

Interpretation Report 6: December 2015 to May 2016

Prepared for
Scarborough
Borough Council

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The interpretation of the level of cliff instability risk presented in this document is based solely on the data provided by JBA. While every effort will be made to ensure the data are correct, Halcrow cannot be held responsible for the quality of monitoring data. This data analysis report comments on the monitoring data collected over the preceding 6 month period at specific locations. It will not make projections of future cliff instability activity or discuss cliff instability risk at areas that are not monitored. It is Scarborough Borough Council's responsibility to determine an appropriate response to the guidance on cliff instability risk provided in this report.

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Summary of findings

This report presents an interpretation of coastal slope monitoring data recorded between December 2015 and May 2016 along the Scarborough Borough Council frontage. It is the sixth in a series of 6-monthly updates on the cliff instability risk of the frontage. The weather over the winter and spring 2016 period covered by this report was average, with above average rainfall only in January and March. Boreholes shows that water levels have remained at previous low levels or risen slightly during the monitoring period, except for Robin Hood's Bay (BH1a), Scalby Ness (P2a, WS4, B9, Sn2a and Sn2b), Scarborough Spa (H5, BH104b, BH108a), South Cliff Gardens (E2a, E2b) and Filey Town (CPBH01a) that remain at atypically high levels. In situ monitoring using inclinometers does not indicate any slope movement, indicating that localised elevated groundwater levels have not triggered ground movement. Experimental in situ monitoring using Acoustic Emissions devices installed by Loughborough University at Scarborough Spa and Flat Cliffs also show negligible slope movement.

Specific sites of concern and issues needing attention are as follows:

- At Robin Hood's Bay, BH1a shows groundwater levels have risen considerably since the covering of tarmac applied prior to last reading has been removed. It is likely that this borehole has been affected by surface water ingress. Piezometers BH3a and BH3b require readings to be re-taken on the next site visit
- At Scalby Ness, piezometers P1a and P1b experienced a problem downloading data and should be investigated and remedied by the monitoring contractor at the next download. Groundwater levels have risen in boreholes P2a, WS4, B9, Sn2a and Sn2b to near historical highs. No movement was detected at inclinometers nearby, but this site should be visually monitored, particularly if rainfall is high during the summer and autumn. Piezometers P4a and P4b record changes in groundwater with the same pattern but at slightly different levels, which suggests piezometers are not monitoring discrete horizons and the seal between the two piezometers may have been damaged. Borehole WS5 remains dry, suggesting damage. These locations should continue to be monitored.
- At Oasis Café attention should be given to piezometer BH4p where rising groundwater during drier than average months suggest an ingress of surface water from cliff top developments or a local source of groundwater not associated with rainfall recharge, such as leaking services.
- At Scarborough North Bay (The Holms), there was a problem downloading data at borehole BH9a. The issue should be investigated and remedied by the monitoring contractor next time.
- At Scarborough Spa, boreholes H5 and BH108a and BH104b show water-levels are at a high level. No movement was detected at inclinometers nearby, but this site should be visually monitored. Several boreholes were dry (G1a, BH106a, BH106b and 5 spa), suggesting the piezometer installations may be damaged, however, these locations should continue to be monitored.
- At the Clock Café, borehole BH15 remains dry, and the integrity of the piezometer should be checked.
- At the South Cliff Gardens, piezometers BH18a, BH18b and BH3b show rapid and short lived peaks, which suggest surface water ingress. The contractor should ensure that plastic caps are in place and that water cannot collect at the top of the boreholes. Rising water levels recorded in E2a and E2b should continue to be monitored to determine longer-term these trends. At borehole D2b and BH3a there was a problem downloading data. The issue should be investigated and remedied by the monitoring contractor next time. No movement has been indicated by the inclinometers in this location.

- At Holbeck Gardens there was a problem downloading data at borehole BH4a. The issue should be investigated and remedied by the monitoring contractor next time. New data logger in BH4b recorded atypically high groundwater levels and the calibration and integrity of the piezometer should be checked.
- At Filey Town, borehole CPBH01a water levels have risen to historical high. This is likely flooding by surface water flows or that the groundwater level is near the surface. This location should be visually checked, particularly if the summer and autumn of 2016 is wet. There is a difference between manually dipped water-levels and diver data at CPBH09b, suggesting the diver needs checking and resetting. Boreholes CPBH08b and CPBH10b are dry suggesting the piezometer installation may be damaged, however, the location should continue to be monitored. There was a problem downloading data from CPBH02a and CPBH06b, and this issue should be investigated and remedied by the monitoring contractor on the next visit.

Introduction

1.1 Background to study

The Scarborough Borough Council coastline is affected by widespread cliff instability, largely due to its geology and climate. Since the Holbeck Hall landslide in June 1993, understanding the risk posed by landslides has been a high priority for the Council. Numerous ground investigations and associated studies at locations of particular concern have been undertaken in the last 20 years meaning the Council now has a widespread network of ground monitoring instrumentation installed, much of which is automated using data-loggers. The Council has also supported the installation of experimental acoustic inclinometers by Loughborough University along its frontage. These experimental devices have the potential to provide cost-effective and accurate real time information on ground movement. The dataset allows the Council to better understand cliff instability risk and support decisions on risk management.

A comprehensive programme of data collection and analysis was commenced by the Council in October 2008, when SBC awarded Mouchel Ltd a contract to design a monitoring strategy for the coastline. Mouchel's recommendations were adopted by SBC and a four-year contract for regular data collection and monitoring reports was awarded. The 7th and final of these reports covered the period up to spring 2012, and was issued in August 2012 (Mouchel 2012).

On completion of this contract, SBC commissioned Haskoning UK Ltd to undertake a thorough review of the condition of boreholes and associated monitoring instruments (Haskoning, 2013). This report highlighted a number of instruments were damaged, due to shearing of the borehole, wear and tear, and vandalism. The work allowed SBC to develop a revised list of instruments and prepare tender documents for re-tendering of data collection and analysis work.

SBC invited tenders on 24 July 2013, with separate contracts for data collection and data analysis being let. Contracts covering an initial three year programme were awarded on 3 September 2013 to JBA Consulting Ltd and Halcrow Group Ltd (a CH2M company), for data collection and data analysis respectively. JBA undertook the first data collection exercise in November 2013. Data analysis is reported in separate CH2M reports (CH2M 2014a & b, 2015a & b, 2016a). A two year extension to the project was awarded to the incumbent team in March 2016.

This report provides the sixth set of data analysis and is presented as a stand-alone document.

1.2 Aims and objectives of monitoring

The main objective of the monitoring programme is to provide property- and land-owners with information on instability hazard and risk in vulnerable areas.

The sites and monitoring devices covered by this work are summarised in Table 1.1. Note that some boreholes may have multiple piezometers installed in order to monitor multiple water tables, inclinometers and piezometers are never located in the same boreholes and water-levels are not recorded in boreholes instrumented with inclinometers.

To meet this objective, the specific aims of the study are as follows:

- To place the preceding 6 months monitoring data in the context of the historical record
- To highlight the implications of the data to coastal instability risk management

In addition, the ultimate aim of the study is:

- To collect sufficient monitoring data to enable site-specific relationships between rainfall, groundwater levels and ground movement to be understood. With sufficient data, it is hoped

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that threshold rainfall and groundwater levels, above which instability is likely to be triggered, can be identified. This understanding will eventually allow early warning of potential ground movement to be provided.

Table 1.1. Monitoring locations and devices.

Location	Inclinometers	Acoustic Inclinometer	Piezometers	Weather station
Runswick Bay	4	0	0	0
Whitby West Cliff	1	0	0	0
Robin Hood's Bay	2	0	4	0
Scalby Ness	4	0	14	0
Scarborough North Bay – Oasis Café	2	0	3	0
Scarborough North Bay – The Holmes	2	0	6	0
Scarborough South Bay	17*	1	38*	0
Filey Town	4	0	24	0
Filey, Flat Cliffs	4	1	4	1
TOTAL	40	2	93	1

*a single inclinometer and a diver piezometer with barometric diver was added at St Nicholas Cliff in 2014 between collection of the 1st and 2nd set of monitoring data.

1.3 Programme of work

The planned programme of future analysis and reporting is shown in Table 1.2, which assumes the final interpretative report will be provided three months following receipt of the preceding 6 months' monitoring data.

Table 1.2. Programme of data collection and reporting

JBA Monitoring Period	CH2M (Halcrow) Analysis Report
Data set 1: June 2012 to November 2013	Report 1: March 2014 (CH2M 2014a)
Data set 2: December 2013 to May 2014 (data received 1 Aug 2014)	Report 2: November 2014 (CH2M 2014b)
Data set 3: June 2014 to November 2014	Report 3: March 2015 (CH2M 2015a)
Data set 4: December 2014 to May 2015	Report 4: October 2015 (CH2M 2015b)
Data set 5: June 2015 to November 2015	Report 5: February 2016 (CH2M 2016a)
Data set 6: December 2015 to May 2016	Report 6: August 2016 (this report)
Data set 7: June 2016 to November 2016	Report 7: February 2017
Data set 8: December 2016 to May 2017	Report 8: August 2017
Data set 9: June 2017 to November 2017	Report 9: February 2018
Data set 10: December 2017 to May 2018	Report 10: August 2018

1.4 Scope of data analysis work

JBA have sole responsibility for collection and checking of all inclinometer and piezometer data at 6 month intervals. JBA provide CH2M with the inclinometer and ground water data presented as graphs, ready for interpretation. The following graphs are provided in Appendices to this report:

- Inclinometer incremental displacement – total displacement at 0.5m intervals down the length of borehole since the baseline reading along two axes (A0 being downslope, A180 being at right angles to the slope). This plot is free from errors associated with past readings as only the most recent and original readings are compared. This plot highlights the depths where most significant movement has occurred.
- Inclinometer cumulative displacement – sum of all incremental displacements down the length of the borehole showing total deformation since the baseline reading along the two axes. If a user error has occurred, it is carried through all cumulative plots, potentially giving misleading results. Errors can usually be identified by comparison to incremental displacement plots.
- Inclinometer absolute position – this plots the absolute position of the inclinometer casing when viewed vertically. While it does not give information on the rate of movement, it highlights the direction of any deformation and can be used to assess error in the data.
- Groundwater data from piezometer divers or data loggers – these data are plotted as a continuous line showing groundwater level fluctuation relative to Ordnance Datum (OD).
- Groundwater data from monitoring wells – these data are plotted as single points, showing groundwater level relative to OD at a particular point in time. They provide an independent check of piezometer data or water level information from boreholes that do not have automatic data logging capability.

The scope of CH2M's data analysis work involves the following tasks:

- Checks of inclinometer and piezometer monitoring data provided by JBA to ensure the correct information is provided, and identification of any obvious errors in the data.
- Downloading and analysis of meteorological data from the weather station installed at Filey Flat Cliffs and Scarborough Spa. The weather station at Filey Flat Cliffs was non-functional for several months in 2015 and therefore supplemental data has been purchased from the MetOffice for Filey, around 3km to the north-northwest. Since 11 January 2016 meteorological data from Scarborough Spa has been used because the reliability of the Flat Cliffs weather station remains poor.
- Acquisition of experimental acoustic inclinometer data from Loughborough University.
- Analysis and interpretation of the data, including commentary on short and long-term patterns of change and observed relationships between rainfall, groundwater levels and ground movement.
- Comment on the implications of the observed data with regard to cliff instability hazard and risk management, allowing SBC to take any appropriate action.

The following sections provide a site-by-site discussion of the history of cliff instability and the monitoring regime, and interpretation of the new monitoring data. Comment is made on the relationships between rainfall, groundwater and ground movement, and the implications of the new data with regard to cliff instability hazard and risk management.

1.5 Cliff instability hazard assessment

Cliff instability hazard at each monitoring location is presented using a simple colour-coding system that summarises the significance of the result (Table 1.3). The assessment provides a simple record of activity that will be developed in subsequent reports to indicate changing levels of hazard.

Table 1.3. Instability hazard assessment guidance level

Hazard (low to high)	Definition
Green	Situation normal. No change in groundwater level from previous records, which are low or falling. Movement in inclinometers within margin of error (<5mm).
Orange	Site requires attention. Moderate or large increase in groundwater level from previous records or moderate movement in inclinometers. Failure of equipment, unreliable or no data requires attention.
Red	Immediate action required. Significant movement of inclinometer indicating high cliff instability hazard potential. Carry out site inspection, consider increasing the frequency of monitoring and managing public access to the area.

1.6 Checks of monitoring equipment integrity

Following completion of checking and interpretation of the first round of monitoring in early 2014, several inclinometer readings appeared to be erroneous, with some locations showing potential ground movement. A series of checks were undertaken during 2014 to determine whether or not the data were accurate, the source of any errors, and the implications to cliff instability risk management. In most cases, the errors were systematic and represent minor settlement of the borehole casing that gives rise to a sinuous pattern of deformation. However, where random errors were reported, it is likely that the borehole is partially blocked, leading to the probe coming away from the key ways. The 17 potentially blocked boreholes were therefore repaired by means of high pressure water jetting that was undertaken in early 2015.

In all cases where systematic or random errors have been identified, it has been recommended that the current reading is taken as a new baseline against which future recordings are made. In this way, potentially misleading historical results leading to cumulative errors will be removed. However, in order to determine whether change has occurred in the preceding 6 month period, data are also compared to the original baseline.

Weather Summary

2.1 Introduction

A meteorological station that records wind speed and direction, air temperature, humidity, air pressure, rainfall and rainfall intensity every 15 minutes has been in place at Flat Cliffs, central Filey Bay, since 29 September 2011. The device was inoperative from September 2014 to July 2015 and additional MetOffice rainfall data were therefore acquired from recording station Filey No 2 (54.20395, -0.30127), c. 3km north-northwest of Flat Cliffs. The Flat Cliffs weather station recorded erroneous data in the period March to May 2016, however at this time a new weather station at Scarborough Spa had become operational and therefore data from that site has been used from 11 January 2016 onwards. Data from all three weather stations are summarised in Table 2.1 and Figure 2.1, which show that January, March and April 2016 were particularly wet when compared to past records.

Table 2.1. Monthly rainfall recorded at Flat Cliffs met station

Month	Long-term mean (upper range)	Rainfall (mm)					
		2011	2012	2013	2014	2015	2016
January	80	No Data	31	41	113 (84.2)	No Data (13.4)	84* [part month]
February	60	No Data	8	38	96 (71.2)	No Data (44.8)	20.7*
March	60	No Data	27	32	29 (40.4)	No Data (22.2)	53.9* [part month]
April	60	No Data	96	4	26 (33)	No Data (15.8)	43.4*
May	60	No Data	34	37 [part month]	59 (50.8)	No Data (81.4)	15*
June	80	No Data	104	No Data	34 (61)	No Data (41.2)	23*
July	60	No Data	70	No Data	70 (93.2)	20	12.8* [part month]
August	80	No Data	45	38 [part month]	No data (108.2)	17	
September	80	0.14 (Part month)	69	15	No data (17)	46	
October	80	35	53	52	No Data (58)	29	
November	80	15	78	25	No Data (70)	63 [part month]	
December	80	72	132	6	No Data (27.2)	76.9	

Note: Data in brackets are from Filey No 2 station. Data marked * are from Scarborough Spa

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Daily rainfall totals recorded by the Scarborough Spa weather station are presented in Figure 2.2, which shows peaks on 3 January and 28 March. The combined dataset has been used for comparison with all coastal slope monitoring data in order to identify relationships. The data are taken to be representative of the whole Scarborough Borough Council frontage, but it is accepted that micro-climate effects may lead to local variations.

The Filey No 2 MetOffice data were provided as weekly totals and therefore the calculated totals do not precisely correspond to calendar months. The data show that the wettest month on record was December 2012 with 132mm, and that the wettest month during 2016 was January, with 84mm.

Seasonal totals are shown in Figure 2.3, which shows that the wettest seasons tend to be winter and summer and that the spring is the driest. The wettest season on record was winter of 2013/14 (i.e. December 2013, January and February 2014) that received a total of 244mm rainfall. The summers of 2012 and 2014 were also very wet, receiving 219mm and 211mm respectively. The winter of 2015/16 received around double the rainfall of 2014/5, but the spring was marginally drier.

Wind speed and air temperature records from Flat Cliffs are presented in Figures 2.4 and 2.5. The data shows January 2016 as the windiest month in the monitoring period and relatively gentle conditions persisted into mid-2016. Recorded temperatures during 2016 are average, except for the relatively mild winter of 2015/2016.

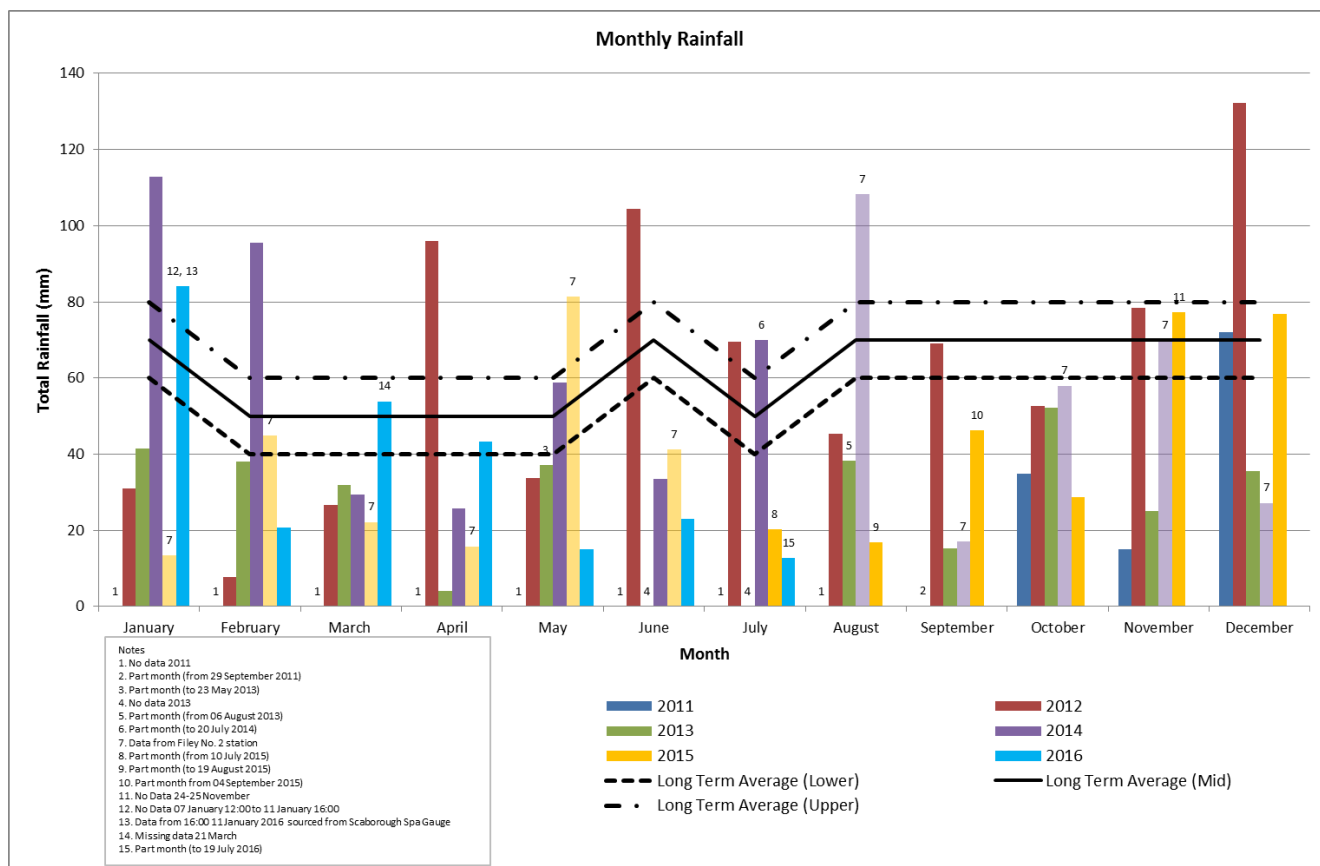


Figure 2.1 Comparison of monthly rainfall records (2011 to 2016).

