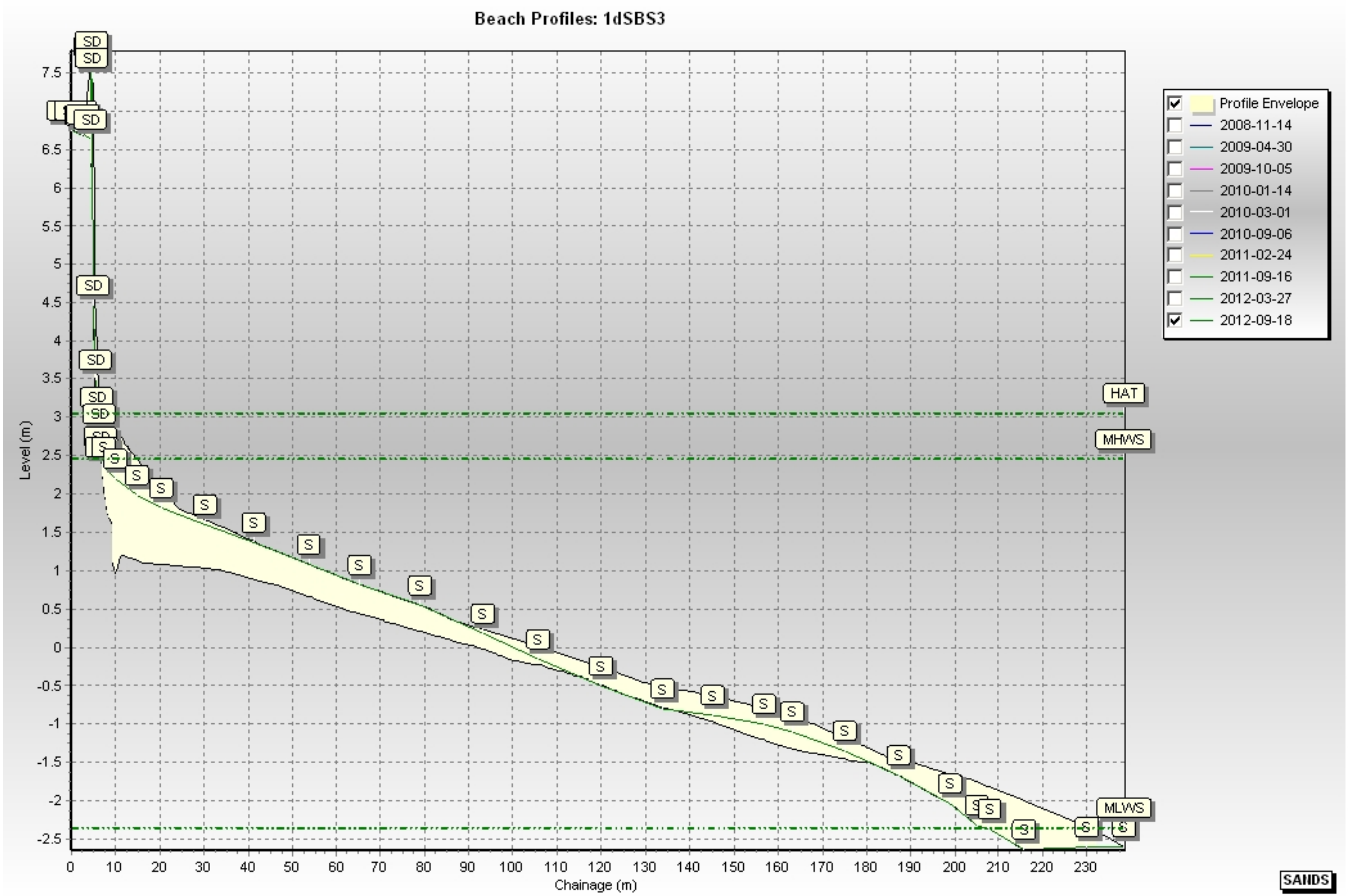


Beach Profiles: 1dSBN5
Level (m)
Chainage (m)
Profile Envelope
2008-11-15
2009-04-30
2009-10-06
2010-03-01
2010-09-07
2011-02-25
2011-09-27
2012-03-27
2012-09-19
HAT
MHWS
MLWS
SANDS

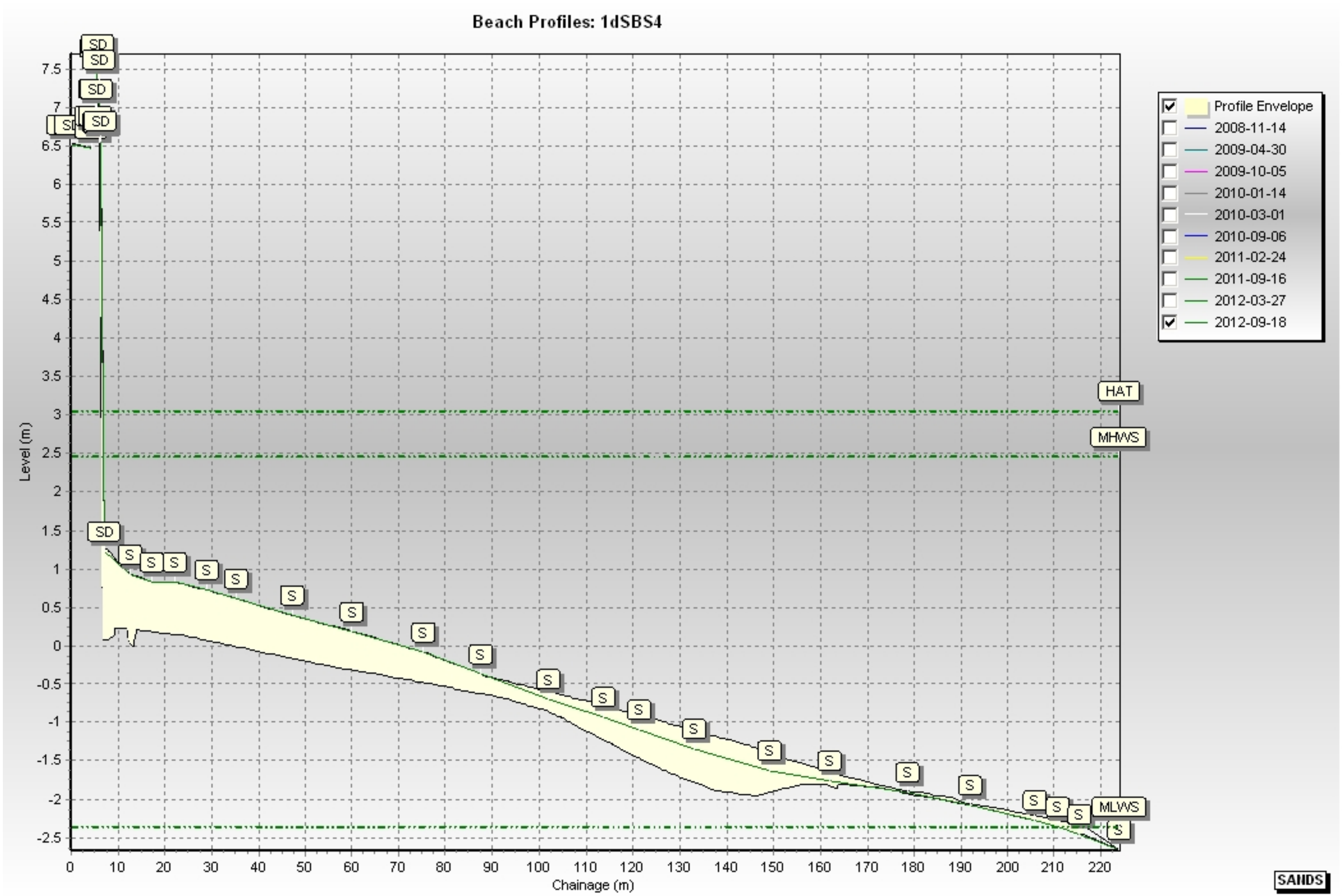


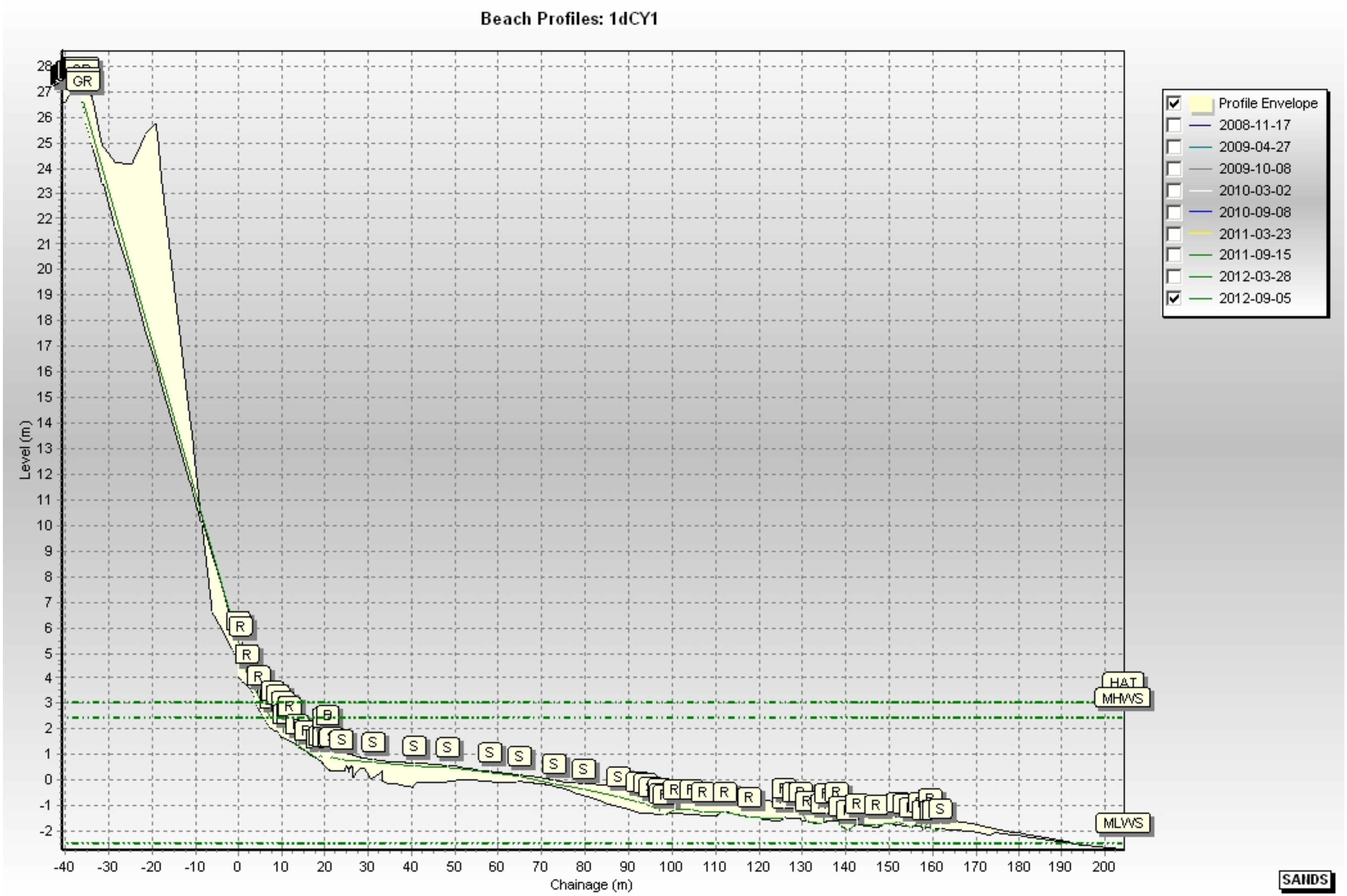
Beach Profiles: 1dSBS1
Level (m)
Chainage (m)
Profile Envelope
2008-11-14
2009-04-30
2009-10-05
2010-01-14
2010-03-01
2010-09-06
2011-02-24
2011-09-16
2012-03-27
2012-09-18
HAT
MHWS
MLWS
SD
ZZ
S
GS
SANDS


Beach Profiles: 1dSBS2
Level (m)
Chainage (m)
Profile Envelope
2008-11-14
2009-04-30
2009-10-05
2010-01-14
2010-03-01
2010-09-06
2011-02-24
2011-09-16
2012-03-27
2012-09-18
HAT
MHWS
MLWS
SD
S
GS
R
1.519
SANDS

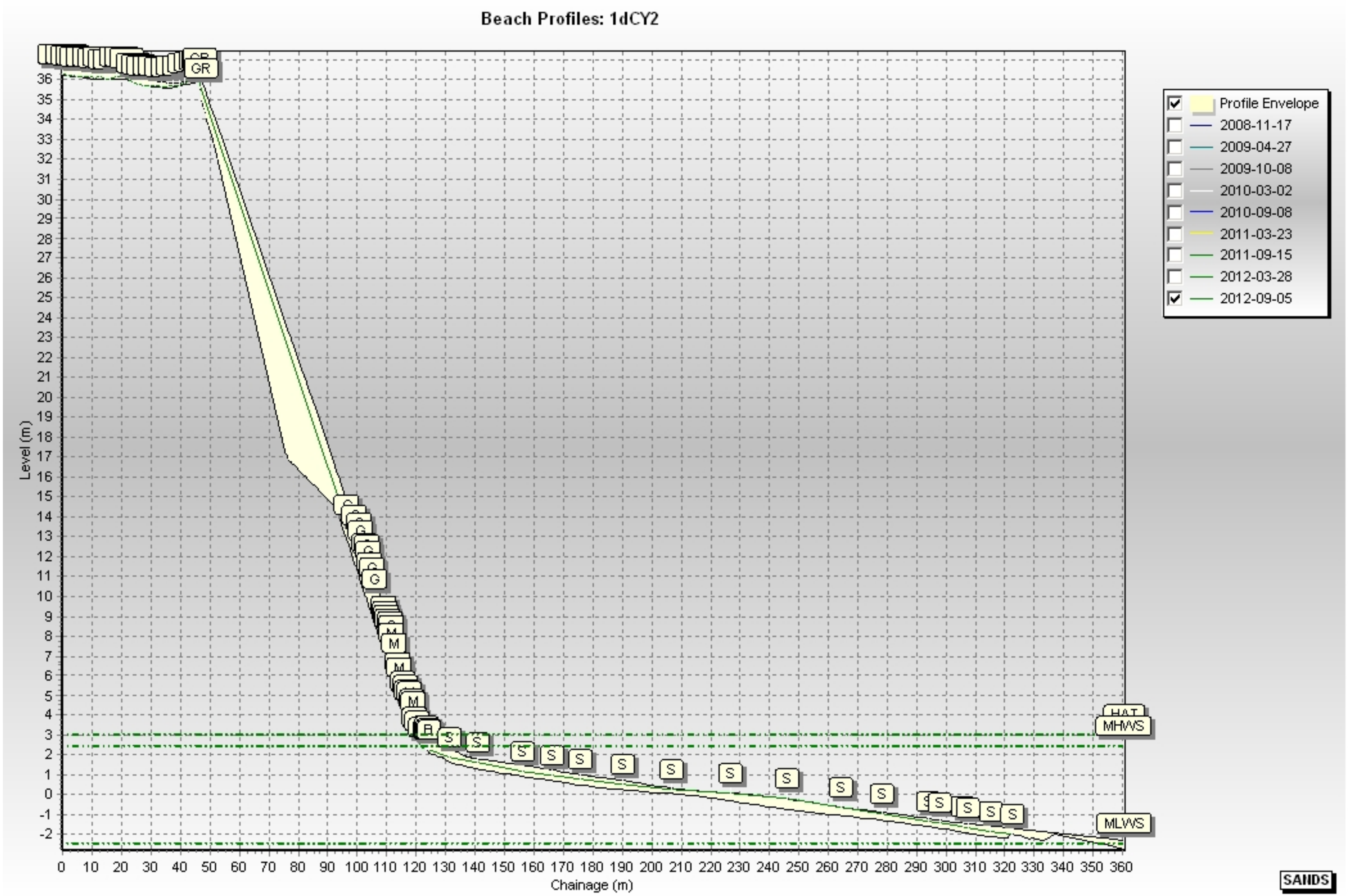


Beach Profiles: 1dSBS3
Level (m)
Chainage (m)
Profile Envelope
2008-11-14
2009-04-30
2009-10-05
2010-01-14
2010-03-01
2010-09-06
2011-02-24
2011-09-16
2012-03-27
2012-09-18
HAT
MHWS
MLWS
SANDS

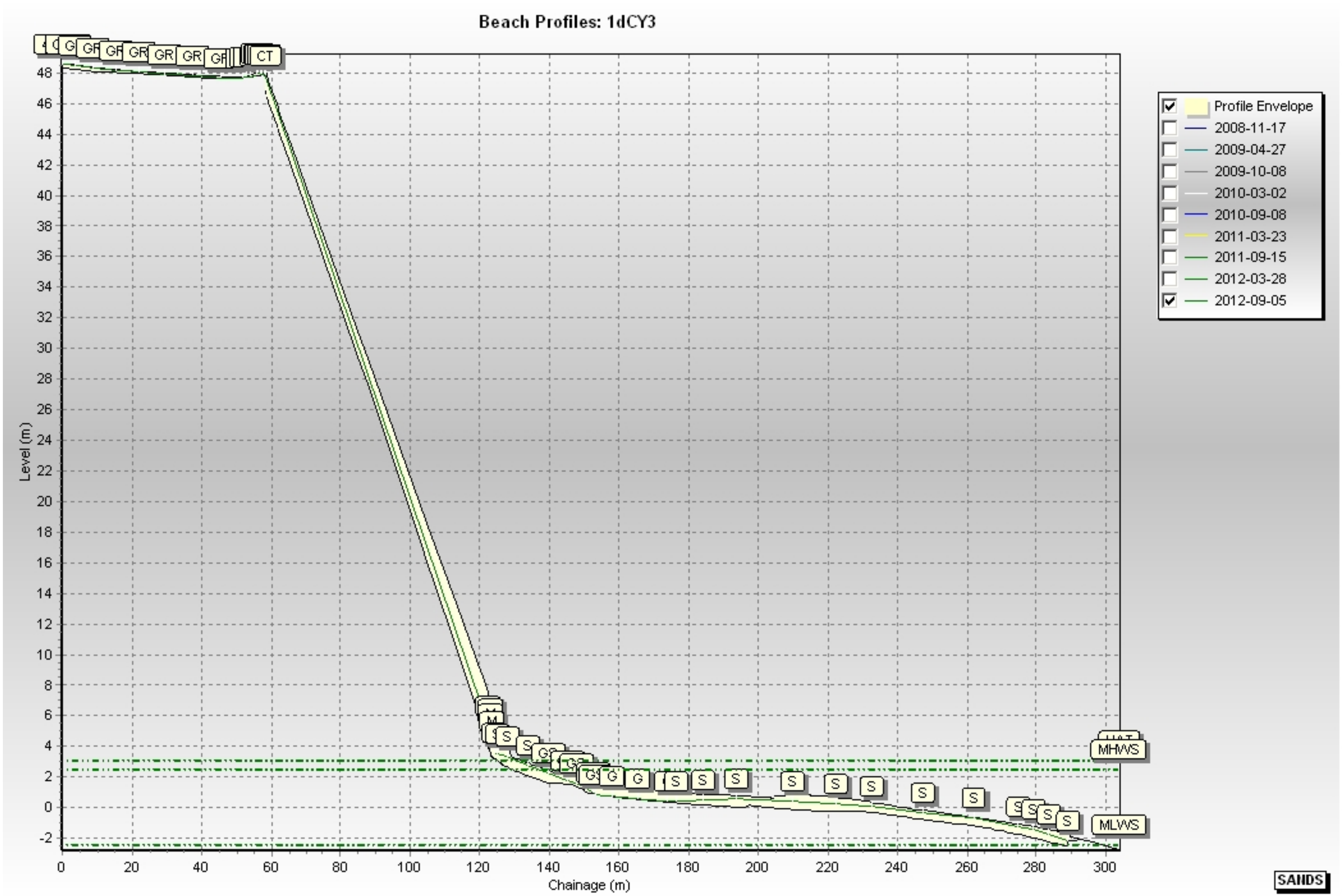

Beach Profiles: 1dSBS4
Level (m)
Chainage (m)
Profile Envelope
2008-11-14
2009-04-30
2009-10-05
2010-01-14
2010-03-01
2010-09-06
2011-02-24
2011-09-16
2012-03-27
2012-09-18
HAT
MHWS
MLWS
SD
S
SANDS



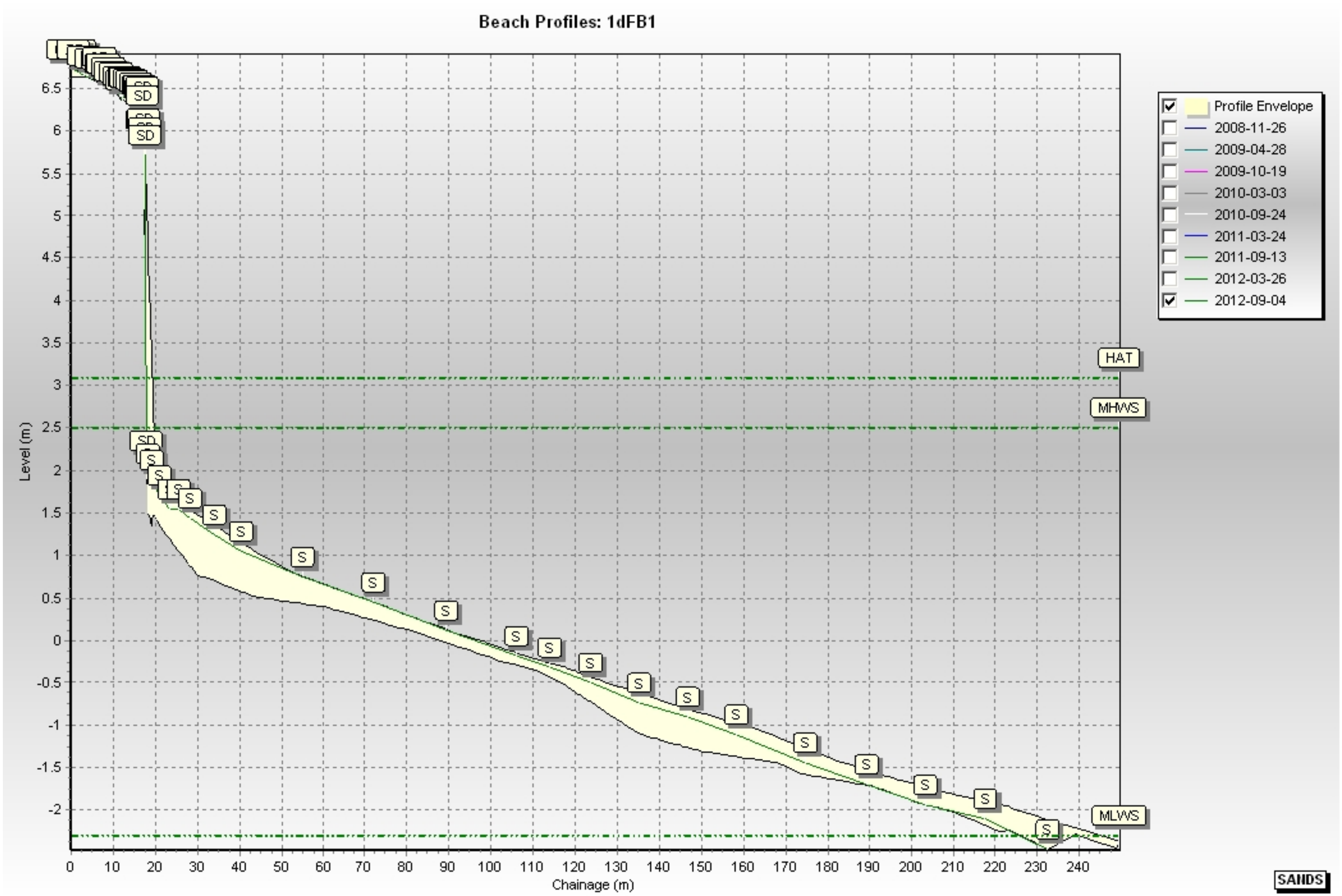
Beach Profiles: 1dCY1
Level (m)
Chainage (m)
Profile Envelope
2008-11-17
2009-04-27
2009-10-08
2010-03-02
2010-09-08
2011-03-23
2011-09-15
2012-03-28
2012-09-05
HAT
MHWS
MLWS
GR
R
S
SANDS



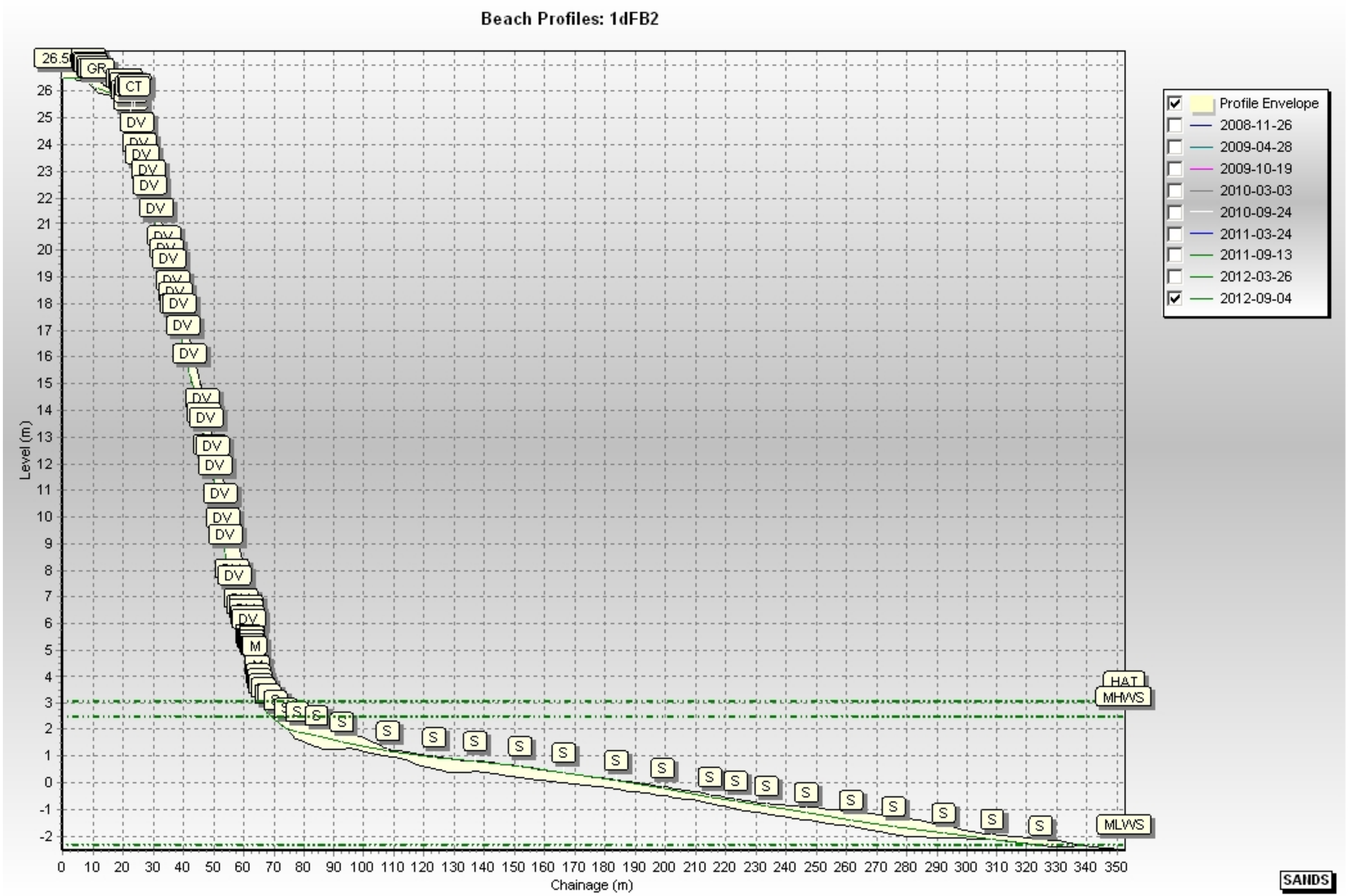
Beach Profiles: 1dCY2
Level (m)
Chainage (m)
Profile Envelope
2008-11-17
2009-04-27
2009-10-08
2010-03-02
2010-09-08
2011-03-23
2011-09-15
2012-03-28
2012-09-05
GR
G
M
B
S
HAT
MHWS
MLWS
SANDS



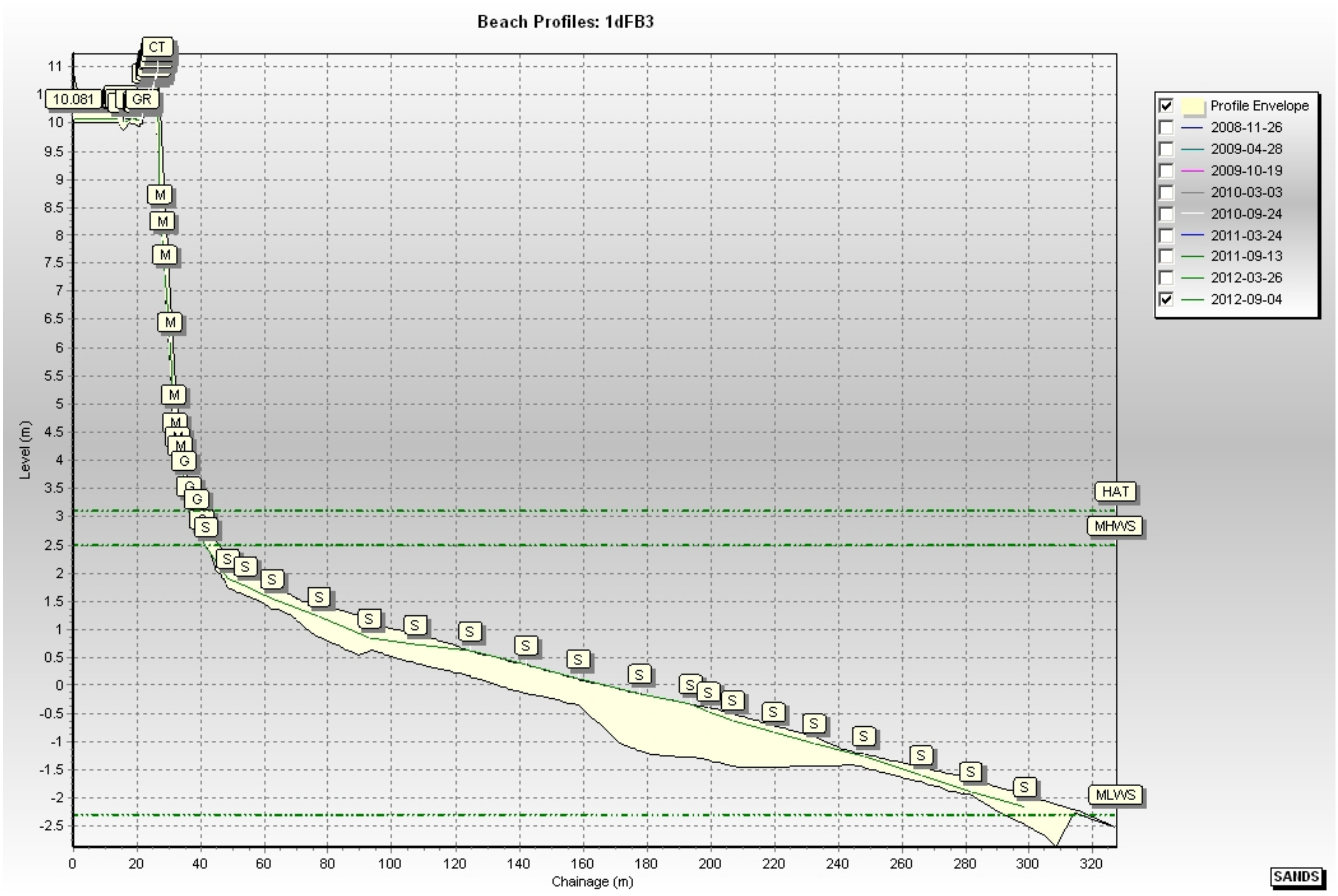
Beach Profiles: 1dCY3
Profile Envelope
2008-11-17
2009-04-27
2009-10-08
2010-03-02
2010-09-08
2011-03-23
2011-09-15
2012-03-28
2012-09-05
Level (m)
Chainage (m)
MHWS
MLWS
CT
SANDS



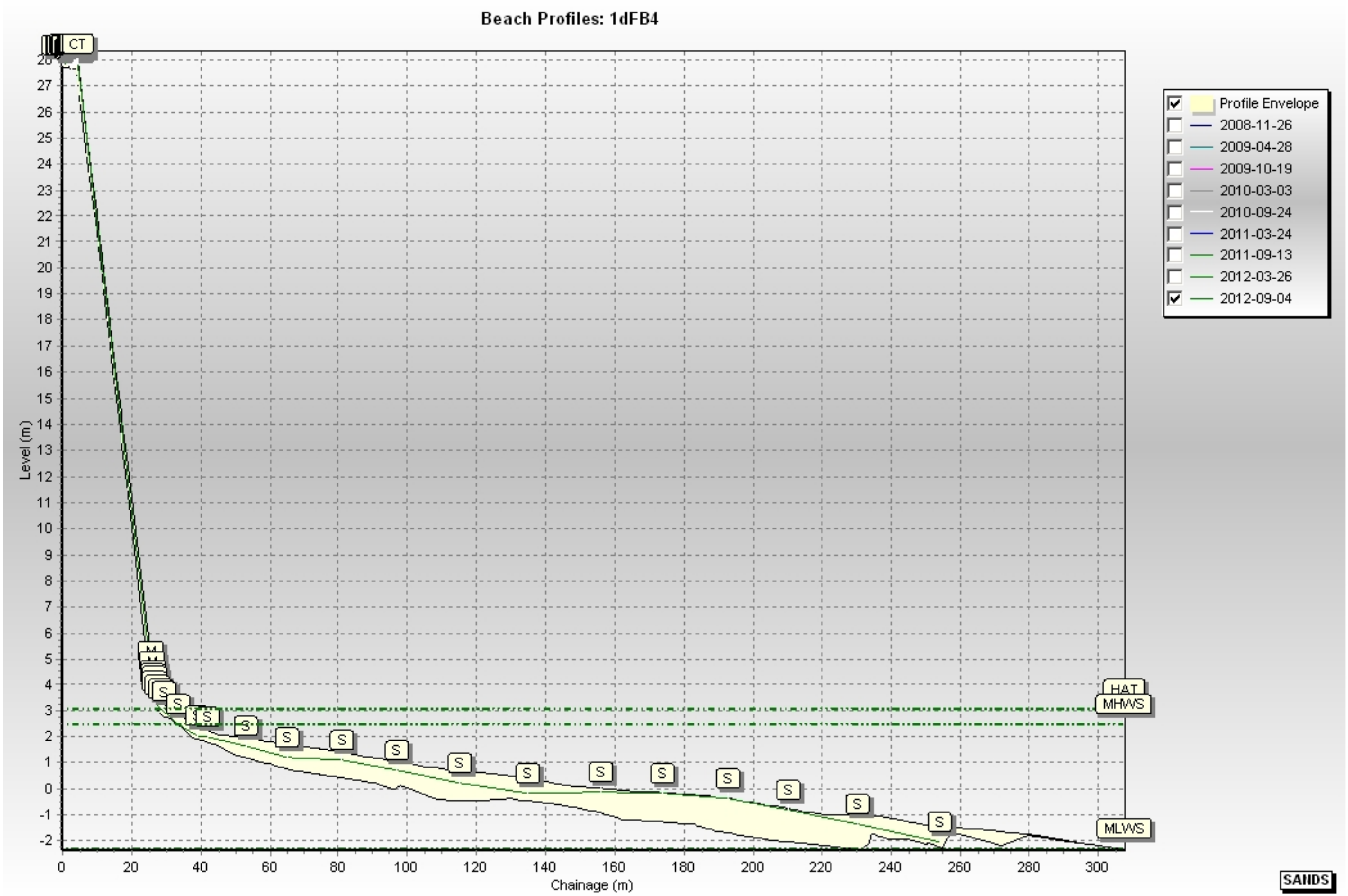
Beach Profiles: 1dFB1
Profile Envelope
2008-11-26
2009-04-28
2009-10-19
2010-03-03
2010-09-24
2011-03-24
2011-09-13
2012-03-26
2012-09-04
HAT
MHWS
MLWS
Level (m)
Chainage (m)
SD
S
SANDS



