Ongoing Analysis and Interpretation of Coastal Monitoring Data

Initial Review of Restricted Suite Monitoring

Geotechnical Interpretative Report

October 2009

Document Ref. No. 721229/002/GIR/003/Final

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Document Control Sheet

Project Title	Ongoing Analysis and Interpretation of Coastal Monitoring Data
Report Title	Initial Review of Restricted Suite Monitoring. Geotechnical Interpretative Report
Report Reference	721229/002/GIR/003/Final
Version	B
Issue Date	October 2009

Record of Issue

Version	Status	Author + Date	Check + Date	Authorised + Date
A	Draft	P. Robinson	Dr. J Maund	Dr. J Maund
B	Final	P. Robinson 12/10/09	Dr. J Maund L. Frances 12/10/09	Dr. J Maund

Distribution

Organisation	Contact	Format	Copies
Scarborough Borough Council	Mr R Siddle	Hard copy + CD	1
Mouchel Ltd	Dr. J Maund	Electronic	1
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EXECUTIVE SUMMARY

In October 2008, Mouchel were instructed by SBC to provide services relating to an Analysis and Interpretation of Coastal Monitoring Data from sites (Runswick Bay, Whitby, Scalby Ness, Scarborough North and South Bay, Knipe Point, Killerby, Filey Town & Brigg and Filey Flat Cliffs) along the North Yorkshire coastline. Mouchel were required to review, analyse and interpret existing data, provided in electronic and hardcopy format, held by SBC for all the sites mentioned above. This data covered previous plans, monitoring records, strategies, ground investigations, borehole records, groundwater information, laboratory test data and geomorphological mapping.

The findings of this analysis and interpretation were presented in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL"*, March 2009. This report detailed a definition and understanding of the problems at each site based upon the existing data, identified current and potential risks associated with ground movements at each site, a series of early warning signs and trigger levels which need to be related to the findings of the ongoing monitoring regime, a series of appropriate response actions in relation to the findings of the above monitoring and recommended frequencies for the ongoing monitoring at each site related to the findings of the above monitoring.

The ongoing analyses are to be undertaken in accordance with the recommendations of monitoring frequency detailed in Mouchel Report No. *721228/001/GR/01/02/FINAL.* Site specific monitoring regimes have been planned to take place at intervals of one, two, three and six months starting from July 2009. As some of the monitoring events for particular sites coincide throughout the three years period, they have been grouped together to be undertaken as 'Full' and 'Restricted' Suites. Table 1 details the frequency of Full and Restricted Suite monitoring to be carried out over this period.

This report presents the data recorded during the **First Restricted Suite** of monitoring event detailed below. This was undertaken during late August and early September 2009 and follows the Initial Full Suite of monitoring (July 2009).

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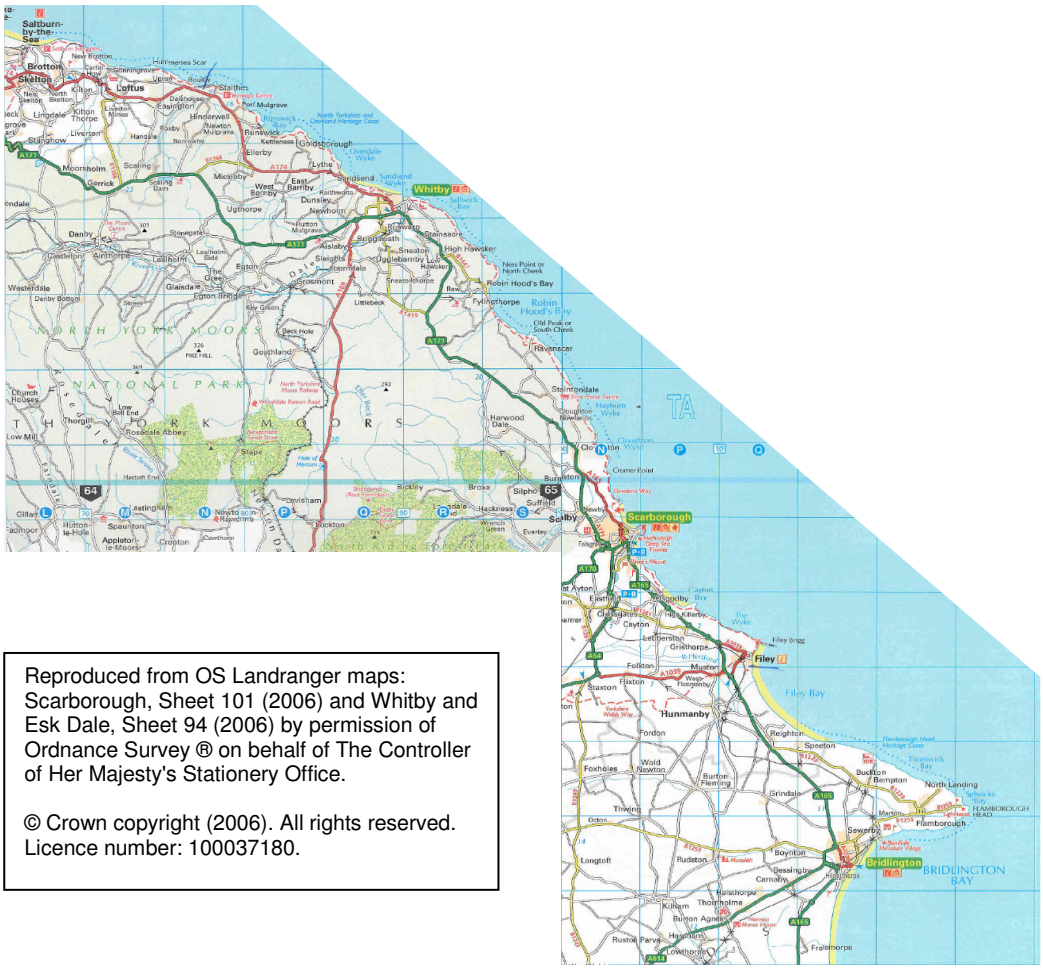
1 Introduction

1.1 Description of the Project

The extent of the monitoring area (Figure 1) considered for the ongoing analysis is along the full length of Scarborough Borough Council's coastline from Staithes to Speeton. Through the Shoreline Management Plan 2007 (SMP2) and Coastal Strategy process, several sites within the borough have been identified and are either subject to an on-going monitoring regime or have been monitored in the past.

Figure 1 Scheme Location



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The ongoing analyses undertaken in accordance with previously detailed recommendations of monitoring frequency were begun in July 2009. As some of the monitoring events for particular sites coincide throughout the three years period, they have been grouped together to be undertaken as 'Full' and

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'Restricted' Suites. Table 1 details the frequency of Full and Restricted Suite monitoring to be carried out over this period.

Table 1 Frequency of Ongoing Monitoring

YEAR	MONTH	SCOPE of MONITORING
ONE (2009)	July (1)	Full Suite
	Aug, Sept, Oct, Nov (2,3,4,5)	Restricted Suite
	Dec (6)	Full Suite
	Feb, Apr (8,10)	Restricted Suite
	June (12)	Full Suite
TWO (2010)	Dec (6)	Full Suite
	June (12)	Full Suite
THREE (2011)	Dec (6)	Full Suite
	June (12)	Full Suite

The Restricted Suite of ongoing analysis incorporates sites at:

Whitby West Cliff - Monthly intervals for six months then every two months until month twelve, reverting to bi-annual intervals for remaining two years if no significant movement detected. Install a single line of survey pins down slope at 5 metre intervals in line with BH2 and monitor these at monthly intervals for six months then reverting to bi-annual intervals for remaining two and a half years if no significant movement detected.

Scarborough North Bay - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

Scarborough South Cliff - Monthly intervals for six months then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected. Install a line of survey pins down slope at 5 metre intervals in line with H4, E3 and BH2 and monitor in line with instrumentation.

Filey Flat Cliffs - Monthly intervals for six months and then every two months until month twelve. Revert to bi-annual intervals for the remaining two years if no significant movement detected.

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SBC instructed Mouchel that the site at Knipe Point and recession point sites along with that at Killerby have been removed from our remit until further notice and are not under consideration for this analysis at the time of writing this report. The monitoring of instrumentation installed at Knipe Point is currently being undertaken by a third party on behalf of The National Trust. As of 28th August 2009, a number of instruments at Oasis Café, North Bay were included within the site's monitoring regime.

Following a monitoring event, the Arcview GIS layer is up-dated with the information (inclinometer and piezometer readings and survey data) retrieved from each of these events.

Site location plans are presented as Figures 2 to 6 within the relevant chapters and exploratory holes location plans, illustrating the locations of instrumentation, are presented in Appendix A.

1.2 Installation Monitoring Procedures

1.2.1 Inclinometers

The initial monitoring event for the Ongoing Monitoring Regime was begun during early July 2009 by a suitably qualified geotechnical engineer. Inclinometer instruments were initially investigated using a test probe (dummy) inclinometer on a 100 metre length cord. The test probe was lowered to the base of the tubing to prove its integrity. Where the instrument did not reach the base, due to a blockage or loss of tubing integrity, this depth was recorded and no further inclinometer data was recorded. Groundwater within the instrument tubing was measured and recorded using a dip meter.

Although some inclinometer instruments are not monitored due to various failures / blockages within the installed tubing, these instruments are still being read with a dip meter to provide an indication of groundwater levels.

Where the instrument tubing was proved to be intact, a Vertical Digital Inclinometer probe (using a Bluetooth system (MkII) with a TDS Recon 200 PDA) was lowered to the base of the tubing, allow the probe to temperature stabilise and measurements were recorded at half metre intervals as the probe is raised.

Readings of inclination were recorded in two directions (A0 and A180) within the inclinometer tube; A0 being the principal direction of interest in ground movements and A180 is in the opposite direction to this. B0 and B180 readings are also recorded automatically, B0 represents +90 degrees to the A0 direction and B180 is +90 degrees to A180 direction. The 'B' directions are not read manually as biaxial accelerometers read both B axes during the survey.

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Successive sets of readings are compared to the initial 'Baseline' readings to provide an indication of ground movements. The follow-up readings consist of recording a single set of readings in the A0 and A180 direction for each individual inclinometer instrument.

1.2.2 Piezometers and Slip Indicators

Groundwater levels within piezometer tubes have been recorded using a dip meter. A comparison of the known installed instrument depth with the dipped depth gives an indication as to whether the tubing is clear to its base or is blocked / impeded at that depth.

Where slip indicators are present, they consist of one metre length mandrels resting at the base of piezometer tubes attached to a chord at ground level. The mandrels are lifted from base to top of the tube to indicate if any distortion or blockages have occurred within the tubing. Where mandrels were found to be jammed within the tubes, a reading was taken from ground level to the top of the mandrel to give an indication of the depth at which possible failure of the ground had taken place. Where this had occurred, the installation ceases to be of use since it has served its purpose in demonstrating failure or movement of the ground. Other installations continue to be read as the inserted mandrels function free of any obstacles. Hence, these instruments continue to demonstrate that no discernible ground movements are occurring.

Groundwater level readings recorded from inclinometer instruments should be viewed and interpreted with care. This type of installation is used for the monitoring of sub-surface ground movements and not groundwater monitoring. However, in conjunction with the correct instrumentation (piezometers), readings extracted from inclinometers can provide extra information on the nature of the prevailing groundwater regime at a site under observation.

1.3 Interpretation Views

1.3.1 Cumulative displacement

The most commonly used plot type is the Cumulative Displacement plot, which shows a displacement profile of a borehole. The plot shows the change in the position of the casing since the initial set of readings. If a user error has occurred during reading, the error will be accumulated through successive readings. If this is suspected, or anomalies occur, the data can be examined using the Incremental Displacement function.

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1.3.2 Incremental Displacement

Another form of data presentation is the Incremental Displacement plot. This shows displacement over each probe length during the period since the initial reading sets. Unlike the Cumulative Displacement plot, operator error or instrument malfunction do not accumulate, as the data are plotted from reading to reading (i.e. delta previous not delta datum).

1.3.3 Absolute Position

This type of plot shows the absolute position of the casing and will determine the verticality of the installation. It does not pick up movement, but can be used for assessing installation error.

1.4 Rainfall Data

Rainfall data records have been made available to Mouchel by SBC and the Environment Agency. Data supplied is referenced to stations throughout the region in particular at Loftus, Fylingdales, Whitby School, Scarborough, Mulgrave Castle, Ruswarp and Knipe Point. Within Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL,* reference was made to 'periods of heavy and / or prolonged rainfall' in terms of considering such an event with respect to their effects upon slope stability.

This subject has been refined through analysis of rainfall data records made available by the Environment Agency and SBC and the definition of such an event has been quantified within the context of the effects of such an event on the present monitoring regime frequency. The analysis and definition of this subject is to be presented in a separate report entitled 'Definition of Heavy and / or Prolonged Rainfall Events – 721229/004/GIR/001/Final'.

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2 Whitby West Cliff

2.1 Site Location and Description

Whitby is located on the north east coast of England approximately 30 miles south of the industrial town of Middlesbrough and 20 miles north of Scarborough. West Cliff is part of a long stretch of exposed cliffs running west-east forming protected soft, glacial till cliffs to the west of Whitby harbour and, further west towards Sandsend the coastline is formed of unprotected soft, glacial till cliffs.

The West Cliff site is bounded by The Spa complex to the east and the Cliff Lift towards the west. The natural slope morphology of the protected cliffs has been modified by several phases of slope stabilisation works which included drainage and slope re-profiling that has been undertaken since the 1960's. The slopes attain a height of up to 40-45 metres at slope angles of 25 to 35 degrees. Set back approximately 10 metres from the crest of the slopes is a main road (North Terrace) and beyond this are large terraced, residential and commercial properties. The faces of the slopes are criss-crossed by pedestrian footpaths which give public access from the top of the cliffs to the beach below. Other features present over the slopes are low retaining walls, gabion walls and relict slip failure scars. At the base of the slopes is a sea wall with a promenade, forming a sea defence, with a wide sandy beach foreshore.

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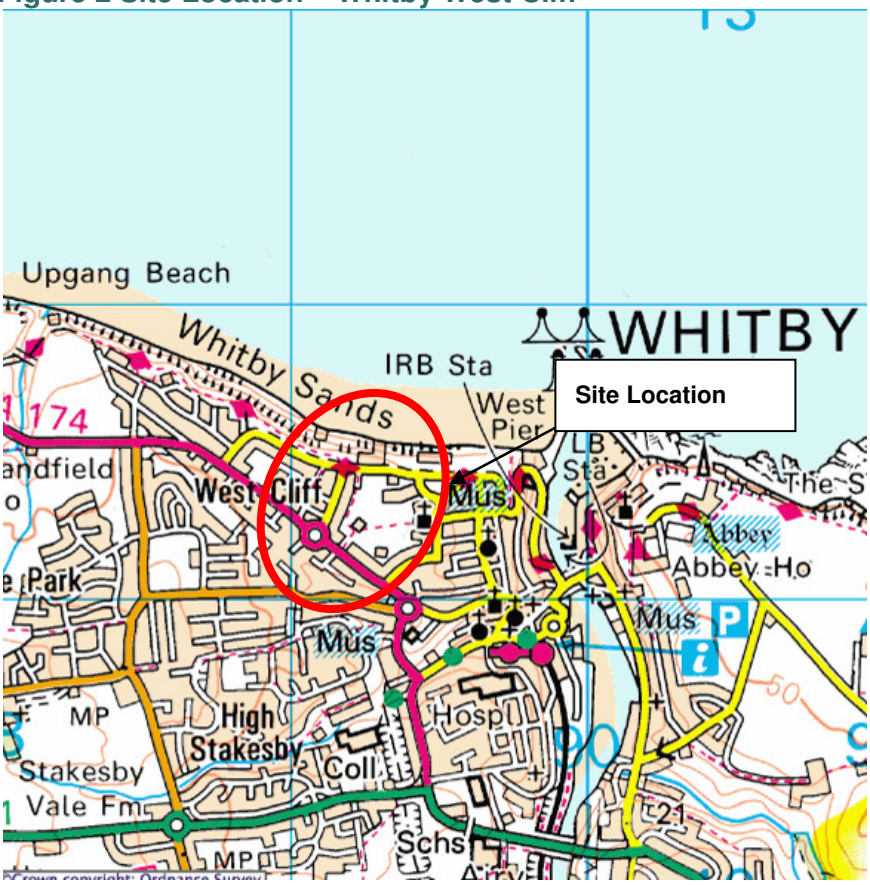
Figure 2 Site Location – Whitby West Cliff



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2.1.1 *Historic Review of Problems*

There is evidence of small scale failures along much of the coastal section being investigated, both in the past and at present. The first sections of coastal defences along this stretch of coast were constructed in the 1930's. These defences comprised vertical concrete and masonry seawalls with a promenade, slipways and access ramps to the beach, possibly founded on glacial till materials. Slope stabilisation measures involving slope re-profiling, placement of gabion baskets and drainage improvements have been undertaken over the coastal slopes of West Cliffs in an attempt to reduce the probability of slope instability occurrences since the late 1960's.

2.1.2 *Existing Information*

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp33-34.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. This data has been placed on an Arcview GIS layer for ease of use and availability.

2.2 Stratigraphy

The 1:50,000 British Geological Survey (BGS) Sheet 35 Solid & Drift, Whitby indicates the site to be underlain by glacial till of Devensian (Quaternary) age. The glacial till is typically comprised of over-consolidated, red-brown sandy silty clays with lenses and discontinuous beds of sands and sandy silts. Within the protected cliffs along West Cliff, there is a persistent mid-slope exposure of fluvio-glacial sand and gravels up to 5 metres in thickness. The underlying solid geology is indicated as the Middle Jurassic Scalby Formation, consisting of limestone, sandstone and mudstone.

2.3 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by soils of intermediate class 1. Soils of class I1 are those possibly able to transmit a wide range of pollutants. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

2.4 Instrumentation

2.4.1 Definition of Existing Problems

The West Cliff area has been modified by slope stabilisation measures which included the re-grading of slopes and the installation of drainage, carried out during the 1960's and 1970's. These remedial works are now showing signs of distress and appear to be near the end of their design life-cycle. During a site walkover there was evidence of slope instability with visible back scars on the slopes and cracks present in the footpaths; drainage problems were also evident as seepages emanating from retaining walls. However, it is not known whether the seepages were from slope drainage or burst water pipes.