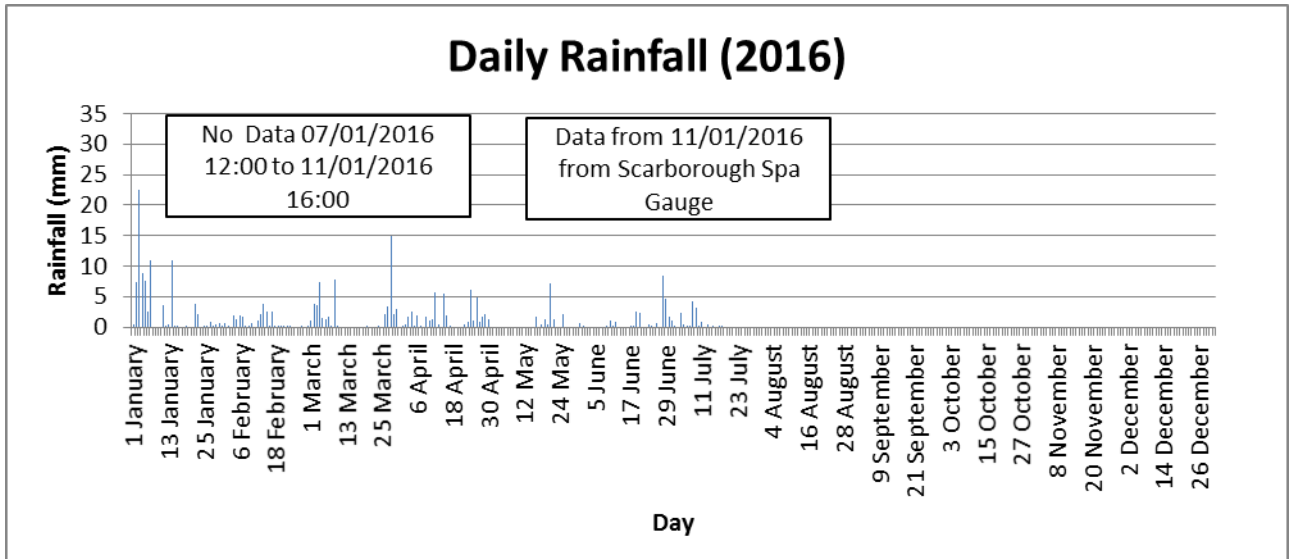


Figure 2.2 Daily rainfall recorded at Flat Cliffs during 2016

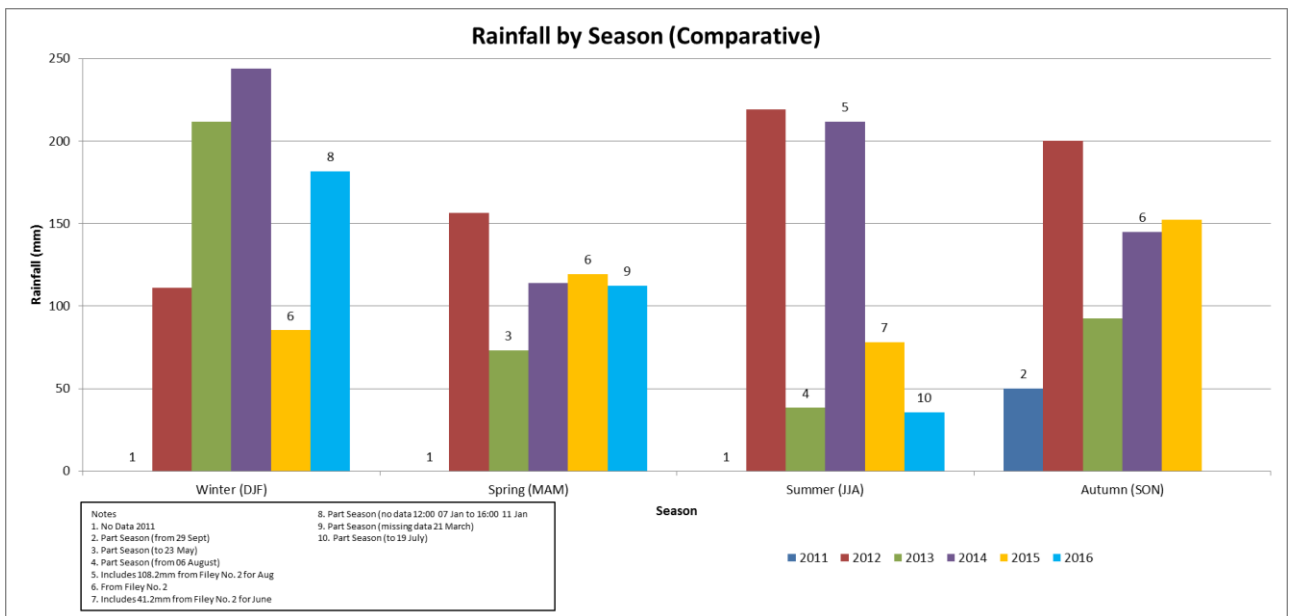


Figure 2.3 Seasonal rainfall comparison (2011-2016)

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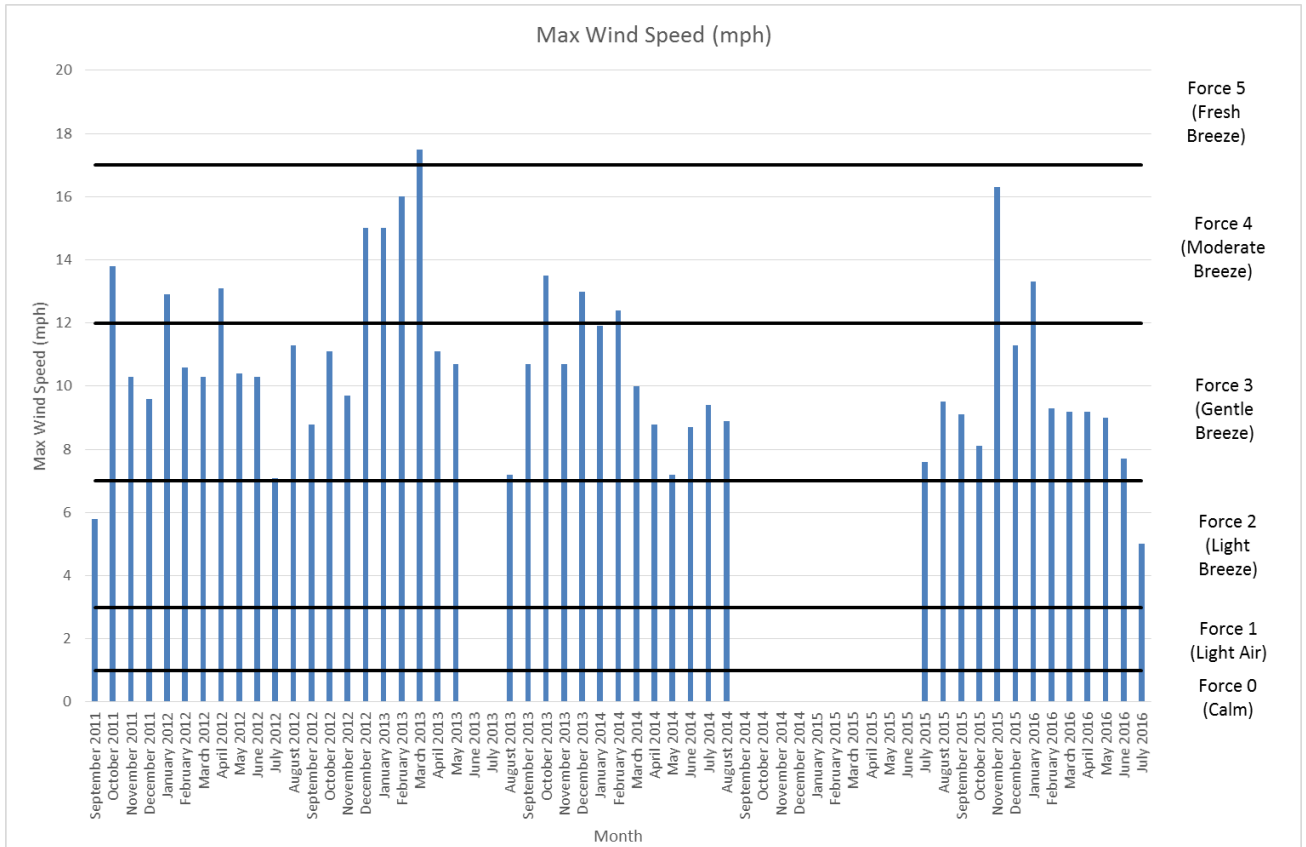


Figure 2.4 Maximum daily wind speed (2011 to 2016)

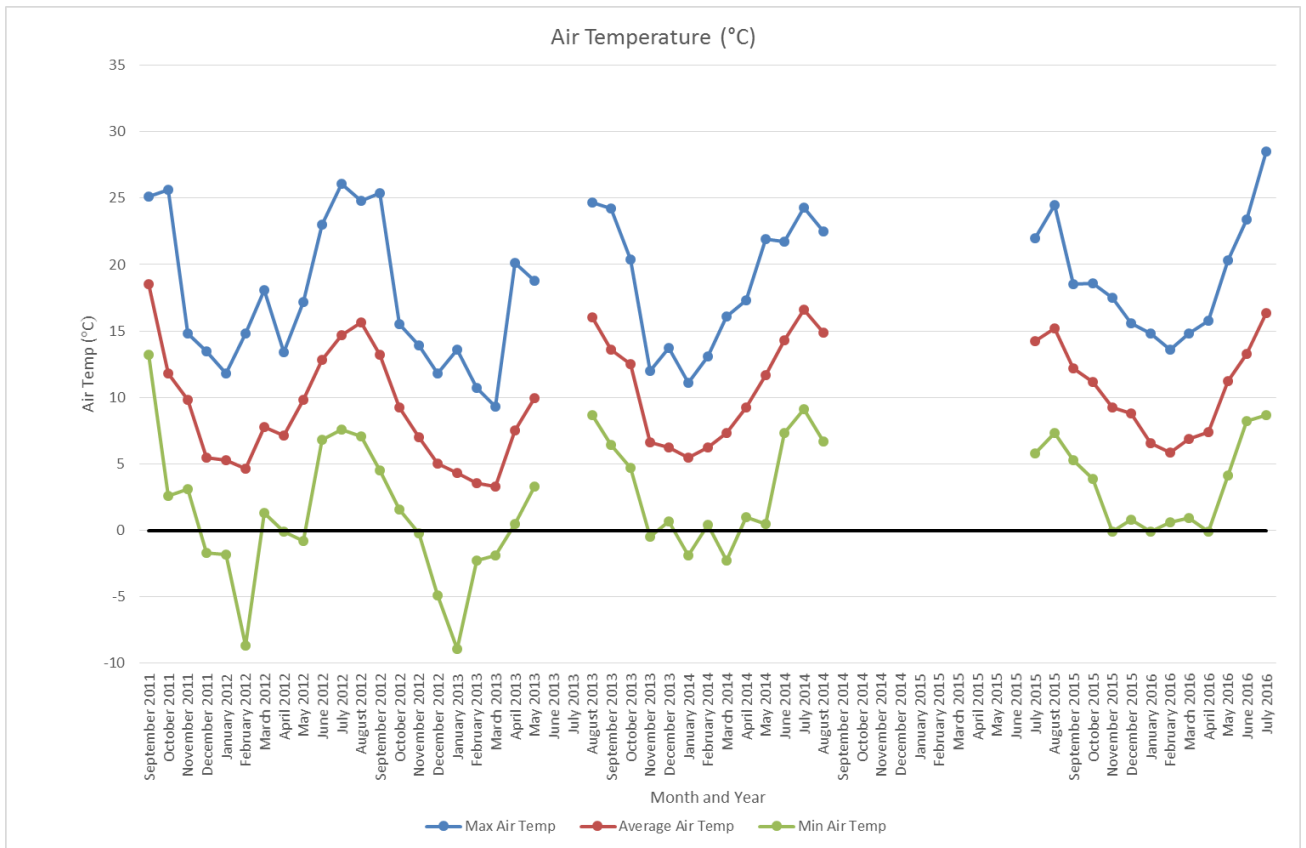


Figure 2.5 Air temperature variation (2011 to 2016)

2.1.1 Rainfall and landslides

The relationship between rainfall and the occurrence of landslides is complex and site-specific. It is often the case that a single intense rainfall event has little effect on a slope formed of relatively impermeable clay strata and soils, and instead cliff instability is only triggered after a period of sustained rainfall that allows groundwater levels to rise above a threshold level. This cumulative effect of sustained wet weather is known as antecedent rainfall. The time period over which antecedent rainfall exceeds a threshold for instability will vary from site to site, based principally on the local hydrogeology. It may vary from a period of days or weeks for sites formed of relatively higher permeability soils and rocks where groundwater responds rapidly to rainfall, to a period of months at locations of lower permeability soils and rocks.

The weather records for the SBC frontage spans a relatively short time period, but does include the particularly wet year of 2012. The only 'significant' ground movements at this time were recorded in BH7 at Scalby Ness, which occurred during December 2012. Monthly rainfall totals are provided in Table 2.1 and antecedent totals are presented in Figure 2.6. Assuming that rainfall was the sole trigger of this ground movement, it suggests a three month antecedent rainfall threshold of 263mm is required to trigger movement. The absence of movements elsewhere on the coast at this time suggests that the antecedent rainfall threshold levels are above this at other locations.

Antecedent rainfall over the current December-May monitoring period show peaks that are lower than December 2012 and with a similar pattern to the previous December to May period.

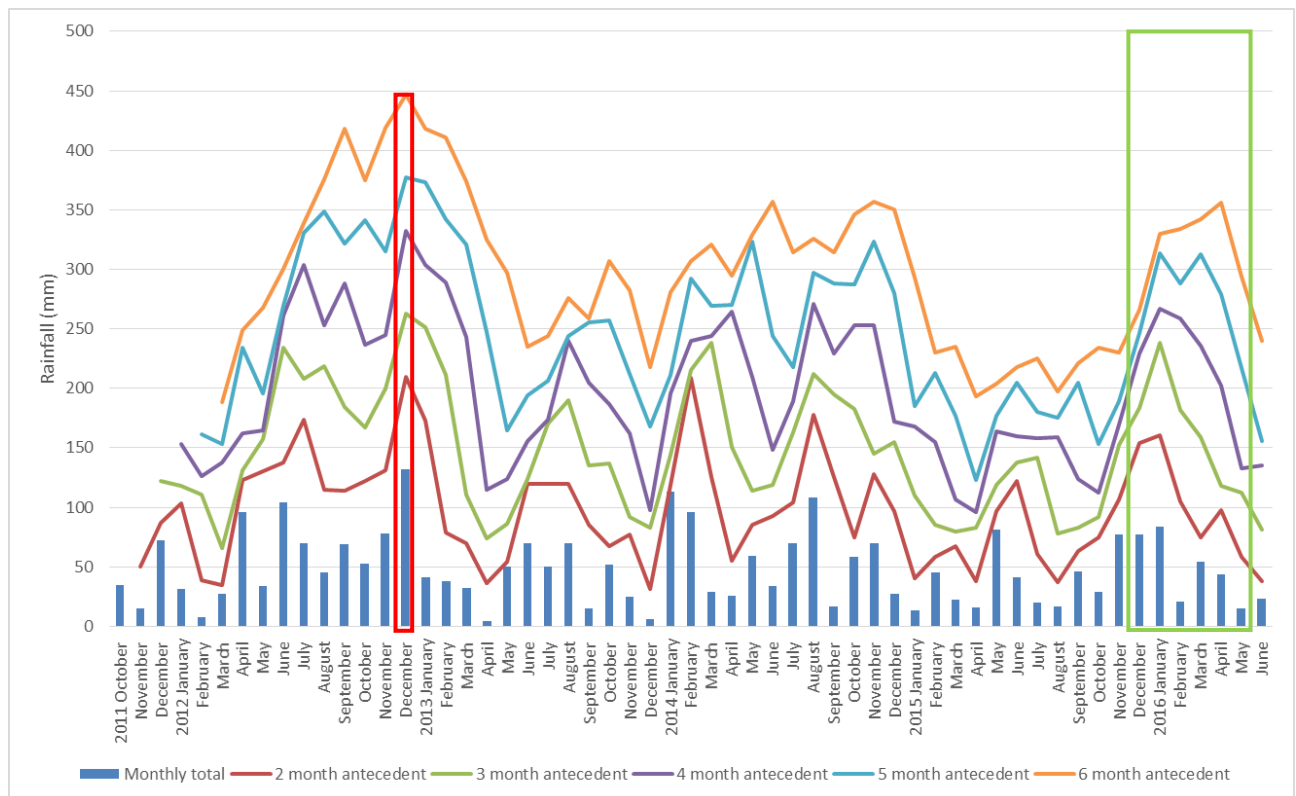


Figure 2.6. Monthly rainfall and two to six month antecedent totals (2011 to 2016). Ground movements were recorded at Scalby Mills during December 2012 (red box). Current monitoring period shown by green box.

2.2 Summary

The weather data collected to date highlights the following:

- 2012 was exceptionally wet, particularly in the months of April, June, July, November and December.
- 2013 was dry. After an unusually stormy spring period the temperatures remained high throughout the summer and rainfall in all months was below average.
- January and February 2014 were much wetter than average, and the period March to July 2014 was comparatively dry.
- While no data were recorded from early September 2014 to February 2015, a review of Met Office records shows the Autumn 2014 period was characterised by dryer than average conditions.
- MetOffice data purchased from Filey shows that the period Dec 2014 to April 2015 was generally much drier than average. Only May 2015 shows wetter than average conditions
- Data from Flat Cliffs collected in late 2015 shows September was wetter than average, and December was wet, although not exceptionally so. Rainfall peaks occurred on 14 September and 21 November and a sustained period of wet weather occurred from 25 to 30 December.
- Scarborough Spa weather station data collected over 2016 has shown that January, March and April have been slightly wetter than average. Rainfall peaked on 3 January and 28 March. Overall, data has shown Dec 2015 to May 2016 to have been typically wet, with mild weather conditions.

Runswick Bay

3.1 Site description

Runswick Bay is the northern-most instrumented site on the Scarborough Borough Council coastline and is located 16 km north west of Whitby. The bay is formed in weak glacial sediments between the more resistant Jurassic-age bedrock headlands of Caldron Cliff to the north and Kettleless to the south. The village of Runswick Bay is developed on a coastal slope formed in glacial sediments and weathered shale bedrock and is bordered by incised valleys of the Runswick Beck and Nettledale Beck. The village and all existing monitoring devices are located in cliff behaviour unit MU7/1 (Figure 3.1).

The village has a long history of coastal instability, with records dating back to 1682 when the whole village was destroyed by landslides. It benefits from a coast protection and slope stabilisation scheme that was constructed in 2001-02 that comprises sections of seawall and rock armour together with drainage, piling and earthworks. The village has been subject to a strategy study review to improve the standard of protection of the coast protection measures and remedy minor issues with the 2001-02 scheme (Halcrow, 2016b). The scheme is currently at the stage of appointing a Design and Build contractor.

3.2 Ground model and monitoring regime

The ground model for Runswick Bay was developed by High Point Rendel in the 1990s as part of the original strategy study for the area (High Point Rendel 1998). Their work included drilling a series of instrumented boreholes, geomorphological mapping and stability analysis. This work highlighted three landslide complexes that threaten properties and infrastructure:

- Topman End (MU7/1) steep till slopes (30° to 40°) between Nettledale Beck and continuing north to Runswick Beck. The village is sited on this landslide complex. The slopes are characterised by an extensive pattern of small scarps and tension cracks behind small shallow failures. Mid-way down the slope the profile shallows to between 5° and 10° over a distance of 10-15m. Where the slope angle exceeds 35° there are a numerous shallow failures that tend to be caused by excessive water entrainment and generally leave behind triangular scars bounded by steep sides and disrupted vegetation. The mechanism is uncertain, but High Point Rendel (1998) suggests a model of superimposed mudslide lobes.
- Upgath Hill (MU 7/1) is the area north of Runswick Beck, beyond the village. The cliffs are formed in weathered Upper Lias shales capped by sandstone beds of the Saltwick Formation and thin veneer of till. Cliffs are fronted by steep talus slopes (20 to 30°) that are protected by a reinforced concrete sea wall. The toe of the southern facing slopes is continually undercut by stream flow in Runswick Beck. Over the years Runswick Beck has cut down through the weathered shale forming an incised valley with sides that are characteristically over-steep. The failure mechanism is believed to be rockfalls with shallow mudslides developed in the talus slope.
- Ings End (MU 7/2 and 7/3) comprises a series of sub-vertical head scarps, up to 2.5m in height, below the cliff top between incised valleys of Nettledale Beck and Limekiln Beck, south of the village. Movement here would adversely impact the village car parks and could trigger movement in Topman End. The headscarps front undulating, low angle slopes formed in till, characterised by springs, streams and water ponding. Shear surfaces are believed to be curved, suggesting the landslide is an ancient degraded multiple-rotational complex with superimposed shallow mudslides that are active during periods of prolonged heavy rainfall.

The monitoring regime at Runswick Bay comprises four inclinometers that are installed within piles of a portal frame shear-key system designed to stabilise the slope within the Topman End landslide (Figure 3.1). The inclinometers were originally intended to monitor the response of the piles to loading, but due to uncertainty over methods to achieve this, the data has been used to simply monitor ground movement and performance of the piles.

3.3 Historical ground behaviour

A summary of historical data, adapted from Mouchel (2012) is summarised in Table 3.1. Overall, the data show no ground movement since 2009 and only subtle variation in groundwater levels, and therefore no relationship between groundwater level and ground movement has been identified.

Table 3.1. Summary of historical ground behaviour at Runswick Bay.

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Slopes indicated as stable. Groundwater levels variable across site in inclinometers, with no change since previous reading, except for A002 that showed a marked drop in water level since Dec 2011.	5mm movement indicated in A001 between 22.0 and 20.0 metres depth and in A004 from 10.0m depth increasing to 15mm at 2.0m depth. Groundwater is relatively static in each borehole, although A002, A003 and A004 experienced lowering of levels in summer 2011, with recovery to previous levels by Dec 2011.

3.4 New data

All monitoring data at Runswick Bay is at the Topman End landslide, and is solely intended to monitor the effectiveness of the piles installed in the late 1990s to stabilise the slope. Water-levels within inclinometer tubes installed in the piles were recorded under the previous Mouchel contract. This has not been continued to the current phase of work as it was recognised that the data were of limited value and potentially misleading. Inclinometer data are summarised in Table 3.2. These data indicate no movement in the piles.

3.5 Causal response relationships

No ground movements have been recorded at Runswick Bay over the monitoring period. Groundwater levels were previously monitored within the inclinometer tubes installed in piles, however, these data are unreliable, and no ground water monitoring is planned at this location. This means determining a relationship between rainfall, groundwater response and ground movement at Runswick Bay is not possible with the current monitoring set-up.

3.6 Implications and recommendations

There are no implications or recommendations arising for this site. Monitoring of the inclinometers should be continued to check the integrity and stability of the piles.

