Ongoing Analysis and Interpretation of Coastal Monitoring Data

Sixth Review of Restricted Suite Monitoring

Geotechnical Interpretative Report

May 2010

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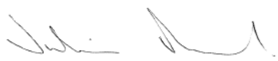
B	Final			
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EXECUTIVE SUMMARY

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. It 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. The report recommended 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 **Sixth Restricted Suite** of monitoring events detailed below. This was undertaken during 6th and 7th April 2010 and follows on from the Second Additional Monitoring Suite (March 2010).

At the majority of sites, little or no ground movements have been identified by the remaining, installed instrumentation during the period of monitoring so far undertaken. Monitoring data from the inclinometers at Whitby West Cliff and Filey Flat Cliffs have so far shown that no discernible ground movements have occurred within the slopes at these two sites (although survey pegs at Whitby have recorded surface movements of +13mm since October). The results of inclinometer monitoring in Scarborough North Bay indicate the slopes above the Oasis Café are presently in a stable condition in the vicinity of the inclinometers although no data is available for The Holms. At South Cliff, monitoring data from the inclinometers and survey pins has generally shown that ground movements are restricted to relatively shallow disturbance around AA08 and AA10, deeper sourced ground movements in AA07 and AA11 and, AA04 with no ground movements indicated.

A summary of observations made from the start of monitoring (July 2009) and observations made since the last monitoring event of April 2010 are presented below in Table 1.

Table 1 Summary of Site Observations

SITE	Observations made since last Monitoring Event (January 2010)*	Total observed movement since first Monitoring Event (July 2009)
Runswick Bay	A001 shows 2-3mm movement from 22.0 to 20.0 metres depth. A004 shows 5mm movement from 10.0m depth, reaching a maximum of 15mm at 2.0m depth. Groundwater relatively static	5mm movement indicated in A001 between 22.0 and 20.0 metres depth. 5mm movement indicated in A004 from 10.0m depth increasing to 15mm at 2.0m depth. Groundwater relatively static
Whitby West Cliff	Survey points not monitored since December. Inclinometer indicates slopes are stable around vicinity of BH2.	Survey pins show -7mm movement in top one metre of ground. Inclinometer indicates slopes are stable.
Oasis Cafe	Previously reported movements of December now considered as erroneous readings. Slopes are indicated as stable. BH1 lost to construction in Jan 2010.	Slopes stable, limited movement of <4mm indicated in BH1 and 3.
North Bay	No coverage of The Holms area	No coverage of The Holms area
South Cliff	Survey points not monitored since December. AA04 shows no further movement AA07 shows <3mm movement from 60.0 to 26.5 metres AA08 shows <2mm movement from 6.5 to 6.0 metres AA10 shows further movement in top 3.50m of ground AA11 shows <2mm movement from 19.5 to 14.0 metres depth Continued development of cracks in pavements	AA04 shows 2mm movement in top 7.0m of ground AA07 <3mm movement from 60.0 to 26.5 metres AA08 shows <2mm movement from 6.5 to 6.0 metres AA10 shows 4mm movement in top 3.50m of ground AA11 shows <3mm movement in top 3.0m of ground
Knipe Point	Slower recession rates of Cornellian, Knipe Point and limited at A165 headscarps.*	New instruction for March 2010
Filey Flat Cliffs	BB02 shows 3mm movement from 12.5 to 10.5 metres and 2-3mm movement at 19.80 metres. Continued development of cracks in road surfaces	BB02 shows 3mm movement from 12.5 to 10.5 metres and 2-3mm movement at 19.80 metres. Continued development of cracks in road surfaces

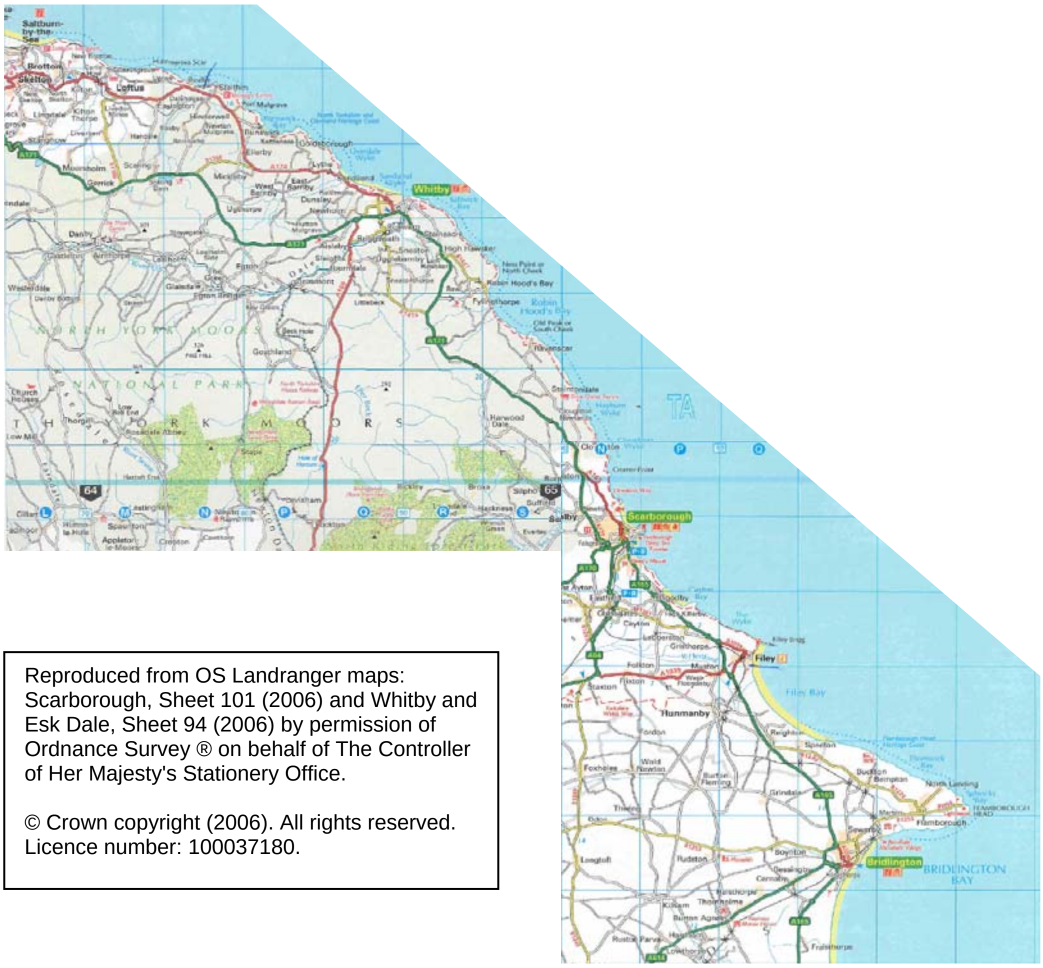
* - Landslip along A165 in January 2010 is outside of monitoring area.

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



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

'Restricted' Suites. Table 2 details the frequency of Full and Restricted Suite monitoring to be carried out over this period.

Table 2 Frequency of Ongoing Monitoring

YEAR	MONTH	SCOPE OF MONITORING
ONE (2009-10)	July (1)	Full Suite
	Aug, Sept, Oct, Nov (2,3,4,5)	Restricted Suite
	Dec (6)	Full Suite
	Feb, Apr (7, 8)	Restricted Suite
	June (9)	Full Suite
TWO (2010-11)	Dec (10)	Full Suite
	June (11)	Full Suite
THREE (2011-12)	Dec (12)	Full Suite
	June (13)	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.

Further to heavy rainfall experienced in December 2009, recommendations were made to SBC to undertake additional Full Suite monitoring events in order to comply with recommendations of monitoring frequency previously stated (Mouchel Report No. *721228/001/GR/01/02/FINAL)*. These events were carried out in January and February 2010, reports detailing the findings of the **First and Second Additional Suite** monitoring events were published in February and April 2010, respectively.

In addition to the sites noted above, Runswick Bay has been included for monitoring from February through to July 2010 due to suspected ground movements observed within inclinometers A001 and A004 from monitoring data in December 2009. SBC initially 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. However, Mouchel is now monitoring Knipe Point at monthly intervals from March to August, in October and, from December 2010 at six monthly intervals up to June 2012.

Following each 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 7 within the relevant chapters and exploratory holes location plans, identifying 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, the majority of these instruments continue to be monitored with a dip meter to provide an indication of groundwater levels.

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

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.

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.

Departures from this monitoring regime were evident where remedial works had not been undertaken at a site, where there were significant 'gaps' in monitoring data from a site and following periods of heavy and prolonged rainfall. The definition of '*significant rainfall*' has been developed through the analysis of rainfall data records (made available by the EA and SBC) and quantified within the context of the effects of such an event on the present monitoring regime frequency. A definition of heavy / prolonged rainfall events was investigated in terms of determining statistically derived values of daily rainfall per month for the period 1995/8 to 2008/9. Limiting values of rainfall in terms of how much rainfall, within a 24 hour period, can occur before advising that site inspections should be undertaken were identified. To this end, having reviewed the rainfall data, the 75th percentile was calculated as a threshold value. This showed that 75% of daily rainfall was below this value and the remaining 25% of rainfall exceeded this amount.

In the event that the 75th percentile of daily rainfall values (a period of heavy / prolonged rainfall) are exceeded, it was recommended to carry out monitoring one week after the end of the rainfall event and at monthly intervals thereafter for three months. Further to the heavy rainfall experienced in December 2009, these recommendations were followed by SBC as Mouchel were invited to undertake additional monitoring events (in January and March) in order to comply with monitoring recommendations. The additional monitoring suites have been reported on and reports have been issued to SBC February and April 2010.

1.5 Scalby Ness Slope Failures

A site visit to Scalby Ness was conducted on 21st April 2010, during this visit a slope failure was noted as having occurred near the base of the North West facing slopes of Behavioural Unit I. This failure had developed between two scheduled monitoring visits of 2nd March and 21st April 2010.

Observations of the slope failure made from the site visit are:

- The slopes are composed of glacial tills with unknown amounts and origins of made ground (asbestos sheet fragments and glass bottles are obvious on the surface).
- The failure consists of a shallow type slip (2 metres depth) up to 10 metres in height from current water level of river and at the base this extends some 7-8 metres from edge to edge.
- There are several ground water issues which would seem to be issuing from half way up the failure surface although the origins are not actually visible.
- To the right of the failure (Plate 3, Appendix G) there is some undisturbed ground beyond which there is another slip failure of lesser extent. The ground between the two slips is evidently unstable and likely to fail imminently (Plate 5, Appendix G) leading to a larger scaled failure which will probably propagate up slope.
- Above the backscarp there are tension cracks present following the shape of the fresh slip face extending some 5 metres above. There are ground water issues presently discharging over the surface at several

locations and some coincident with tension cracks. The groundwater will help to lubricate any failure surfaces present leading to further failures. Tension cracks are well developed, open (up to 150mm wide) and can be seen to be at least 300mm in depth. From their appearance it is evident that further slip failure of the slopes will occur in the near future.

- A combination of the two previous features noted above will lead to a greater chance of failure in the slope which could well extend at least half way up the slope face. If a failure occurs it is possible this may propagate higher up the existing slope leading to recession of the cliff face and loss of land, bringing this closer to the properties.

- A lobe of glacial till / made ground has formed extending across a third the width of the river (Plate 6, Appendix G).

- At the time of inspection there was a falling tide. The river is tidal beyond the point of the failure which will adversely affect the toe of the slopes (rapid draw-down, toe washout and erosion, etc).

A walkover of the slopes of Behavioural Unit II and III revealed further development and widening of tension cracks over the mid-slope areas (Appendix G, Plate 1) of the former unit. Ponded water levels in this area were noted to have fallen noticeably and issues from this were observed on the slopes lower down. Immediately below the southern plateau of the latter unit (Behavioural Unit III) a relict slope failure is evident where the cliff headscarp has receded and dropped some 500-600mm. This feature has recently been exposed by the clearance of trees in this vicinity (Appendix G, Plates 7 and 8) although this feature is not a recent occurrence. The de-vegetation of slopes such as these can lead to an increase in slope instability and reduced factors of safety. Further loss of vegetation cover, whether accidental or deliberate, should be discouraged.

Following the discovery of slope failures and associated features on the North West side of Scalby Ness, Mouchel recommended to SBC that a series of walkover surveys should be carried out immediately on a weekly basis for four weeks in order to observe and collect data on this slip in order to formulate a long term strategy. Each event was to pick up all salient slope features such as tension cracks in the slopes and the plateau above, ground water issues, etc and published as a letter style report. SBC have chosen not to undertake this course of work but to include this area into the Cell 1 Project with the installation of virtual recession points and analysis in line with other Cell 1 cliff top monitoring at some time in the future. In addition, SBC are to carry out observations of this site outside of the scheduled monitoring events currently made by Mouchel.

2 Runswick Bay

2.1 Site Location and Description

Runswick Bay is situated on the north east coast of England some 16 km north west of Whitby town at NGR NZ 800 160. It is formed between the headlands of Caldron Cliff to the north and Kettleness to the south and comprises a deeply indented sandy bay approximately 2 km in length. The bay is backed mostly by cliffs and steep glacial till coastal slopes. The village of Runswick Bay is developed within the general valley formed by the Runswick and Nettledale Becks. The village straddles the boundary between the glacial till slopes which occupy most of the bay and the Jurassic shale and sandstone cliffs to the north. Most of the village is founded on weathered shale but properties to the southern edge and the access road (Runswick Bank) and car parks are founded on glacial till landslide debris. The village is fronted by four separate sea defences, of varying age and construction, which stretch from Runswick Beck north of Caldron Cliff around to Nettledale Beck to the south.

Figure 2. Site Location - Runswick Bay

2.1.1 Historic Review of Problems

Runswick Bay has a long history of slope instability, the first recorded slope failures occurred in 1682 when the whole village, located further north than at present, collapsed towards the shore. Successive landslips of varying severity occurred in 1873, 1953 and, in 1958 when the old road was closed twice in one week due to landslides. This road was abandoned in 1961 with the construction of a new access road constructed further to the west between 1961 and 1963, on its present alignment. Around the same time a sea wall extension and new car park were constructed at the base of this road. Landslips and rockfalls were experienced immediately north of the village during the 1970's, including a landslip at Rose Cottage in 1975, resulting in the loss of various, limited assets.

A mass concrete sea-wall constructed in 1970 provided coastal protection to the southern edge of the village, access road and car park areas. Since its' construction, the sea-wall was subjected to a combination of marine and land based erosional mechanisms causing the wall to move in a seaward direction with backwards rotational tilting. Sea-wall deterioration and failure has been caused by earth pressure loading from slope failures behind the wall, beach erosion exposing the toe of the wall and wall toe failure of the fractured and folded shale bedrock.

Three areas of slope instability have been identified within Runswick Bay which have influenced the failure of the previous sea-wall and other sea defences and are still having an effect. These areas are identified in Figure 3 and are described as being:

- Upgarth Hill – The Upper Lias shales and sandstones of the Saltwick Formation forming the cliffs below Upgarth Hill are covered by a thin mantle of glacial clay. Intact cliffs stand at angles of 50 to 70 degrees whereas previous failures have led to slopes of talus debris standing at 20 to 30 degrees with light vegetation cover. The toe of the east facing slopes are protected by a concrete sea-wall and the toe of the south facing slopes are continually being undercut by Runswick Beck which forms an incised valley with over steepened sides to the north east of Runswick village.

- Topman End – is located immediately north of the village, with heavily vegetated, glacial slopes characterised by a network of scarps and transverse tension cracks behind small superficial failures. Slope angles vary between 30 and 40 degrees, decreasing to 5 to 10 degrees mid-slope. These superficial failures are caused by the entrapment of excessive ground water.

- Ings End – this area extends from south of Nettledale Beck to Limekiln Beck a distance of approximately 500 metres over an area known as Dother Pits. Sub-vertical headscarps, formed in glacial tills, are present below the cliff tops between the two becks. Below this scarp are a series of undulating slopes formed by the retrogressive failure of deep seated basal shear planes along the shale bedrock. The slopes can be divided into three distinct zones characterised by uneven ground, ponding water, irregular springs and streams and dense vegetation. Slope angles vary between 15 and 20 degrees with the crests of individual landslide blocks well defined by breaks of slope at lesser angles of between 5 and 10 degrees. Subsequent failures have been triggered by the destabilising effect of an initial failure caused by undercutting of the leading block by progressive coastal erosion. The back scarp areas of the landslip complex has been found to contain saturated sand layers and lenses which are thought to be supplied by the sandstone present further inland. Groundwater seepages have been experienced, during ground investigations, from the basal backscarp areas and from within disturbed shales immediately below the glacial tills some distance from the slope toe.

Due to the ground movements detailed, it became evident by 1998 that the sea-wall was in danger of imminent collapse which would have lead to large scale landslip failures and loss of amenities in the village. Accelerated movements of the sea-wall, particularly at the southern end, eventually lead to the structure being replaced by a rock armoured revetment and an intermediate compressible buffer zone.

2.1.2 Site Walk-over

An initial site walkover was undertaken by a geotechnical engineer from Mouchel on 28th November 2008 and, in early June 2009 as part of the Condition Survey. The Condition Survey (Mouchel Report No. 721229/001/CSR/02/FINAL, July 2009) was conducted in order to provide factual information on the existence, condition and functionality of the existing installations. The instruments were recorded as being in good working order and as such, they were deemed to be of use in providing useful ongoing data for recording ground movements where this phenomenon occurs.

2.1.3 Topography and Geomorphology

The village of Runswick is situated at the foot of a steep, 80 metre high bank and has a long history of slope instability. It occupies the northern end of the bay in a confined site bounded by Nettledale Beck to the south and Runswick Beck to the north.

The geological structure of the bay is inferred to be derived from a shallow syncline trending north-south and shallowing westwards away from the coastline. This feature forms a buried glacial channel extending some distance inland. The southern side of the village comprises the main access road with car parking facilities beyond as far as Nettledale Beck. This area is founded upon the glacial till deposits which appear actively unstable, based on the surface morphology. Beyond Runswick Beck which forms the northern limit of the village lies sheer cliff headland of Middle Jurassic sandstones and ironstones which lie unconformably on Lower Jurassic shales. These shales form a wave cut platform below the foot of the cliffs at the north end of the bay.

2.1.4 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, pp9-10.* Additional reports were provided by SBC for further consultation by Mouchel for the Ongoing Analysis. This data has been placed on an Arcview GIS layer for ease of use and availability.

2.2 Stratigraphy

The published geological map of the area 1:50,000 British Geological Survey (BGS) Sheet 34 Solid and Drift Guisborough indicate the site is underlain by superficial deposits of glacial till (Boulder Clay). These comprise stiff silty sandy clays, sands and gravels and laminated stiff silty clays. The solid succession of the area is indicated as Middle Jurassic sandstones (Saltwick Formation) and ironstones (Dogger Formation) (rocks of the high cliff headland north of the village) which lie unconformably on Lower Jurassic shales (Whitby Mudstone Formation). The shales are exposed as a wave cut platform, dipping at 2^{o} in a southerly direction, at the front of the cliffs along the north of the bay. The map indicates a north-south trending fault passing beneath the village and across the upper beach area to the south, with down throw and inclination to the west.

2.3 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.

2.4 Instrumentation

2.4.1 Definition of Existing Problems

Since the failure mechanisms affecting the old sea-wall and car parks were identified during the late 1990's, remedial works were instigated and completed in 2001.

The reduction in the rate of displacement of the land-slipping is evidence that the permanent works which comprised of drainage and earthworks, undertaken on the slopes to the north of and at the toe of the slopes below Ings End, have had a positive effect upon increasing slope stability. The greater significance has been the re-orientation of the vector angle of slope movement in a clockwise direction, in a more easterly direction. It is envisaged that following prolonged periods of heavy rainfall, the slopes would continue to fail. However, the probability and risk to village infrastructure of deep seated failures occurring in the future is considered low due to the stabilising effects of the piling and earthworks.

2.4.2 History of Monitoring

Data provided by SBC indicated, from reports, that there had been several ground investigations undertaken at Runswick including those between 1967 and 1998. However, although details of the specific ground investigations are not available, the locations, depths, general stratigraphy, water regime and general remarks for boreholes drilled were derived from numerous records held by SBC.

Coastal protection and slope stabilisation incorporating remediation works to the sea wall and car park areas was completed by April 2001. In March 2000, 4no inclinometers were installed into piles to a maximum depth of 20 metres within bored pile portal frame shear keys. These instruments had been periodically monitored from this date onwards although monitoring records were only available from March 2000 to July 2002 and for 20th November 2008. The instruments may have been monitored through the intervening periods although data was not made available to confirm this.

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 Runswick Bay were that a regime of regular monitoring and inspection be undertaken at six monthly intervals (bi-annually). This should 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. The monitoring encompasses recording readings of inclination in two directions (A0 and A180) within the inclinometer tubes and also monitoring groundwater levels.

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. Taking into consideration the findings of the *Condition Survey Report,* the monitoring regime consists of the existing inclinometers (A001, A002, A003 and A004) located along the edge of the main access road leading down into Runswick village. The instruments were monitored using a Vertical Digital Bluetooth Inclinometer system (MkII) and a TDS Recon 200 PDA. Groundwater was measured using a dip meter.

In light of the suspected ground movements reported from previous monitoring visits (December 2009 and January 2010), it was recommended that the Runswick Bay site should be monitored more frequently, on a monthly basis, for a minimum period of six months. With additional monitoring events, this would provide monitoring data (covering the period December 2009 to July 2010) with which to more confidently identify and interpret the nature and rates of any ground movements occurring at Runswick Bay.

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. Monitoring at Runswick Bay has taken place on numerous occasions, the first in July, December 2009 and monthly from January to April 2010.

The initial visit collected 'baseline' readings against which all successive readings are compared. The latest readings indicate some movement has occurred within inclinometers installed in A001 and A004. Within A001, 5mm of incremental movement is indicated between 22.0 and 20.0 metres depth and in A004; 5mm incremental movement is indicated from 10.0m depth increasing to 15mm at 2.0m depth. In each installation the ground movements are indicated as taking place in a down slope direction.

Inclinometer readings are presented in Appendix B of this report.

Groundwater Readings

Groundwater levels have been recorded on several occasions between June 2009 and April 2010. A comparison of the readings shows very little change in groundwater levels occurring over this period. Where fluctuations in borehole water levels have been recorded, these are probably in response to changing groundwater levels. Groundwater readings are presented in Appendix C.

2.6 Conclusions

Inclinometer instrumentation was installed within the piles of a portal frame shear key system which was constructed as part of remedial works to restrict ground movements within the Runswick Bay area. Inclinometers were installed in piles in order to measure shear stresses within the piles caused by ground movements. Within Report 136 (from SBC) reference has been made to the determination of the piles response to loading from successive inclinometer readings. It has not been stated how this was to be done or how it was to be achieved. To date, Mouchel Ltd have been made aware by the Client that this information is not available and therefore no further comment can be made relating to this. Hence, initial and successive inclinometer readings are related to any general ground movements indicated by instrument readings.

Successive readings from December 2009 indicated that some movement had occurred within inclinometers installed in boreholes A001 and A004. Within A001, 5mm of movement was indicated at the base between 22.0 and 20.0 metres depth and in A004; 5mm movement was indicated from 10.0m depth increasing to 15mm at 2.0m depth. Readings from January to March 2010 indicated this pattern of movement to be repeated, although to a lesser degree of 2-3mm between 22.0 and 20.0 metres depth.

The data recorded in April 2010 has again followed a similar pattern to that previously identified of 5mm of movement at the base between 22.0 and 20.0 metres depth. In each installation the ground movements were indicated as taking place in a down slope direction. Inclinometer data from A002 and A003 has so far indicated that no ground movements have taken place in and around the vicinity of these instruments.

Groundwater levels recorded from the inclinometers have remained relatively stable since monitoring began in June 2009. These results would be expected given that the instruments are installed within concrete piles of unknown diameters and as such are 'isolated' to some degree from the natural groundwater regime prevailing at this site.

Successive inclinometer readings taken from December 2009 to March 2010 indicate some movement had occurred within inclinometers installed in A001 and A004. Within A001, 5mm of movement was indicated between 22.0 and 20.0 metres depth, reducing to 2-3mm in the March readings and since increasing to 5mm for April readings. In A004; 5mm movement had been recorded from 10.0m depth increasing to 15mm at 2.0m depth. Readings recorded through to April 2010 plot as identical readings when compared to the 'baseline' reading of July 2009. By replacing this initial reading with the reading from December 2009, successive readings plot as a straight line and hence do not indicate ground movements. This comparison would indicate that there may be an anomaly in the 'baseline' readings of July 2009 which is showing 'apparent' ground movements occurring at the stated depths. It is recommended that this instrument continues to be monitored in order to build on the data already recorded. When applying the same procedure of referencing data to December 2009 readings for A001, the modified results continue to show ground movements at identical depths. In each installation the ground movements were indicated as taking place in a down slope direction. The results from monitoring inclinometers A002 and A003 continue to show that no movement has taken place within the vicinity of these instruments.

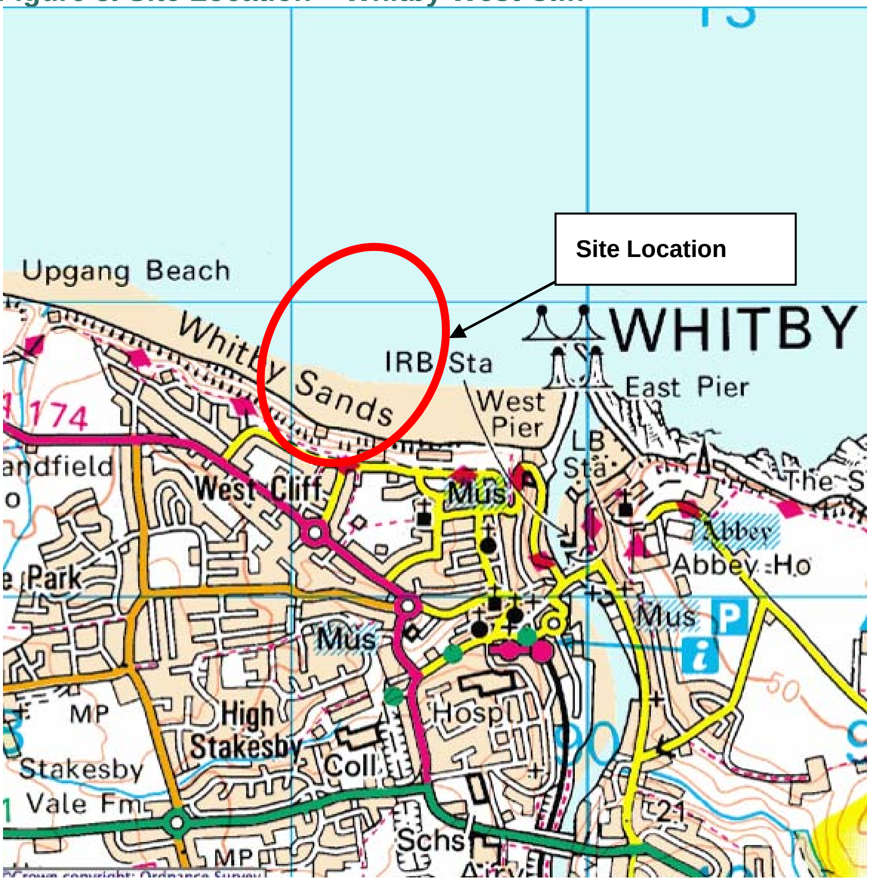
3 Whitby West Cliff

3.1 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.