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The existing problems on site relate to the instability of the glacial till slopes of West Cliff site which have been the subject of modifications by remedial works over a period of seventy years. The slopes are susceptible to shallow failures of varying size and extent, being 1 to 2 metres in depth and up to 5 metres in extent. Their size has often been determined by the spacing of vertical drainage. Without remedial measures, small and medium sized slope failures can develop into more serious deep-seated failures which may cause substantial damage and cliff top recession leading to the loss of amenities and possible danger to the public.

2.5 Monitoring Regime

2.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

The recommendations for Whitby West Cliff were that a regime of regular monitoring and inspection should be undertaken at monthly intervals for six months then reverting to bi-annual intervals for the remaining two and a half years if no significant movement is detected.

A line of survey pins was installed at 5 metre intervals down the line of the slope from beyond the crest and in line with the existing inclinometer (BH2). The survey stations are being measured at a monthly frequency for six months to build up base data. If there is no significant movement (<5 mm) between each survey point, (between each monitoring event) then the frequency will be reduced to that in line with the inclinometer monitoring i.e. on a bi-annual frequency.

2.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 2.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring consists of a single inclinometer (B001 / BH2) located within a path near the base of the coastal slope of West Cliff and the monitoring of surveying points. Groundwater was measured using a dip meter.

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2.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.3 of this report and are presented in Appendix B of this report. Readings have so far proved to be inconclusive in terms of illustrating any ground movements.

Groundwater Readings

Groundwater levels were recorded during the Initial Full Suite Survey (9th July 2009) and the initial Restricted Suite set of readings from the Ongoing monitoring (25th August 2009). The two sets of readings show a fluctuation of +900mm occurring between the two dates, representing a change in tidal levels. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

Survey Point Readings

A single line of survey pins was set out from the slope crest down slope to borehole BH2 in order to supplement the monitoring of slope movements at this location. The pins were surveyed in July and August and showed that over a distance of 49metres, 4mm of surface movement had occurred during that period.

2.6 Conclusions

Monitoring data from the inclinometer and survey points has proved to be inconclusive in terms of illustrating any ground movements. A slight deviation is evident in the second set of inclinometer readings though this is more likely to be due to temperature variations and due to using two different probes for the readings.

Groundwater levels within BH2 are influenced by the changing tidal regime and seem to reflect this.

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3 Scalby Ness

3.1 Site Location and Description

Scalby Ness forms a broad promontory to the north of Scarborough North Bay, approximately 3 km north of Scarborough. The headland is incised by Scalby Beck which acts as an overflow from the River Derwent when in flood. The beck flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly at Scalby Ness and outfalls to the sea between Scalby Ness headland and the Sea Life Centre.

A housing development was constructed during the 1970's and 1980's on land forming a plateau approximately 25-30 m above the beck at Scalby Ness. Over-steepened glacial till cliffs are present on the north west and north east sides of the development, falling down towards the beck. The beck contributes to toe erosion of these slopes and is a contributing factor of the mechanism of slope instability. Scalby Mills Road bounds the southern edge of the north east slopes. This road was constructed to give access to the Sea Life Centre on the coast. Part of the works involved re-profiling slopes with toe protection offered by rock outcrops at Scalby Beck and emplaced toe protection around the Sea Life Centre.

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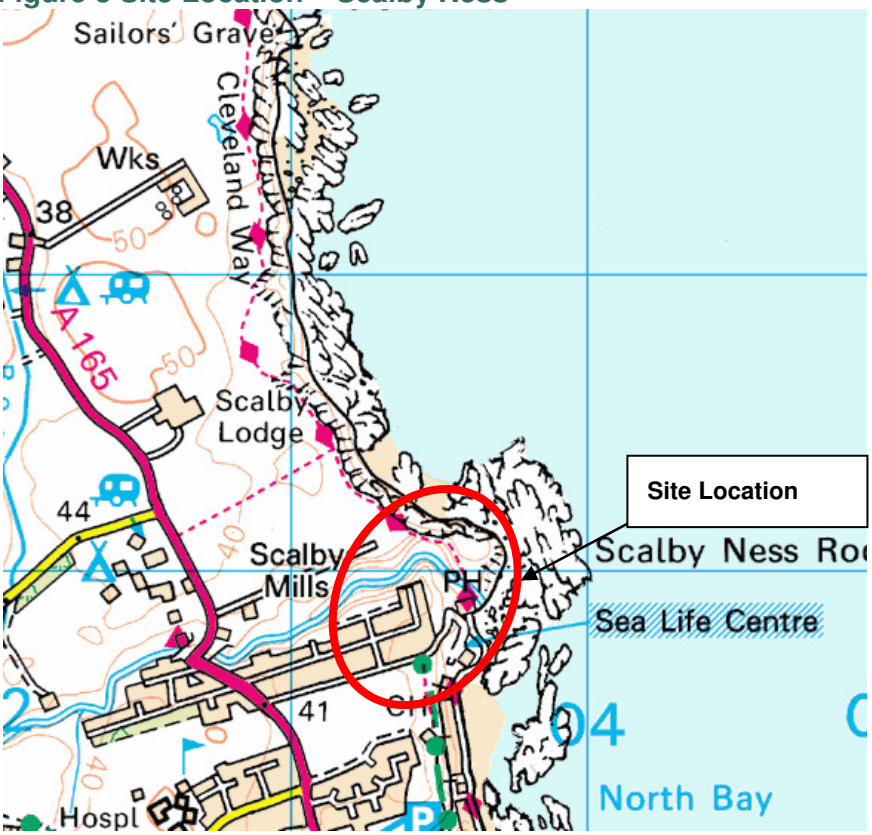
Figure 3 Site Location – Scalby Ness



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3.1.1 Historic Review of Problems

A review of the available data detailed in Section 5.1.4 covers previous ground investigations and interpretative report work on the site of Scalby Ness. An interpretation of the over-riding mechanisms acting upon the slopes has identified three landslide behavioural units.

- Behavioural Unit I (North west slopes) – Intermittently active non-circular failure within the glacial till unit, characterised by over-steepened slopes which have been subjected to shallow translational movements accompanied by localised mudslide / debris flows. The head scarp (crest) is undergoing periodic movement giving rise to blocky detachment with cracks forming in mid-slope. Active erosion at the toe is leading to unloading of the slope with a reduction of support for material above.

- Behavioural Unit II (North east slopes, northern part) – This is an episodically active unit characterised by an over-steep head scarp with cracking and shallow surface movements. A mid-slope deep seated, back-tilted block is present across the unit. The location and morphology of this block suggest that it is part of a large, ancient deep-seated translational or rotational landslide. Localised active toe unloading is present within parts of the lower slopes which are also characterised by ponding surface water, tension cracks and hummocky ground. Active toe erosion is taking place by the tidally influenced beck.

- Behavioural Unit III (North east slopes, southern part) – The slopes have been re-profiled during earthworks as part of construction works for the access road into the Sea Life Centre and car park. These slopes show no signs of instability and are currently considered to be stable.

3.1.2 Topography and Geomorphology

The site of Scalby Ness consists of a row of houses (Scholes Park Road) built during the 1970's -1980's and bounded by glacial till slopes, up to 30 metres in height, to the north west and north east. The headland is incised by Scalby Beck which flows in an east-north easterly direction through Scalby, where at Scalby Mills it changes direction sharply through 90 degrees to flow south easterly to the sea.

The north west facing slopes are composed of a 1 metre high vertical face at the crest of the slope. The slope angle decreases below this feature before steepening from the centre of the slope to the base where the slope angles again become shallow at the beck.

The north east facing slopes consist of a deep embayment in glacial till with a back scar and a mid-slope reverse slope bench below this. The slopes steepen below the reverse slope bench suggesting that this is the upper surface of a large back-tilted block. Below this and down to the beck, slope angles vary from 12 to 29 degrees.

3.1.3 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, p50.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

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3.2 Stratigraphy

The 1:50,000 British Geological Survey (BGS) Sheets 35 and 44 Solid & Drift, Whitby and Scalby, indicates that the site is underlain by superficial deposits of glacial till of Quaternary age. The underlying solid geology is indicated as the Long Nab Member of the Scalby Formation (Middle Jurassic) characterised by interbedded mudstones, siltstones and sandstones.

3.3 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the northern area of Scalby Ness as a Minor Aquifer, overlain by soils of low leaching potential. Soils of class L are those in which pollutants are unlikely to penetrate the soil layer because either water movement is largely horizontal or because they have the ability to attenuate diffuse pollutants. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

The southern part of Scalby Ness is classified as a Minor Aquifer, overlain by class HU soils. Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential.

3.4 Instrumentation

3.4.1 Definition of Existing Problems

It has been that there is a risk of slope failure on the north west and north east slopes (in Behavioural Unit I and II) of Scalby Ness if groundwater levels were to rise significantly following periods of prolonged heavy rainfall. The presence of more permeable layers of sand and gravel within the glacial tills could lead to localised failures and the possibility of this could be increased if these layers are prevented from draining freely due to slipped soils from above.

The main threat to slope instability and the assets located above results from coastal erosion of the toe and crest erosion from surface water flowing down the slopes.

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Behavioural Unit III is considered to be in a stable state since undergoing re-profiling and re-grading works as part of earthworks for the access road to the Sea Life Centre.

3.5 Monitoring Regime

3.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

The recommendations for Scalby Ness were that a regime of regular monitoring and inspection be undertaken at three monthly intervals. Monitoring is to be carried out over a period of three years to retrieve long term data for analysis in order to determine any seasonal patterns of rainfall, ground water levels and ground movements. In addition to this, survey pins set out at four locations on the upper plateau area are to be monitored at monthly intervals for six months and then bi-annually for the remaining two and a half years.

3.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 3.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring at Scalby consists of 3no. inclinometers (I1, I2 and I3) and 2no. piezometers (B6 and B9) located within the inner headland of Scalby Ness. The monitoring of automated piezometers (P1, P2, P3 and P4) is to begin presently. The inclinometers were monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) with a TDS Recon 200 PDA and piezometers were monitored using a dip meter.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report.* This detailed 6no. piezometers recommended for replacement due to differences in dipped and installed depths and, an inclinometer (Sn1) and a piezometer (BH114) as not being located due to dense vegetation and hence not available to monitor. Following vegetation clearance and location, these instruments are to be brought into the monitoring regime.

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3.5.3 Monitoring Results

Survey Readings

Survey pins were set out at four locations on the upper plateau area around the existing houses, some distance from the slope crest. Measurements are taken, in the same direction at each event, from these points to the slope edge in order to monitor cliff recession rates and slope movements at these locations. Initial readings are presented in Appendix D.

3.6 Conclusions

The survey pins were measured in July and August, a comparison of measurements taken from three stations (MP1, MP2 and MP4) showed zero cliff recession rates over this period. However, over the same period, a cliff recession rate of 10mm was recorded at MP3.

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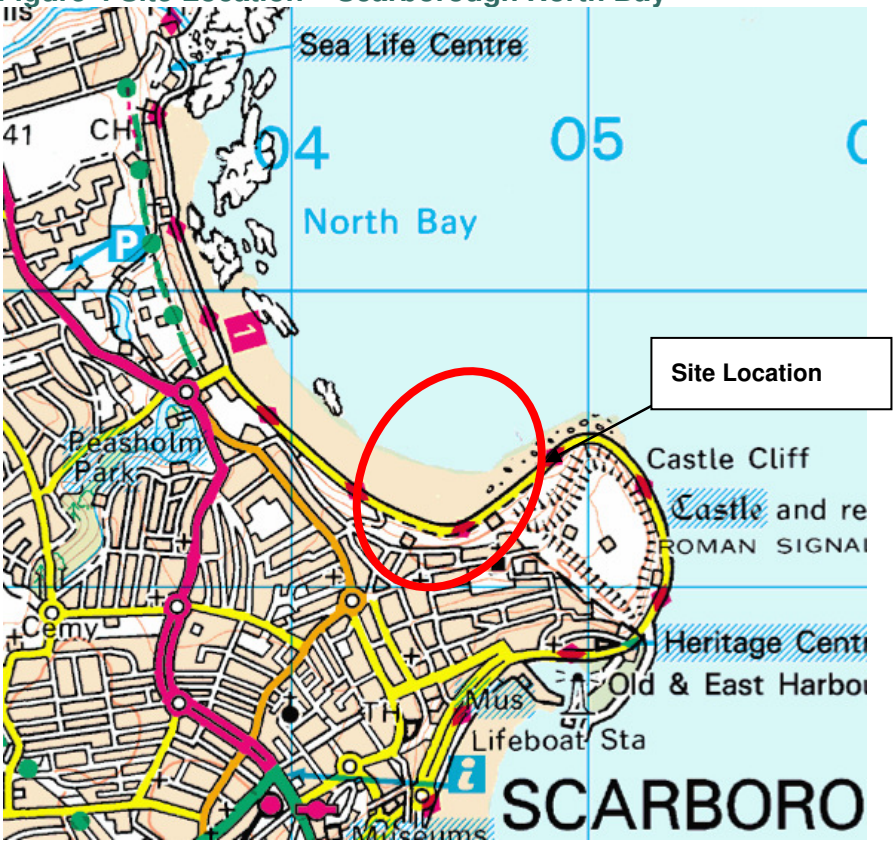
4 Scarborough North Bay

4.1 Site Location and Description

North Bay is one of two bays either side of a headland around which the town of Scarborough has developed on the north east coast of Yorkshire. North Bay extends from Castle Cliff northwards to Scalby Ness. The site is known as The Holms, an area of sloping, open parkland between the Castle above and Royal Albert Drive (Marine Drive) along the coast. The parkland consists of open grassed areas with groups of semi-mature trees and shrubs and, meandering tarmac footpaths which increase in steepness from the sea front leading up to the south western flanks of Castle Headland. Discrete rock outcrops are clearly visible across the slopes.

Figure 4 Site Location – Scarborough North Bay



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4.1.1 Historic Review of Problems

In 2000, a 200mm displacement of the seawall was monitored. These movements were caused by the widespread reactivation of a deep-seated, pre-

existing landslide system at The Holms. Although this caused extensive damage to footpaths and cracking of the seawall, movements were relatively minor, with ground displacements of the main landslide body probably in the order of 10's of centimetres. Following this event, a programme of Preventative Emergency Works was undertaken in 2000-2001. This pre-empted the main works of improvement and reconstruction of the seawall defences under the Coastal Protection Scheme.

The underlying landslide system comprises 10 to 17metres of landslide debris overlying intact Scalby Formation of inter-bedded sandstone, siltstone and mudstone. Two units have been identified from ground investigations carried out in 2000.

- An eastern unit, comprising of a deep-seated landslide which 'daylights' close to foreshore level.

A western unit, composed of a shallower landslide which 'daylights' approximately 1.50m above Marine Drive.

4.1.2 Topography and Geomorphology

The Holms is an area of public open space laid over to informal gardens with a network of tarmac footpaths which provide access from the sea front to the Castle Headland above. The slopes are heavily terraced, displaying hummocky, irregular ground comprising glacial till and possible landslide debris with a mid-slope bench feature dominating the slopes. The glacial slopes rise from Marine Drive, at approximately 7.0mAOD, at angles of 20-35 degrees to a mid-slope bench and terrace at 35.0mAOD, beyond this plateau the slopes composed of rock debris and scree rise to approximately 50 to 55.0mAOD to near shear cliff faces. These cliff faces rise to the pinnacle (83.31mAOD) of Castle Hill on which the remains of Scarborough Castle are apparent. A thin mantle of top soil, up to 0.17m thick directly overlying bedrock, is present in the mid-slope plateau of the site where glacial till is absent. Glacial till is present over the remainder of the site varying in thickness between 16.0m in the west section and 2.50m-2.95m in the eastern section. Outcrops of the Cornbrash Limestone Formation are prominent on the lower and middle slopes of The Holms.

4.1.3 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp67-68.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

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4.2 Stratigraphy

The 1:50,000 British Geological Survey (BGS) Sheets 35 and 44 Solid & Drift, Whitby and Scalby, indicate that the northeast of the site is underlain by superficial deposits of glacial till of Quaternary age. This directly overlies Scalby Formation deposits of mudstones and sandstones. A north west –south east trending fault and a north – south trending fault gives rise to glacial tills underlying Oxford Clay, which in turn overlies the Hackness Rock Member sandstones of the Osgodby Formation. The Scalby Formation sandstones and mudstones are unconformably overlain by the Cornbrash limestones and the Osgodby Formation. The strata generally dip at an angle of 7 degrees in a south easterly direction.

4.3 Groundwater Regime

Hydrology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by class HU soils. Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

4.4 Instrumentation

4.4.1 Definition of Existing Problems

Widespread reactivation of a deep-seated landslide system at The Holms occurred during 2000. This caused extensive damage to footpaths and cracking of the seawall. Ground displacements of the main landslide body were in the region of 10's of centimetres although monitoring of the seawall revealed movements of 200mm had occurred.

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4.5 Monitoring Regime

4.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

Due to the lack of valid continuous data from the installed piezometers, it has been recommended that piezometer monitoring is reinstated. Inclinometer and piezometer monitoring is to be carried out at monthly intervals for six months then every two months until month twelve. If no significant movement is revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for the remaining two years.

4.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 4.5.1, above. Taking the findings of the *Condition Survey Report* into account, monitoring consists of 3 no. piezometers (L1, L3 and L5) located within the grounds of The Holms and 2 no. inclinometers (L11 and L12) located atop the cliffs above The Holms. Following vegetation clearance inclinometers L4 and L6 are to be brought into the monitoring regime.

A number of additional installations comprising 3 No. inclinometers and 4 No. piezometers located on slopes above The Oasis Café, North Bay were added to the monitoring regime in August 2009. The instruments are to be read in line with the existing monitoring regime.