Table 3.2. Summary of inclinometer data at Runswick Bay

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
A001	Data collected from within 22m deep concrete pile near the top of the slope. The data indicates no significant movement has been recorded in the pile					Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.
A002	Data collected from within 17m deep concrete pile near the top of the slope. The data indicates no significant movement in the pile.					Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.
A003	Data collected from within 10.5m deep concrete pile near the bottom of the slope. The data indicates no significant movement in the pile.					Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.
A004	Data collected from within 10.5m deep concrete pile near the bottom of the slope. The data indicates no significant movement in the pile up to Dec 2011.					Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.

Whitby West Cliff

4.1 Site description

Whitby West Cliff extends from the West Pier of Whitby harbour to Upgang Beach and Sandsend (Figure 4.1). A short (c. 500m long) section at the eastern-most extent fronting the Whitby Spa Complex comprises Jurassic-age limestone, sandstone and mudstone of the Scalby Group overlain by glacial sediments (CBUs 11/3 and 11/4), but the greater part of the cliff line is cut entirely in glacial sediments (CBUs 11/1 and 11/2). The cliffs cut in glacial sediments have a long history of instability and numerous relict landslide scars associated with shallow failures and seepage lines are visible. West Cliff benefits from coastal defences and slope stabilisation measures comprising a seawall, slope drainage and slope re-profiling that were installed in phases between the 1930s and 1970s. These measures have significantly reduced the risk of cliff instability, but they are near the end of their design life and distress in the slope has been observed.

4.2 Ground model and monitoring regime

The cliff instability features of West Cliff comprise shallow mudslides that are periodically active, but there is a concern that deep-seated failures may develop. The defended stretches show evidence of historical failures and despite toe protection the slopes are susceptible to periodic phases of movement associated with sustained rainfall. The unprotected cliff sections at Upgang beach have active mudslides. Historically, the monitoring regime at Whitby West Cliffs has comprised a series of survey pins that follow the line of the slope, which were intended to record deformation associated with cliff instability, and a single inclinometer (BH2) located near the base of the slope to the west of the Whitby Spa complex within CBU 11/2 (Figure 4.1). The inclinometer was read at 6 monthly intervals and also dipped to record water level. Survey pin data revealed no significant change during the period of monitoring by Mouchel. As water-level data derived from inclinometers is not recommended and liable to error, these readings are no longer taken and the current monitoring regime comprises six-monthly inclinometer readings only.

4.3 Historical ground behaviour

A summary of historical data, adapted from Mouchel (2012) is summarised in Table 4.1. Overall, the data show no deep ground movement since 2009 and only subtle creep of the upper metre of the slope, which is typical of glacial sediments. Groundwater data collected by dipping the inclinometer tube appeared to show a relationship with tide level and not groundwater. Groundwater data collected in this way are known to be very unreliable and therefore no relationship between groundwater level and ground movement can be identified.

The single monitoring location means the data from BH2 may not be representative of all of West Cliff. Caution should therefore be taken before extrapolating results across the site and monitoring should be supplemented with regular site inspection.

Table 4.1. Summary of historical ground behaviour at Whitby West Cliff

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Survey pins show a total of 3mm movement at ground surface. Inclinometer indicates local slopes are stable, with surface creep in the top metre of ground.	Survey pins show -7mm movement in the top metre of ground. Inclinometer indicates local slopes are stable.

4.4 New data

Current data from the single inclinometer installed at Whitby West cliff is documented in Table 4.2 below.

Table 4.2. Summary of inclinometer data from Whitby West Cliff

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH02	Inclinometer installed in a 20m deep borehole that passes through glacial sediment. Ground level is 13.78m OD and the base of the borehole is at -6.22m OD.					Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.

4.5 Causal-response relationships

No relationships have been detected at this location.

4.6 Implications and recommendations

Monitoring at Whitby West Cliff is limited to a single inclinometer located near the base of the cliff to the west of the Whitby Spa complex. The device has not highlighted any cliff instability within the glacial sediments, although shallow failures have been observed on the cliff face during regular walk over inspections. The absence of any water level data at Whitby means it is not possible to determine the relationship between rainfall and ground movement, therefore, opportunities for installation of automated piezometer(s) should be considered.

Robin Hood's Bay

5.1 Site description

Robin Hood's Bay village is located on the coastal slopes and cliff top area of the northern-most part of Robin Hood's Bay. The cliff top part of the village is known as Mount Pleasant. The old village, situated on the coastal slope, has a long history of landsliding and currently benefits from a coast protection and slope stabilisation scheme that was installed in 2001.

The area being monitored in this study is the Mount Pleasant area, between Victoria Hotel and the cliffs to the north, where cliff instability is a concern. Cliff behaviour units in this area are composite cliffs formed of near-vertical sea-cliffs cut in Lower Jurassic clays overlain by glacial sediments. CBU 16/1 fronts Mount Pleasant and CBU 16/2 fronts the Victoria Hotel and the slope down to the old village (Figure 5.1). This section of coastline is not defended and has no slope stabilisation measures. Despite the bedrock cliff eroding at a slow rate, the overlying glacial sediments are prone to instability, and landslides occur episodically in response to sea cliff erosion and/or prolonged wet weather.

5.2 Monitoring regime

In response to the risk from landslides affecting the village, four instrumented boreholes have been installed in CBUs 16/1 and 16/2. These comprise two inclinometers and two double piezometers installed in bedrock and glacial sediments (Figure 5.1).

5.3 Historical ground behaviour

Robin Hood's Bay was not included in the original programme of monitoring and the first readings were taken in March 2010. The readings documented by Mouchel (2012) are summarised in Table 5.1.

Table 5.1. Summary of historical ground behaviour at Robin Hood's Bay

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Inclinometer BH2 shows movement at 22m depth. BH4 shows movement at 25m depth. Groundwater levels reduced.	n/a. First investigated in Dec 2011. Total change is as recorded between Dec 2011 and June 2012.

5.4 New data

The inclinometer and piezometer data recorded up to May 2016 is summarised in Tables 5.2 and 5.3.

Inclinometer data shows no significant movements recorded at any of the boreholes.

The piezometer data show groundwater levels have remained steady over the monitoring period in BH1b. BH1a, which is a shallower piezometer, shows groundwater levels have risen considerably following uncovering of the tarmac. Given the close proximity of these boreholes, it is likely that the shallower borehole has been affected by surface water ingress from cliff top developments.

Readings for piezometers BH3a and BH3b require re-taking.

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Table 5.2. Summary of inclinometer data from Robin Hood’s Bay

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH2	The borehole is 41m deep but inclinometer records are only provided for the upper 22m. Ground level is c. 55.1m OD. Readings have been taken between March 2010 and May 2012 and show up to 15mm incremental displacement, particularly at 5 to 15m depth on the A-axis and up to 80mm displacement between 8 and 21m depth on the B-axis. The pattern of movement is hard to explain and is likely to represent accumulated error.					Incremental movements are less than 1mm since the last reading.	Incremental movements are less than 1mm since the last reading.
BH4	The borehole is 40m deep and passes through 12m of glacial sediment and 28m of siltstone bedrock. Ground level is c. 74.2m OD and the base of the hole is at 34.2m OD. Cumulative movement plots suggest error in the data and it seems likely that the readings taken since 17 June are error as no evidence for significant ground movement has been reported or observed on site.					Incremental movements are less than 1mm since the last reading.	Incremental movements are less than 1mm since the last reading. At 30m depth 2mm minor displacement.

Table 5.3. Summary of groundwater data from Robin Hood's Bay

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH1a	Ground level is 51.63m OD, the piezometer tip is targeting a shallower horizon. Water-levels have remained reasonably constant at c. 30m OD since installation. Once equilibrated, water levels rose by 2.7m from May 2010 to June 2011. Levels then fell back by 1.3m to May 2012.	22.7m OD 39.7m OD 17m					Ground surface tarmacked over and piezometer could not be accessed.	Increase in groundwater level by 9.14m since last reading in November 2014 to historical high at 39.65m OD. It is unclear if the tarmac covering affected this result.
BH1b	Ground level is 51.63m OD, the piezometer tip is targeting a deeper horizon. Water levels in this elevation have been less variable, having remained at 37.6m OD from March 2010 to Nov 2011. Between Nov 2011 and May 2012, levels rose by 1.2m reflecting the wet months of Dec 2011 and/or April 2012	37.6m OD 39.9m OD 2.3m					Ground surface tarmacked over and piezometer could not be accessed.	Readings remain steady at 37.8m OD.

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH3a	Ground level is 60.35m OD, the piezometer tip is targeting a shallower horizon. Water level has remained between 44.3m and 44.8m OD between installation in March 2010 and May 2012.	44.5m OD 56.1m OD 11.6m					Water levels remain at an elevated position of 54m OD.	Site readings lost due to saving error. Readings should be re-taken on next visit.
BH3b	Ground level is 60.35m OD, the piezometer tip is targeting a deeper horizon. Water levels have fluctuated by no more 2m about a mean of c. 56m OD. Low groundwater levels occurred in May 2010 and highs occurred in July 2010 and Nov 2011.	55.3m OD 56.7m OD 1.4m					The water level has remained at 56m OD.	Site readings lost due to saving error. Readings should be re-taken on next visit.

5.5 Causal-response relationships

A subtle relationship between rainfall and groundwater levels, particularly in the shallower piezometer BH1a, was observed for the wet December of 2011 and the wet summer of 2012, and wet winter of 2015/2016. However, the dry conditions of 2013 were not reflected in the groundwater data, suggesting surcharge of groundwater from local sources may be occurring. Water levels in BH3a remain high to the autumn of 2015, however the latest records are unavailable. There is also the possibility that the low resolution of monitoring at this location, particularly in shallow piezometers, may simply be picking-up short duration responses to brief but intense rainfall events.

5.6 Implications and recommendations

The groundwater data indicates a continuation of past patterns at Robin Hood's Bay. BH1a shows groundwater level to be elevated since uncovering the tarmac at the surface, but this is thought to represent ingress of surface water. This location requires investigation and repair of inclinometers and piezometers. Boreholes BH3a and BH3b require readings to be re-taken on the next site visit.

Previous work by Mouchel has noted that piezometer tubes have progressively become shallower, suggesting ingress of sediment. It is therefore recommended that the piezometer tubes be flushed out. Results from inclinometers are hard to interpret, meaning there is uncertainty over the nature of any recent ground movement. These data should be carefully reviewed in future monitoring reports and erroneous data removed from record.

To improve understanding of the relationship between groundwater and rainfall, this site would benefit from installation of automated piezometers to provide a continuous record of groundwater fluctuations.

Scalby Ness

6.1 Site description

Scalby Ness is the promontory that forms the northern boundary of Scarborough's North Bay. The headland is incised by Scalby Beck which flows through a steep-sided valley cut in glacial sediments and the underlying Jurassic sandstone/siltstone bedrock. Scalby Beck acts as a flood relief channel for the River Derwent via the 'Sea Cut', a man made channel connecting the Derwent with the headwaters of Scalby Beck. The south side of the beck has housing that is threatened by ground instability in the over-steepened slopes cut in glacial sediments.

6.2 Ground model and monitoring regime

This site includes the cliff behaviour units MU19/11 and MU20/1 (Figure 6.1). The strategy study into the instability problems (Halcrow, 2005) characterised the area into three distinct landslide systems:

- CBU1 (northwest slopes) – periodically active translational landslides in glacial sediment that lead to gradual headscarp recession. Instability is partly caused by toe erosion by Scalby Beck, but rising ground water levels following prolonged or intense rainfall are the principal trigger.
- CBU2 (northern part of the northeast slopes) – large, ancient, deep-seated, periodically active landslide. Back-tilted blocks indicate a rotational failure, but translational mechanisms are also possible. Instability is partly caused by toe erosion by Scalby Beck but rising ground water levels following prolonged or intense rainfall are the principal trigger.
- CBU3 (southern part of the northeast slopes) – stable slopes that have been reprofiled when the Sealife Centre access road was constructed.

Both CBUs 1 and 2 are at risk of failure, particularly if groundwater levels rise significantly. CBU3 is not considered to be at risk.

The monitoring regime at Scalby Ness is summarised in Figure 6.1. The slope is instrumented with three inclinometers and fourteen piezometers, seven of which are automated. Two inclinometers and nine piezometers are on the slope itself and the remaining installations are positioned on the cliff top.

6.3 Historical ground behaviour

Ground movement and groundwater levels were monitored by Mouchel from July 2009 to June 2012 and limited additional records of groundwater data back to June 2004. Mouchel's observations showed significant movement in BH7 between June and December 2010. No relationship between groundwater level and ground movement was reported by Mouchel, although relationships between rainfall and ground water levels in piezometers with shallow tips are identified. The readings documented by Mouchel (2012) are summarised in Table 6.1.

Table 6.1. Summary of historical ground behaviour at Scalby Ness.

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Mouchel's piezometer graphs show notable increases in groundwater level in some piezometers (WS4 and WS6) to May 2012.	<p>Ground movement reported at 12.0m BGL in BH7 at contact between gravelly sand and sandstone between June and December 2010, indicative of a developing shear plane although this movement has not yet manifested itself as recession of the headscarp. A failure was observed near the base of CBU1 between March and April 2010.</p> <p>They report decreasing groundwater levels in CBU1, and peaks in groundwater levels in the shallower piezometers linked to intense rainfall events. Deeper piezometers remained at approximately the same level and were therefore less susceptible to variations in rainfall.</p>

6.4 New data

Tables 6.2 and 6.3 summarise the monitoring data from the inclinometers and piezometers at Scalby Ness.

Table 6.2 Summary of inclinometer data from Scalby Ness *Surface elevations and borehole depths calculated from digital elevation model

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
L1(C003)	Borehole is c.32m deep and situated on the cliff top above CBU1. Ground level is 35.47m OD and the borehole extends to c. 2.5m OD. It passes through 29m of glacial sediment and 3m of sandstone/mudstone bedrock. No displacements of the inclinometer tube greater than 2mm.					Incremental movements are less than 1 mm during the monitoring period, which is insignificant.	Incremental movements are less than 1 mm during the monitoring period, which is insignificant.
L2(C002)	Borehole is c. 35m deep and situated on the cliff top above CBU2. Surface elevation is 34.1m OD and borehole extends to c.-1.0m OD penetrating c. 31m of glacial sediment and 4m of mudstone bedrock. No displacements of the inclinometer.					Incremental movements are less than 1 mm during the monitoring period, which is insignificant.	Incremental movements are less than 1 mm during the monitoring period, which is insignificant.
L3(C004)	Borehole is ca. 17m deep, surface is 13.4m OD and					Incremental movements are less than 1 mm during	No significant movement since last reading, except for minor displacement, likely relatively

	borehole extends to c. -3.6m OD through 8.5m of glacial sediment and 8.5m of mudstone and sandstone that is weathered in the upper 3m. Cumulative plot is almost vertical with the exception of a large apparent displacement between June 2011 and December 2011 and minor (<5mm total displacement) near the surface, possibly due to surface creep.					the monitoring period, which is insignificant.	shallow surface creep that extends to ca. 2m BGL in clay.
BH7	Borehole is c.20.5m deep and situated in the mid-slope of CBU2. Surface elevation is c. 16.7m OD and the borehole extends to c.-3.8m OD through 13m of glacial sediment and 7.5m of sandstone /mudstone bedrock. The cumulative plot shows around 20mm displacement between Feb 2011 and June 2011, above the contact between sandstone bedrock and gravelly sand at c.4.7m OD. Subsequent readings show positive and negative displacements on B axis that may be error.					Incremental movements are insignificant at less than 1mm. There has been no additional movement along the shear surface at c. 11 to 12m depth.	Incremental movements are insignificant at less than 1mm. There has been no additional movement along the shear surface at c. 11 to 12m depth.

Table 6.3. Summary of groundwater data at Scalby Ness. *Indicates approx. tip and surface elevations calculated from elevation from digital elevation model and known tip depth, rather than topographic survey

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
P1a	Automated piezometer. Tip at approx.25.65m OD*. Surface elevation at c. 35.6m OD* (cliff top above CBU 1, co-located with P1b). Fluctuates	27.1m OD 28.9m OD 1.8m					Fall in groundwater level from 27.7m OD to 27.3m OD over monitoring period.	Data not downloaded correctly, to collect on next visit.

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	between 27.5 and 28.5m OD, with rapidly rising and falling peaks linked to higher rainfall and subsequent dry periods.						
P1b	Automated piezometer. Tip at c. 18.1m OD*. Surface elevation at c. 35.6m OD (co-located with P1a). Relatively steady ground water level at ca.18.5m OD although fluctuations up to ca. 19.0m OD occur.	18.4m OD 19.2m OD 1.8m				Readings steady at 18.4m OD.	Data not downloaded correctly, to collect on next visit.
P2a	Automated piezometer. Tip at c. 25.6m OD*. Surface elevation at c. 34.7m OD* (co-located with P2b). Fluctuates between 27.5 and 28.5m OD with peaks overlying a general trend of increasing water. Peaks and general trend correspond to the Filey rainfall record.	27.2m OD 28.7m OD 2.6m				Following a short-lived spike in groundwater level in May 2015, groundwater continues to fall to 27.4m OD in October 2015.	Groundwater levels rapidly increased in December 2015 to 28.3m OD, which close to the historical high. It has since remained high at 27.8 m OD.
P2b	Automated piezometer. Tip at c. -0.6m OD*. Surface elevation at c. 34.7m OD* (co-located with P2a). Prior to Oct 2009, ground water levels appear generally steady at c. 1.2m OD, except for fluctuations up to 2.5m OD in late 2007/early 2008. Records are absent between Oct 2009 and Mar 2010, after which levels are steady at around 2.5m OD.	0.9m OD 3.5m OD 1.7m				Readings remain steady at 2.3m OD.	Readings remained steady at 2.4m OD, with the exception of a short-lived spike in February reaching a historical high of 3.5m OD.
P3	Automated piezometer. Tip at c. 10.5m OD*. Surface elevation at c. 30.7m OD. Steady at around 14.6-14.7m	14.2m OD 17.5m OD 3.3m				Continuation of past pattern, with levels constant at c. 17.2m OD.	Continuation of past pattern, with levels constant at c. 17.2m OD.

	OD until Oct 2009. Apparent recalibration between Oct 2009 and Mar 2010 after which groundwater levels are again steady at ca.17.2-17.3m OD						
P4a	Automated piezometer. Tip at c. 8.3m OD*. Surface elevation at 18.6m OD (co-located with P4b). Fluctuating pattern occurs between June 2004 and Feb 2009 varying around 12m to 13.6m OD. Peaks show steep rise and gentler fall, which is a characteristic response to heavy rainfall. After this, the base level appears to show a decline.	12.7m OD 15.1m OD 1.4m				Continuation of cyclical pattern with several month's spacing showing rapid rise followed by gradual falls. Since May 2015 there has been a constant gradual fall in groundwater level to 13.0m OD in October 2015.	Rapid increase in groundwater levels in late December 2015 and January 2016 to 14.6m OD. Levels remain elevated.
P4b	Automated Piezometer. Tip at c. 6.35m OD*. Surface elevation at c. 18.6m OD (co-located with P4a). Fluctuating pattern between June 2004 and Feb 2009 with lows at around 12m OD and peaks to 13.6m OD. Peaks show steep rise and gentler fall characteristic of response to heavy rainfall of Jan 2011, May 2012 and December 2012.	12.4m OD 14.8m OD 1.4m				Same pattern as P4a, but offset by c. -0.3m since early 2010.	Same pattern as P4a, but offset by c. -0.3m since early 2010.
WS4	Tip at 9.9m OD. Surface elevation at 16.3m OD (midslope, CBU 2). Fluctuations from c. 10m OD to c.15m OD in response to long-term/seasonal rainfall patterns. Limited response to short-lived rainfall peaks.	10.0m OD 15.4m OD 5.4m				Slight fall in groundwater level to 12.3m OD.	Increase in groundwater level by 3.1m since last reading to historical high at 15.4m OD. Ponding of water noted on slope during data collection.

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<p>WS5</p>	<p>Tip at 6.5m OD. Surface elevation at 11.3m OD (lower slope, CBU 2). Fluctuates between 6.5m OD and 7.5m OD between September 2010 and June 2011 (low in summer/early autumn, high in winter). Gap in record until May 2012 when groundwater level of ca. 9.0m OD recorded.</p>	<p>6.5m OD 9.7m OD 3.2m</p>		<p>Borehole remains dry. This borehole should be investigated and repairs made if possible.</p>	<p>Borehole no longer functioning.</p>
<p>WS6</p>	<p>Tip at 9.72m OD. Surface elevation at 16.2m OD (midslope, CBU2). After an initial sharp rise post installation from ca. 10m OD to 12.5m OD, measurements from this piezometer show a gradual and uninterrupted increase to a high of 14.3m OD in May 2012.</p>	<p>10.0m OD 14.3m OD 4.3m</p>		<p>Groundwater remaining steady at 13.0m OD.</p>	<p>Groundwater levels remain steady at 13.3m OD.</p>
<p>B6</p>	<p>Tip at 10.0m OD. Surface elevation at 18.55m OD (midslope, northern edge of CBU2). Pattern of substantial fluctuation, usually between 14m OD and 17m OD, with the exception of major low in August 2008 when installation may have been almost dry (groundwater level ca. 10m OD).</p>	<p>10m OD 13.8m OD 3.8m</p>		<p>Groundwater level fallen from 10.7m OD in July 2015 to 10m OD in October 2015.</p>	<p>Groundwater levels increase slightly from historical low to 10.6m OD.</p>
<p>B9</p>	<p>Tip at 9.25m OD. Surface elevation at 17.8m OD (upper slope, CBU2). Fluctuation between ca. 10.0m OD and 12m OD except for substantial peaks in January 2008 (13.8m OD) and</p>	<p>9.8m OD 16.7m OD 6.9m</p>		<p>Groundwater level fallen from 14.8m OD in July 2015 to 14.1m OD in October 2015.</p>	<p>Groundwater levels increase by 1.4m to 15.5m OD following a general falling trend in groundwater level.</p>

	May 2008 (13.4m OD). Most recent peak in December 2011 at 11.5m OD.						
Sn2a	Tip depth at c. 13.9m OD*. Surface elevation at 16.35m OD* (co-located with SN2b). Likely that past results for 2a and 2b confused or tip depth for Sn2a incorrect, as groundwater elevations not possible for tip depth stated.	12.5m OD 13.3m OD 0.8m				Levels remain constant since 2010 at 12.5m OD	Groundwater levels increase by 0.8m to 13.3m OD, reaching a new historical high.
Sn2b	Tip depth at c. 8.35m OD*. Surface elevation at 16.35m OD* (co-located with SN2a). Likely that past results for 2a and 2b confused or tip depth for Sn2a incorrect. Sn2b shows groundwater levels between 1.6m OD and 11m BGL during 2011 and 2012.	10.3m OD 11.9m OD 1.6m				Groundwater level fallen from 10.8m OD in July 2015 to 10.3m OD in October 2015.	Groundwater levels increased by 1.6m from historical low to a historical high of 11.9m OD.