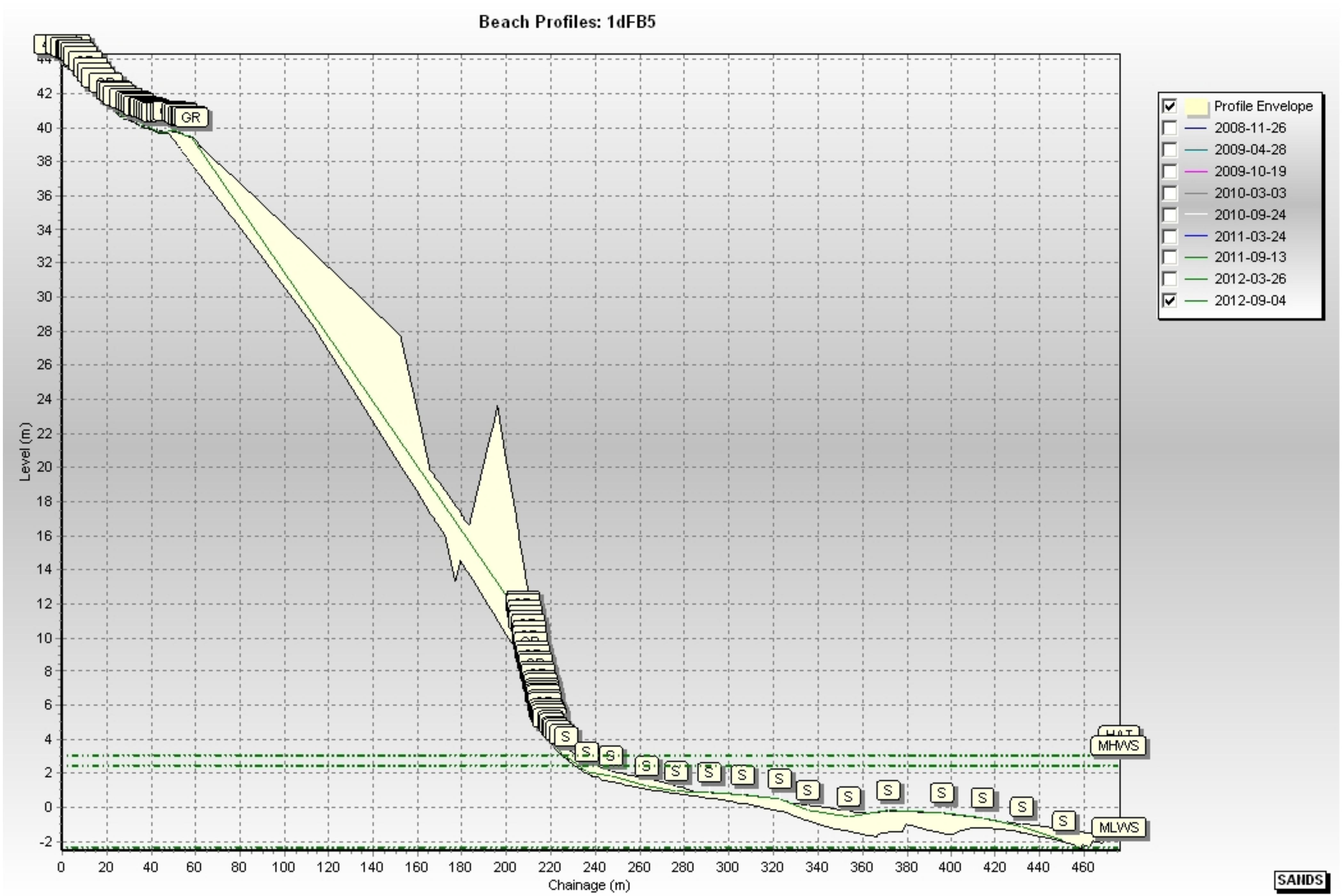
Beach Profiles: 1dFB2
Level (m)
Chainage (m)
Profile Envelope
2008-11-26
2009-04-28
2009-10-19
2010-03-03
2010-09-24
2011-03-24
2011-09-13
2012-03-26
2012-09-04
HAT
MHWS
MLWS
GR
CT
DV
M
S
SANDS



Beach Profiles: 1dFB3
Profile Envelope
2008-11-26
2009-04-28
2009-10-19
2010-03-03
2010-09-24
2011-03-24
2011-09-13
2012-03-26
2012-09-04
Level (m)
Chainage (m)
10.081
CT
GR
M
G
S
HAT
MHWS
MLWS
SANDS

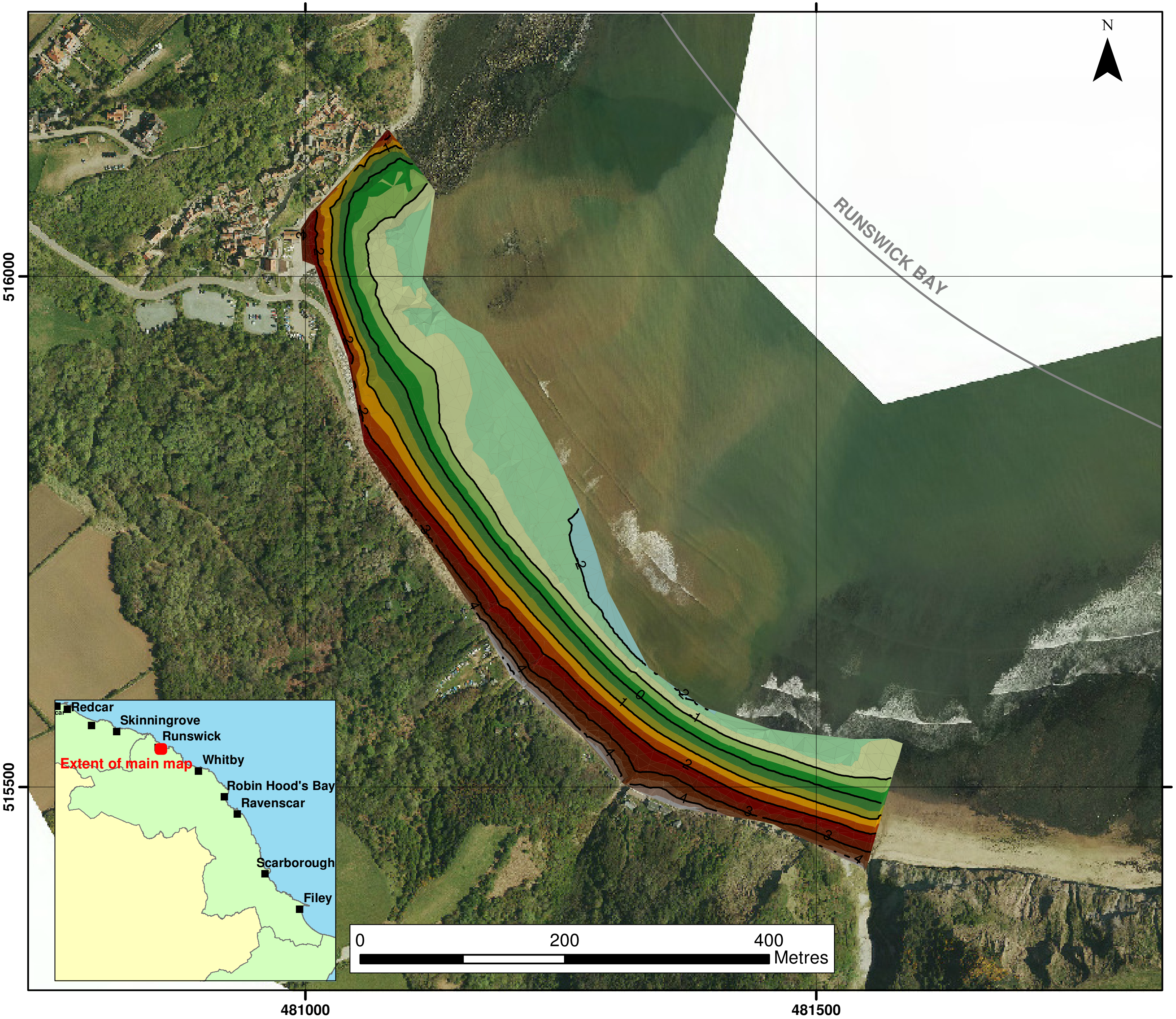


Beach Profiles: 1dFB4
CT
Level (m)
Chainage (m)
HAT
MHWS
MLWS
Profile Envelope
2008-11-26
2009-04-28
2009-10-19
2010-03-03
2010-09-24
2011-03-24
2011-09-13
2012-03-26
2012-09-04
SANDS


Beach Profiles: 1dFB5
Profile Envelope
2008-11-26
2009-04-28
2009-10-19
2010-03-03
2010-09-24
2011-03-24
2011-09-13
2012-03-26
2012-09-04
Level (m)
Chainage (m)
GR
S
MHWS
MLWS
SANDS

Appendix B

Topographic Survey



KEY

Elevation (m OD)

5.5 - 6
5 - 5.5
4.5 - 5
4 - 4.5
3.5 - 4
3 - 3.5
2.5 - 3
2 - 2.5
1.5 - 2
1 - 1.5
0.5 - 1
0 - 0.5
-0.5 - 0
-1 - -0.5
-1.5 - -1
-2 - -1.5
-2.5 - -2
Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

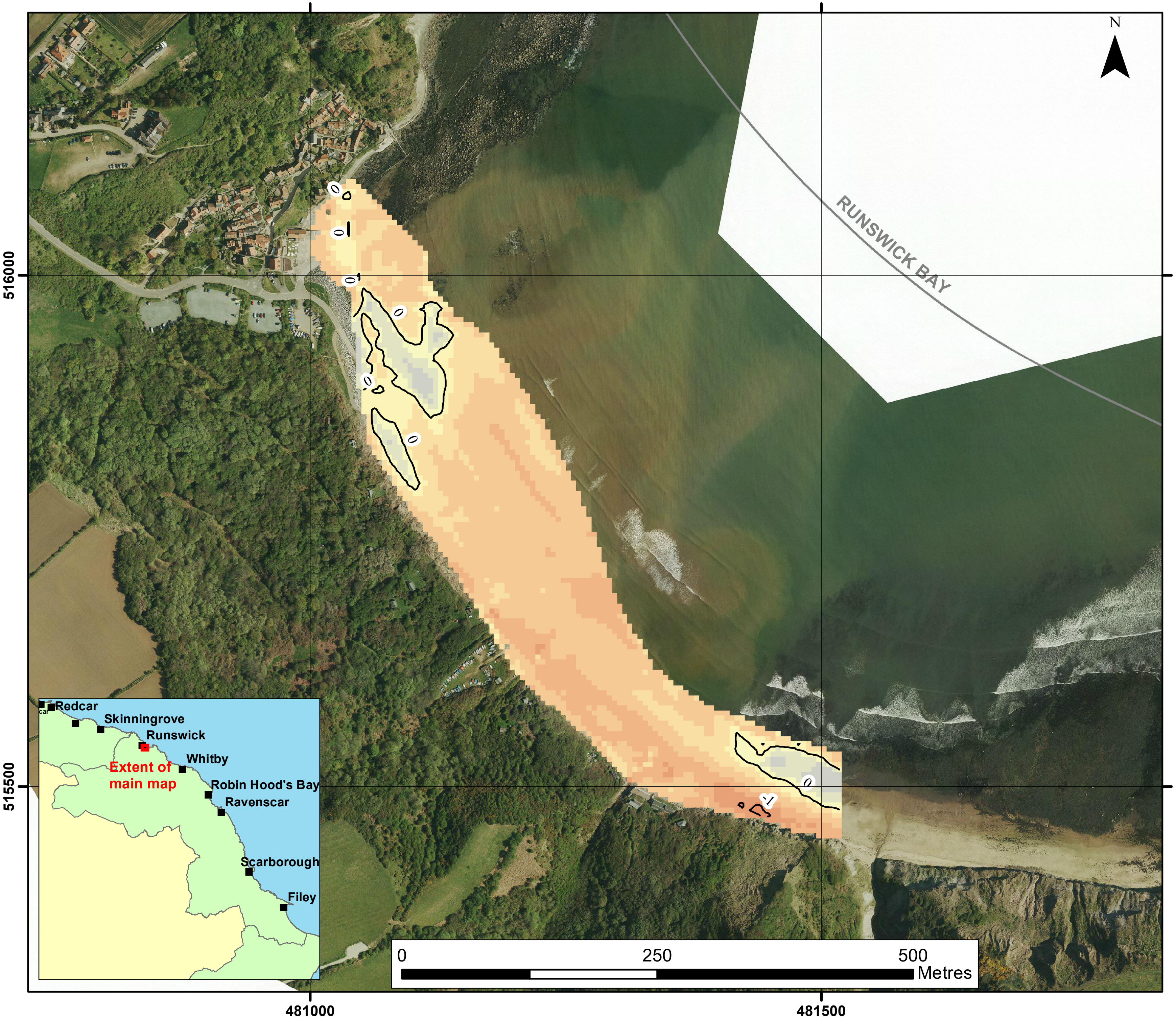
Appendix B - Map 1a
Topographic Survey
Runswick
Scarborough Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Spring 2012 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

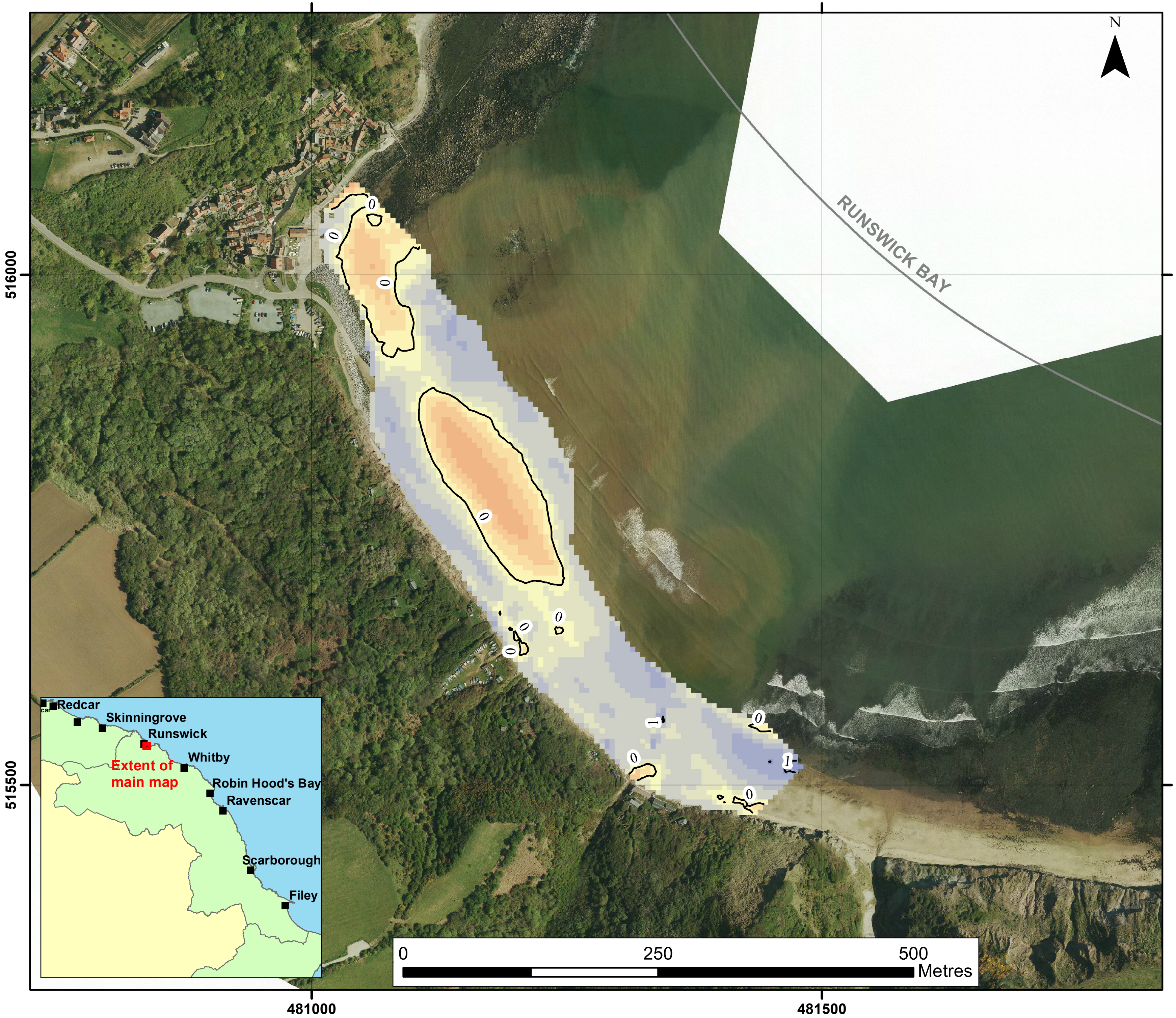
Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 1b
Short-term Elevation change
Runswick
Scarborough Borough Council

Analytical Report 5
Full Measures Surveys
Spring 2012 to Autumn 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE
Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 1c
Long-term Elevation change Runswick Scarborough Borough Council

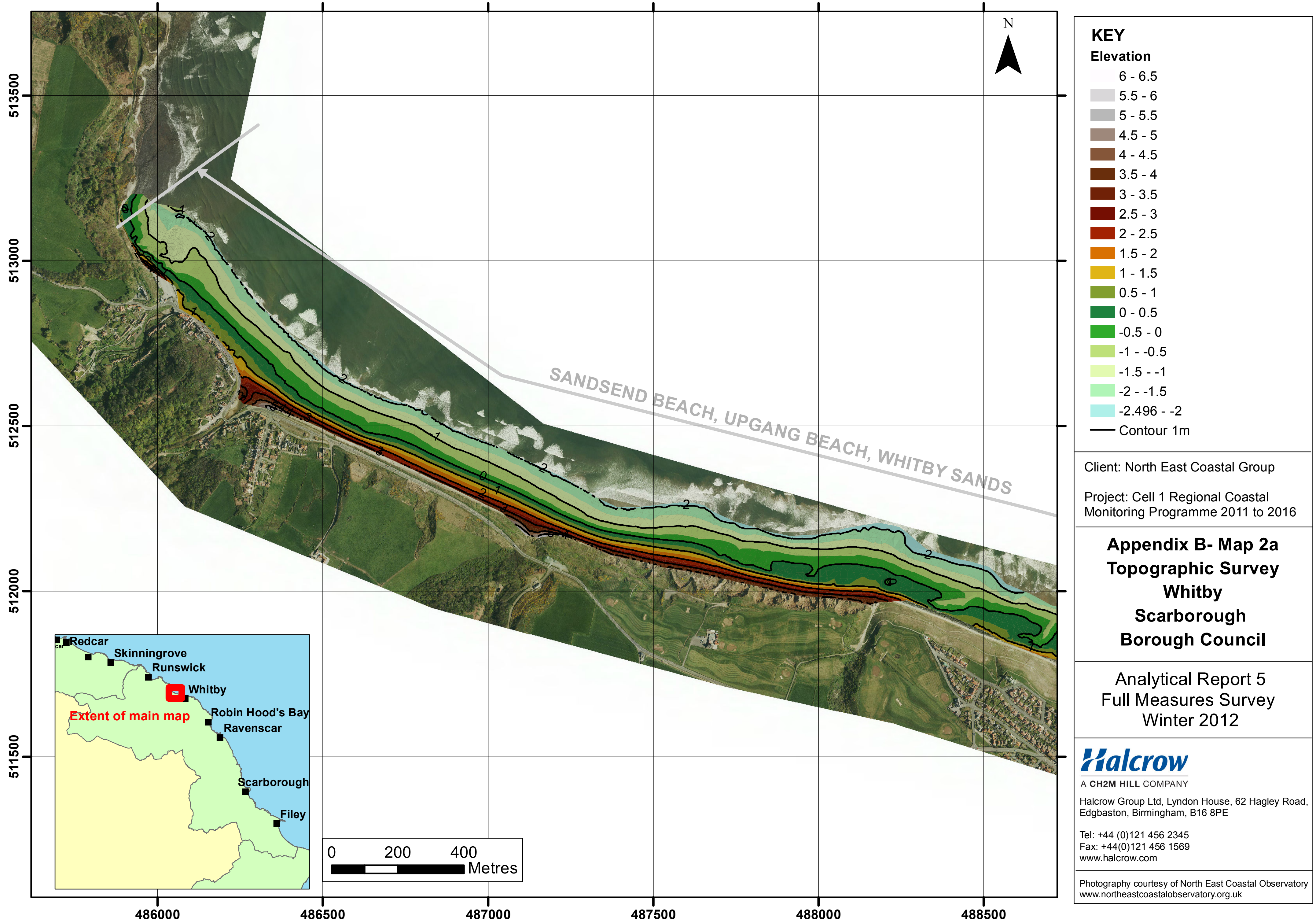
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

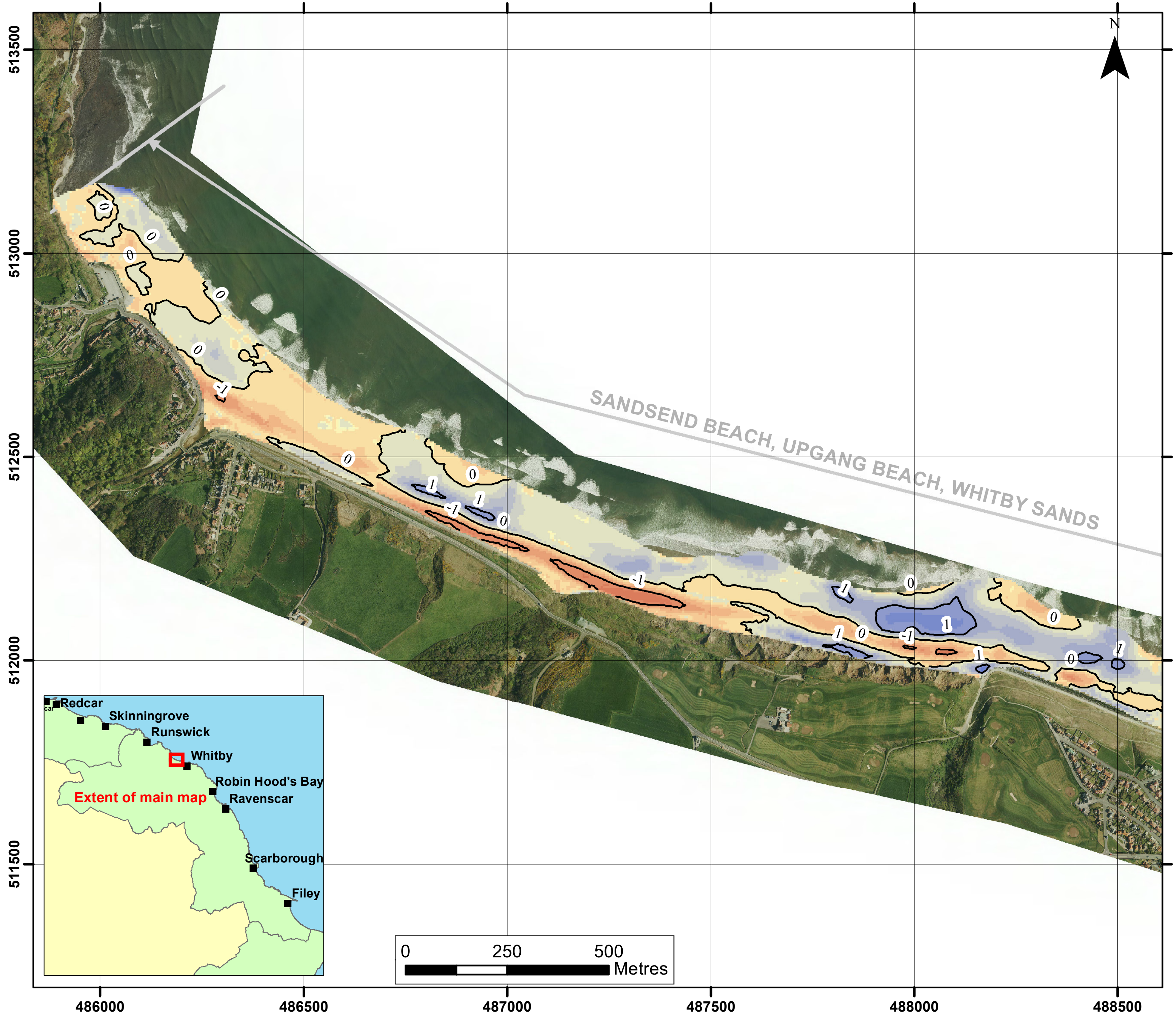
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



N
KEY
Elevation
6 - 6.5
5.5 - 6
5 - 5.5
4.5 - 5
4 - 4.5
3.5 - 4
3 - 3.5
2.5 - 3
2 - 2.5
1.5 - 2
1 - 1.5
0.5 - 1
0 - 0.5
-0.5 - 0
-1 - -0.5
-1.5 - -1
-2 - -1.5
-2.496 - -2
Contour 1m
SANDSEND BEACH, UPGANG BEACH, WHITBY SANDS
Redcar
Skinningrove
Runswick
Whitby
Extent of main map
Robin Hood's Bay
Ravenscar
Scarborough
Filey
0 200 400
Metres
513500
513000
512500
512000
511500
486000
486500
487000
487500
488000
488500
Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016
Appendix B- Map 2a
Topographic Survey
Whitby
Scarborough
Borough Council
Analytical Report 5
Full Measures Survey
Winter 2012
Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE
Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com
Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2011 and Autumn 2012

Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 2b Short-term Elevation change Whitby Scarborough Borough Council

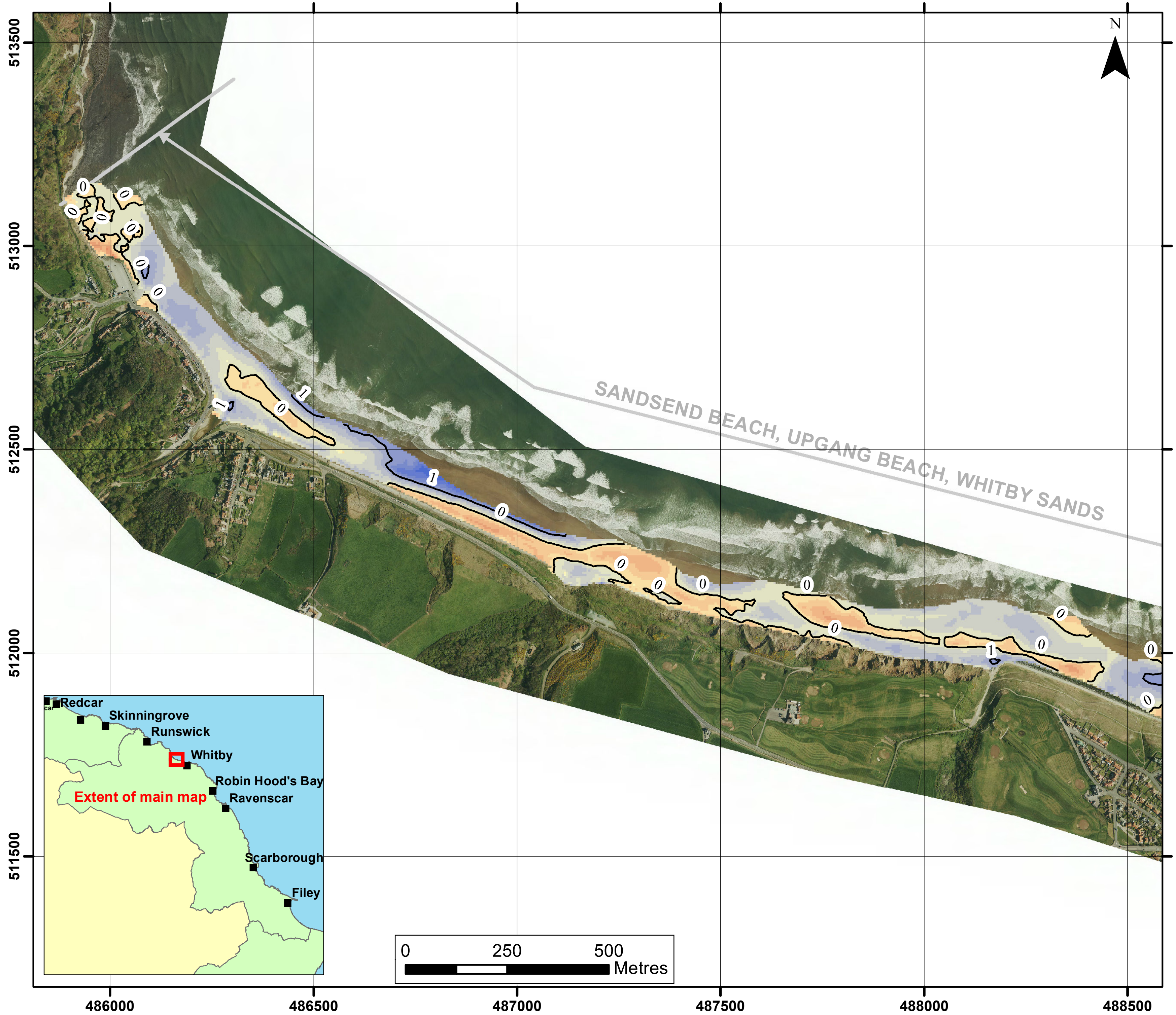
Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44 (0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 2c
Long-term Elevation change Whitby Scarborough Borough Council

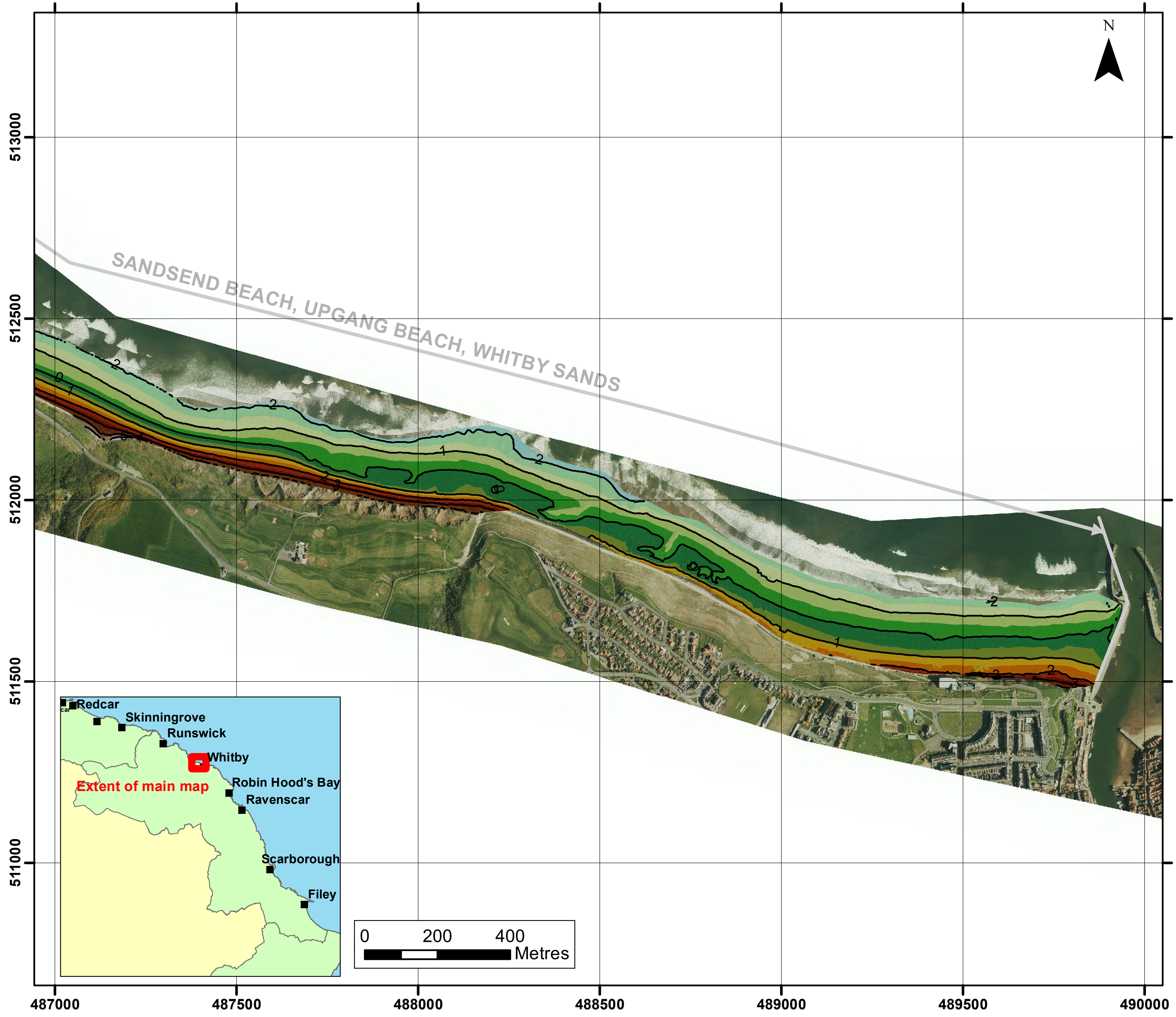
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation

- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.496 - -2
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 3a
Topographic Survey
Whitby
Scarborough Borough Council

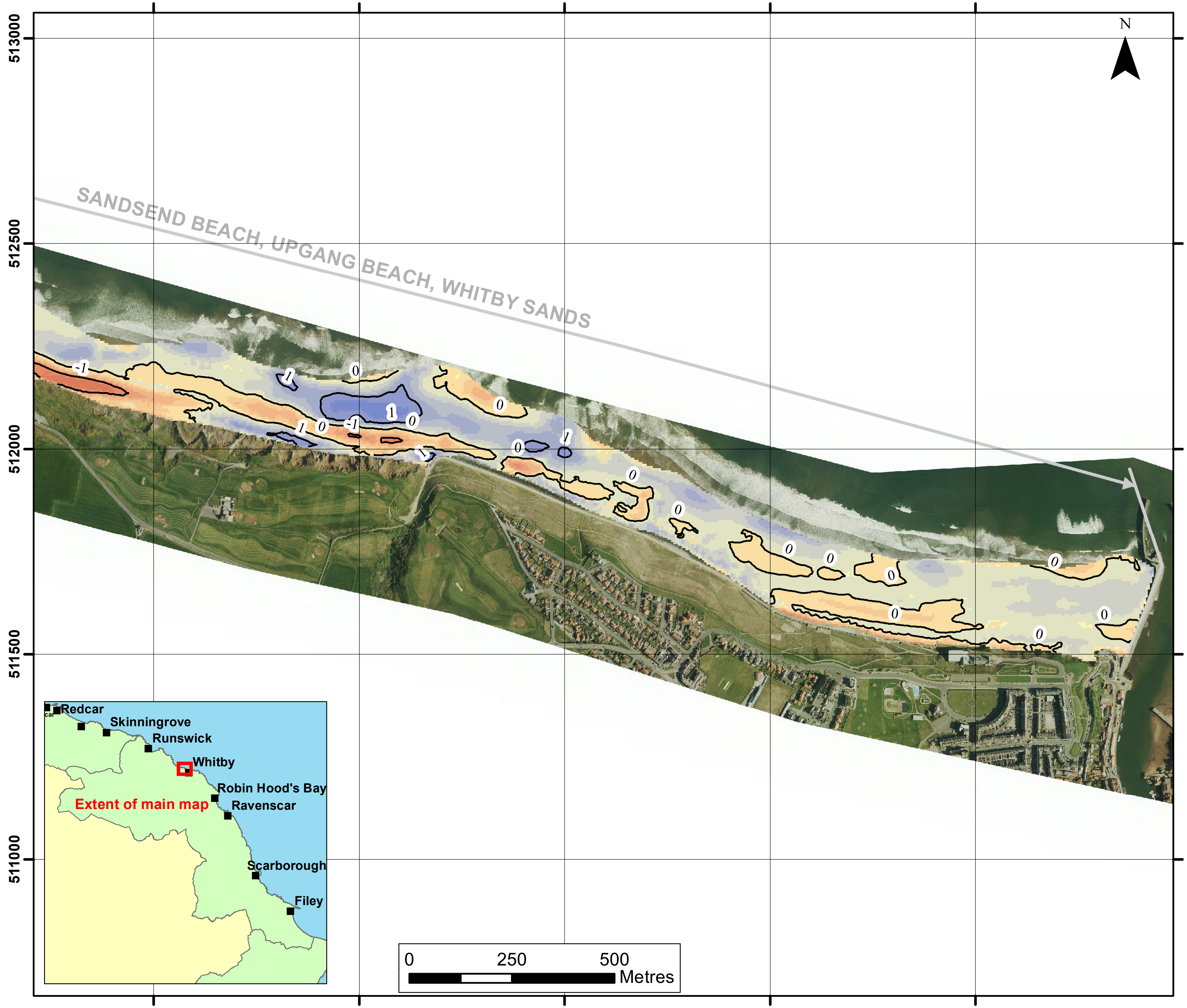
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Autumn 2011 and Autumn 2012
Change in elevation (m OD)

<-2
-2 - -1.75
-1.75 - -1.5
-1.5- -1.25
-1.25 - -1
-1 - -0.75
-0.75 - -0.5
-0.5 - -0.25
-0.25 - -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
>2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 3b
Short-term Elevation change Whitby Scarborough Borough Council