Figure 3. Site Location – Whitby West Cliff



3.1.1 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.

3.1.2 *Topography and Geomorphology*

The Whitby coastline lies at the eastern fringe of a dissected plateau which forms the North York Moors. During the last glacial period (Devensian), ice sheets spread south and east across this area to the North Sea. As these ice sheets retreated glacial till was emplaced over the landscape, formed of Jurassic rocks, completely infilling pre-glacial valleys and embayments. 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 composed of unprotected, soft glacial till cliffs. The slopes of West Cliff attain a height of up to 40-45 metres at slope angles of 25 to 35 degrees. 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 with thin and bare patches of grasses. At the base of the slopes is a sea wall with a broad promenade, forming a sea defence, with a wide sandy beach foreshore.

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, 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.

3.2 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.

3.3 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.

3.4 Instrumentation

3.4.1 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 functioning slope drainage or burst water pipes.

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.

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 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 on 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.

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 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.

3.5.3 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 shown that little or no ground movement has occurred within the slopes around BH2 at West Cliffs.

Groundwater Readings

Groundwater levels have been recorded on a monthly basis from the Initial Full Suite Survey (9th July 2009) up to the Sixth Restricted Suite Monitoring Survey (6th April 2010). From an initial reading of 7.73 metres bGL (taken on 9th July 2009) consecutive readings have recorded successive rises in water levels up to January 2010. From January to February 2010 a fall in the groundwater level of 440mm was been experienced, a rise of 1040mm occurred up to March and from March to April 2010 another fall in water levels of 560mm was observed. Given that tidal positions are known and observed at the time water readings were taken, this data can be interpreted as reflecting the tidal levels at the time of monitoring. Groundwater monitoring graphs are presented in Appendix C.

Survey 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 monthly between July and December 2009 and showed that over a distance of 49metres, -7mm of surface movement had occurred during that period.

The survey points are programmed to be monitored next in June 2010. Readings from the survey points are presented in Appendix D.

3.6 Conclusions

Previous inclinometer data (22 March 2001 to 28 November 2005) illustrated the occurrence of surface creep taking place within the top 1.50 metres of ground. Although current inclinometer readings do not reflect this type of movement, ground movements of up to +13mm, in a down slope direction, have been recorded by survey pins within the surface of the slopes between October and November 2009. During the previous period, from September to October, a difference of +11mm was recorded illustrating that there is some differential fluctuation in ground movements. The total recorded movement within the slope is -1mm, measured between July and November 2009. The variation in spacing between the survey pegs could be accounted for by seasonal temperature fluctuations and not wholly representative of ground movements.

Groundwater levels within BH2 are influenced by and reflect the tidal regime. Successive results would seem to confirm this as the tidal condition is know and observed at the time readings are recorded.

Monitoring data from the inclinometer installation in BH2 has so far shown no discernible ground movements within the slopes at West Cliff. A slight deviation was evident in the second set of inclinometer readings and was interpreted as being attributed to the use of a different probe for the recording of readings rather than an indication of ground movements. Successive readings recorded between October 2009 and April 2010 confirm this as these plots follow the first set of readings and illustrate no indication of ground movement. The inclinometer data, recorded so far, currently indicate the slopes within the vicinity of BH2 to be in a stable state.

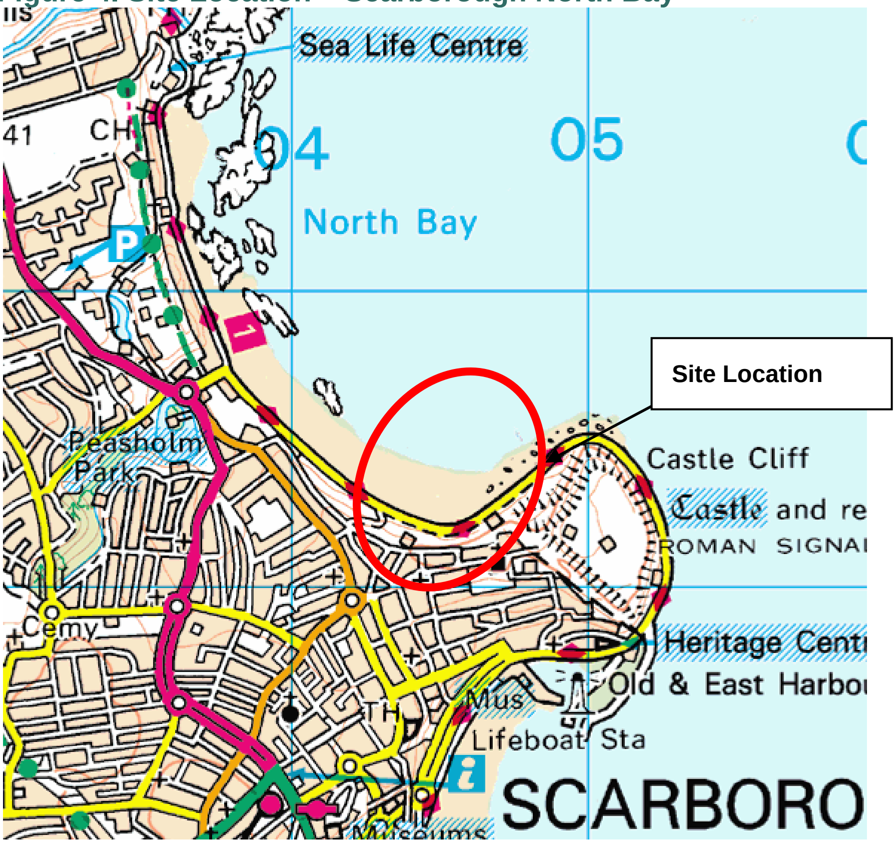
Due to the limited coverage of the site offered by the single inclinometer, there is the possibility of undetected ground movements occurring elsewhere along the site of West Cliffs.

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



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 17 metres 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, comprised of a deep-seated landslide which 'daylights' close to foreshore level.

A western unit, composed of a shallower landslide which 'daylights' approximately 1.50 metres 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. This data has been placed on an Arcview GIS layer for ease of use and availability.

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.

Newly installed instrumentation was located above an existing café near Clarence Gardens, in order to monitor the steep slopes above and behind this and the proposed site of relocating this facility. These instruments have been included in the existing monitoring regime for North Bay.

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 and 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. In consideration of the findings of the *Condition Survey Report*, 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.

Inclinometers L4 and L6 at The Holms were located by SBC staff although the integrity of these was such that they were unsuitable for monitoring purposes other than to provide groundwater levels data.

Additional installations comprising 3 No. inclinometers and 4 No. piezometers located on slopes above The Oasis Café, North Bay were included in the monitoring regime in August 2009. Instruments BH1P and 1I are no longer available to monitor following the construction of a new café building in early January 2010.

4.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometers L4, L6, L11 and L12 and slip indicator in N2 have been proved to be sheared / blocked at various depths and hence, readings have not been taken from these instruments. Inclinometer 1I was lost to construction works in early January 2010. Inclinometers (3I and 4I) above The Oasis Café continue to be monitored within the regime of North Bay.

Groundwater Readings

Groundwater levels have been recorded on a monthly basis from the Initial Full Suite Survey (9th July 2009) up to the Sixth Restricted Suite Monitoring Survey (7th April 2010). Across The Holms, groundwater levels recorded since March have been fairly static, showing no or very little fluctuation. Groundwater levels recorded in L1 show a reduction of 540mm and 350mm in the two instruments, both are attributed to a change in tidal levels. Also, within L11 and L12 rises in groundwater levels of 1330mm and 380mm, respectively have been recorded and a rise of 50mm was noted in L3b. Instrumentation installed above the Oasis Café area has reflected a decrease of the groundwater regime except BH4P which has recorded an increase in water levels of 300mm since March 2010. Groundwater monitoring graphs are presented in Appendix C.

4.6 Conclusions

Incremental inclinometer data from BH4I (Oasis Café) appears to indicate very slight ground movements of less than 2mm at a depth of between 12.0 and 10.0 metres (bGL) within glacial till deposits. Data from BH3 indicates no movement has occurred, although readings from December 2009 show apparent movement within the inclinometer. These movements are considered as erroneous and not indicative of true ground movements. Inclinometer BH1I is no longer operable, being lost to construction works in January 2010.

The results of inclinometer monitoring indicate that slopes above the Oasis Café are presently in a stable condition within the vicinity of the inclinometer instruments. However, due to the limited coverage of the site offered by the inclinometers at Oasis Cafe, there is the possibility of undetected ground movements occurring elsewhere in North Bay. There are no inclinometers capable of recording ground movements across The Holms area although piezometers installed within this site have mostly sheared at varying depths and thus indicate probable active ground movements.

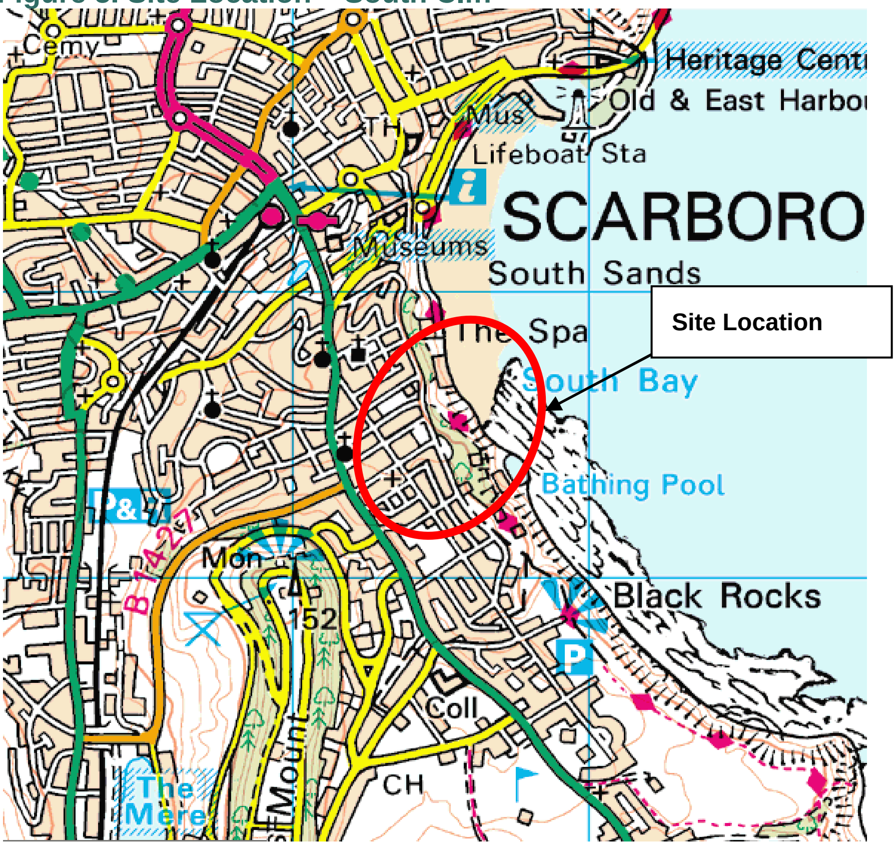
Groundwater levels within borehole L1 would appear to be affected by tidal influences. In general, the instrumentation across The Holms is considered inadequate to provide reliable data on groundwater levels; there being only two operable piezometers across this site at present. Elsewhere piezometers at Clarence Gardens demonstrate reductions in groundwater levels though the highest lying of these (BH4P) shows an increase in groundwater levels occurring within these slopes.

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



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.

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 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.

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, eighteen piezometers and three lines of survey pins (associated with boreholes H4, E3 and BH2) located within the various gardens of South Cliff.

The reduced monitoring regime is based upon the findings of the *Condition Survey Report* which, in addition, also includes non-intact inclinometers which continue to be monitored for groundwater levels only.

5.5.3 Ongoing Monitoring Results

Inclinometer Readings

Inclinometers readings have been undertaken in accordance with the procedures detailed in Section 1.3 of this report and are presented in Appendix B. Readings have so far illustrated the occurrence of very slight ground movements within several inclinometers at South Cliff.

Groundwater Readings

Groundwater levels have been recorded from the Initial Full Suite Survey (15th July 2009) up to the Sixth Restricted Suite Monitoring Survey (7th April 2010). A comparison of the readings show a wide variation in groundwater depths illustrating changes in the groundwater regimes active across the sites of South Cliffs. Groundwater monitoring graphs are presented in Appendix C.

SBC have recently provided information regarding boreholes installed behind The Spa Complex (SBC Report No. 273). Boreholes 1 to 5 (drainage wells) were installed in the early 1990's on the slopes behind The Spa Ocean Ballroom in order to drain the slopes and hillside thereby reducing groundwater levels and prevent the build-up of pore water pressures behind the ballroom retaining wall.

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 between August and December 2009 and showed that at H4, over a distance of 42 metres, a total of 4mm of surface movement had occurred during that period, at E3 a total of 19mm of surface movement had occurred over 47.8 metres and at BH2, over a distance of 25 metres, 6mm ground movement had taken place. Survey point monitoring was last carried out in December 2009, the next event is scheduled for June 2010.

5.6 Conclusions

The most recent suite of monitoring data from inclinometer readings generally indicates little ground movements occurring within the slopes of South Cliff gardens. Inclinometers AA04 and AA11 demonstrate that no movement has occurred within the vicinity of these instruments since the last monitoring suite of March 2010. Within inclinometer AA10 ground movements of 2-3mm are apparent from 3.5 metres depth to ground level. This movement has occurred in made ground and is probably evidence of surface creep. Additionally, ground movements are evident in AA08 where <2mm movement is illustrated in Glacial Till from 6.5 to 3.0 metres depth. Deeper ground movements are evident in AA07 where <3mm of movement is illustrated between 30.0 and 26.5 metres depth which coincides with the presence of alternating bands of sandstone and siltstone.

Due to the limited coverage of the site offered by the reduced number of inclinometers, there is the possibility of undetected ground movements occurring elsewhere particularly along the promenade (cliff top) where the majority of instruments are recorded as having failed or blocked.

Piezometer instruments located behind The Spa area and extending southwards to Holbeck Gardens of South Cliffs have generally recorded decreases in groundwater levels in comparison to the previous monitoring event of March 2010. The only exceptions to this have been displayed in BH1 Prom, G1b, D2b and E2 which have recorded increases in groundwater levels. Each of these installations is located near to or on the promenade of South Cliffs at depths varying between 5.0 and 19.0 metres bGL. Water levels within inclinometer instruments AA01, AA03, AA09, AA06 installed along the Promenade and AA10 and AA11 installed within South Cliff Gardens have experienced increases in water levels of up to 1.70 metres. It would seem that the results of groundwater monitoring across the gardens of South Cliff have not illustrated the expected general increases in water levels in response to the high rainfall experienced near the end of March 2010. This may be due to the low permeability of the glacial soils, present across the whole of these coastal slopes, retarding the infiltration of groundwater and the response of piezometers to rainfall events.

Groundwater readings may be influenced by blocked drainage or other external influences. Discounting the 'exceptional' readings recorded from inclinometers, in general the groundwater monitoring results to-date reflect fluctuations in the prevailing groundwater regime within the various horizons into which piezometers have been installed.

Ground movements are evidently on-going within the slopes of South Cliff gardens. At Spa Cliff the effects of ground subsidence is apparent where cracking has occurred in the pavement along the promenade to the south of BH01 Prom. This part of the cliff top is immediately above an arcuate embayment formed from a past deep-seated retrogressive rotational failure. This has left mid-slope benches with a steep rear scarp up to the promenade. At other locations within the gardens, there is evidence of slope movements as seen in hummocky ground in slopes, collapsed edging stones to pavements and pavement cracking. Tarmac surfaced pavements behind the Clock Tower Café display evidence of slope instability where cracked pavements are present below which the slopes display bulging and have a hummocky ground appearance. The pavements here have since been replaced with fresh tarmac construction and the cracks can no longer be observed for further development. However, a series of monitoring survey pins have been installed across the slopes in this locale for short term monitoring purposes as well as a topographic survey of the slopes. A programme of monitoring the pins has yet to be established with SBC.

Due to the limited coverage of the site offered by the reduced number of inclinometers and slip indicators, there is the possibility of undetected ground movements occurring elsewhere particularly along the promenade (cliff top) where the majority of instruments are recorded as having failed (blocked / sheared).

6 Knipe Point

6.1 Site Location and Description

Knipe Point is a promontory located at the north of Cayton Bay, 3.5km south of Scarborough and 7km north of Filey, on the north east coast of England. Set back beyond the promontory the main coastal route (A165) between Scarborough and Filey follows an almost parallel course to the coastline. From the A165, north of Tenants' Cliff, to Knipe Point a series of holiday homes occupies the crest and the southern side of the promontory. The land north of the crest and the holiday homes complex is given over to agriculture. Osgodby Village is located immediately west of the A165.

Figure 7: Site Location

6.1.1 *Historic Review of Problems*

The landslide complex at Knipe Point abuts the steep sided ridge to the north and Tenants' Cliff landslide complex to the south. The landslide complex comprises a series of retrogressive rotational slides developed primarily in the glacial till deposits, with a deep-seated basal shear surface within the Oxford

Clay, and in the toe area, the Kellaway Rocks. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability. The landslide complex is active with tension cracks and ground displacements evident over much of the area. Ground movements are degradational and appear to be mostly contained within the existing boundaries of the landslide complex.

6.1.2 Site Walk-over

A site walkover was conducted by a geotechnical engineer from Mouchel accompanied by a member of SBC staff on 4th march 2010 in order to determine the extent and range of monitoring required by the client.

6.1.3 Topography and Geomorphology

The relatively erosion-resistant rock outcrops of the promontory Osgodby (Knipe) Point forms the northern most limit of Cayton Bay. The site is bounded by the steep-sided ridge of Knipe Point to the north and Tenants' Cliff to the south. The crest of the promontory trends south west rising in elevation up to the old coast road (A165) and the village of Osgodby. The crest and southern side of this physical feature are occupied by holiday homes which have been present on this site in some form or other since the 1930's. Immediately south of the holiday village the slopes of Cayton Cliffs are present and are continuously encroaching upon this development at an unpredictable rate. The Cayton Cliff landslide complex is developed in glacial tills, up to 30metres thick, overlying the Oxford Clay and Kellaway Rocks. The area is densely wooded with areas of denudation the results of mudslides and ground movements and, ponded water, springs and other features of poor drainage are also present over the slopes. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability.

6.1.4 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, pp89-96* and supplemented by further reports from SBC. Additional reports have been provided by SBC for further consultation by Mouchel for the Ongoing Analysis. 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), underlain by Oxford Clay of up to 36-76m in thickness. This overlies 3-13m of Osgodby Formation calcareous sandstone above a thin (1.5-3m) layer of undifferentiated Cayton Clay Formation and Cornbrash Formation consisting of limestones and mudstones. An unconformity is encountered, beneath which there is 60 metres of the Scalby Formation mudstones and sandstones. Outcrops of strata generally young in a southerly direction, trending north west to south east. A fault trending NNW-SSE dissects the point, truncating the aforementioned strata. The tip of the point comprises the Gristhorpe and Lebberston Members (limestones and mudstones) of the Cloughton Formation.

6.3 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.

6.4 Instrumentation

6.4.1 Definition of Existing Problems

The landslide complex comprises a series of retrogressive rotational slides developed in the glacial till deposits, with a deep-seated basal shear surface within the Oxford Clay, and in the toe area, the Kellaway Rocks. A combination of groundwater seepages from granular horizons within the tills and toe erosion by wave action at the base of the cliffs represents the main mechanisms of cliff instability. The landslide is active, with tension cracks and displaced ground evident over much of the area. These movements are degradational and appear to be restricted to the existing boundaries of the landslip complex, with only minimal failure of the sides and rear scarp.

6.4.2 History of Monitoring

A previous ground investigation was carried out in 1975, as referenced in Report No. 198. This ground investigation comprised four boreholes to various depths across Knipe Point site. The factual report has not been made available, though details of sub-surface geology and hydrogeology were inferred from a MSc. project (Mills, 1981) which included details of this ground investigation.

Mills (1981) carried out a geotechnical investigation at Cayton Cliff which identified three distinct soil units within the glacial tills. These soils comprised sandy coarse units interbedded with laminated and sandy clay tills. These till units are considered to control the nature and mechanism of landsliding as they are likely to be brittle and prone to progressive failure.

A series of fixed ground marker pins forming part of the National Trust (NT) Monitoring network were installed in April 2008. The survey pins were observed to cover the whole area of instability of Knipe Point and Tenants' Cliff. Survey data from this network has not been made available to Mouchel. Cliff recession survey pins, installed along the Cornelian Bay, Knipe Point and A165 head scarp, have been monitored since installation at monthly intervals and this information along with groundwater monitoring data has been made available to Mouchel. Since installation, some of these markers have been lost to ground movements particularly at Cornelian Bay where only two of the original eight markers remain in place.

A photographic record of the site covering Knipe Point has been undertaken on a periodic basis since June 2001 onwards. The photographs record damage caused by slope instability including slip failures, back scars, tension cracks, cracking in paths, pavements and structural damage to footsteps, buildings and retaining walls.

Scarborough Borough Council commissioned a ground investigation, in late 2008, involving the drilling of boreholes and installation of piezometer and slip-indicator instrumentation.

6.5 Monitoring Regime

6.5.1 Recommended Monitoring Regime

During early 2008 the main landslide complex at Knipe Point became reactivated resulting in the retreat of the south facing head scarp up to existing property boundaries. The increased development of the head scarp eventually led to the demolition of three properties (No.s 21, 23 and 24) and the distinct possibility that more properties could be similarly affected. A detailed ground investigation including the installation of 6 No. piezometers and slip indicators was commissioned over this site in late 2008. These instruments along with weather station monitoring and cliff recession points along the Former A165 (old Filey road), Knipe Point Headland and Cornelian Bay Headland have become part of the Coastal monitoring regime from March 2010. The site is to be monitored at monthly intervals from March to August 2010, in October and, from December 2010 at six monthly intervals up to June 2012.

6.5.2 Ongoing Monitoring Regime

The monitoring regime includes groundwater levels from the existing boreholes except BH02 and BH03 which are blocked due to ground movements at depth and, BH04 which gradually collapsed into a void which formed at ground level in late February 2010; possibly the result of a heavy period of rainfall on or around 26th February 2010.

6.5.3 Ongoing Monitoring Results

Mouchel began monitoring at Knipe Point under a new instruction from SBC, from March 2010 onwards. Monitoring data and a photographic record are ongoing exercises carried out in a similar manner to that previously undertaken on behalf of The National Trust (NT) along with surveying cliff top marker pins and retrieving data from the automatic weather station.

Groundwater Readings

Groundwater readings recorded in March and April 2010 are presented in Appendix D.

Survey Point Readings

A survey of the recession survey points is undertaken at regular intervals as described in section 6.5.1. and are presented in Appendix E.

Weather Records

Continuous rainfall, air and ground temperatures are recorded on site by an automatic weather station located within the residential area of the site. Data from this is to be downloaded in April 2010 following a hand-over meeting with NT and SBC. A photograph of this equipment is presented in Appendix H, Plate 15.

6.6 Conclusions

Knipe Point was introduced into the coastal monitoring programme in March 2010 as a new instruction. A comparison of previously recorded data, collected on behalf of SBC, from February with that of March 2010 indicates that a landward retreat of the Cornelian Bay headscarp is ongoing with made ground failures prevalent as the disappearance and re-positioning of markers C1 to C8 indicates. Also, the fence posts to properties No.s 5 and 6 have been moved landward as recent cliff recession continues to undermine the boundary fence posts. Recent reports and monitoring data on recession rates, available from the National Trust, have also detailed the rates of landward degradation of the headscarps of Cornelian Bay and Knipe Point.

A photographic record of the site, presented in Appendix H, shows the degradation of the headscarps under observation particularly the areas around monitoring points C1 to 8 and H04I to 11I. At Cornelian headscarp most of the original monitoring points have been lost to cliff recession, C1 and C4 are still used although C8 has been repositioned inland and measurements are taken in a northerly and easterly direction. Recession at C8 continues in a northerly direction although eastwards recession seems to have abated, the reduction would seem to be related to drier weather conditions. The slopes are evidently less active with a reduction in ground movements and mudslides as shown in photographs of the site (see Appendix H, Plates 1 to 4). Knipe Point headscarp also shows a continuation of recession rates at a reduced intensity between monitoring points H04I and H11I. This section of cliff has been the most active in terms of recession, leading to the demolition of several properties as the cliff edge has receded. During the previous month recession rates between these points of -5mm to -59mm have been recorded. The greater loss was at H11I which coincides with groundwater seepage, present approximately 5 metres below ground level (Appendix H, Plate 9) and has lead to the development of a mudslide and headscarp recession.

During the survey of April 2010 a ‘fresh’ mudslide was observed on the slopes of Knipe Point immediately below monitoring point H06I. The mudslide can be seen approximately 10 metres below ground level and extends some way down the slopes (Appendix H, Plate 6). Ground water seepages can be observed to be active from this point in the slope and are coincident with the mudslide.

Limited cliff recession of 14mm is also indicated along the A165 headscarp at monitoring point R1. (Comparisons of data from February and that of March 2010 are not entirely consistent as they have been taken by different engineers. Some changes in the methods and manner of data collection are inevitable which can lead to the resulting anomalies). Since the closure of this road, any such failures at this location do not pose an immediate, impending danger to the public or to assets. The headscarp along this section is currently separated from the public and the thoroughfare by a thick blackthorn hedge.