The new data indicate:

- No significant ground movements recorded in any of the inclinometers.
- Water levels increased slightly or in some circumstances significantly increased and remained elevated.
- Groundwater levels have risen in a number of boreholes reaching historical highs at boreholes P2a, WS4, B9, Sn2a and Sn2b. However, no significant movements over the monitoring period were indicated at adjacent inclinometers.
- Water levels recorded in boreholes P4a and P4b follow the same pattern but at slightly differing levels, and it is recommended the piezometer calibration be checked.

6.5 Causal-response relationships

Since the summer of 2012, much of the rainfall in the study area has been atypical. Following a dry start to 2012, the spring and summer were exceptionally wet and the latter half of 2012 was also wet. Overall, 2013, 2014 and 2015 were drier than average. The majority of shallow piezometers at Scalby Ness closely reflect that pattern of rainfall. Those installed with data loggers show peaks in April/May 2012, July 2012 and December 2012, and falling groundwater levels until December 2013, after which groundwater levels rise and peak in mid-late February 2014, before falling and stabilising at lower levels by late 2014. Groundwater levels are typically lower than average during the first and second half of 2015, except for May where levels peak following higher than average rainfall. The above average rainfall in December 2015 and January 2016 is reflected in rising groundwater levels

at many of the piezometers, however these levels have been maintained during drier months that follow.

Deeper piezometers have a longer lag between rainfall and groundwater response. Those with data loggers show a much more muted response and those without data loggers tend to show peaks in May 2012, or in earlier winter periods. The exception to this rule is WS5 which appears to show a rising groundwater level towards 2013 but was dry in July and November 2014.

The inclinometers in BH7 and L2 show significant sub-surface movement. BH7 is the most pronounced and indicates movement on an existing shear surface in glacial sediments above sandstone bedrock. Movement occurred between November 2013 and March 2014, associated with a period of high groundwater levels (nearby piezometers P4a and P4b show elevated groundwater peaking in mid-February 2014 at 13.5 and 13.8m respectively). Neither inclinometer recorded movement between June and November 2014, associated with low groundwater levels. The relationship between groundwater level and ground movement is unclear. While movement in the winters of 2010/11 and 2013/14 can be associated with elevated groundwater, similarly high groundwater levels in the winter of 2012/13 and 2015/2016 are not associated with ground movement, possibly due to slow borehole equilibration with the surrounding ground.

6.6 Implications and recommendations

The groundwater data indicates levels have generally increased in the area. Rising water levels in B9 and Sn2b experienced during early to mid-2015 suggest discharge from cliff top developments or a natural response to the localised movement at the slope toe. During this monitoring period, groundwater levels have increased at both boreholes. While localised reactivation at the slope toe is apparent in past reports, no movements were indicated at adjacent inclinometer BH7 or other inclinometers at the location. The location will be reviewed in the next report. In addition, piezometers P1a and P1b require readings to be re-taken on the next site visit.

Scarborough North Bay – Oasis Café

7.1 Site description

Oasis Café cliffs are situated in the southern part of Scarborough’s North Bay and occupy part of Clarence Gardens, which are landscaped coastal slopes open to the public (Figure 7.1). The cliffs rise to c. 30m OD and have a typical angle of 25-30°, although the main headscarp reaches 50°. The upper c. 15m of cliff is cut in glacial sediments and Jurassic sandstones and mudstones form the basal part of the cliff. The Holbeck to Scalby Mills strategy study (High-Point Rendel, 1999) classified the cliffs as multiple rotational landslides formed predominantly in the Jurassic bedrock. The landslides are fronted by the Marine Parade road and coast protection scheme and have not experienced toe erosion for over 100 years. Despite the toe protection, cliff instability risk in response to extreme rainfall remains a concern.

7.2 Ground model and monitoring regime

This frontage is covered by a single cliff behaviour unit, MU20/4a. Geomorphological mapping undertaken as part of the strategy study recognises a series of discrete landslides within this CBU, but all are classified as multiple rotational landslides formed predominantly in bedrock. It is assumed the basal shear surface is near Ordnance Datum and has formed in weak layers within the interbedded sandstones and mudstones. The monitoring regime comprises inclinometers and co-located automated piezometers at the cliff top, mid-slope and cliff toe positions aligned along a southwest to northeast bearing (Figure 7.1).

7.3 Historical ground behaviour

Table 7.1 summarises the observations in Mouchel (2012) from the monitoring undertaken at the Oasis Café.

Table 7.1. Summary of historical ground behaviour at Oasis Café

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Static groundwater at around 8.05m at BH2p, and increase in water levels at BH3p and a decrease at BH4p. Slopes here appear to be stable from inclinometer readings although shallow ground movements were observed.	Apparent movements reported but these are attributed to operator error or temperature fluctuation rather than actual ground movements.

7.4 New data

Tables 7.2 and 7.3 summarise the monitoring data from inclinometer and piezometer installations at the Oasis Café

The new data indicate:

- No significant ground movements recorded in any of the inclinometers.
- Groundwater data shows a continuation of past patterns at an elevated position.
- The early winter period has been wetter than average and water levels have increased, showing a lagged response particularly by mid-March. Spring rainfall is below average and groundwater levels fall.
- Elevated and fluctuating water levels in BH4p over drier months may suggest an influence from cliff top developments.

Table 7.2. Summary of inclinometer data at Oasis Café

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH3	BH3 is situated in the midslope and extends to c. 5.5m BGL. Surface elevation is 17.8m OD and the base of the hole is at c. 12.3m OD. The borehole extends through c. 3 m of glacial sediment before encountering 2.5m of mudstone, the uppermost metre of which is weathered. Past readings show no significant ground movement.					Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
BH4	BH4 is situated on the cliff top and extends to ca.13.5m BGL. Ground level is 31.1m OD and the borehole extends to c 17.6m OD, penetrating 14m of glacial sediment and 3.5m of sandstone bedrock. Past readings show no significant ground movement.					Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

7.5 Causal-response relationships

The winter 2013 to summer 2014 monitoring period was characterised by higher rainfall compared to the previous 6 months. The latter half of 2014 and 2015 were slightly drier than average and water levels tend to show very slight falls with superimposed monthly fluctuations. The higher than average rainfall in early winter 2015/2016 is reflected by elevated groundwater levels which fall in response to drier than average conditions which follow. The patterns seen in the past are still visible, with BH2p having an unclear response to rainfall and/or tides. Shallow piezometer BH3p continues to show a very rapid response to rainfall events (which probably explains the spikes on 10 Aug and 8 Oct 2014, and 9 May and 12 Dec 2015, 3 Jan 2016), while only marginally deeper piezometer BH4p shows a lag response to prolonged periods of high rainfall. Groundwater levels in all boreholes remain below their peaks of winter 2012/13 and the inclinometers do not indicate movement.

7.6 Implications and recommendations

All the piezometers appear to read correctly and provide reliable data. The inclinometers also appear to be functioning correctly. No movements have been recorded at Oasis Café, and there are no specific recommendations at this location beyond on-going collection and analysis of data.

Future reports should pay particular attention to the midslope piezometer (BH3p) which shows rapid response to rainfall conditions, but no associated ground movements to date. In addition, attention should be given to piezometer BH4p where rising groundwater over drier than average months may suggest an ingress of water from cliff top developments.

Table 7.3. Summary of groundwater data at Oasis Café

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH2p	Tip depth at 8.05m OD. Situated in the lower cliff. Manual dip readings from Sept 2009 to May 2012 show fluctuation between 8.0 and 8.5mOD from Sept to Dec 2009 followed by no change to December 2011. Groundwater level then rises to 8.5m OD by May 2012.	7.9m OD 8.6m OD 0.7m					Continuation of past pattern. Transition to larger fluctuations of c. 0.5m in early September 2015. Average groundwater level c. 8.4m OD.	Continuation of past pattern. In March groundwater level rapidly rises and falls near to historical low at 8m OD, and gradually rises to higher levels at 8.5m OD. Average groundwater level c. 8.3m OD.
BH3p	Tip depth at 12.4m OD. Situated in the midslope. Manual dip readings from Sept 2009 to Dec 2011 show fluctuation between ca. 13.8m OD (June 2010) and 14.7m OD (Dec 2010). Final manual reading May 2012 shows substantial rise to 17.6m OD, reflecting high rainfall during spring 2012.	13.5m OD 16.7m OD 3.2m					Continuation of past near-monthly cyclical pattern. Gradual fall in groundwater level average and magnitude of fluctuations to 0.8m since mid-2015. Average groundwater level c. 14.4m OD.	Groundwater level follows a two-week cyclical pattern, with rapid rises and gradual falls. Levels are elevated initially during this period at an average of c. 15.5m OD, however this falls significantly in May to 14m OD.
BH4p	Tip Depth at 17.0m OD. Situated at the cliff top. Manual dip readings from September 2009 to May 2012 show groundwater levels fluctuating between 18.0m to 19.3m OD with peaks in April 2010, December 2010 and May 2012.	17.2m OD 19.4m OD 2.2m					Continuation of past cyclical pattern, increase in sub-weekly variation in early September 2015 to c. 0.5m with mean level of 18.8m OD and peak of 19.1m. Rise in groundwater over drier than average months may suggest a long antecedent rainfall period or inputs from developments upslope.	Continuation of past cyclical pattern with sub-weekly variation, averaging 18.9m OD. Groundwater peaks in March near historical high at 19.2m OD but rapidly falls on 28 March when rainfall peaks. Groundwater level remains at elevated position.

Scarborough North Bay – The Holms

8.1 Site description

The Holms is situated towards the southern end of North Bay, adjacent to Castle Headland. It is an area of sloping, hummocky, open parkland with a deeply-indented, arcuate headscarp between the castle at the cliff top and Marine Drive along the coast.

The slopes rise from Marine Drive at angles of c. 25-30° to a midslope bench at 35m OD and upper cliff at c.55m OD, where a near-vertical cliff face rises to the cliff top at c 85m OD. A variable thickness glacial sediments overlie interbedded sandstones and mudstones of Jurassic age. Two faults cross the site, one of which delineates the boundary of younger more resistant geological strata that form Castle Headland from the succession underlying much of the rest of North Bay.

The Holbeck to Scalby Mills strategy study (High-Point Rendel, 1999) classified the cliffs as multiple rotational landslides formed predominantly in the Jurassic bedrock. The landslides are fronted by the Marine Parade road and coast protection scheme and have not experienced toe erosion for over 100 years. Previous instability problems include a 200mm displacement of the sea wall, likely a result of reactivation of the pre-existing landslides. Movements of the main landslide body are estimated to be in the order of 10s of centimetres. Therefore, despite the toe protection, cliff instability risk in response to extreme rainfall remains a concern.

8.2 Ground model and monitoring regime

This site includes the Cell 1 cliff units MU21/1, which is the main landslide embayment, and MU20/4b which covers the cliffs to the west towards Oasis Café.

Mouchel (2012) state 'The Holms landslide system comprises 10 to 17m of landslide debris which overlies the intact Scalby Formation'. Two units within the landslide have been identified from ground investigations undertaken in 2000:

- An eastern unit, comprising a deep-seated landslide which daylights close to the foreshore
- A western unit, composed of a shallower landslide which daylights approximately 1.5m above Marine Drive (c. 8.5m OD)

The monitoring regime at The Holms comprises:

- Lower slope – two co-located piezometers. Each piezometer measures groundwater level at a different depth.
- Midslope – two sets of two co-located piezometers, one set on the more north-easterly midslope bench and one set on the more westerly slopes. Each multiple piezometer location measures groundwater levels at different depths.
- Upper slope – inclinometer in the central part, c. 50m NE and downslope of the bridge on the entrance road to the castle.
- Cliff top – one inclinometer on the cliff top at the northern end of Mulgrave Place c. 50m to the west of the western end of the arcuate headscarp of The Holms.

8.3 Historical ground behaviour

The Holms was monitored by Mouchel between summer 2009 and summer 2012. A summary of their results is provided at Table 8.1. The pattern of groundwater variation at L1 appears to be affected by tidal influences and all other piezometers are affected by accuracy issues which prevent meaningful conclusions being reached about the groundwater regime at The Holms.

Table 8.1. Summary of historical ground behaviour at The Holms.

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
Mouchel (2012) comments that no ground movement has been indicated at BH10A. They mention continued ground movements of around 14mm between 13 and 10m depth (ca. 46-43m OD) in BH11. They report erratic groundwater readings from BH8 and BH9 a & b, and recommended flushing them as they believed they were blocked. As such, they report it was not possible to provide definitive information about the groundwater regime at The Holms.	Displacements of around 18mm at 10-13m depth (46-43m OD) in BH11, 4mm of which occurred between December 2010 and June 2011 and a further 14mm between June 2011 and June 2012. Groundwater at L1 shows fluctuations of between 40mm and 120mm which is attributed by Mouchel (2012) to tidal level fluctuations.

8.4 New data

Tables 8.2 and 8.3 summarise the readings from the inclinometers and piezometers at The Holms up to May 2016.

The new data indicate:

- No significant ground movements recorded in any of the inclinometers.
- Groundwater data shows a continuation of past patterns.
- Water levels remained steady or increased slightly, with a wet start to the monitoring period in winter followed by drier the average conditions in spring.
- No data recorded since November 2014 in BH9a. This site requires attention, to fix or replace the piezometer.

Table 8.2. Summary of inclinometer data at The Holms

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH10A	BH10A c. 42m deep. Surface of borehole is 46.75m OD, base at 4.75m OD. Borehole passes 2m of made ground, 1m of clay and c.8m of clayey sand before encountering sandstone bedrock. Progressive movements in the positive A axis direction (upslope) are recorded between the surface and 5m BGL (a. 42m OD). The total maximum displacement that occurred by May 2012 was around 10mm.					Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH11	BH11 is c.22m deep. Surface elevation is 55.86m OD, base at c.34m OD. Borehole passes through 5m of till before encountering weathered sandstone at c. 51m OD and intact sandstone at 41m OD. The inclinometer readings show a series of progressively larger deformations of around 20mm in the both axes within the weathered sandstone.					No change detected in sinusoidal pattern of deformation between 9 and 13m depth.	No change detected in sinusoidal pattern of deformation between 9 and 13m depth.

8.5 Causal-response relationships

Rainfall has been lower than average since mid-2015, with the exception of above average rainfall in winter 2015/2016. The piezometers at The Holms show a lagged response to these conditions with only BH8a showing a rapid response to May 2015 and March 2016 rainfall. Other boreholes show a continuation of past fluctuating or steady levels of groundwater, suggesting they respond to several months' antecedent rainfall. Over the whole record, BH8b shows a different pattern of gradual highs followed by sharp falls however movements are not shown in the inclinometer upslope at BH10A.

8.6 Implications and recommendations

Data from BH9b should be reviewed in the next report to establish whether the trend of rising groundwater levels continues. No data was recorded since November 2014 in BH9a. This site requires attention, to fix or replace the piezometer.

Table 8.3. Summary of groundwater data at The Holms

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
L1a	Tip depth at -8.03m OD, co-located with L1b. Manual dip readings from June 2009 to May 2012 show limited groundwater with variation between 5.9m OD (June 2010) to 4.6m OD (March 10). Piezometer tip is deeper than BH1Lb, but shows a higher piezometric level that may indicate a confined aquifer under artesian pressure	0.5m OD 2.5m OD 2m					Continuation of past cyclical patterns, with 2 to 3 week variations of up to c. 0.5m in September 2015. The monitoring period represents a slight increase in average groundwater levels from 0.8m OD to 1.0m OD. Readings remain comparably low to past records.	Continuation of past cyclical patterns, with 2 to 3 week variations of up to c. 0.6m in March 2016. The monitoring period represents a decrease in average groundwater levels from 1m OD to 0.6m OD. Readings are comparably very low to past records, reaching a historical low of 0.5m OD in March.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
L1b	Tip depth at -2.97m OD co-located with L1a. Manual dip readings between June 2009 and May 2012 show steady groundwater level around 1.9m OD.	3.7m OD 4.7m OD 1.0m					Continuation of 2 to 3 week cyclical pattern. Average groundwater level remains steady at 4.2m OD, with increasing magnitude of variations to 0.4m.	Continuation of 2 to 3 week cyclical pattern. Average groundwater level has increased slightly at 4.4m OD, with a rapid increase to historical high and fall in March by 0.7m.
BH8a	Tip depth at 10.16m OD. Borehole top at 31.16m OD Co-located with BH8b. Monitoring from Sept 2010 shows an initial fall in level to a low of 10.43m OD in June 2011 then a gradual rise to Dec 2011, reflecting wetter weather, before a sharp rise to 23.6m OD by May 2012, possibly as a result of exceptional rainfall.	9.7m OD 10.7m OD 1.0m					Water levels rapidly fall in the summer to 10.2m OD, then gradually rise and steady in the second half of 2015 to c. 10.3m OD. Over the monitoring period values fluctuated on a sub-weekly basis from 9.9 to 10.5m OD.	Groundwater levels gradually rise over the period, averaging 10.3m OD, comparably still low to past records. A rapid rise and fall in groundwater by 0.6m occurs in March 2016, in a similar pattern to other boreholes located in the vicinity.
BH8b	Tip depth at 3.16m OD. BH top at 31.16m OD, co-located with BH8a. Groundwater levels dropped from an initial high of 17.3m OD at installation in Sept 2010 to a low of 9.55m OD in Feb 2011. Levels then gradually rise through 2011 to c. 10.6m OD in Dec 2012 before a sharp rise to 22.2m OD by May 2012. This shows a very similar rainfall-influenced pattern to BH8a.	9.4m OD 14.5m OD 5.1m					Water levels rapidly fell from 12.9m OD in August 2015 to 9.4m OD mid-September and have since remained steady at an average of 9.5m OD. These are the lowest groundwater levels recorded at this borehole.	Groundwater levels have increased gradually over the period to 12.1m OD, well below the historical high.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH9a	Tip depth at 9.49m OD. Surface at 33.49m OD co-located with BH9b. Shows sharp increase after installation from c. 11.5m OD to a high of 26.6m OD by Feb 2011 before falling to 24.3m OD in June 2011. Between June and Dec 2011 ground water levels rise again to around 27.0m OD before falling slightly again to 26.3m OD.	13.6m OD 24.5m OD 10.9m					No data recorded since November 2014. This site requires attention, to fix or replace the piezometer and damaged cable.	No data recorded since November 2014. This site requires attention, to fix or replace the piezometer and damaged cable.
BH9b	Tip depth at 0.49m OD, surface at 33.49m OD co-located with BH9a. Shows sharp increase in ground water levels from c. 10m OD after installation in Sept 2010 to c. 25m OD in Feb 2011. Continues to gradually rise to c. 26m OD in June 2011 before gradually falling to 23.2m OD by May 2012. This pattern is similar to that recorded in BH9a, but contrary to that in BH8a and BH8b.	9.7m OD 28.2m OD 18.5m					Continuation of pattern of large and irregular changes. Peak of 21.2m OD in mid-October, with levels in mid-2015 typically between 13.4 and 17.1m OD. Since late September 2015 groundwater levels have continued to show significant fluctuations about a general rise.	No data. Communication error.

Scarborough South Bay

9.1 Site description

South Bay is formed from cliffs cut in Jurassic sandstones and siltstones that are overlain by a thick sequence of glacial sediments. A series of deep-seated landslides have developed in the glacial sediments and underlying weathered bedrock in post-glacial times. Since Victorian times, the cliffs have been extensively landscaped into public areas that include the Spa conference centre complex. The coastline has marginal stability, but first time failures do occur: the Holbeck Hall Hotel landslide occurred in June 1993 and there are records of similar cliff failures occurring elsewhere along the frontage over the last several hundred years. The whole frontage benefits from coastal defences, but ground movements in pre-existing landslides and over-steep cliff sections continue to occur, particularly in response to periods of elevated ground water levels, and there remains concern of first-time failures and reactivation failures in the cliffs. Instability risk is therefore a concern along the whole of South Bay.

The majority of South Cliff (from St Nicholas Cliff to Holbeck Gardens) was mapped in 2011 as part of the Scarborough Spa Coast Protection scheme. This mapping underpins the ground model for this site. Cliff behaviour units (CBUs) have been defined and their activity status classified under the Cell 1 Regional Monitoring Programme.