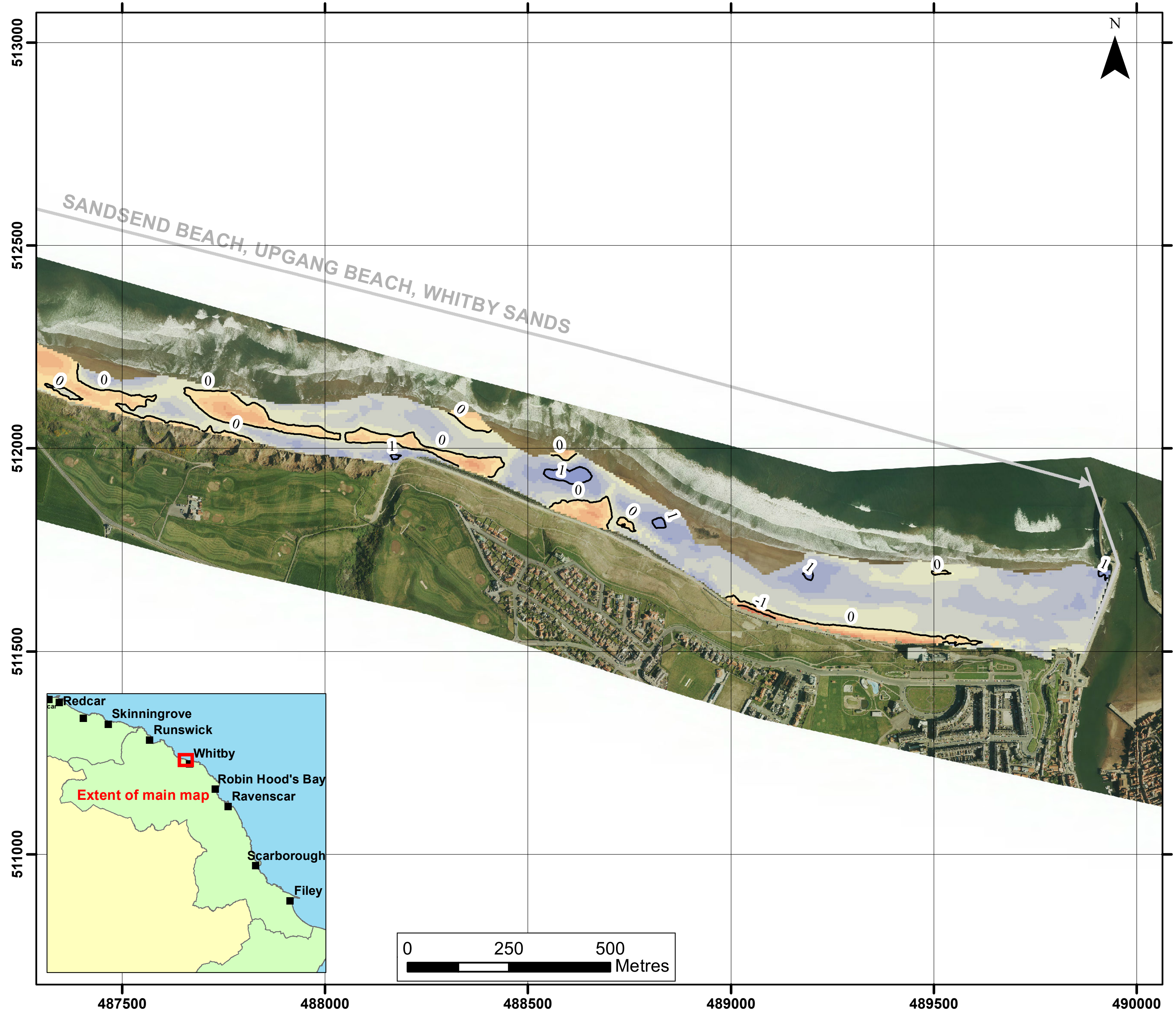
Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 3c
Long-term Elevation change Whitby Scarborough Borough Council

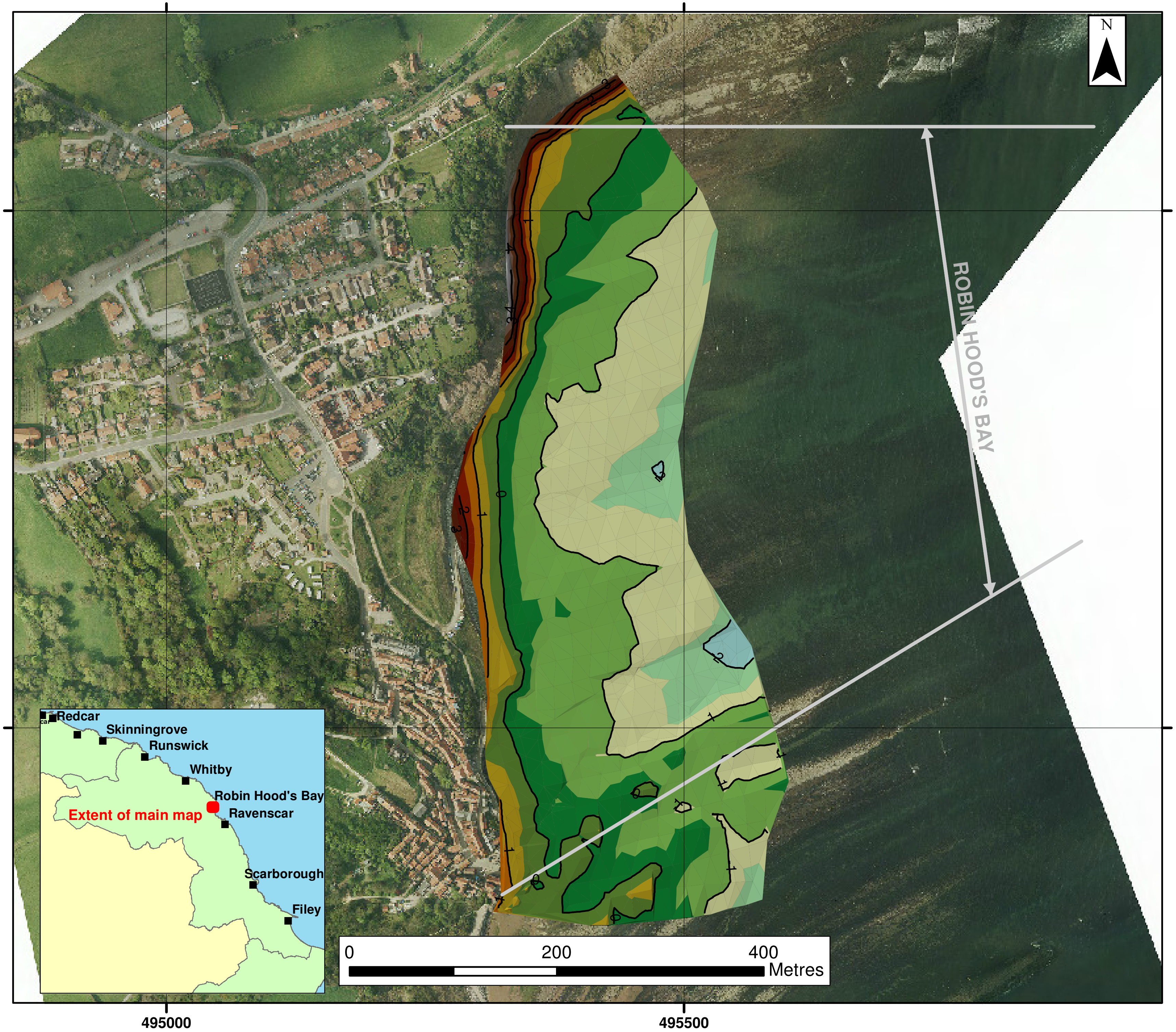
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation (m OD)

- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 4a
Topographic Survey
Robin Hood's Bay
Scarborough Borough Council

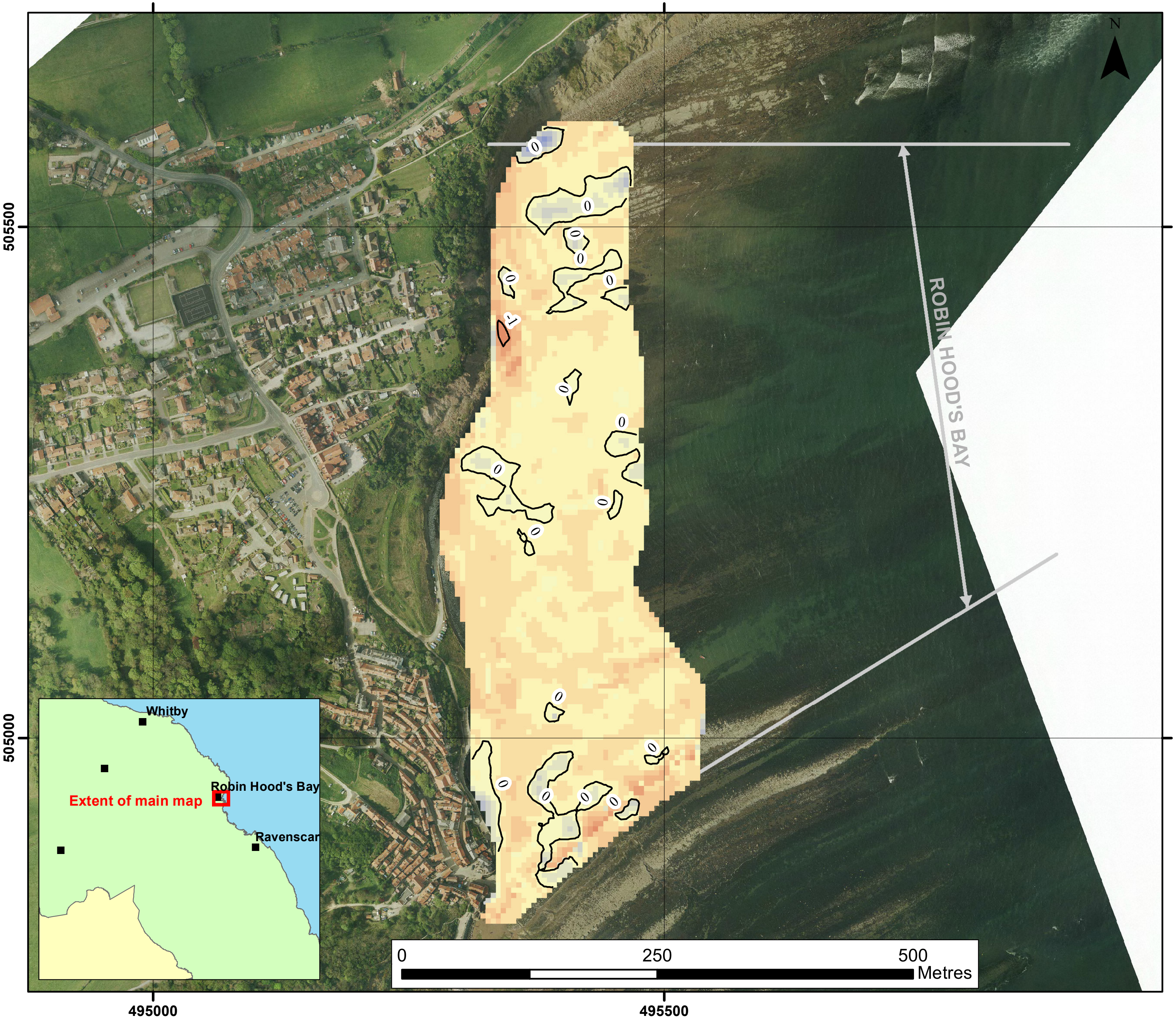
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Spring 2012 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

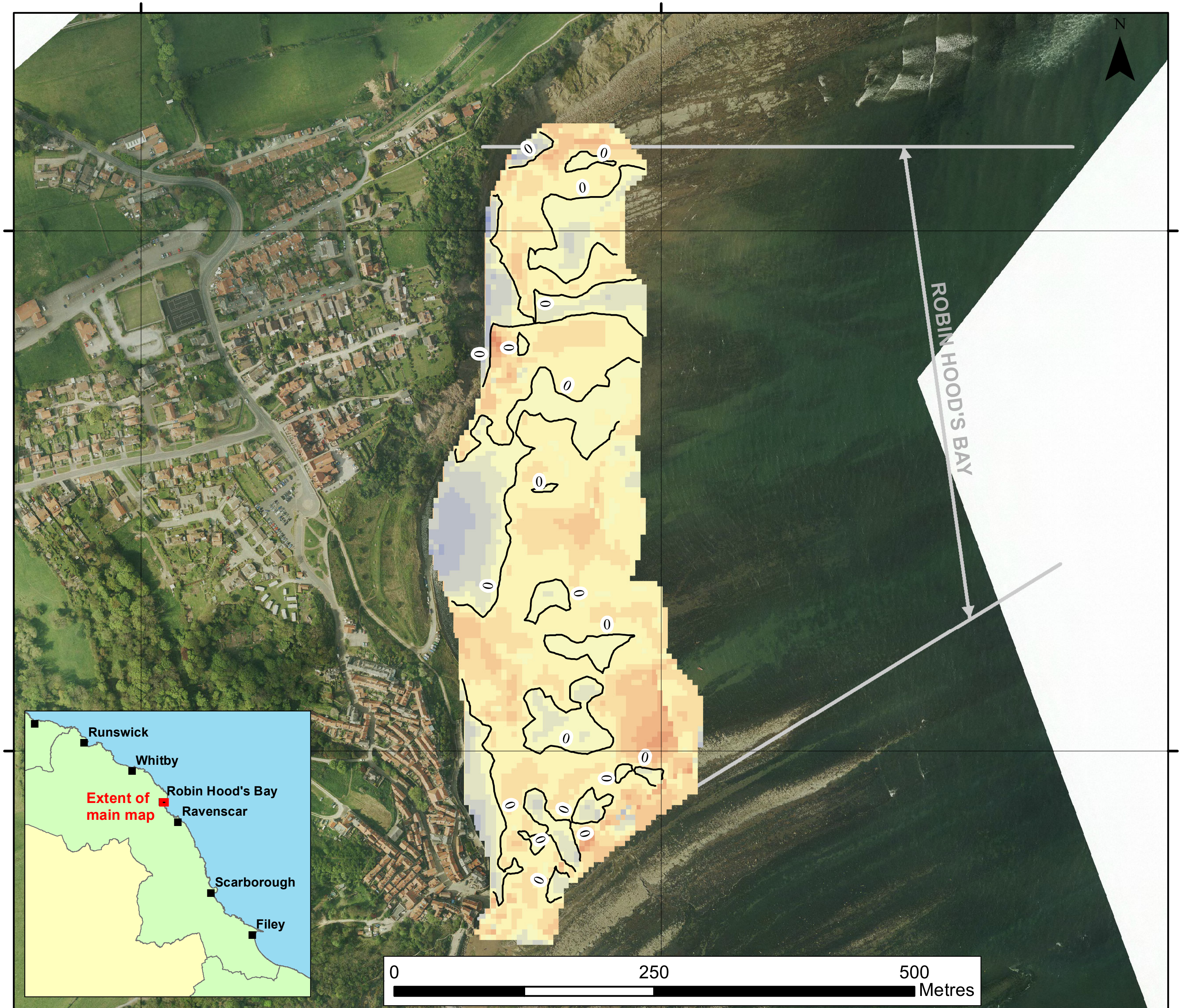
Appendix B- Map 3b Short-term Elevation change Robin Hood's Bay Scarborough Borough Council

Analytical Report 5
Full Measures Surveys
Spring 2012 and Autumn 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY **Autumn 2008 and Autumn 2012**
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 4c
Long-term
Elevation change
Robin Hood's Bay
Scarborough
Borough Council

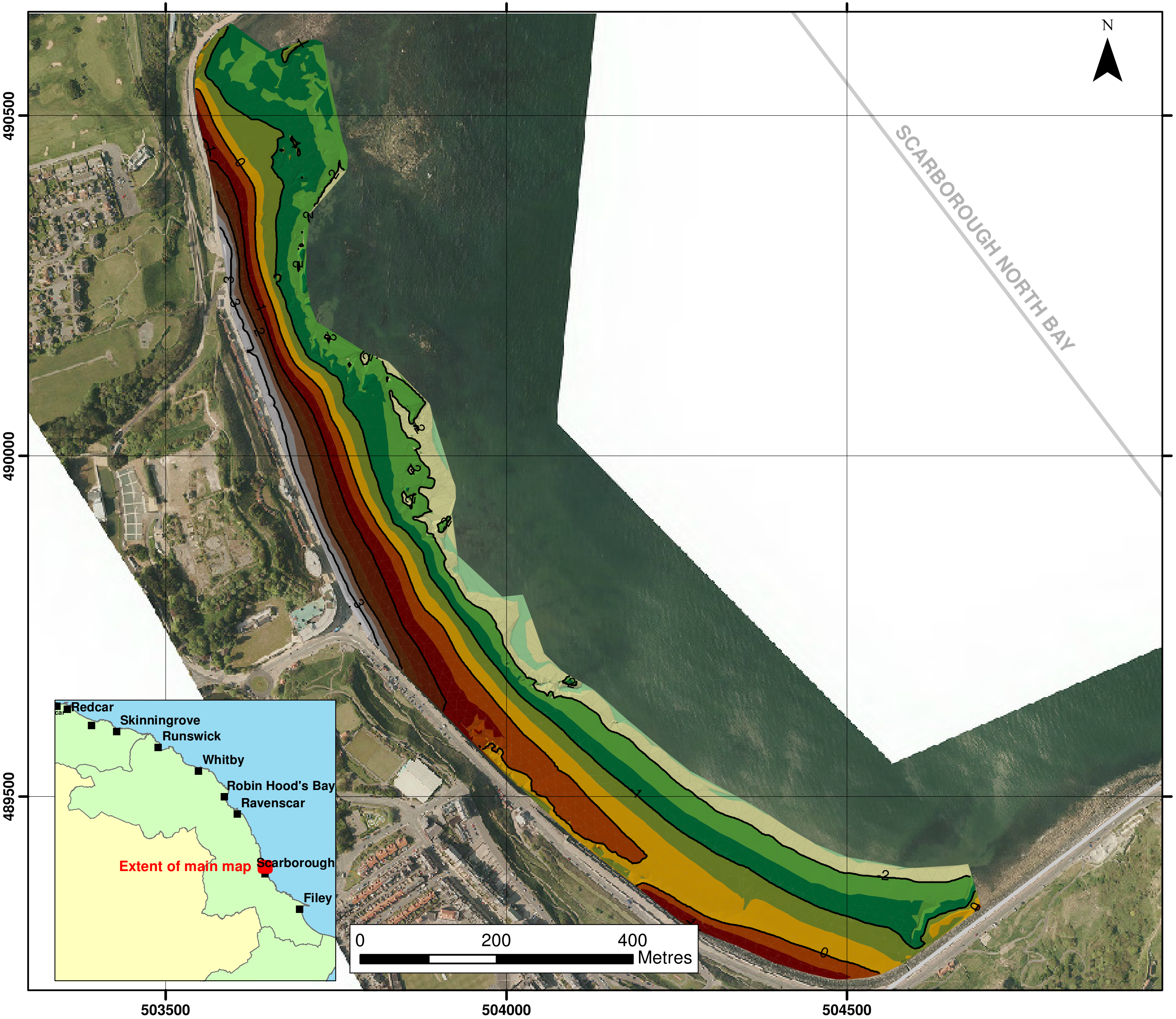
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation (m OD)

- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- -3.5 - -3
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 5a
Topographic Survey
Scarborough North
Scarborough Borough Council

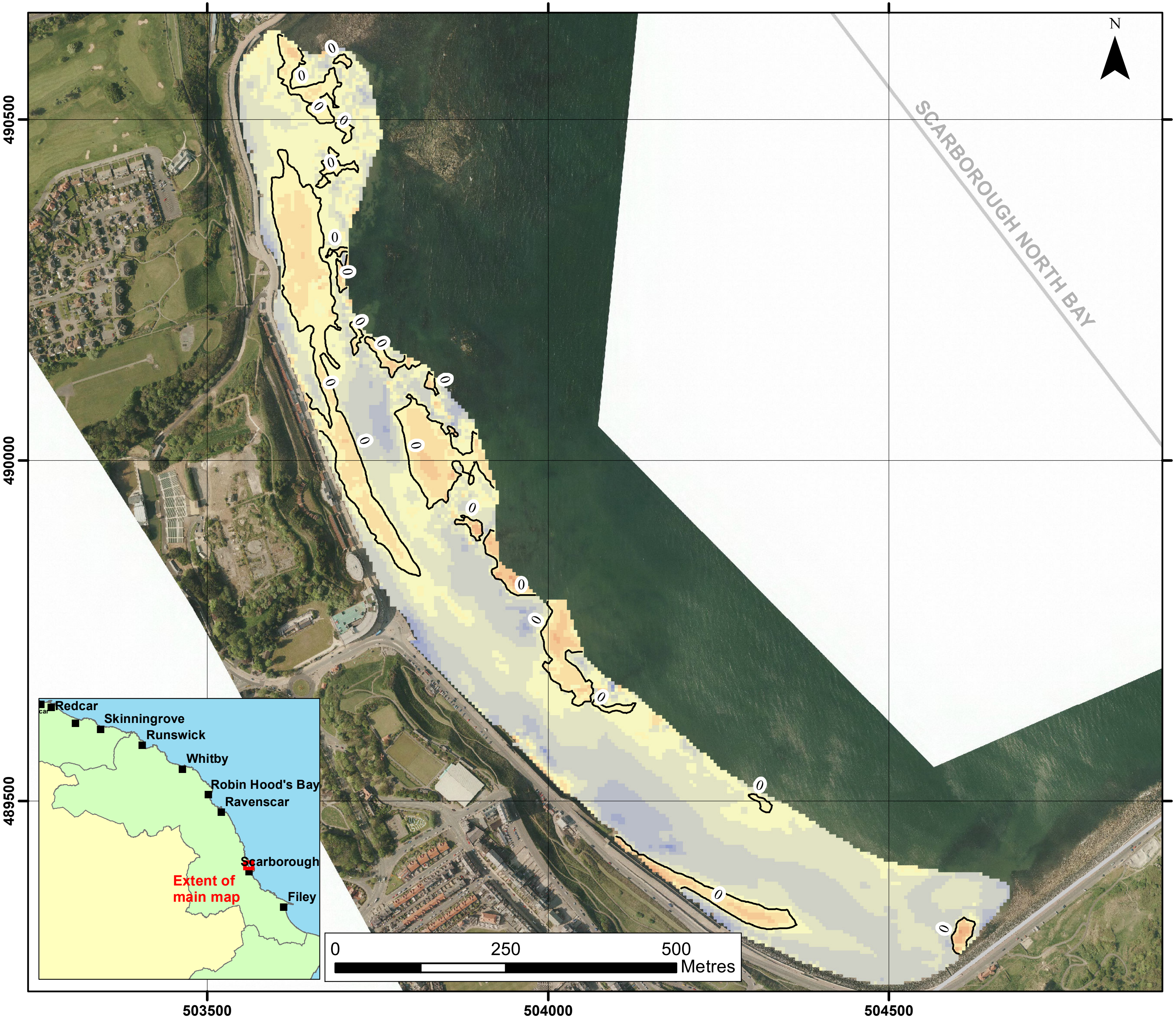
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 5b
Short-term
Elevation change
Scarborough North
Scarborough
Borough Council

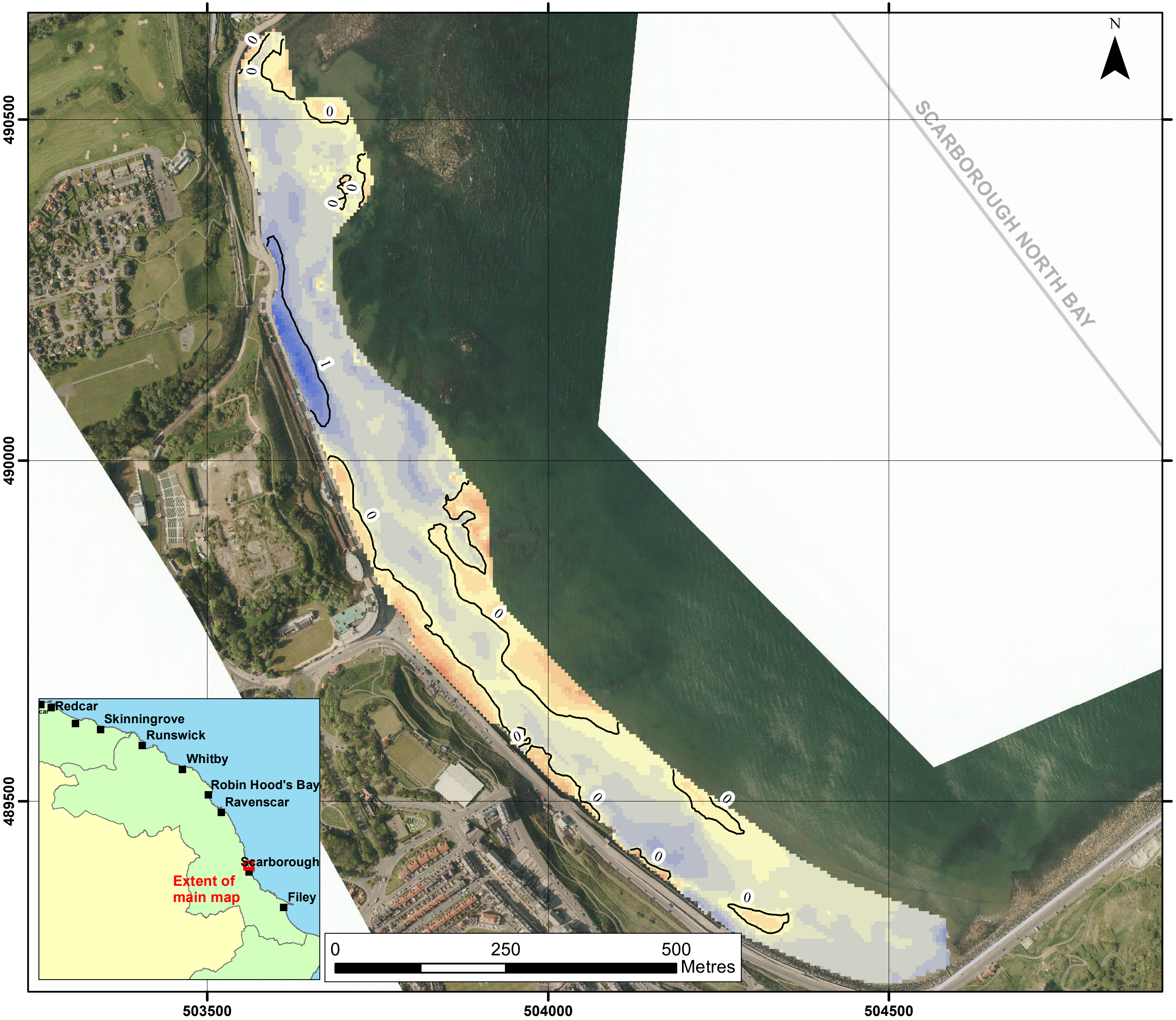
Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44 (0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2
-2 - -1.75
-1.75 - -1.5
-1.5- -1.25
-1.25 - -1
-1 - -0.75
-0.75 - -0.5
-0.5 - -0.25
-0.25 - -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
>2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

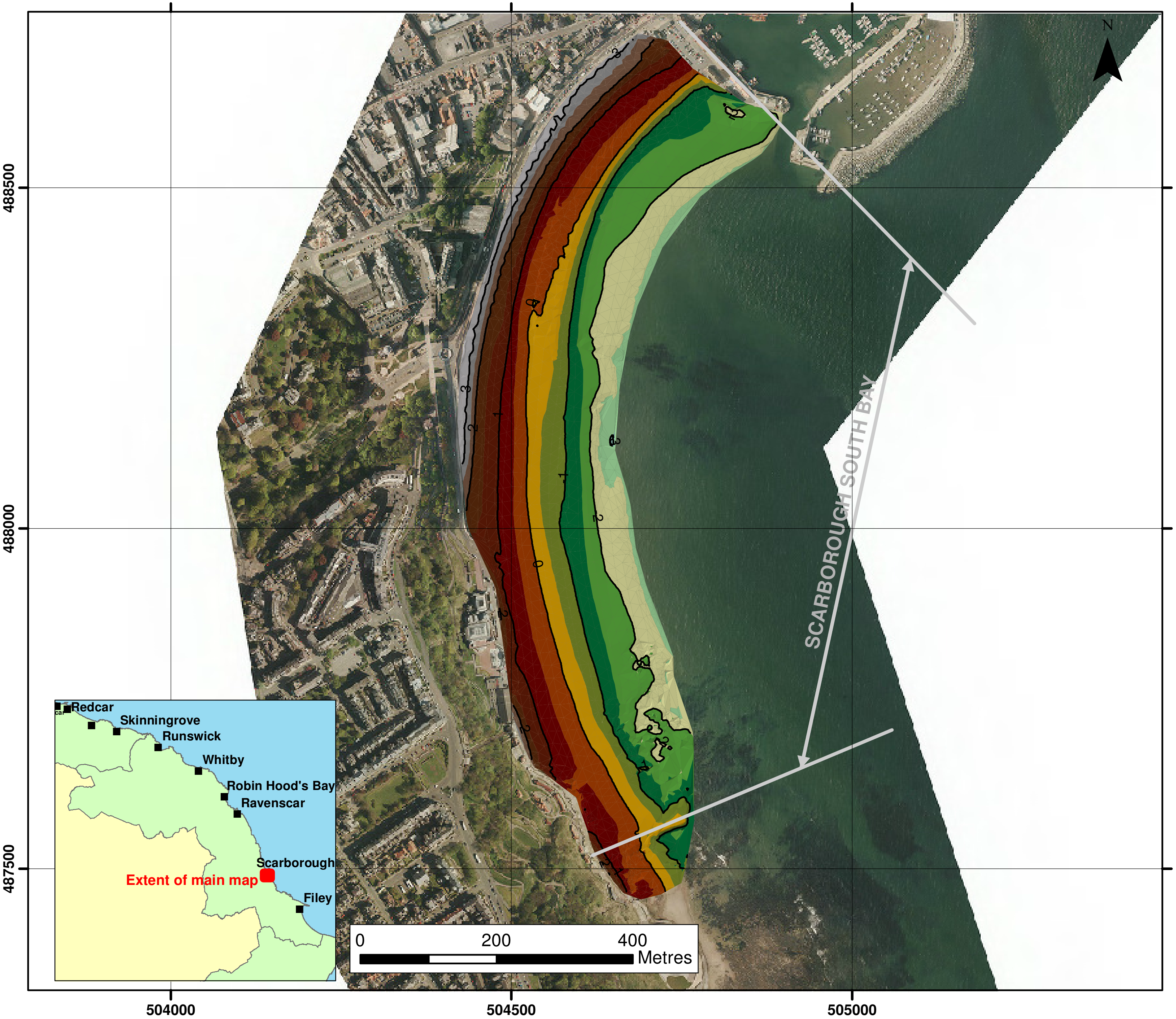
Appendix B- Map 5c
Long-term
Elevation change
Scarborough North
Scarborough
Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation

- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- -3.158 - -3
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 6a
Topographic Survey
Scarborough South
Scarborough
Borough Council

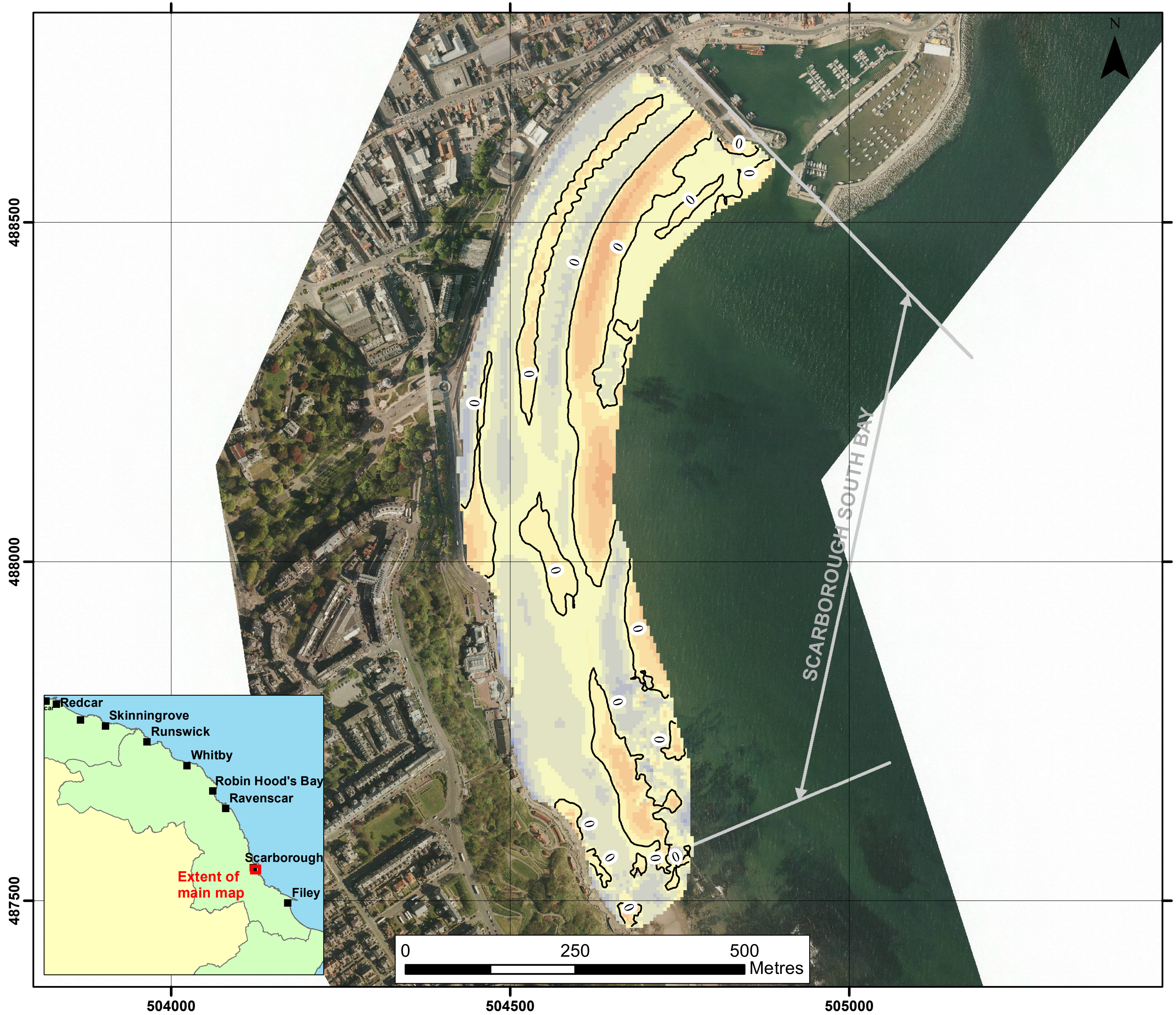
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Spring 2012 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 6b
Short-term
Elevation change
Scarborough South
Scarborough
Borough Council

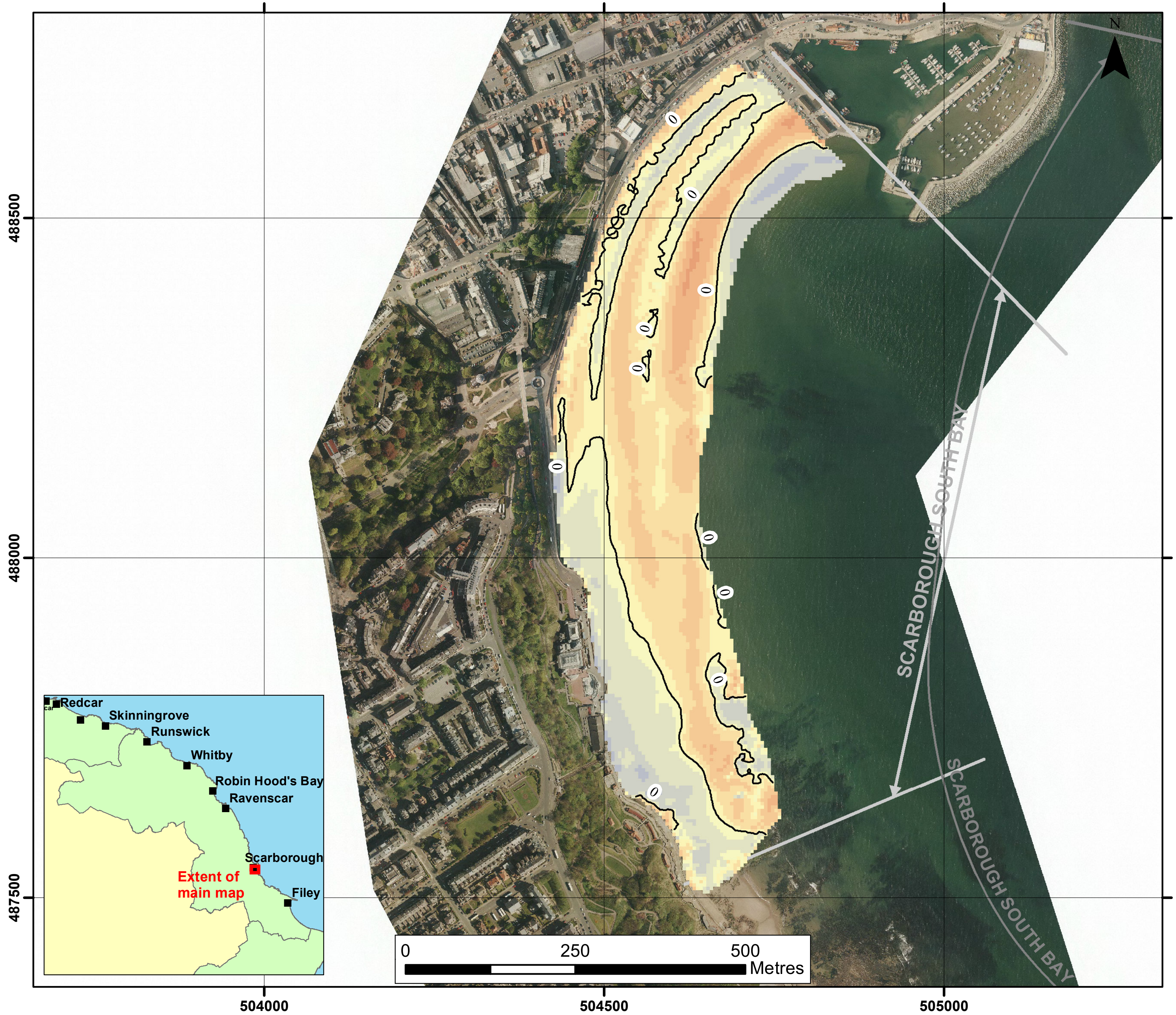
Analytical Report 5
Full Measures Surveys
Spring 2012 and Autumn 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 6c
Long-term Elevation change Scarborough South Scarborough Borough Council