In mid-February 2010, a small landslip, which coincided with periods of heavy snowfall and freeze / thaw conditions, occurred along the Cayton Bay headscarp adjacent to the Former A165. The slope failure resulted in this section of road to be permanently closed to traffic. To date there has been no further development of this slope failure although this feature is located outside of Mouchel’s remit of the Knipe Point site.

7 Filey Flat Cliffs

7.1 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 above which holiday homes and static caravans have been located, accessed by narrow tarmac roads. The site is bounded to the north, west and south by the holiday park and to the east by the cliffs.

Figure 7. Site Location – Filey Flat Cliffs

7.1.1 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.

7.1.2 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.

7.1.3 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.

7.2 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.

7.3 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.

7.4 Instrumentation

7.4.1 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.

7.5 Monitoring Regime

7.5.1 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.

7.5.2 Ongoing Monitoring Regime

The ongoing monitoring regime was initialised in July 2009 and follows that detailed in Section 7.5.1, 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.

7.5.3 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.

Groundwater Readings

Groundwater levels have been recorded at monthly intervals from the Initial Full Suite Survey (8th July 2009) up to April 2010. A comparison of the readings showed maximum variations of groundwater levels within boreholes of up to -30mm BB02 (A2), -1470mm (D1), -270mm (A3) and +310mm (B1). Borehole BB01 (D2) was recorded as dry on each occasion. Groundwater monitoring graphs are presented in Appendix C.

7.6 Conclusions

Monitoring data from inclinometer BB02 (A2) indicates that slight ground movements have occurred within the vicinity of this borehole since the previous monitoring in March 2010. A slight deviation of 3mm, between 12.5 and 10.5 metres depth, is apparent from the inclinometer readings. This disturbance coincides with the presence of a layer of mudstone at this depth. Inclinometer readings also indicate irregular, movement of up to 2-3mm from 8.00 metres depth to ground level.

The single inclinometer offers very limited coverage of the site of Flat Cliffs and there is the distinct possibility of undetected ground movements occurring elsewhere at this site. Previous interpretative reports (provided by SBC) have drawn attention to the fact that there is a lack of valid geotechnical data retrieved from this area with which to build a meaningful geotechnical model and also carry out slope stability analyses.

Between November 2009 and February 2010, monthly monitoring of groundwater has shown that levels across the site have increased in response to high levels of rainfall experienced at Flat Cliffs. Between March and the last readings taken in April 2010, groundwater levels have reduced across the site except in B1 where water levels have continued to remain fairly static from November 2009 at 13.58m AOD to a current high of 13.62m AOD. This piezometer was installed in glacial tills of fine to medium SAND with clay bands (present overlying the bedrocks of the Speeton Clay Formation) in order to target the groundwater regime present.

As porewater pressures increase within the slopes, this can lead to a reduction in the stability of the slopes caused by a decrease in shear strength. These effects are more pronounced during periods of intense, heavy rainfall and where such an event follows a dry period this can cause a sudden increase in pore water pressures in the slopes. Any desiccation and tension cracks which may have developed will permit the ingress of rainwater into the slopes quickly increasing the possibility of slope failure.

Further evidence of ground movements is provided in the form of cracking within the surface tarmac of the access road which has advanced over a short period of time. A repair to the cracks was carried out some time during August 2009 and since then it is apparent that the cracks have continued to develop and widen in line with ground movements. Other evidence of ground movements at Flat Cliffs is the development of a ridge across the top of the access road. This has noticeably increased in size over the period monitoring visits have taken place and continues to develop.

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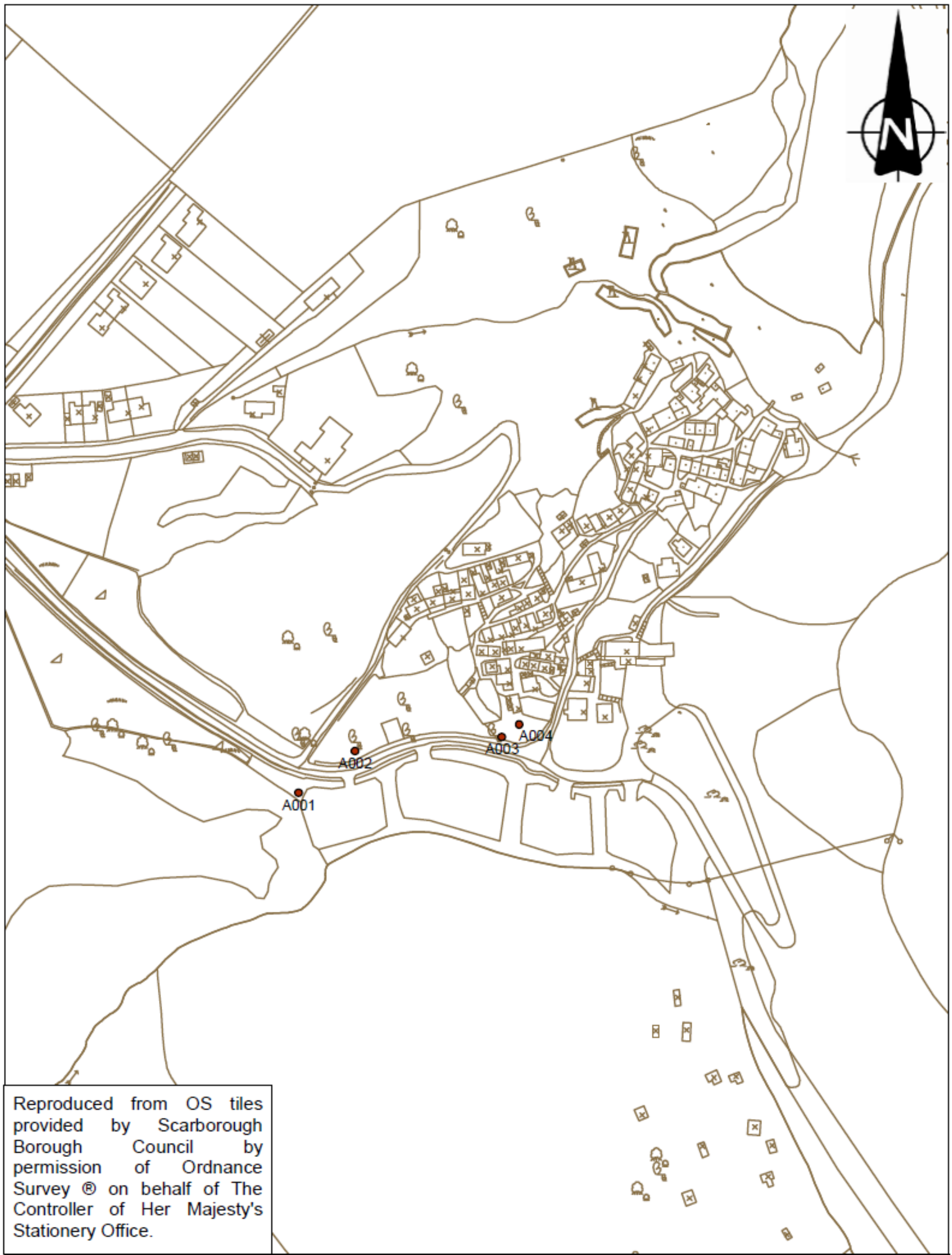
Appendix A Exploratory Holes Location Plans



Runswick Bay Inclinometer Location Plan	Scale: 1:2,500
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data	

mouchel

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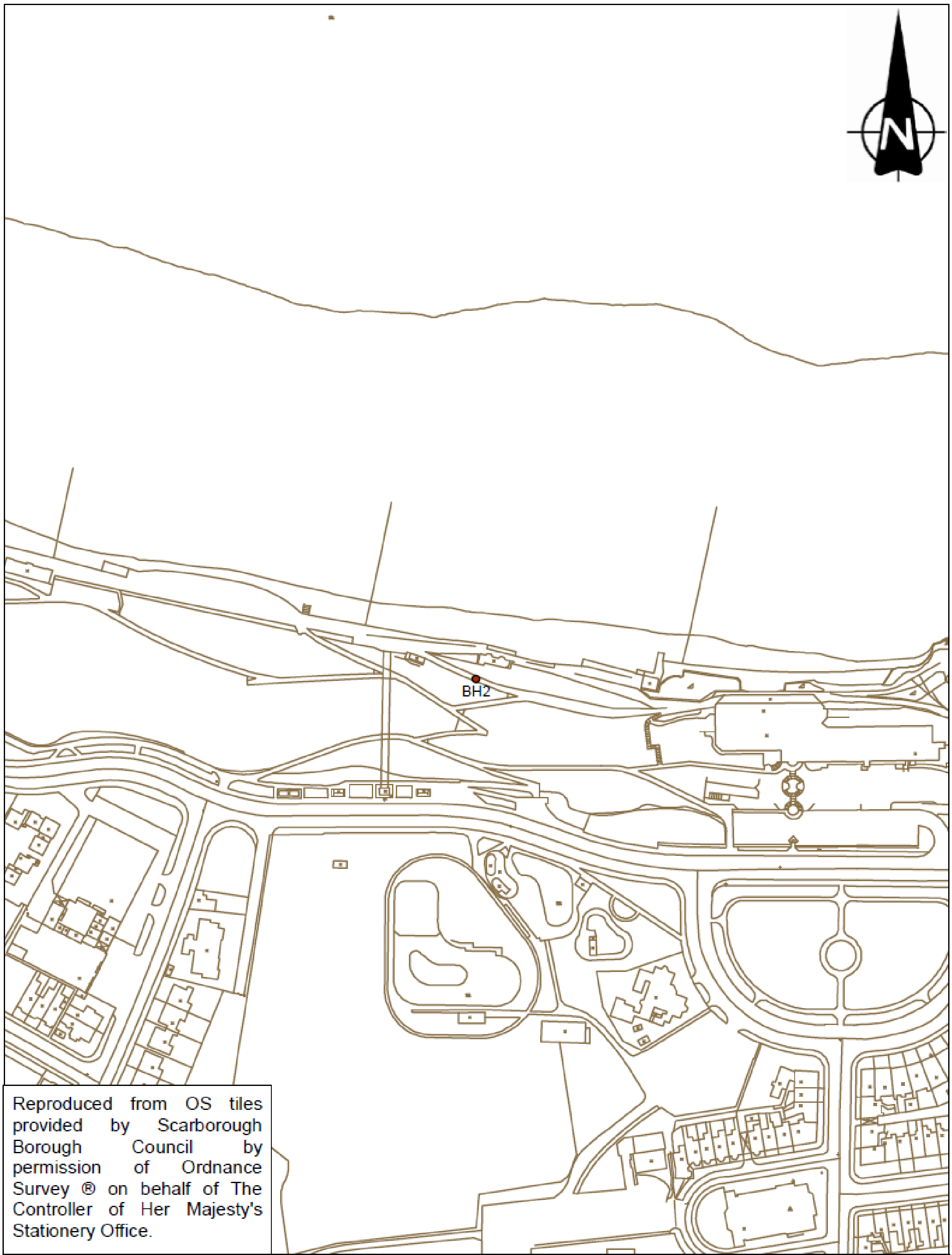
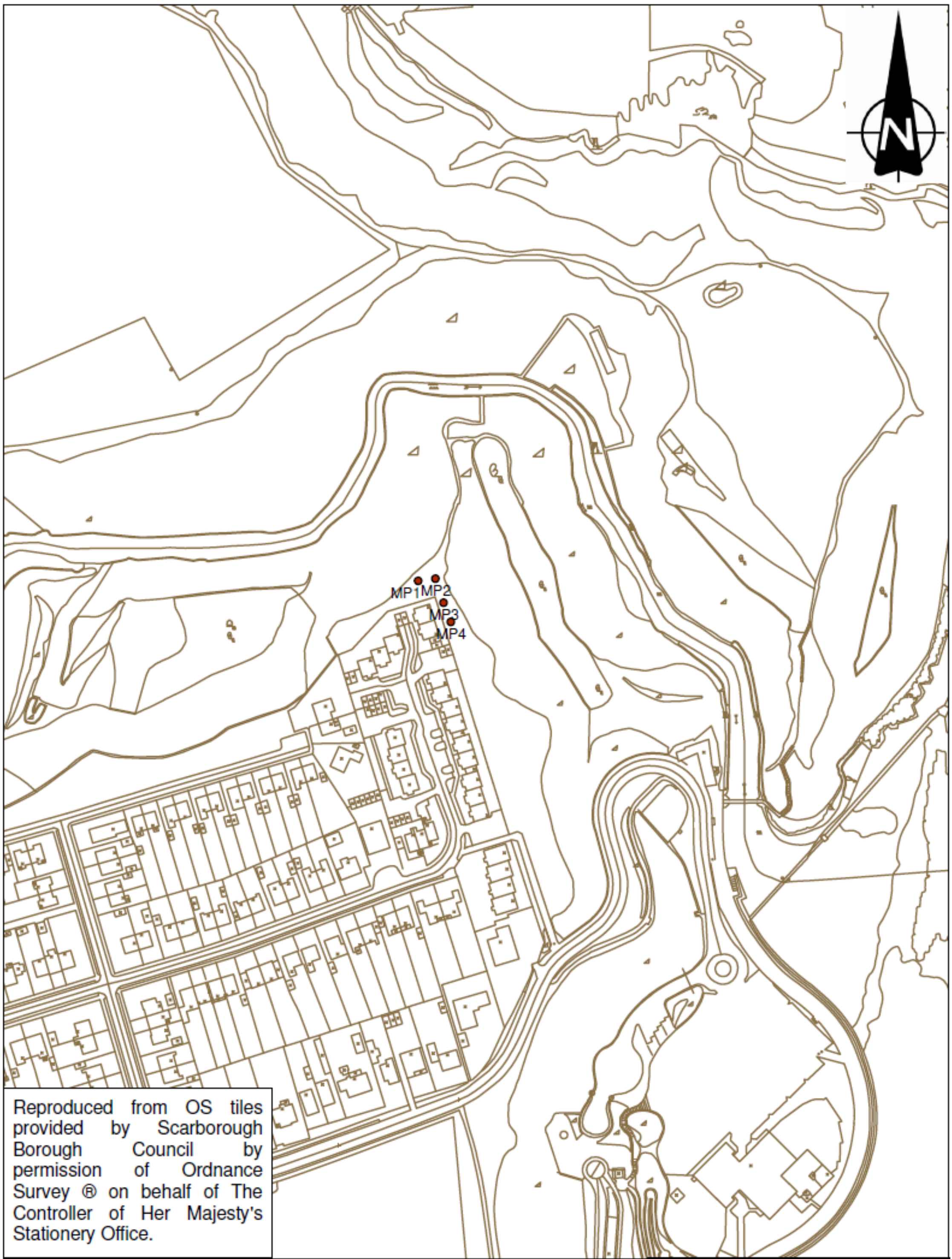
Drawing No. 1 Location Plan of Runswick Bay



Whitby West Cliff Inclinometer Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 2 Location Plan of Whitby West Cliff



Scalby Ness Survey Points Location Plan

Scale: 1:2,500

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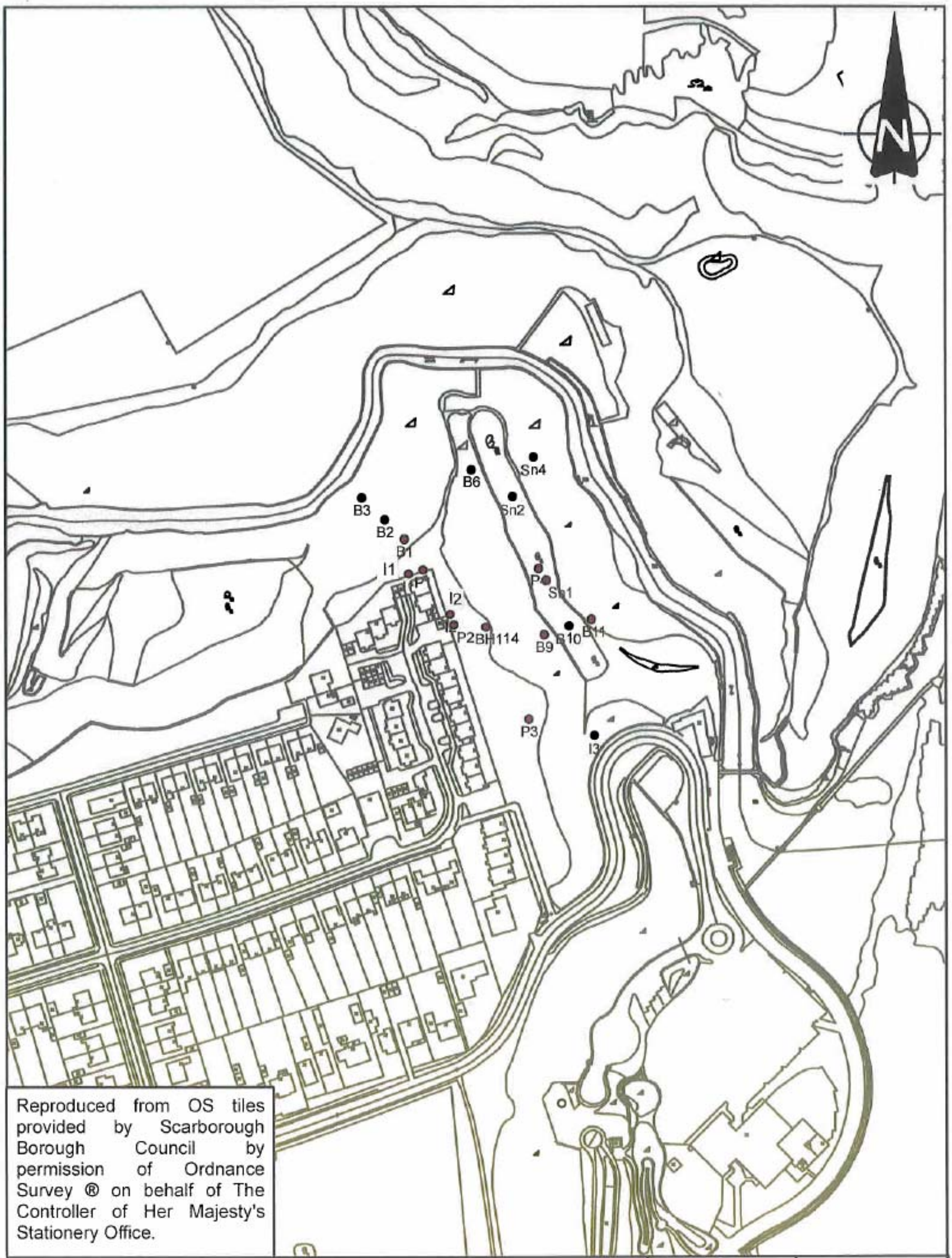
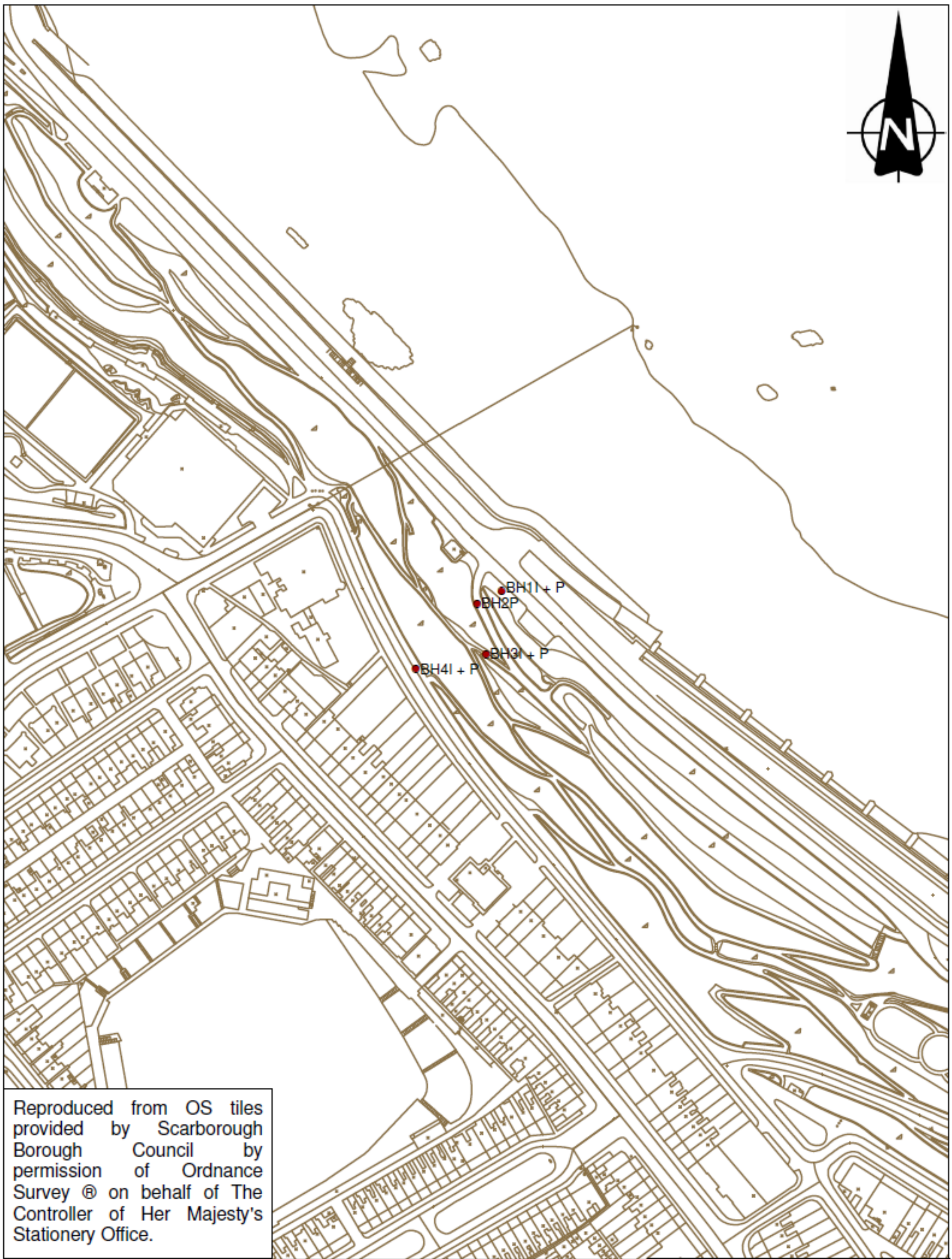
Drawing No. 3 Location Plan of Scalby Ness



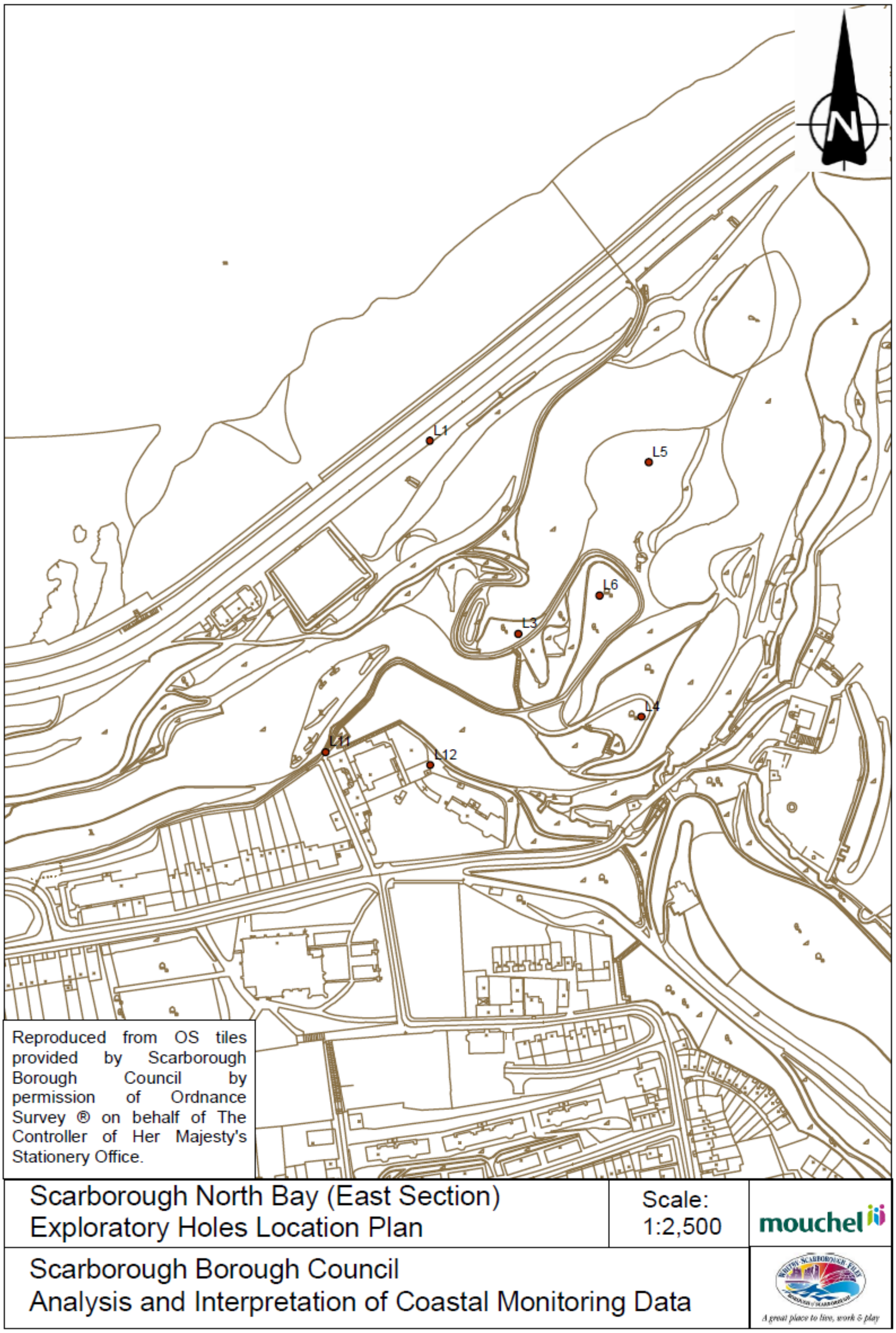
Scalby Ness Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 4 Location Plan of Scalby Ness