4.5.3 Monitoring Results

Inclinometer Readings

'Baseline' inclinometer readings have been undertaken on BH1I and BH4I at the site. BH3I was not monitored on this visit due to poor installation leading to the stop cock cover not operable.

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Groundwater Readings

Groundwater levels were recorded during the Initial Full Suite Survey (9th July 2009) and the initial set of Ongoing monitoring (Restricted Suite) readings (25th August 2009). The two sets of readings show very little change, the largest difference being 5070mm recorded in L1(b) which illustrates changes in tidal levels. Within L11 a variance in groundwater of 4660mm was recorded over this same period. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

4.6 Conclusions

Inclinometer data presented in Appendix B show the initial 'baseline' reading traces for BH1I and BH4I. No further analysis of this data can be made at present.

At present, there does not seem to be an obvious reason for the wide fluctuation of groundwater levels within L11. The borehole location, geology and surrounding topography do not readily offer an explanation for the groundwater behaviour observed to-date. Further monitoring data may provide an answer to the nature of the groundwater regime at this location.

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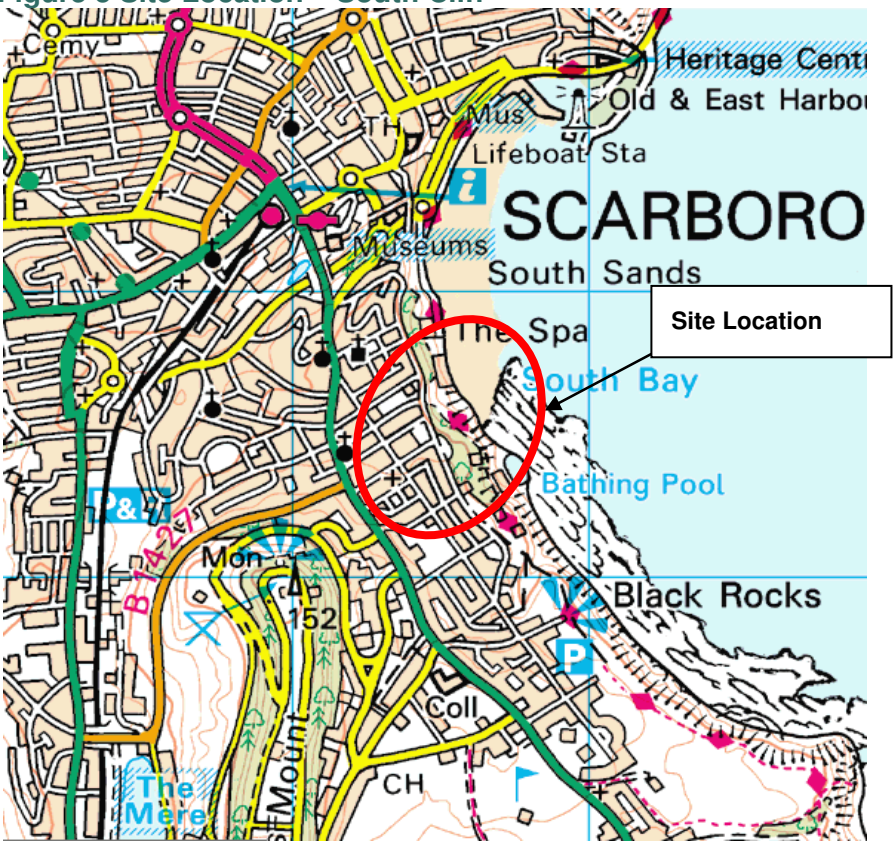
5 Scarborough South Cliff

5.1 Site Location and Description

Scarborough is a popular sea-side resort located on the north east coast of England. The South Cliff occupies the southern bay of Scarborough town with a gently sweeping coastline from the northern promontory of Castle Hill to the Black Rocks some 2km southwards. The South Cliff site comprises a variety of landscaped gardens stretching from north to south in the following order: Spa Chalet Cliff, Spa Cliff, Prince of Wales Cliff, South Cliff Gardens, Rose Gardens, South Bay Pool Cliff, Holbeck Gardens, Holbeck Cliff and Wheatcroft Cliff. The cliff top is a gently undulating plateau surface with a road, Esplanade Crescent, running parallel to the cliff line. Large houses and hotels line the landward side of the road, set-back generally 30metres, but up to 100metres in places, from the cliff edge.

Figure 5 Site Location – South Cliff



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5.1.1 Historic Review of Problems

The cliffs of Scarborough's south bay are formed from glacial till slopes of varying thickness, underlain by Jurassic sandstones and siltstones, which are prone to landsliding. All of the cliffs along this section have toe protection provided by seawall / coastal defences, but localised activity on the slopes and head scarps is common. At the Spa Cliffs, South Cliff Gardens and South Bay Pool the cliffs comprise steep rear scarps, forming arcuate embayments up to 200metres in width, with gentle sloping stepped slopes at the base. Geomorphological features such as the steep rear scarps and mid-slope benches, present at these gardens, possibly display the remnants of historic deep-seated retrogressive rotational failures within the glacial tills. At Holbeck Cliff, the 1993 landslide involved a complex series of retrogressive displacements which overwhelmed the seawall and extended 150metres across the foreshore.

The remaining sites present between those mentioned above consist of Spa Chalet Cliff, Prince of Wales Cliff, Rose Gardens, Holbeck Gardens and Wheatcroft Cliff. These sites represent intact coastal slopes which are subjected to localised small-scale shallow slope failures within the glacial tills due in part to increases in porewater pressures which lead to softening of and a decrease in shear strength of the tills. Such failures result in disrupted footpaths and minor damage to other structures and could be expected to occur on a yearly basis.

5.1.2 Topography and Geomorphology

Late Devensian age glacial tills have been emplaced across much of the landscape composed of Jurassic sedimentary rocks (predominantly sandstones and siltstones). These tills include stiff silty sandy clays, sands and gravels and, laminated silty clays. At South Cliff, the till has completely in-filled a pre-glacial valley and now the whole cliff profile has developed in these glacial tills attaining a height of between 50m and 65m. The glacial till slopes have been subjected to coastal protection measures, landscaping and drainage improvements since becoming the property of SBC in the late 19th century.

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The South Cliff is occupied by a series of terraced gardens developed into glacial till slopes of varying thickness underlain by Jurassic sandstones and siltstones. At the Spa Cliffs, South Cliff Gardens and South Bay Pool the cliffs comprise steep rear scarps, forming arcuate embayments up to 200metres in width, with gentle sloping stepped slopes at the base. At other areas of the garden complex the landscaped slopes attain angles of up to 40 degrees becoming steeper at the base and are criss-crossed by a network of footpaths, bench-cut into the slopes and supported by small walls and revetments. A concrete seawall and promenade has been built along the base of the cliffline from Spa Chalet Cliff to Holbeck Cliff where in the absence of a seawall, a rock armour revetment was constructed to replace the seawall destroyed in 1993 by a landslide. A variety of buildings occupy sites within South Cliff from the Spa Complex and Ocean Ballroom constructed at the base of Prince of Wales Cliff, a cliff railway operating from cliff top down slope to the Spa complex and, a swimming pool and a series of chalets at South Bay Pool Cliff.

5.1.3 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, pp80-81.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

5.2 Stratigraphy

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of Quaternary glacial till comprising stony clay, underlain by Oxford Clay of up to 36-76 metres in thickness. This overlies Osgodby Formation calcareous sandstones above undifferentiated strata of the Cayton Clay Formation and Cornbrash Formation consisting of limestones and mudstones. An unconformity separates this stratum from the underlying Scalby Formation mudstones and sandstones. The Scalby Formation is underlain by the Scarborough Formation limestones and mudstones, which outcrop as the Black Rocks of the South Bay foreshore.

5.3 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Minor Aquifer, overlain by class HU soils.

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Due to the less reliable nature of data collected in urban areas, the worst case scenario is assumed and soils are classified as having a high leaching potential. Minor Aquifers are variably permeable rocks, usually fractured rocks with a low primary permeability or unconsolidated deposits. They rarely produce large quantities of water for abstraction but often provide important base flow supplies to rivers. Major Aquifers may occur beneath Minor Aquifers.

5.4 Instrumentation

5.4.1 Definition of Existing Problems

Existing problems of slope failure along South Cliffs vary between and include both first-time shallow slip failures within the intact slopes and the reactivation of existing deep-seated rotational failures related to increased ground water pressures.

5.5 Monitoring Regime

5.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.*

The recommendations for South Cliff were that a regular monitoring and inspection regime should be undertaken at monthly intervals for a period of six months and then every two months until month twelve. If no significant movement was revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for a further two years.

5.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 5.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring consists of five inclinometers, fourteen piezometers and three lines of survey pins (associated with boreholes H4, E3 and BH2) located within the gardens of South Cliff.

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The reduced monitoring regime is based upon the findings of the *Condition Survey Report* and includes 5no. inclinometers (G2, F2, F4, D3, BH2) and 16 no. piezometers / slip indicators (!2A, H2, H1, H5, 1-5 Spa, G3, G1, E2, D2, BH3, BH4, BH1). Also, all inclinometers are monitored for groundwater levels. Inclinometer A1 was reported as not being located due to dense vegetation and hence not available to monitor. Following vegetation clearance this instrument is to be introduced into the monitoring regime.

5.5.3 Ongoing Monitoring Results

The monitoring regime, based upon the findings of the *Condition Survey Report,* detailed five inclinometers and fourteen piezometers to be in a serviceable condition and have been included in the monitoring regime.

Inclinometer Readings

Inclinometer readings have been undertaken in accordance with the procedures detailed in Section 1.3 of this report. Two sets of readings were recorded in the A0 and A180 directions in order to gain an accurate 'Baseline' reading from which all successive readings are referenced to. The 'Baseline' readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels were recorded during the Initial Full Suite Survey (15th July 2009) and the initial set of Ongoing monitoring (Restricted Suite) readings (25th August and September 2009). The two sets of readings show a wide variation in depth changes illustrating variations in tidal levels and groundwater regimes active across the sites of South Cliffs. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

Survey Point Readings

Three lines of survey pins were set out from the slope crest down slope to boreholes H4, E3 and BH2 in order to supplement the monitoring of slope movements at these locations. The pins were surveyed in July and August and showed that at H4 over a distance of 42 metres, no surface movement had occurred during that period, at E3 a total of 5mm of surface movement had occurred over 47.8 metres and, at BH2 over a distance of 25 metres 7mm ground movement had occurred.

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5.6 Conclusions

Monitoring data from the inclinometers and survey pins has generally proved to be inconclusive in terms of illustrating any ground movements. In the second set of inclinometer readings in AA04, a slight deviation of 4mm from 25 metres depth to ground level is evident though this is more likely to be due to temperature variations and the use of two different probes. However, in AA10 ground movements of 4mm from 3.5 metres to ground level are illustrated from the read-out. This movement has occurred in made ground and is probably evidence of surface creep. Further monitoring data may provide a more conclusive answer as to the nature of any suspected ground movements.

The results of groundwater monitoring have so far shown little variation over a months' period, although within three inclinometers there have been differences of 5.0m (H4), 3.55m (F2) and 4.56m (E3) recorded over this same period. These readings may be affected by tidal influences. Discounting the exceptional readings recorded in inclinometers, generally the groundwater monitoring results to-date reflect fluctuations in the prevailing groundwater regime within the various horizons in which piezometers have been installed.

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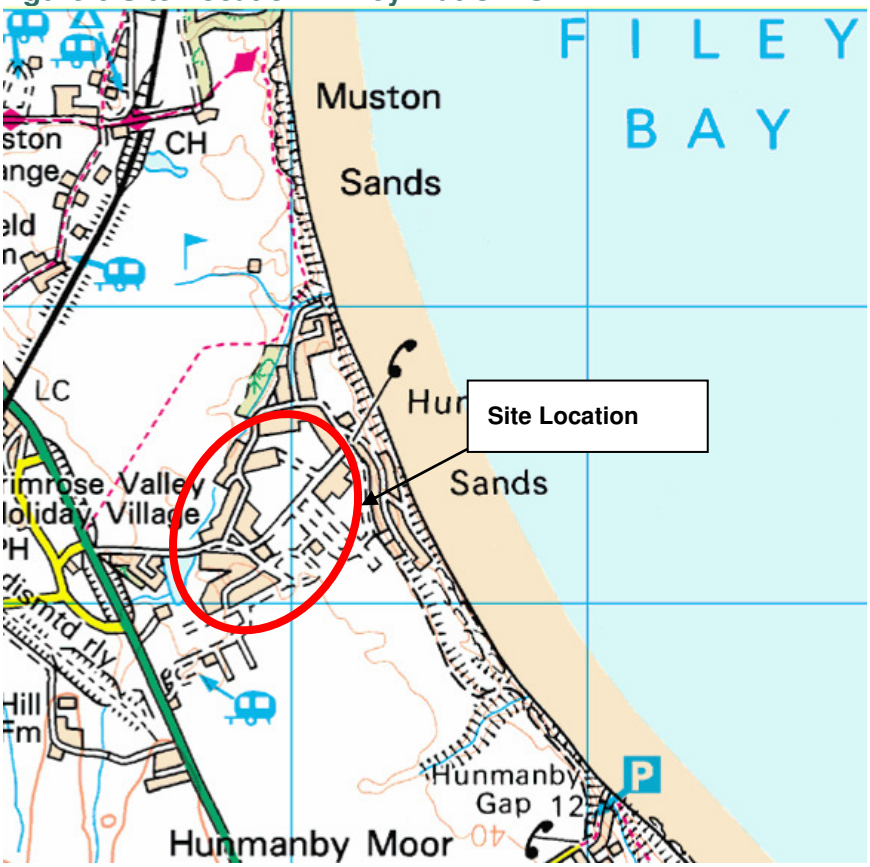
6 Filey Flat Cliffs

6.1 Site Location and Description

Filey Flat Cliffs is situated near Primrose Valley Holiday Park, 2 km south of Filey town centre on the north east coast of England. The site comprises steep unprotected coastal slopes of glacial till on which holiday homes and static caravans have been constructed with narrow tarmac access roads. The site is bounded to the north, west and south by the holiday park and to the east by the cliffs.

Figure 6 Site Location – Filey Flat Cliffs



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6.1.1 Historic Review of Problems

At Flat Cliffs there is evidence of active slope erosion, cliff-top recession and slope instability. Slope instability is particularly apparent at this site where an active landslip (rotational failures forming a benched slope profile) now threatens to breach the only vehicle access route into the area.

6.1.2 Topography and Geomorphology

The coastal cliffs are entirely composed of glacial till with solid rock formations dipping below sea level. The glacial till deposits comprise a highly variable mixture of clays, silts and, sands and gravels. They are easily eroded by wave action and are susceptible to groundwater effects and mass movements. Complex landslides are present at Flat Cliffs, large-scale, deep-seated failure of the glacial till cliffs has occurred. At the north end of Flat Cliffs, the surface morphology indicates rotational failure of the glacial till has occurred. At Flat Cliffs (south), large undercliffs have formed which appear from the surface morphology to be formed by translational failure of the glacial till slopes, possibly founded upon or within weathered bedrock at depth.

6.1.3 Existing Information

A number of reports were provided by SBC for consultation, these are detailed in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL, p117.* Additional reports were presented by SBC for further consultation for the Ongoing Analysis. All of this data has been placed on an Arcview GIS layer for ease of use and availability.

6.2 Stratigraphy

The 1:50,000 British Geological Survey (BGS) Sheet 54 Solid & Drift, Scarborough indicates that the site is underlain by superficial deposits of glacial till (Quaternary), overlying the Speeton Clay Formation. This formation overlies the Kimmeridge Clay Formation.

6.3 Groundwater Regime

Hydrogeology

The Groundwater Vulnerability Map (Sheet 9) of North East Yorkshire has classified the area as a Non-Aquifer because of their negligible permeability. These formations are generally regarded as containing insignificant quantities of groundwater. However, groundwater flow through such soils, although imperceptible, does take place and needs to be considered in assessing the risk associated with persistent pollutants. Some Non-Aquifers can yield water in sufficient quantities for domestic use. Major and Minor Aquifers may occur beneath Non-Aquifers.

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6.4 Instrumentation

6.4.1 Definition of Existing Problems

The presence of confined granular strata within the glacial till slopes may result in excess groundwater pressures to develop resulting in the collapse and recession of the head scarp and cliff crest.

6.5 Monitoring Regime

6.5.1 Recommended Monitoring Regime

As a consequence of the analysis and interpretation of monitoring data and reports made available by SBC, a regime of future monitoring was formulated. These recommendations have been reported in Mouchel Report "*Analysis and Interpretation of Coastal Monitoring Data" 721228/001/GR/01/02/FINAL.* The recommendations for Flat Cliffs were that a regular monitoring and inspection regime should be undertaken at monthly intervals for a period of six months and then every two months until month twelve. If no significant movement was revealed during this twelve month period then monitoring should revert to six monthly intervals (bi-annually) for a further two years.

6.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 6.5.1, above. Following on from the findings of the *Condition Survey Report*, monitoring consists of a single inclinometer (BB02/A2) located on the landside of the main access road down through Flat Cliffs and 3 no. piezometers (A3, B1 and D1), one located within Flat Cliffs and the remainder located above the village beyond the cliff crest.

6.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometer readings for BB02 (A2) have been undertaken in accordance with the procedures detailed in Section 1.3 of this report and are presented in Appendix B of this report.

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Groundwater Readings

Groundwater levels were recorded during the Initial Full Suite Survey (8th July 2009) and the initial set of Ongoing monitoring (Restricted Suite) readings (25th August 2009). The two sets of readings showed variations in groundwater levels within boreholes of -170mm BB02 (A2), -230mm (D1), 100mm (A3) and 30mm (B1). Borehole BB01 (D2) was recorded as dry on each occasion. Groundwater readings are presented in Appendix C, *Groundwater Monitoring Data*.

6.6 Conclusions

Monitoring data from the inclinometer has proved to be inconclusive in providing evidence of any ground movements. A very slight deviation (<1mm) is apparent in the second set of inclinometer readings though this is likely to be due to temperature variations and the use of two different probes for the readings.