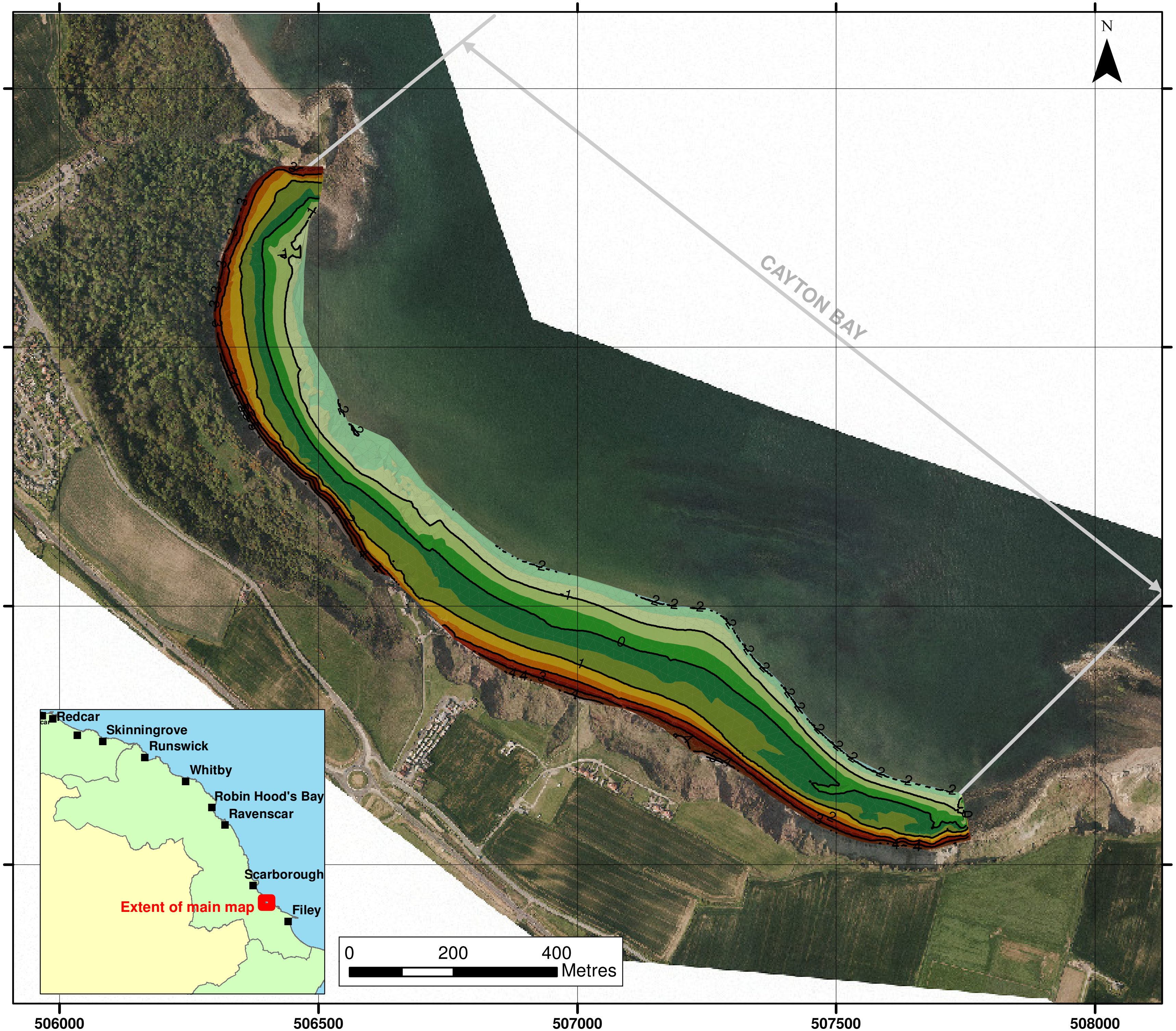
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44 (0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation (m OD)
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 7a Topographic Survey Cayton Bay Scarborough Borough Council

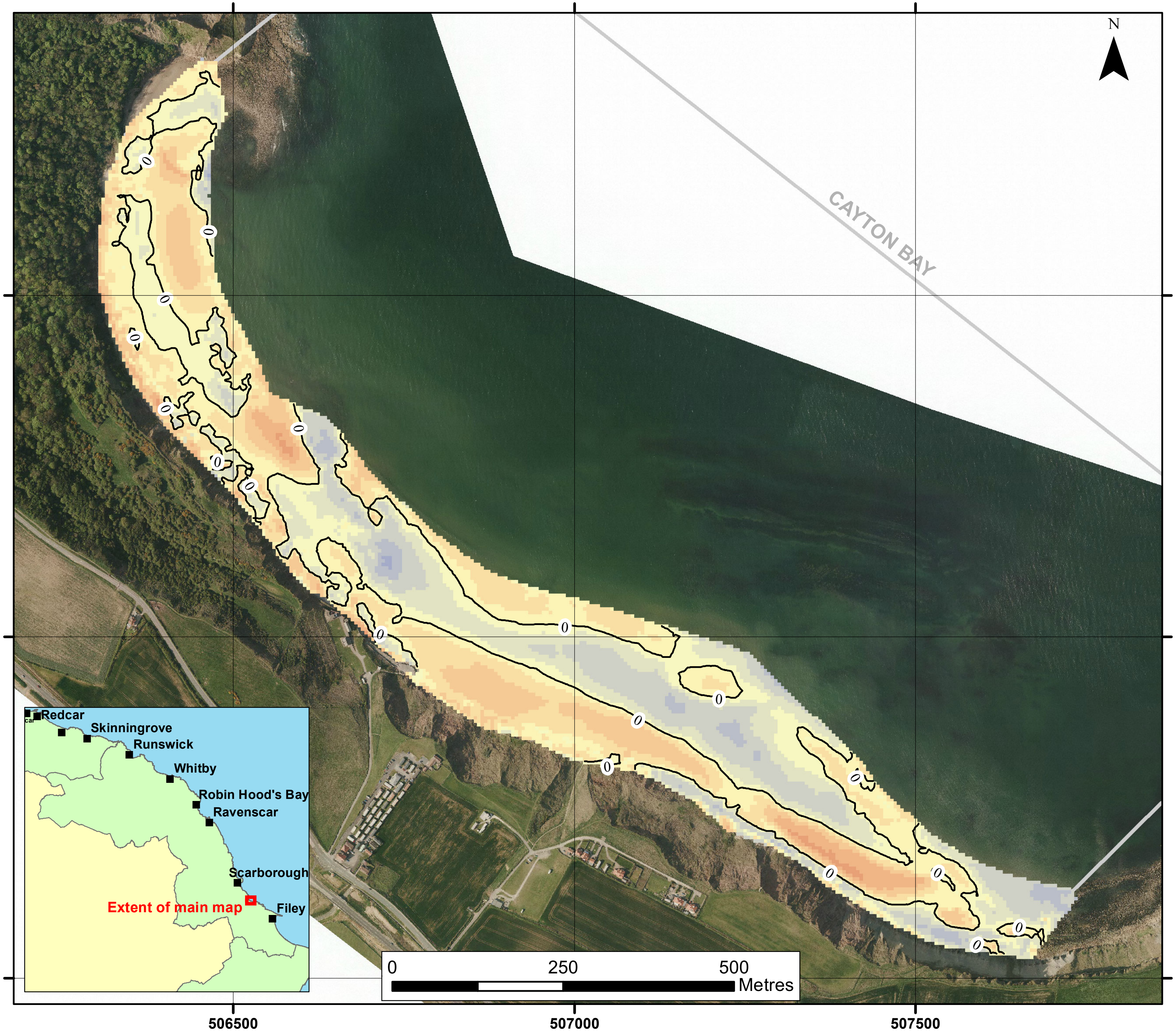
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 7b
Short-term Elevation change Cayton Scarborough Borough Council

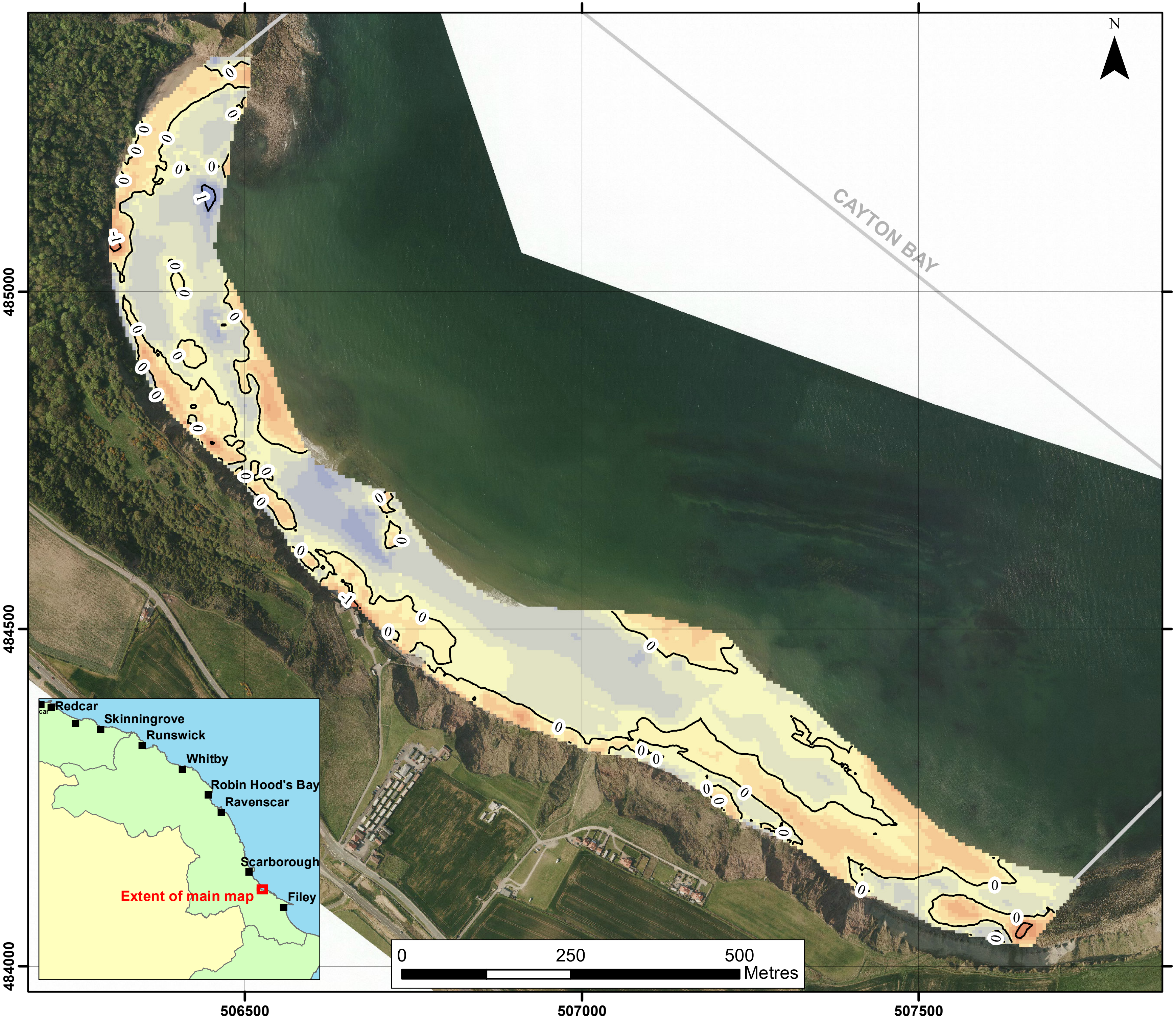
Analytical Report 5
Full Measures (Autumn) Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44 (0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 7c
Long-term Elevation change Cayton Scarborough Borough Council

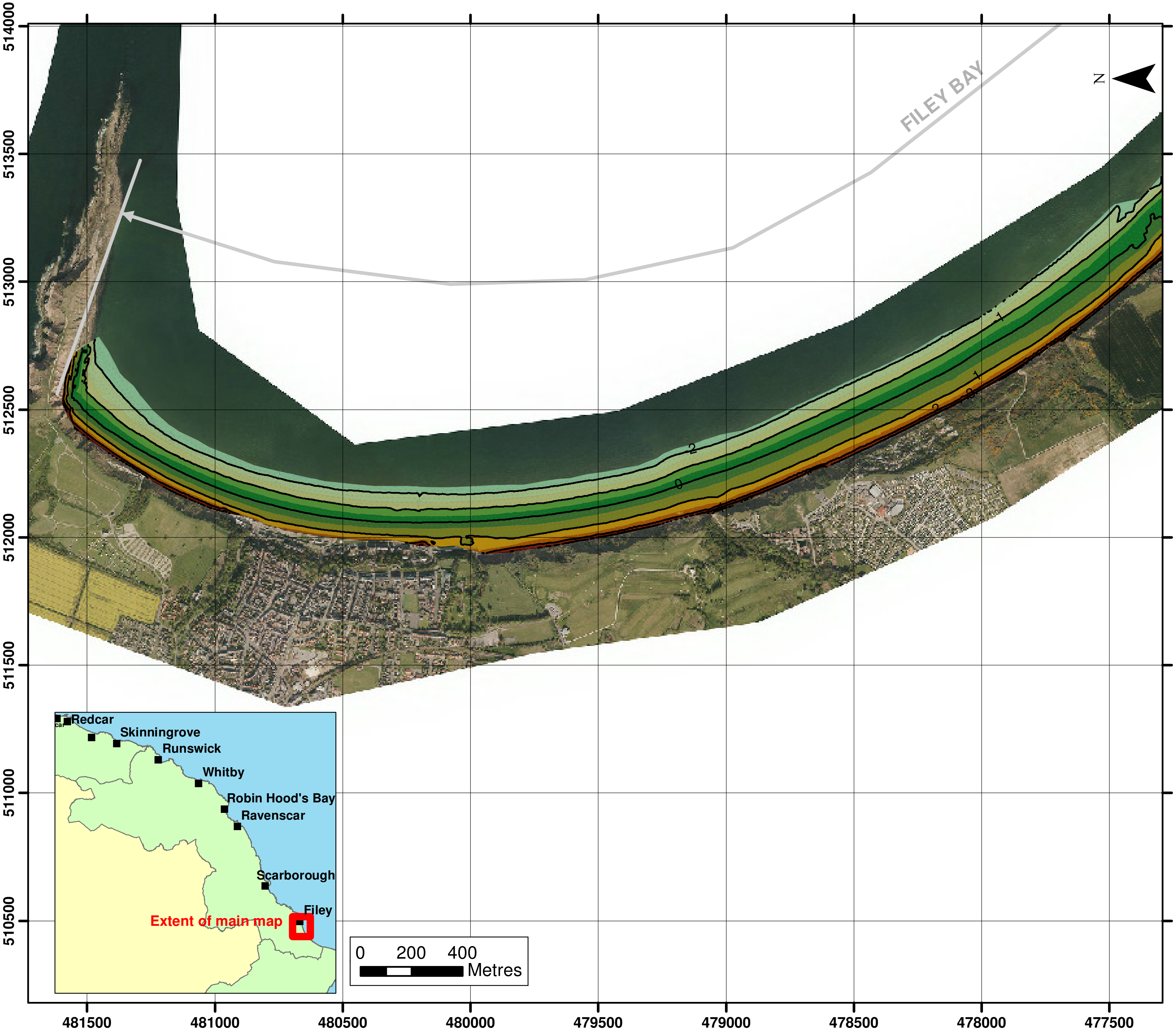
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Elevation (m OD)

- 6.5 - 7
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

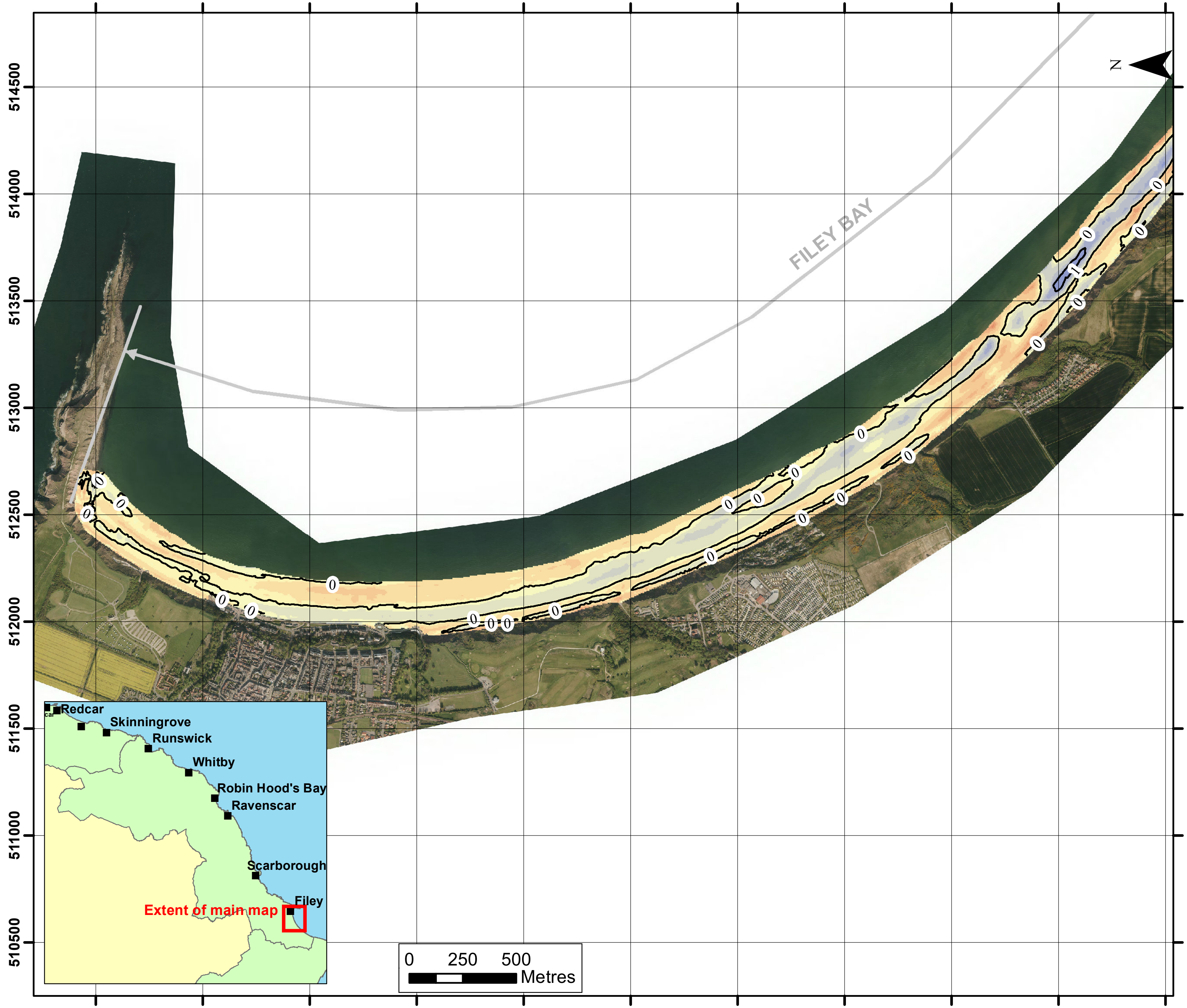
Appendix B- Map 8a Topographic Survey Filey Bay a Scarborough Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 8b
Short-term Elevation change Filey a Scarborough Borough Council

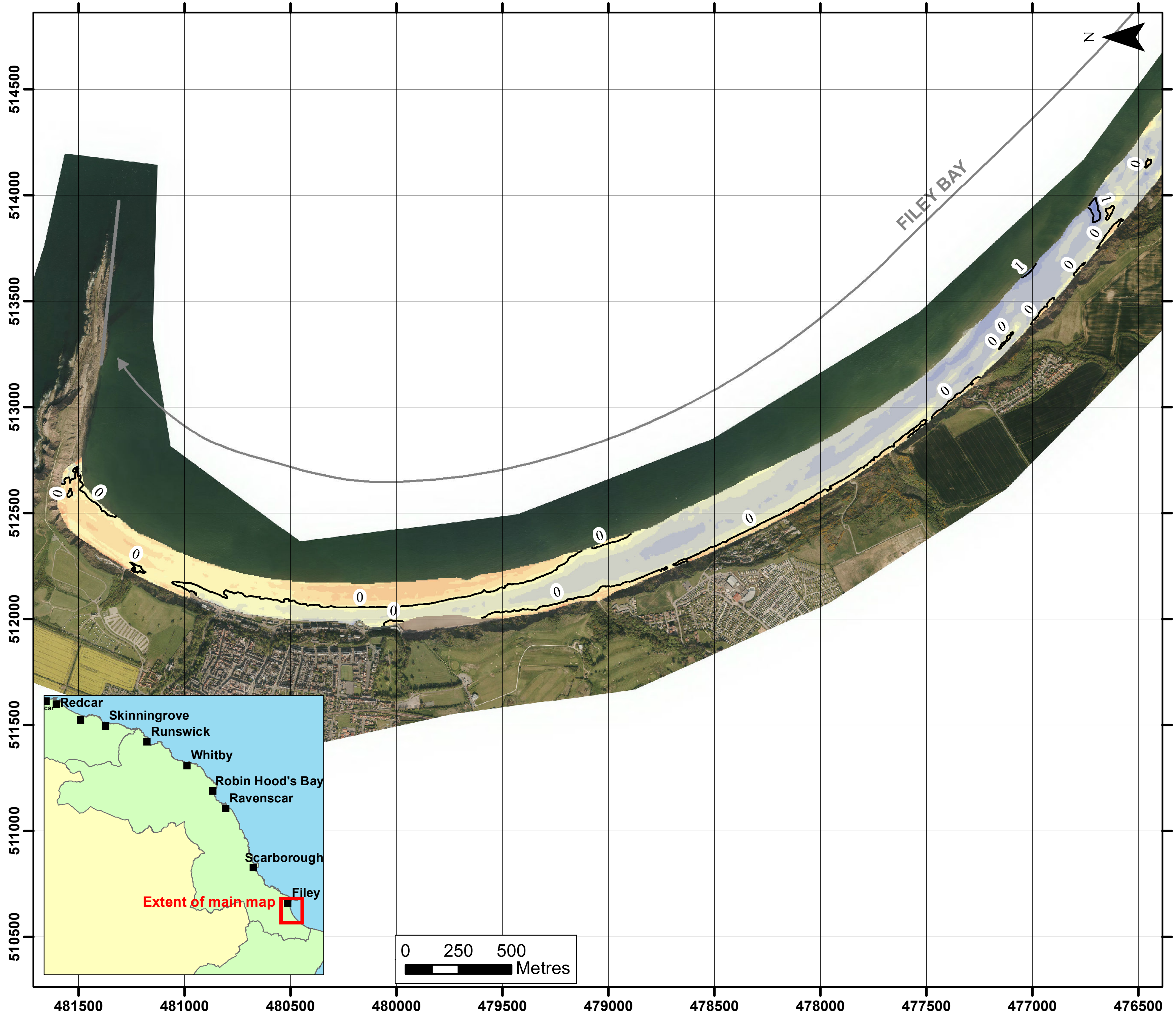
Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C- Map 8c
Long Term Elevation change
Filey a Scarborough Borough Council

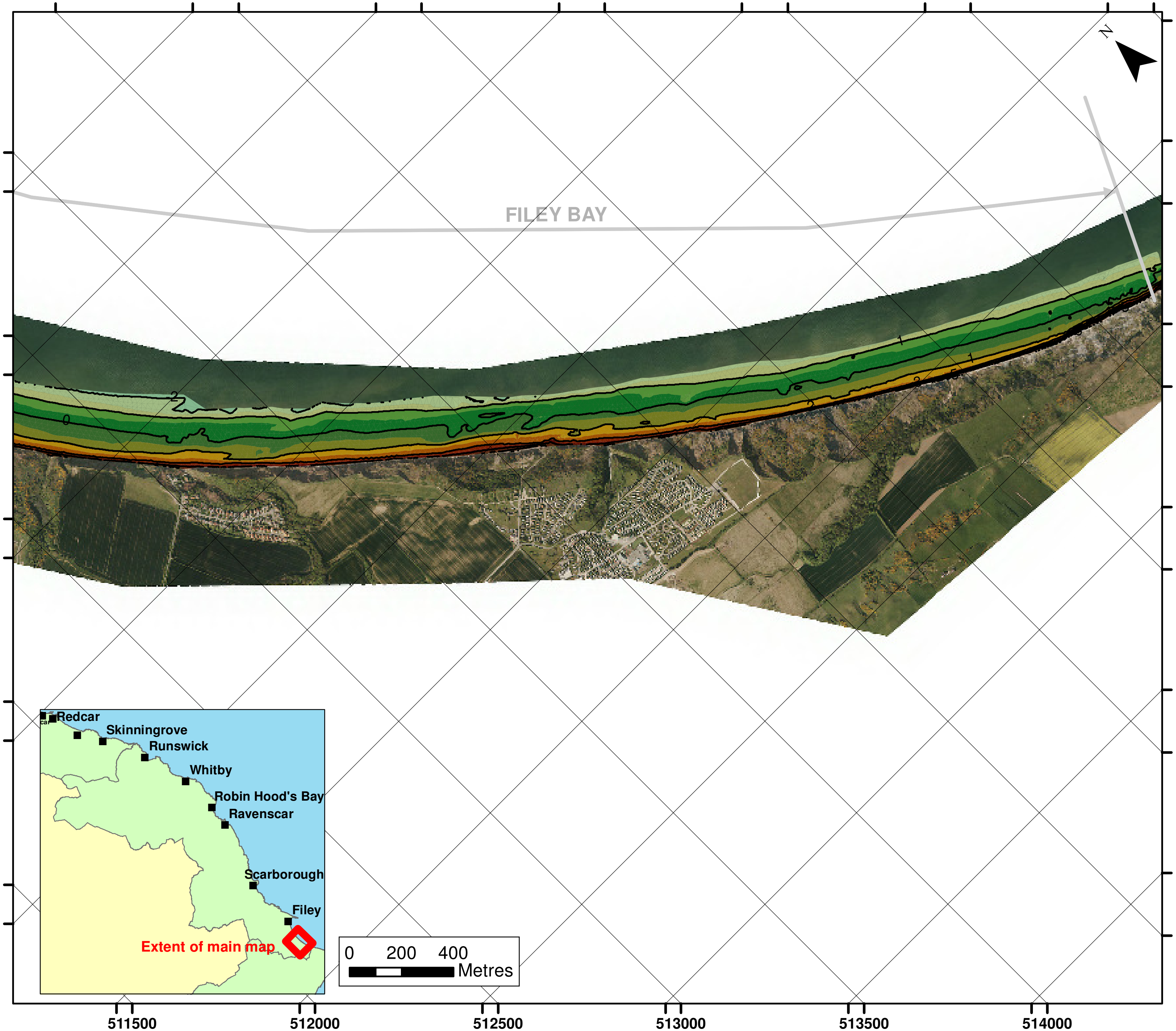
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 9a
Topographic Survey
Filey Bay b
Scarborough
Borough Council

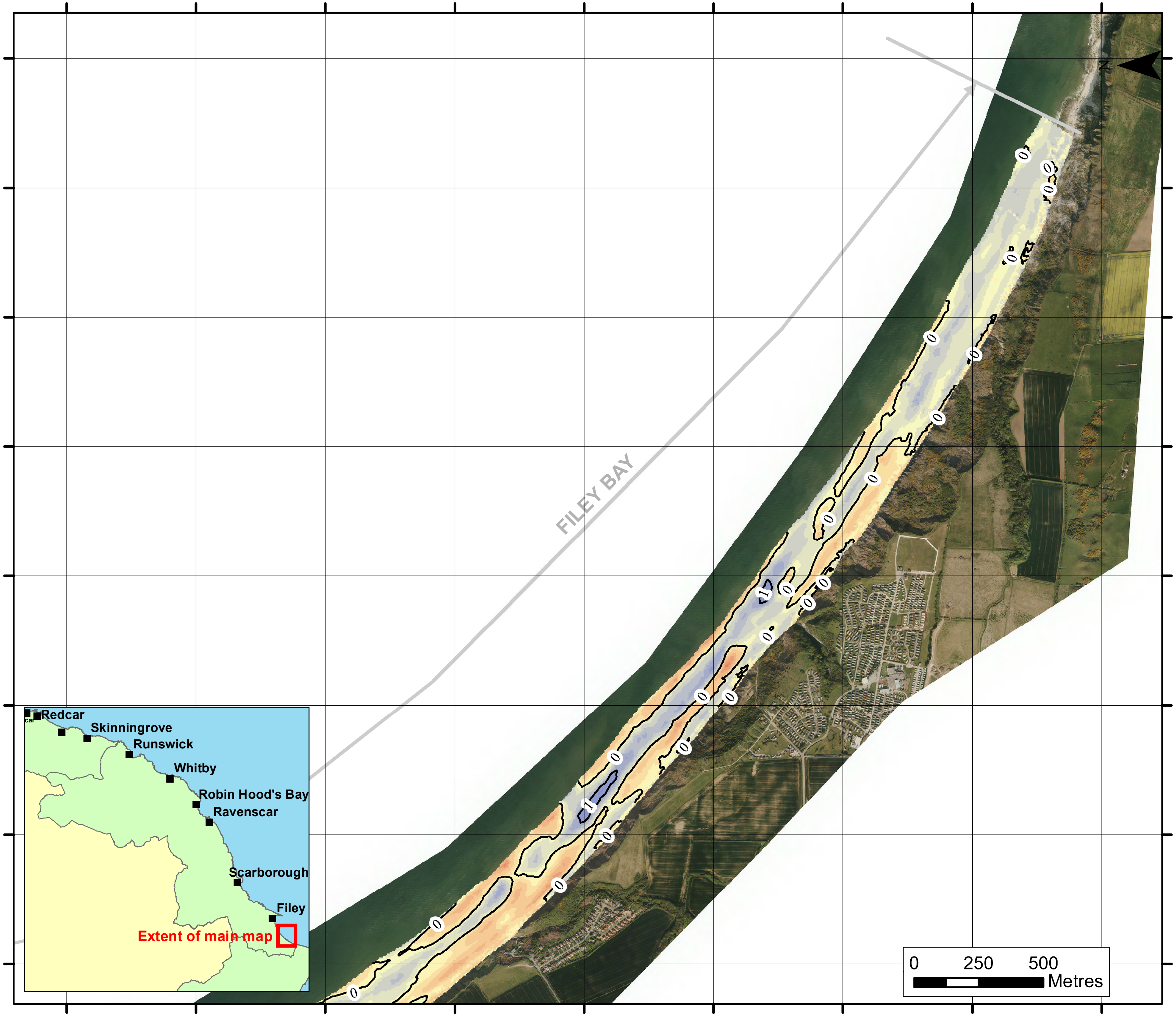
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

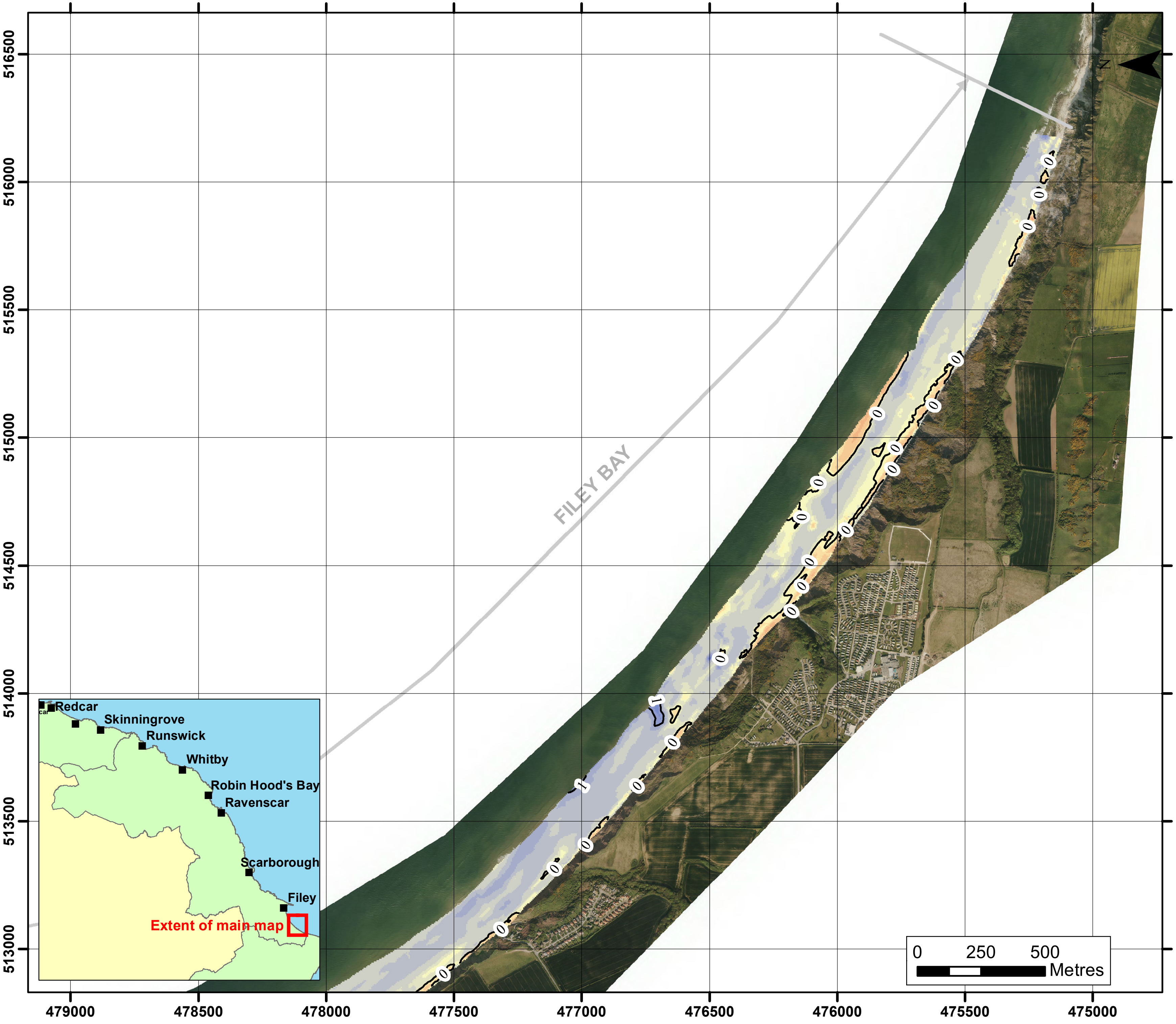
Appendix B- Map 9b
Short-term
Elevation change
Filey b
Scarborough
Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C- Map 9c
Long Term
Elevation change
Filey b
Scarborough Borough Council

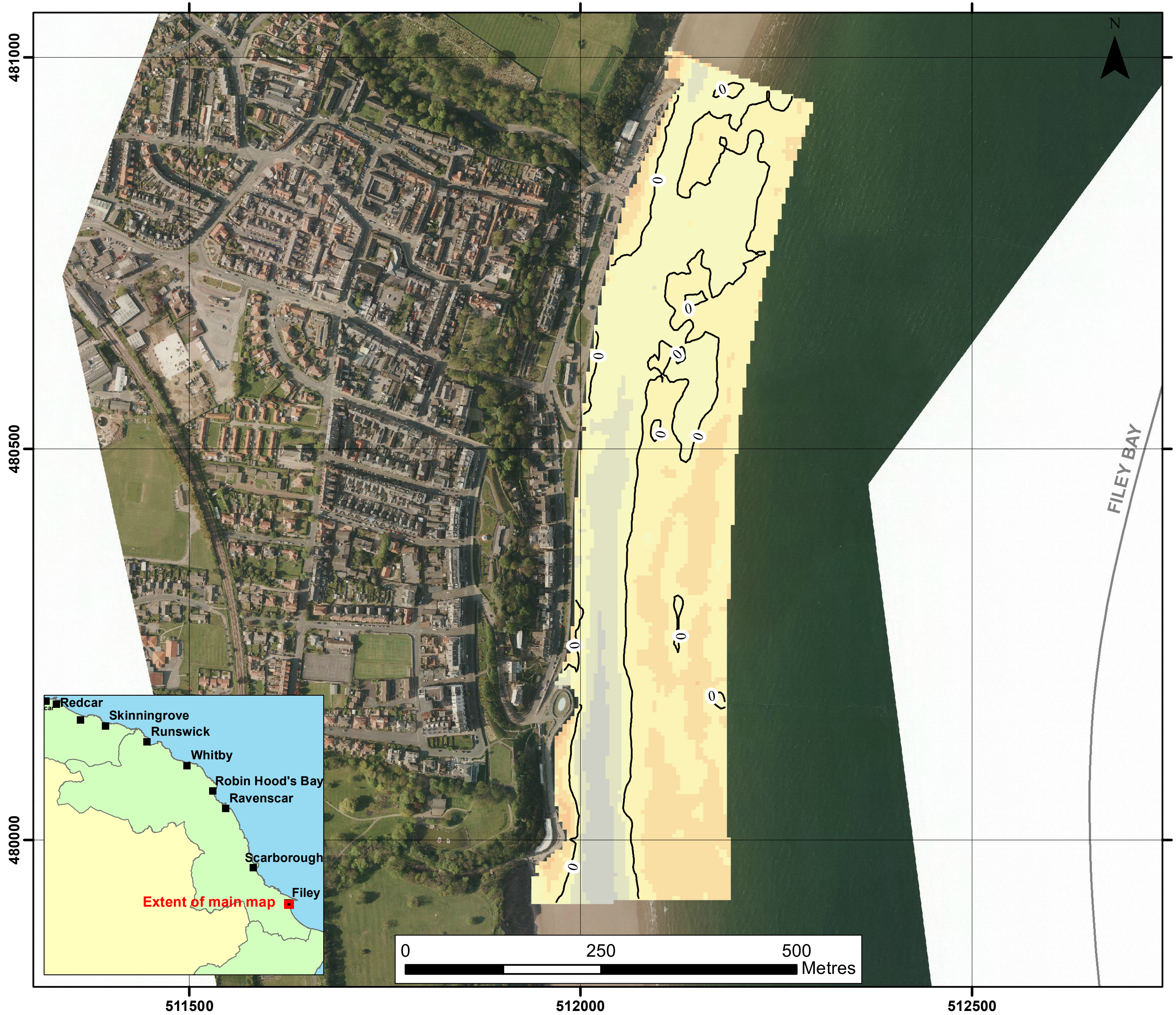
Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Spring 2012 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 10a
Short-term
Elevation change
Filey
Scarborough
Borough Council