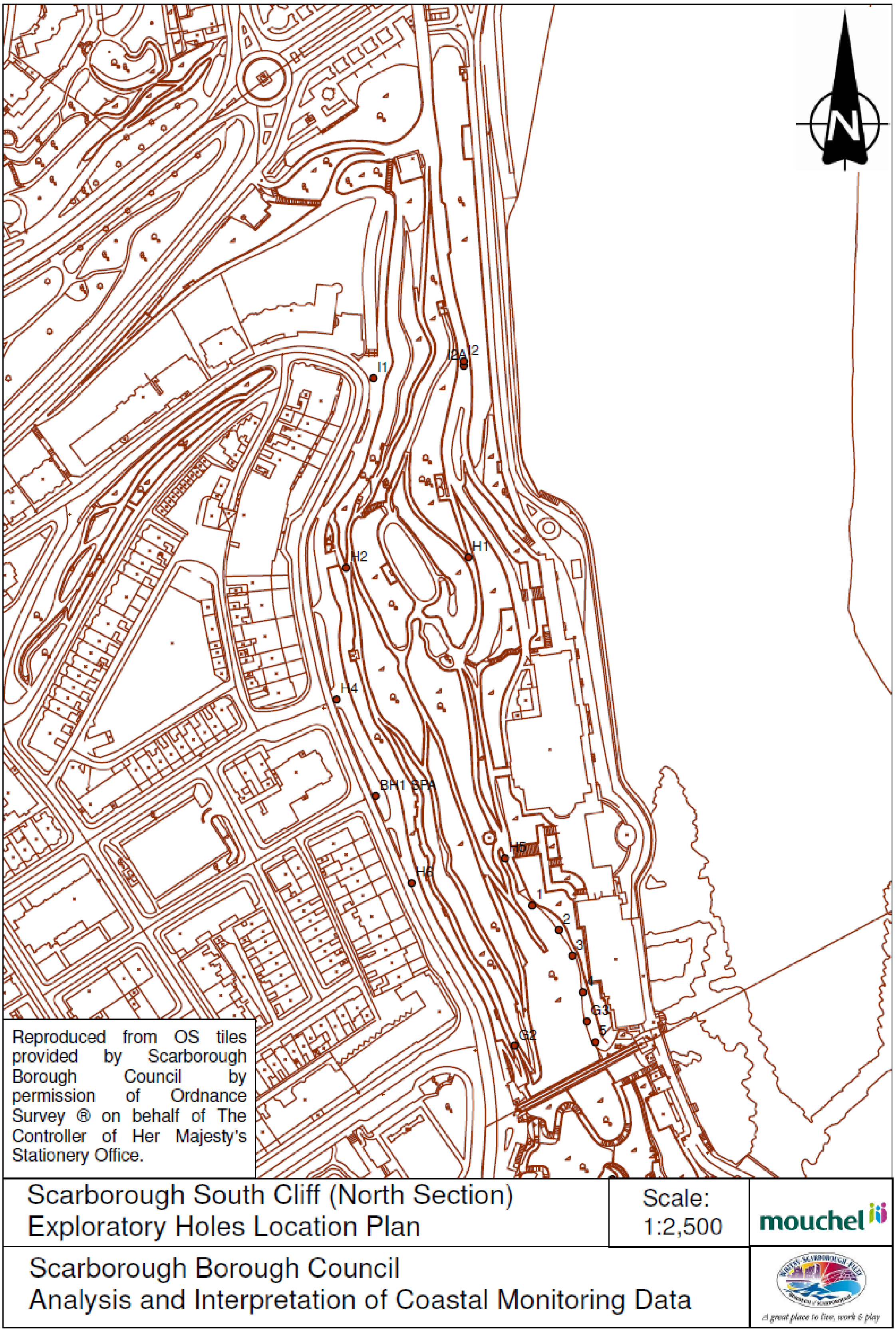


Scarborough North Bay Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 5 Location Plan of Scarborough North Bay (West)



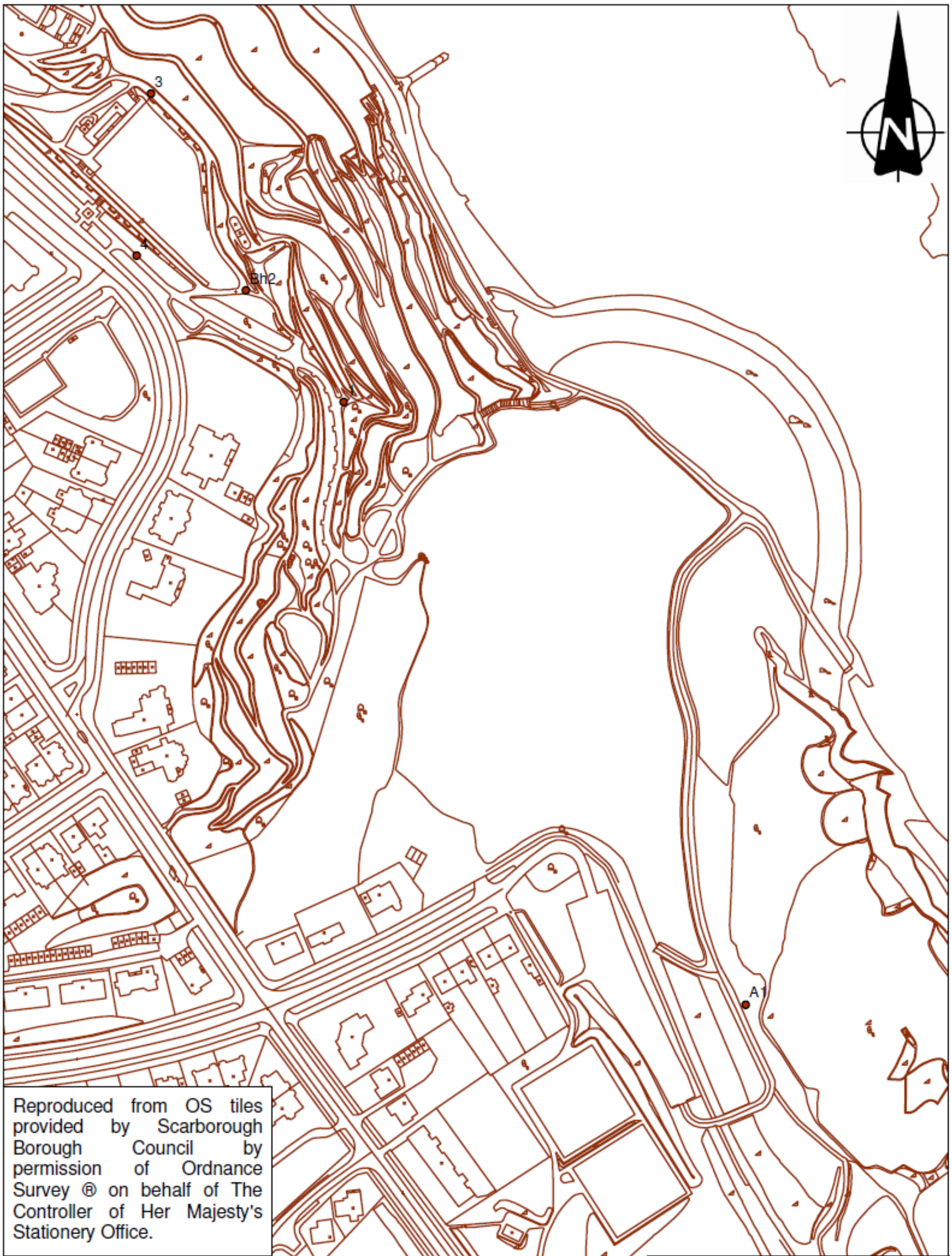
Drawing No. 6 Location Plan of Scarborough North Bay (East)



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

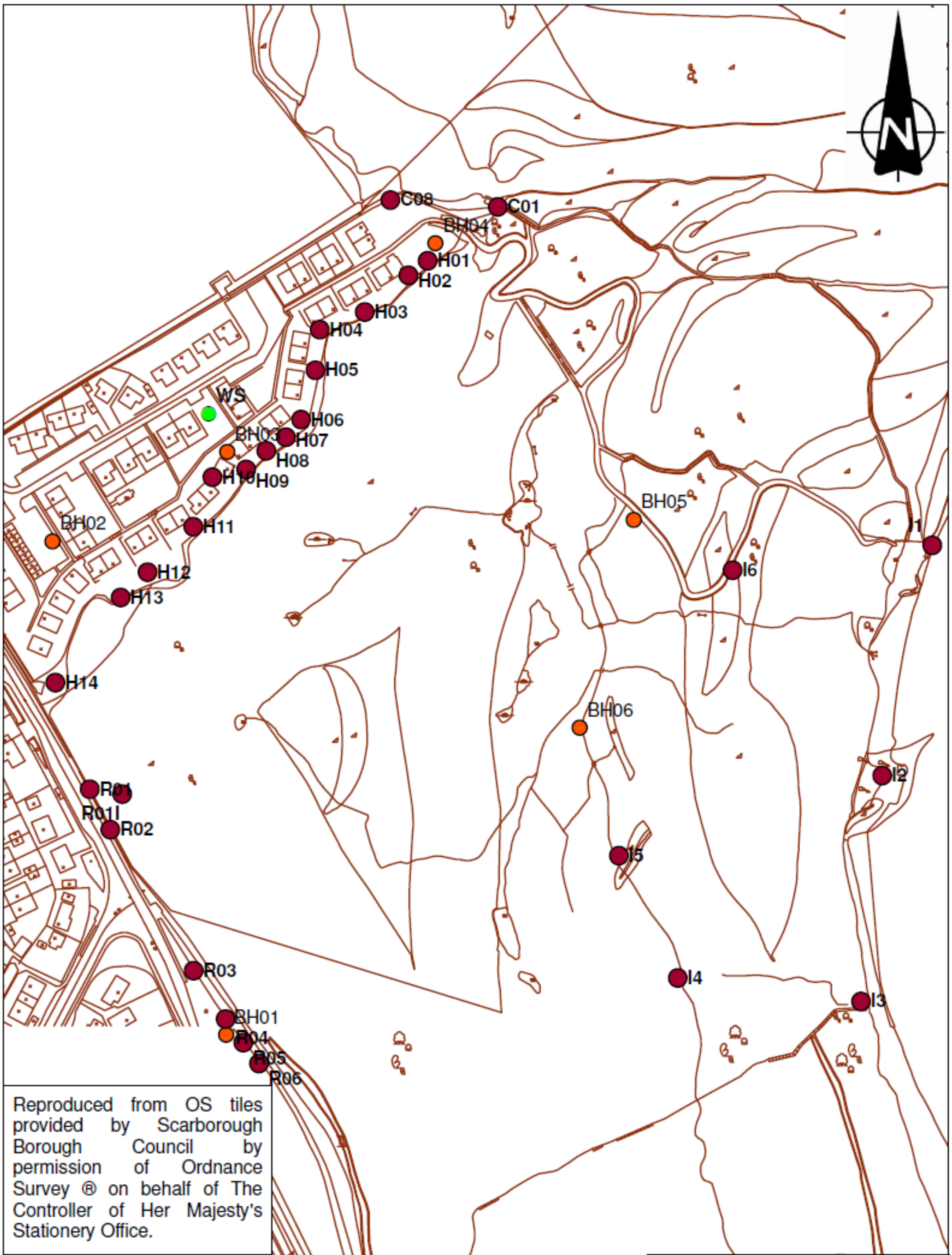
Scarborough South Cliff (Central Section) Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 8 Location Plan of Scarborough South Cliff (Central)



Scarborough South Cliff (South Section) Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 9 Location Plan of Scarborough South Cliff (South)



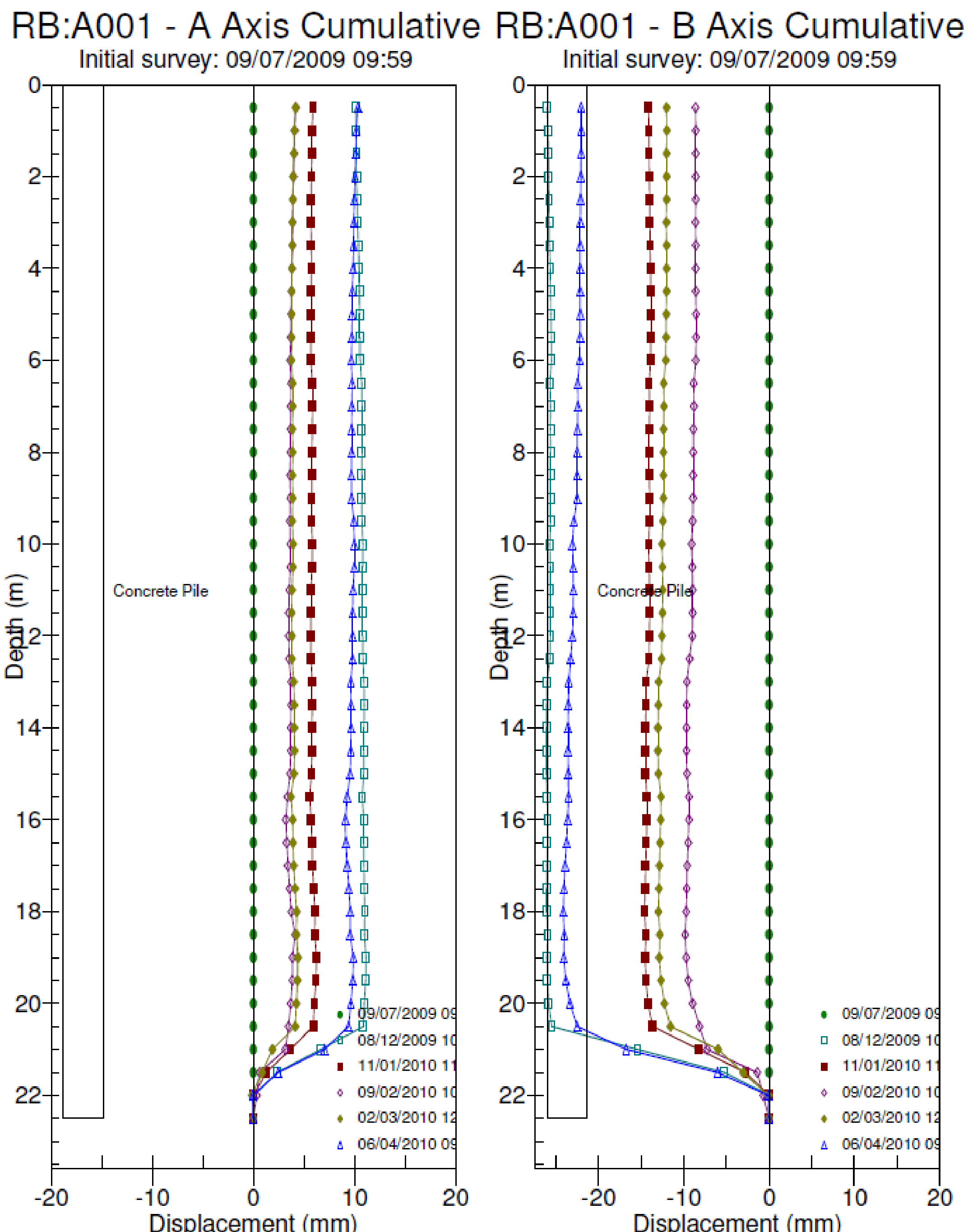
Knipe Point Exploratory Hole and Inspection Point Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 10 Location Plan of Knipe Point

Filey Flat Cliffs Exploratory Holes Location Plan	Scale: 1:2,500	mouchel
Scarborough Borough Council Analysis and Interpretation of Coastal Monitoring Data		A great place to live, work & play

Drawing No. 11 Location Plan of Filey Flat Cliffs

Appendix B Inclinometer Data Graphs



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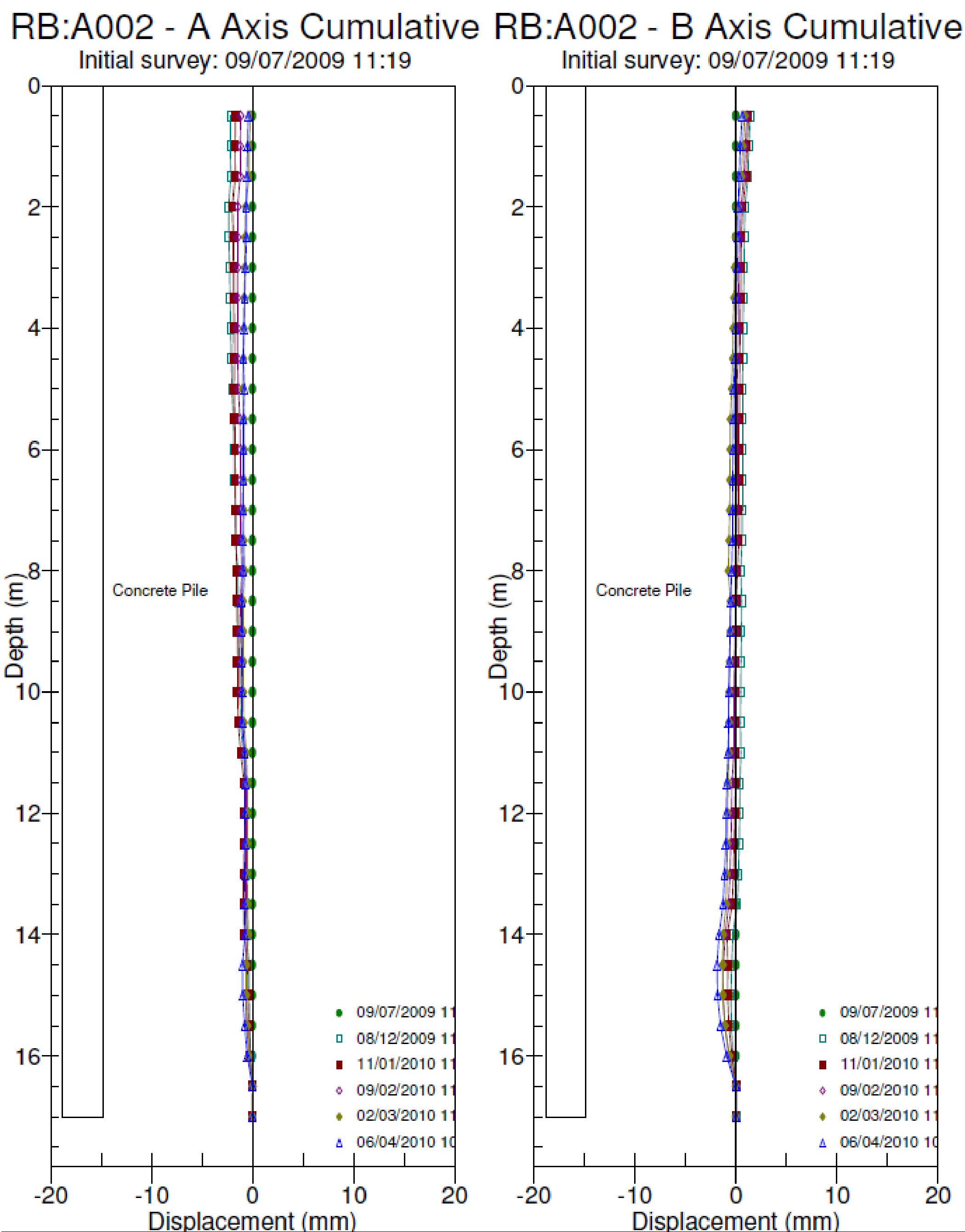
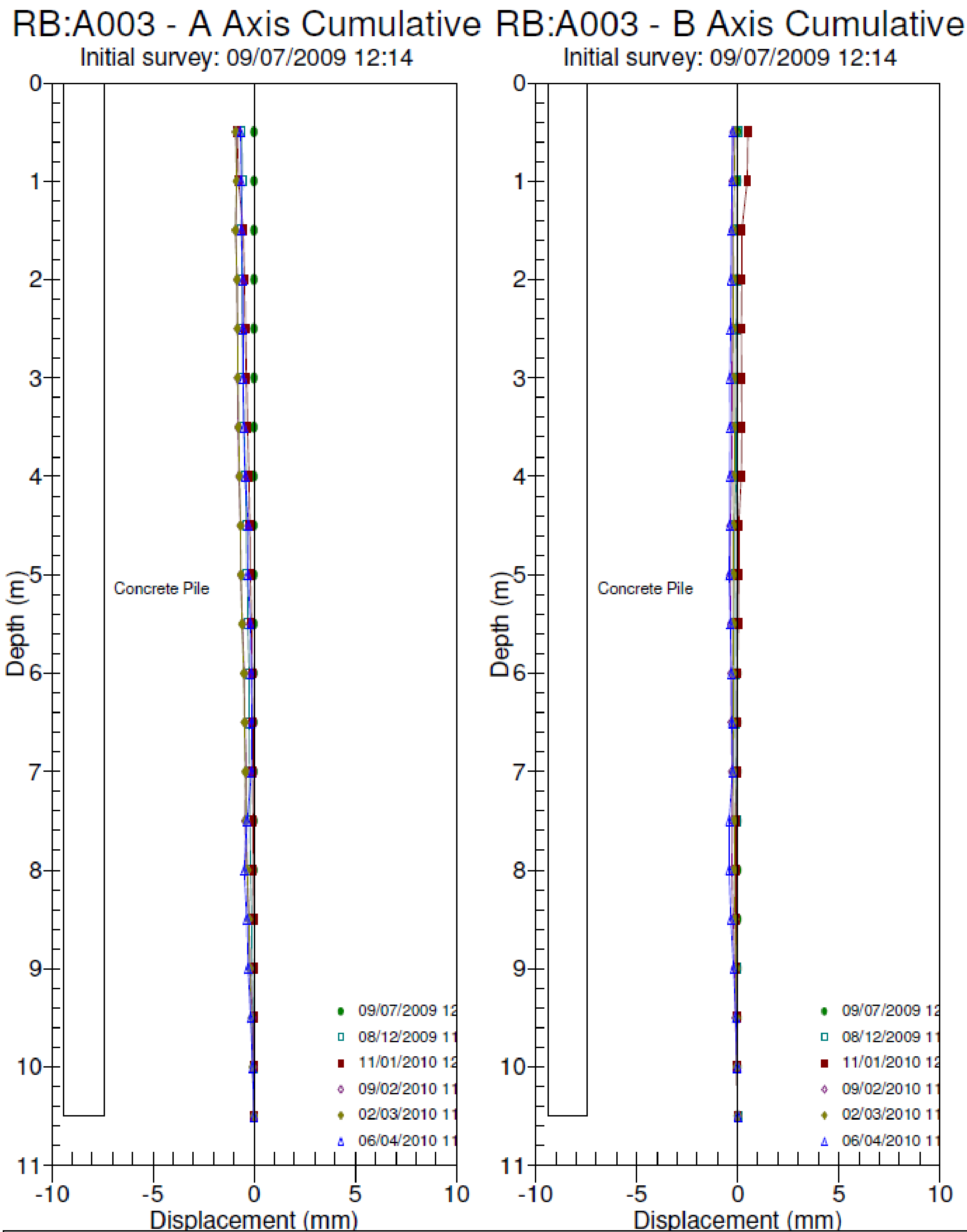
SITE: Runswick Bay
INSTALLATION: A001
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East



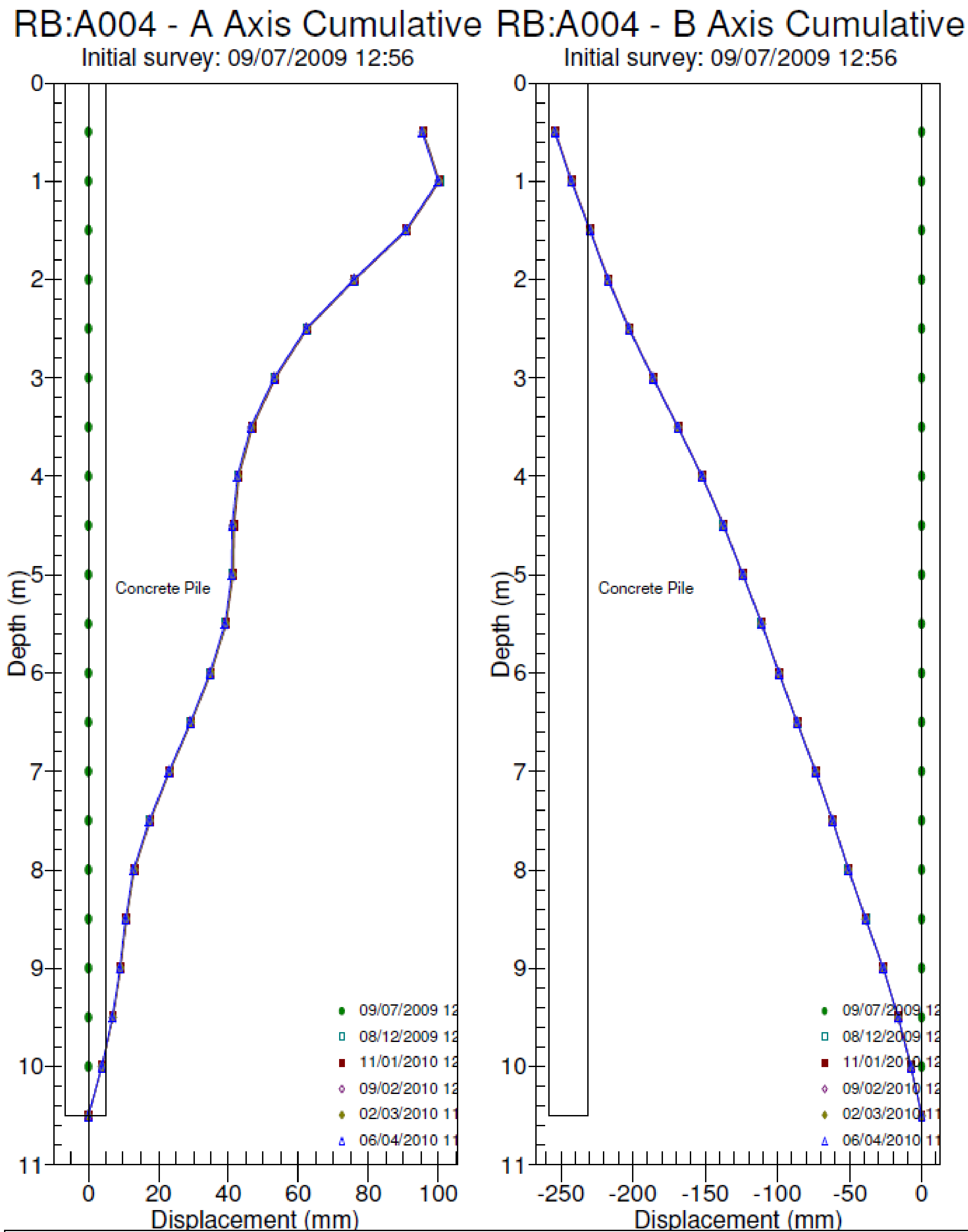
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A002
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East