Groundwater levels at this site indicate the variations prevalent in the groundwater regime at Flat Cliffs, although BB02 (A2) is probably influenced by tidal fluctuations.

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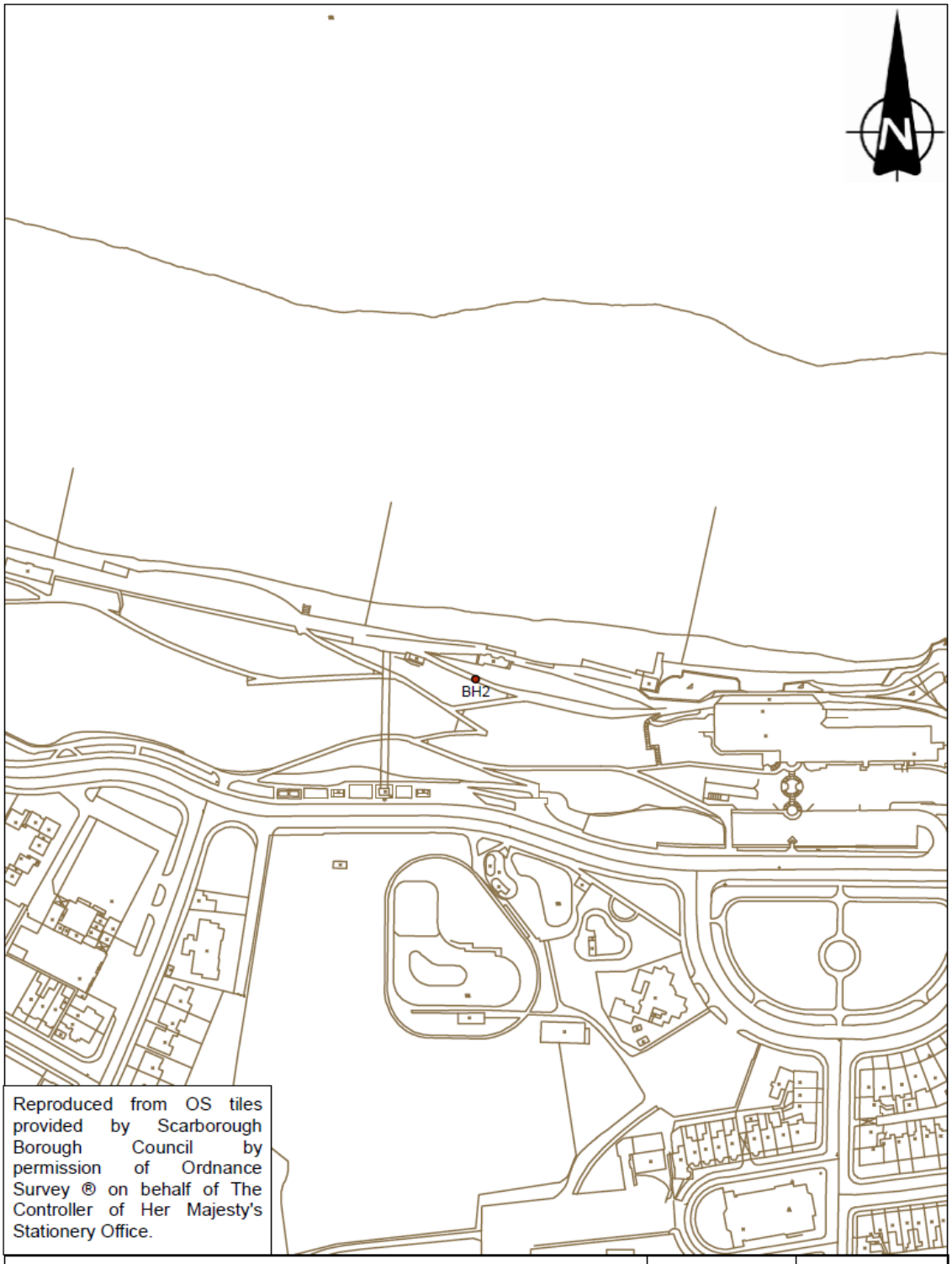
Appendix A Exploratory Holes Location Plans



Whitby West Cliff Inclinometer Location Plan

Scale: 1:2,500

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Analysis and Interpretation of Coastal Monitoring Data

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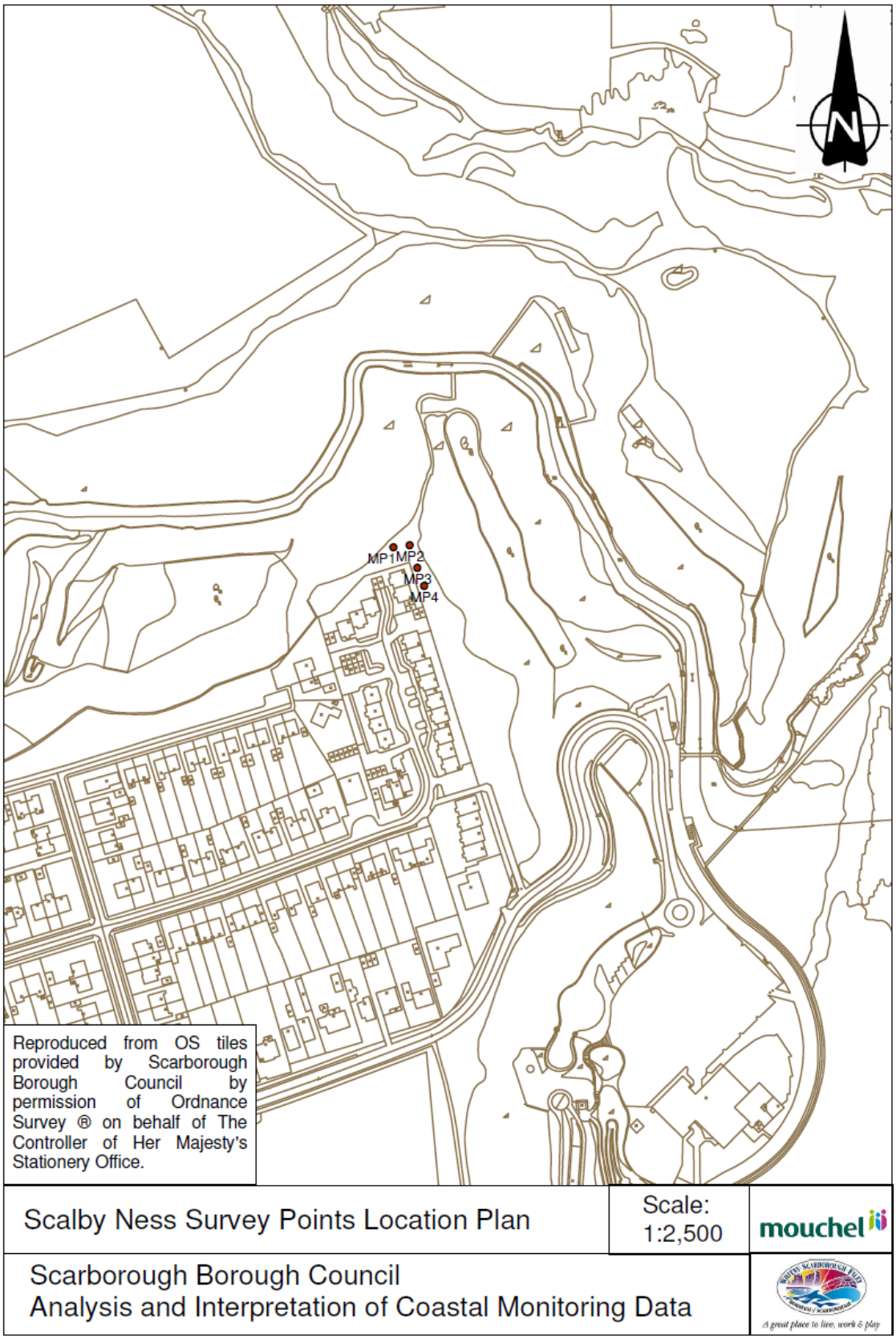
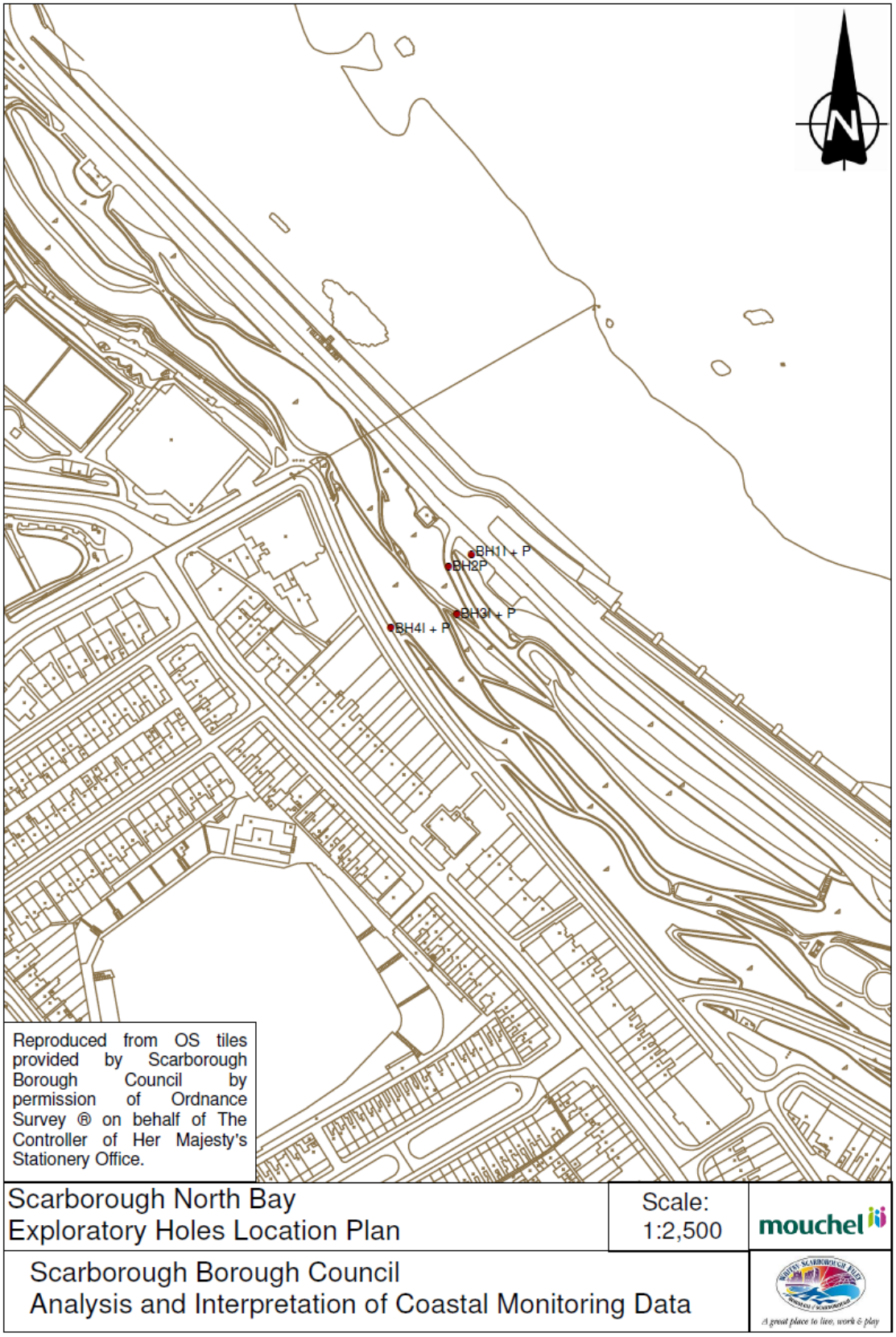
Drawing No. 1 Location Plan of Whitby West Cliff



Drawing No. 2 Location Plan of Scalby Ness



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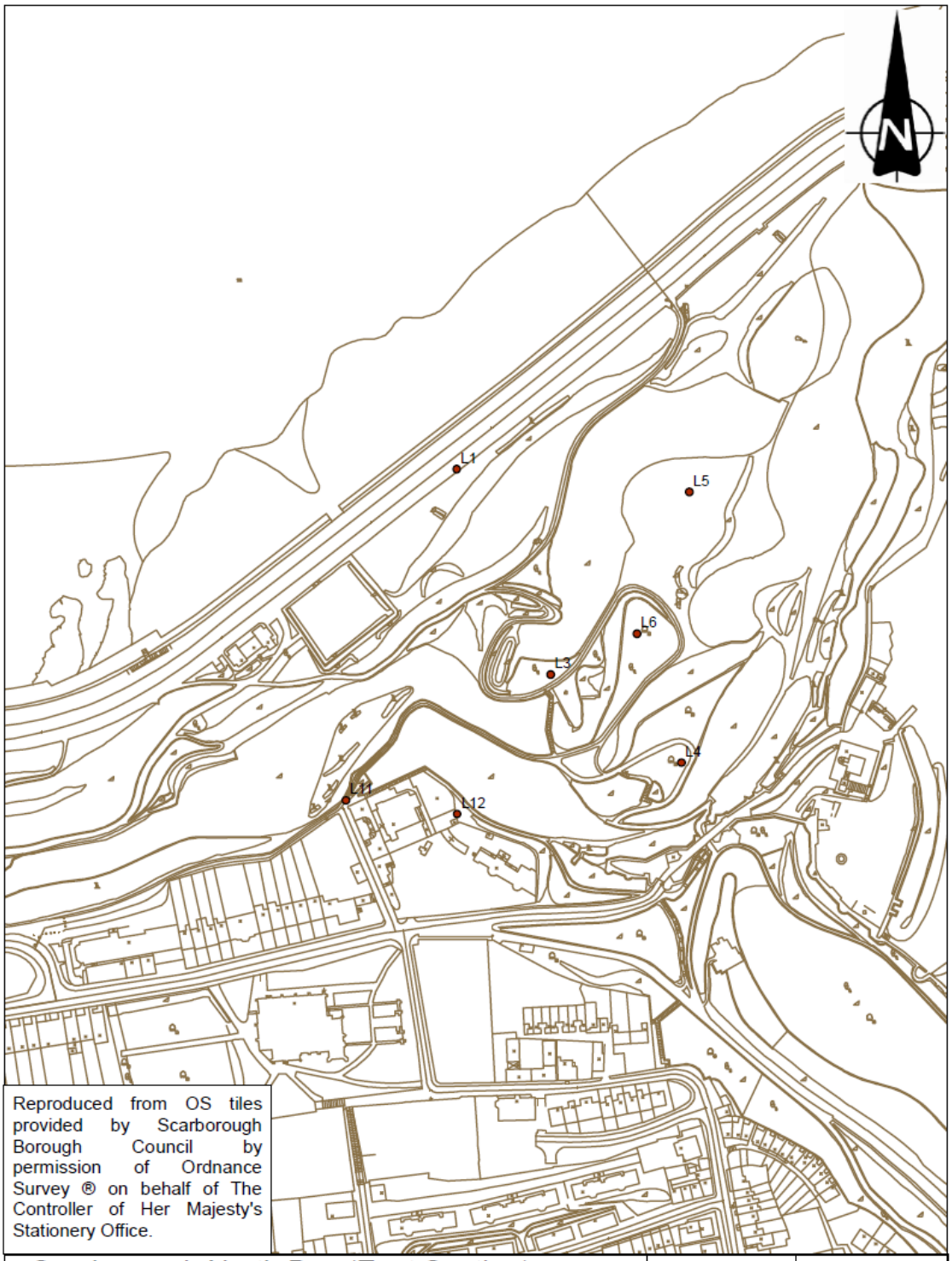
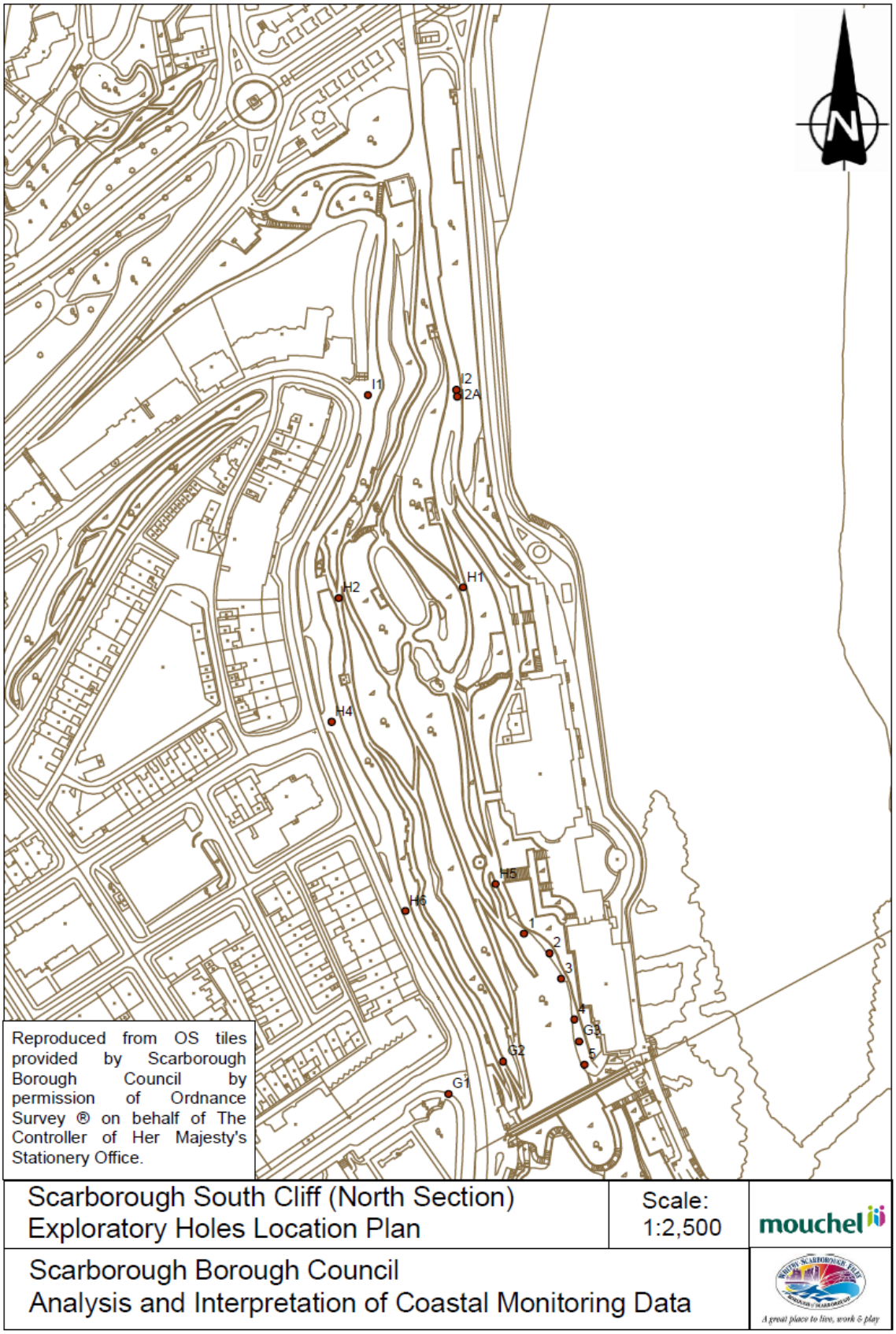
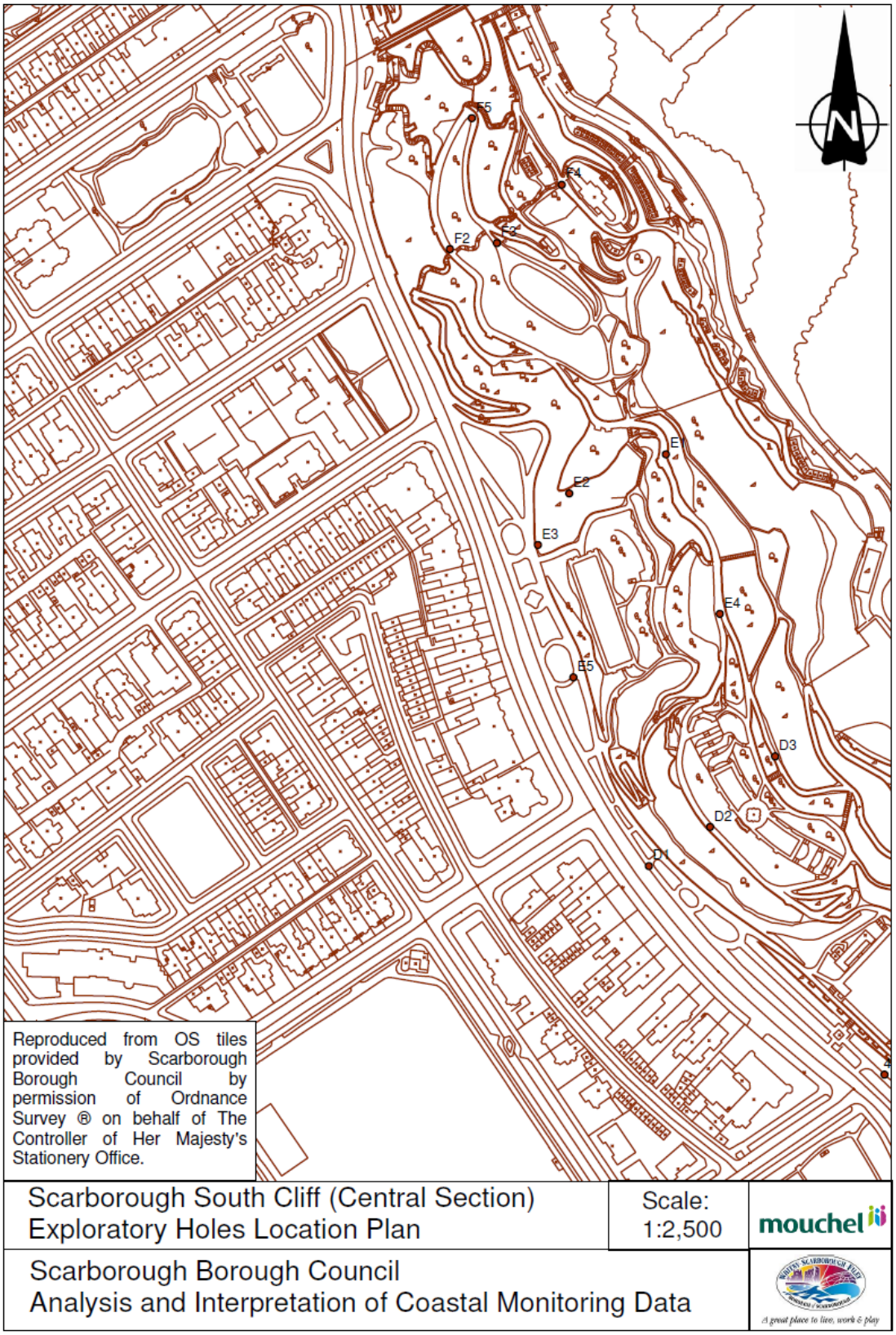