9.2 Ground model and monitoring regime

Pre-existing landslides have developed in the thick sequence of glacial sediments that form the upper coastal slope. Their geomorphology generally comprises arcuate landslide embayments with mid-slope benches that are fronted by elongate mudslide tracks and vertical *in situ* bedrock cliffs. The basal shear surface typically appears at the contact between the glacial sediment and underlying Jurassic bedrock, but it is likely that the significant local variation in the glacial sediments allows secondary shear surfaces to form along clay layers.

The monitoring regime at South Bay is summarised in Appendix A and Figure 9.1. It comprises an extensive suite of inclinometers and piezometers, most of which are automated, and an experimental acoustic inclinometer installed near the Spa Centre.

The areas being monitored comprise, from north to south:

- St Nicholas Cliff – till cliff fronting the Grand Hotel and cliff lift with a co-located single inclinometer and diver piezometer with barometric diver that were installed in 2014 (MU22/0)
- Spa Chalet Gardens – till cliff with groundwater monitoring at its toe and an inclinometer inland of the cliff top (MU22/1).
- Spa Centre and gardens – rotational landslide (MU 22/2) and very steep till cliff (MU22/3) in the vicinity of the Spa buildings. Extensive monitoring of groundwater levels and ground movements at locations inland of the cliff top, on the slope and at the cliff toe.
- Clock Café – rotational landslide (MU 22/3) that is monitored with transect of devices comprising two inclinometers on the slope and a piezometer inland of the headscarp.
- South Cliff Gardens – till cliff with a mudslide embayment north of the Rose Garden (CBU 22/5), a small rotational landslide at the Rose Garden and a much larger rotational landslide at the Italian Garden, known as the South Bay Pool landslide (CBU 22/6). The area is monitored by three transects of devices that cover each of the landslides.
- Holbeck Gardens (CBU 22/7) – till cliff monitored at three locations.

These areas include both pre-existing landslides and also intact cliffs and headscarps where instability is considered to be a risk. The Spa Centre is the focus of monitoring and is also the subject of an on-going coast defence scheme to improve the seawall and stabilise the slope.

At each location a suite of instruments are installed on the promenade, on the coastal slope and at the cliff toe allowing ground models to be developed and stability modelling to be undertaken.

9.3 Historical ground behaviour

South Bay was monitored by Mouchel Ltd for the period between summer 2009 and summer 2012. A summary of their results is provided in Table 9.1, which shows slight movement in a number of inclinometers and variable groundwater levels. No relationship between groundwater level and ground movement was reported by Mouchel.

Table 9.1. Summary of historical ground behaviour at Scarborough South Bay.

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total change observed between July 2009 and June 2012
AA10 (Clock Cafe) and AA08 (south Cliff Gardens) showed slight movement at shallow depths. Movement at greater depth was indicated in BHs 12, 13, 14 (at the Spa) and 16A (South Cliff Gardens). No movements indicated by other inclinometers. Groundwater levels are generally variable across the sites, except in the south of the Spa, where levels were reduced.	In addition to observations between Dec 2011 and June 2012, slight movement was recorded at AA04 in the upper 7m of ground, at AA10 in the upper 3.5m and at AA11 in the upper 3m. All net movements have been less than 10mm.

9.4 New data

For clarity, new data for South Bay are presented for each of the monitoring areas separately.

9.4.1 St Nicholas Cliff (MU 22A)

The cliff here is around 30m high and heavily landscaped with terraces and footpaths and formed in fine-grained glacial sediments (Figure 9.1A). Average slope angle is 20 to 30° but is locally steeper with sections supported by retaining walls. The cliff is crossed by a cliff lift and the cliff top is occupied by the Grand Hotel. There is no history of instability in recent years and this CBU was not reported by Mouchel.

Table 9.2 Summary of inclinometer data at St Nicholas Cliff

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
FR01	FR01 is situated above Foreshore Road in front of the Grand Hotel at 11.43m OD. The borehole is c.20m deep with its base at c.-8.5m OD and passes through c.10.5m of made ground and 9.5m of fine grained glacial sediments. FR01 has been monitored since 16 June 2014.	n/a				No significant movement recorded. Changes of less than 1mm in the upper 3m of the borehole are within the margin of reading error.	B-Axis incremental readings show error at base of borehole leading to systematic offset of c. 2mm. No genuine movements are apparent.

Table 9.3 Summary of groundwater data at St Nicholas Cliff

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
FR02	FR02 has been monitored since 21 May 2014. Tip is at 18.0m depth (c.-6.5m OD). Pattern shows variation consistent with short and medium term tidal cycles.	7.4m OD 8.4m OD 9m	n/a				Continuation of past cyclical pattern. Levels range from 7.7 to 8.2m OD.	Continuation of past cyclical pattern. Groundwater levels fell in December 2015 and have remained steady, reaching a historical low of 7.4m OD by May 2016.

No ground movement is recorded at this site and water levels are stable.

9.4.2 Spa Chalet (MU 22/1)

This cliff is very steep and formed in glacial sediment that does not appear to have been affected by landsliding. The cliff has been previously stabilised with soil nails and netting. Monitoring comprises a single inclinometer on the promenade and a pair of closely located piezometers at the cliff toe. Inclinometer data are summarised in Table 9.4 and piezometer data in Table 9.5.

Table 9.4 Summary of inclinometer data at Spa Chalet

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH12	BH12 is 65m deep (ground level at 48.05m OD, base at -16.95m OD) and extends through 60m of glacial sediment and 5m of sandstone/mudstone bedrock. Cumulative readings show creep along the whole length of the borehole with total displacement at the ground surface of c.10mm by 15 June 2011 and subsequent recovery. The nature of movement is likely to be error. 60mm displacement between 9.05m and 17.05mAOD in a sand and gravel horizon occurred between Feb and Aug 2011. This is likely to represent localised collapse of the casing.					Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

Table 9.5. Summary of groundwater data at Spa Chalet.

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH12	Tip at -8.4 OD. Cyclical pattern with c. two-week frequency between peaks. Maximum levels are between 1.25 and 1.5m above OD and minimum levels are between 0.3 and 0.5m above OD. Given the tip is below mean sea-level it is possible the cyclical pattern is related to tidal phases.	0.0m OD 2.3m OD 2.3m					Range of fluctuations within past limits and linked to tidal cycles. Fluctuations range from 0.5 to 1.7m OD, averaging c. 1m OD.	Range of fluctuations within past limits and linked to tidal cycles. Fluctuations range from 0.2 to 1.5m OD, averaging c. 0.9m OD.
BH12a	Tip at 3.6m AOD. High degree of variability, with rapid fluctuation about a mean water level of c. 3.6m above OD. Peak water levels are c. 3.9m AOD and minimum levels are c. 3.3m AOD.	3.2m OD 3.9m OD 0.7m					Range of fluctuations within past limits and linked to tidal cycles. Fluctuations range from 3.4 to 3.9m OD, averaging c. 3.6m OD.	Range of fluctuations within past limits and linked to tidal cycles. Fluctuations range from 3.3 to 3.9m OD, averaging c. 3.6m OD. There is a rapid rise and fall in groundwater level over March 2016.

No ground movement has been recorded and fluctuations in groundwater levels are within the ranges previously observed.

9.4.3 Spa (MU 22/2 and 22/3)

The Spa is the focus of monitoring in South Bay, with eight inclinometers and 21 piezometers installed in the area (Figure 9.1B). The cliffs are generally steep and formed in glacial sediment. Shallower cliff sections are associated with a deep-seated landslide seen immediately north of the Spa Centre and localised shallow landslides. The monitoring results are described in Tables 9.6 and 9.7.

Table 9.6. Summary of inclinometer data at the Spa

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
AA04 (G2)	40.5m deep borehole penetrating 34.5m of glacial sediments and 6m of sandstone/siltstone bedrock. Ground level is 47.62m OD, base of hole is 7.12m OD.					No significant movement recorded. Changes of less than 1mm in the upper 3m of the borehole are within the margin of reading error.	Readings are less than 1mm and therefore not significant.

Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
BH13	61m deep borehole inland of the headscarp that penetrates 52m of glacial sediment and 9m of sandstone bedrock. Ground level is 53.93m OD, base of hole at -7.07 OD. Deflection of up to 80mm in the upper 35m (i.e. above 19m OD) of the borehole associated with creep.					Displacements of up to +/- 1mm are within margin of reading error and therefore not significant.	No significant movements recorded since the last readings.
BH14	55m deep borehole penetrating c. 50m of glacial sediments and 5m of sandstone bedrock. Ground level at 55.73m OD, base of hole at 0.73m OD. Uniform cumulative displacement of c. 5mm in the upper 35m of the borehole, with peaks of up to 10mm displacement from 35 to 55m depth. Readings are not progressive in time, suggesting shrink-swell behaviour.					No significant movements recorded since the last readings.	No significant movements recorded since the last readings.
BH101	Borehole is located in the seawall, beyond the toe of the Spa landslide and is 26.5m deep, passing through 21m of glacial sediment and 5.5m of sandstone and mudstone bedrock. Ground level is 6.77m OD and the base is -19.7m OD. No significant movement has been detected in the past.					Displacements of up to +/- 1mm are within margin of reading error and therefore not significant.	No significant movement.
BH103	10m deep borehole that only penetrates glacial sediments. Ground level is 6.65m OD, base of hole at -3.35m OD. Apparent displacements between installation in Oct 2012 and Dec 2012 are <1mm.					No significant movement.	No significant movement.
BH107	18m deep borehole that passes through 13m of glacial sediments and 5m of sandstone/mudstone bedrock. Ground level is 20.39m OD, base of hole at 2.39m OD. No displacements between installation in Oct 2012 and Dec 2012. Historical readings unavailable at current time therefore current reading cannot be compared to baseline.					No significant movement.	No significant movements since last reading, except between ground level and 10.5m depth (BGL) with minor displacement <2mm.
BH109	15m deep borehole that passes through 9m of glacial sediment and 6m of sandstone/mudstone bedrock. Ground level is 31.6m OD, base of hole is 16.6m OD. Apparent displacements between					Movements of less than 1mm in the borehole are not significant.	Movements of less than 1mm in the borehole are not significant.

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Borehole	Summary of past data	Report Status					Change Dec 2015 to May 2016
		1	2	3	4	5	
	installation in Oct 2012 and Dec 2012 are <1mm.						
BH105	45m deep borehole passing through 44m of glacial sediments an 1m of sandstone bedrock. Ground level is 41.75m OD and base of hole is -3.25m OD. Apparent displacements between installation in Oct 2012 and Dec 2012 are <1mm.					No significant movements since last reading, except at 9 - 13m depth where minor displacement of up to +/- 2mm occurs at two locations.	No significant movements since last reading.
BH105a	Acoustic inclinometer installed to a depth of 40m since 14 Nov 2012 adjacent to BH105. Ground level is 42m OD, base of hole is 2m OD. Since installation in Feb 2013, the device has detected a relatively low level of activity in response to rainfall events. No significant ground deformations have been indicated by the acoustic monitoring.					AE measurements between July 2015 and November 2015 do not show significant slope movements. Periods of elevated AE activity are likely to be a response to rainfall events.	AE measurements between February 2016 and August 2016 do not show significant slope movements. Periods of elevated AE activity are likely to be a response to rainfall events generating seepage in the gravel beds.

Table 9.7. Summary of groundwater data at the Spa

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
H2a	Located near the headscarp of the Spa landslide. Tip at 17.3m AOD. 3 to 5 day frequency fluctuation around mean of c. 17.25m OD with amplitude of c. 0.5m. No clear long term trend or temporal pattern. Maximum water level 17.6m OD on 4 June 2013, minimum of 16.9m OD on 15 March 2013.	16.7m OD 17.6m OD 0.9m					No change in past pattern. Levels range from 16.9 to 17.4m OD, and average c. 17.2m OD.	No change in past pattern. Levels range from 16.8 to 17.5m OD, and average c. 17.2m OD. Rapid rise and fall in groundwater level by 0.5m in March 2016.
H2b	Located near the headscarp of the Spa landslide. Tip at 11.1m AOD. 3 to 7 day frequency fluctuation around mean of c. 12.7m OD with	12.0m OD 13.0m OD 1.0m					Water levels increase to previous levels recorded prior to 2015. No change in pattern, ranging from 12.5 to 12.9m OD, averaging at 12.7m.	No change in pattern, groundwater levels steadily fluctuate around an average of 12.7m OD. Levels range from 12.4m OD to 12.9m OD. A rapid rise and fall in groundwater level in March 2016 is apparent.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	amplitude of c. 0.3m. No clear long term trend or temporal pattern. Maximum water level 12.9m OD on 3 June 2013 and 7 July 2013, minimum of 12.3m OD on 14 December 2012.							
H5	Located near the base of the cliff behind the Spa building. Tip at 15.5m OD. Marked drop in water level from 22m OD in late 2012 to 17.5m OD in late 2013. Slight but short-lived recoveries on 5 Nov 2012 and 15 Aug 2013 when water-levels rose by almost 1m in a day.	17.0m OD 23.0m OD 6m					Change in pattern with gradual fall in groundwater level to 19.2m OD in early September, with a rapid rise to 22.8m OD mid-September, which may be associated with peak in the rainfall record on 14 Sept. Groundwater level then falls to 20.2m OD on 23 September and rises to 22.8m OD on 24 September. Groundwater remains high at 20.8 by mid-October.	New telemetry logger installed 24/03/15. Groundwater levels increase from 20m OD to 22.3m OD in March, and gradually fall to 20.9m OD though remain higher than past recordings.
1 spa	Located near the base of the cliff. Tip at 6.3m OD. Water levels fluctuate between c. 7m OD and c. 12m OD. High levels over 11m AOD occurred in May 2008, Dec 2009 to Apr 2009 with historical low of c.7m OD between Aug 2008 and Aug 2009.	6.7m OD 11.9m OD 5.2m					Groundwater level remains steady at 7.3m OD.	Groundwater levels rise to 9.2m OD by May 2016, well within the range of historical records.
2 spa	Located near the base of the cliff. Tip at 6.4m OD. Water levels fluctuated between c. 10m OD and c. 12m OD between Jan 2003 and Aug 2009. Thereafter,	7.2m OD 12.1m OD 4.9m					Ongoing slight fall in groundwater to 9.9m OD.	Groundwater levels rise slightly to 10.3m OD, well within range of historical records.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	variation increases with low levels recorded down to c. 8m OD. Low levels recorded during the winters of 2010 and 2011.							
3 spa	Located near the base of the cliff. Tip at 7.2m OD. As in '2 spa' water levels fluctuated between c. 12m OD and c. 13m OD between Jan until Aug 2009 and thereafter, variation increases with low levels recorded down to c. 7m OD.	7.1m OD 13.0m OD 5.9m					Ongoing slight fall in groundwater to 11.8m OD.	Groundwater levels rise slightly to 12.3m OD, well within range of historical records.
4 spa	Located near the base of the cliff. Tip at 10.9m OD. Very similar pattern to '3 spa'. Water levels fluctuated between c. 10m OD and c. 13m OD between Jan until Aug 2009 and thereafter, variation increases with low levels recorded down to c. 6m OD	6.1m OD 12.6m OD 6.5m					Ongoing fall in groundwater to 11.5m OD.	Groundwater levels rise slightly to 12.2m OD.
G3	Located near the base of the cliff. Tip at 13.6m OD. Complex pattern comprising c. 7 month period cycle of rising water level with superimposed sub-weekly fluctuations. 7 month cycle shows rise in water levels of c 1m from 13.3m	13.3m OD 14.4m OD 1.1m					Net fall in groundwater level overlying cyclical pattern of variation seen in the past. Level falls to 13.8 in September 2015 and remains steady at 13.9m OD in October.	New telemetry logger installed 24/03/15. Between April and May 2016, groundwater level falls by 0.3m to 13.6m OD.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	OD in Oct 2012 to high of 14.4m OD in Feb 2013, falling to low of 13.5m OD in June 2013.							
5 spa	Located near the base of the cliff. Tip at 9.4m OD. No correlation with the upper tip in this well. Data only recorded between Sep 2006 and May 2012, after which the hole is dry. Limited fluctuation between c. 8.5m and c.9.5m OD.	8.5m OD 9.6m OD 1.1m					No data.	No data.
BH1a spa	Located at the toe of the Spa landslide. Tip at 2m OD. Sub-weekly fluctuation about mean around 4.4m. Water levels were at their highest during Jan and Feb 2012 when they were c. 0.5m higher than average. Sub-weekly fluctuations are c. 0.4m in the period Oct 2012 to Mar 2013.	3.9m OD 5.0m OD 1.1m					Continuing cyclical pattern overlain onto steady groundwater levels during the monitoring period. Fluctuations within range of previous records. Average groundwater level c. 4.4m OD.	Continuing cyclical pattern overlain onto steady groundwater levels during the monitoring period. Fluctuations within range of previous records. Groundwater rapidly peaks and falls in January and March 2016. Average groundwater level c. 4.6m OD.
BH1b spa	Located at the toe of the Spa landslide. Tip at 10.1m OD. Similar pattern to BH1a. Sub-weekly fluctuation in water level about mean of c. 12.4m OD. Water levels highest in late Feb 2012 when they reached 12.7m OD. Sub-	12.0m OD 12.7m OD 0.7m					Continuing cyclical pattern overlain onto minor rise in groundwater levels during the monitoring period. Fluctuations within range of previous records. Average groundwater level c. 12.5m OD.	Continuing cyclical pattern overlain onto minor rise in groundwater levels during the monitoring period. Levels rapidly peak at historical high of 12.7m OD in March and fall to an average of 12.5m OD.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	weekly fluctuations were up to 0.5m in the period Oct 2012 to Mar 2013.							
BH1 Prom	Located inland of the cliff top. Tip at 41.4m OD. 5 month period where water-level rose c. 1m from 41.5m OD in Oct 2012 to 42.6m OD in late Feb 2013, followed by period of gradual fall to 41.8 in late 2013. Superimposed on this trend are sub-weekly fluctuations of c. 0.3m.	41.2m OD 43.7m OD 1.4m					Fluctuations of c. 0.4m with decreasing trend in groundwater level, averaging at 41.6m OD in November 2015.	New telemetry logger installed 24/03/15. Groundwater levels rise to historical maximum of 43.7m OD following installation of logger and remain steady at 43.6m OD.
G1a	Located inland of the cliff top. Dipped piezometer that shows consistent water levels of c. 53.5m OD since late 1997.	53.4m OD 53.9m OD 0.3m					Borehole dry.	Borehole dry.
G1b	Located inland of the cliff top. Dipped piezometer that shows significant variability from late 1997 to early 2003 when water levels dropped from c 50m OD to c. 20m OD with significant fluctuations, and subsequent period of consistent level at c. 19m OD. There was a short lived rise to c. 21m during Dec 2012.	19.2m OD 51.1m OD 31.9m					Consistent water level since previous recordings in 2014 at c. 19m OD. No significant change.	Consistent water level since previous recording at 19.2m OD.
BH108a	Deep piezometer tip located mid-slope. Solinst	9.3m OD 31.4m OD					Continuation of pattern of rapid rises to ground level then less rapid	New telemetry logger installed 24/03/15. Groundwater levels gradually

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	data logger. Record begins on 18 Dec 2012 and shows several sharp fluctuations that are possibly in response to rainfall events. However fluctuations recorded by BH108b show an unexpected pattern, with sharp apparent rises in groundwater level up to ground level followed by a slower and decelerating drop. It is possible this pattern represents a sudden ingress of surface water into the installation which then slowly dissipates.	22.1m					falls. Fluctuations range at a reduced magnitude to previous months, between 28.5m OD and 31.4m OD. Groundwater level remains near the historical high, at c. 30.8m OD during the monitoring period.	fall to 24.5m OD, which is well below previous readings.
BH108b	Shallow piezometer tip co-located with deeper BH108a. Dry between Sept 2012 and Jan 2013.	25.6m OD 31.6m OD 5.8m					Water level rises to historical high at 31.4m OD.	Water level rises to historical high at 31.6m OD.
BH106a	Located at the cliff top. Solinst data logger. Borehole dry between Oct 2012 and Jan 2013.						Borehole dry. Check piezometer integrity	Borehole dry. Check piezometer integrity
BH106b	Located at the cliff top. Located at the cliff top. Borehole dry between Oct 2012 and Jan 2013.	n/a (dry)					Borehole dry. Check piezometer integrity	Borehole dry. Check piezometer integrity
BH104a	Located near the base of the slope.	5.0m OD					Water level remains steady at c. 5m OD	New telemetry logger installed 24/03/15. Water

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	Solinst data logger.	20.0m OD 15.0m						levels fall from 5.9m OD to 4.3m OD, with a peak in April 2016.
BH104b	Located near the base of the slope. Manual piezometer tube. Borehole dry between Sept 2012 and Jan 2013.	4.3m OD 11.0m OD 6.6m OD					Slight fall in level to 10.3m OD, remains near historical high.	Groundwater level rises to 11.0m OD, equal to historical high.
BH102a	Located at the base of the slope behind the seawall. Solinst data logger. Reading will be reported in next report.	-0.3m OD 2.6m OD 2.9m					Increase in magnitude of cyclical change during mid to late 2015 from c. 1m to 1.3m. Average ground water remains steady over monitoring period at 1.5m OD.	Increase in magnitude to cyclical change to 1.8m. Average groundwater remains steady at 1.6m OD over monitoring period.
BH102b	Located at the base of the slope behind the seawall. Manual piezometer.	1.1m OD 2.1m OD 1.0m					Slight rise in groundwater level at 1.7m OD, remaining well below historical high.	Slight fall in groundwater level at 1.5m OD.