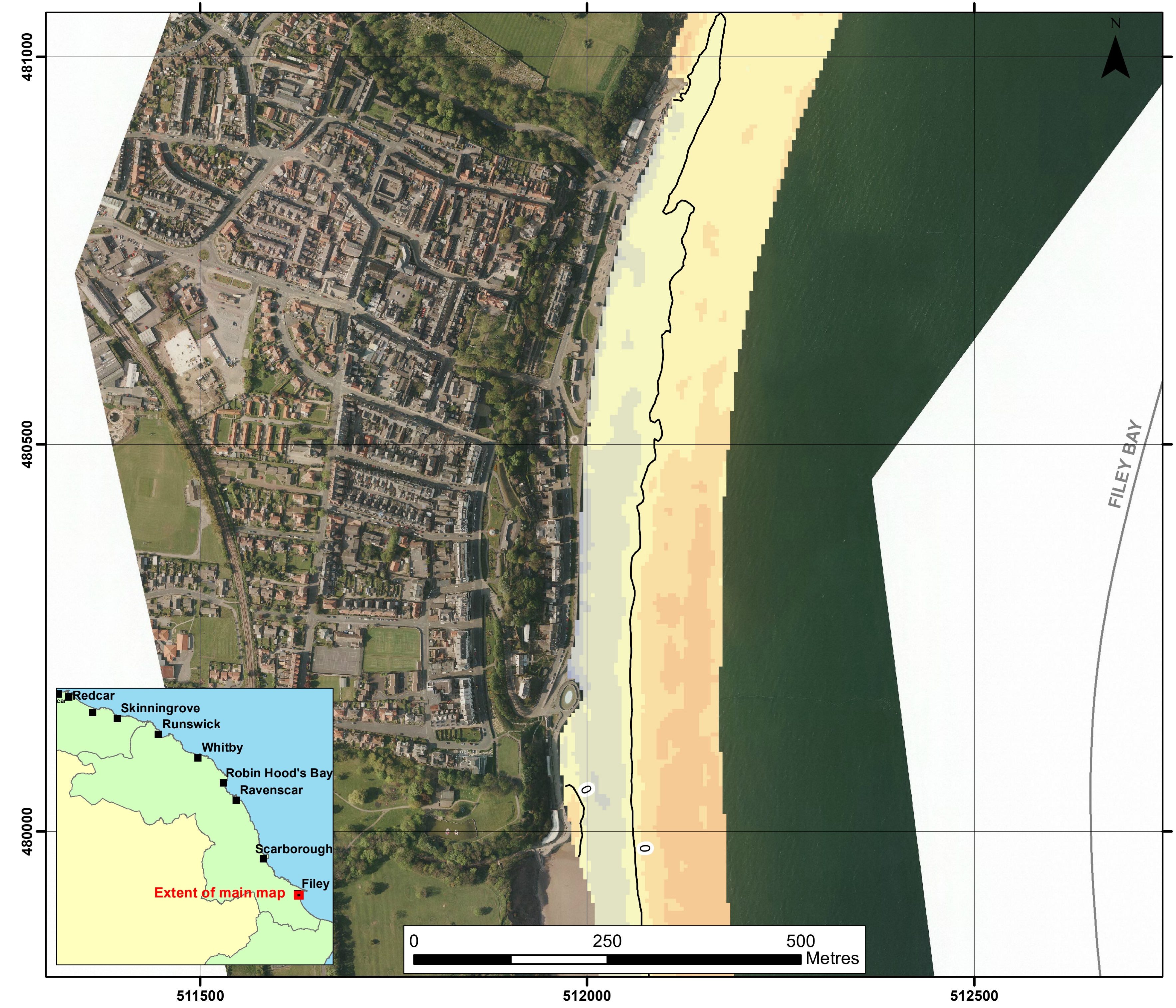
Analytical Report 5
Full Measures Surveys
Spring 2012 and Autumn 2012

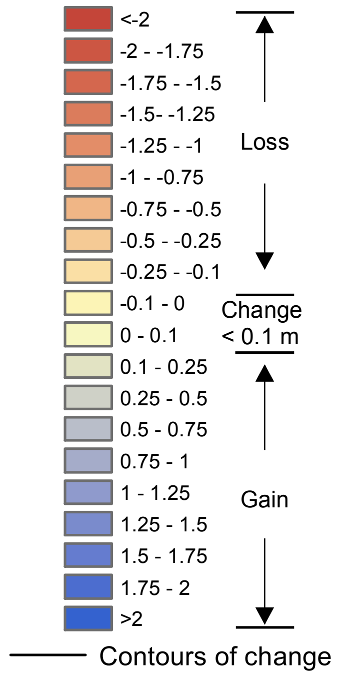
Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk





Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 10b
Long-term Elevation change
Filey
Scarborough Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

Halcrow
A CH2M HILL COMPANY
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE
Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Appendix C

Cliff Top Survey

Cliff Top Survey

Staithes

Twenty ground control points have been established within Staithes (Figure C1). The maximum separation between any two points is nominally 100m. The cliff top surveys at Staithes are undertaken bi-annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

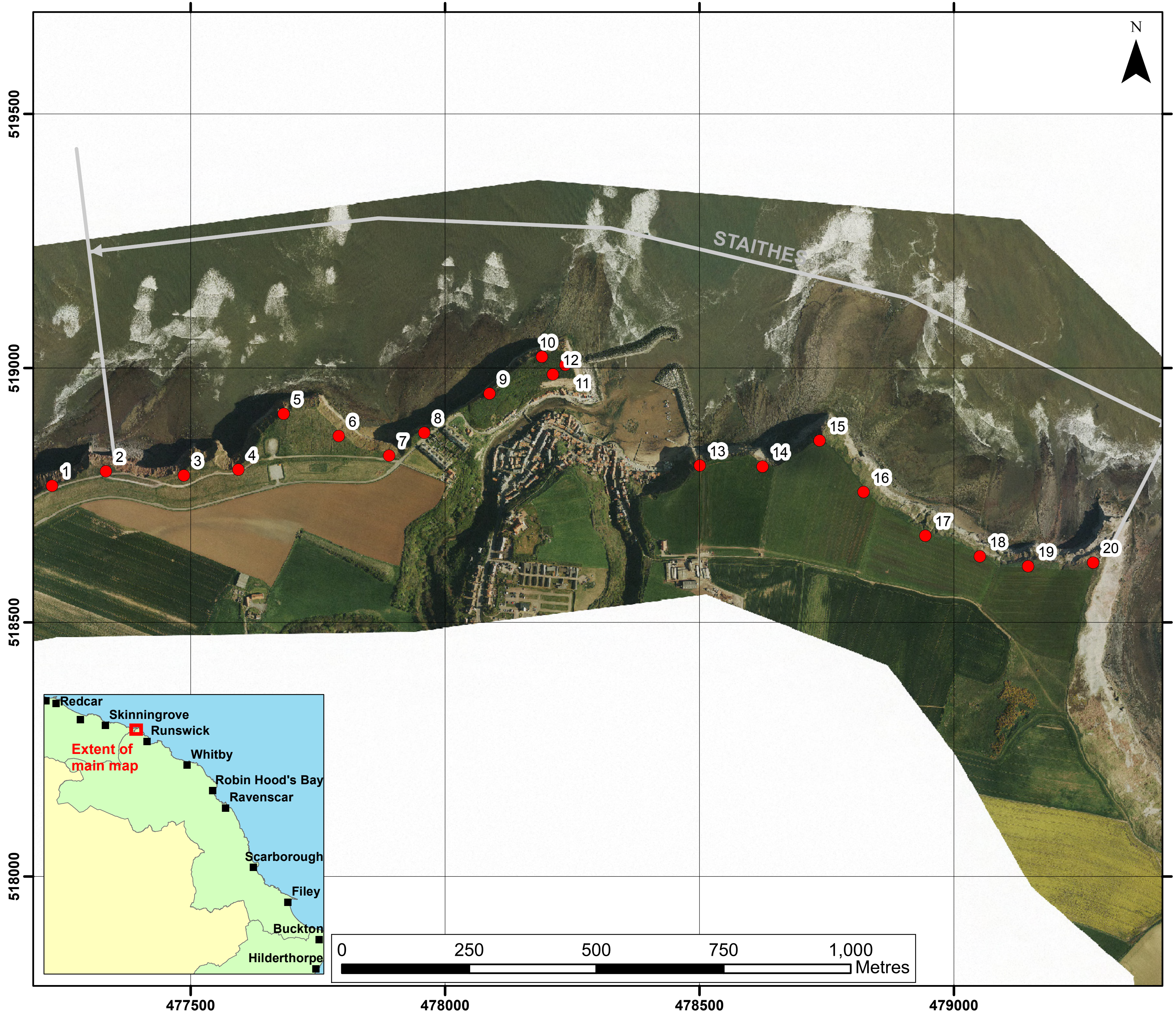
Table C1 provides baseline information about these ground control points and results from the 2008 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C1 – Cliff Top Surveys at Staithes

Ground Control Point Details				Distance to Cliff Top (m)*			Total Erosion (m)*		Erosion Rate (m/year)*
Ref	Easting	Northing	Bearing (º)	Baseline Survey (Nov 2008)	Previous Survey (Oct 2011)	Present Survey (March 2012)	Baseline (Nov 2008) to Present (March 2012)	Previous (Oct 2011) to Present (March 2012)	Baseline (Nov 2008) to Present (March 2012)
1	477228	518769	320	1.9	1.6	1.7	-0.2	0.1	-0.1
2	477334	518798	0	10.9	10.6	10.8	-0.1	0.2	0.0
3	477487	518789	350	7.1	8.2	8.4	1.3	0.2	0.4
4	477594	518801	340	5.9	5.2	5.2	-0.7	0.0	-0.2
5	477683	518911	350	8.4	9.4	9.3	0.9	0.0	0.3
6	477792	518867	30	8.6	8.5	8.5	-0.1	0.0	0.0
7	477891	518828	60	7.7	7.5	7.6	-0.1	0.1	0.0
8	477959	518873	350	8.7	9.6	9.8	1.1	0.1	0.3
9	478088	518950	350	7.6	8.0	8.3	0.7	0.3	0.2
10	478191	519023	340	8.4	8.7	8.8	0.4	0.1	0.1
11	478237	519007	60	6.9	6.7	6.8	-0.1	0.1	0.0
12	478213	518988	150	6.1	6.5	6.5	0.4	0.0	0.1
13	478501	518809	15	11.4	9.2	9.1	-2.3	-0.1	-0.7

14	478624	518807	20	7.5	7.5	7.5	0.0	0.0	0.0
15	478737	518858	60	6.1	6.4	6.4	0.3	0.0	0.1
16	478823	518757	60	8	8.4	9.0	1.0	0.7	0.3
17	478944	518671	30	9.3	9.4	9.5	0.2	0.1	0.0
18	479052	518630	20	9.2	9.3	9.3	0.1	0.0	0.0
19	479147	518610	0	14.2	14.3	14.4	0.2	0.1	0.1
20	479274	518618	20	11.4	11.2	11.4	0.0	0.1	0.0

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.



KEY

Ground Control Points

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 1
Ground Control Points
Staithes
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Robin Hoods Bay

Thirteen ground control points have been established within Robin Hoods Bay (Figure C1). The maximum separation between any two points is nominally 200m.

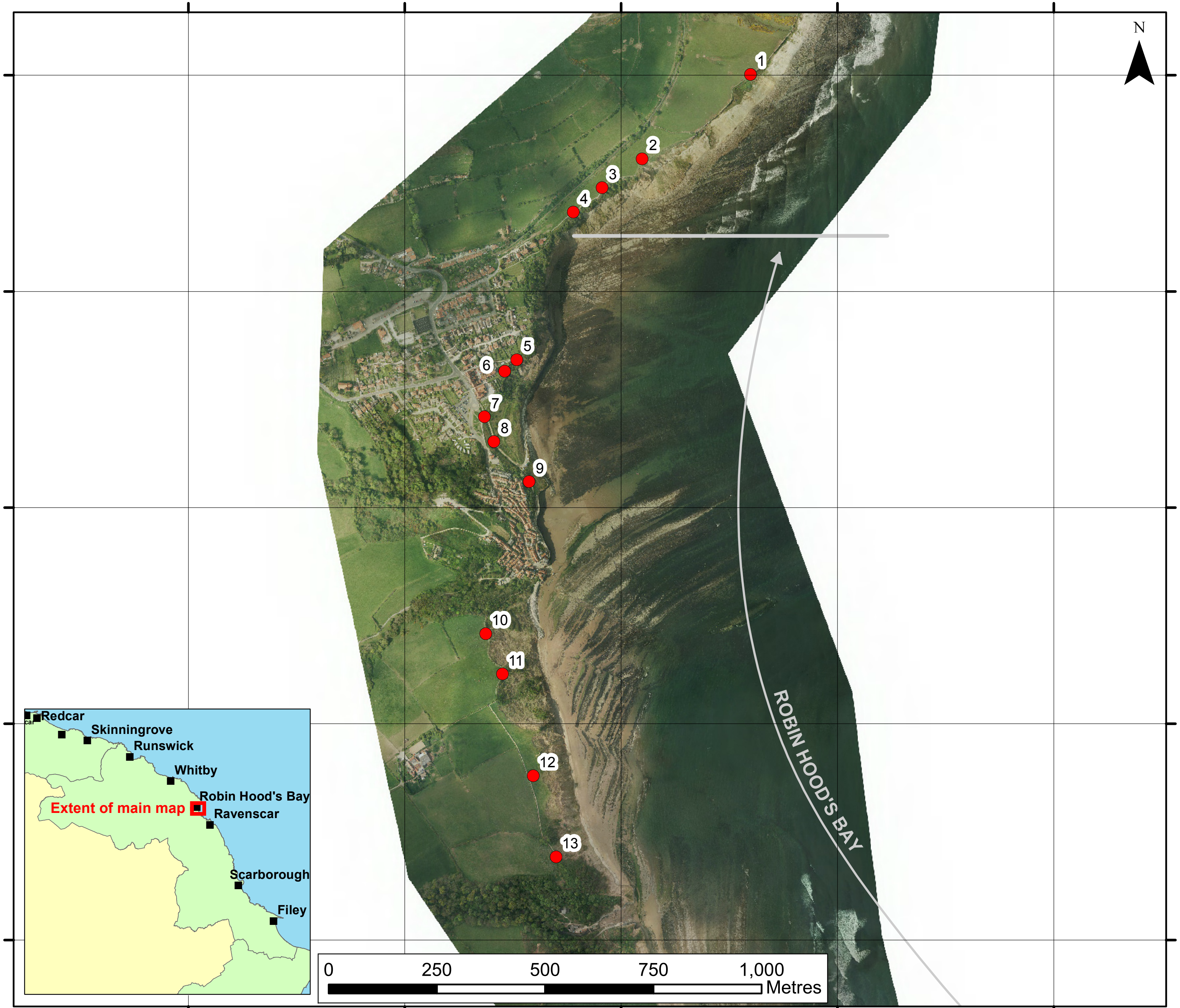
The cliff top surveys at Robin Hoods Bay are undertaken annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

Table C2 provides baseline information about these ground control points and results from the 2008 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C2 – Cliff Top Surveys at Robin Hoods Bay

Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (º)	Baseline Survey (March 2010)	Previous Survey (March 2012)	Present Survey (Sept 2012)	Baseline (March 2010) to Present (Sept 2012)	Previous (March 2012) to Present (Sept 2012)	Baseline (March 2010) to Present (Sept 2012)
1	495799.5	506002.2	130	11.6	8.1	7.9	-3.5	-0.1	-1.4
2	495549.2	505807.3	135	9.3	9.2	9.3	-0.1	0.0	0.0
3	495456.3	505740	130	5	5.2	5.0	0.2	-0.2	0.0
4	495389.9	505683.7	140	6.3	6.3	6.5	0.0	0.2	0.1
5	495259.4	505342.5	130	11.3	9.7	10.9	-1.6	1.2	-0.2
6	495231.2	505315.7	95	5.9	5.8	5.8	-0.1	0.0	0.0
7	495184.8	505210.7	85	6.4	6.2	6.1	-0.2	-0.1	-0.1
8	495206.5	505153	75	5	5.4	5.4	0.4	0.0	0.2
9	495287.8	505060.5	80	4.3	4.5	4.5	0.2	0.0	0.1
10	495187.8	504708.8	70	3.1	2.5	2.5	-0.6	0.0	-0.2
11	495226.2	504615.7	120	3.8	3.8	3.9	0.0	0.1	0.0
12	495297.5	504380.2	80	11	11.0	11.0	0.0	0.0	0.0
13	495350.4	504193	55	3.7	3.7	3.7	0.0	0.0	0.0

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.



KEY

Ground Control Points

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C- Map 2
Ground Control Points
Robin Hood's Bay
Scarborough
Borough Council

Analytical Report 5
Partial Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Scarborough South Bay

Thirteen ground control points have been established between Scarborough South Bay and Cayton Bay (Figure C1). The maximum separation between any two points is nominally 300m.

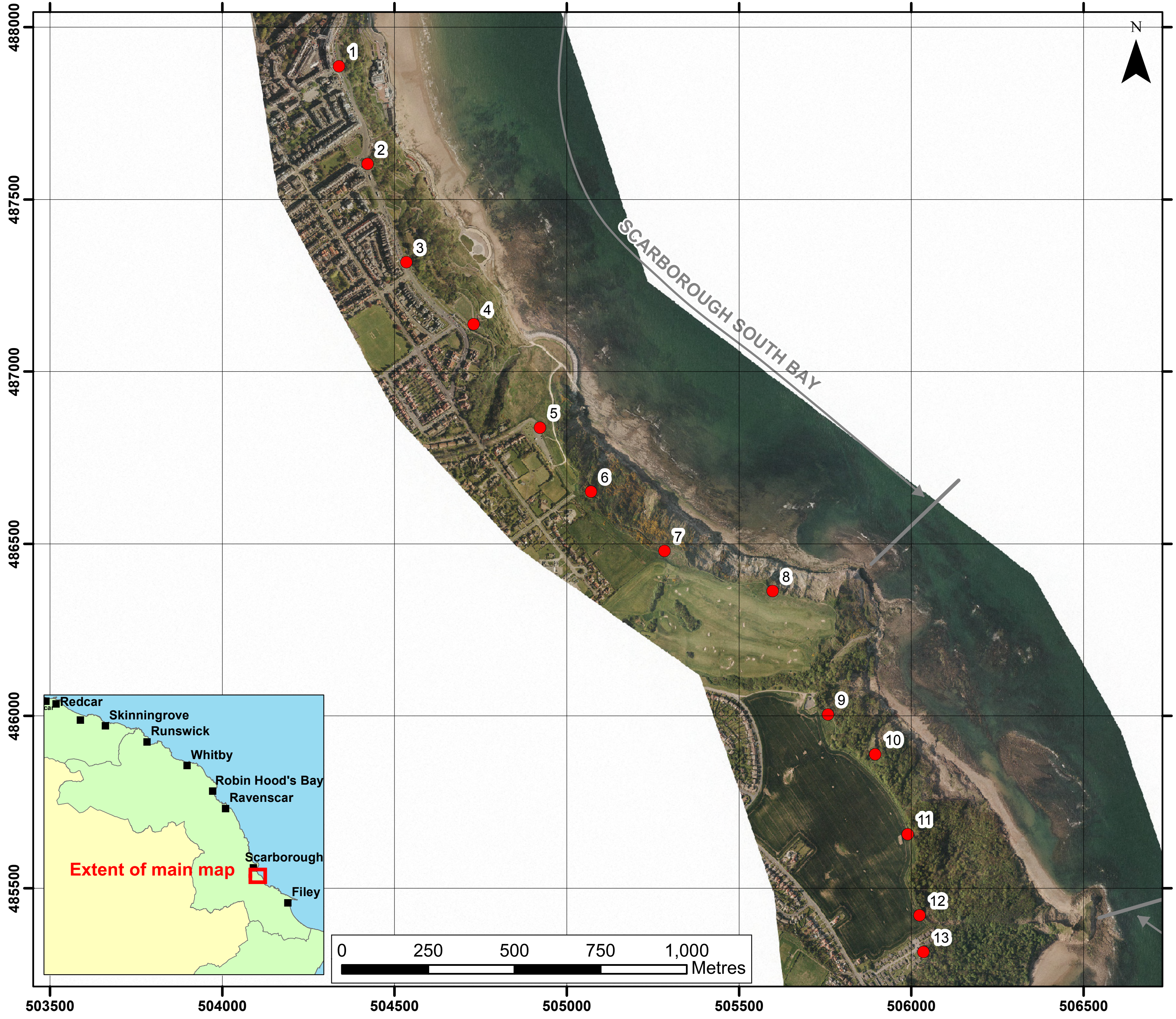
The cliff top surveys at Scarborough South Bay are undertaken annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

Table C3 provides baseline information about these ground control points and results from the 2010 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C3 – Cliff Top Surveys at Scarborough South

Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (°)	Baseline Survey (March 2010)	Previous Survey (March 2012)	Present Survey (Sept 2012)	Baseline (March 2010) to Present (Sept 2012)	Previous (March 2012) to Present (Sept 2012)	Baseline (March 2010) to Present (Sept 2012)
1	504339.5	487887.3	70	7.0	7.0	7.0	0.0	-0.04	-0.02
2	504422.3	487603.7	80	4.8	4.9	4.8	0.0	-0.04	0.01
3	504534.8	487318.3	40	15.1	14.9	15.2	0.1	0.31	0.03
4	504730.2	487137.9	55	9.6	9.6	9.5	-0.1	-0.15	-0.05
5	504922.9	486837.8	60	8.8	8.7	8.4	-0.4	-0.23	-0.14
6	505071.1	486652.1	75	3.8	3.5	3.4	-0.4	-0.14	-0.16
7	505284.3	486480	35	7.0	7.0	6.9	-0.1	-0.13	-0.05
8	505597.9	486363.4	30	8.6	8.6	8.6	0.0	-0.04	-0.02
9	505758.6	486005.1	45	9.1	9.0	9.0	-0.1	-0.05	-0.05
10	505896	485889.6	15	14.8	14.8	14.7	-0.1	-0.10	-0.03
11	505990	485657.1	80	4.7	4.3	4.3	-0.4	-0.01	-0.15
12	506024.9	485421.8	55	6.1	5.8	5.8	-0.3	0.02	-0.12
13	506036	485315.3	90	7.0	7.0	7.0	0.0	0.02	0.02

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.



KEY

Ground Control Points

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 3
Ground Control Points
Scarborough South Bay
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Cayton Bay

Eight ground control points have been established within Cayton Bay (Figure C1). The maximum separation between any two points is nominally 300m.

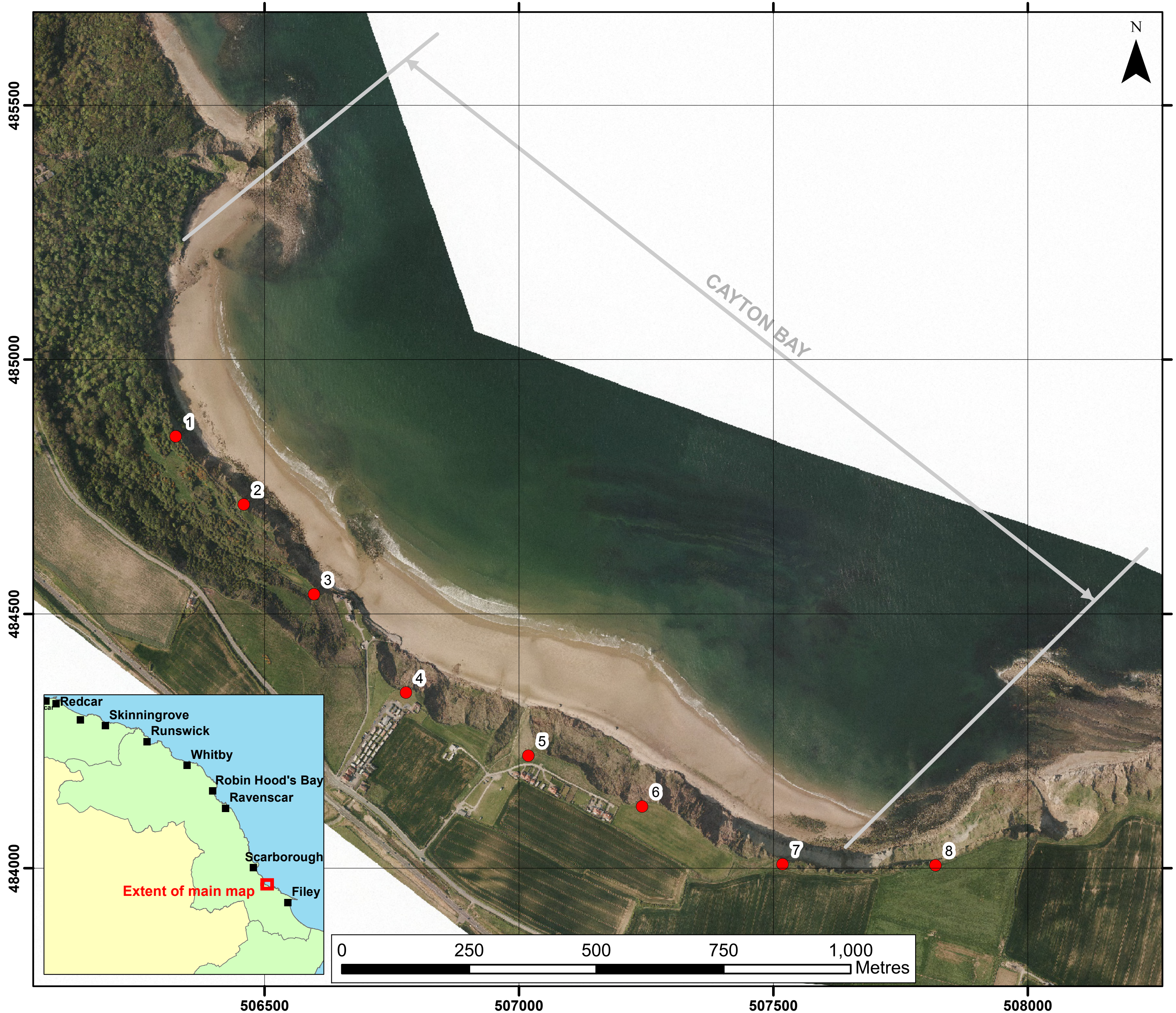
The cliff top surveys at Cayton Bay are undertaken annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

Table C4 provides baseline information about these ground control points and results from the 2008 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C4 – Cliff Top Surveys at Cayton Bay

Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (º)	Baseline Survey (Nov 2008)	Previous Survey (Mar 2012)	Present Survey (Sept 2012)	Baseline (Nov 2008) to Present (Sept 2012)	Previous (March 2012) to Present (Sept 2012)	Baseline (Nov 2008) to Present (Sept 2012)
1	506325.5	484849.7	50	4	3.5	3.4	-0.6	-0.1	-0.2
2	506459.4	484715.9	65	5	0.0	-0.1	-5.1	0.0	-1.3
3	506597.4	484538.6	65	5	6.3	6.3	1.3	0.0	0.3
4	506778.1	484345.5	21	9	9.0	8.7	-0.3	-0.2	-0.1
5	507018.6	484221.6	342	7.7	8.0	8.1	0.4	0.1	0.1
6	507242.3	484121.7	2	7.4	7.5	6.6	-0.8	-0.9	-0.2
7	507518.2	484008.2	25	7.5	7.9	8.0	0.5	0.1	0.1
8	507818.7	484006	1	5.5	5.9	6.1	0.6	0.1	0.1

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.



KEY

Ground Control Points

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 4
Ground Control Points
Cayton Bay
Scarborough
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Filey Bay
Twenty-seven ground control points have been established within Filey Bay (Figure C1). The maximum separation between any two points is nominally 300m.

The cliff top surveys at Filey Bay are undertaken annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

Table C5 provides baseline information about these ground control points and results from the 2008 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C5 – Cliff Top Surveys at Filey Bay

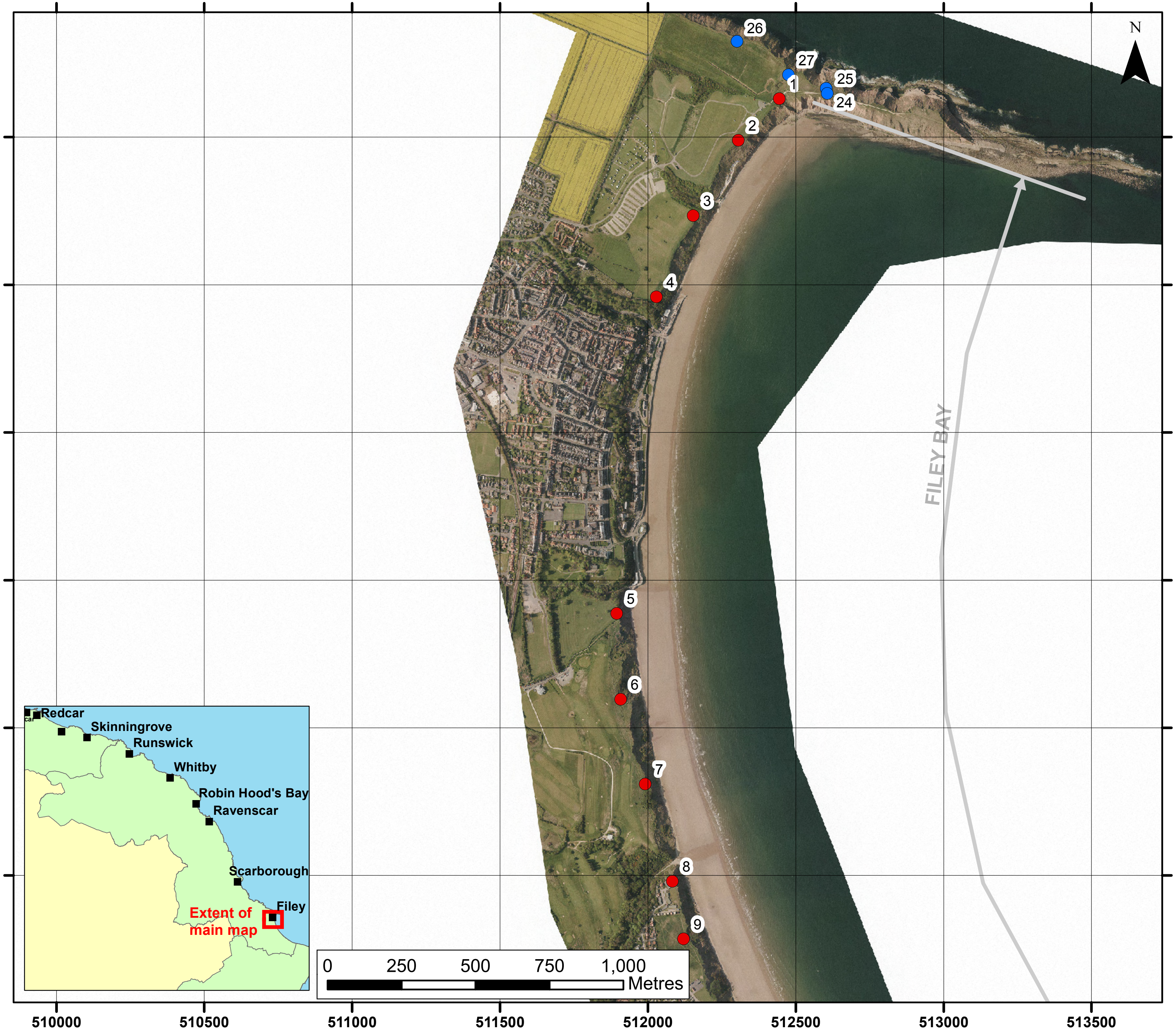
Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (º)	Baseline Survey (Nov 2008)	Previous Survey (March 2012)	Present Survey (Sept 2012)	Baseline (Nov 2008) to Present (Sept 2012)	Previous (March 2012) to Present (Sept 2012)	Baseline (Nov 2008) to Present (Sept 2012)
1	512444.9	481630.9	130	8.7	8.9	8.8	0.1	-0.1	0.0
2	512306.7	481490.3	144	7.6	7.8	7.7	0.1	-0.1	0.0
3	512153.6	481234.6	122	8.3	8.4	8.4	0.1	0.0	0.0
4	512029.2	480959.9	115	7.4	7.5	7.5	0.1	0.0	0.0
5	511895.4	479888	89	7.1	1.4	1.4	-5.7	0.0	-1.5
6	511908.5	479597.1	48	6.7	6.9	6.9	0.2	0.0	0.1
7	511991.4	479310.4	69	6.7	5.0	4.8	-1.9	-0.2	-0.5
8	512083.4	478981.5	66	10.2	10.3	10.2	0.0	-0.1	0.0
9	512121.3	478786.3	76	8.3	8.4	8.4	0.1	0.0	0.0
10	512226.2	478547.9	74	7.5	7.2	7.3	-0.2	0.1	-0.1
11	512471.4	478153.5	53	6.6	6.5	6.5	-0.1	0.0	0.0
12	512558.9	477901.9	66	7.7	7.7	7.7	0.0	0.0	0.0
12A*	512655.8	477822.4	67	13.9	13.9	13.9	0.0	0.0	0.0

13	512697.6	477719	34	4.2	4.2	No Data	No Data	No Data	No Data
14	512939.4	477400.9	66	8	7.3	7.3	-0.7	0.0	-0.2
15	513157	477192.7	51	5.2	5.2	5.0	-0.2	-0.1	0.0
16	513299.5	477024.6	30	7.7	7.8	7.4	-0.3	-0.3	-0.1
17	513507.7	476821.1	34	10.7	10.9	10.4	-0.3	-0.5	-0.1
18	513721	476602.3	31	7.2	7.1	7.0	-0.2	0.0	-0.1
19	513916.6	476354.1	51	6.6	6.2	6.8	0.2	0.5	0.0
20	514174.8	476179.4	32	7	7.3	7.3	0.3	0.0	0.1
21	514471.5	475965.7	66	7.6	7.5	7.5	-0.1	0.0	0.0
22	514656.2	475728.8	101	8.1	8.1	8.1	0.0	0.0	0.0
23	514889.5	475537.6	60	9.1	9.0	9.1	0.0	0.1	0.0
24*	512603.7	481665.9	14	19.9	19.8	19.7	-0.2	-0.1	-0.1
25*	512607.1	481648.9	184	17.2	17.2	17.1	-0.1	-0.1	0.0
26*	512301.9	481825.5	18	11	11.0	10.9	-0.1	-0.1	-0.1
27*	512475.8	481712.1	20	11.6	11.6	11.5	-0.1	-0.1	-0.1

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.

*baseline for 12A and 24-27 is March 2011.

.



KEY

Ground Control Points

- Established March 2011
- Established Nov 2008

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 5
Ground Control Points
Filey Bay North
Scarborough
Borough Council

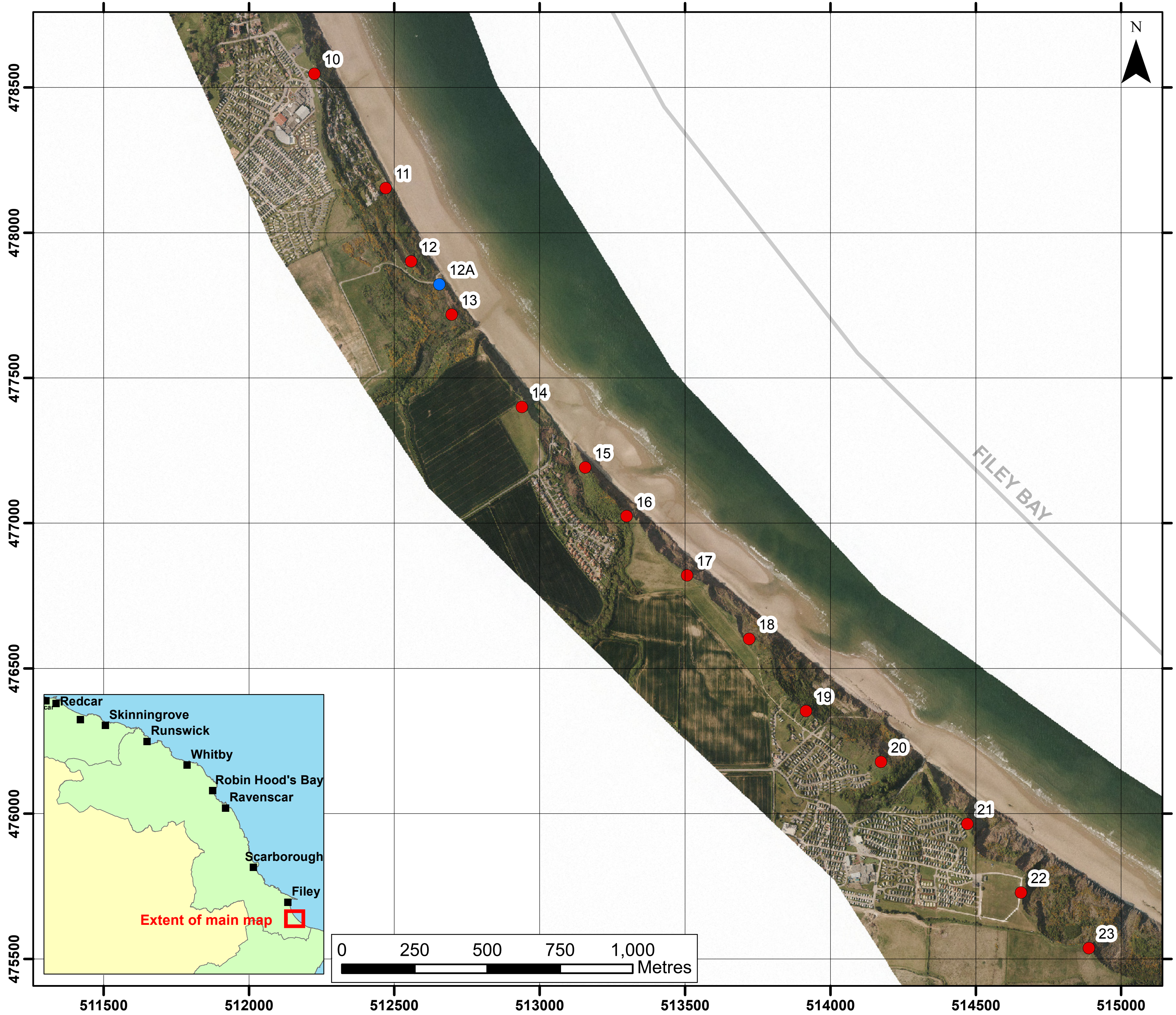
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Ground Control Points

- Established March 2011 (blue)
- Established Nov 2008 (red)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 6
Ground Control Points
Filey Bay South
Scarborough Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

Appendix D

Durham University Report on Staithes

Cowbar Coastal Cliff Monitoring, Staithes, N. Yorkshire

February 2012

Dr N Rosser

Dr S Waugh

University of Durham

Prepared for and on behalf of:

Redcar and Cleveland Borough Council

Steve Dunning

1. Table of Contents

2. List of Tables

3. List of Figures

3. Context

This report summarizes the installation and Year 1 results from an ongoing monitoring program at Cowbar Nab, Staithes, N. Yorkshire. The monitoring program is being undertaken for and on behalf of Redcar and Cleveland Borough Council.