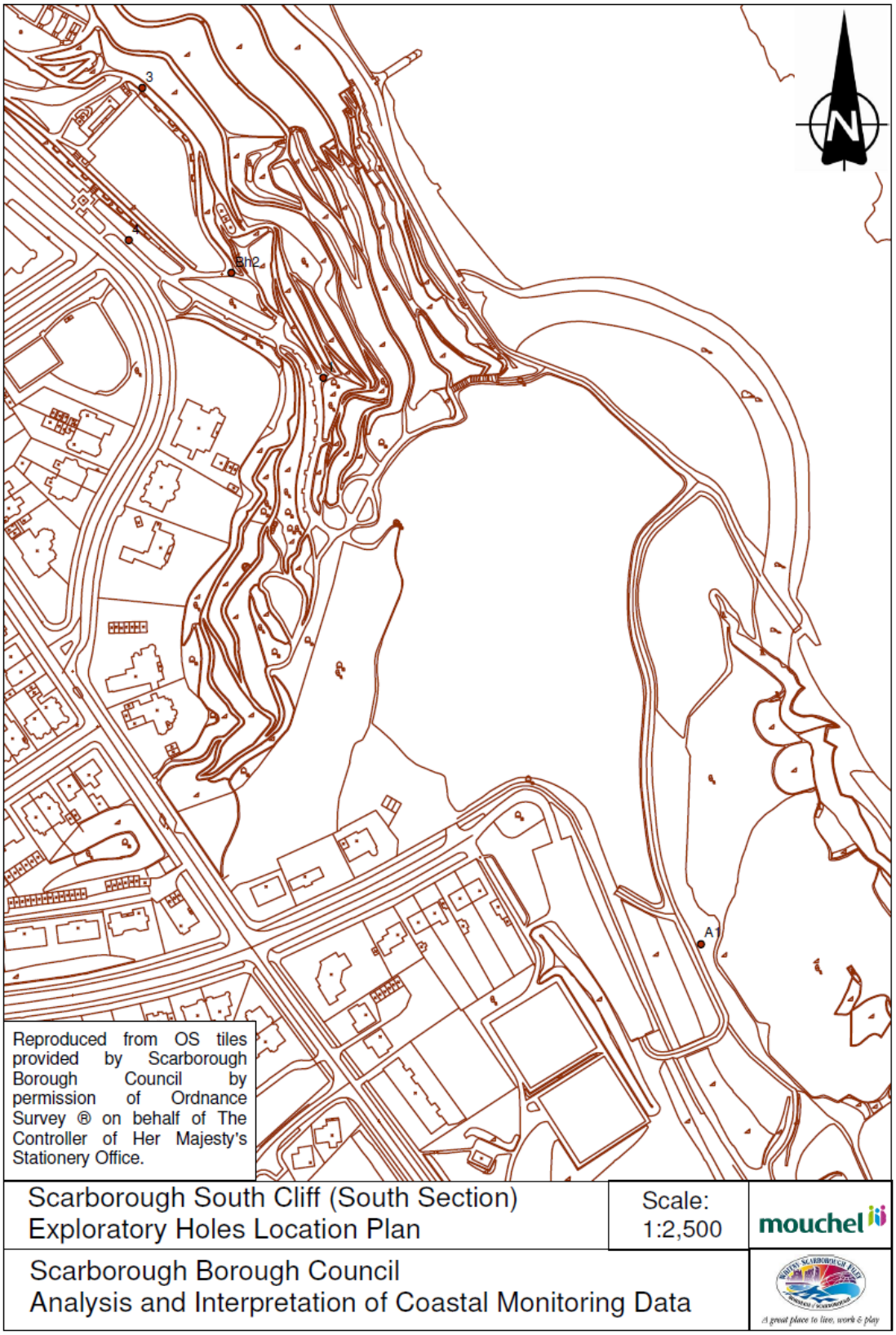
Drawing No. 4 Location Plan of Scarborough North Bay (East)



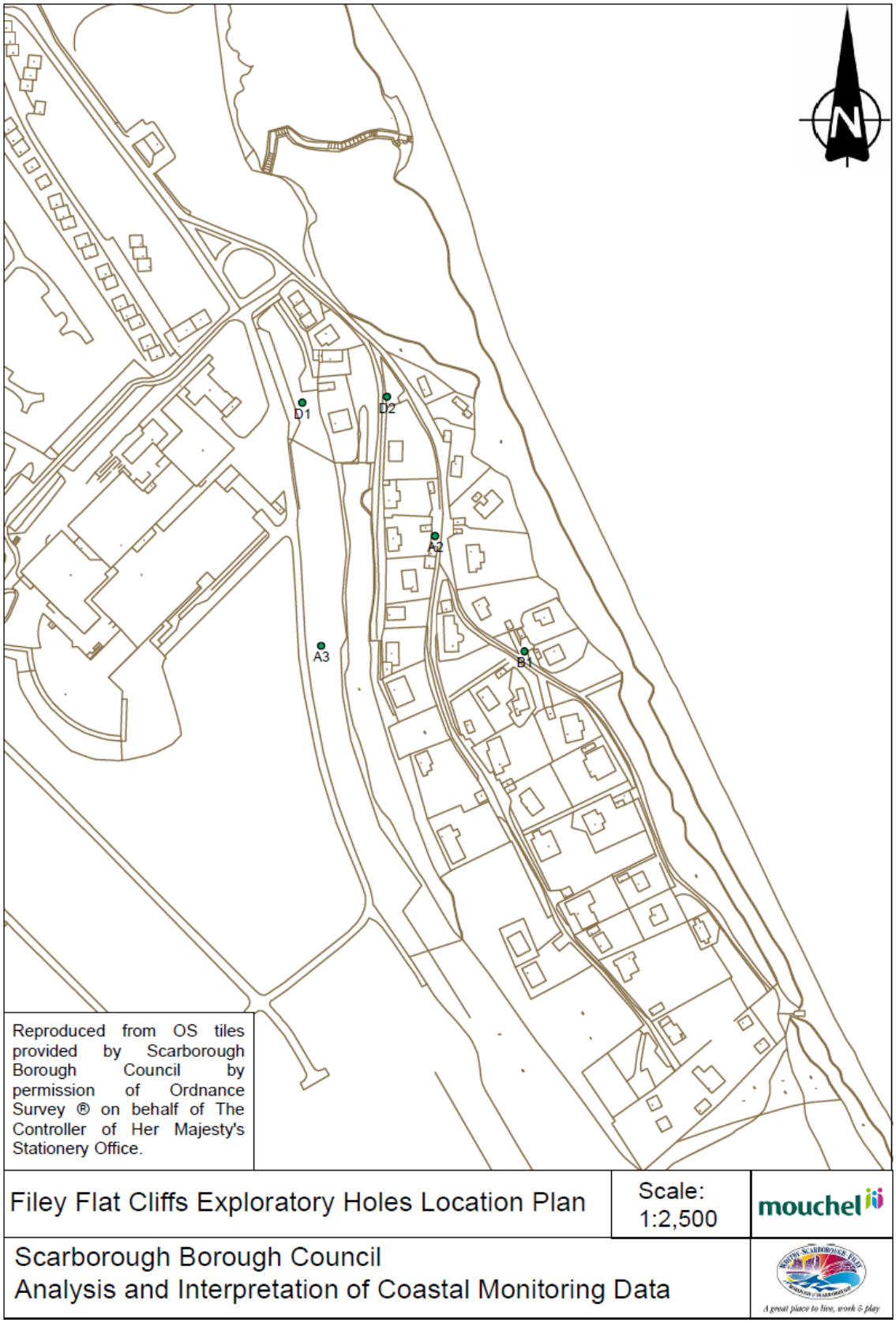
Drawing No. 5 Location Plan of Scarborough South Cliff (North)



Drawing No. 6 Location Plan of Scarborough South Cliff (Central)

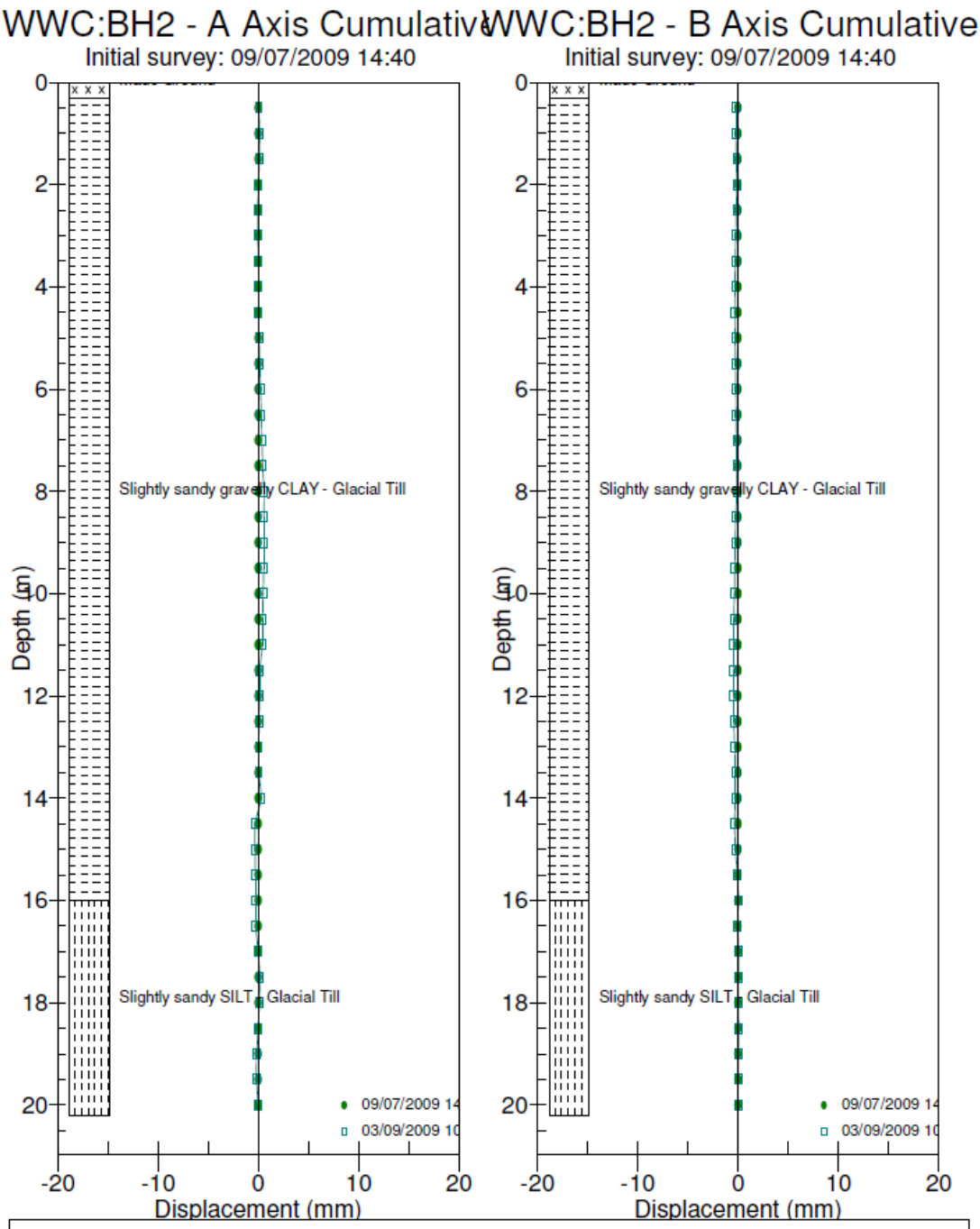


Drawing No. 7 Location Plan of Scarborough South Cliff (South)



Drawing No. 8 Location Plan of Filey Flat Cliffs

Appendix B Inclinometer Data Graphs



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Whitby West Cliff
INSTALLATION: BH2
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North

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OASIS:BH1 - A Axis Cumulativ

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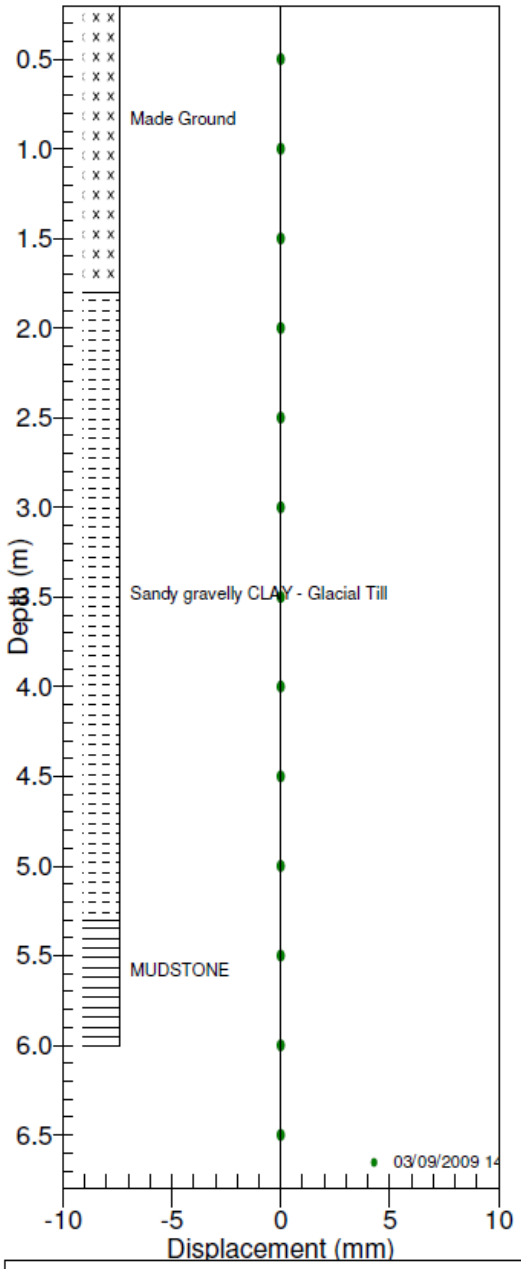