These data indicate:

- Inclinometers show no significant movement in the monitoring period.
- Most locations show continuation of past patterns or slight rises in water level over the monitoring period.
- Piezometers 5 Spa, G1a and BH106a and b should be checked because they remain dry. This equipment may be damaged and required attention to determine whether they can be repaired.
- New telemetry loggers installed at H5 and BH1 Prom show a step-change in groundwater levels at an elevated position relative to earlier recordings. These locations should be reviewed in the next report to establish whether the trend in elevated groundwater levels continues. No movements were recorded in adjacent inclinometers BH107 and BH109.
- Piezometer data from BH108a shows that the earlier trend in rising groundwater level has changed following installation of the new telemetry logger. This shows groundwater is falling well below earlier levels. Piezometer BH108b is adjacent, and shows levels reaching historical highs which may likely represent ingress of water at the surface. These trends should be reviewed in the next report.
- Acoustic emissions (AE) detected are negligible and do not suggest slope movement. Fluctuations in the data represent the specific hydrogeological conditions at this site (i.e. time dependent seepage conditions following rainfall events). This is supported by the inclinometer measurements at BH105, which show negligible movement. (Figure 9.2 and 9.3)

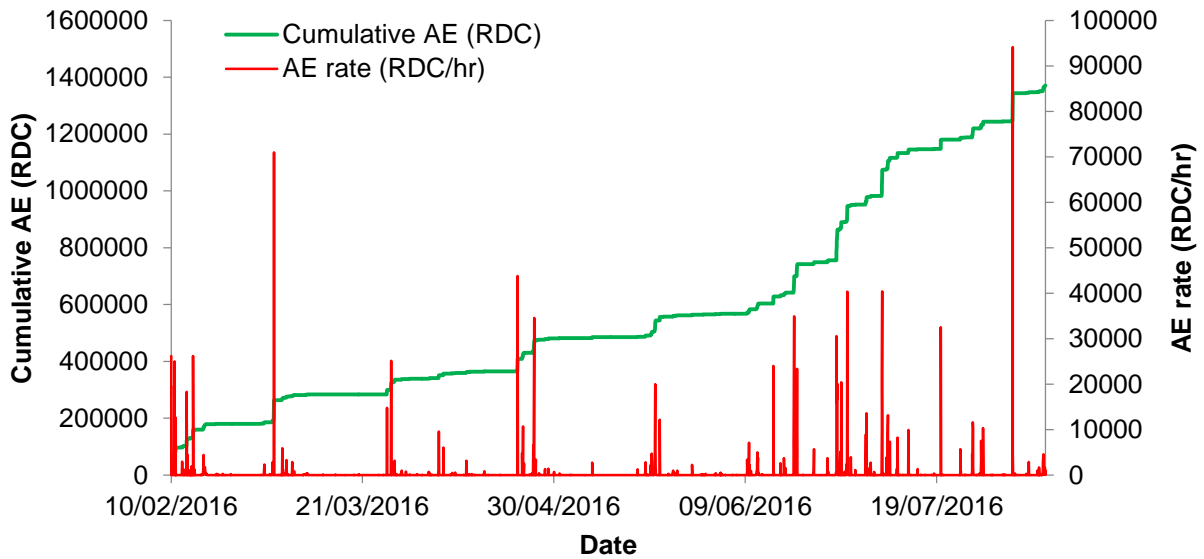


Figure 9.2. Cumulative AE (RDC) and AE rate (RDC/hr) time series at Scarborough Spa for the period February 2016 to August 2016.

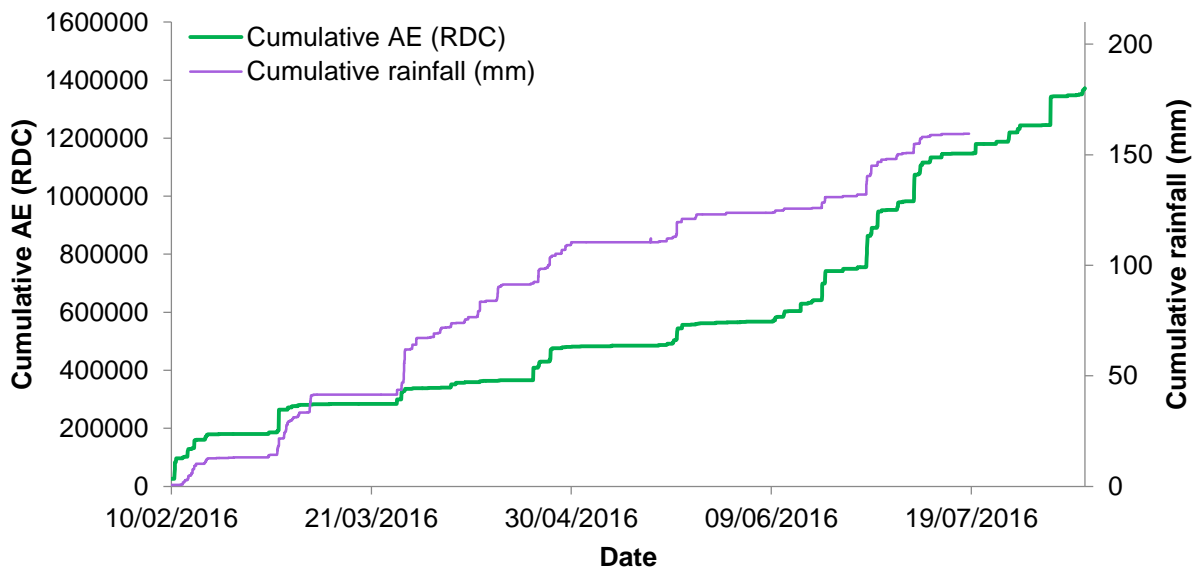


Figure 9.3. Cumulative AE (RDC) and cumulative rainfall time series at Scarborough Spa for the period February 2016 to August 2016.

9.4.4 Clock Café (MU 22/4)

Monitoring at the Clock Café comprises a line of three boreholes from the promenade (BH15) to the midslope (AA10 F2) and lower slope (AA11 F4) (Table 9.8, Figure 9.1B).

Table 9.8. Summary of inclinometer data at the Clock Café

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
AA10 (F2)	30m deep borehole through 3m of made ground, 21m of glacial sediment and 6m of siltstone/sandstone bedrock at the headscarp of the Clock Café landslide. Ground level is 34.98m OD, base of hole is 4.98m OD. Very low creep indicated in the upper 5m, with incremental displacements of up to 5mm. 30 June 2012 reading is erroneous.					No significant change.	No significant change.
AA11 (F4)	20m deep borehole penetrating 8m of glacial sediment and 12m of siltstone/sandstone bedrock near the toe of the Clock Café landslide. Very low cumulative movement along whole length of borehole of up to 3mm is within tolerance of the device.					No significant change.	No significant change.

Table 9.9. Summary of groundwater data at the Clock Café

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH15	Located inland of the landslide headscarp. No historical data	n/a					Borehole dry. Check function of piezometer.	Borehole dry. Check function of piezometer.

The data show no ground movements at the Clock Café, which is a continuation of the past pattern of stability at this location. The one piezometer at this location continues to be dry. This equipment may be damaged and required attention to determine whether it can be repaired.

9.4.5 South Cliff Gardens (MU 22/5 and 22/6)

The South Cliff Gardens area comprises landscaped public areas and the former South Bay Pool, which lies at the foot of a relict landslide complex (the South Bay Pool landslide). There are three transects of monitoring locations (Tables 9.10 and 9.11; Figure 9.1C).

Table 9.10. Summary of inclinometer data at South Bay Gardens

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
AA08 (D3)	24m deep borehole that penetrates 12m of glacial sediment and 12m of siltstone/sandstone bedrock. Ground level is 38.43m OD, base of hole is at 14.43m OD. Data indicate slight progressive creep along the whole length of the borehole, with a maximum cumulative displacement of 5mm.					No significant change.	No significant change.
BH17	50m deep borehole than penetrates 34m of glacial sediment and 16m of siltstone bedrock at the top of a mudslide embayment. Ground level is 57.46m OD, base of hole at 7.46m OD.					No significant change.	No significant change.
BH16A	54m deep borehole than penetrates of 33m of glacial sediment and 21m of siltstone/sandstone bedrock inland of the Rose Garden rotational landslide. Ground level is 62.88m OD, base of hole is 8.88m OD.					No significant change.	No significant change.
BH20	41m deep borehole that penetrates 27m of glacial sediments and 14m of sandstone bedrock within the body of a small landslide. Ground level is 58.98m OD, base of borehole is 17.98m OD.					No significant change.	No significant change.

Table 9.11. Summary of groundwater data at the South Bay Gardens

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH18a	Tip at 26.8m OD near the base of the cliff and Rose Garden landslide. Complex pattern, with sub-weekly peaks 4m to 5m higher than base readings associated with storms. From Nov 2012 to May 2013 base readings were 37m OD.	34.4m OD 42.5m OD 6.1m					Continuation of past pattern of short lived spikes, but base levels fall from c. 36m OD to 34.5m OD over the monitoring period.	Continuation of past pattern of short lived spikes. Base levels are high in December 2015 at c. 38m OD but this falls to c. 36m OD over the monitoring period. Base levels remain elevated compared to historical records.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	Between May and Aug 2013 levels rose to 38m OD.							
BH18b	Tip at 23.8m OD near the base of the cliff and Rose Garden landslide. Pattern very similar to BH18a installed higher in the borehole	34.3m OD 42.4m OD 6.1m					Same pattern and water levels as BH18a. Spikes on same days, suggesting connectivity between both piezometer tips and possible ingress of surface water to the borehole. Base levels falling over monitoring period from c 36m OD to c. 34m OD. Recommend integrity of installation is checked.	Same pattern and water levels as BH18a. Spikes on same days, suggesting connectivity between both piezometer tips and possible ingress of surface water to the borehole. Base levels falling over monitoring period from c 36m OD to c. 34m OD. Recommend integrity of installation is checked.
BH19a	Tip at 53.8m OD inland of the headscarp of the South Bay Pool landslide. This piezometer has been dry since installation.	52.8m OD 53.3m OD 0.5m OD					Cyclical pattern with magnitude of variation ranging 0.5mm averaging 53.1m OD.	Cyclical pattern with magnitude of variation ranging 0.5mm averaging 53.1m OD.
BH19b	Tip at 47.3m OD inland of the headscarp of the South Bay Pool landslide. Sub-metre variation about an average level of 47.8 OD. Periods of slightly higher water level from Dec 2012 to Mar 2013, late May 2013 and early Aug 2013.	47.1m OD 48.6m OD 1.5m					Continuation of sub-weekly fluctuation of c. 1.2m about monthly variation. Levels high in mid-October.	Continuation of sub-weekly fluctuation of c. 1.2m about monthly variation. Levels high in March at 48.1m OD, and fall to minimum of 47.4m OD during monitoring period.
D2a	Tip at 27.5m OD at the headscarp of the South Bay Pool landslide. Sub-metre variation about an average level of 40.5m OD. Periods where hole appears dry occurred regularly from late June to early July 2013,	31.1m OD 40.9m OD 9.8m					Levels remain around 31.5m OD with sub-weekly fluctuations of c. 0.2m. Slight net rise in levels over monitoring period.	Levels remain steady around 31.6m OD with sub-weekly fluctuations of up to c. 1m in December. Slight net rise in levels over monitoring period.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	following which no data has been recorded.							
D2b	Tip at 41.5m OD at the headscarp of the South Bay Pool landslide. Pattern similar to that recorded by lower elevation tip, with sub-metre variation about mean of c. 45.8m OD. Slight peak in water level occurred in late Nov to late Dec 2012. Gap in data between April and Aug 2013.						No data. Logger removed for repair.	No data, logger to be checked.
Bh3a	Tip at 41.5m OD at a mid-slope position adjacent to the South Bay Pool landslide. Sub-metre variation about a mean value. Change occurs in Apr 2013, before which mean is 44.5m OD, after which it drops to c. 44m AOD.	Original logger: 43.6 44.8 1.2 Replacement logger: 45.6m OD 50.0m OD 4.4m					New data logger installed. Sept 2015 shows significantly different levels to those of 2012-2013. Check VWP calibration.	No data. Logger sat in water. Logger to be checked.
Bh3b	Tip at 10.5m OD at a mid-slope position adjacent to the South Bay Pool landslide. Similar pattern to high elevation tip, however uniform level of 10.5m OD is interrupted by frequent short-duration (1 day) peaks that are up to 8m higher. Peaks particularly common during period Nov 2012 to Feb 2013 and May to June 2013.	10.3m OD 18.6m OD 8.3m					Continuation of past pattern with levels fluctuating by 0.2m about mean of 10.6m OD. Data spikes suggest ingress of surface water to the borehole.	Continuation of past pattern with levels fluctuating by 0.5m about mean of 10.6m OD. Data spikes suggest ingress of surface water to the borehole. Levels peak at 10.8m OD in March falling to 10.3 m OD.
E2a	Tip at 31.4m OD below the headscarp of the mudslide	43.3m OD 46.5m OD 3.2m					Water level declines at c. 43.3m OD to a historical low.	Groundwater level gradually rises to 44.7m OD throughout monitoring period.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
	embayment. Cyclical long-term pattern with sub-metre fluctuations superimposed. Water levels rise from c. 44m AOD to 46.5m OD between Oct 2012 and late Feb 2013 thereafter they fall gradually to 44.7m OD in Oct 2013							
E2b	Tip at 43.6m OD below the headscarp of the mudslide embayment. Different pattern to shallower tip, with sub-metre variation about a mean of 51m OD.	49.6m OD 51.4m OD 1.7m					Groundwater level remains steady at c. 50m OD, fluctuating within 0.5m.	Groundwater levels increase gradually from a low of 49.6m OD to 50.4m OD.

These data indicate:

- No movement has been recorded in any boreholes at South Cliff Gardens.
- Water levels are generally stable or show gradual increases. Short-lived peaks are recorded in BH18a, BH18b and 3b, which suggests ingress of water to the borehole.
- No data are recorded at D2b because data logger has been removed for repair.
- BH3a data logger requires integrity to be checked as saturated in water and unable to provide readings for this monitoring period.
- Gradually rising water levels occur in E2a and E2b. This may reflect the antecedent rainfall occurring during in the winter 2015/2016. The integrity of piezometer tip should be checked and the next monitoring data reviewed, whether this trend continues.

9.4.6 Holbeck Gardens (MU 22/7)

This area comprises two monitoring locations (Figure 9.1C); water levels are monitored at two depths along the promenade and ground movements are recorded by an inclinometer on the upper slope (Tables 9.12 and 9.13).

Table 9.12. Summary of inclinometer data at Holbeck Gardens

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
AA07 (BH2)	60m deep borehole penetrating 31m of glacial sediments and 29m of siltstone/sandstone bedrock. Ground level is 56.33m OD, base of hole is -3.67m OD. Data show progressive displacement of the glacial sediments, with up to c. 15mm at the ground surface. There is a suggestion of a shear developing at the contact between the glacial sediments and underlying bedrock and also at c.14m depth, within the glacial sediments.					Incremental movements at same depths seen before are not significant.	Incremental movements at same depths seen before are not significant.

Table 9.13. Summary of groundwater data at Holbeck Gardens

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
Bh4a	Tip at 31.5m OD. Complex pattern with periods of stability interspersed by rapid rises or falls of up to 2m.	47.1m OD 58.8m OD 11.7m					Unable to download logger data. Check integrity of piezometer.	Unable to download logger data. Check integrity of piezometer.
Bh4b	Tip at 35m OD. Different pattern to records of shallower tip. Highly variable	31.8m OD 59.9m OD 26.7m					New data logger. High groundwater levels recorded at c. 57.6m OD are unusually. Check VWP calibration.	Groundwater levels remain elevated reaching historical high of 59.9m OD in March 2016. Levels fell by 1m in May.

The data logger was at fault for Bh4a and data was not downloaded. The integrity of the piezometer should be checked. The data logger at BH4b has been replaced showing comparatively peak groundwater levels and has been maintained in this monitoring period. The integrity of piezometer should be checked and the next monitoring data reviewed, whether this trend continues. No evidence of movement is shown in the current inclinometer data.

9.5 Causal-response relationships

For the most part, groundwater levels show a slight increase or remain steady, reflecting the initially wet start to winter and relatively mild and dry weather which followed. There is little evidence of movement in the inclinometers and no critical groundwater level thresholds have been identified during this period. However, several piezometers show a trend of rising water level which should be closely monitored.

9.6 Implications and recommendations

None of the inclinometers indicate ground movement.

The majority of piezometers show groundwater levels have either been maintained or increased. Several piezometers have had data loggers removed for repair and so no data have been recorded during the current monitoring period. Some replaced data loggers show step-changes in groundwater levels whereby levels have increased. The integrity of piezometer tips should be checked and the next monitoring data reviewed, whether these trends continue. Others show short-lived peaks in water level that suggests ingress of surface water during storms. Checks should be made at these locations to ensure water-proof caps are in place.

Filey Town

10.1 Site description

The cliffs at Filey are formed in thick (c. 50m) glacial sediments that overlie the Upper Jurassic Kimmeridge Clay Formation across the town frontage and Upper Calcareous Grit north of the town towards Filey Brigg. The cliffs are protected by a sea wall at Filey and unprotected to the north and south of the town. Outflanking of the seawall and cliff instability of both the protected and unprotected cliffs at Filey is a concern. The cliffs across the town frontage have been landscaped and are criss-crossed with public footpaths. The glacial sediments have been deeply incised to form Church Ravine to the north of the town and Martin's Ravine to the south.

In July 2007, an intense rainstorm resulted in severe and widespread flooding throughout Filey; the storm water run-off caused many slope failures and extensive scour damage to paths and bridge abutments within Martin's Ravine. Existing drainage was overwhelmed and extensively damaged due to the excessive storm water run-off around Glen Gardens and this also caused drainage to collapse leading to slope instability behind Royal Parade chalets and Crescent Hill (Mouchel, 2012). The unprotected cliffs to the north and the south of the town are susceptible to toe erosion by the sea and are actively retreating. Cliff behaviour units (CBUs) have been defined and their activity status classified under the Cell 1 Regional Monitoring Programme.

10.2 Ground model and monitoring regime

Cliff behaviour units, reflecting individual mudslides and areas of relict cliff protected by the seawall, have been mapped for the frontage (Figure 10.1):

- MU29/AA and /AB are cliffs and mudslides south of the town
- MU 28/Z is a till cliff protected by rock armour immediately south of the sea wall
- MU27/X and MU28/Y are dormant cliffs protected by the seawall
- MU27/T /U, /V and /W are cliffs and mudslides north of the town

Halcrow (2012a) provides an overview of the ground models throughout the Filey Town frontage. The whole cliff line is comprised of weak glacial sediments that tend to fail through simple landslides triggered by both toe erosion and elevated groundwater levels.

The cliffs at Filey town, which are protected by a seawall, display evidence of historical instability. Shallow failures last occurred in this area in response to the intense storm event of July 2007.

Within the ravines, the steep till slopes are susceptible to shallow failure resulting from toe undercutting and excess groundwater levels due to intense and prolonged rainfall events.

The monitoring regime at Filey Town comprises the following:

- Filey Park – Till cliff with ground water monitoring at the cliff top.
- Golf Course – Ground water monitoring at the cliff top.
- Church Ravine/Coble Landing – Ground water monitoring at the cliff top and an inclinometer at the cliff toe.
- The Crescent/Rutland St – Groundwater monitoring at the cliff top and an inclinometer at the cliff toe.
- Glen Gardens/Martin's Ravine – Ground water monitoring on the cliff top and toe. Inclinometers at the cliff top and toe.

- Muston Sands – Ground water monitoring at the cliff top.
- Inland North – Groundwater monitoring near Church Cliff Farm, Pinewood Avenue and Parish Wood.
- Inland South – Groundwater monitoring near Filey Fields Farm, Long Plantation (west of Rivelin Way and Fewston Close) and Filey School.

10.3 Historical ground behaviour

Filey town was monitored by Mouchel Ltd for the period between summer 2009 and summer 2012. A summary of their results is provided in Table 10.1, which shows minor movement in one borehole during the autumn of 2009 but without subsequent movement and limited fluctuation in ground water level which Mouchel attribute to tidal variation in some boreholes and variations in stream flow in others. No relationship between groundwater level and ground movement was reported by Mouchel. Additional monitoring covering the period April 2011 to Dec 2012, associated with the recent seawall outflanking study, are provided in Halcrow (2013a).

Table 10.1 Summary of historical ground behaviour at Filey Town.

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total Change observed between July 2009 and June 2012
<p>Groundwater levels in BH5B (toe of Glen Gardens/Martin's Ravine) and BH6 (midslope Glen Gardens/Martin's Ravine) rose by 49mm and 560mm respectively. BH1 (cliff top Glen Gardens/Martin's Ravine, now inactive) rose 152mm which appeared to reflect prevailing water level in Martin's Ravine. BH04 (midslope Glen Gardens) was noted to be recording erratically. The inclinometer in BH3 was not readable during this time and no new movement was reported at BH6.</p>	<p>Mouchel report that ground water levels have increased since December 2011, the maximum rise having been identified as 560mm at BH4, Mouchel also describe erratic readings from this borehole. Mouchel describe an increase of 49mm at BH5b and attribute this to tidal fluctuations. Ground water readings from BH1 and BH2 appear to have remained relatively constant at about 15m OD. Only 'baseline' inclinometer readings have been determinable from BH3. Mouchel observe that ground water readings from BH1 seem to reflect water levels within the stream flowing in Martin's Ravine. Initially (between September and December 2009), displacements of <5mm were noted in BH6 but no further movements have been identified.</p>

10.4 New data

Tables 10.2 and 10.3 summarise the inclinometer and piezometer data from Filey Town to August 2014.