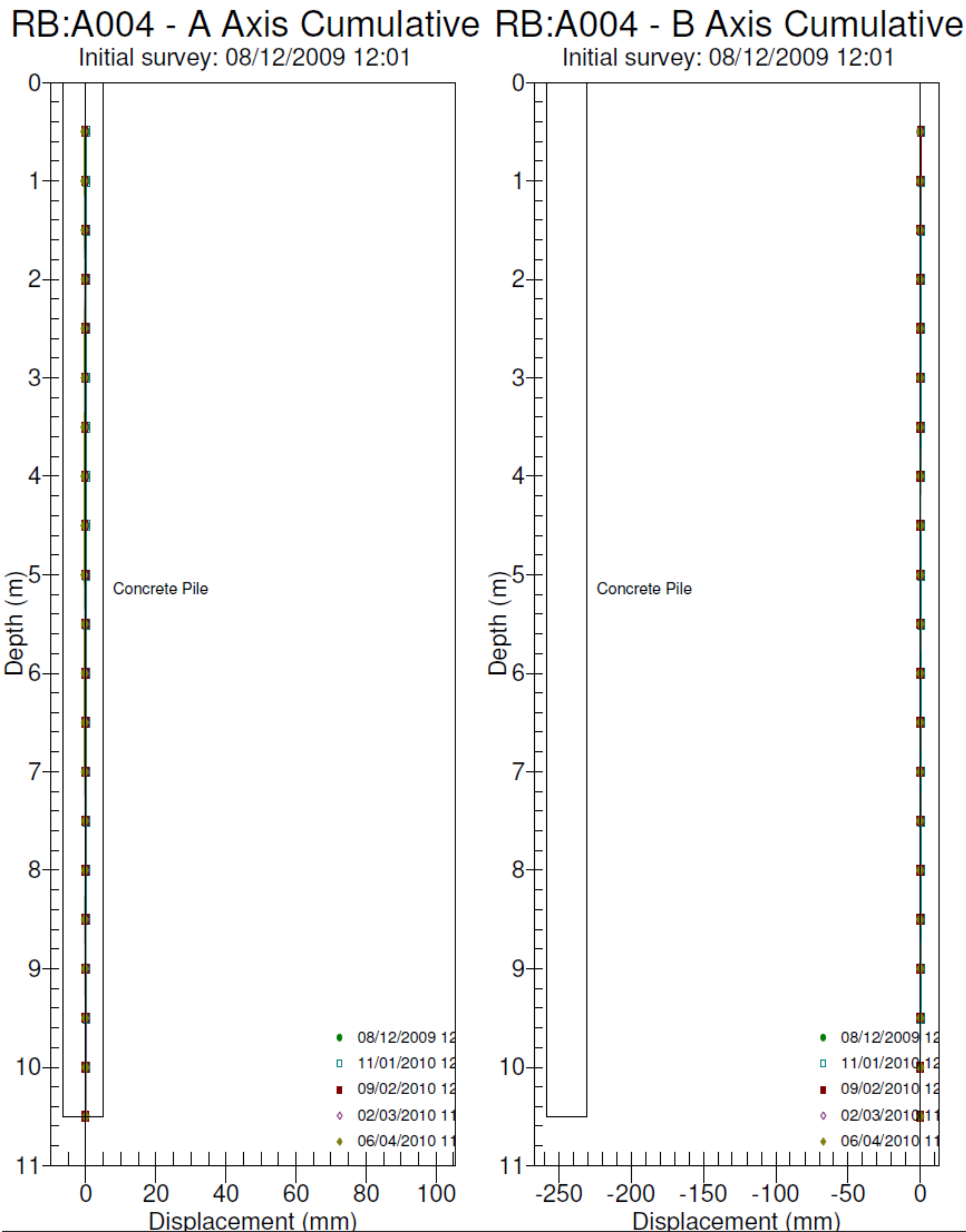
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A003
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: South East



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A004
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Runswick Bay
INSTALLATION: A004
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

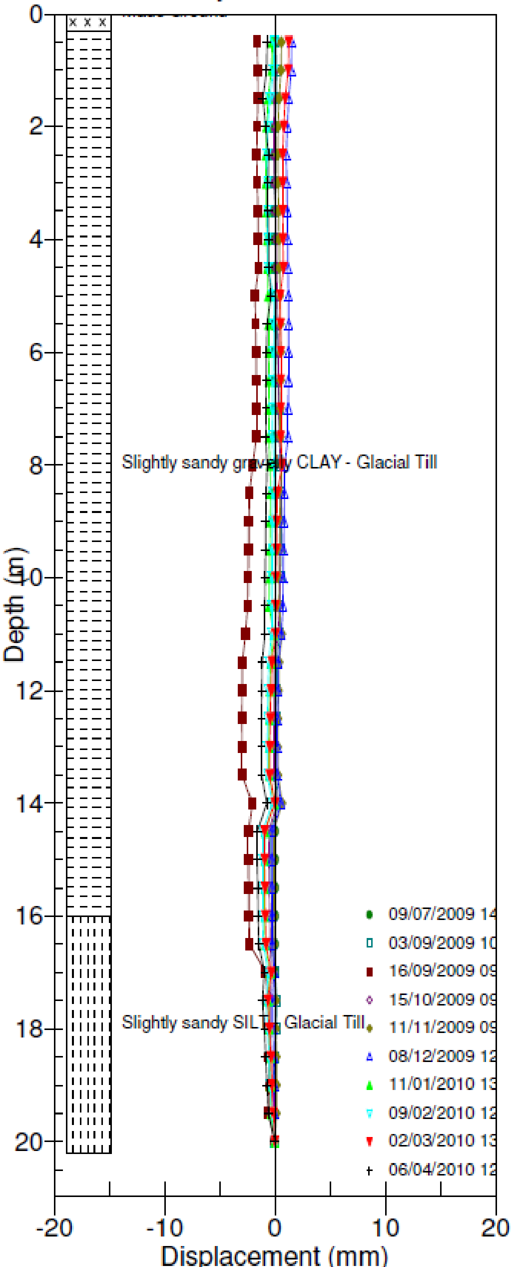
NOTE: A0 direction: East

mouchel

Adjusted RB-004

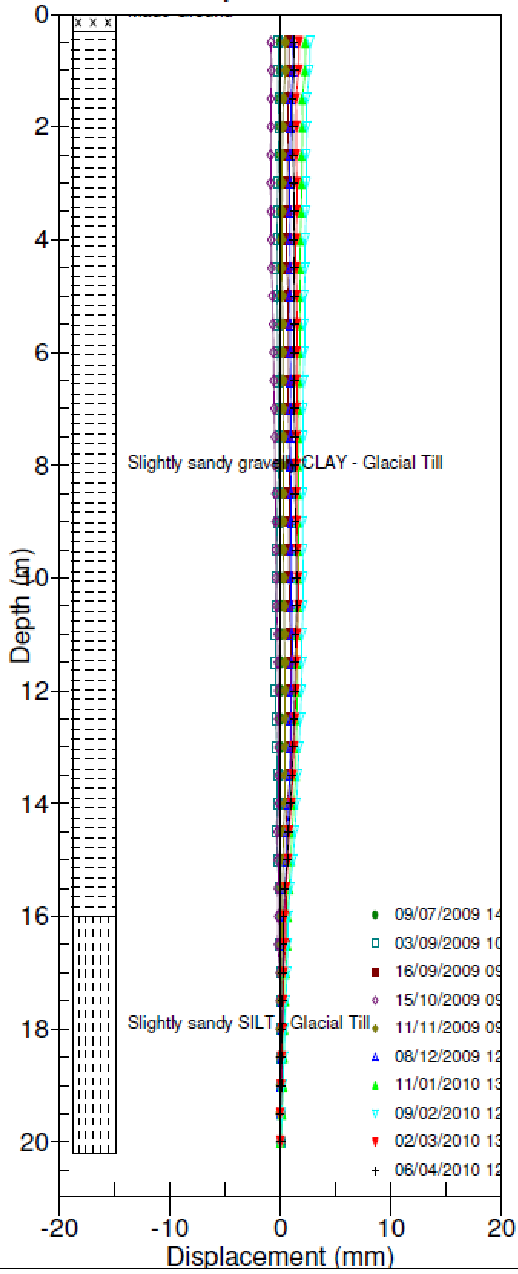
WWC:BH2 - A Axis Cumulative

Initial survey: 09/07/2009 14:40



WWC:BH2 - B Axis Cumulative

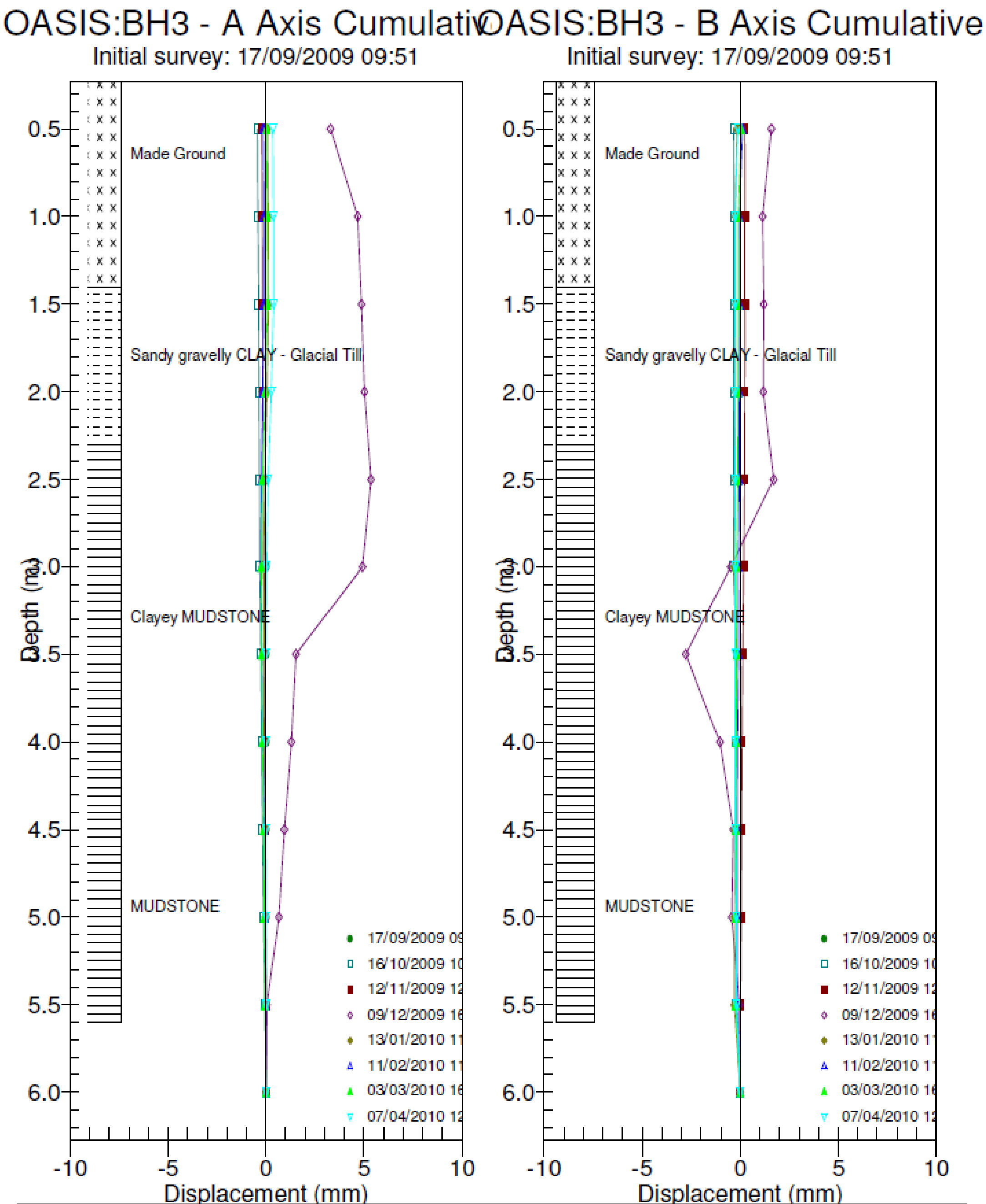
Initial survey: 09/07/2009 14:40



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

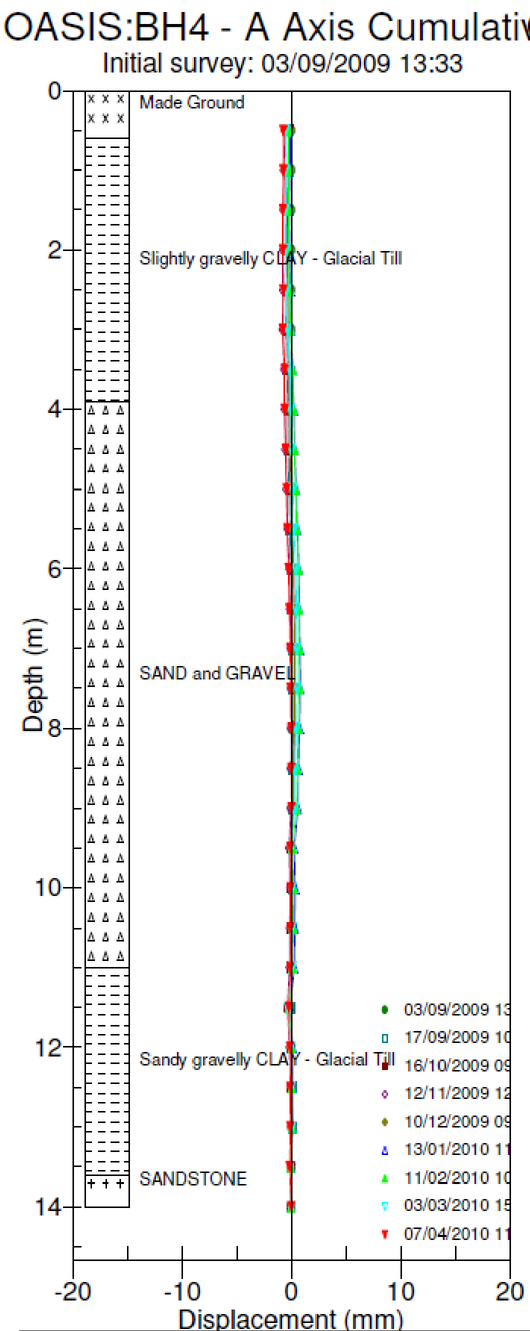
NOTE: A0 direction: North

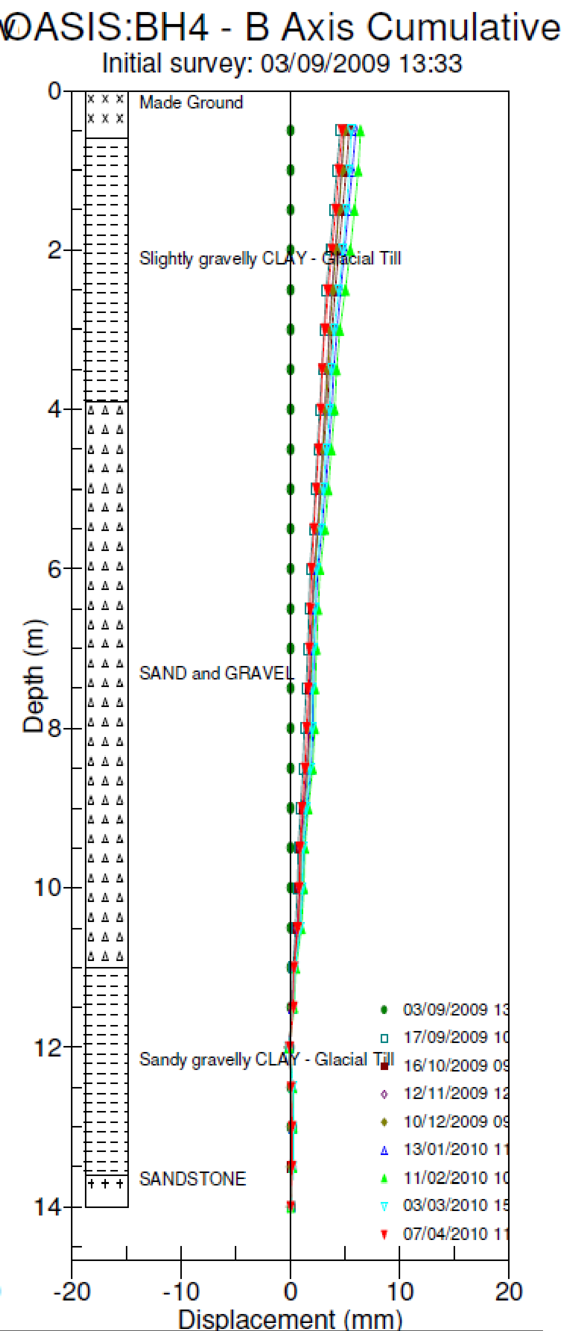
mouchel



PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Oasis North Bay
INSTALLATION: BH3
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East





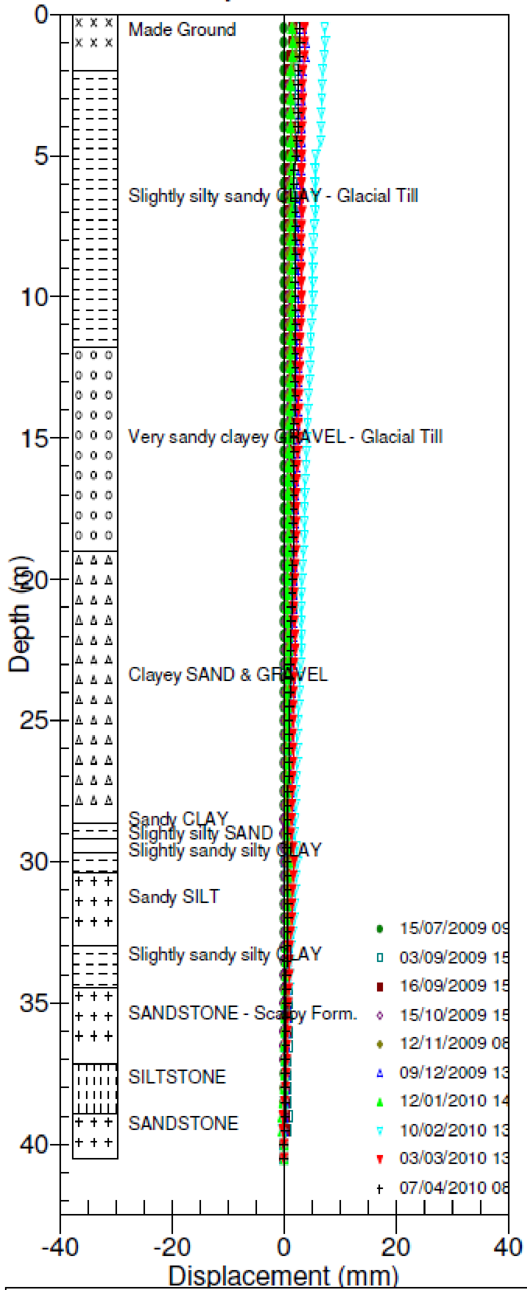
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Oasis North Bay
INSTALLATION: BH4
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

mouchel

NOTE: A0 direction: East

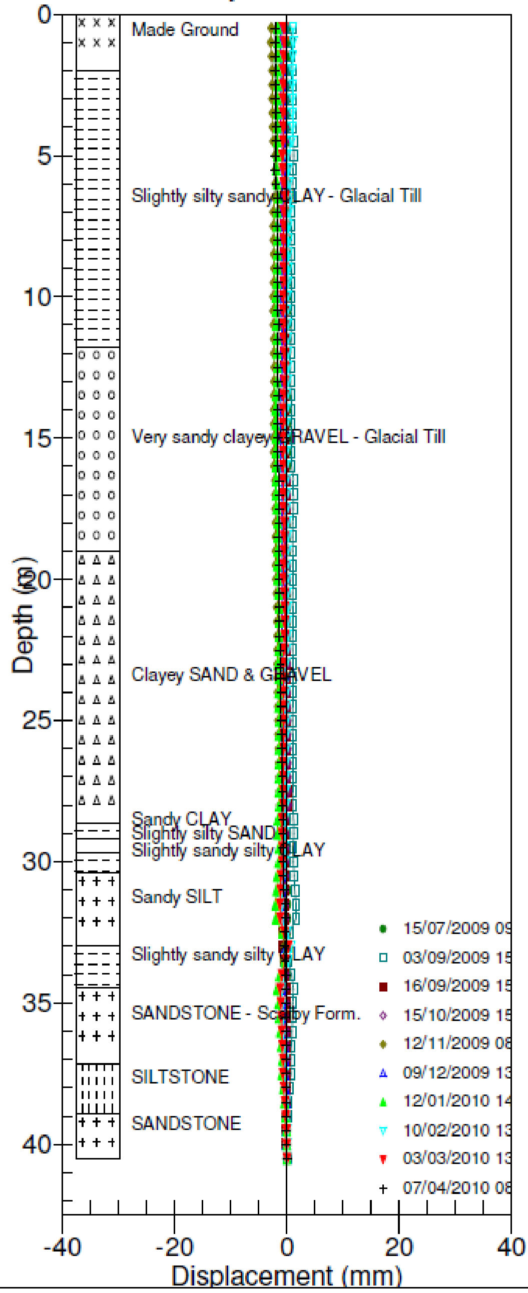
SSC:AA04 - A Axis Cumulative

Initial survey: 15/07/2009 09:26



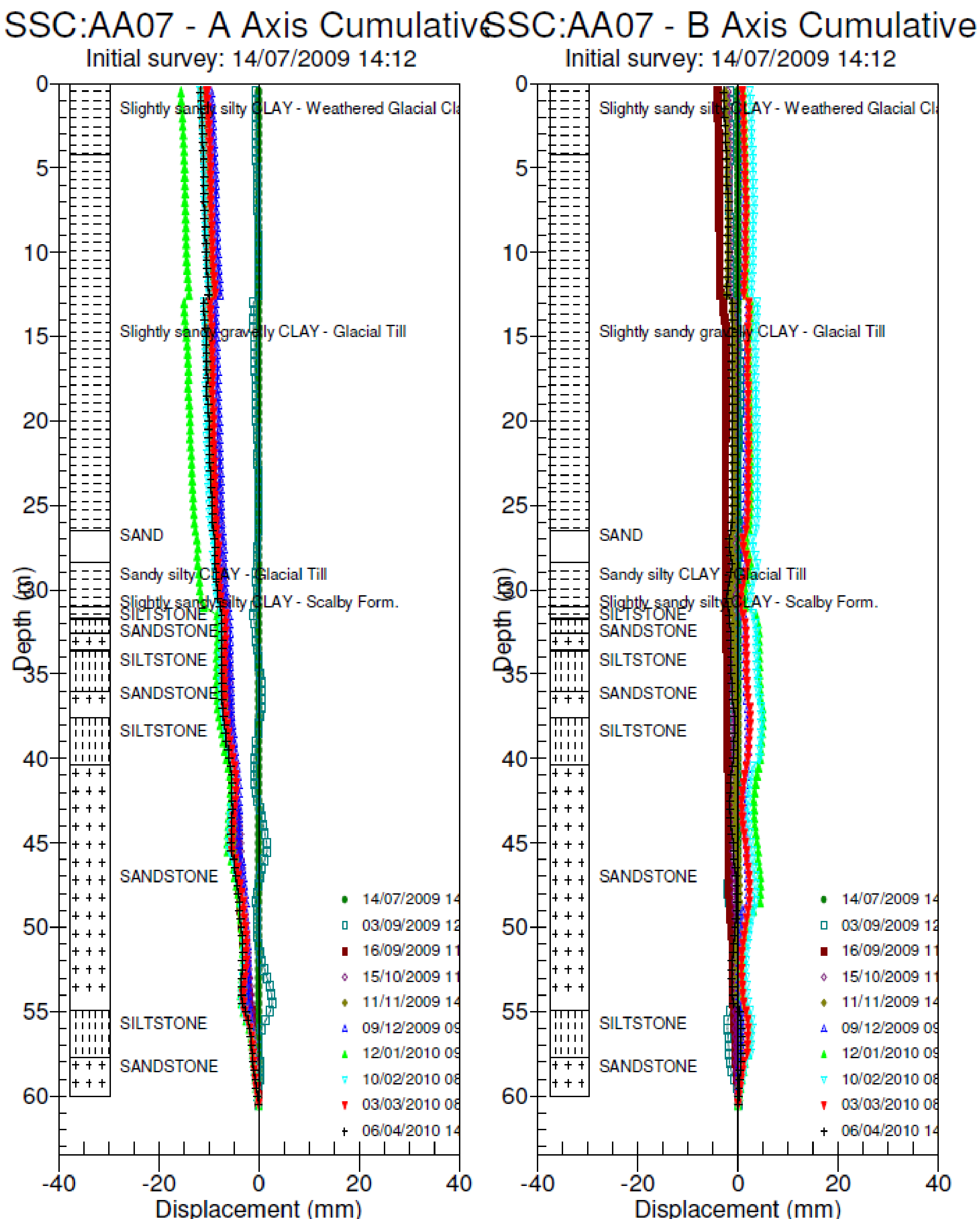
SSC:AA04 - B Axis Cumulative

Initial survey: 15/07/2009 09:26



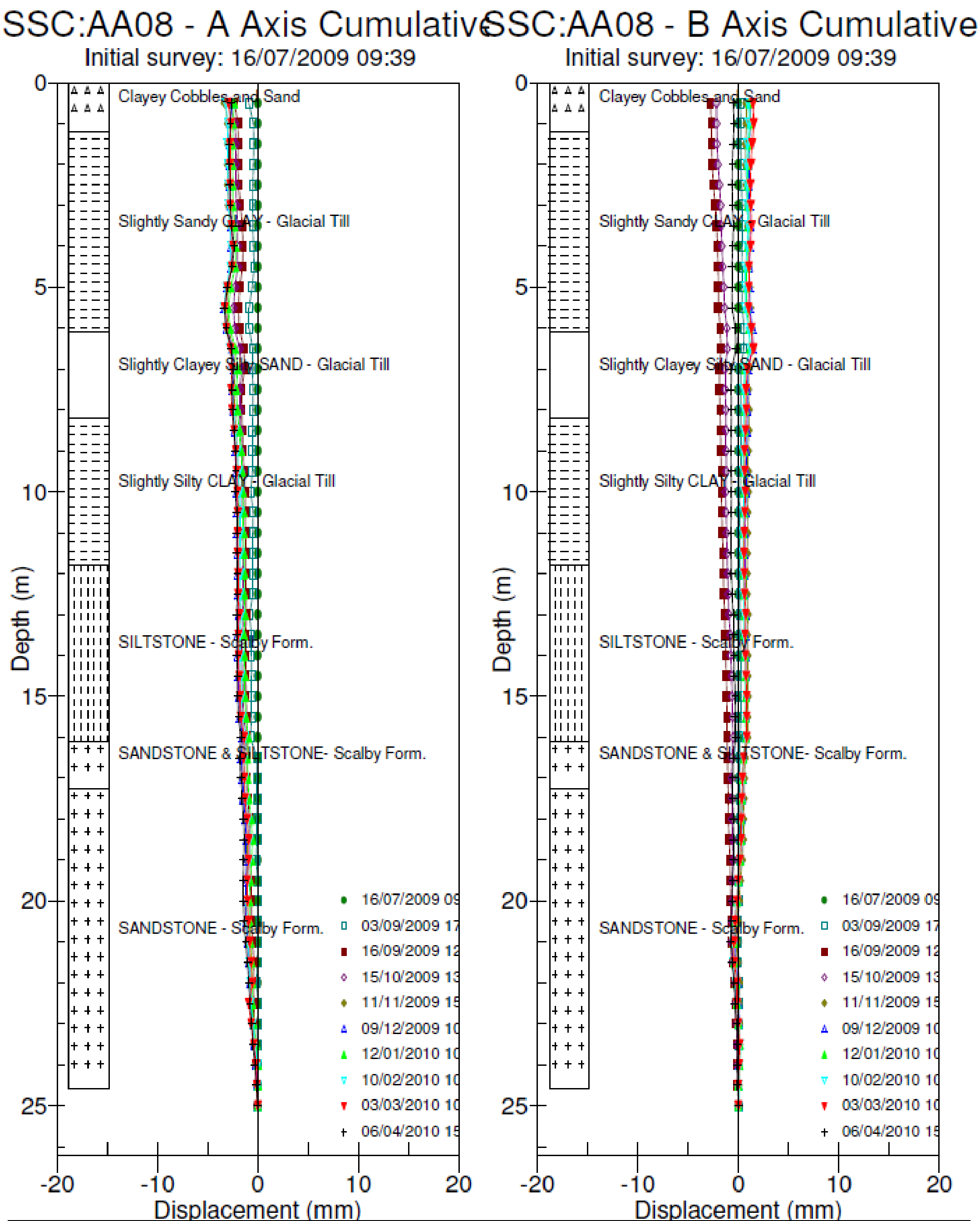
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA04 (G2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East