The report includes detail on the design and specification of the instrumentation installed at the site, the underlying rationale for equipment choice and the methods used for data processing and analysis to aid the interpretation of results, and to permit comparison with other sites.

The latter part of the report describes the results collected to date, and generates erosion rates based upon this data. The report concludes with an interpretation of findings to date, and implications for the site.

4. Summary

The following tasks have been completed as part of this study in Year 1:

- Monthly high-resolution terrestrial laser scans of the cliff at Cowbar Nab have been undertaken since January 2011.
- The design and installation of 3-axis seismic monitoring station, and real-time data stream back to Durham has been completed (Section 8).
- The design and installation of cliff face environmental monitoring system to collect data on near-cliff weather conditions has been completed (Section 8).
- The design and installation of a laser-radar water-level gauge to measure sea surface elevation and cliff toe wave climate has been completed (Section 8).
- The design and installation of permanent terrestrial laser scanning system to observed changes to the cliff on a daily basis, has been completed (Section 11).

The following erosion rates have been calculated:

- The calculation of monthly erosion and long-term 15 month erosion rates has been completed, and compared to past rates measured at this site (Sections 10 & 12). A total of 318.99 m3 of rockfall in 9,968 discrete events has occurred during this period. Considerable month-on-month variability is observed, with May 2011 experiencing effectively no discernible change (Section 12).
- The net rate observed in the period January 2011 to March 2012 was 1.99 x 10-3 m yr-1 (Section 12).
- On average the observed rate is less than that previously observed at this site (358 m3 of rockfall from 4,494 m2 of cliff face, deriving 25 x 10 -3 myr-1 erosion).

The following conclusions have been drawn based upon this analysis:

- A preliminary analysis of Year 1 seismic monitoring data in respect of environmental conditions at site has been completed (Section 12). The seismic response of the cliff is in line with observations made elsewhere on this coast, and elsewhere worldwide. The set-up is now calibrated, and collecting continuous data on wave energy and impacts at the cliff toe. Future analysis will focus upon the correlation of this data with the rockfall and erosion output.
- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The concentration of erosion is currently focused away from the ‘pinch points’ at this site.

- No loss of cliff line was observed during this period, although critically this indicates cliff steepening, which will in time result in failure of the cliff top in future. Continued monitoring will help identify where and when this may occur.
- There is no evidence in the monitoring data of the development of a deeper-seated failure which would threaten the road and / or houses.

5. Site description & previous assessments of erosion rates

A series of previous studies have identified that the cliffs at Cowbar Nab are actively eroding, and with time may threaten the infrastructure and dwellings at the cliff top. This monitoring project has been developed to provide the best possible data on the rates and controls on erosion at Cowbar, to support future decision making.

The cliffs are near-vertical, interbedded shales, sandstones, limestones and mudstones, capped with a c. 5 m depth of glacial till.

The rates of erosion at this site have been measured by various authors. Agar (1960) using basic cliff top survey techniques, identified a rate of 4 feet per century (1.2 cm p.a.) and 13 feet per century (3.9 cm p.a.) for headlands, in general. More recently Lim (2006) studied the cliff line directly below Cowbar Cottages. The area of rock armour represents roughly the centre of the studied section, which had a length of about 140 m and a surface area of 3,922 m^2. The monitoring period extended over a period from October 2003 to April 2005 (19 months), during which a laser scan of the site was collected at as close to monthly intervals as the tidal conditions permitted and analysed to determine the volume changes through time. The total recorded volume of detachments in the monitoring period was about 576 m^3 according to Table 6.1 of Lim (2006).

Caution should be taken here is directly comparing the volumes derived by Lim (2006) and this study, given different cliff area (survey extent) under consideration, and the different definition of the survey (see section 6 below). Based upon this the total recession during the 19 months of monitoring was 15.5 cm, which represents a rate of approximately 9.8 cm yr^{-1}. Note that this rate is dominated by the effects of the single large rock fall event in a highly fractured area of rock mass above an engineered area where a drainage pipe protrudes from the cliff face.

Most recently, in a study for the Cowbar Residents Association, Rosser et al (2006), used historic photography and maps to estimate the long-term retreat rates at 3 cross-cliff profiles (P1 – P3) at Cowbar Nab (Table 1). Critically, this study identified the significant errors associated with using mapping data for retreat rate estimation at sites such as this, such that retreat rates did not exceed the error associated with the method adopted.

Table 1 Retreat rates estimated from historic datasets in the study, relative to the 2000 cliff line. NB: Negative values indicate that the cliff line is *apparently* moving to seaward.

Dataset	Retreat rate p1 (cm yr^{-1})	Retreat rate p2 (cm yr^{-1})	Retreat rate p3 (cm yr^{-1})	Ave. retreat rate (cm yr^{-1})
1895	-10.7	3.0	-3.2	-3.6
1919	-10.5	2.6	-2.5	-3.5
1930	-14.3	2.5	-1.9	-4.6
1946	-15.9	-7.3	1.1	-7.4
2000	0.0	0.0	0.0	0.0

6. Monitoring system overview, design & timescale

The approach taken to monitoring the seaward facing cliff at Cowbar Nab is based upon 9 years of research on erosion on this stretch of coastline. The monitoring comprises the use of high-resolution 3D laser scanning to capture erosion, microseismic monitoring of ground motions as a result of wave impacts, and environmental monitoring at the cliff face, to document the occurrence of erosion and rockfall, and to permit in future the analysis of specific drivers of erosion.

Monitoring design

The monitoring system is based around 2 data types:

1. Periodic 3D monitoring of erosion of the cliff face
2. Continuous monitoring of the environmental conditions at site

Periodic monitoring is achieved using monthly terrestrial laser scans, captured from the foreshore at low tides. A full methodology for the data collection and processing is provided in Sections 7 - 10.

Monthly monitoring is supplemented by daily laser scans captured using a permanently installed remote control laser scanner housed in a secure box on the cliff top on the opposite side of the Bay to the Nab, providing an almost uninterrupted view of the Nab cliff face. This scanner provides high-frequency but lower resolution data, which allows us to identify the day on which specific events occurred.

Continuous monitoring of environmental conditions is achieved using a combination of a cliff top weather station and web-cam, and a 3-axis broadband seismometer, and a laser radar water height gauge. The seismometer is able to characterize a wide bandwidth of microseismic accelerations due to wind, offshore- and nearshore-waves, in addition to anthropogenic noise. Recent research has shown this approach to be the more robust approach of characterizing energy delivery to coast, negating the need to model offshore data to the nearshore and coastline.

Timescale of installation

Periodic laser scans commenced at the outset of the project, and have continued as planned at near-monthly intervals since. Data is processed on a monthly basis, to provide an oversight on activity at the site and highlight any significant changes in behaviour.

The seismometer was custom built for this installation by Guralp Systems. The seismometer was ordered at the outset of the project, and was installed on site in June 2011. The seismometer suffered a firmware failure in August 2011. The instrument was replaced by a loaned sensor from the NERC SEIS-UK equipment pool to maintain data collection whilst the original instrument was repaired.

The weather station, laser radar and camera system were installed in August, 2011 by professional rope access contractors.

The permanent laser scanner was designed and developed specifically for this project, which required a series of laboratories test, software development and modification, and field-testing. The final field installation was conducted in September 2011.

7. Monitoring installation

3-axis seismometer

A 3-axis seismometer (Guralp CMG3-ESP) with data-logger, server and modem has been installed on the cliff top adjacent to the cottages on the Nab. The seismometer is housed in a custom constructed seismic well, to specification defined by the NERC supported SEIS-UK facility. A 1 m x 0.6 m x 1.5 m breeze-block lined well, with a 0.1 m deep granite slab base provides isolation from seismic noise, whilst ensuring a high degree of seismic connectivity with the cliff rock mass.

The CMG3-ESP was chosen due to its broad frequency response, which ranges from 100 Hz to 120 seconds, allowing infragravity waves to be captured. Recent research indicates that infragravity waves are key to wave energy delivery to rock coasts, to which this instrument is uniquely tuned (e.g. Norman, 2012).

The CMG3-ESP logs at 100 Hz recording ground displacements in N-S, E-W and vertical components. Data is streamed in real-time via a GPRS modem to SEIS-UK (University of Leicester), who run the UKs seismic research facility. Power for the system is provided from the adjacent lamppost, which also holds a GPS antenna for time synchronization, and a GPRS antenna for communication.

Servers at SEIS-UK process the data in real-time, whilst providing real-time status checks, via the following URL:

http://143.210.23.110/

Processed data (median signal powers of 5 set frequency bands, as defined by Norman (2012); total displacement; all at 15 minute intervals) is streamed to the data archive server in Durham, where it is merged with other monitoring data collected at site.

The methods and use of this data is more fully described in this paper and thesis:

- *Lim, M., Rosser, N.J., Petley, D.N., Keen, M. 2011. Quantifying the controls and influence of tide and wave impacts on coastal rock cliff erosion Journal of Coastal Research, Volume 27, issue 1, year 2011, pp. 46 - 56*
- *Norman, E.C. (2012) Microseismic monitoring of the controls on rocky coastal cliff erosion. Unpublished PhD Thesis, University of Durham.*

Figure 1 View into the seismic well, showing the Guralp seismometer encased within a foam box to minimize the effects of air circulation on the instrument. The data logger and model is contained with the black Peli-case. 12 v power and communications are provided via a buried conduit to the lamp-post adjacent to the site, which is seen entering the well at the top of this photo.

Figure 2 View of the sealed seismometer installation, flush with the ground, and set back from the edge of the cliff by 5 m.

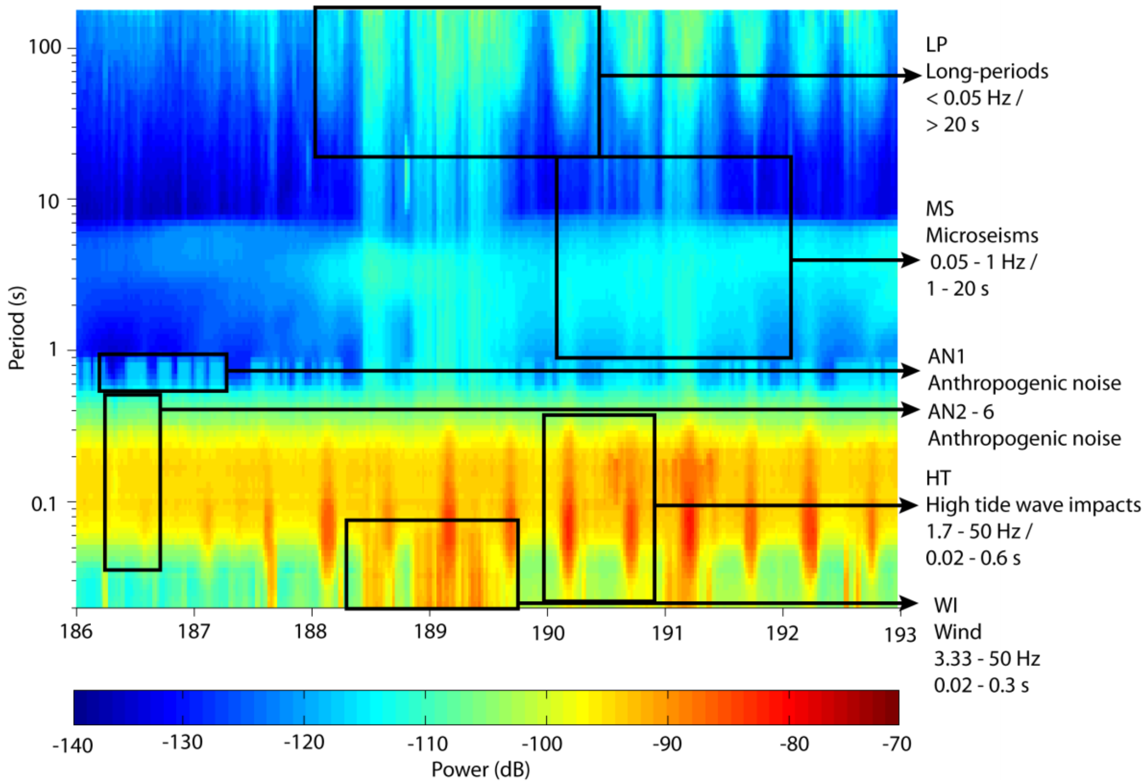


Figure 3 An example spectrogram from the dataset and the different bands of ground motion frequencies observed. Frequency power is presented in decibels (dB) calculated as 10 $\log_{10}((ms^{-1})^2/Hz)$. Each of the black boxes highlights an example of the typical temporal and power characteristics of each frequency band.

Figure 3 shows an example of the output from the seismometer, here for a 1-week period, showing signal power across the instruments frequency response. A series of characteristics frequencies are identified:

Long-period frequency band (LP): There is a clear range of long-period signals < 0.05 Hz (> 20 s), which have a distinct pattern, differentiating these from the microseisms (MS) (1 – 0.05 Hz / 1 - 20 s) by a band of low powers (approximately -130 dB) at around 0.1 Hz / 10 s. Increases in LP power often occur with simultaneous increases in the microseism (MS) frequency range and high power high tide (HT) or wind (WI) frequencies (explained below).

The frequency of these LP signals and association with tides and incoming wind and wave characteristics suggests that the LP frequency band represents long-period ocean waves called infragravity waves. Infragravity waves lie within the period range of 0.05 – 0.003 Hz / 20 - 300 s and are generated as groups of swell waves from distant storms arrive at the coast resulting in ‘surf beat’ an increase and decrease of the mean sea level at the period of the groups (Munk, 1949; Tucker, 1950).

Microseism frequency band (MS): Microseisms are widely acknowledged to be generated by sea waves near the coast, and take two forms:

- Primary microseisms are microseismic waves that have the same periodicity as the incoming ocean waves (Haubrich et al., 1963);

- Double frequency (DF) microseisms are generated by the constructive superposition of waves of the same periodicity travelling in opposite directions (Longuet-Higgins, 1950).

Waves travelling from different directions can be generated either by storms of varying wind directions generating waves heading in multiple directions or by the meeting of landward waves with those reflected from the coast (Longuet-Higgins, 1950). The microseisms can be clearly distinguished in the spectrogram in the period range of 1 - 0.05 Hz / 1 - 20 s. The MS frequency band power corresponds well to the increased power at the high and low frequency bands (non-anthropogenic) e.g. LP, HT and WI frequencies, which are all associated with incoming waves and / or wind.

Anthropogenic frequency band (AN): Within the high-frequency range 1.1 - 25 Hz / 0.04 - 0.9 s there are six discrete frequency bands that have constant frequency power. This suggests that these features are generated by anthropogenic activity

- **AN1:** There is an intermittent short-period signal tightly constrained within the frequencies 1.1 - 2 Hz / 0.5 - 0.9 s. Both the frequency range and the power values have an 'on / off' nature, with powers at around -115 dB or -130 dB, rather than the gradual increase and decrease of the signals from natural sources. As a result, this frequency band is not considered further in the analysis.
- **AN2:** At 2 - 5 Hz / 0.2 - 0.5 s; the power typically ranges between -105 to -115 dB;
- **AN3:** Between 5 - 10 Hz / 0.1 - 0.2 s; the power is typically around -97 dB;
- **AN4**: In the region between 10 - 14.3 Hz / 0.07 - 0.1 s the average power is highest throughout this signal range (AN2 - 6) averaging -95 dB;
- **AN5:** Between 14.3 - 16.7 Hz / 0.06 – 0.07 s there is a band of power that mirror that of the 5 - 10 Hz / 0.1 - 0.2 s range;
- **AN6:** Between 16.7 – 25 Hz / 0.04 - 0.06 s the signal mirrors that of the 2 - 5 Hz / 0.2 - 0.5 s range.

There are two different types of high-frequency bands that are clearly driven by environmental conditions, rather than anthropogenic sources. These are high-power events that overlap with the high-frequency anthropogenic signals (AN1 - 6). Naturally generated high-frequency signals have increases in power that coincide with increased power in the microseism (MS) and long-period (LP) bands, suggesting that the signals are related:

High tide frequency band (HT): Regularly occurring high-power signals around -85 to -95 dB are monitored in the frequency range 1.7 - 50 Hz / 0.02 - 0.6 s. As shown later, these occur during some, but not every, high tide. Adams et al. (2005) observed a coastal cliff ground motion signal at 20 Hz / 0.05 s representing high-frequency ringing of the cliff mass in response to direct wave impacts against the toe. It is anticipated that the HT frequency band observed here represents the same phenomenon.

Wind frequency band (WI): Sporadic increases in power that have similar values to the high tide frequencies (HT), occur within the 3.3 - 50 Hz / 0.02 - 0.3 s frequency band. Young et al. (1996) identified that wind velocities of 3 ms^{-1} and stronger result in a significant increase of seismic energy delivery to the ground surface at frequencies of 15 - 60 Hz / 0.066 - 0.017 s, although found signal amplitude to be non-linear with wind velocity. Other studies (e.g.

Bungum et al., 1985; Given, 1990; Gurrola et al., 1990), observed wind seismic signals at lower frequencies, reaching as low as 1 Hz for winds above 3 ms^{-1} (Withers et al., 1996). Wind velocities above 3 ms^{-1} are frequent at the study site. The intermittent, high-power, high-frequency and stochastic nature of this frequency band, and commonly its coincidence with wave-generated frequencies, suggests that this frequency band represents the influence of wind upon the monitored cliff.

The data analysis of the seismic data focusses upon the analysis of these set frequency bands, subsampling this data to 15 minute intervals. Examples of the data are its relationship to the prevailing environmental conditions is provided below (Section 12).

Water level

A key component of the monitoring system is a high-frequency water level sensor, which monitors sea surface height (tides + set up + waves) at the cliff toe. This negates the need to model offshore wave buoy data across the near- and foreshore, which invokes inherent uncertainties.

Water level is measured using a high-frequency laser radar, mounted on a bracket at the top of the rock cliff, directly below the cottages, targeted at the cliff toe. This allows the water level to be monitored when in contact with the cliff toe. The laser records at a frequency of 100 hz, which is then averaged to 5 Hz to provide the mean water surface level. The laser has a range of 1,200 m, which at this range (32.5 m above sea level) overcomes problems associated with the limited reflection of near-infrared laser from the sea water surface. The system uses a Class 1 eye laser, at 905 µm, and so has no effect on wildlife or people.

The laser has a cabled connection to a PC housed in the seismic well on the cliff top, where software logs the data internally, and streams the data via a GPRS modem to Durham. The data is then archived and processed to 15-minute intervals, and merged into the rest of the monitoring data. An example of the data is provided in Figure 4, which shows the raw data stream (red - left axis) and a 1000 sample smoothed derivative (blue – right axis). The raw data minus the smoothed data gives wave heights, whereas purely the smoothed data gives mean sea surface water level.

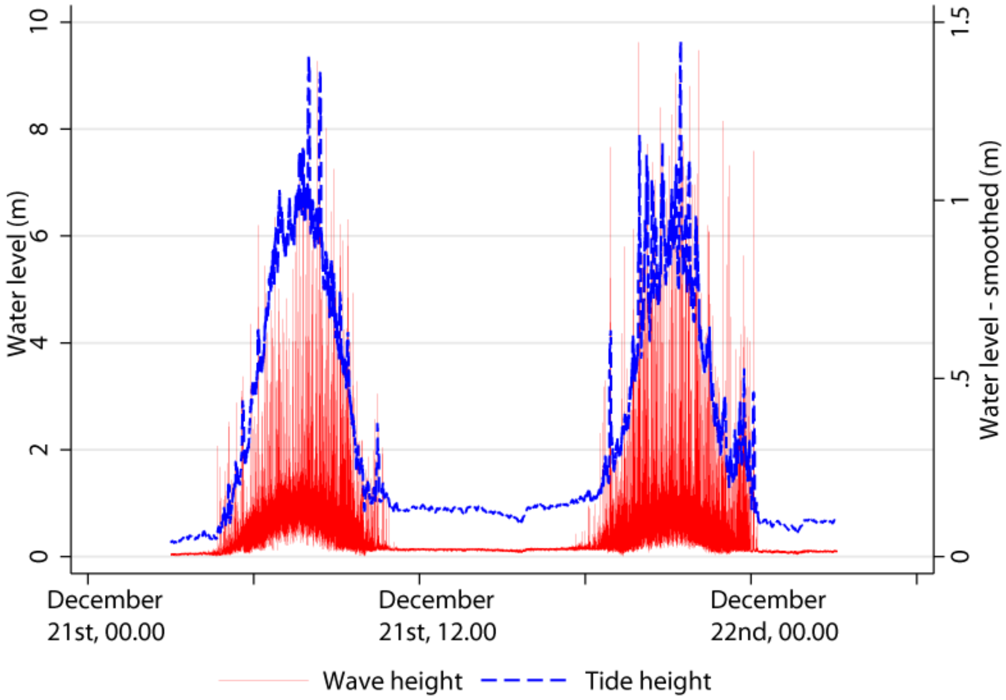


Figure 4 Water level obtained from laser radar, over a single day (21st December 2012)

Camera

To provide context to the monitoring data, a web-cam is positioned at the top of the rock cliff viewing the toe of the cliff and foreshore. The camera collects VGA photographs (1280 x 1600 pixels) at 5-minute intervals, and logs these to the PC in the seismic well. The camera also has UV illumination, although this is effective only over a short range, so is of limited utility in this context.

An example of the output from the camera is show in Figure 5.

Figure 5 View from the web-cam during low tide (left) and high tide (right)

Weather station

Cliff face environmental data is collection at site. Recent research has demonstrated that there is limited correlation between the occurrence of rockfalls from the cliff face and environmental conditions monitored at conventional weather stations further inland (e.g. Lim et al, 2011). More recently efforts have been made to explore the degree to which weather conditions on the cliff face differ to those inland, and then the degree to which these can explain rockfall occurrence (e.g. Norman, 2012).

An automatic weather station is mounted on a bracket at the top of the rock cliff, some 32 m above the toe of the cliff. The weather station has independent solar power, and connects wireless to an interface at the cliff top, which logs to the PC housed in the seismic well. This data is made available externally in real-time via an ftp:// server mounted on the PC, accessible via the GPRS modem, from which the data is archived in Durham and merged with the other monitoring data.

The weather station records the following variables:

- Barometric pressure
- Temperature
- Humidity
- Rainfall
- Wind speed
- Wind direction
- UV

Form these variables a series of secondary data is calculated, including:

- Dew-point
- Evapotranspiration
- Heat Index
- Solar Radiation
- Radiation dose
- Radiation index
- Temperature Humidity Sun Wind Index


Figure 6 Installation of the cliff face instrumentation, including weather station, laser radar and camera.

8. Monthly 3D laser survey

A full monthly survey of the cliff face of the Nab and the surrounding embayment is made from the foreshore using terrestrial laser scanning. The survey is collected using a Riegl VZ1000 terrestrial laser scanner. Specifications of this system are available at the following web-site:

http://www.riegl.com/uploads/tx_pxpriegldownloads/10_DataSheet_VZ1000_12-09-2011.pdf

The TLS system is calibrated annually by the manufacturer. Relevant certification can be provided on request.

Survey set-up

Two survey benchmarks have been established on the foreshore marked with standard survey nails, over which the TLS system is repositioned each month. In the first months survey the 3D position of the survey points was located using a Leica GPS System 1200, to within + / - 0.005 m (Figure 7 & 8). The coordinates of the control points are as follows:

Table 2 Control point surveys

ID	Lat (d.degrees)	Long (d.degrees)	Elevation OD (Nelwyn)
QP1	54.561062	54.560689	-0.23
QP2	-0.797309	-0.795425	-0.14

The manufacturer calibrates the dGPS system annually. Relevant certification can be provided on request.

Survey specification

Each survey is collected in a systematic manner, following methods established in previous work on this coast (see: Rosser et al, 2005).

A data set with a point spacing of 0.03 m across the cliff face of interest is collected, in addition to orthorectified full-color imagery, using the TLS system.

The first survey scan (January 2011) was georeferenced using a network of additional control points, positioned both with the TLS and the dGPS. This dataset is subsequently used to georeference all future scans using a registration work-flow based upon picking common points in successive scans, and then a multi-station adjustment which statistically matches scans, typically to within < 0.01 m across the survey scene.

The output of each survey is a point-cloud, geo-referenced into OSGB'02, and height corrected to the Newlyn Datum. Each survey contains around 5.6 m points, with attributes of RGB, reflectivity and signal amplitude, which are used for qualitative assessment of the cliff face (Figure 9 & 10).

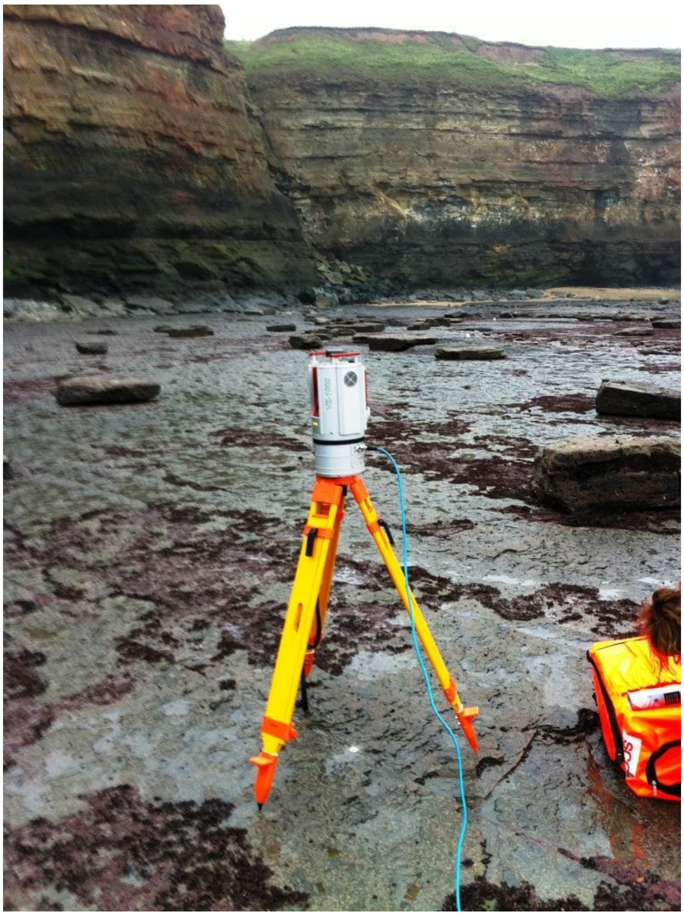


Figure 7 Reigl VZ-1000 at QP1 on the foreshore below Cowbar Nab.

Figure 8 Reigl VZ-1000 at QP1 on the foreshore below Cowbar Nab.

9. Calculation of erosion rates

Erosion rates are calculated by comparing successive scans, and each most recent scan with the first scan at the site, providing both a monthly and a rolling assessment of change. This data is also considered in the context of previously published results from this site.

Two methods are employed to calculate the erosion rate at Cowbar Nab using the TLS data:

1. Spatially averaged retreat rate
2. Rockfall magnitude - frequency retreat rate

Spatially averaged retreat rate

Two scans are aligned and co-registered, and then for each survey point the distance between it and the nearest point in the subsequent scan is calculated. This distance is commonly referred to as the Hausdorrf distance. The output from this process is a 3D point cloud, in which each point is attributed with a change distance. This data is then rasterised to a grid projected face-on to the cliff face, at 0.1 m resolution across the area of interest, allowing erosion to be mapped.

The scanner error threshold (0.03 m in this survey design) is then used to discretise the rockfalls from noise. Error assessments indicated a minimum reliably detectable rockfall size as 1.25×10^{-4} m^3 by change detection between sequential data sets with an absolute minimum detectable size of 1×10^{-6} m^3 (Lim et al., 2005). Zonal statistics are then used to isolate each rockfall, from which volume is calculated. The method does assume that single events captured within a single month are individual rockfall, with no superimposition.

The total volume of all rockfalls is calculated from the database, and then spatially averaged across the rockface surface, to obtain an average erosion rate for the site.

This method is fully described in the following papers:

- *Schürch, P., Densmore, A.L., Rosser, N.J., Lim, M. & McArdell, B. Detection of surface change in complex topography using terrestrial laser scanning: application to the Illgraben debris-flow channel. Earth Surface Processes and Landforms. 2011;36:1847-1859.*
- *Rosser, N.J., Petley, D.N., Lim, M., Dunning, S.A. & Allison, R.J. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. Quarterly Journal of Engineering Geology and Hydrogeology. 2005;38:363-375.*

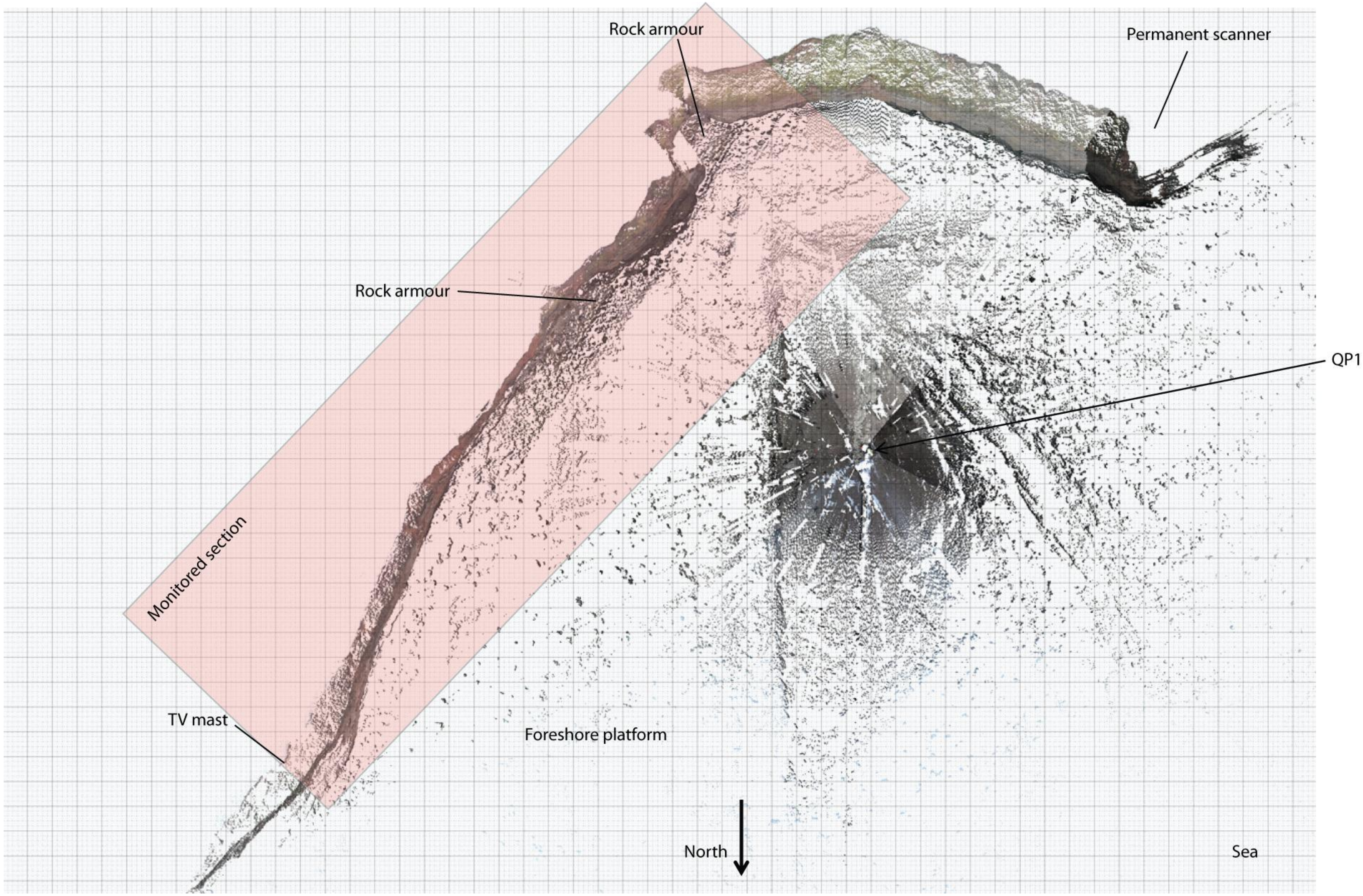


Figure 9 Orthophoto of the TLS data from QP1, from a bird's eye viewpoint. Major grid is 10 m intervals; minor grid is 2 m intervals. Points are coloured with RGB from the scanner. The monitored extent is highlighted in the red box.

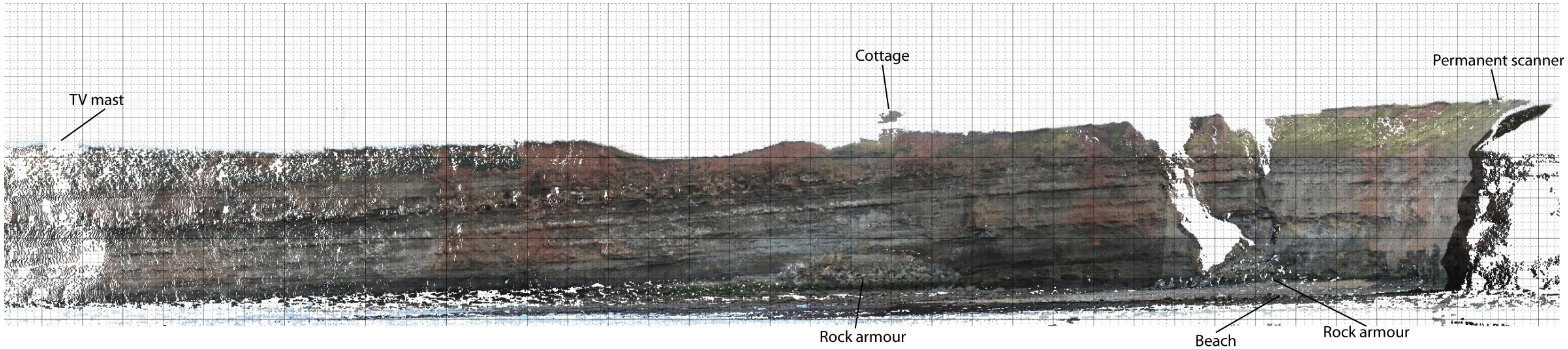


Figure 10 Orthophoto of the laser scan data collected from QP1. Major grid is 10 m intervals; minor grid is 2 m intervals. Points are coloured with RGB from the scanner

Rockfall magnitude - frequency retreat rate

The above method is widely utilized for deriving rock face erosion rates, and is arguably the accepted standard. However, this approach is limited by the possibility of the lack of inclusion of *all possible* event sizes in the erosion rate calculation. For example, over a short monitoring period such as a single year, it is quite likely that the largest possible event size at a given site is not captured within the monitoring period, which may have a significant influence on the long-term (decadal) retreat rate calculation.

To overcome this, we have developed an approach that uses widely observed magnitude frequency scaling relationships for rockfall (e.g. Malamud et al, 2004), to model erosion rates by accounting for the full range of possible event sizes at any given site.

The methods used in generating the rockfall inventory are discussed in detail by Lim et al. (2005) and summarized here. Frequency densities were calculated for rockfalls of differing magnitudes using the formula given by Malamud et al. (2004):

$$f(V_R) = \frac{\delta N_R}{\delta V_R} \quad (1)$$

where *f(VR)* is the frequency density of a rockfall of magnitude *VR*, *δNR* is the number of rockfalls with volumes that fall within the range of *δVR*, and *δVR* is the bin-width of the histogram. Parameter estimation is typically undertaken using least squares regression (LSR) on logarithmically transformed data (e.g. [Hovius et al., 1997], [Hovius et al., 2000] and [Korup, 2005]). It has been noted that the use of LSR may be inaccurate at the tails of power law distributed data (Goldstein et al., 2004). This is because the double logarithmic transformation of the data tends to distribute the error in the tail unevenly. It has therefore been suggested that a maximum likelihood estimator (MLE) is a more appropriate method in the modeling of power law distributions ([White et al., 2008] and [Rossi et al., 2010]). However, Goldstein et al. (2004) demonstrate that LSR is capable of producing models that are identical to MLE, provided the plot includes points from the mid-range of the data. As our inventories are considered to be complete through the mid-range of the data, LSR was considered the most appropriate parameter estimator.