OASIS:BH1 - B Axis Cumulative

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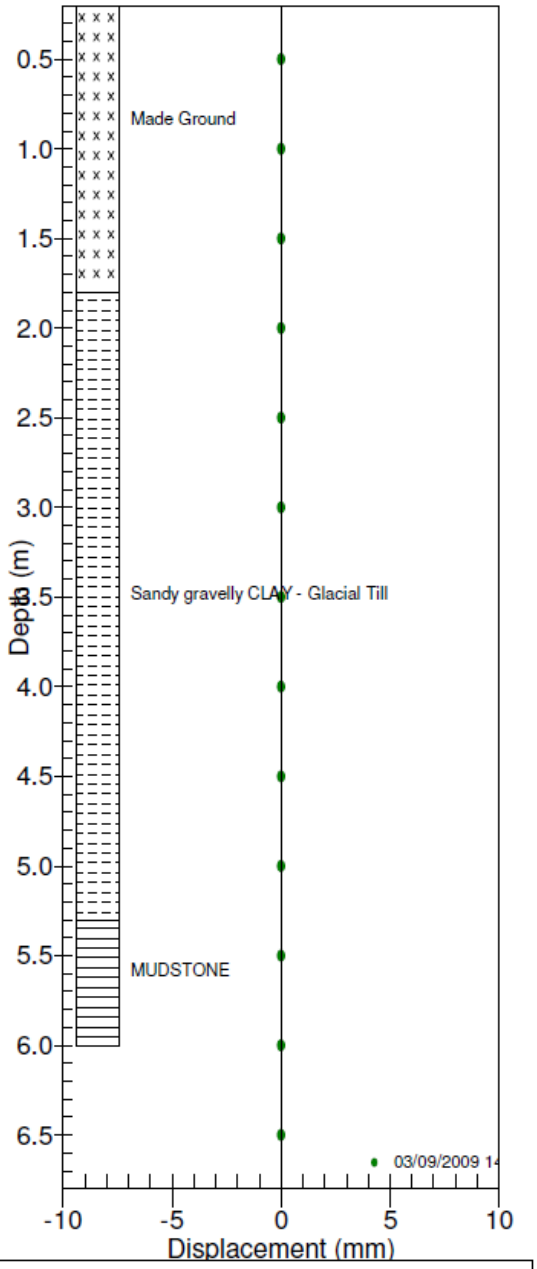

PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Oasis North Bay
INSTALLATION: BH1
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East

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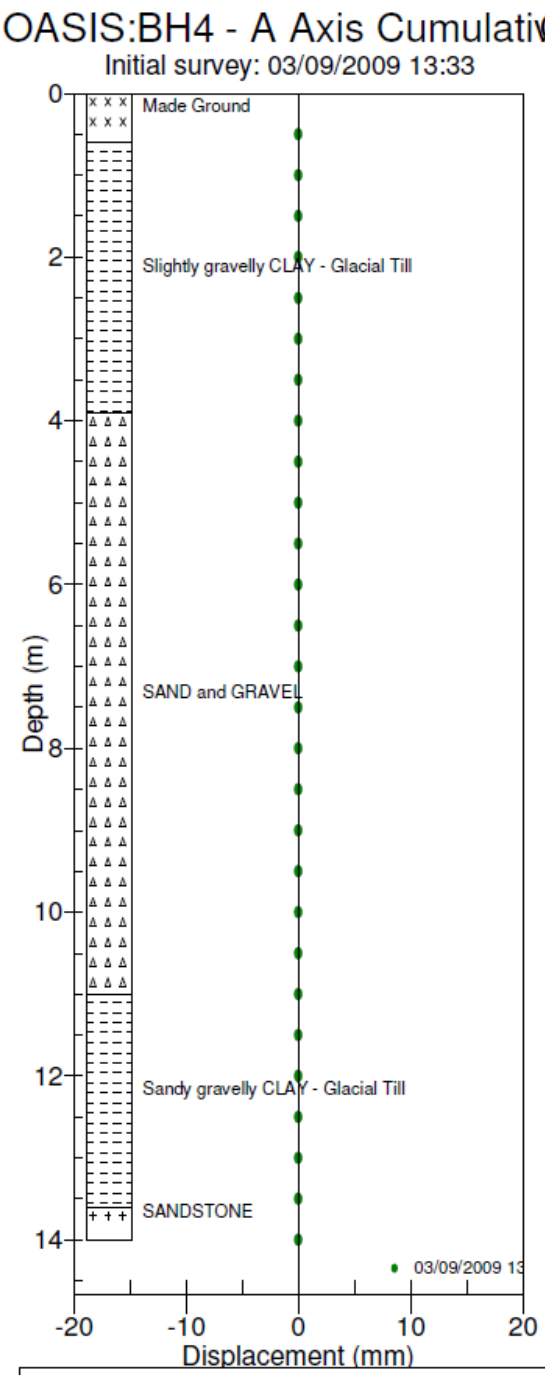
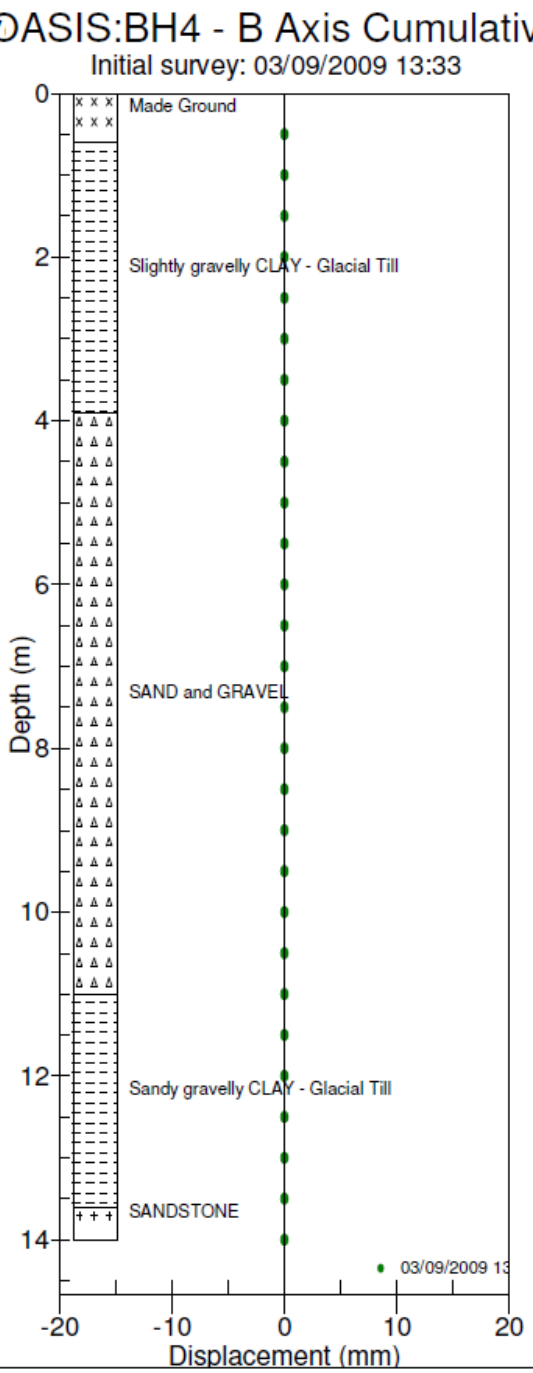
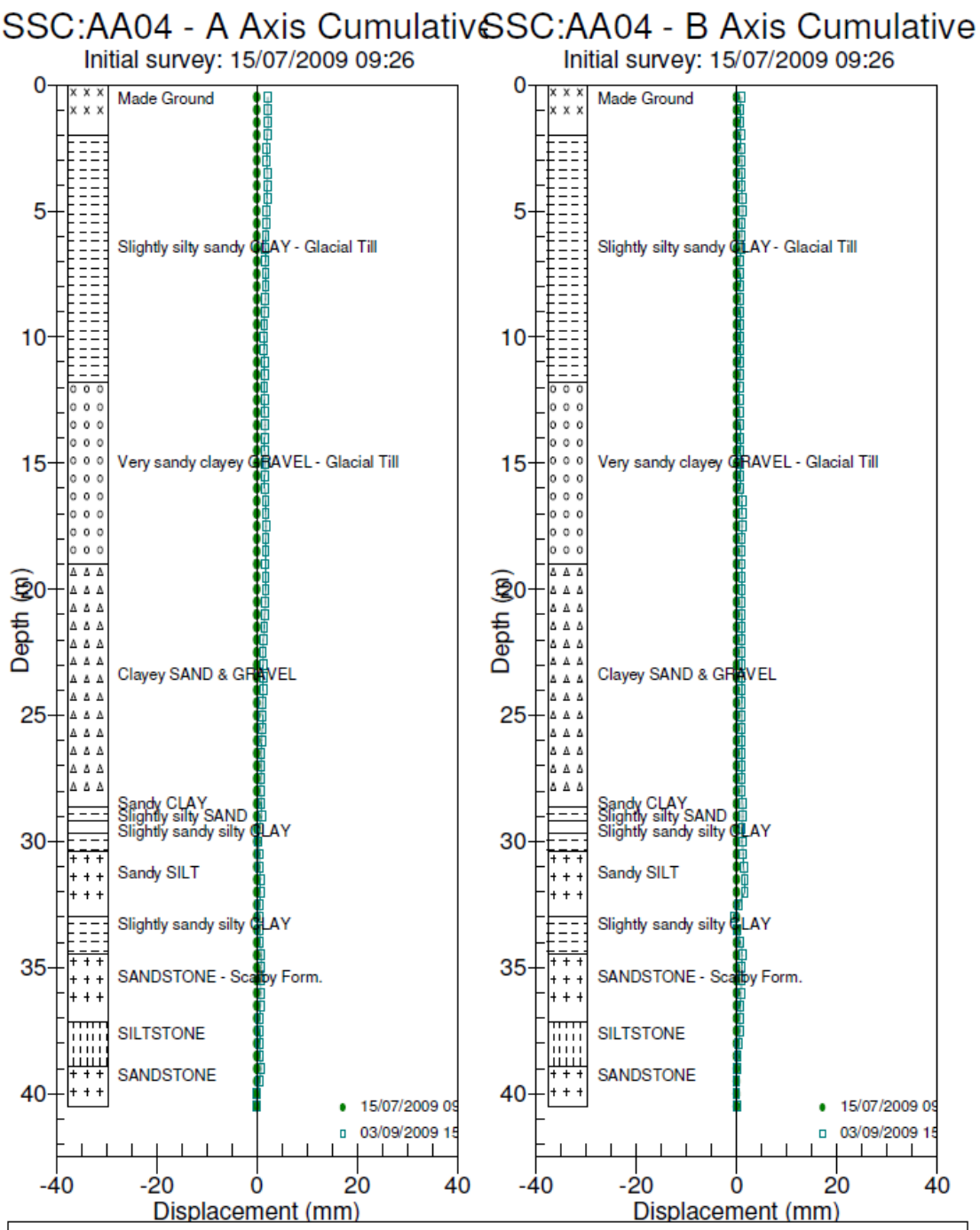




PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Oasis North Bay
INSTALLATION: BH4
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East

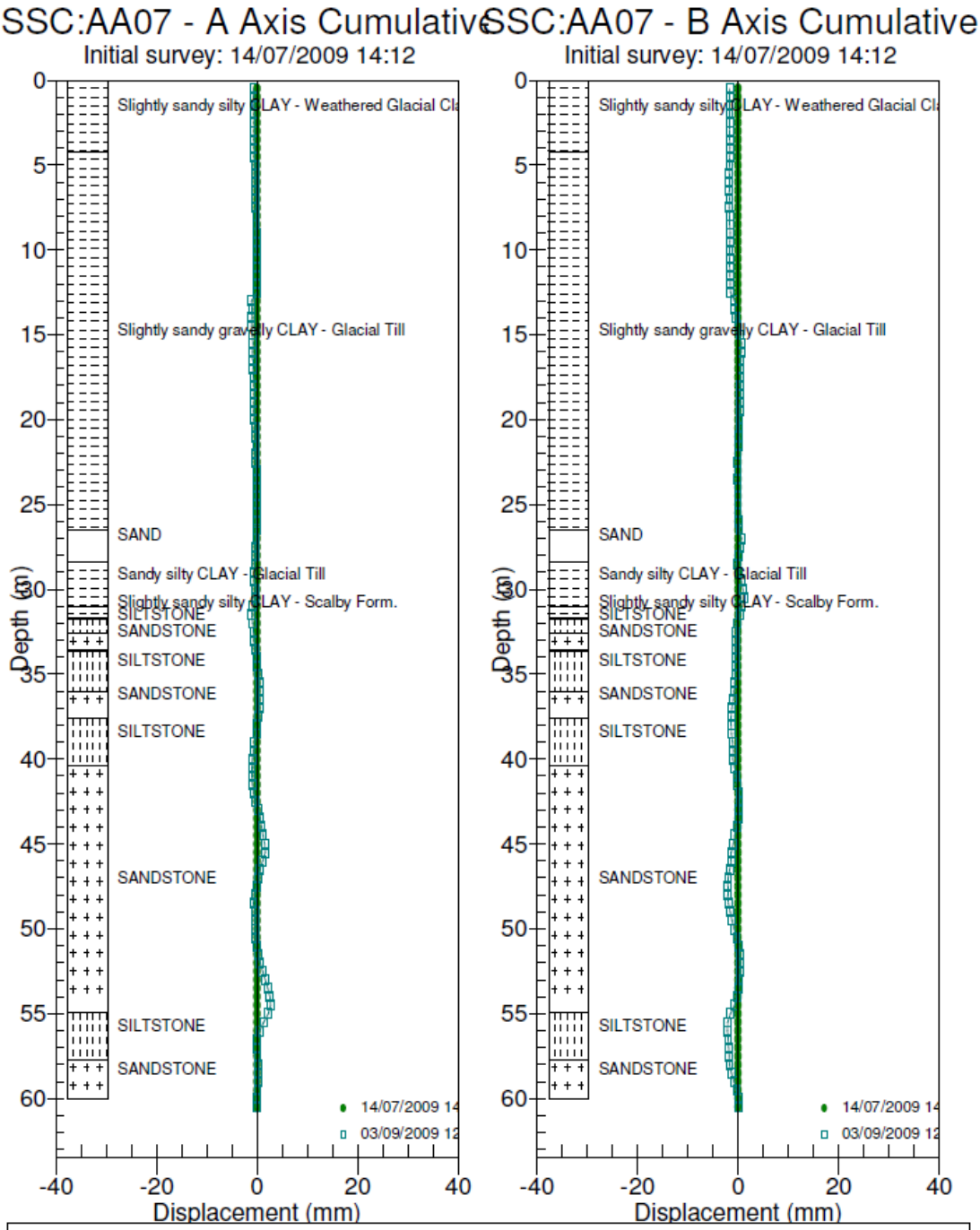
mouchel



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA04 (G2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East

mouchel



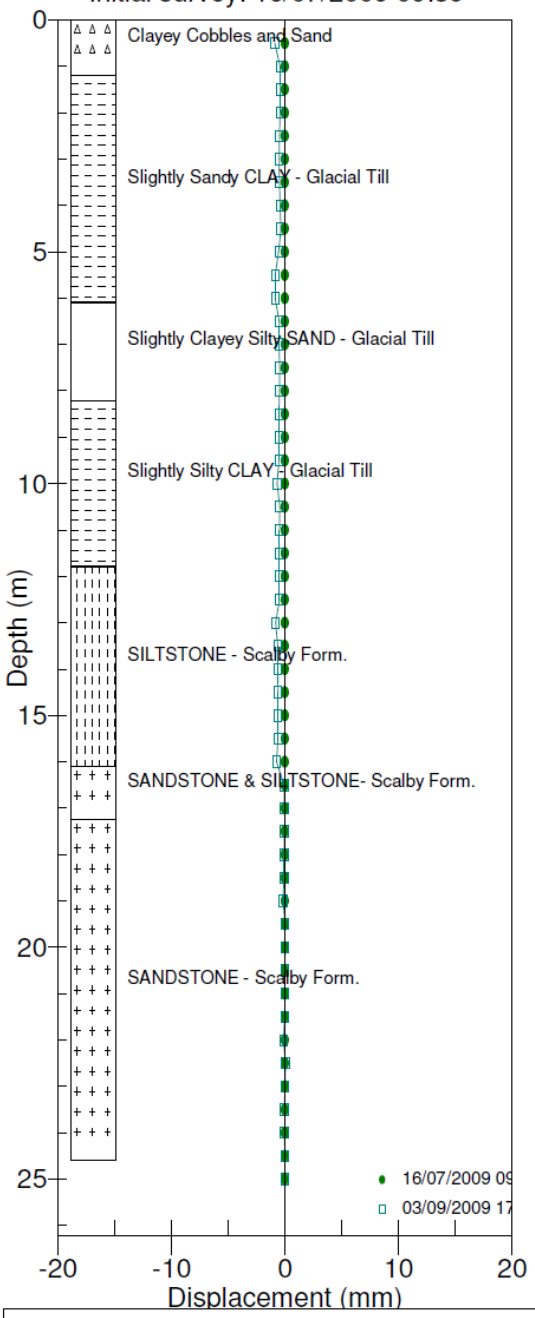
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA07 (BH2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East