These data indicate:

- No movement has been recorded in any boreholes at Filey Town.
- Water levels are generally stable or increasing slightly.
- CPBH01a groundwater levels have reached a new historical high following an earlier falling trend. Levels rise by 9.1m which suggests the borehole is being flooded by surface water flows or that the groundwater level is near the surface.
- Dip meter reading at CPBH09b does not reflect water levels recorded by the diver, suggesting a systematic error. It is recommended that the diver be checked and recalibrated if necessary.
- Boreholes CPBH10b and CPBH08b are dry.
- CPBH02a and CPBH06b were not downloaded for this monitoring period.

Table 10.2. Summary of inclinometer data at Filey Town. Note: *Surface elevation and borehole depth calculated from digital elevation model.

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
CPBH03	CPBH03 is 10m deep. Surface elevation is c. 6m OD* therefore the base of the borehole is at -4.0m OD* and extends through 4.4m of made ground and 5.6m of glacial sediment.					No significant movement.	No significant movement.
CPBH05	CPBH05 is 10m deep. Surface elevation is c.6.5m OD* therefore the borehole extends to ca. -3.5m OD* through glacial sediments.					No significant movement.	No significant movement.
RCBH07	CPBH07 is 20m deep. Surface elevation is at c. 5m OD* therefore the borehole extends to c. -15m OD through glacial sediments.					No significant movement.	No significant movement.
BH6	BH6 is 30m deep. Surface elevation is c.27.4m OD* therefore the base of the hole is c. -2.6m OD. The borehole extends through glacial sediment. Cumulative displacements of 10mm in a negative B axis between Sept and Dec 2009 likely to be error.					No significant movement. Large displacement (20mm) at base of borehole is likely to be associated with debris.	No significant movement. Large displacement (20mm) at base of borehole is likely to be associated with debris.

Table 10.3. Summary of groundwater data at Filey Town

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
BH5b	Tip depth at 1.09m OD. Levels constant with limited fluctuation between 1.1m OD (Aug 2008) and 1.7m (Dec 2009).	1.1m OD 7.5m OD 6.4m					Level falls slightly to 1.3m OD during monitoring period.	Levels increase slightly to 1.5m OD during monitoring period.
BH4	Tip at 18.07m OD. Major fluctuations (>7m) in groundwater elevation between Dec 2009 and June 2011. Mouchel (2012) have previously reported groundwater readings from this piezometer as 'erratic'. Readings have been more settled 2011 albeit showing an increase to 20.2m OD in May 2012.	19.7m OD 27.1m OD 7.4m					Level continues to fall to 20.1m OD, near to historical low.	Levels slightly increase to 21.4m OD, remaining well within historical range.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
CPBH01a	Readings sporadic BH often dry. Mean level is 17.17m OD, with variation between 16.89m OD (15/12/2011) and 17.48m OD (20/12/2012). This latter measurement is likely to reflect the cumulative impact of the wet spring, summer and winter of 2012.	16.9m OD 26.2m OD 8.3m					Water levels fall to 17.1m OD.	Water levels rise to highest on record at 26.2m OD.
CPBH01b (Diver)	Tip at 32.63m OD. Fluctuating but steadily rising water level from 33m OD in late 2011 to 34m OD in summer 2012. Slight drop in autumn 2012 before sudden rise to maximum of 35.0m OD on 14 Dec 2012.	33.0m OD 35.0m OD 2.0m					Groundwater level remains steady at 33.2m OD. Dip meter readings from CPBH01a corroborate the diver data	No data. Readings to be re-taken.
CPBH02a	Tip at 1.57m OD. Mean groundwater elevation at c. 5m OD with minor fluctuations. Short lived drop to 3.57m in Sept 2012. Maximum level 5.23m OD on 19/04/2012.	3.6m OD 5.2m OD 1.6m					Slight fall in water level to 4.1m OD.	Water levels increase slightly to 4.9m OD, within range of historical records.
CPBH02b (Diver)	Tip at 8.17m OD. Generally steady at c. 8.7m OD except for spikes in on 6 July 2012 (to 15.6m OD) and 7 Dec 2012 (to 20.0m OD). Smaller spikes (to c. 9.7m OD in late Nov/early Dec 2012).	5.1m OD 20.0m OD 14.9m					Water level steady at 8.7m OD during October.	Water level steady at 8.6m OD.
CPBH04a	Tip at 2.90m OD. Mean ground water level at 7.2m OD, with range of fluctuation between 7.02m OD (06/09/2012) and 7.33m OD (19/04/2012).	7.1m OD 32.9m OD 25.8m					Slight fall in water level to 7.1m OD.	Water levels slightly increase to 7.2m OD.
CPBH04 (Diver)	Tip at 9.9m OD. Steady around 13.5m OD until Dec 2012 although dip in Dec2012 reads significantly higher (16.3m OD).	13.2m OD 13.6m OD 0.4m					Water level static at 13.5m OD.	Water level static at 13.5m OD.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
CPBH06a	Tip depth at 0.13m OD. Mean groundwater elevation at 19.86m OD. Range between 18.85m OD (27/02/2012) and 20.11 (20/12/2012). Notable increase in March/April 2012 followed the dry period of late autumn 2011 to winter of 2011/12. Rises to highest level in Dec 2012 after very wet year.	18.9m OD 20.0m OD 1.1m					No data recorded for bottom.	Water level remains within historical range at 19.0m OD.
CPBH06b (Diver)	Tip depth at 8.63m OD. Steady at c. 18m OD except for sudden drop to around 14.5m OD and immediate recovery on 20/03/2012 and 06/09/2012 and sudden drop on 19/04/2012 followed by a prolonged steady period at c. 15m OD before sudden recovery on 24/05/2012 to 18m OD.	9.2m OD 19.1m OD 9.9m					Water level static at 14.8m OD. In late Oct 2013 diver readings fell sharply by c. 4m to a new base level. Dip meter readings do not reflect this drop in level, which suggests a systematic error in the diver that needs to be investigated.	No data. Readings to be re-taken.
CPBH08a	Mean groundwater elevation is 8.71m OD ranging between 8.48m OD (19/04/2012) and 9.46m OD (20/12/2012), suggesting a greater lag time or less responsiveness to antecedent rainfall conditions.	8.5m OD 11.4m OD 1.9m					Slight fall in water level to 8.9m OD.	Slight increase in water level to 9.3m OD.
CPBH08b (Diver)	Very steady with fluctuations over whole period only between 17.90m OD and 17.97m OD.	17.7m OD 19.3m OD 1.6m					Water-levels static at 17.9m OD. Dip meter data suggest borehole is dry so diver may need resetting.	Water levels static at 17.9m OD. Dip meter data suggest borehole is dry so diver may need resetting.
CPBH09a	Tip depth at 0.64m OD. Mean groundwater elevation is 20.27m OD and ranges between 19.86m OD (01/08/2012) and 20.98m OD (06/09/2012).	19.9m OD 21.0m OD 1.1m					No change in water-level which is at 20.2m OD. Dip meter readings corroborate diver data.	No change in water-level which is at 20.2m OD. Dip meter readings corroborate diver data.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
CBPH09b (Diver)	Tip Depth at 17.74m OD. Between 01/01/2012 and 20/12/2012 levels fluctuate between 19.9m OD and 20.5m OD. There is a general trend of slight decline towards June 2012 followed by a rise towards peaks in late Oct and mid-Dec 2012.	3.0m OD 21.1m OD 18.1m					Diver replaced in October 2015. Groundwater levels fall to 3m OD to a new base level. Dip meter readings do not reflect this drop in level, which suggests diver needs to be recalibrated.	Groundwater levels remain steady at 3.0m OD. Dip meter readings do not reflect this drop in level, which suggests diver needs to be recalibrated.
CPBH10a (Diver)	Tip depth at 23.82m OD. Shows pattern of sharp increases over a week, followed by gentle decreases over several weeks, to c. 28.5m OD. Comparison to rainfall records indicates borehole has a comparatively 'flashy' response to rainfall, with lag times reducing towards the end of 2012 as atypically low groundwater levels recovered. Max peak is 30.8m OD in late Dec 2012.	24.6m OD 30.8m OD 6.2m					Continuation of saw-tooth pattern with rapid rises 28.6m OD and falls to 28m OD. Levels are comparatively low.	Continuation of saw-tooth pattern. Rises over 30m OD in January and falls to 29m OD. Levels are comparatively low.
CPBH10b	Tip depth at 11.92m. No data prior to October 2013 due to blockage by slip rod.	n/a (dry)					Borehole dry Recommend installation integrity is checked.	Borehole dry Recommend installation integrity is checked.
BHA	Tip depth at 27.62m OD. No previous data available at present	36.2m OD 37.6m OD 1.6m					Fall in water level to 36.2m OD.	No longer monitored in this programme
BHB	Tip depth at 30.97m OD. No previous data available at present	40.2m OD 41.0m OD 0.8m					Borehole dry.	No longer monitored in this programme
BHC	Tip depth at 32.87m OD. No previous data available at present	41.7m OD 42.9m OD 1.2m					Fall in water level to 41.7m OD.	No longer monitored in this programme
BHD	Tip depth at 21.57m OD. No previous data available at present	30.8m OD 31.6m OD 0.8m					Slight fall in water level to 30.9m OD.	No longer monitored in this programme
TP3	Tip depth at 29.73m OD. No previous data available at present	32.0m OD 33.7m OD 1.7m					Fall in water level to 32m OD.	Slight increase in water level to 32.3m OD.

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report Status					Change Dec 2015 to May 2016
			1	2	3	4	5	
TP6	Tip depth at 33.85m OD. No previous data available at present	35.7m OD 37.9m OD 2.2m					Fall in water level to 35.7m OD.	No longer monitored in this programme
TP8	Tip depth at 39.81m OD. No previous data available at present	37.4m OD 43.8m OD 6.4m					Slight fall in water level to 43.3m OD.	No longer monitored in this programme
TP9	Tip depth at 45.35m OD. No previous data available at present	49.4m OD 50.6m OD 1.2m					Slight fall in water level to 49.8m OD.	No longer monitored in this programme

10.5 Causal-response relationships

Most piezometers show a weak response to rainfall with the exception of shallow piezometers CPBH01a and CPBH10a which respond rapidly within a month to peaks in rainfall. Most of the piezometers show steady groundwater levels or slight increases. There has not been movement in inclinometers and therefore no relationships between groundwater and ground movement have been identified.

10.6 Implications and recommendations

The diver installed in CPBH09b requires recalibration as readings differ markedly from data derived from dip meter data. Readings in CPBH10a still show rapid rises to a peak level that may indicate ingress of surface water to the borehole. This location should be checked to ensure a water-proof cap is in place. Boreholes CPBH02a and CPBH06b require readings to be re-taken on the next site visit. CPBH10b and CPBH08b are dry and require investigation and repair work where necessary. In addition, borehole CPBH01a requires investigation to establish whether the borehole has been flooded by surface water flows or that the groundwater level is near the surface.

Inclinometer at BH6 appears to have debris at its base, causing error at the base of the borehole.

Filey Flat Cliffs

11.1 Site description

Flat Cliffs is a private residential settlement located on coastal slopes in central Filey Bay. The settlement includes private homes and a Yorkshire Water pumping station accessed via a private road down the cliffs that is particularly steep near the top of the cliffs (Halcrow, 2012b). The cliffs are formed in thick and variable glacial sediments that continue to at least 12.4m below OD and which are prone to cliff instability. There is concern that ongoing cliff instability threatens properties and the only access road to about 40 homes at Flat Cliffs (Halcrow, 2012b).

11.2 Ground model and monitoring regime

This site comprises three cliff behaviour units: MU29/AQ, which is an active mudslide complex north of the main settlement and MU29/AR and MU29/AS that form the main landslide undercliff upon which the settlement has been developed.

The undercliff ground model can be described as a complex landslide system that is backed by a steep headscarp and fronted by a sea-cliff (Halcrow, 2012b). The undercliff morphology comprises landslide scarps and benches, some of which are back-tilted although interpreted as failing on translational shear surfaces rather than rotational failure. A large mudslide complex in the north of the site is periodically active, and threatens the access road and properties. Activity is generally associated with accelerated toe erosion and elevated groundwater levels.

The monitoring regime at Flat Cliffs includes the following (Figure 11.1):

- North of site – automated piezometer on the cliff top and inclinometer on the access road.
- Central site – Piezometers with data loggers on the cliff top and next to the access road in the lower slope. Two inclinometers either side of the main access road (Flat Cliffs Road and Lower Flat Cliffs) on the coastal slope (one of which is an experimental acoustic inclinometer installed by Loughborough University).
- South of site – Co-located automated piezometer and inclinometer on the Lower Flat Cliffs part of the coastal slope.

11.3 Historical ground behaviour

Filey Flat Cliffs was monitored by Mouchel Ltd for the period between summer 2009 and summer 2012. A summary of their results is provided in Table 11.1, which shows some movement in Borehole A2. No relationship between groundwater level and ground movement was reported by Mouchel. Additional monitoring covering the period April 2011 to Dec 2012, associated with a landslide investigation, are provided in Halcrow (2013b).

Table 11.1. Summary of historical ground behaviour at Flat Cliffs

Observations in Mouchel 2012 (covering 6 month period between Dec 2011 and June 2012)	Total Change observed between July 2009 and June 2012
Mouchel monitored inclinometer A2 during this period and reported no movement. Mouchel report a groundwater level reading from B1 in June 2012 as revealing a reduction of 520mm relative to December 2011. The report mentions that groundwater readings up to May 2012 are reported in Appendix E to that report, but no readings after June 2010 are identifiable from the graph.	Deviation of 15mm near the surface indicated in A2 between December 2010 and June 2011. This had increased by a further 5mm to 20mm by December 2011. No specific comment is made on ground water levels but it appears from the chart in the appendix that ground water levels remain relatively constant at piezometers A2, A3 and D2, with minor fluctuations in B1 and major fluctuations in D1.

11.4 New data

Tables 11.2 and 11.3 summarise the monitoring results from inclinometers and piezometers at Flat Cliffs up to May 2016.

Table 11.2. Summary of inclinometer data at Flat Cliffs. *Surface elevations and borehole depths calculated from digital elevation model.

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
A2	A2 is 27.5m deep (surface elevation at 17.93m OD) and extends through glacial sediment. Moderate movements (<5mm cumulative) between Dec 2009 and Dec 2010 increase by a further c. 10mm by June 2011 at shear at c. 6m to 7m OD					No significant movement.	No significant movement.
C1	C1 is c. 25m deep. Surface elevation is 25.7m OD* the base of the hole is c. 0.7m OD. Shows very minor (<2mm cumulative) displacements up to and including October 2012.					No significant movement.	No significant movement.
C2	C2 is c. 21m deep. Surface elevation is at 16.5m* and the borehole extends to - 4.5m OD through glacial sediments. Displacements to Oct 2012 within margin of instrument error					No significant movement.	No significant movement.
C5	C5 is c. 16m deep. Surface elevation is 12.0m OD* and the borehole extends to - 4.0m OD passing through variable glacial sediments. No movement to Oct 2012 apart very minor displacement in the uppermost 1.5m					No significant movement, except for minor displacement in the uppermost 1.5m.	No significant movement.

Borehole	Summary of past data	Report status					Change Dec 2015 to May 2016
		1	2	3	4	5	
C1A	Acoustic inclinometer. The Acoustic Emissions (AE) monitoring has not detected any movement of the landslide to the end of 2012. Higher than average rainfall from April to Dec 2012 had no impact on ground movement. The AE monitoring and inclinometer measurements are consistent					AE measurements between August 2015 and December 2015 do not show significant slope movements. Periods of elevated AE activity are likely to be a response to rainfall events.	AE measurements between February 2016 and August 2016 do not show significant slope movements. The period of elevated AE activity after June 2016 could be indicative of minor deformations. It is likely that this is a function of the deterioration of the cover lid generating spurious AE.

Table 11.3. Summary of groundwater data at Flat Cliffs

Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
B1	Tip Depth at - 7.64m OD. Monitored since July 2001. Fluctuates between c. 11.2 m OD and 15.6m OD with peaks in July 2003, April 2004 and Dec 2010. Groundwater at 12.9m OD in May 2012.	11.2m OD 15.6m OD 4.4m					Groundwater level rises to 15.6m OD in October 2015, reaching the historical high.	Groundwater level falls to 13.9m OD in May 2015.
D1	Tip depth at 15.61m OD. Monitored with data loggers since late 2011. Levels show large fluctuations between 15.7 m OD (Sept 2008) and 38.4m OD (March 2010). Peaks of 28.2m OD in July 2012 and 24.5m OD in early Jan 2012. Mean base groundwater level is 18 to 18.5m OD.	18.1m OD 29.9m OD 11.8m OD					Falling slightly. Groundwater levels at 17.8m OD with occasional short-lived falls to 17.4m OD.	Groundwater levels increased significantly from late December to mid-January reaching an historical high of 29.9m OD. From late January levels gradually fell to 20.4m OD.

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Borehole	Long-term Pattern	Groundwater summary Min/Max/Range	Report status					Change Dec 2015 to May 2016
			1	2	3	4	5	
A3	Tip depth at 6.37m OD. Monitored since March 2001. Dipped readings show static ground water level at c. 18.75m OD with for peaks in July 2001 (19.8m OD) and Dec 2010 (21.4m OD) and a low in July 2008 of 11.63m OD. Vibrating wire piezometer installed in Sept 2011 shows static groundwater level of c. 18.0m OD with minor fluctuation.	17.7m OD 18.2m OD 5.0m					No significant change with continuation of 4 to 6 week fluctuations of +/- 0.2m around 18m OD.	No significant change with continuation of 4 to 6 week fluctuations. Gradual increase in groundwater level from 17.8m OD to 18.1m OD. Highest levels occur in March 2016.
C4a	Tip depth at -3.7m OD. Monitored since Sept 2011. Levels vary between 7.5m OD and 8.4m OD in response to short and medium term tidal cycles (ca. 6 hourly and 4-weekly).	7.5m OD 8.5m OD 1.0m					No significant change. Continued fluctuation of +/- 0.3m around an average of 8.0m OD, rising slightly to 8.1m OD in November 2015.	No significant change. Continued fluctuation of +/- 0.3m around an average of 8.0m OD.

The new data indicate:

- No evidence for ground movements is shown by inclinometers.
- AE measurements between February 2016 and August 2016 do not show significant slope movements. The period of elevated AE activity after June 2016 could be indicative of minor deformations of a very slow rate and magnitude. It is likely that this is a function of the deterioration of the cover lid generating spurious AE.
- Groundwater data show no significant change except for Borehole D1 near the top of the slope adjacent to the main access road. Here, water levels rise sharply during late December and January and remain high.

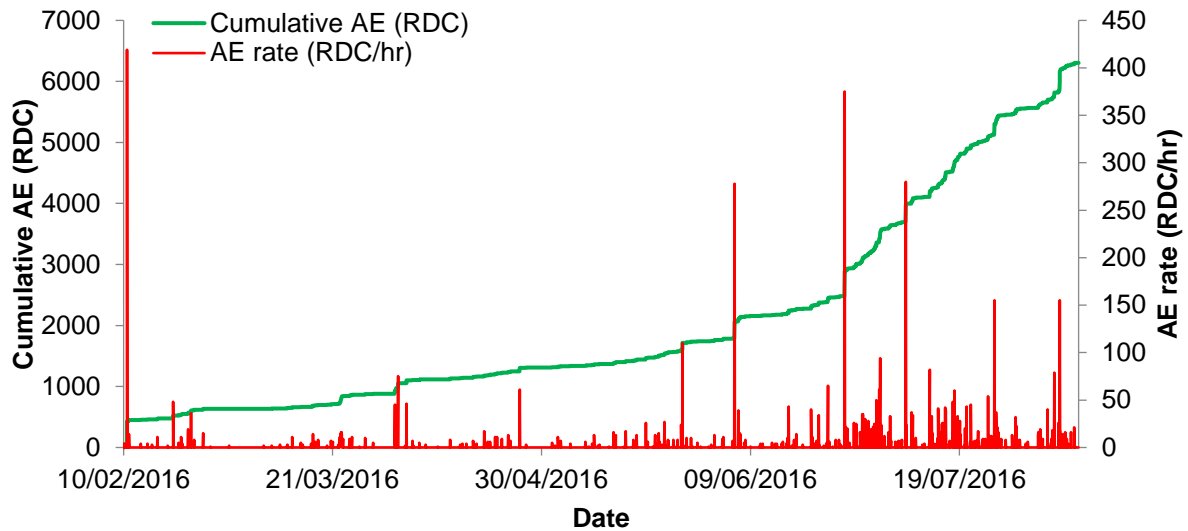


Figure 11.2 Cumulative AE (RDC) and AE rate (RDC/hr) time series at Flat Cliffs, Filey for the period February 2016 to August 2016.