In order to test the accuracy of the parameter estimation, the integral of Eq. (1) is derived:

$$\delta N_R = \int_{min}^{max} s{V_R}^{-\beta}\, dV_R \quad (3)$$

$$\delta N_R = \frac{sV_{R_{max}}^{1-\beta}}{1-\beta} - \frac{sV_{R_{min}}^{1-\beta}}{1-\beta}. \quad (4)$$

By setting the maximum and minimum values to fit the bin widths used to produce the histogram, it is possible to compare the actual number of failures within a given bin to those predicted by Eq. (4). Our parameterization is accurately describes the frequency distributions of rockfalls within the study area. Frequency densities were normalized by both time and area (events km^{-2} yr^{-1}).

Once the power law scaling parameters have been defined, it becomes possible to interpret the erosional flux (retreat rate) associated with a given event magnitude simply by multiplying the frequency density of the event by the magnitude. Applying this to the power law equation we get:

VRC=sVR⁻βVR (5)

$$V_{RC} = sV_R{}^{-\beta+1} \quad (6)$$

where *VRC* is the contributing volume in m^3km^{-2} yr^{-1} for an event of magnitude *VR*. Therefore, the total volumetric erosional flux (*VT*) of rock between a minimum and maximum magnitude can be calculated via:

$$V_T = \int_{min}^{max} sV_R{}^{-\beta+1}\, dV_R \quad (7)$$

$$V_T = \frac{sV_{R_{max}}^{2-\beta}}{2-\beta} - \frac{sV_{R_{min}}^{2-\beta}}{2-\beta} \quad (8)$$

A numerical consequence of Eq. (8) means as the value of *β* approaches 1, the volume of material contributed by larger events approaches unity with that contributed by smaller events. Once the value of *β* exceeds 1, the smaller events begin to contribute more material per km^2/yr than the larger events. Eq. (8) requires volumetric values for the minimum and maximum failure magnitudes. For long-term studies the maximum value can easily be identified from the inventory itself; at present at we make a judgment based upon experience of this coastline more widely.

The method, applied to the cliffs of N. Yorkshire, is fully described in the following paper:

- *Barlow, J., Lim, M., Rosser, N.J., Petley, D.N., Brain, M.J., Norman, E.C. & Geer, M. Modeling cliff erosion using negative power law scaling of rockfalls. Geomorphology. 2012;139-140:416–424.*

10. Permanent laser scanner

A fixed laser scanner has been developed and installed on the cliff top west of Cowbar Nab, providing a view onto the Nab cliff face. This is the only system of its kind in the UK. The scanner runs on an automated schedule run by a PC to capture the cliff face everyday at 2 am to maintain constant ambient light conditions (full darkness throughout the year), and to capture data at the least conspicuous time of day.

The scanner is a modified version of and MDL QuarryMan Pro (http://mdl.co.uk/en/15118.aspx), which has a reflectorless range of 1,200 m onto a 90% reflective white planar surface, with an encoder accuracy of 0.01^{o} in pan and tilt. From the location of the installation, the full length of the Nab from the inflection of the bay to the end of the Nab can be captured. We have developed custom controls software to control the scanner remotely, and to run scheduled sequences of scans each day.

The scanner is housed in a custom built steel box, mounted on a stable 0.5 m deep concrete foundation (Figures 11, 12, 13 & 14). The box contains deep cycle batteries to provide power back-up, a control PC with GPRS modem, and a series of relays which open and close the box window, and trigger the scanner. A motor driven window mechanism opens each night providing a secure installation for the scanner. Power is provided by a solar array located adjacent to the scanner on a pre-existing concrete slab.

Data is transmitted back to Durham via a GPRS modem each night, allowing for daily checks on system status, data quality and critically changes to the cliff face. All cabling and antennas have been buried > 0.5 m beneath the ground surface for protection and to reduce the potential impact of vandalism.

The scanner has been configured to capture the cliff face at 0.25 m point spacing, with a range precision of + / - 0.1 m (Figure 15). Although at a lower resolution than the VZ1000 data, the system provides very high temporal resolution, which is key to identifying the timing and hence controls on cliff change. The system uses an eye-safe laser (905 µm), firing at 250 points per second, and so has no effect on wildlife or people.

A significant portion of Year 1 has been in the design, installation and testing of this system. Ongoing work is focusing upon automating workflow for processing the daily scans to obtain rockfall geometry and changes in cliff reflectivity.

Note that the laser scanner was funded by a University of Durham research development grant.

Figure 11 Foreground: Permanent laser scanner installation, showing the view of Cowbar from the scanner housing in the background.

Figure 12 View inside the permanent scanner installation, showing the scanner nearest to the window mechanism, and the controls PC at the rear of the box

Figure 13 View of the automatic window (closed) on the scanner housing.

Figure 14 Fencing erected around the scanner housing

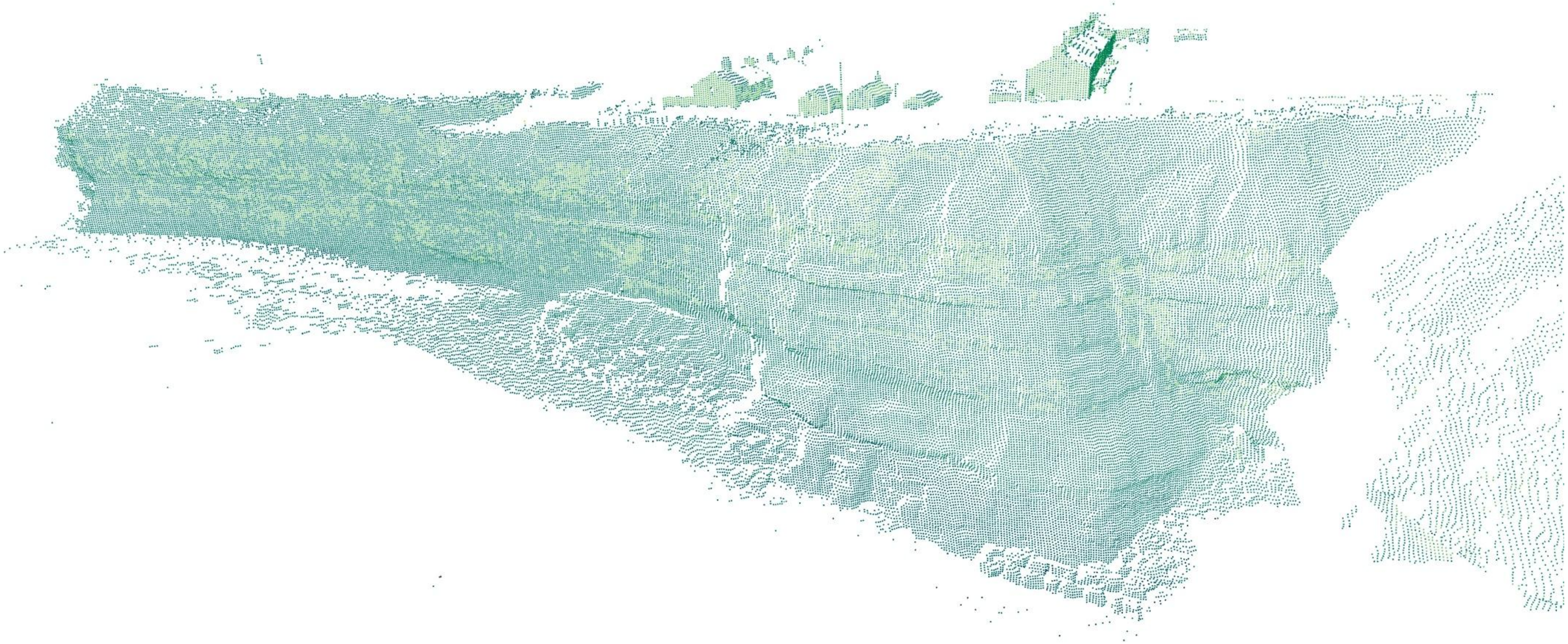


Figure 15 Laser scan data collected from the permanent TLS installation on the cliff top opposite to Cowbar Nab. Points are coloured by reflectivity.

11. Results – Year 1

Erosion rate calculation – Cowbar Nab, January 2011 – March, 2012

Table 3 summarizes the survey results from monitoring between January 2011 and March 2012. Months since the beginning of the monitoring program are named 1, 2, 3 . . . , with the corresponding date of the survey. The length of each survey epoch is calculated in days since the previous survey, and days since the first survey. For each month the total number of rockfalls is calculated, in the method discussed in Section 9, and the cumulative total volume of rockfalls measured during this period. Total change during the monitoring is shown in Figure 18.

Erosion rate is calculated in two ways. First the total rockfall volume is averaged across the survey area, and second by modeling rockfall magnitude frequency distribution (Section 10).

We measure the survey area from the cliff surface in the laser scan (9,125.2 m^2). The total number of measured rockfalls during this period was 9,968, with a total volume of 318.99 m^3. This equates to a spatially averaged erosion rate of **1.99×10^{-3} myr^{-1}**, over this 15-month period. The maximum monthly erosion rate was 3.7x 10^{-3} myr^{-1} (Feb, 2012), and the minimum 0.01 x 10^{-3} myr^{-1} (May, 2011).

Using the modelled erosion rate calculated by modelling the rockfall magnitude frequency distribution, we derive a mean erosion rate of **2.23×10^{-3} myr^{-1}**, with a maximum of 4.64 x 10^{-3} myr^{-1} and a minimum of 0.001 x 10^{-3} my^{-1}. In this assessment we assume a maximum event volume of 2,500 m^3, during a 100-year return period. See Barlow et al, 2011 for a discussion of this method.

We observe two notable rockfalls. The first larger rockfall from the monitoring is shown in Figure 16. Although large in extent, this rockfall is shallow in depth, whereby over 90% of its area, the rockfall depth does not exceed 0.05 m. The rockfall occurred in Dec 2011. It is likely that an initial failure at the apex resulted in the dislodgment of loss rock and superficial material from the cliff face below. The maximum depth of the failure at the apex was 1.23 m, reflecting a single sandstone block detachment, most probably triggered as a result of the upward propagation of failure from the cliff toe over a period of years.

The second large rockfall (Figure 17) shows a failure of the cliff toe, removing c. 15 m^3 of material. Future surveys should examine how this failure propagations upslope, and whether this leads to destabilization of the cliff face above. This rockfall occurred in January 2012. Critically, this section of the coast is a promontory that juts out from the cottages above, so any failure here is unlikely to influence critical infrastructure above.

We note also in Figure 16, clear evidence of the action of waves at the toe of the cliff, with the preferential removal of blocks in lower 6 m of the cliff face, that area which is regularly inundated by marine action. This process ultimately leads to undercutting of the cliff face, which is likely to failure via the propagation of smaller rockfalls moving up-cliff, rather than a deeper seated failure of the cliff rock mass. Continued monitoring will indicated which of these processes is likely to dominate at this site.

The area averaged erosion rate (Figure 19) shows a broadly seasonal pattern.

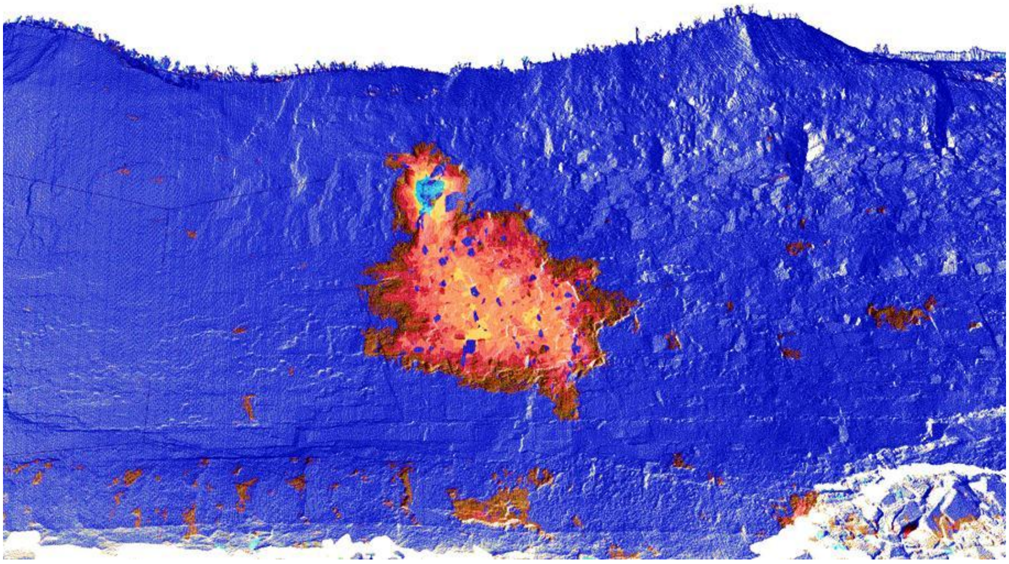


Figure 16 Rockfall from the cliff at Cowbar Nab, approximately 12.5 x 8 m, but < 0.05 m in depth across most of its extent. The deep loss of material is at the apex of the failure, reaching c. 1.23 m. The area shown in this image is approximately 52 m across, and 37.4 m in height. The limit of the rock armor is show on the right of the image.

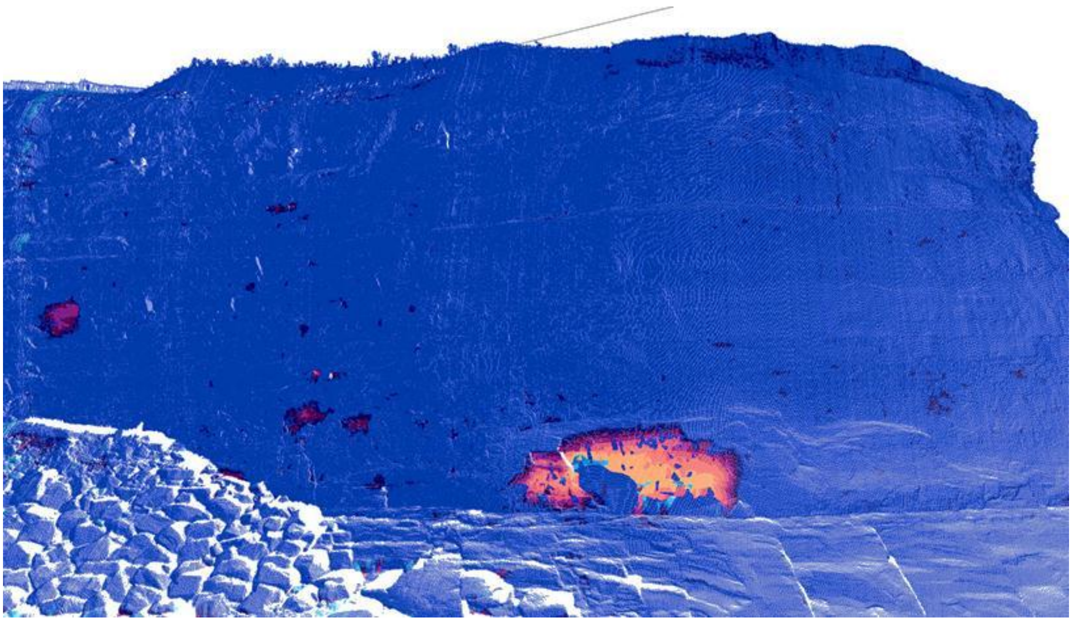


Figure 17 Rockfall at cliff toe, to the right of the rock armour. The size of the rockfall is approximately 8.5 m wide x 2.4 m high, and at its peak 1.1 m deep. The volume, assuming this to be a single event is 14.8 m^3.

Month	Month	Year	Survey date	Survey epoch length (days)	Running total of days	Number of rockfalls	Total volume of rockfalls (m^3)	Area average erosion rate (myr^{-1})	m/f modelled erosion rate (myr^{-1})
1	January	2011	14/01/2011	0	0	0	0	0.00	0.00
2	February	2011	18/02/2011	35	35	990	31.69	2.77	3.344
3	March	2011	21/03/2011	31	66	969	31.00	2.71	2.816
4	April	2011	28/04/2011	38	104	1036	33.15	2.90	1.716
5	May	2011	20/05/2011	22	126	4	0.13	0.01	0
6	June	2011	17/06/2011	28	154	21	0.68	0.06	0.022
7	July	2011	21/07/2011	34	188	660	21.11	1.85	0.484
8	August	2011	25/08/2011	35	223	560	17.93	1.57	2.684
9	September	2011	27/09/2011	33	256	972	31.11	2.72	4.554
10	October	2011	21/10/2011	24	280	802	25.66	2.24	4.642
11	November	2011	17/11/2011	27	307	708	22.65	1.98	3.85
12	December	2011	19/12/2011	32	339	207	6.62	0.58	0.176
13	January	2012	17/01/2012	29	368	609	19.48	1.70	1.76
14	February	2012	23/02/2012	37	405	1323	42.33	3.70	2.816
15	March	2012	26/03/2012	32	437	1108	35.45	3.10	2.86

Table 3 Erosion rate calculations from January 2011 to March 2012

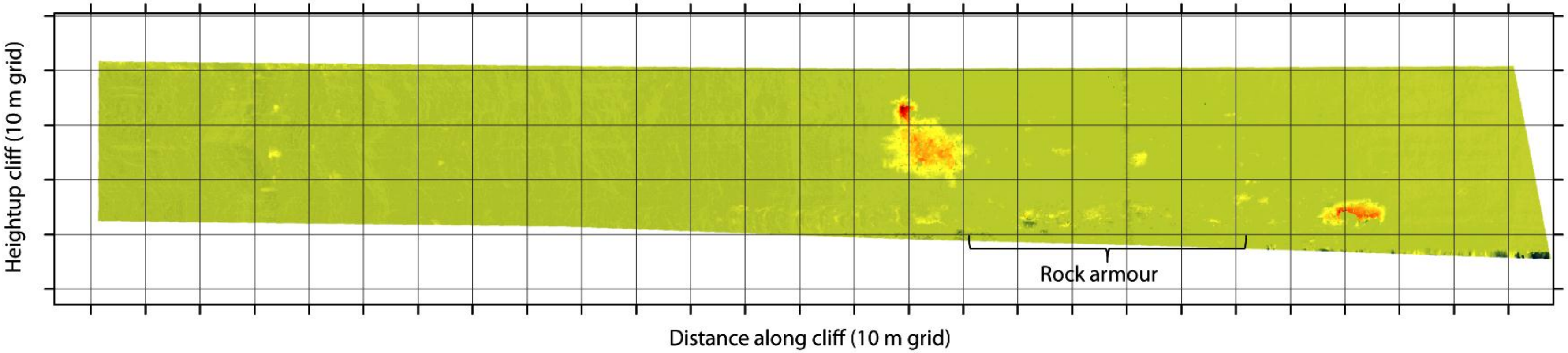


Figure 18 Total change from January 2011 – March 2012, viewed face-on to the cliff. Colour scale indicates: green 0.03 - -0.03 m; yellow 0.03 – 0.1 m; orange 0.1 – 0.25 m; and red 0.25 – 1.2 m. Grid is at 10 m intervals. The two large rockfalls shown in this image are illustrated in more detail in Figure 16 and 17.

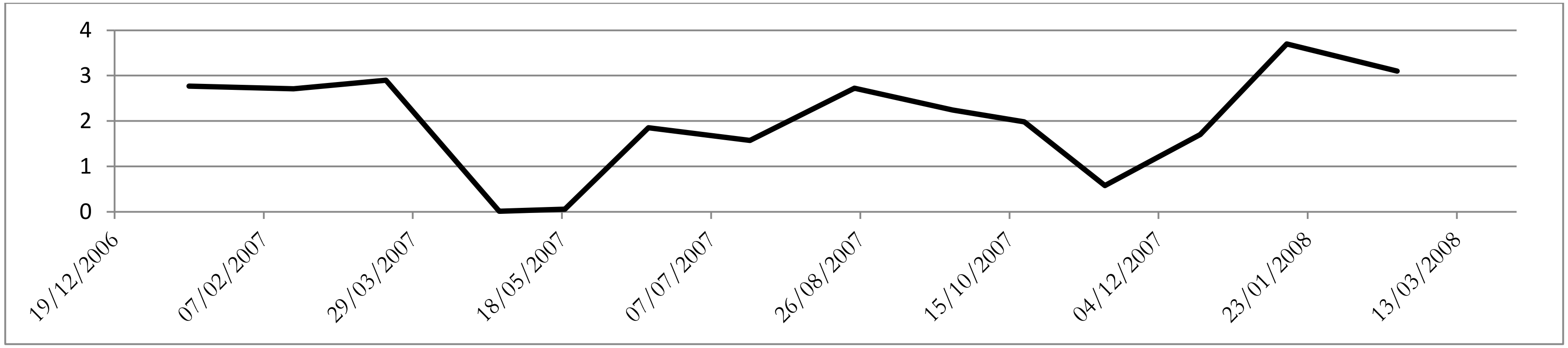


Figure 19 Area averaged erosion rate from January 2011 – March 2012, show in units of mm yr^{-1}.

Environmental conditions:

For Year 1 we have explored the correlation between the seismometer data and the prevailing environmental conditions at the site. We present 3 sub-sets of this data as illustration of how we intend to use this information in future.

First (Figure 20), we consider a single day with 2 tides. We plot marine conditions (wave heights – here modeled from the Tees Wave Buoy, sea level (monitored from the Whitby Tide Gauge), wind conditions captured by the cliff face installation, and the seismic data (ground motion velocity; 3-component power-spectrums.

In line with results from sites nearby, we observe a clear tidal signal in the seismic data, reflecting the increase in energy delivery as the water surface inundates the foreshore and then is in contact with the cliff face.

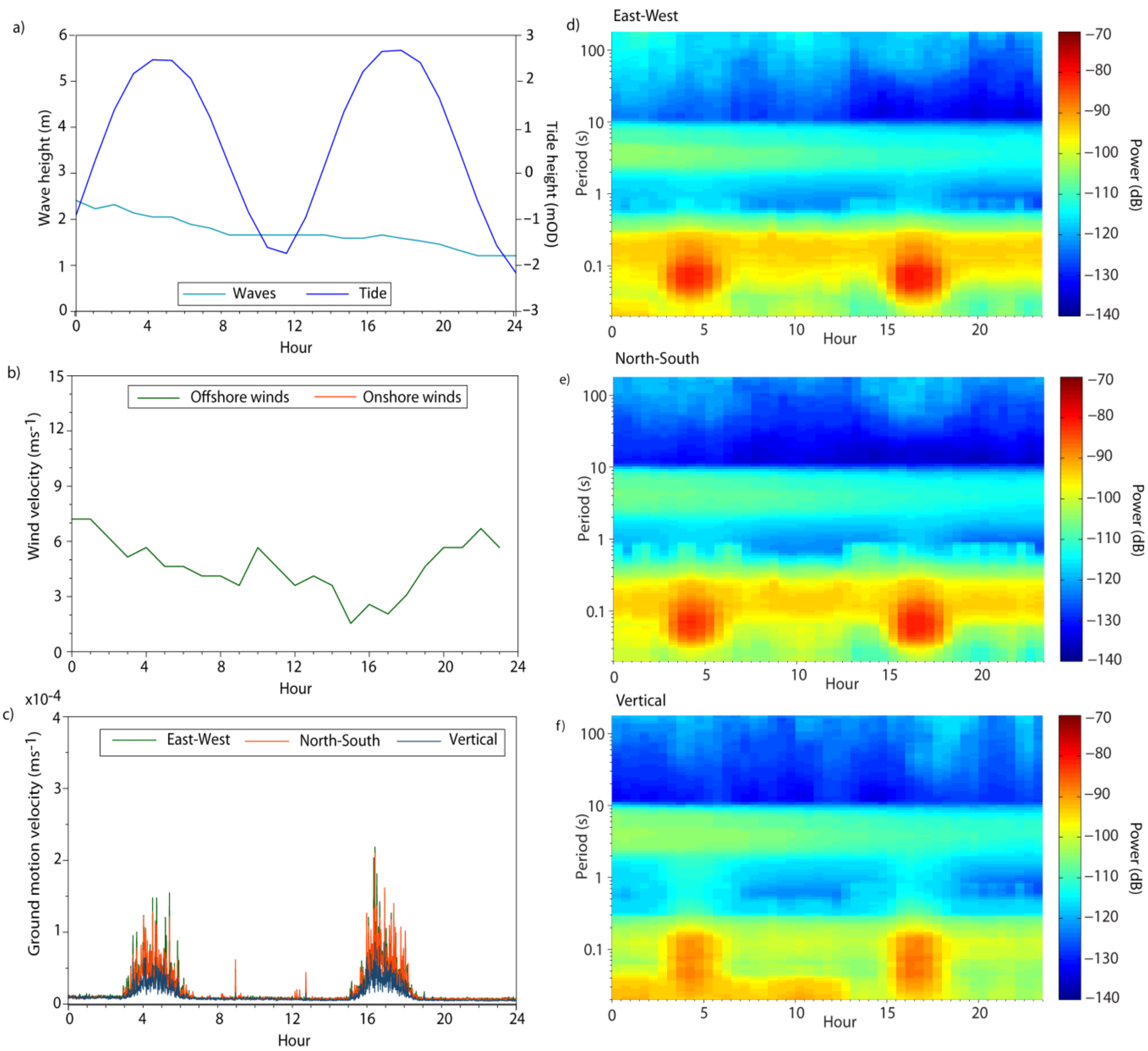


Figure 20 Spectrograms and environmental data for 04/12/11. a) Hourly max tide height modelled and hourly max wave heights obtained from the Tees wave buoy; b) Mean onshore and offshore wind speeds monitored hourly at Loftus; c) Ground motion velocity for all three components; d) East-west component spectrogram; e) North-south component spectrogram; f) Vertical component spectrogram.

Second, we consider a full tidal cycle, from Spring to Neap, which includes a period of on-shore, and offshore winds, and variable wave conditions as a result. We observe a considerable increase in wave energy delivery to the cliff during period of onshore winds during high tides, during which water depths permit long-period waves to propagate to the cliff toe, without significant energy loss in the near-shore or foreshore. It is during these periods that we expect the majority of the erosive work to be undertaken by the sea on the cliff face.

Future work during Year 2 will focus upon building a model based upon the numerical analysis of the environmental data with the cliff change data.

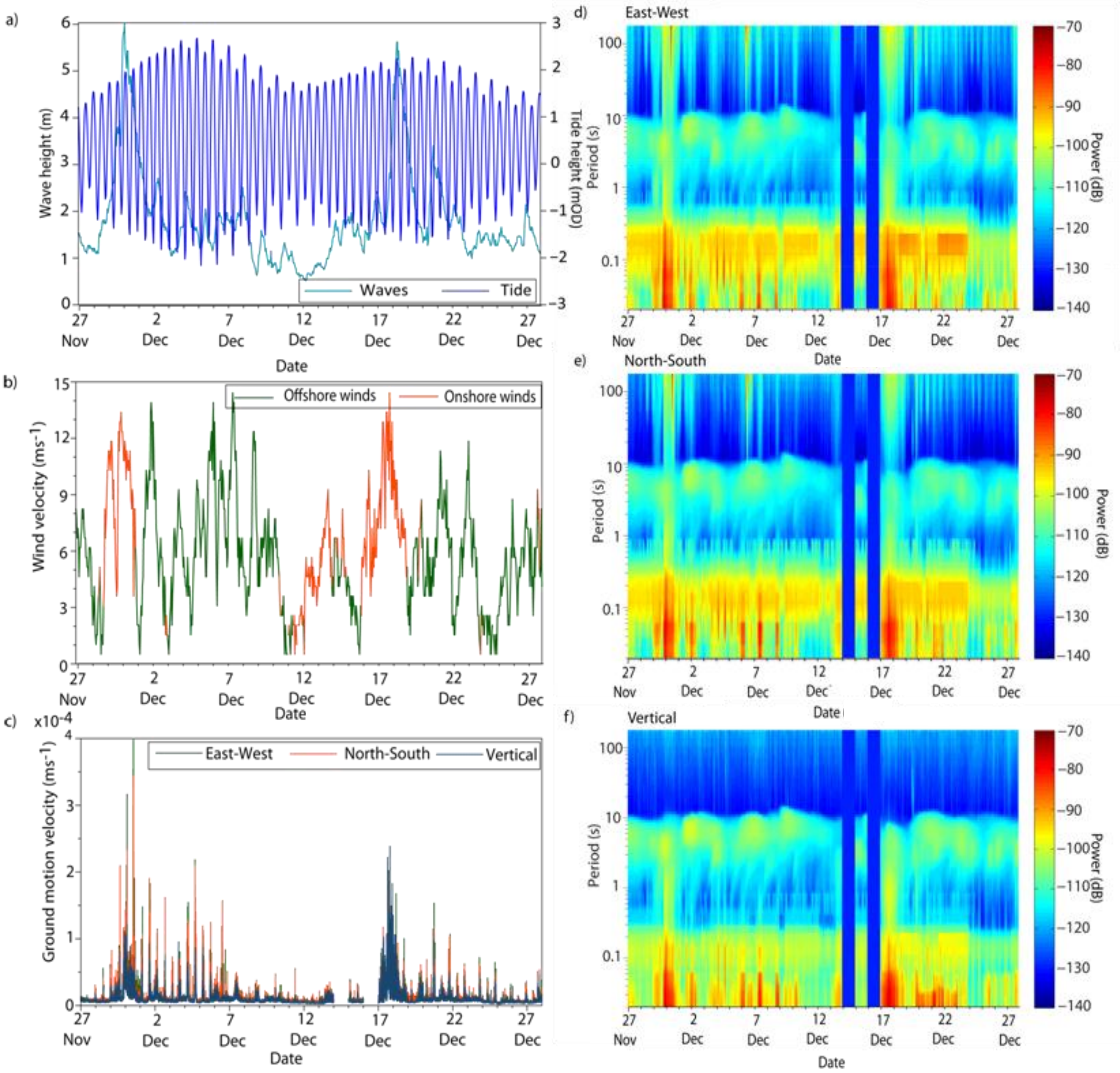


Figure 21 Spectrograms and environmental data for the winter month of December 2011 a) Hourly max tide height modelled for Boulby and hourly max wave heights obtained from the Tees wave buoy; b) Onshore and offshore wind speeds monitored hourly at Loftus; c) Ground motion velocity for all three components; d) East-west component spectrogram; e) North-south component spectrogram; f) Vertical component spectrogram. The 14th and 16th December contained noise across the spectrum as there were people working in the seismometer field on these days. The power values have been replaced with a null value, represented by the blue bands.

The 3rd period we consider is the full dataset collected to data (August 2011 to March 2012 (Figure 22). Two significant periods of data loss are illustrated by the blue areas in late September, and early January.

The spectrograms clearly show the seasonal variation in energy delivery in the 1 to 10 second period data, the long-period (> 100 s) and in the tidally modulated energy delivery at the cliff toe (< 0.1 s). Based upon previous work, it is likely that future analysis of this data in relation to the erosion signal will yield more significant correlations than using standard environmental variables alone.

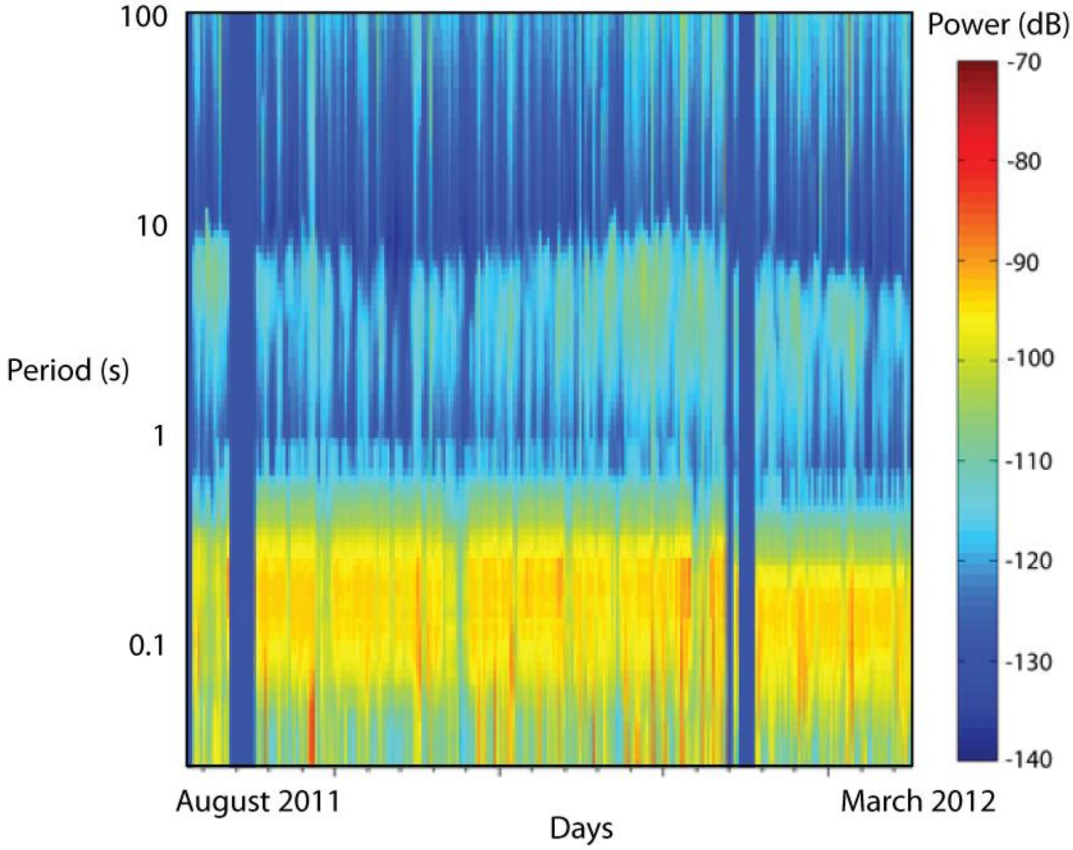


Figure 22 Full seismic data set from August 2011 – March 2012

12. Summary of results – Year 1

The following erosion rates have been calculated:

- The calculation of monthly erosion and long-term 15 month erosion rates has been completed, and compared to past rates measured at this site (Sections 10 & 12). A total of 318.99 m3 of rockfall in 9,968 discrete events has occurred during this period. Considerable month-on-month variability is observed, with May 2011 experiencing effectively no discernible change (Section 12).
- The net rate observed in the period January 2011 to March 2012 was 1.99 x 10-3 m yr-1 (Section 12).
- On average the observed rate is less than that previously observed at this site (358 m3 of rockfall from 4,494 m2 of cliff face, deriving 25 x 10 -3 myr-1 erosion).

The following conclusions have been drawn based upon this analysis:

- A preliminary analysis of Year 1 seismic monitoring data in respect of environmental conditions at site has been completed (Section 12). The seismic response of the cliff is in line with observations made elsewhere on this coast, and elsewhere worldwide. The set-up is now calibrated, and collecting continuous data on wave energy and impacts at the cliff toe. Future analysis will focus upon the correlation of this data with the rockfall and erosion output.
- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The concentration of erosion is currently focused away from the 'pinch points' at this site.
- No loss of cliff line was observed during this period, although critically this indicates cliff steepening, which will in time result in failure of the cliff top. Continued monitoring will help identify where and when this may occur.
- There is no evidence in the monitoring data of the development of a deeper-seated failure which would threaten the road and / or houses.

13. References

Agar, R. 1960. Post-glacial erosion of the North Yorkshire coast from the Tees Estuary to Ravenscar. Proceedings of the Yorkshire Geological Society, 32 (4), 409-428.

Barlow, J., Lim, M., Rosser, N.J., Petley, D.N., Brain, M.J., Norman, E.C. & Geer, M. Modeling cliff erosion using negative power law scaling of rockfalls. Geomorphology. 2012;139-140:416–424.

DEFRA, 2006. Shoreline management plan guidance, Volume 1: Aims and requirements. Department for Environment, Food and Rural Affairs, London, 48 pp.

IPCC, 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge, 1005 pp.

Leatherman S.P. 1990. Modeling shore response to sea-level rise on sedimentary coasts. Progress in Physical Geography, 14 (4): 447-464.

Lee, M. and Clark, A.R. 2002 Soft Cliffs, Prediction of recession rates and erosion control techniques. DEFRA Research project R&D Project FD2403/1302

Lim, M., Rosser, N.J., Petley, D.N., Keen, M. 2011. Quantifying the controls and influence of tide and wave impacts on coastal rock cliff erosion Journal of Coastal Research, Volume 27, issue 1, year 2011, pp. 46 - 56

Lim, M., Petley, D.N., Rosser, N.J. Allison, R.J., and Long, A.J. 2005. Digital photogrammetry and time-of-flight laser scanning as an integrated approach to monitoring cliff evolution. Photogrammetric Record, 20 (110), 109–129

Lim, M. 2006. Coastal cliff evolution with reference to Staithes, North Yorkshire. Unpublished PhD thesis, University of Durham, 376 pp.

National Research Council, 1987. Responding to changes in sea level – engineering implications. Marine Board Research Council. National Academy Press, Washington DC.

Norman, E.C. (2012) Microseismic monitoring of the controls on rocky coastal cliff erosion. Unpublished PhD Thesis, University of Durham.

Pearson, S., Rees, J., Poulton, C., Dickson, M., Walkden, M., Hall, J., Nicholls, R., Mokrech, M., Koukoulas, S. and Spencer, T. (2005) Towards an integrated coastal sediment dynamics and shoreline response simulator, Tyndall Centre Technical Report 38

Rosser, N.J., Petley, D.N., Lim, M., Dunning, S.A., and Allison, R.J. 2005. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. Quarterly Journal of Engineering Geology and Hydrogeology, 38 (4), 363-376.

Schürch, P., Densmore, A.L., Rosser, N.J., Lim, M. & McArdell, B. Detection of surface change in complex topography using terrestrial laser scanning: application to the Illgraben debris-flow channel. Earth Surface Processes and Landforms. 2011;36:1847-1859.