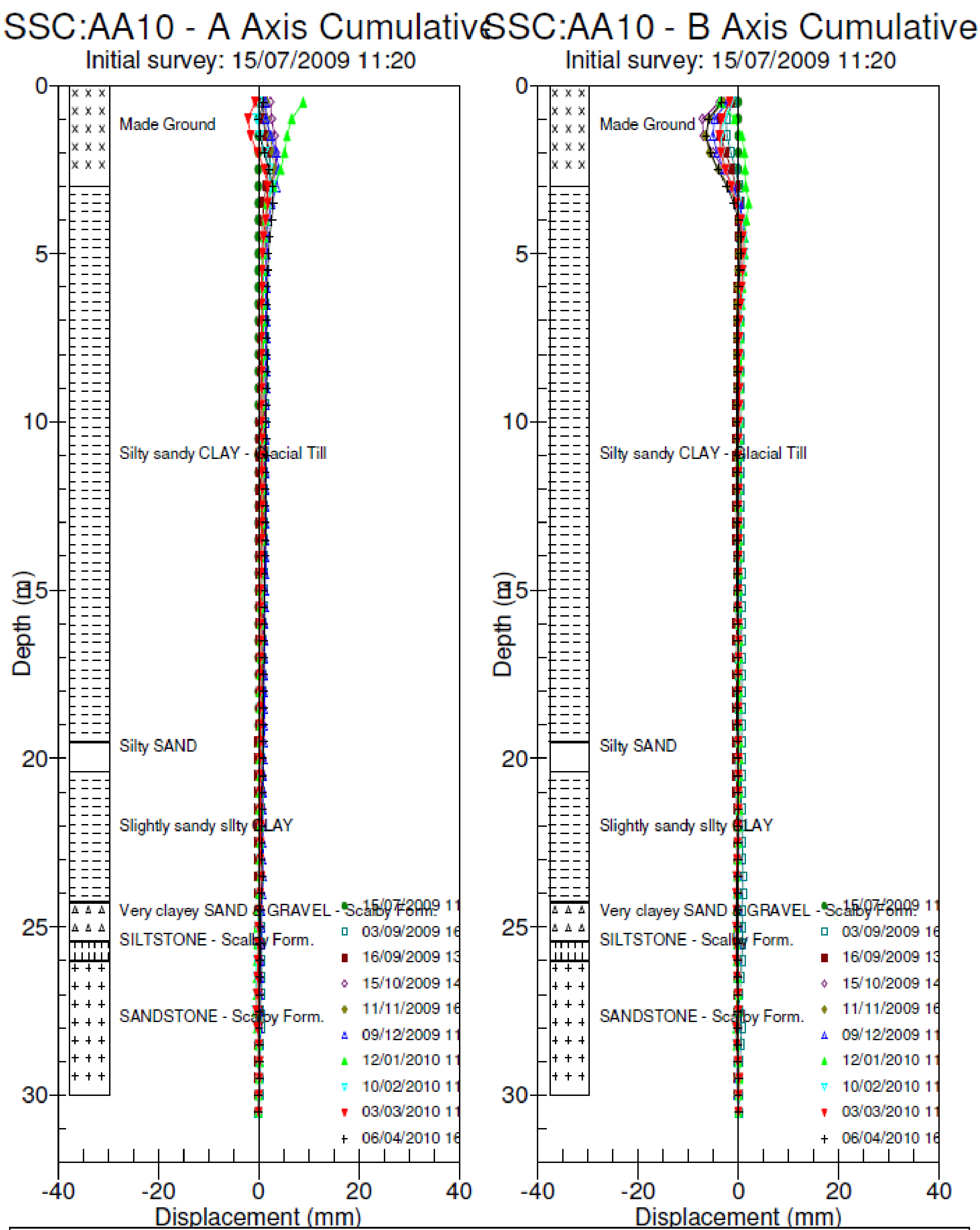
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Scarborough South Cliff
INSTALLATION: AA07 (BH2)
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East



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

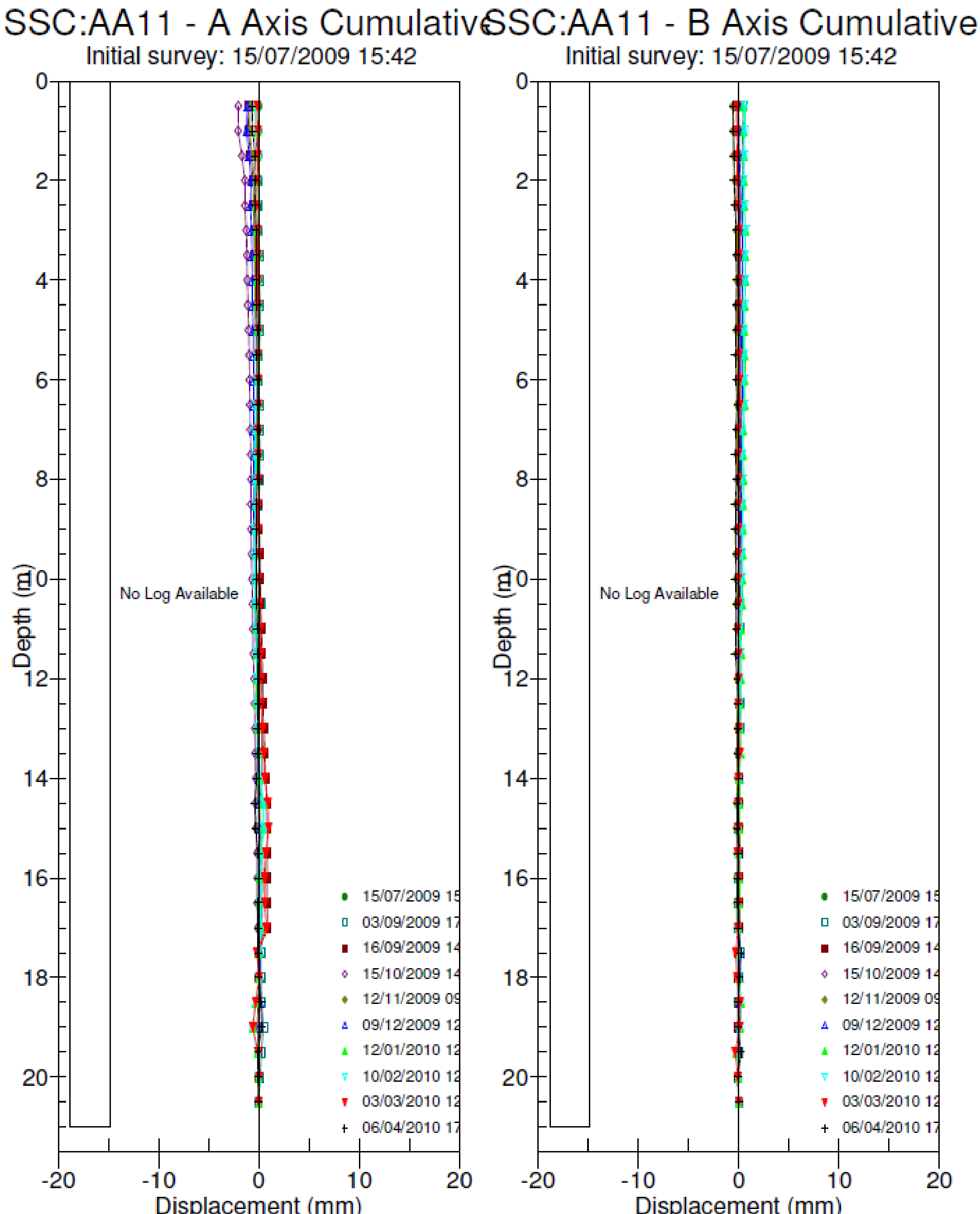
NOTE: A0 direction: East



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

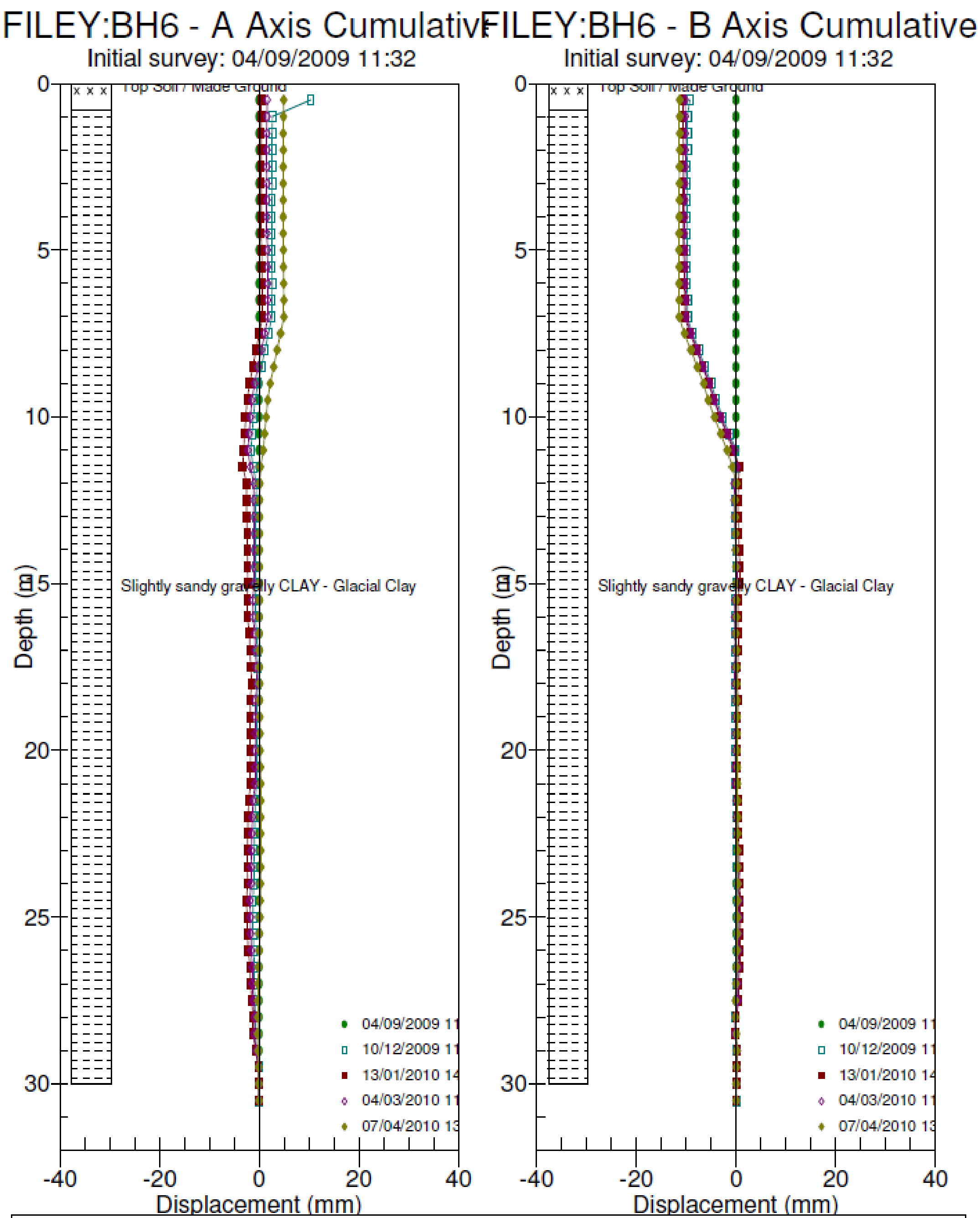
mouchel



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

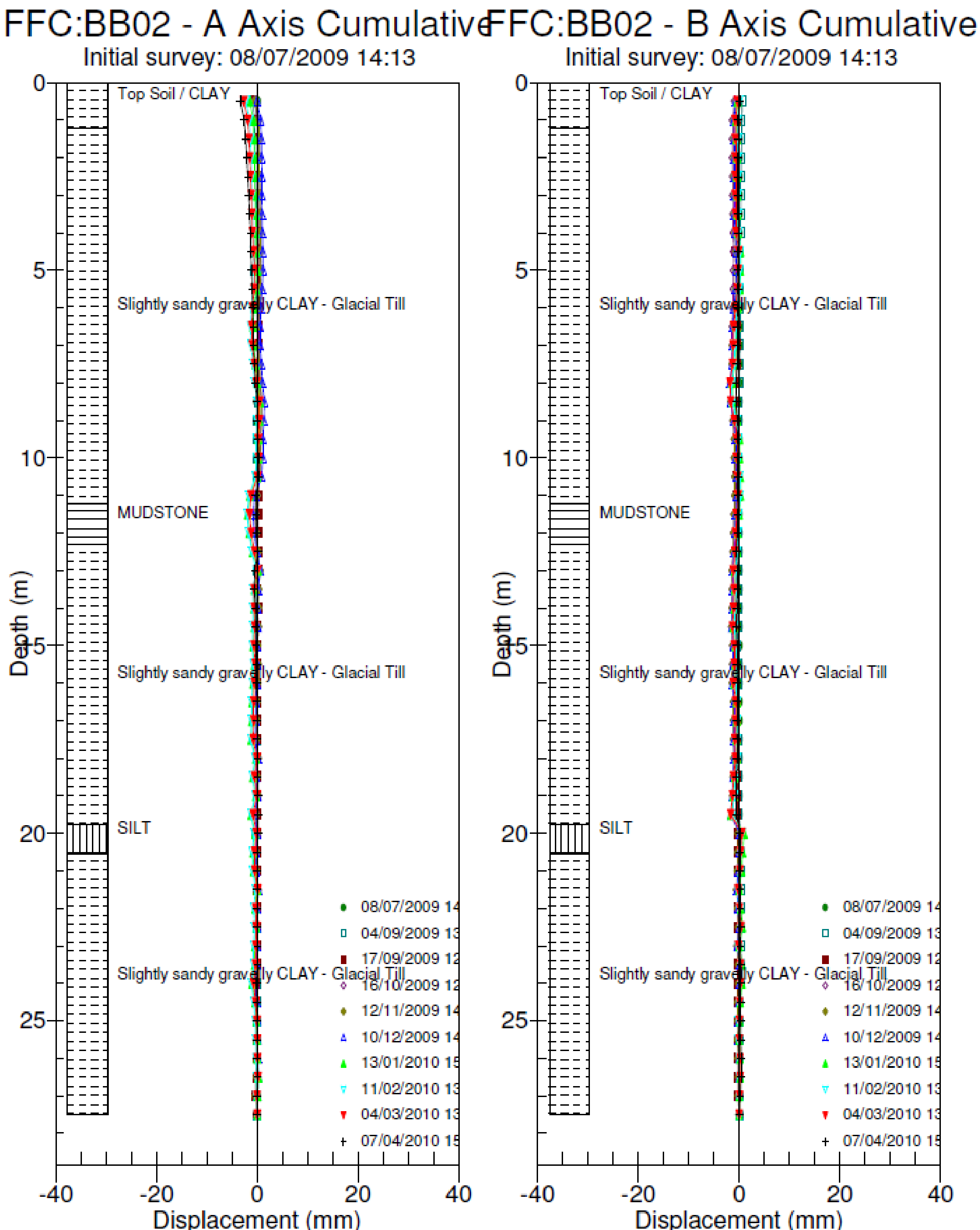
mouchel

NOTE: A0 direction: North East



PROJECT: Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Town
INSTALLATION: BH6
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: North East

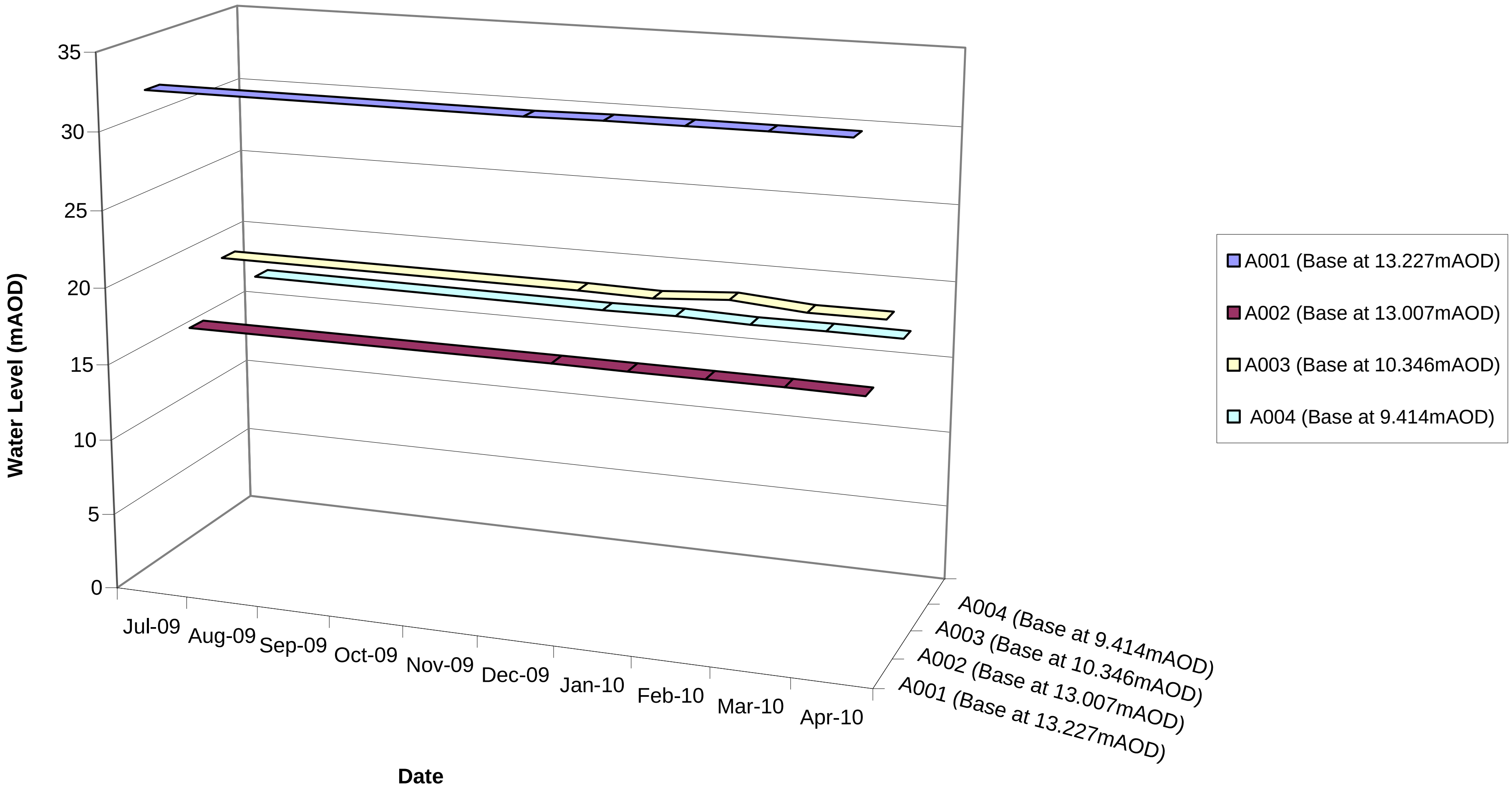


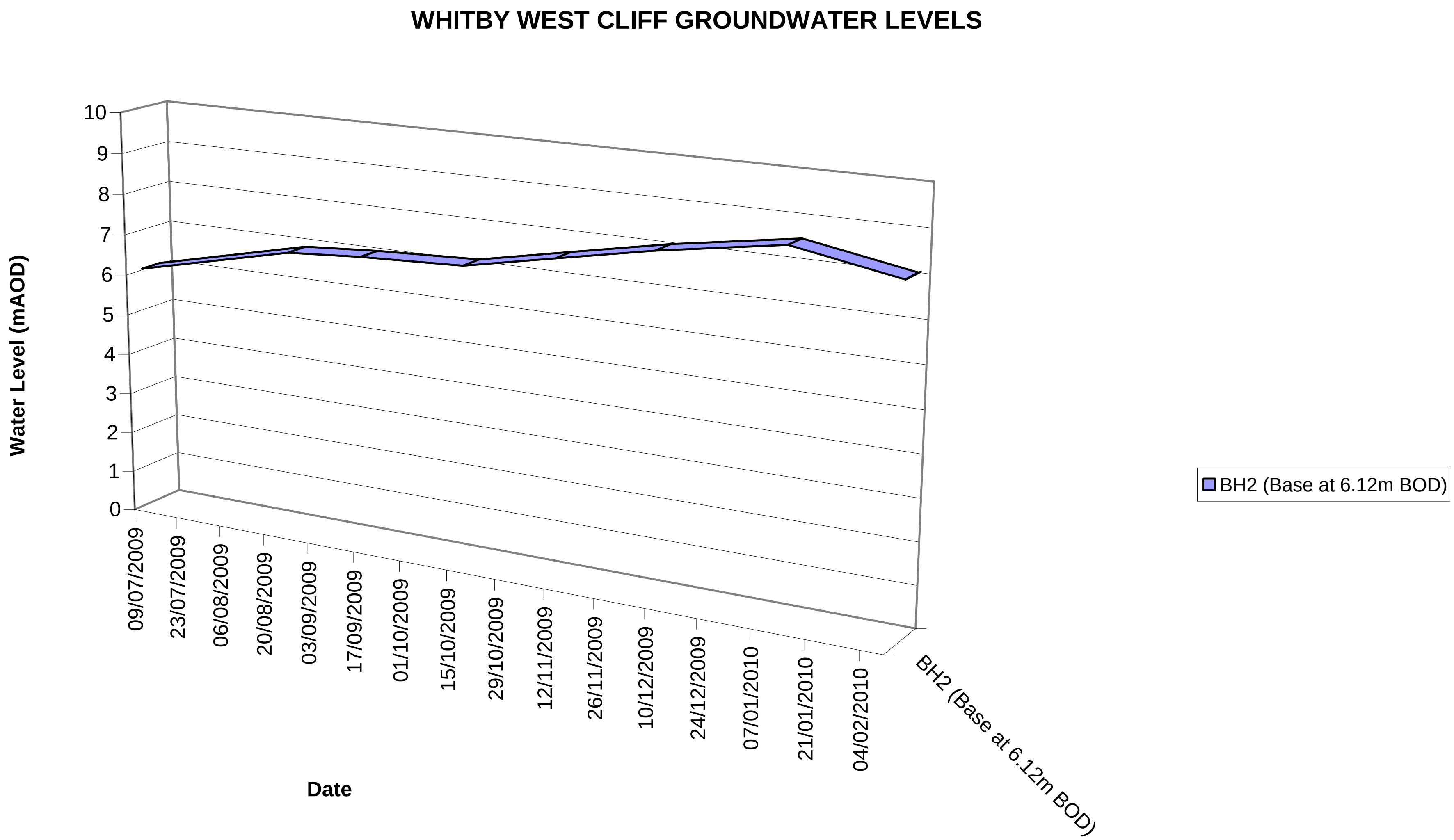
PROJECT: 721229 Ongoing Analysis of Coastal Monitoring Data
SITE: Filey Flat Cliffs
INSTALLATION: BB02
COMPANY: Mouchel Ltd
CLIENT: Scarborough Borough Council