mouchel

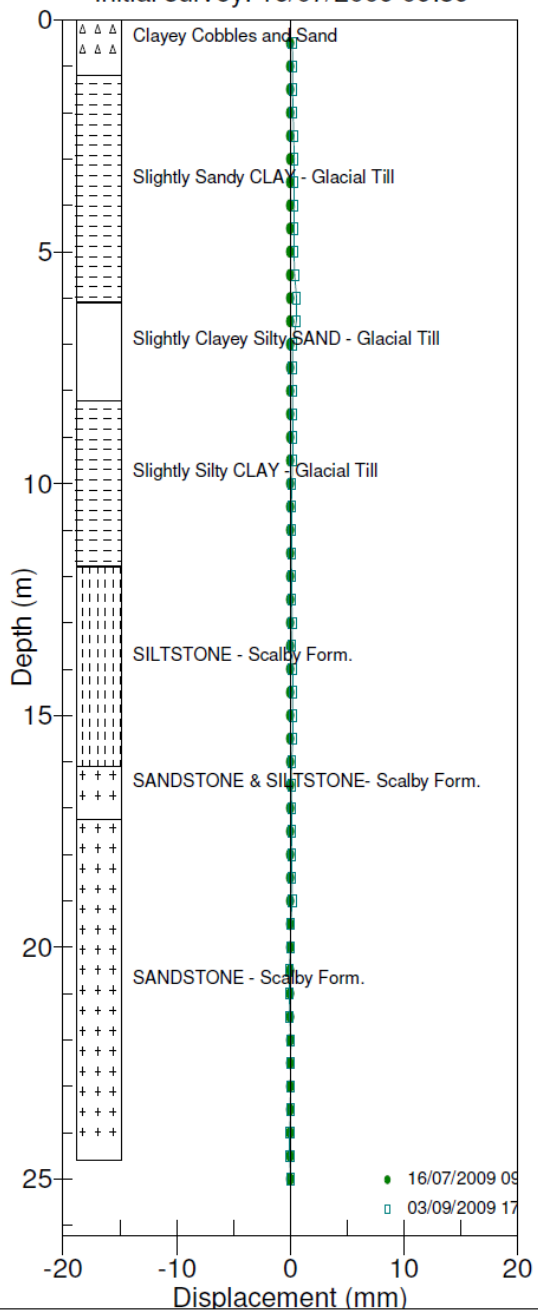
SSC:AA08 - A Axis Cumulative

Initial survey: 16/07/2009 09:39



SSC:AA08 - B Axis Cumulative

Initial survey: 16/07/2009 09:39



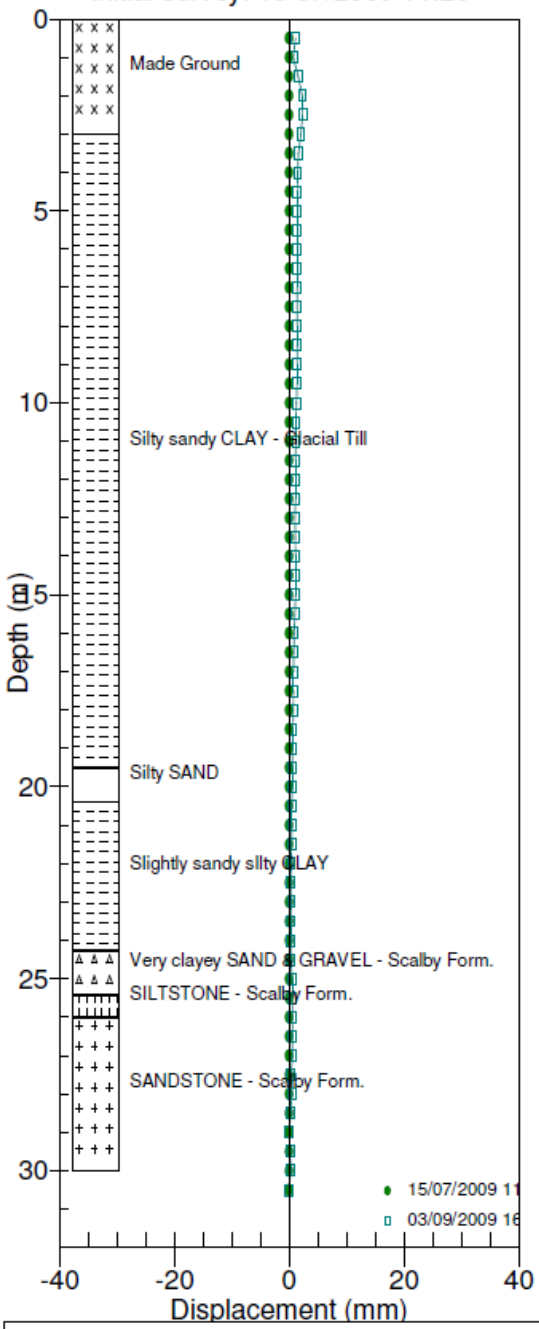
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA08 (D3)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East

mouchel

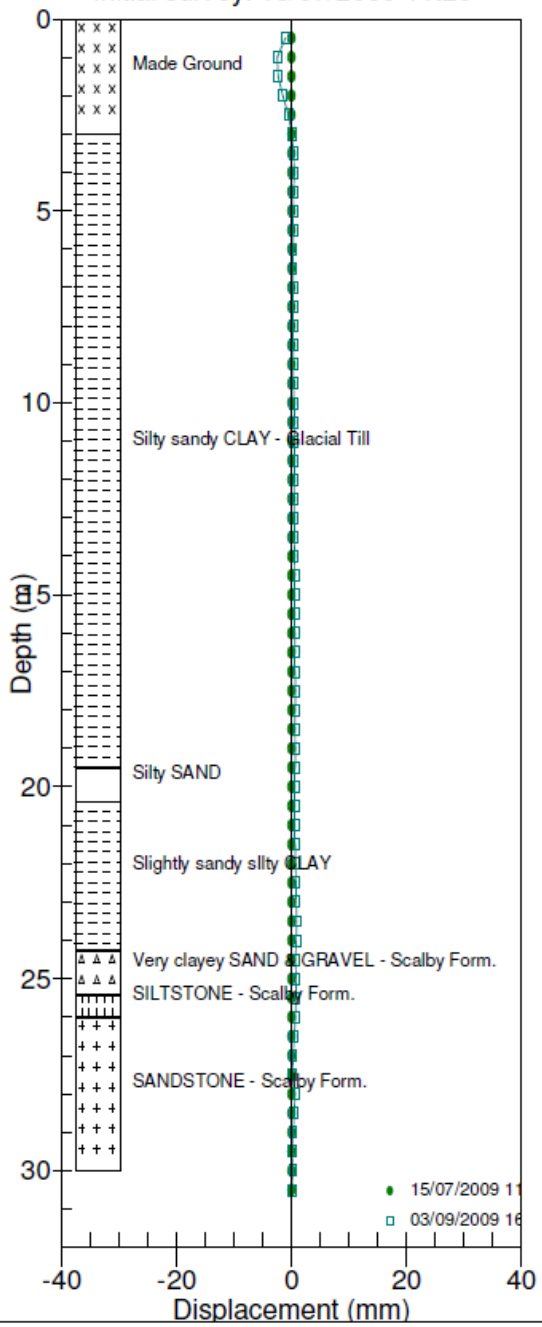
SSC:AA10 - A Axis Cumulative

Initial survey: 15/07/2009 11:20



SSC:AA10 - B Axis Cumulative

Initial survey: 15/07/2009 11:20

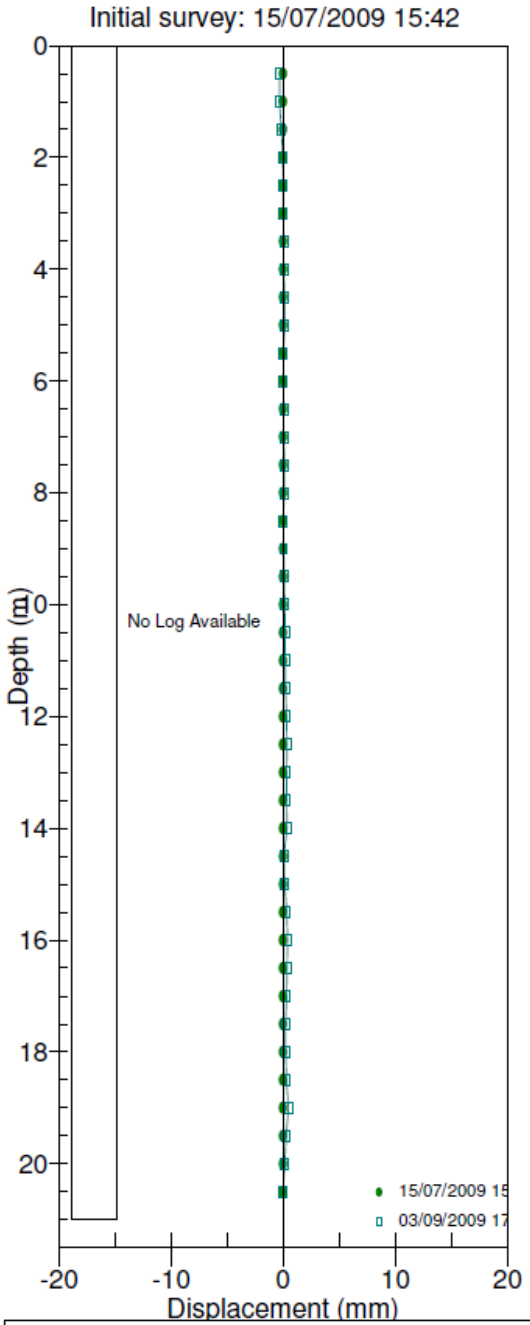


PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA10 (F2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

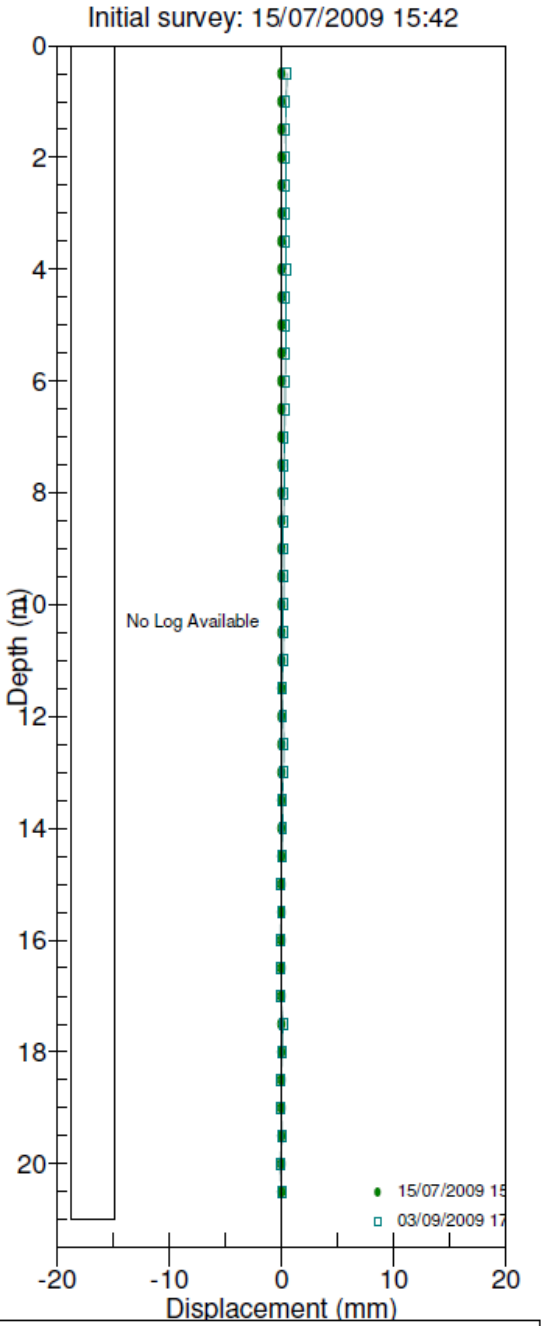
NOTE: A0 direction: North East

mouchel

SSC:AA11 - A Axis Cumulative



SSC:AA11 - B Axis Cumulative



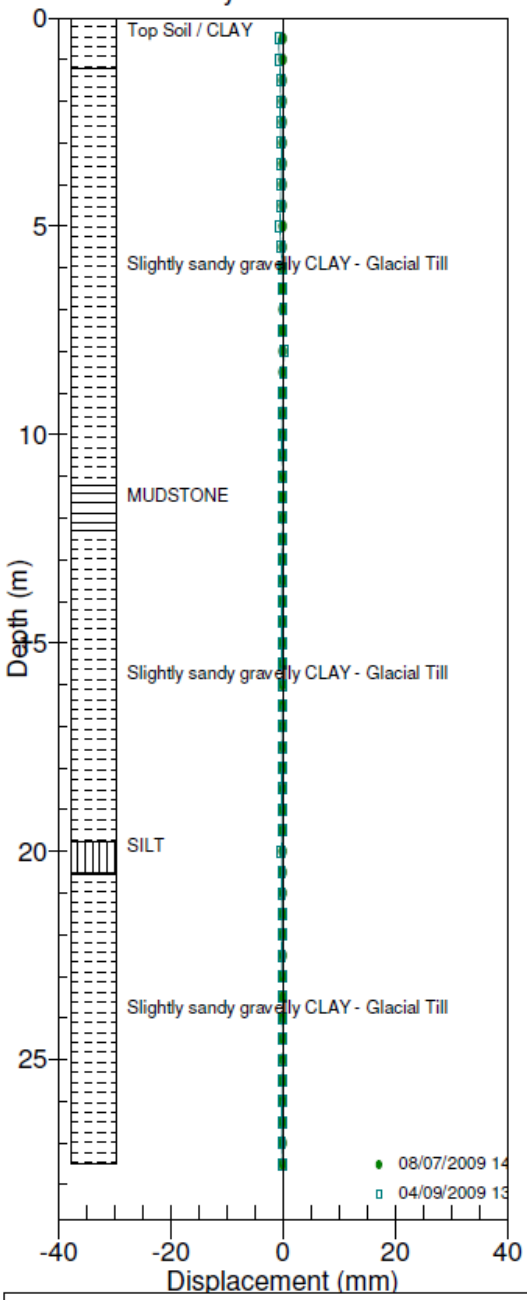
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA11 (F4)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East

mouchel

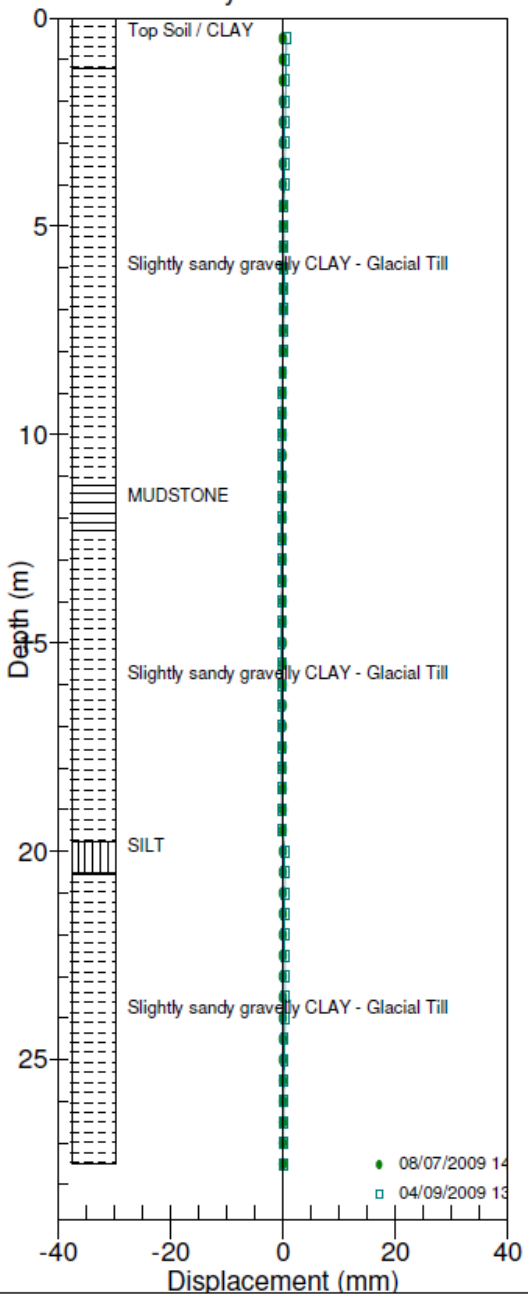
FFC:BB02 - A Axis Cumulative

Initial survey: 08/07/2009 14:13



FFC:BB02 - B Axis Cumulative

Initial survey: 08/07/2009 14:13



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Flat Cliffs
INSTALLATION: BB02
COMPANY: Mouchel Ltd
CLIENT: Scarboruough Borough Council

NOTE: A0 direction: East

mouchel

Appendix C Groundwater Monitoring Data

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
WHITBY WEST CLIFF							
BH2	9th July	Inclino	13.78	7.73	19.90	20.00	Stiff, sandy silt

Groundwater Monitoring Readings –August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
WHITBY WEST CLIFF							
BH2	25th Aug	Inclino	13.78	6.83	19.93	20.00	Stiff, sandy silt

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' NORTH BAY							
L1 (a)	15th July	Piezo	7.03	2.00	8.00	10.00	Slightly sandy siltstone
L1 (b)	15th July	Piezo	7.03	10.27	15.04	16.00	Slightly weathered siltstone
L3 (a)	15th July	Piezo	30.78	1.41	1.41	20.70	Highly weathered sandstone
L3 (b)	15th July	Piezo	30.78	DRY	20.19	27.40	Moderately weathered sandstone to highly weathered mudstone
L5 (a)	15th July	Piezo	33.33	DRY	13.77	24.00	Highly weathered sandstone to slightly weathered siltstone
L5 (b)	15th July	Piezo	33.33	DRY	13.77	33.00	Sandstone and siltstone
L11	15th July	Piezo	55.63	7.23	14.30	14.50	Fine to medium grained sandstone
L12	15th July	Piezo	56.24	DRY	15.30	15.90	Fine to medium grained sandy siltstone