14. Document control sheet

Project title: Coastal cliff monitoring, Cowbar Nab, Staithes, N. Yorkshire

Revision: 1.2

Status: Revision

Date: 18/06/12

Distribution:

Client :

Redcar and Cleveland Borough Council
Steve Dunning

Authors :

Dr N J Rosser
Dr S Waugh

QA :

Dr M Brian
Insurance Officer

Copies :

Research Office
IHRR Archive

Durham University

Durham University

Appendix E

Volume Analysis for Scarborough South Bay

Technical note

Project	**Scarborough South Bay Beach Volume Analysis**	**Date**	8th April 2013
Subject	Analysis of beach topographic survey data before and after sediment recycling, April to May 2012.	**Ref**	
Author	Ross Fitzgerald and Lily Booth		

1 Aims and Objectives

Scarborough South Bay experiences a net drift of sediment towards the north. This natural process means sediment accumulates at the back of the beach and harbour wall and impedes beach access. To mitigate this, the beach at is periodically reprofiled, with sand from the north of the bay being mechanically excavated and transported to the south.

At present, Scarborough Borough Council do not keep records of the volumes of sand moved. However, topographic surveys of the beach affected are collected before and after reprofiling. During the 2012 reprofiling exercise, topographic surveys were carried out in April 2012 and May 2012 to capture the change in the beach before and after the reprofiling. In addition, surveys were undertaken in March and September 2012 as part of the standard full and partial measures surveys of the Cell 1 Regional Monitoring Programme.

This technical note documents analysis of the four beach survey data sets in order to determine the volume of sand moved during beach re-profiling. This type of assessment has not been undertaken under the Cell 1 Regional Monitoring Programme before and therefore two methods have been trialled, using 3D DEMs-of-Difference calculated in GIS from the beach topographic survey data, and using 2D profiles analysed in Halcrow's SANDS software package. Specific tasks were:

- Use ArcGIS to generate 3D DEMs-of-difference to show the pattern and magnitude of change.
- Use SANDS to calculate beach volumes at specific 2D profile locations and to calculate total volume change by extrapolation between profiles.
- Use ArcGIS and SANDS to calculate the magnitude of change in terms of volume of sediment moved between each beach survey.
- Interpret the results to assess sediment movement and the suitability of the two approaches.

2 Methodology

2.1 ArcGIS

DEMs of the raw survey data were prepared using an inverse distance weighting (IDW) surface interpolation in ArcGIS 10. This multivariate interpolation assigns values to unknown points, in this case at an idealised of 5 m-spaced grid, by calculating weighted averages from the known data points.

2.1.1 Elevation and Volumetric Change Analysis

Based on the different long-shore and cross-shore units identified in Figure 1 the study site was split into four sub-units. This was done to isolate volumetric change between beach areas (storm beach and foreshore, north and south areas) and to define sediment pathways between them. Areas of net erosion and accretion were then mapped by calculating the net elevation change between successive DEMs.

The DEMs used were generated from the following survey data that cover a 12 month period:

- September 2011 survey that provides a pre reprofiling baseline
- April 2012 immediately before reprofiling,
- May 20112 immediately after reprofiling, and
- September 2012 four months after reprofiling.

To illustrate erosion and deposition relative to known features, the output DEMs of difference were contoured at 0.25 m intervals, colour coded and superimposed onto an aerial photograph.

Beach volume change was calculated between each survey by firstly calculating a nominal beach volume from each survey and then subtracting surveys from each other. To ensure consistency between surveys and to allow comparison of data with that derived from SANDS, the nominal beach volume was calculated using a standard beach base of -1.6 m O.D, which is the master profile depth used in SANDS (see below) equivalent to mean low water.

2.1.2 Surveying/Processing Error

Systematic error for both the sampling and processing methods is evaluated by measuring the vertical difference between identical points recorded manually by dGPS during the transect surveys (these were carried out at the same time as the area surveys and are assumed to be accurate to 2 mm) and the surface interpolations from the area surveys.

A mean vertical survey/processing error of 5.2 cm was recorded between the profile points and surface interpolation. Estimates of surveying and processing error are calculated as twice the standard deviation value of 9.2 cm. Therefore, the calculated of DEMs-of-difference between pairs of surveys should yield net errors of no more than 18.4 cm. To account for this error, change of between -10 and 10 cm elevation cannot be taken as real and is ignored.

2.2 SANDS

Relevant four beach profiles in Scarborough South Bay are SBS1 to SBS4 (Figure 2). These profiles have been surveyed at the time as the beach topographic surveys described above, and the same four time periods of data were used.

SANDS uses a master profile to calculate the volume within the x and y axis. The master profiles were defined in order to capture as much of the beach profile as possible and in this assessment have an x-axis (i.e. base of beach) of -1.6m. The y axis runs down the back of the defence to capture the beach in front. The cross sectional area of each of the profiles is defined as the area of the beach above the master profile. Then volumes were interpolated by SANDS using the CSA for adjacent profiles and interpolating by the distance between the profiles. The volumes for each of the sections and the change in volume are presented in the following sheets. Finally SANDS was used to calculate the volumes, the volume changes and to create graph of beach profile volumes over time.

3 Results and Discussion

3.1 ArcGIS

Figures 3 to 6 illustrate the elevation change between different survey epochs. Table 1 and Figure 7 show the volume change data. The data demonstrates the following:

- Under natural conditions before reprofiling, (September 2011 to April 2012), there is a net gain of sediment at the back of the beach adjacent to harbour wall. The pattern of change in the northern part of the bay shows linear zones of erosion and accumulation caused by migration of sand bars. In the southern part of the bay, the pattern of change is more patchy. The shoreline fronting the Spa is experiencing net loss of material. Volume change analysis shows despite waves and the dominant drift direction tending to erode a small amount of material from the south of the beach and deposit it on the north of the beach, the beach sub-units are in equilibrium with only a small net loss 810 m^3 of material. This material is likely to have been lost below mean low water.

- Between April and May 2012 the volume change map clearly shows the influence of beach recycling, with net loss at the back of the beach in the north and net gain in the south. Patterns of change on the foreshore, caused by sand bar migration, are more subtle. The volume data shows a loss on the North Beach section of 8,511m^3 and a very similar gain of 8,869m^3 on the South Beach section. The 358 m^3 difference between the two surveys is of a similar magnitude to that lost between September 2011 to April 2012 and reflects other coastal processes that may move sediment beyond the study area, either along- or shore. **The volume of sediment moved during reprofiling is therefore indicated to be c. 8,000 m^3.**
- Between May 2012 and September 2012 the majority of sediment redistributed to the south has been re-accreted at the North Beach.
- The cumulative volume trend demonstrates that during winter (between surveys September 2011 and April 2012) the beach naturally loses material, most likely to a nearshore sink below mean low water.
- The cumulative volume trend demonstrates that during summer (between May 2012 and September 2012) the beach naturally gained 5,149 m^3 of sediment. This is potentially accounted for by the influence of calm summer water conditions returning sediment from a nearshore sink.
- Overall during the 12 month period between September 2011 and 2012 the study area experienced a net gain in sediment of 4,790 m^3.

3.2 SANDS

The results of the SANDS analysis of four 2D beach profiles are presented in Table 2. The data indicate:

- The amount of material removed from the north is indicated to be 3,153m^3, with a gain of 8,496m^3 in the south. This imbalance in sediment volumes reflects the limited number of profiles and error resulting from interpolation between them and suggests that the profile data are not capturing all of the changes on the beach.
- The net changes in volume recorded at the time of the reprofiling (i.e. April to May 2012) are much greater (5,344m^3) than those observed in the monitoring periods beforehand (gain of 1,192m^3 between September 2011 to April 2012) and afterwards (loss of 566m^3 between May to September 2012).

4 Conclusions

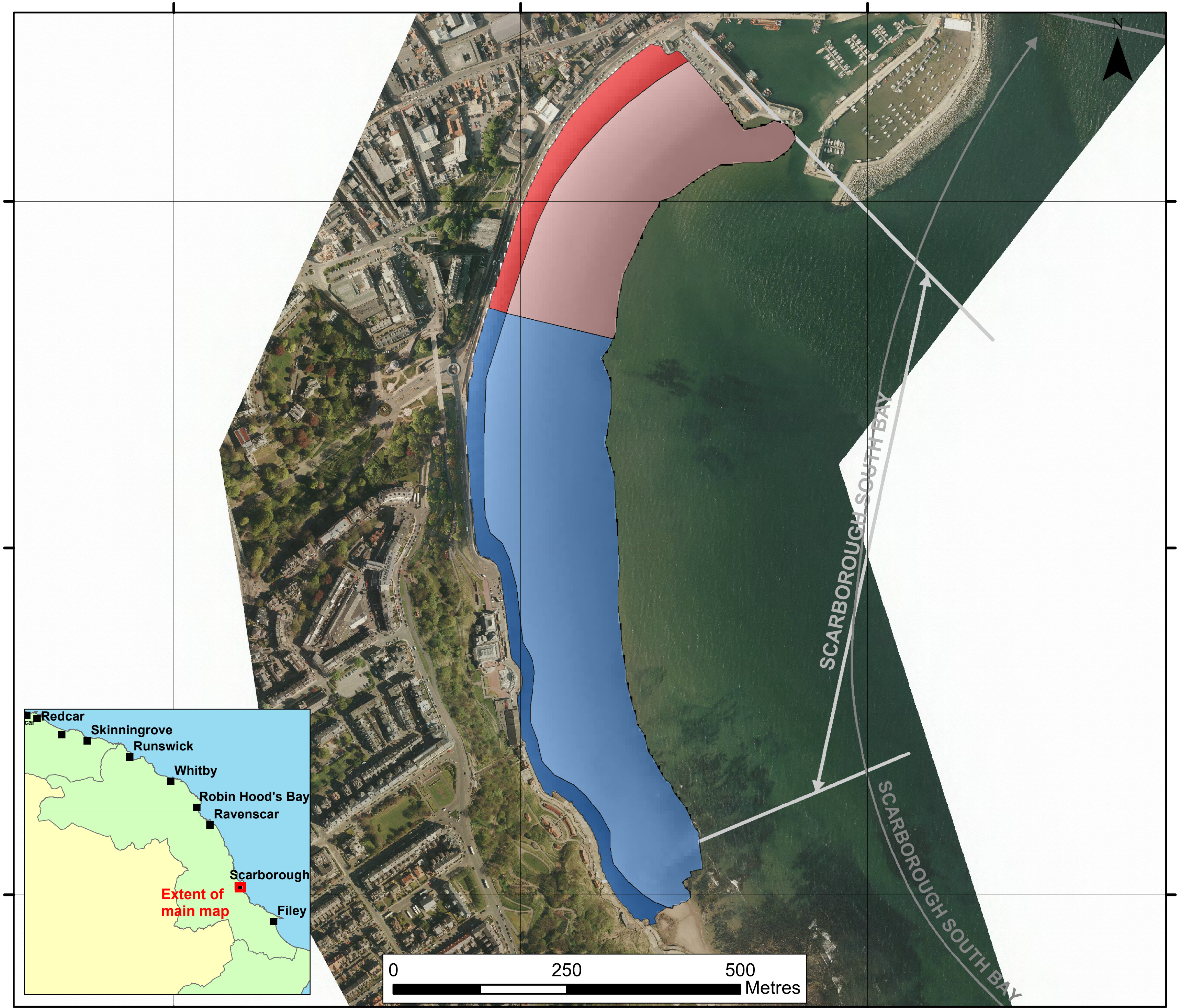
GIS analysis of 3D topographic survey data and analysis of four 2D beach profiles data collected before and after the beach re-profiling scheme in April and May 2012 have been used to calculate changes in the volume of sediment in the beach. Two additional surveys collected in the Septembers before and after the reprofiling have also been assessed to put these changes in context.

The GIS analysis indicates the volume gained on the southern part of the bay was c. 8,869m^3, while 8,511m^3 was lost from the northern section. The SANDS analysis indicates loss of 3,153m^3 in the north with a gain of 8,496m^3 in the south.

The small imbalance in gains and losses in the GIS assessment reflects uncertainty about offshore sediment movements in the area beyond mean low water, where no survey data are available. The imbalance in the SANDS volume data is significantly greater and principally reflects the limited number of survey profiles and error introduced by interpolation between them.

Taken as a whole, the data suggest that a volume of c. 8,000m^3 was moved from the north of the bay to the south. The data also indicate that by September 2012, four months after the reprofiling work, the redistributed sediment had been transported back north as the frontage moved back to its equilibrium profile.

The comparison of approaches indicates that the wide spacing of profiles limits the accuracy of any beach volume analysis undertaken in SANDS. This problem is eliminated in the GIS analysis of topographic data that provides a map of the spatial pattern of change and data on the volume of change. Both approaches are limited by the coverage of data that does not extend beyond mean low water and which therefore cannot determine the volumes of sediment transferred to the nearshore zone.



Key

Scarborough South Bay beach and foreshore units

- North beach
- North foreshore
- South beach
- South foreshore

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Map 1 Topographic Difference Scarborough South Scarborough Borough Council

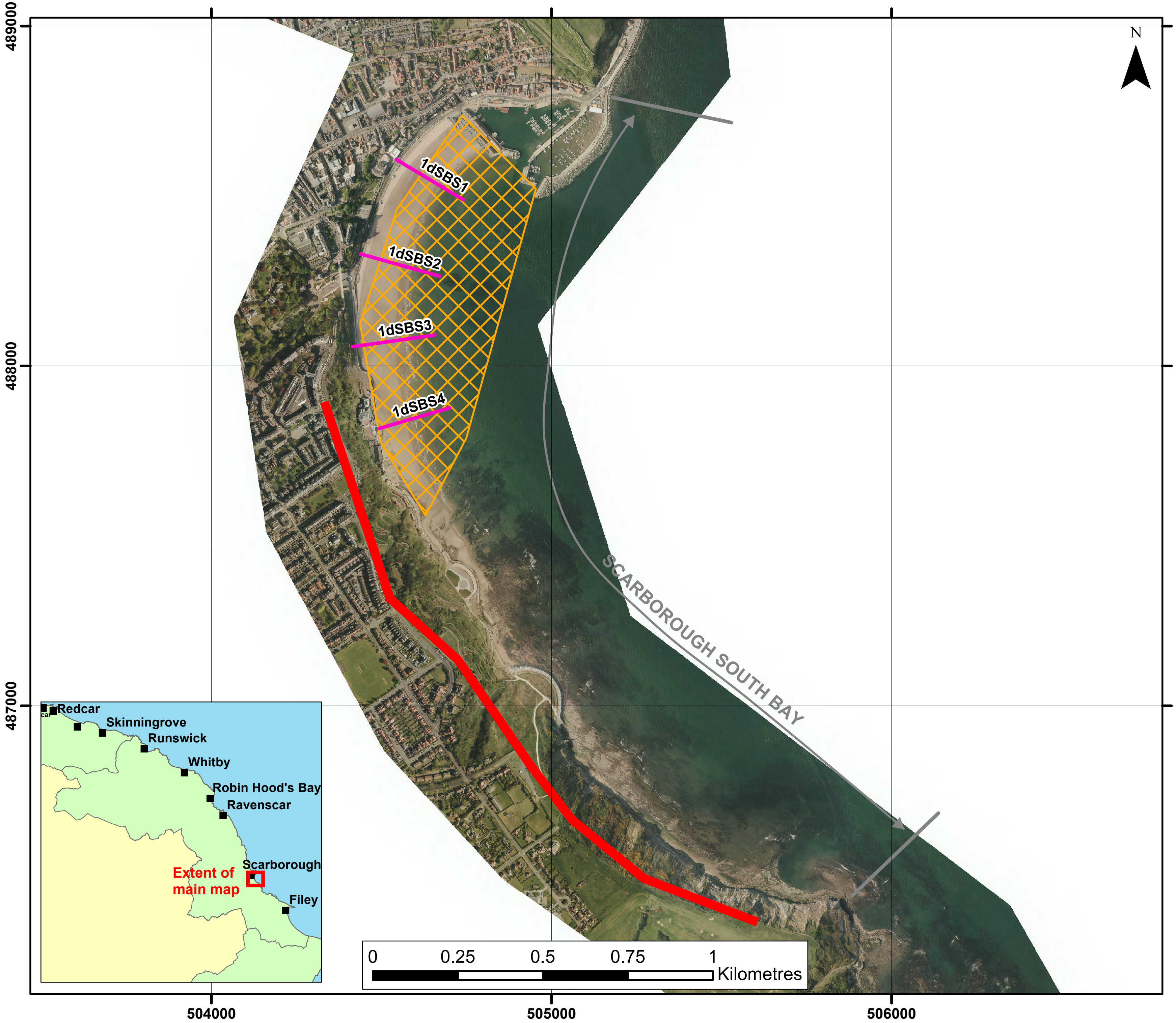
Analytical Report 5
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

Topographic Profiles

Annual

6 monthly

Topographic Surveys

6 monthly

yearly

5 yearly

Cliff Top Monitoring Pegs

50m centres

100m centres

300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Map 2
Survey Locations
Scarborough South Bay
Scarborough Borough Council

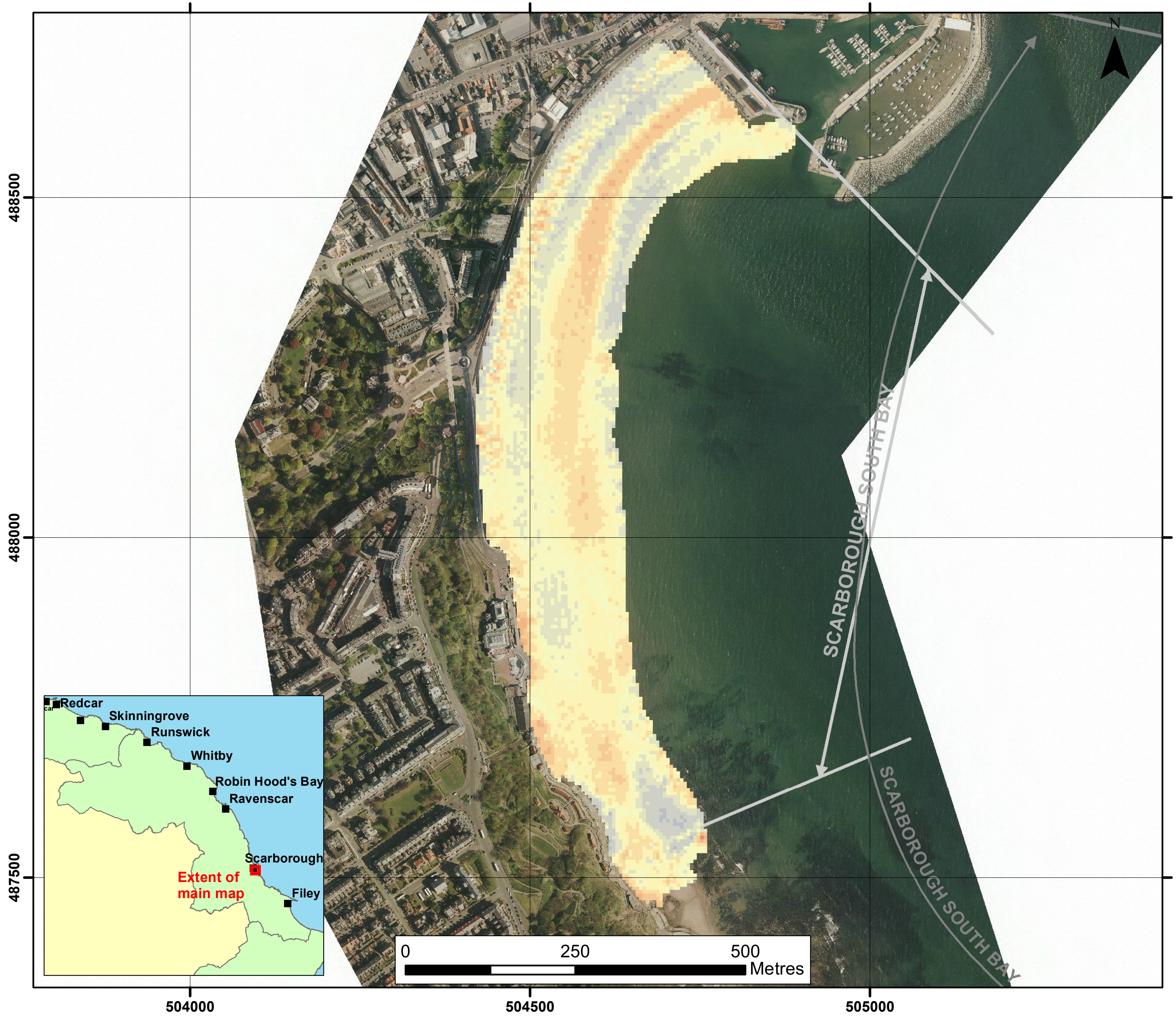
Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Sept 2011 and April 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Figure 3
Topographic Difference
Scarborough South
Scarborough
Borough Council

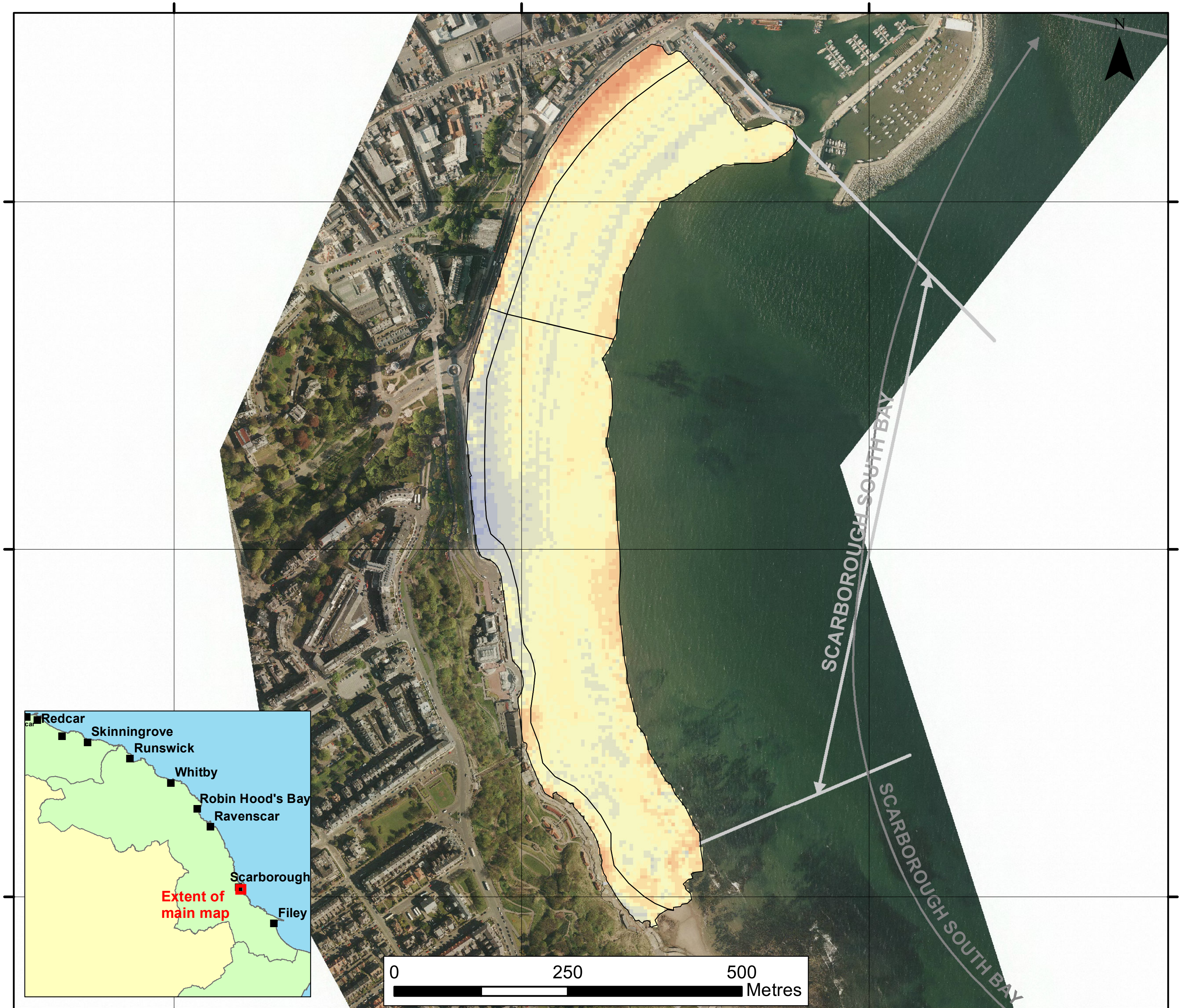
Analytical Report 5
Short-term Change Survey
Pre remodelling April 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY

April 2012 an May 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Figure 4
Topographic Difference
Scarborough South
Scarborough
Borough Council

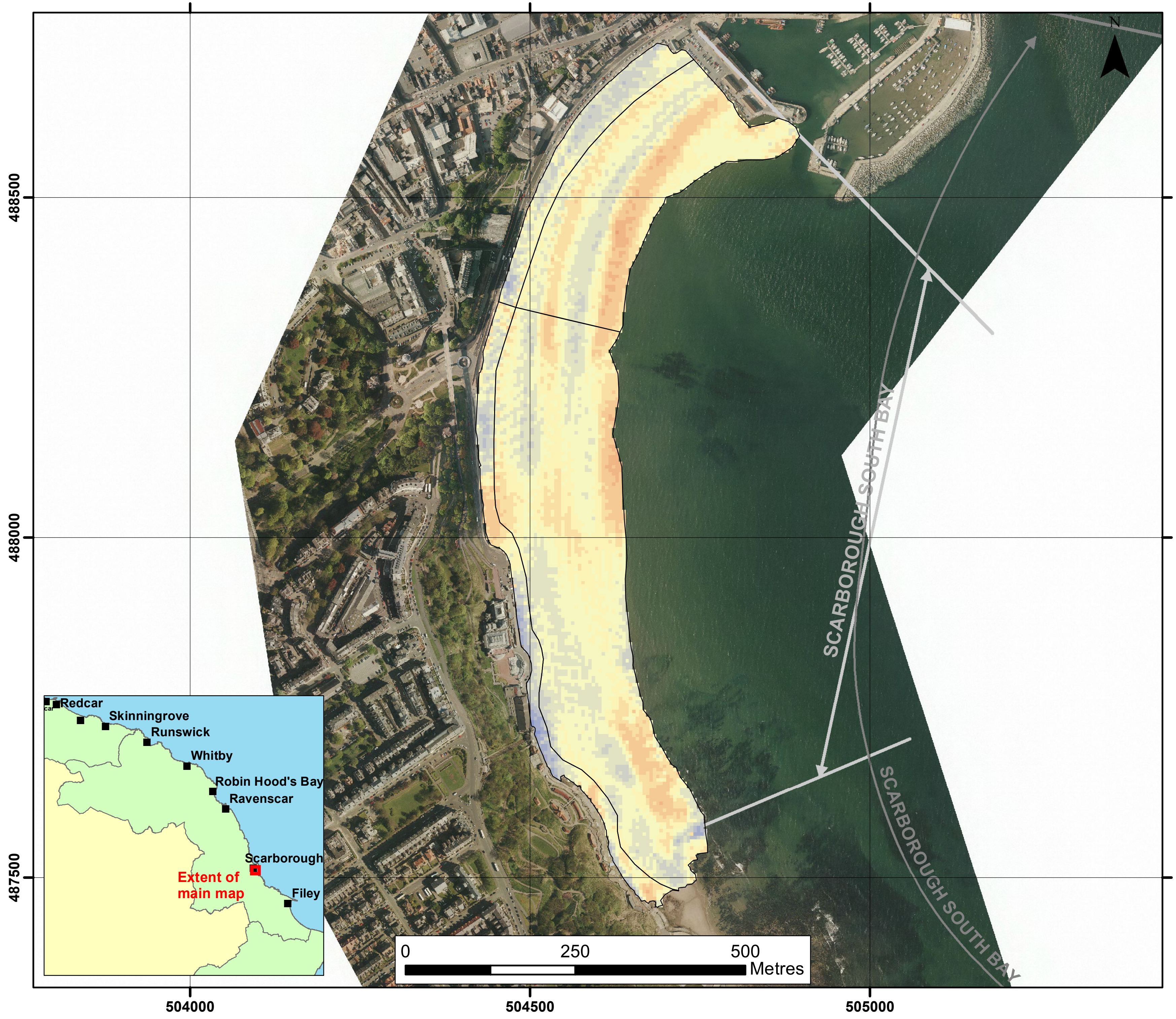
Analytical Report 5
Short-term Change Survey
Post remodelling May 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY May 2012 and Sept 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss
Change < 0.1 m
Gain

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Figure 5
Topographic Difference
Scarborough South
Scarborough
Borough Council

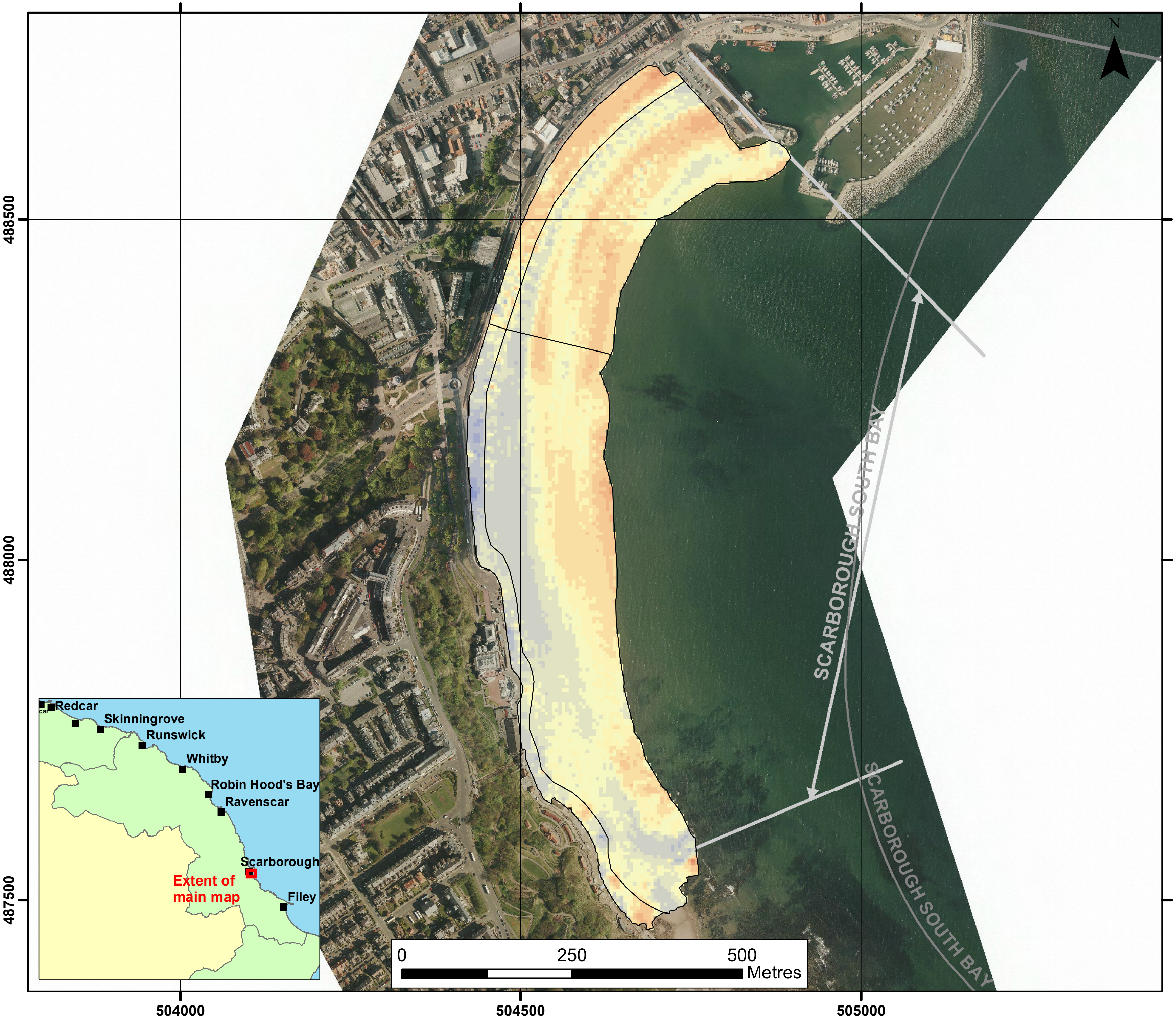
Analytical Report 5
Short-term Change Survey
Post remodelling Sept 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Sept 2011 and Sept 2012
Change in elevation (m OD)

Change in elevation (m OD)	
<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix E - Figure 6
Topographic Difference
Scarborough South
Scarborough Borough Council

Analytical Report 5
Short-term Change Survey
Autum 2011 - Autumn 2012

Halcrow
A CH2M HILL COMPANY

Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk

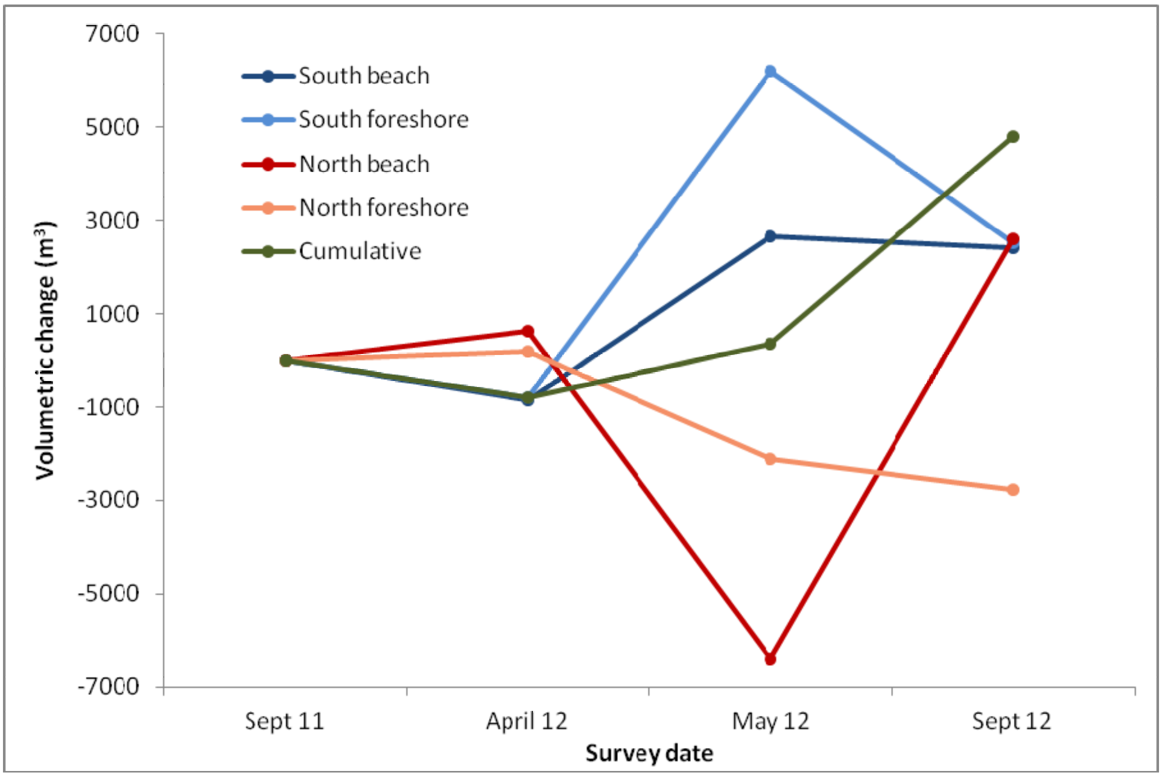


Figure 7. Volumetric change data for Scarborough South Bay calculated from analysis of beach topographic surveys.

Table 1. Beach volume change data calculated by ArcGIS.

	Site: South Beach			Site: South foreshore			Total South
Survey date	Volume above - 1.6 m OD m^3	Change m^3	Change %	Volume above - 1.6 m OD	Change m^3	Change %	Total volume change m^3
Sep-11	49935	0	0	160311	0	0	N/A
Apr-12	49079	-856	-1.74	159525	-786	-0.49	-1642
May-12	51737	2658	5.14	165736	6211	3.75	8869
Sep-12	54149	2412	4.45	168266	2530	1.5	4942

	Site: North beach			Site: North foreshore			Total North
Survey date	Volume above - 1.6 m OD m^3	Change m^3	Change %	Volume above - 1.6 m OD	Change m^3	Change %	Total volume change m^3
Sep-11	60989	0	0	80710	0	0	N/A
Apr-12	61629	640	1.04	80902	192	0.24	832
May-12	55223	-6406	-11.6	78797	-2105	-2.67	-8511
Sep-12	57834	2611	4.51	76034	-2763	-3.63	-152

	Whole site		
Survey date	Volume above - 1.6 m OD m^3	Change m^3	Change %
Sep-11	351945	0	0
Apr-12	351135	-810	-0.23
May-12	351493	358	0.1
Sep-12	356283	4790	1.34

Table 2. Beach volume change calculated by SANDS.

Cross Sectional Area Analysis Scarborough South Bay: Volume Changes Above the Master Profile							
Changes Between Locations		**27-03-2012 to 20-04-2012**		**20-04-2012 to 08-05-2012**		**08-05-2012 to 18-09-2012**	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
1dSBS1	1dSBS2	164.0	0.2	-3152.2	-3.2	682.9	0.7
1dSBS2	1dSBS3	702.7	0.9	4444.5	5.8	-700.1	-0.9
1dSBS3	1dSBS4	325.2	0.6	4051.4	7.2	-549.2	-0.9
Total		1191.9		5343.7		-566.5	