NOTE: A0 direction: East

Appendix C Groundwater Monitoring Graphs

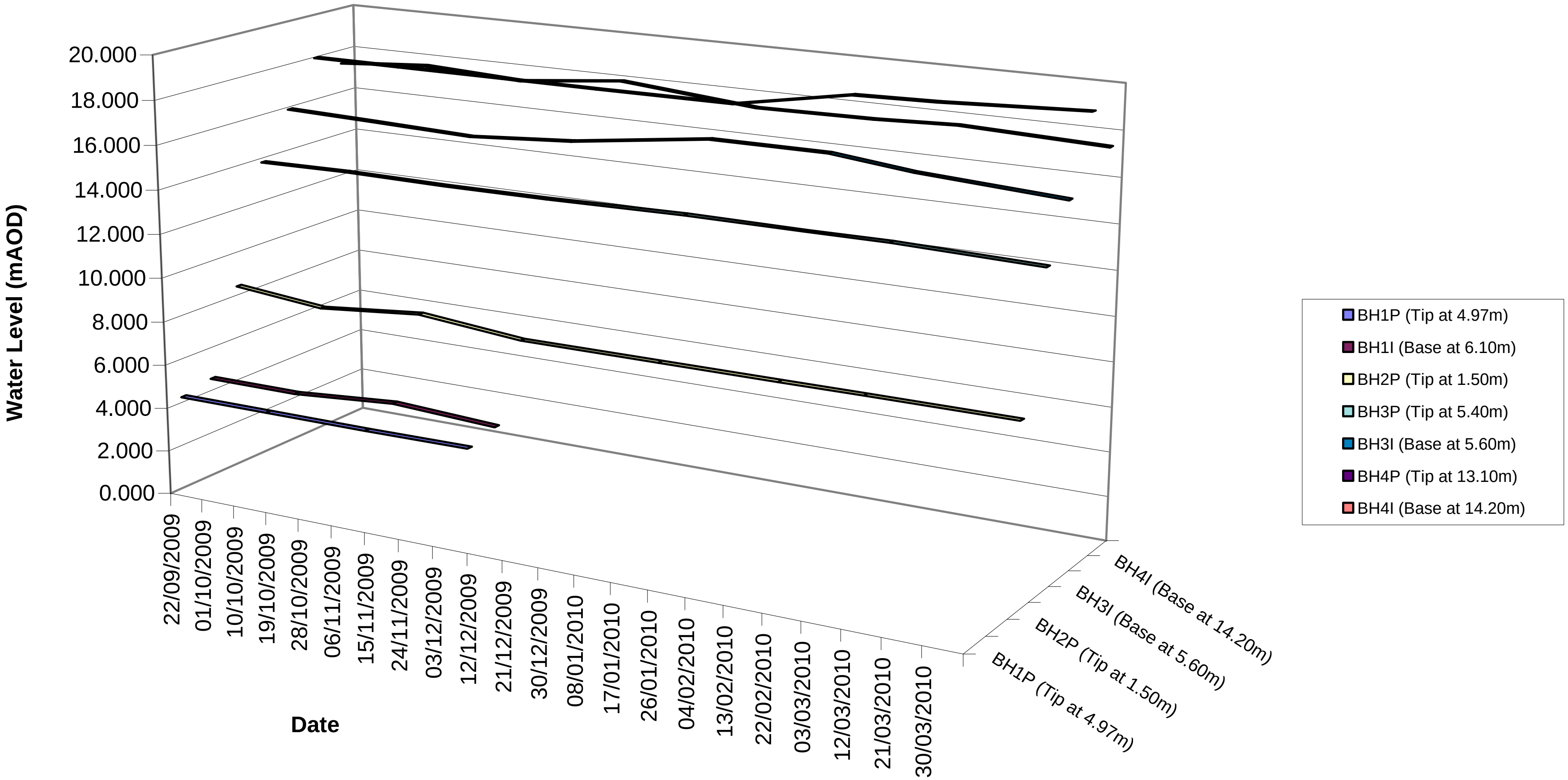
RUNSWICK BAY GROUNDWATER LEVELS



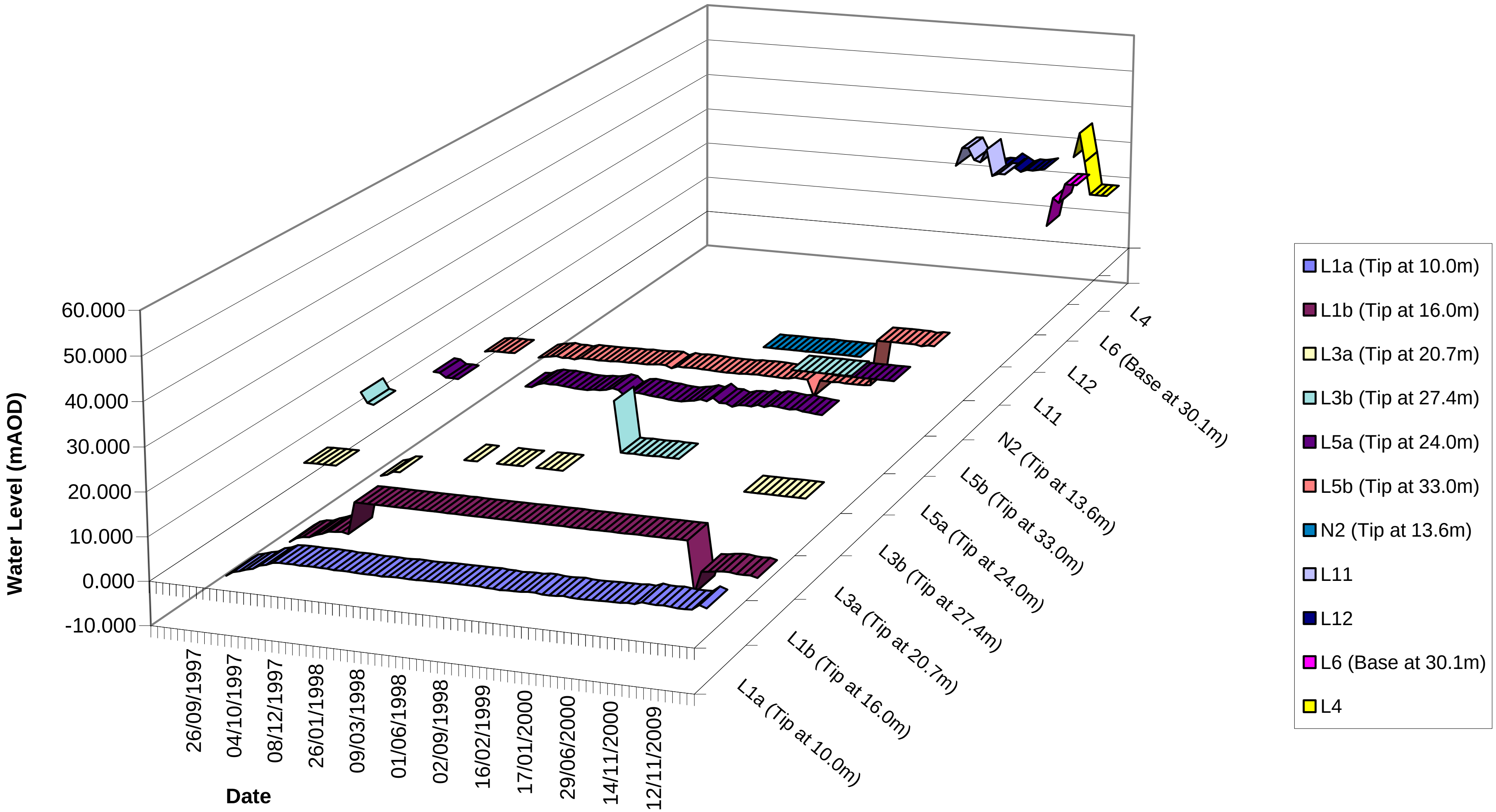


WHITBY WEST CLIFF GROUNDWATER LEVELS
Water Level (mAOD)
0
1
2
3
4
5
6
7
8
9
10
09/07/2009
23/07/2009
06/08/2009
20/08/2009
03/09/2009
17/09/2009
01/10/2009
15/10/2009
29/10/2009
12/11/2009
26/11/2009
10/12/2009
24/12/2009
07/01/2010
21/01/2010
04/02/2010
Date
BH2 (Base at 6.12m BOD)
BH2 (Base at 6.12m BOD)

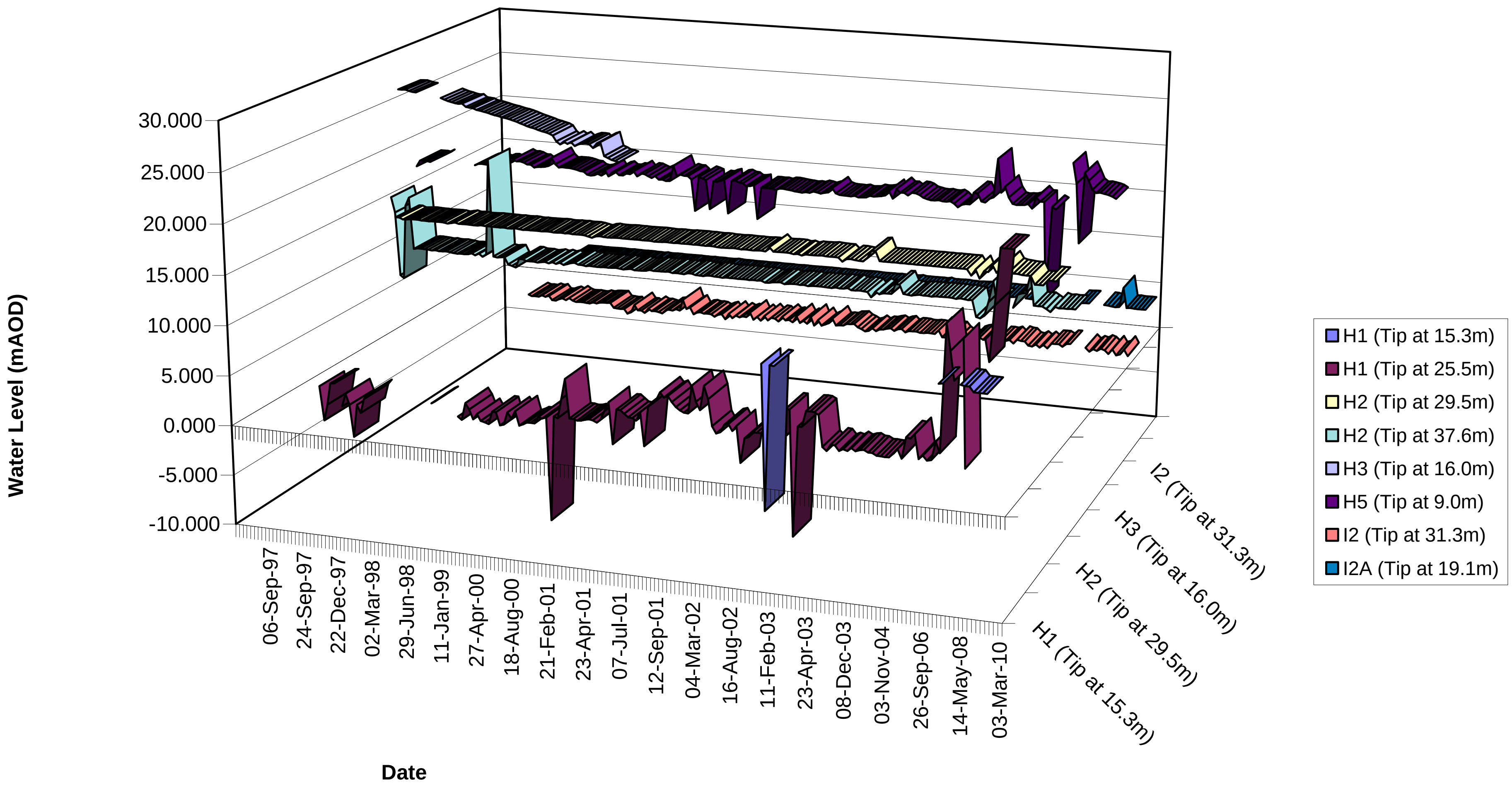
OASIS CAFÉ GROUNDWATER LEVELS

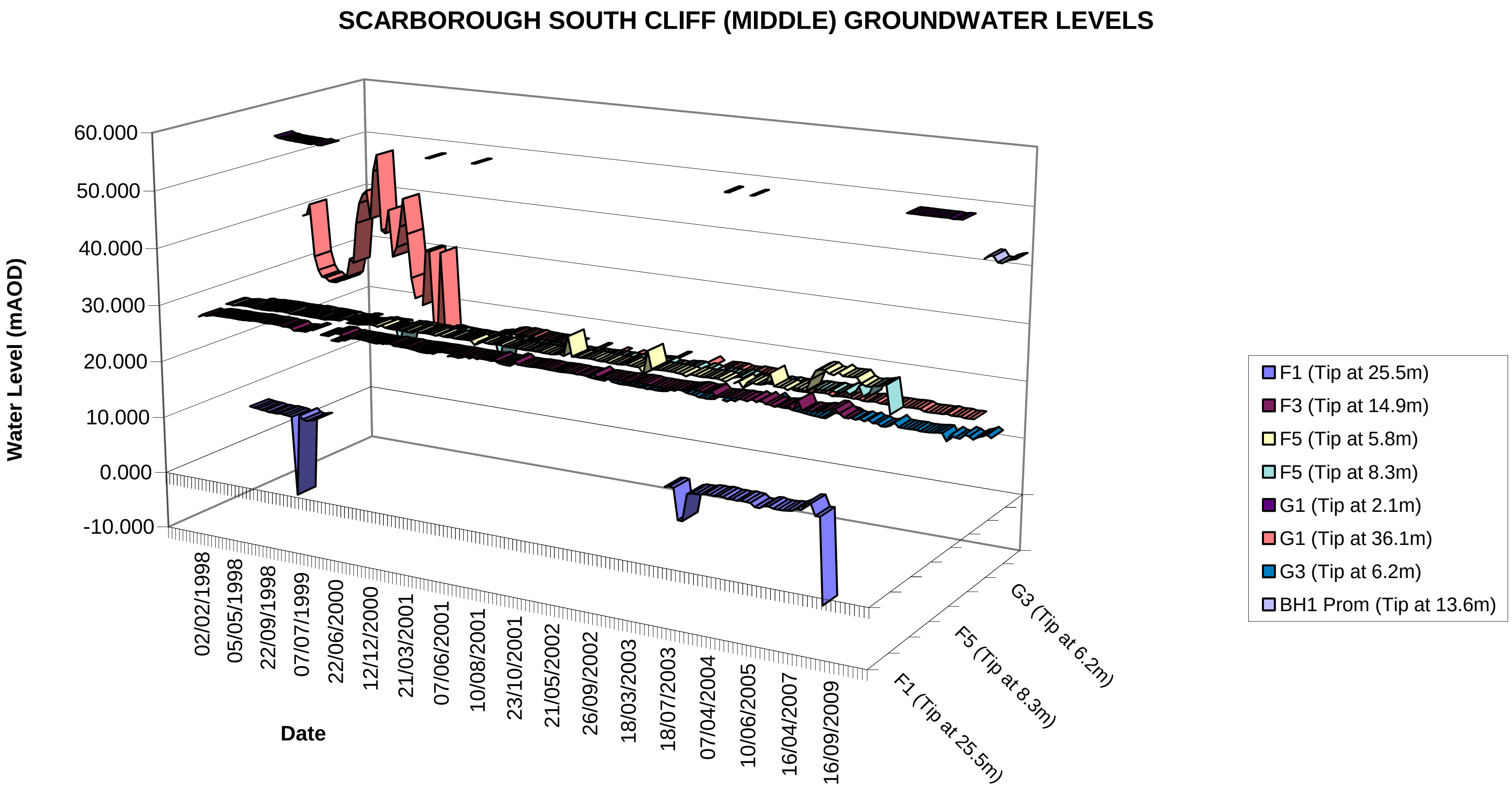


SCARBOROUGH NORTH BAY GROUNDWATER LEVELS

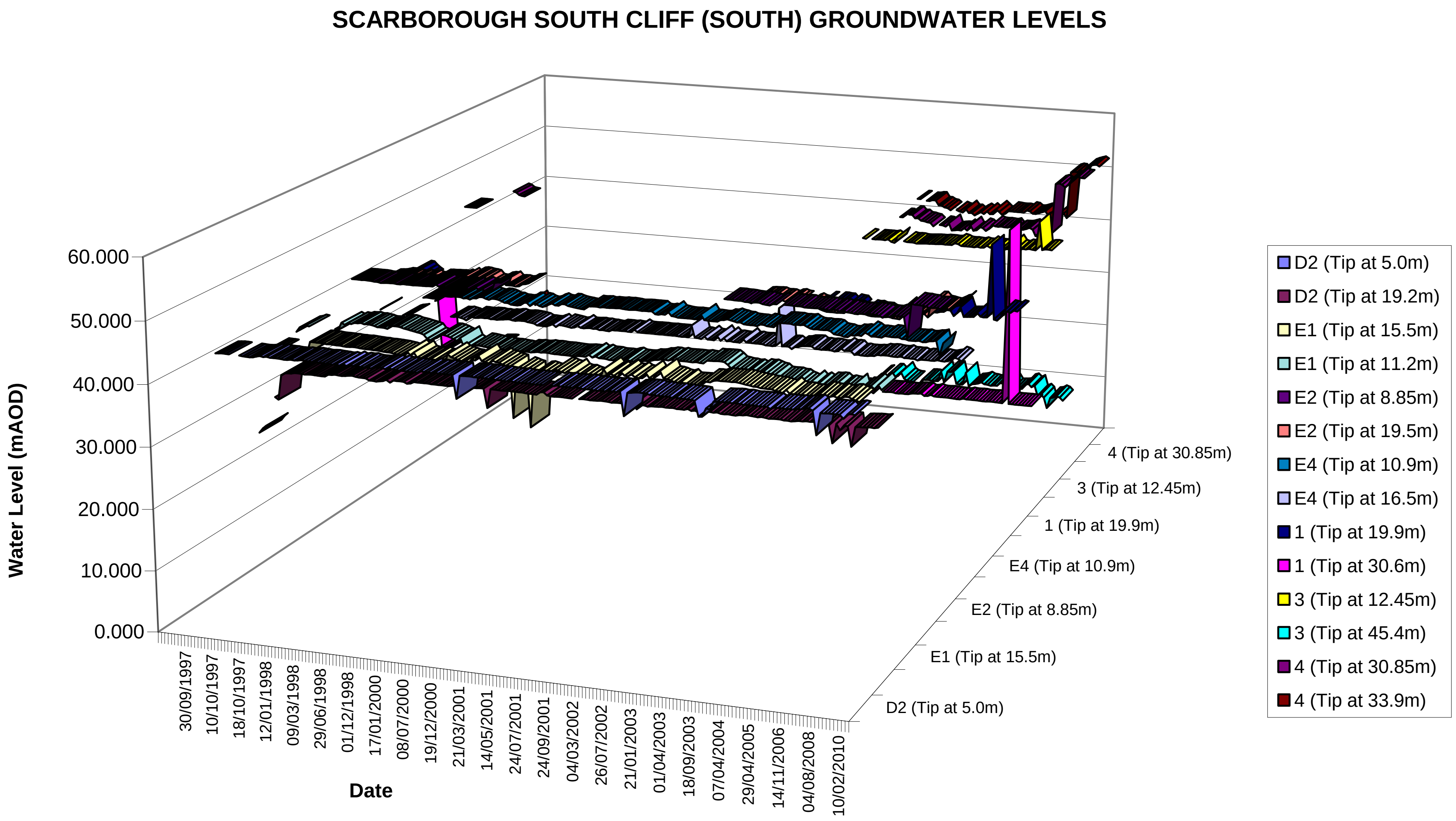


SCARBOROUGH SOUTH CLIFF (NORTH) GROUNDWATER LEVELS

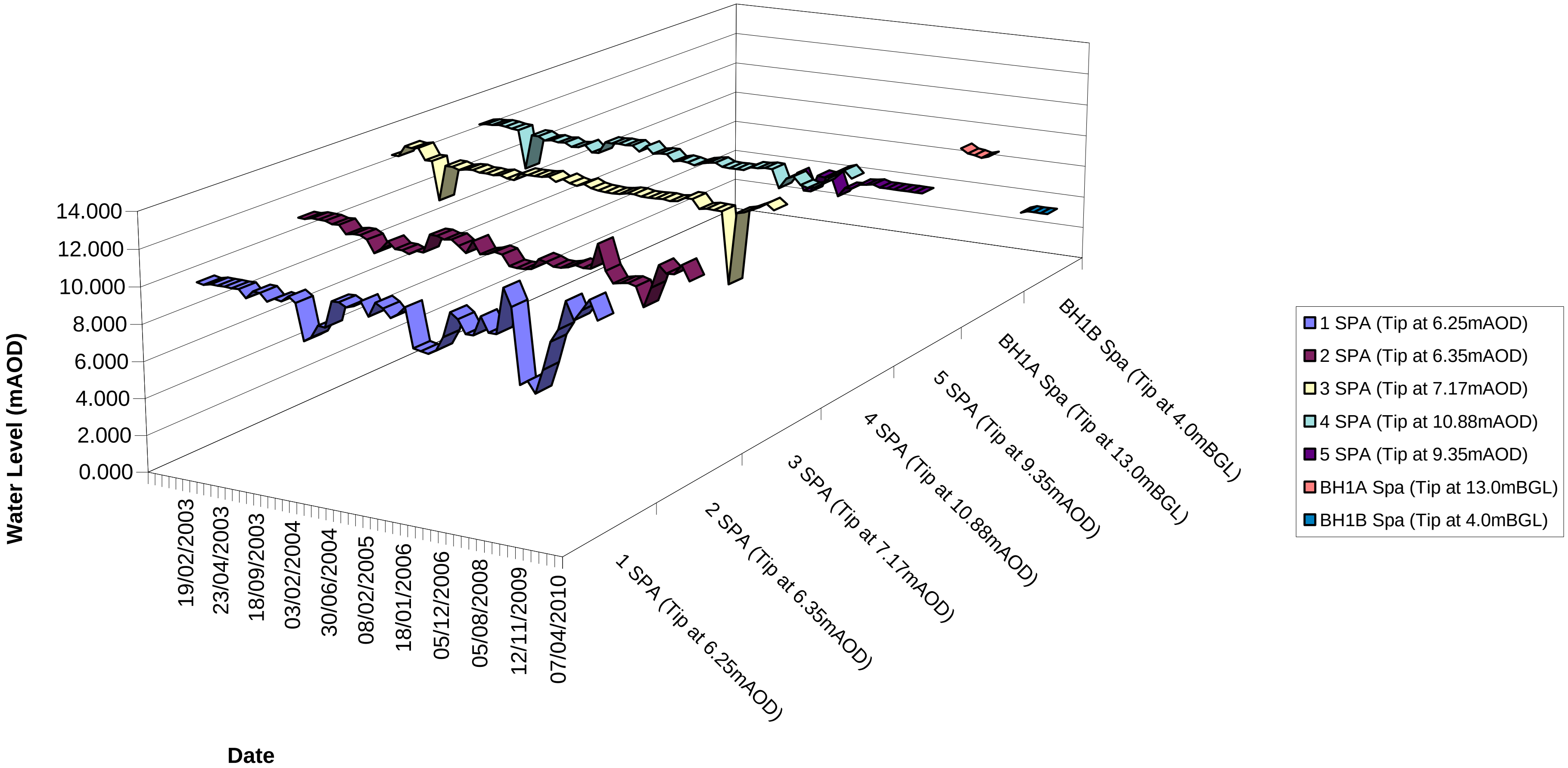


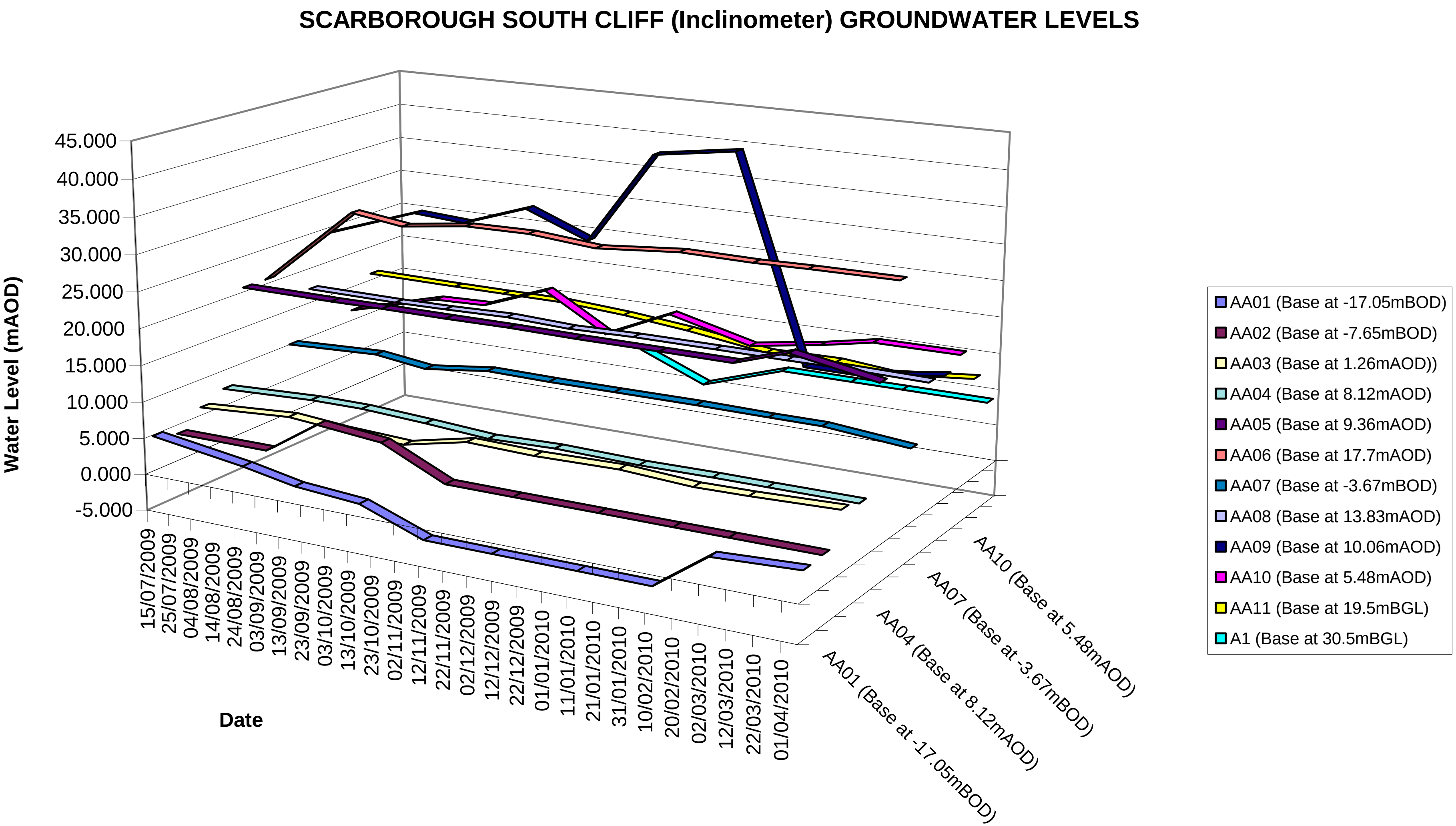


SCARBOROUGH SOUTH CLIFF (MIDDLE) GROUNDWATER LEVELS
Water Level (mAOD)
60.000
50.000
40.000
30.000
20.000
10.000
0.000
-10.000
02/02/1998
05/05/1998
22/09/1998
07/07/1999
22/06/2000
12/12/2000
21/03/2001
07/06/2001
10/08/2001
23/10/2001
21/05/2002
26/09/2002
18/03/2003
18/07/2003
07/04/2004
10/06/2005
16/04/2007
16/09/2009
Date
G3 (Tip at 6.2m)
F5 (Tip at 8.3m)
F1 (Tip at 25.5m)
F1 (Tip at 25.5m)
F3 (Tip at 14.9m)
F5 (Tip at 5.8m)
F5 (Tip at 8.3m)
G1 (Tip at 2.1m)
G1 (Tip at 36.1m)
G3 (Tip at 6.2m)
BH1 Prom (Tip at 13.6m)