Groundwater Monitoring Readings – August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' NORTH BAY							
L1 (a)	3rd Sept	Piezo	7.03	2.18	8.00	10.00	Slightly sandy siltstone
L1 (b)	3rd Sept	Piezo	7.03	5.20	15.04	16.00	Slightly weathered siltstone
L3 (a)	3rd Sept	Piezo	30.78	1.41	1.41	20.70	Highly weathered sandstone
L3 (b)	3rd Sept	Piezo	30.78	DRY	20.18	27.40	Moderately weathered sandstone to highly weathered mudstone
L5 (a)	3rd Sept	Piezo	33.33	Not read, Fouled	-	24.00	Highly weathered sandstone to slightly weathered siltstone
L5 (b)	3rd Sept	Piezo	33.33	Ditto	-	33.00	Sandstone and siltstone
L11	3rd Sept	Piezo	55.63	2.57	14.30	14.50	Fine to medium grained sandstone
L12	3rd Sept	Piezo	56.24	15.50	15.50	15.90	Fine to medium grained sandy siltstone

Groundwater Monitoring Readings – August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' NORTH BAY							
BH1P	3rd Sept	Piezo		3.54	4.97	4.97	
BH1I	3rd Sept	Inclino		3.30	6.10	6.10	
BH2P	3rd Sept	Piezo		Flooded	-	-	
BH3P	3rd Sept	Piezo		Flooded	-	-	
BH3I	3rd Sept	Inclino		Siezed	-	-	
BH4P	3rd Sept	Piezo		DRY	13.10	13.10	
BH4I	3rd Sept	Inclino		13.60	13.60	13.60	

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
AA01 (I1)	15th July	Inclino	47.95	43.00	65.10	65.00	Sandstone
AA02 (H4)	15th July	Inclino	53.85	DRY	61.30	61.50	Sandstone
AA03 (H6)	15th July	Inclino	55.76	49.57	54.40	54.50	Sandstone
AA04 (G2)	15th July	Inclino	47.62	40.10	40.60	39.50	Sandstone and siltstone
AA10 (F2)	15th July	Inclino	34.98	23.40	30.50	29.50	Sandstone and siltstone
AA11 (F4)	15th July	Inclino	N/A	16.02	20.20	19.50	No details
AA09 (E3)	15th July	Inclino	58.06	33.81	48.50	48.00	Sandstone and siltstone
AA05 (E5)	15th July	Inclino	63.06	42.34	54.80	53.50	Sandstone and siltstone
AA08 (D3)	15th July	Inclino	38.43	21.35	25.02	24.60	Fine sandstone
AA06 (D1)	15th July	Inclino	64.1	32.20	46.50	46.40	Silty mudstone
AA07 (Bh2)	15th July	Inclino	56.33	46.20	60.00	60.00	Fine to coarse grained sandstone
I2	15th July	Piezo	22.69	21.55	31.00	31.10	Clayey fine sand

Groundwater Monitoring Readings - August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
AA01 (I1)	4th Sept	Inclino	47.95	44.84	65.10	65.00	Sandstone
AA02 (H4)	4th Sept	Inclino	53.85	45.00	61.30	61.50	Sandstone
AA03 (H6)	4th Sept	Inclino	55.76	48.66	54.40	54.50	Sandstone
AA04 (G2)	25th Aug	Inclino	47.62	39.50	40.60	39.50	Sandstone and siltstone
AA10 (F2)	25th Aug	Inclino	34.98	19.85	30.50	29.50	Sandstone and siltstone
AA11 (F4)	25th Aug	Inclino	N/A	15.90	20.20	19.50	No details
AA09 (E3)	4th Sept	Inclino	58.06	29.25	48.50	48.00	Sandstone and siltstone
AA05 (E5)	4th Sept	Inclino	63.06	42.41	54.80	53.50	Sandstone and siltstone
AA08 (D3)	25th Aug	Inclino	38.43	21.40	25.02	24.60	Fine sandstone
AA06 (D1)	25th Aug	Inclino	64.1	32.20	46.50	46.40	Silty mudstone
AA07 (Bh2)	25th Aug	Inclino	56.33	45.64	60.00	60.00	Fine to coarse grained sandstone
I2	25th Aug	Piezo	22.69	21.30	31.00	31.10	Clayey fine sand

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
I2A	15th July	Piezo	22.69	19.00	19.00	19.00	Clayey coarse sand
H2 (a)	15th July	Piezo	46.52	29.20	29.20	30.00	Silty fine and medium sand
H2 (b)	15th July	Piezo	46.52	34.30	37.50	38.50	Silty fine and medium sand
H1 (a)	15th July	Piezo	26.45	DRY	15.30	15.75	Gravel in a clayey silty sand
H1 (b)	15th July	Piezo	26.45	DRY	4.28	36.00	Fine to coarse sand and gravel
H5	15th July	Piezo	23.35	1.64	6.91	9.70	Firm to stiff sandy silty clay
1 Spa	15th July	Piezo	N/A	12.92	13.90	13.90	No details
2 Spa	15th July	Piezo	N/A	9.10	12.80	12.80	No details
3 Spa	15th July	Piezo	N/A	6.69	11.48	11.48	No details
4 Spa	15th July	Piezo	N/A	6.48	7.27	7.27	No details
G3	15th July	Piezo	18.15	4.88	6.17	6.17	Medium coarse gravel

Groundwater Monitoring Readings - August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
I2A	25th Aug	Piezo	22.69	18.94	19.00	19.00	Clayey coarse sand
H2 (a)	25th Aug	Piezo	46.52	29.20	29.20	30.00	Silty fine and medium sand
H2 (b)	25th Aug	Piezo	46.52	34.53	37.50	38.50	Silty fine and medium sand
H1 (a)	25th Aug	Piezo	26.45	DRY	15.30	15.75	Gravel in a clayey silty sand
H1 (b)	25th Aug	Piezo	26.45	DRY	4.28	36.00	Fine to coarse sand and gravel
H5	25th Aug	Piezo	23.35	2.40	8.91	9.70	Firm to stiff sandy silty clay
1 Spa	25th Aug	Piezo	N/A	13.50	13.90	13.90	No details
2 Spa	25th Aug	Piezo	N/A	9.04	12.80	12.80	No details
3 Spa	25th Aug	Piezo	N/A	6.70	11.48	11.48	No details
4 Spa	25th Aug	Piezo	N/A	6.30	7.27	7.27	No details
G3	25th Aug	Piezo	18.15	5.25	6.17	6.17	Medium coarse gravel

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
5 Spa	15th July	Piezo	N/A	DRY	8.80	8.80	No details
G1 (a)	15th July	Piezo	55.48	36.40	36.40	36.60	Clayey silty coarse sand
G1 (b)	15th July	Piezo	55.48	DRY	2.10	16.80	Clayey fine to coarse gravel
E2 (a)	15th July	Slip Indicator	51.81	3.80	17.70	19.00	Slightly clayey slightly silty fine sand
E2 (b)	15th July	Piezo	51.81	1.29	8.20	8.85	Sandy silty clay
D2 (a)	15th July	Piezo	46.54	6.12	19.09	19.00	Firm silty sandy clay
D2 (b)	15th July	Piezo	46.54	1.10	5.04	5.00	Clayey fine to coarse sand
Bh3 (a)	15th July	Piezo	53.83	37.56	42.40	45.40	Slightly sandy mudstone
Bh3 (b)	15th July	Piezo	53.83	9.94	12.30	12.45	Stiff sandy, silty clay
Bh4 (a)	15th July	Piezo	59.00	8.40	30.85	30.85	Firm to stiff, sandy silty clay
Bh4 (b)	15th July	Piezo	59.00	8.56	33.90	33.90	Firm to stiff, sandy silty clay

Groundwater Monitoring Readings - August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
5 Spa	25th Aug	Piezo	N/A	8.75	8.80	8.80	No details
G1 (a)	25th Aug	Piezo	55.48	36.40	36.40	36.60	Clayey silty coarse sand
G1 (b)	25th Aug	Piezo	55.48	DRY	2.00	16.80	Clayey fine to coarse gravel
E2 (a)	3rd Sept	Slip Indicator	51.81	3.80	17.70	19.00	Slightly clayey slightly silty fine sand
E2 (b)	3rd Sept	Piezo	51.81	1.37	8.20	8.85	Sandy silty clay
D2 (a)	3rd Sept	Piezo	46.54	6.14	19.00	19.00	Firm silty sandy clay
D2 (b)	3rd Sept	Piezo	46.54	1.07	5.04	5.00	Clayey fine to coarse sand
Bh3 (a)	3rd Sept	Piezo	53.83	39.40	42.40	45.40	Slightly sandy mudstone
Bh3 (b)	3rd Sept	Piezo	53.83	10.00	12.30	12.45	Stiff sandy, silty clay
Bh4 (a)	3rd Sept	Piezo	59.00	8.18	30.85	30.85	Firm to stiff, sandy silty clay
Bh4 (b)	3rd Sept	Piezo	59.00	8.33	33.90	33.90	Firm to stiff, sandy silty clay

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
Bh1 (a)	15th July	Piezo	49.77	DRY	30.60	30.60	Silty sandstone
Bh1 (b)	15th July	Piezo	49.77	12.58	19.90	19.90	Stiff, sandy, silty clay

Groundwater Monitoring Readings - August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
SCARBORO' SOUTH CLIFF							
Bh1 (a)	3rd Sept	Piezo	49.77	Flooded	30.60	30.60	Silty sandstone
Bh1 (b)	3rd Sept	Piezo	49.77	Flooded	19.90	19.90	Stiff, sandy, silty clay

Groundwater Monitoring Readings - July 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
FLAT CLIFFS							
BB01 (D2)	8th July	Inclino	25.54	DRY	14.20	22.50	Firm slightly sandy, slightly gravely CLAY
BB02 (A2)	8th July	Inclino	17.93	1.59	28.10	28.85	Firm slightly sandy, slightly gravely CLAY
B1	8th July	Piezo	15.64	2.06	23.38	24.50	Fine to medium SAND with clay bands
D1	8th July	Piezo	36.09	16.37	20.48	20.50	Stiff slightly sandy gravely CLAY
A3	8th July	Piezo	36.77	18.04	30.40	30.50	Firm slightly sandy gravely CLAY

Groundwater Monitoring Readings - August 2009

SITE Exploratory hole No.	Date (2009)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
FLAT CLIFFS							
BB01 (D2)	25th August	Inclino	25.54	DRY	14.20	22.50	Firm slightly sandy, slightly gravely CLAY
BB02 (A2)	25th August	Inclino	17.93	1.76	28.10	28.85	Firm slightly sandy, slightly gravely CLAY
B1	25th August	Piezo	15.64	2.03	23.38	24.50	Fine to medium SAND with clay bands
D1	25th August	Piezo	36.09	16.60	20.48	20.50	Stiff slightly sandy gravely CLAY
A3	25th August	Piezo	36.77	17.94	30.40	30.50	Firm slightly sandy gravely CLAY

N/A - Not Available
Piezo - Piezometer
Inclino – Inclinometer

Automated Piezometer Groundwater Monitoring Readings

(To Be Inserted)

Appendix D Survey Data

Ongoing Coastal Monitoring of Survey Points – 22nd July 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	511468.120	489306.554	40.864	8.319	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	511474.546	489308.296	35.887	7.869	
MP3	511481.188	489310.241	32.126	8.655	
MP4	511487.066	489313.968	26.988	12.623	
MP5	511498.358	489315.765	21.652	11.657	
MP6	511508.928	489314.795	16.825		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.846	490962.702	35.853	3.15	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	503425.536	490962.701	36.059	4.30	
MP3	503429.459	490952.269	35.509	2.66	
MP4	503434.045	490941.940	34.969	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.903	487885.382	48.508	7.206	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.701	487888.093	45.197	6.079	
MP3	504364.788	487888.922	41.974	9.117	
MP4	504372.839	487890.600	38.039	10.317	
MP5	504381.799	487893.850	34.090	9.246	
MP6	504389.334	487897.564	30.228		

Ongoing Coastal Monitoring of Survey Points – 22nd July 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504549.325	487431.090	54.322	10.724	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.474	487434.499	53.691	12.989	
MP3	504571.837	487437.291	50.847	10.254	
MP4	504579.847	487440.336	45.212	13.849	
MP5	504592.579	487444.628	41.856		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504754.082	487134.614	55.305	12.050	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.242	487137.096	49.350	6.004	
MP3	504769.607	487136.013	46.881	7.211	
MP4	504775.961	487137.850	44.007		

Ongoing Coastal Monitoring of Survey Points – 24th August 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	511468.120	489306.554	40.864	8.311	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	511474.546	489308.296	35.887	7.874	
MP3	511481.188	489310.241	32.126	8.657	
MP4	511487.066	489313.968	26.988	12.612	
MP5	511498.358	489315.765	21.652	11.665	
MP6	511508.928	489314.795	16.825		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.846	490962.702	35.853	3.15	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	503425.536	490962.701	36.059	4.30	
MP3	503429.459	490952.269	35.509	2.65	
MP4	503434.045	490941.940	34.969	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.903	487885.382	48.508	7.206	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.701	487888.093	45.197	6.081	
MP3	504364.788	487888.922	41.974	9.114	
MP4	504372.839	487890.600	38.039	10.320	
MP5	504381.799	487893.850	34.090	9.246	
MP6	504389.334	487897.564	30.228		

Ongoing Coastal Monitoring of Survey Points – 24th August 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504549.325	487431.090	54.322	10.724	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.474	487434.499	53.691	12.983	
MP3	504571.837	487437.291	50.847	10.260	
MP4	504579.847	487440.336	45.212	13.855	
MP5	504592.579	487444.628	41.856		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504754.082	487134.614	55.305	12.050	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.242	487137.096	49.350	5.997	
MP3	504769.607	487136.013	46.881	7.236	
MP4	504775.961	487137.850	44.007		

Ongoing Coastal Monitoring of Survey Points - Monthly Comparison

Whitby West Cliff					
BH2	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance	Slope Distance	Slope Distance
MP1	8.319	8.311			
MP2	7.869	7.874			
MP3	8.655	8.657			
MP4	12.623	12.612			
MP5	11.657	11.665			
MP6					

Scalby Ness					
	Distance to Edge 22/07/09	Distance to Edge 24/08/09	Distance to Edge	Distance to Edge	Distance to Edge
MP1	3.15	3.15			
MP2	4.30	4.30			
MP3	2.66	2.65			
MP4	4.18	4.18			

Scarborough South Cliff (North Section)					
H4	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance	Slope Distance	Slope Distance
MP1	7.206	7.204			
MP2	6.079	6.081			
MP3	9.117	9.114			
MP4	10.317	10.320			
MP5	9.246	9.246			
MP6					

Ongoing Coastal Monitoring of Survey Points - Monthly Comparison (Continued)

Scarborough South Cliff (Central Section)					
E3	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance	Slope Distance	Slope Distance
MP1	10.724	10.724			
MP2	12.989	12.983			
MP3	10.254	10.260			
MP4	13.849	13.855			
MP5					

Scarborough South Cliff (South Section)					
BH2	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance	Slope Distance	Slope Distance
MP1	12.050	12.050			
MP2	6.004	5.997			
MP3	7.211	7.236			
MP4					

Appendix E Installation Photographs

Plate 1. Whitby West Cliff BH2

Plate 2 Scalby Ness MP1

Plate 3 Scalby Ness MP2

Plate 4 Scalby Ness MP3

Plate 5 Scalby Ness MP4

Plate 6 Scarborough North Bay L11

Plate 7 Scarborough North Bay L12

Plate 8 Scarborough North Bay L1

Plate 9 Scarborough North Bay L5

Plate 10 Scarborough North Bay L3

Plate 11 Scarborough North Bay (Oasis Café) BH1I

Plate 12 Scarborough North Bay (Oasis Café) BH1P

Plate 13 Scarborough North Bay (Oasis Café) BH2P

Plate 14 Scarborough North Bay (Oasis Café) BH3I

Plate 15 Scarborough North Bay (Oasis Café) BH3P

Plate 16 Scarborough North Bay (Oasis Café) BH4I

Plate 17 Scarborough North Bay (Oasis Café) BH4P

Plate 18 Scarborough South Cliff I1

Plate 19 Scarborough South Cliff H4

Plate 20 Scarborough South Cliff H6

Plate 21 Scarborough South Cliff G2

Plate 22 Scarborough South Cliff F2

Plate 23 Scarborough South Cliff F4

Plate 24 Scarborough South Cliff E3

Plate 25 Scarborough South Cliff E5

Plate 26 Scarborough South Cliff D3

Plate 27 Scarborough South Cliff D1

Plate 28 Scarborough South Cliff Bh2

Plate 29 Scarborough South Cliff I2

Plate 30 Scarborough South Cliff I2A

Plate 31 Scarborough South Cliff H2

Plate 32 Scarborough South Cliff H1

Plate 33 Scarborough South Cliff H5

Plate 34 Scarborough South Cliff 1 Spa

Plate 35 Scarborough South Cliff 2 Spa

Plate 36 Scarborough South Cliff 3 Spa

Plate 37 Scarborough South Cliff 4 Spa

Plate 38 Scarborough South Cliff G3

Plate 39 Scarborough South Cliff 5 Spa

Plate 40 Scarborough South Cliff F5

Plate 41 Scarborough South Cliff F3

Plate 42 Scarborough South Cliff E2

Plate 43 Scarborough South Cliff E1

Plate 44 Scarborough South Cliff E4

Plate 45 Scarborough South Cliff D2

Plate 46 Scarborough South Cliff Bh3

Plate 47 Scarborough South Cliff Bh4

Plate 48 Scarborough South Cliff Bh1

Plate 49 Filey Flat Cliffs A2

Plate 50 Filey Flat Cliffs B1

Plate 51 Filey Flat Cliffs D1

Plate 52 Filey Flat Cliffs A3