SCARBOROUGH SOUTH CLIFF (SOUTH) GROUNDWATER LEVELS
Water Level (mAOD)
60.000
50.000
40.000
30.000
20.000
10.000
0.000
30/09/1997
10/10/1997
18/10/1997
12/01/1998
09/03/1998
29/06/1998
01/12/1998
17/01/2000
08/07/2000
19/12/2000
21/03/2001
14/05/2001
24/07/2001
24/09/2001
04/03/2002
26/07/2002
21/01/2003
01/04/2003
18/09/2003
07/04/2004
29/04/2005
14/11/2006
04/08/2008
10/02/2010
Date
4 (Tip at 30.85m)
3 (Tip at 12.45m)
1 (Tip at 19.9m)
E4 (Tip at 10.9m)
E2 (Tip at 8.85m)
E1 (Tip at 15.5m)
D2 (Tip at 5.0m)
D2 (Tip at 5.0m)
D2 (Tip at 19.2m)
E1 (Tip at 15.5m)
E1 (Tip at 11.2m)
E2 (Tip at 8.85m)
E2 (Tip at 19.5m)
E4 (Tip at 10.9m)
E4 (Tip at 16.5m)
1 (Tip at 19.9m)
1 (Tip at 30.6m)
3 (Tip at 12.45m)
3 (Tip at 45.4m)
4 (Tip at 30.85m)
4 (Tip at 33.9m)

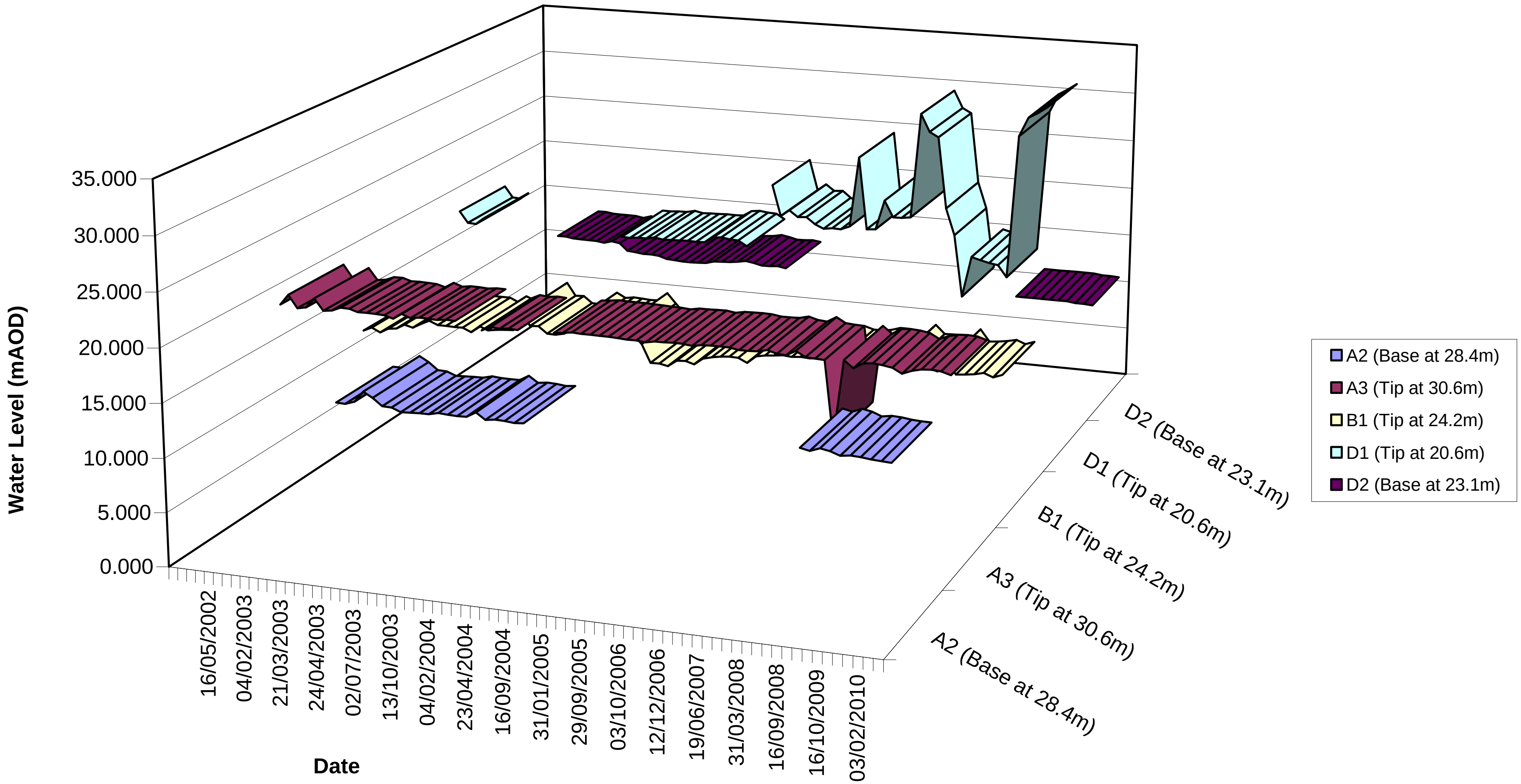
SCARBOROUGH SPA GROUNDWATER LEVELS





SCARBOROUGH SOUTH CLIFF (Inclinometer) GROUNDWATER LEVELS
Water Level (mAOD)
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
Date
15/07/2009
25/07/2009
04/08/2009
14/08/2009
24/08/2009
03/09/2009
13/09/2009
23/09/2009
03/10/2009
13/10/2009
23/10/2009
02/11/2009
12/11/2009
22/11/2009
02/12/2009
12/12/2009
22/12/2009
01/01/2010
11/01/2010
21/01/2010
31/01/2010
10/02/2010
20/02/2010
02/03/2010
12/03/2010
22/03/2010
01/04/2010
AA01 (Base at -17.05mBOD)
AA04 (Base at 8.12mAOD)
AA07 (Base at -3.67mBOD)
AA10 (Base at 5.48mAOD)
AA01 (Base at -17.05mBOD)
AA02 (Base at -7.65mBOD)
AA03 (Base at 1.26mAOD))
AA04 (Base at 8.12mAOD)
AA05 (Base at 9.36mAOD)
AA06 (Base at 17.7mAOD)
AA07 (Base at -3.67mBOD)
AA08 (Base at 13.83mAOD)
AA09 (Base at 10.06mAOD)
AA10 (Base at 5.48mAOD)
AA11 (Base at 19.5mBGL)
A1 (Base at 30.5mBGL)

FILEY FLAT CLIFFS GROUNDWATER LEVELS



Appendix D Groundwater Readings – Knipe Point

Groundwater Monitoring Readings – April 2010

SITE Exploratory hole No.	Date (2010)	Inst. Type	Ground Level (mOD)	Water Level (mBGL)	Dipped Depth (mBGL)	Instrument Depth (mBGL)	Response Stratum
Knipe Point							
BH01	14th April	Piezo	86.10	39.63	-	45.00	S'st & Siltstone
BH02a	14th April	Piezo	86.60	-	3.38[1]	97.00	Glacial Till
BH02b	14th April	Piezo	86.60	-	3.38[1]	25.00	Mudst & Siltstone
BH03a	14th April	Piezo	79.10	-	63.80[2]	75.00	S'st & Siltstone
BH03b	14th April	Piezo	79.10	-	0.43	38.00	Glacial Till
BH04a	14th April	Piezo	70.00	-	0.50[3]	63.00	Mudstone and Siltstone
BH04b	14th April	Piezo	70.00	-	0.50[3]	90.00	Siltstone
BH05a	14th April	Piezo	30.10	10.12	19.89	75.00	Siltstone & S'st
BH05b	14th April	Piezo	30.10	14.53	20.04	32.00	Silty sandy CLAY
BH06	14th April	Piezo	34.40	0.34	28.42	30.00	Glacial Till

[1] - Borehole blocked at 3.38m bGL.

[2] - Dip meter jammed in borehole 'a' at 63.80m bGL, 'b' blocked at 0.43m bGL.

[3] - Borehole collapsed at ground level creating a depression 0.50m depth, 1.20m diameter (See Plate 57, Appendix F).

Appendix E Survey Data

Initial Monitoring of Survey Points – 22nd July 2009

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

Scalby Ness					
	Easting	Northing	Height (m)	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 (m)	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		

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

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (m)	Slope Distance	Remarks
MP1	504549.325	487431.090	54.322	10.725	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.474	487434.499	53.691	12.990	
MP3	504571.837	487437.291	50.847	10.256	
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 (m)	Slope Distance	Remarks
MP1	504754.082	487134.614	55.305	12.035	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	7.212	
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	489306.554	511468.120	40.864	8.311	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	489308.296	511474.546	35.887	7.874	
MP3	489310.241	511481.188	32.126	8.657	
MP4	489313.968	511487.066	26.988	12.612	
MP5	489315.765	511498.358	21.652	11.665	
MP6	489314.795	511508.928	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. Distances to edge measured with tape measure.
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 – 21st September 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	489306.567	511468.127	40.840	8.310	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	489308.298	511474.546	35.879	7.870	
MP3	489310.263	511481.188	32.156	8.643	
MP4	489313.967	511487.050	26.974	12.617	
MP5	489315.744	511498.361	21.666	11.658	
MP6	489314.790	511508.925	16.801		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.839	490962.717	35.822	3.15	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	503425.535	490962.710	36.027	4.30	
MP3	503429.464	490952.274	35.489	2.65	
MP4	503434.037	490941.924	34.953	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.945	487885.398	48.508	7.207	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.739	487888.114	45.193	6.082	
MP3	504364.829	487888.943	41.968	9.112	
MP4	504372.873	487890.619	38.039	10.323	
MP5	504381.838	487893.883	34.086	9.241	
MP6	504389.366	487897.596	30.221		

Ongoing Coastal Monitoring of Survey Points – 21st September 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504549.295	487431.105	54.318	10.719	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.441	487434.504	53.688	12.990	
MP3	504571.812	487437.273	50.852	10.264	
MP4	504579.833	487440.319	45.218	13.848	
MP5	504592.569	487444.599	41.863		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504754.076	487134.606	55.300	12.039	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.241	487137.088	49.346	6.000	
MP3	504769.602	487136.004	46.879	7.219	
MP4	504775.963	487137.837	44.999		

Ongoing Coastal Monitoring of Survey Points – 12th October 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	489306.567	511468.127	40.840	8.313	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	489308.298	511474.546	35.879	7.870	
MP3	489310.263	511481.188	32.156	8.657	
MP4	489313.967	511487.050	26.974	12.613	
MP5	489315.744	511498.361	21.666	11.656	
MP6	489314.790	511508.925	16.801		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.839	490962.717	35.822	3.15	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	503425.535	490962.710	36.027	4.30	
MP3	503429.464	490952.274	35.489	2.65	
MP4	503434.037	490941.924	34.953	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.973	487885.396	48.512	7.211	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.771	487888.116	45.197	6.079	
MP3	504364.855	487888.946	41.970	9.110	
MP4	504372.897	487890.625	38.032	10.319	
MP5	504381.858	487893.891	34.092	9.247	
MP6	504389.389	487897.611	30.225		

Ongoing Coastal Monitoring of Survey Points – 12th October 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504549.310	487431.103	54.320	10.726	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.463	487434.503	53.688	12.978	
MP3	504571.821	487437.280	50.859	10.262	
MP4	504579.839	487440.330	45.227	13.848	
MP5	504592.573	487444.612	41.868		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504754.075	487134.604	55.300	12.050	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.249	487137.102	49.345	5.997	
MP3	504769.605	487136.013	46.878	7.225	
MP4	504775.968	487137.847	43.989		

Ongoing Coastal Monitoring of Survey Points – 16th November 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	489306.563	511468.127	40.911	8.315	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	489308.307	511474.548	35.933	7.871	
MP3	489310.278	511481.208	32.181	8.655	
MP4	489313.954	511487.061	26.987	12.618	
MP5	489315.753	511498.365	21.685	11.663	
MP6	489314.803	511508.927	16.838		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.830	490962.730	35.860	3.15	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	503425.526	490962.706	36.066	4.30	
MP3	503429.456	490952.269	35.520	2.65	
MP4	503434.022	490941.926	34.975	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.978	487885.391	48.529	7.200	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.768	487888.104	45.218	6.082	
MP3	504364.856	487888.946	41.992	9.112	
MP4	504372.898	487890.614	38.050	10.318	
MP5	504381.859	487893.876	34.111	9.251	
MP6	504389.392	487897.598	30.241		

Ongoing Coastal Monitoring of Survey Points – 16th November 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1 MP2 MP3 MP4 MP5	504549.296 504559.463 504571.811 504579.828 504592.567	487431.089 487434.491 487437.268 487440.319 487444.614	54.307 53.673 50.844 45.206 41.852	10.723 12.989 10.265 13.856	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1 MP2 MP3 MP4	504754.080 504764.252 504769.608 504775.975	487134.589 487137.084 487135.997 487137.827	55.312 49.359 46.882 44.004	12.047 6.000 7.223	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.

Ongoing Coastal Monitoring of Survey Points – 14th December 2009

Whitby West Cliff					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	489306.570	511468.135	40.864	8.309	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	489308.301	511474.548	35.863	7.870	
MP3	489310.275	511481.195	32.104	8.657	
MP4	489313.963	511487.086	26.918	12.623	
MP5	489315.748	511498.376	21.605	11.657	
MP6	489314.790	511508.950	16.764		

Scalby Ness					
	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	503417.829	490962.715	35.861	3.15	Monitor point co-ordinates derived directly from GPS observations. Distances to edge measured with tape measure.
MP2	503425.527	490962.707	36.077	4.30	
MP3	503429.466	490952.282	35.546	2.65	
MP4	503434.021	490941.941	34.985	4.18	

Scarborough South Cliff (North Section)					
H4	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504353.925	487885.364	48.513	7.207	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504359.724	487888.078	45.204	6.078	
MP3	504364.808	487888.912	41.979	9.112	
MP4	504372.852	487890.587	38.039	10.320	
MP5	504381.815	487893.847	34.098	9.252	
MP6	504389.352	487897.569	30.233		

Ongoing Coastal Monitoring of Survey Points – 14th December 2009 (Continued)

Scarborough South Cliff (Central Section)					
E3	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504549.289	487431.079	54.292	10.721	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504559.438	487434.479	53.670	12.999	
MP3	504571.816	487437.252	50.829	10.266	
MP4	504579.838	487440.302	45.195	13.849	
MP5	504592.573	487444.589	41.841		

Scarborough South Cliff (South Section)					
BH2	Easting	Northing	Height (mAOD)	Slope Distance	Remarks
MP1	504754.082	487134.597	55.319	12.046	Monitor point co-ordinates derived directly from GPS observations. Slope distances calculated from separate TPS observations.
MP2	504764.252	487137.083	49.361	6.006	
MP3	504769.616	487135.994	46.888	7.219	
MP4	504775.976	487137.828	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 21/09/09	Slope Distance 12/10/09	Slope Distance 16/11/09	Slope Distance 14/12/09
MP1	8.319	8.311	8.310	8.313	8.315	8.309
MP2	7.869	7.874	7.870	7.870	7.871	7.870
MP3	8.655	8.657	8.643	8.657	8.655	8.657
MP4	12.623	12.612	12.617	12.613	12.618	12.623
MP5	11.657	11.665	11.658	11.656	11.663	11.657
MP6						

Scalby Ness						
	Distance to Edge 22/07/09	Distance to Edge 24/08/09	Distance to Edge 21/09/09	Distance to Edge 12/10/09	Distance to Edge 16/11/09	Distance to Edge 14/12/09
MP1	3.15	3.15	3.15	3.15	3.15	3.15
MP2	4.30	4.30	4.30	4.30	4.30	4.30
MP3	2.66	2.65	2.65	2.65	2.65	2.65
MP4	4.18	4.18	4.18	4.18	4.18	4.18

Scarborough South Cliff (North Section)						
H4	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance 21/09/09	Slope Distance 12/10/09	Slope Distance 16/11/09	Slope Distance 14/12/09
MP1	7.206	7.204	7.207	7.211	7.200	7.207
MP2	6.079	6.081	6.082	6.079	6.082	6.078
MP3	9.117	9.114	9.112	9.110	9.112	9.112
MP4	10.317	10.320	10.323	10.319	10.318	10.320
MP5	9.246	9.246	9.241	9.247	9.251	9.252
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 21/09/09	Slope Distance 12/10/09	Slope Distance 16/11/09	Slope Distance 14/12/09
MP1	10.724	10.724	10.719	10.726	10.723	10.721
MP2	12.989	12.983	12.990	12.978	12.989	12.999
MP3	10.254	10.260	10.264	10.262	10.265	10.266
MP4	13.849	13.855	13.848	13.848	13.856	13.849
MP5						

Scarborough South Cliff (South Section)						
BH2	Slope Distance 22/07/09	Slope Distance 24/08/09	Slope Distance 21/09/09	Slope Distance 12/10/09	Slope Distance 16/11/09	Slope Distance 14/12/09
MP1	12.050	12.050	12.039	12.050	12.047	12.046
MP2	6.004	5.997	6.000	5.997	6.000	6.006
MP3	7.211	7.236	7.219	7.225	7.223	7.219
MP4						

Ongoing Coastal Monitoring of Survey Points - Monthly Comparison

Knipe Point						
Marker ID	Baseline Distance 12/02/10	Slope Distance 09/03/10	Slope Distance 14/04/10	Slope Distance	Slope Distance	Slope Distance
Knipe Point Headscarp						
H1	12.25m	12.30m	12.28m			
H2	5.30m	5.35m	5.35m			
H3	4.40m	4.41m	4.44m			
H4	6.20m	6.20m	6.15m			
H5	19.80m	19.24m	19.22m			
H6	20.90m	20.72m	20.96m			
H7	19.10m	18.88m	18.73m			
H8	3.60m	3.65m	3.62m			
H9	7.40m	7.35m	7.30m			
H10a	10.70m	10.64m	10.59m			
H10b	14.00m	14.00m	14.01m			
H11	7.40m	7.05m	6.81m			
H12	15.90m	15.88m	15.90m			
H13	4.90m	5.10m	4.85m			
H14	4.07m	4.08m	4.04m			
H14	8.80m	8.80m	8.80m			
H14	11.18m	11.20m	11.19m			
Former A165 (Old Filey Road) Headscarp						
R0	8.21m	8.21m	8.21m			
R0	17.25m	17.25m	17.25m			
R0	11.21m	11.21m	11.21m			
R0	3.10m	3.10m	3.10m			
R1	20.10m	19.96m	19.96m			
R2	11.10m	11.14m	11.14m			
R3	9.20m	9.39m	9.39m			
R4	6.20m	6.35m	6.35m			
R5	7.60m	7.99m	7.99m			
R6	*	*	*			
Cornelian Bay Headscarp						
C1	3.70m	3.70m	3.70m			
C4	3.90m	3.90m	3.88m			
C8	New	N2.20,E3.01m	N2.01,E2.98m			

* - Inaccessible due to blackthorn cuttings

Appendix F Installation Photographs

Plate 1 Runswick Bay A001

Plate 2 Runswick Bay A002

Plate 3 Runswick Bay A003

Plate 4 Runswick Bay A004

Plate 5. Whitby West Cliff BH2

Plate 6 Scarborough North Bay L1

Plate 7 Scarborough North Bay L11

Plate 8 Scarborough North Bay L12

Plate 9 Scarborough North Bay L3

Plate 10 Scarborough North Bay L4

Plate 11 Scarborough North Bay L5

Plate 12 Scarborough North Bay L6

Plate 13 Scarborough North Bay (Oasis Café) BH1I

Plate 14 Scarborough North Bay (Oasis Café) BH1P

Plate 15 Scarborough North Bay (Oasis Café) BH2P

Plate 16 Scarborough North Bay (Oasis Café) BH3I

Plate 17 Scarborough North Bay (Oasis Café) BH3P

Plate 18 Scarborough North Bay (Oasis Café) BH4I

Plate 19 Scarborough North Bay (Oasis Café) BH4P

Plate 20 Scarborough South Cliff I1 (AA01)

Plate 21 Scarborough South Cliff H4 (AA02)

Plate 22 Scarborough South Cliff BH1 Prom

Plate 23 Scarborough South Cliff H6 (AA03)

Plate 24 Scarborough South Cliff G2 (AA04)

Plate 25 Scarborough South Cliff F2 (AA10)

Plate 26 Scarborough South Cliff F4 (AA11)

Plate 27 Scarborough South Cliff E3 (AA09)

Plate 28 Scarborough South Cliff E5 (AA05)

Plate 29 Scarborough South Cliff D3 (AA08)

Plate 30 Scarborough South Cliff D1 (AA06)

Plate 31 Scarborough South Cliff Bh2 (AA07)

Plate 32 Scarborough South Cliff I2

Plate 33 Scarborough South Cliff I2A

Plate 34 Scarborough South Cliff H2

Plate 35 Scarborough South Cliff H1

Plate 36 Scarborough South Cliff H5

Plate 37 Scarborough South Cliff 1 Spa

Plate 38 Scarborough South Cliff 2 Spa

Plate 39 Scarborough South Cliff 3 Spa

Plate 40 Scarborough South Cliff 4 Spa

Plate 41 Scarborough South Cliff G3

Plate 42 Scarborough South Cliff 5 Spa

Plate 43 Scarborough South Cliff BH01 SPA

Plate 44 Scarborough South Cliff F5

Plate 45 Scarborough South Cliff F3

Plate 46 Scarborough South Cliff E2

Plate 47 Scarborough South Cliff E1

Plate 48 Scarborough South Cliff E4

Plate 49 Scarborough South Cliff D2

Plate 50 Scarborough South Cliff Bh3

Plate 51 Scarborough South Cliff Bh4

Plate 52 Scarborough South Cliff Bh1

Plate 53 Scarborough South Cliff A1

Plate 54 Scarborough South Cliff. Pavement cracks above the Clock Café (March. 2010)

Plate 55 Scarborough South Cliff. Pavement repair above the Clock Café (April 2010).

Plate 56 Scarborough South Cliff Slope bulging adjacent the Clock Café (Jan 2010).

Plate 57 Footpath degradation around Holbeck Gardens.

Plate 58 Knipe Point BH01 (4th March 2010)

Plate 59 Knipe Point BH02 (4th March 2010)

Plate 60 Knipe Point BH03 (4th March 2010)

Plate 61 Knipe Point BH04 (4th March 2010)

Plate 62 Knipe Point BH05

Plate 63 Knipe Point BH06

Plate 64 Filey Flat Cliffs A2

Plate 65 Filey Flat Cliffs B1

Plate 66 Filey Flat Cliffs D1

Plate 67 Filey Flat Cliffs A3

Appendix G Scalby Ness Instability Photographs

Plate 1 Mid-slope tension crack development on Behavioural Unit II slopes. (14th April 2010)

Plate 2 Slope failures along river's edge of Behavioural Unit I. (14th April 2010)

Plate 3 Slope failure along river's edge of Behavioural Unit I. (14th April 2010)

Plate 4 Slope failure along river's edge of Behavioural Unit I. (14th April 2010)

Plate 5 Slope failure along river's edge of Behavioural Unit I. (14th April 2010)

Plate 6 Slope failure along river's edge of Behavioural Unit I. (14th April 2010)

Plate 7 Tree clearance along relict slope failure at crest of Behavioural Unit III

Plate 8 Tree clearance along relict slope failure at crest of Behavioural Unit III

Appendix H Site Photographs from Knipe Point

Plate 1 Slope failures on Cornelian Bay side of Knipe Point looking northwest

Plate 2 Slope failures on Cornelian Bay side of Knipe Point looking northwest

(Photographs taken 16th March and14th April 2010, respectively)

Plate 3 Slope failures on Cornelian Bay side looking east (16th March 2010)

Plate 4 Slope failures on Cornelian Bay side looking east (14th April 2010)

Plate 5 View of Knipe Point Headscarp at Monitoring Pin H4 (14^{th} April 2010)

Plate 6 View of ‘fresh’ mudslide on Knipe Point Headscarp below Property No. 18 (14^{th} April 2010)

Plate 7 Cliff recession at Knipe Point Headscarp (20th January 2010)

Plate 8 Cliff recession at Knipe Point Headscarp (8th March 2010)

Plate 9 Cliff recession at Knipe Point Headscarp (16th March 2010)

Plate 10 Cliff recession at Knipe Point Headscarp (14th April 2010)

Plate 11 Cliff recession at Knipe Point Headscarp (8th March 2010) looking east

Plate 12 Cliff recession at Knipe Point Headscarp (14th April 2010) looking east

Plate 13 Cliff recession at Knipe Point Headscarp (14th April 2010) looking east

Plate 14 Knipe Point Residential Plan

Plate 15 Knipe Point Weather Station with Chalet No. 50 behind this.