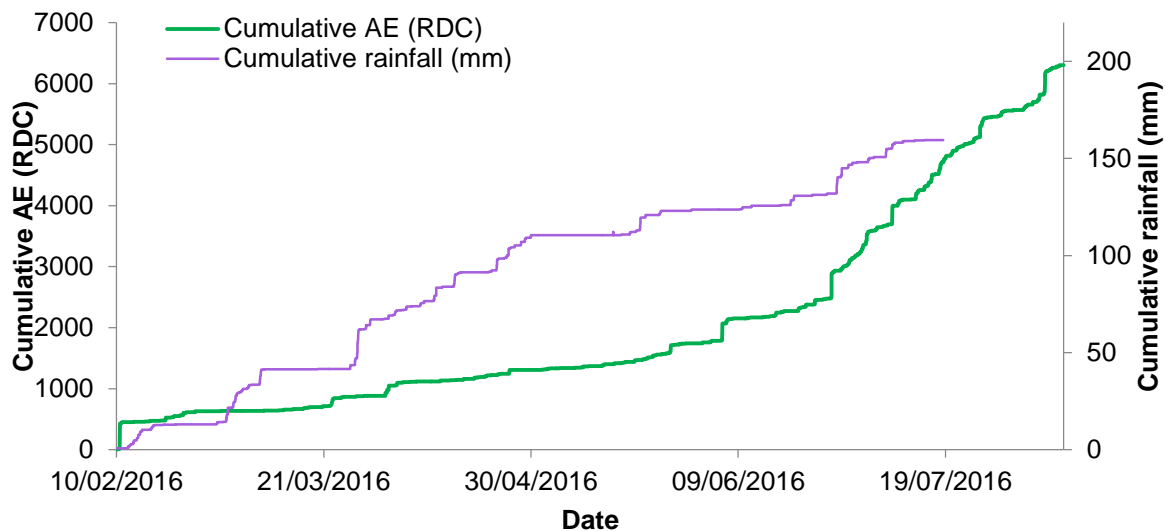


Figure 11.3 Cumulative AE (RDC) and cumulative rainfall time series at Flat Cliffs, Filey for the period February 2016 to August 2016.

11.5 Causal-response relationships

No relationship is identifiable between ground movements and rainfall as no substantial ground movements have occurred. However, borehole D1 appears to show a response to above average rainfall in January and February 2014 and borehole C4a clearly shows the effect of the 5 December 2013 storm surge on groundwater levels as the highest peak in the record. Much of the current monitoring period experienced lower than average rainfall, with only May 2015 experiencing wetter-than-average conditions. The data from borehole D1 and C4a do not record a peak associated with May rainfall, however B1 rise in groundwater level follows a month antecedent rainfall.

11.6 Implications and recommendations

Previous reports have highlighted a possible relationship between groundwater levels in piezometer D1 and movements in inclinometer C1. Groundwater levels in Piezometer D1 have previously shown a strong relationship with rainfall and this relationship should be specifically reviewed in future reports when data is available to refine understanding of that relationship.

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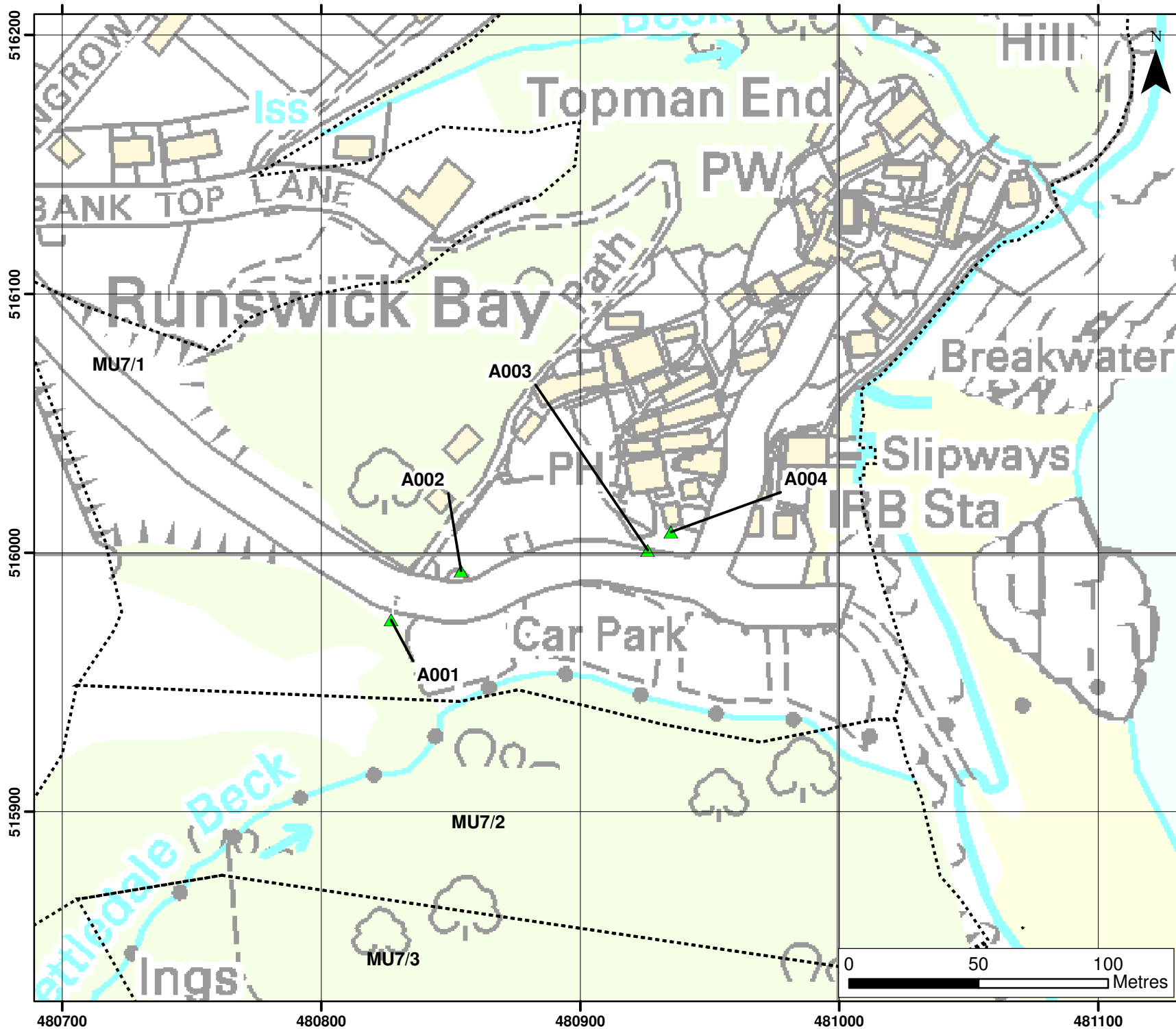
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Appendix A

Digital data



Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Cliff behaviour unit

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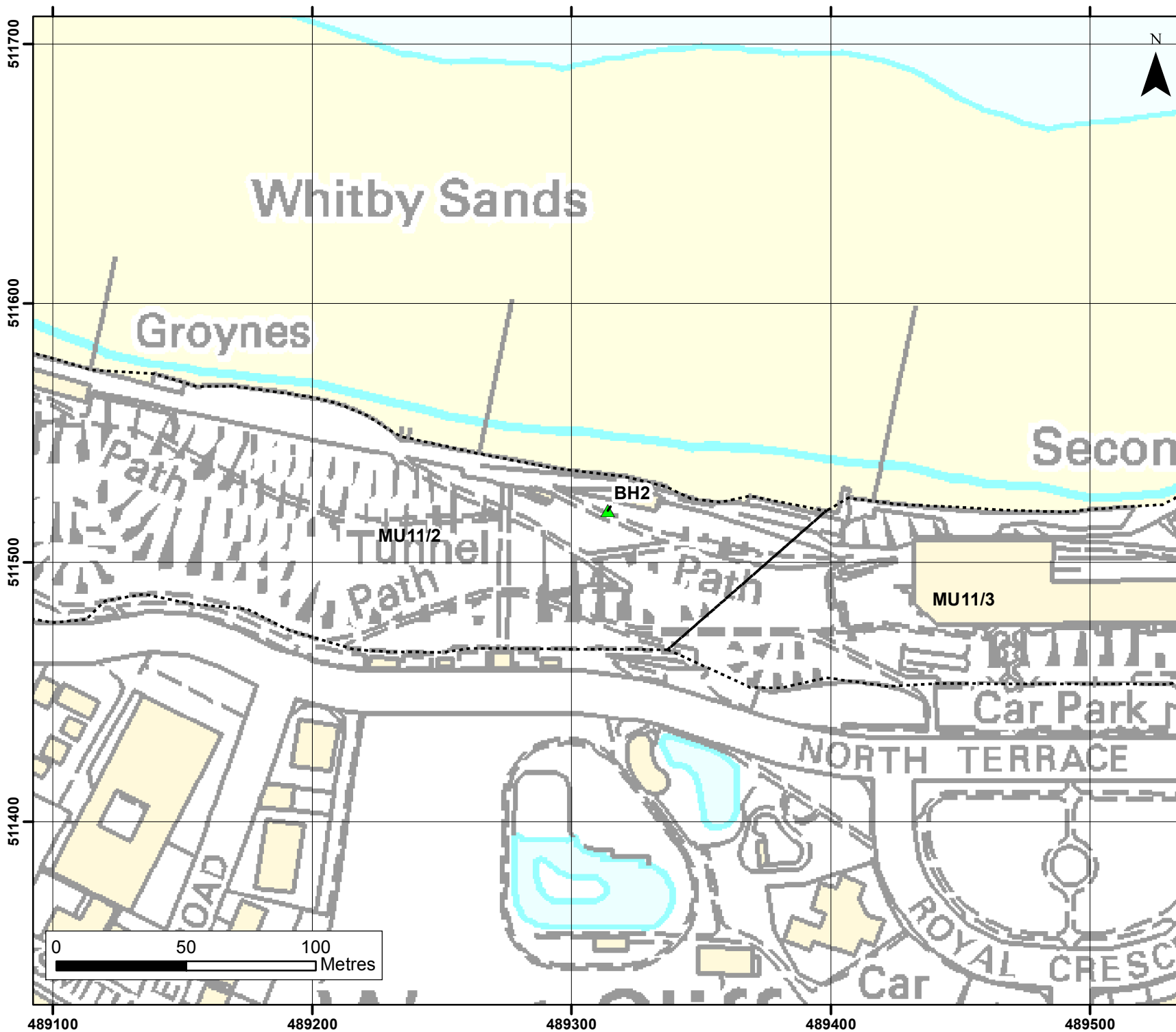
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Figure 3.1 Location of slope monitoring at Runswick Bay

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Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- △ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
- ⋯ Cliff behaviour unit

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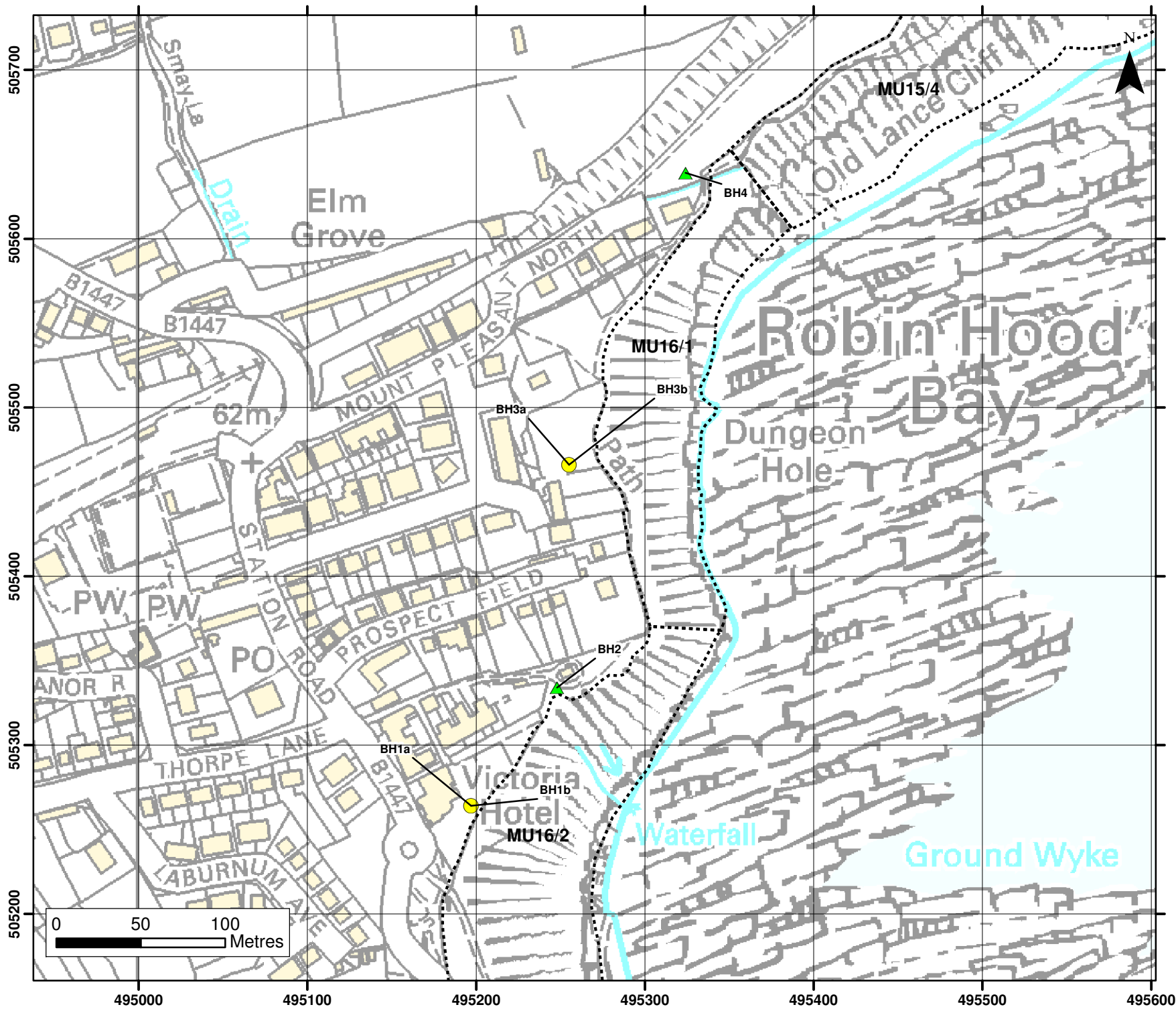
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Figure 4.1 Location of slope monitoring at Whitby West Cliff

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Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- △ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
- ⋯ Cliff behaviour unit

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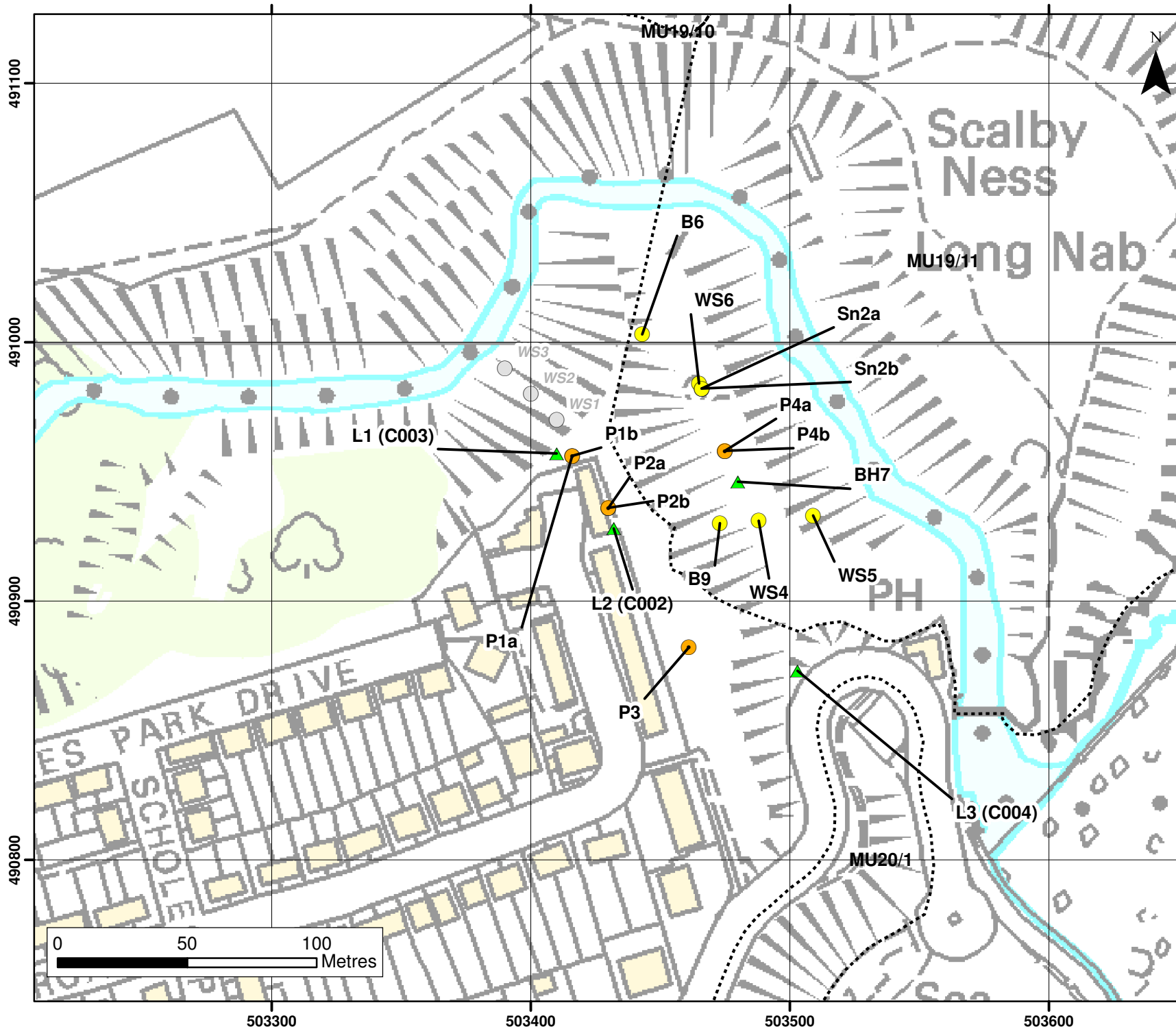
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Figure 5.1 Location of slope monitoring at Robin Hood's Bay

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Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)

 Cliff behaviour unit

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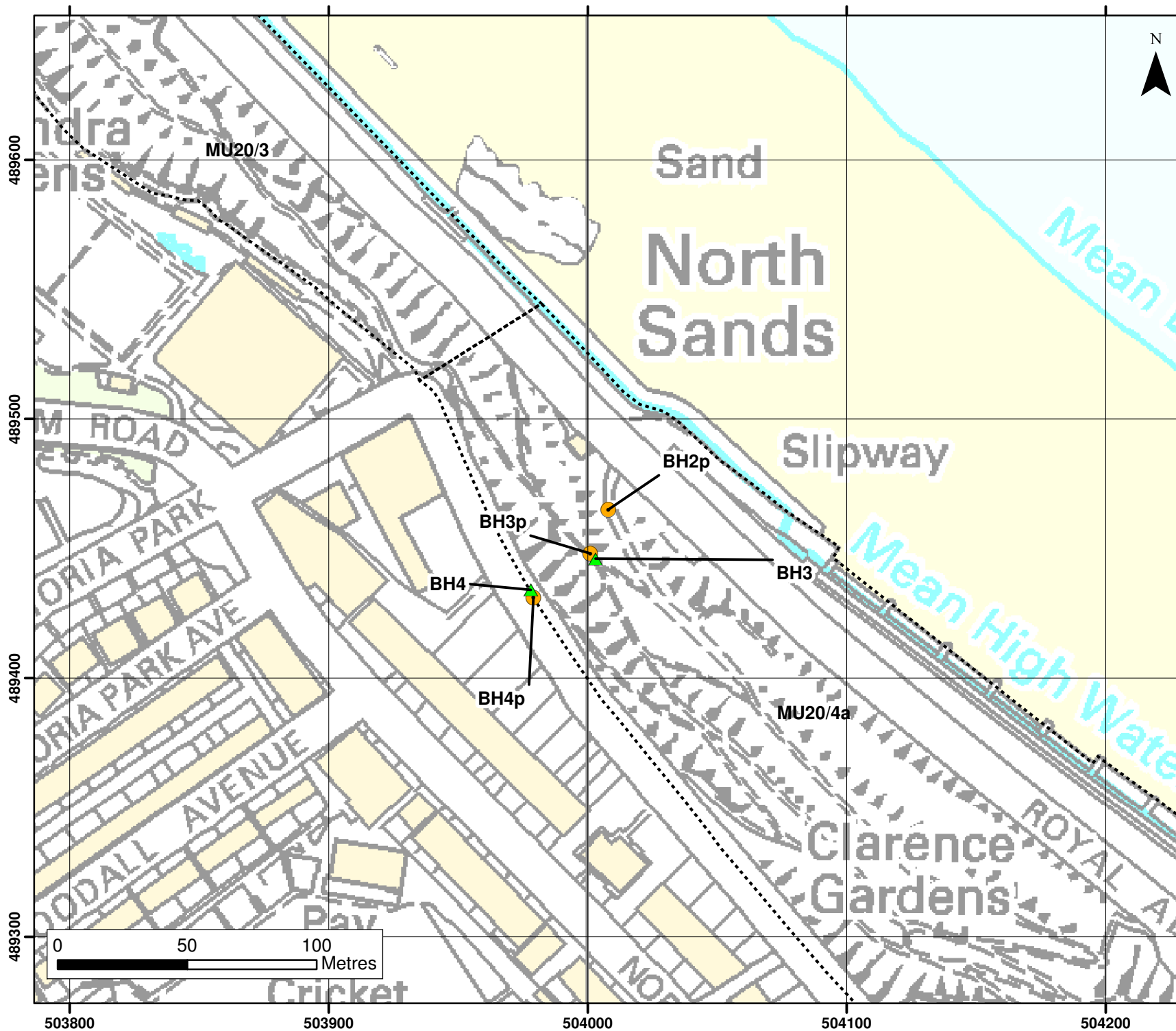
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Figure 6.1 Location of slope monitoring at Scalby Ness

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Active

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- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)

Inactive

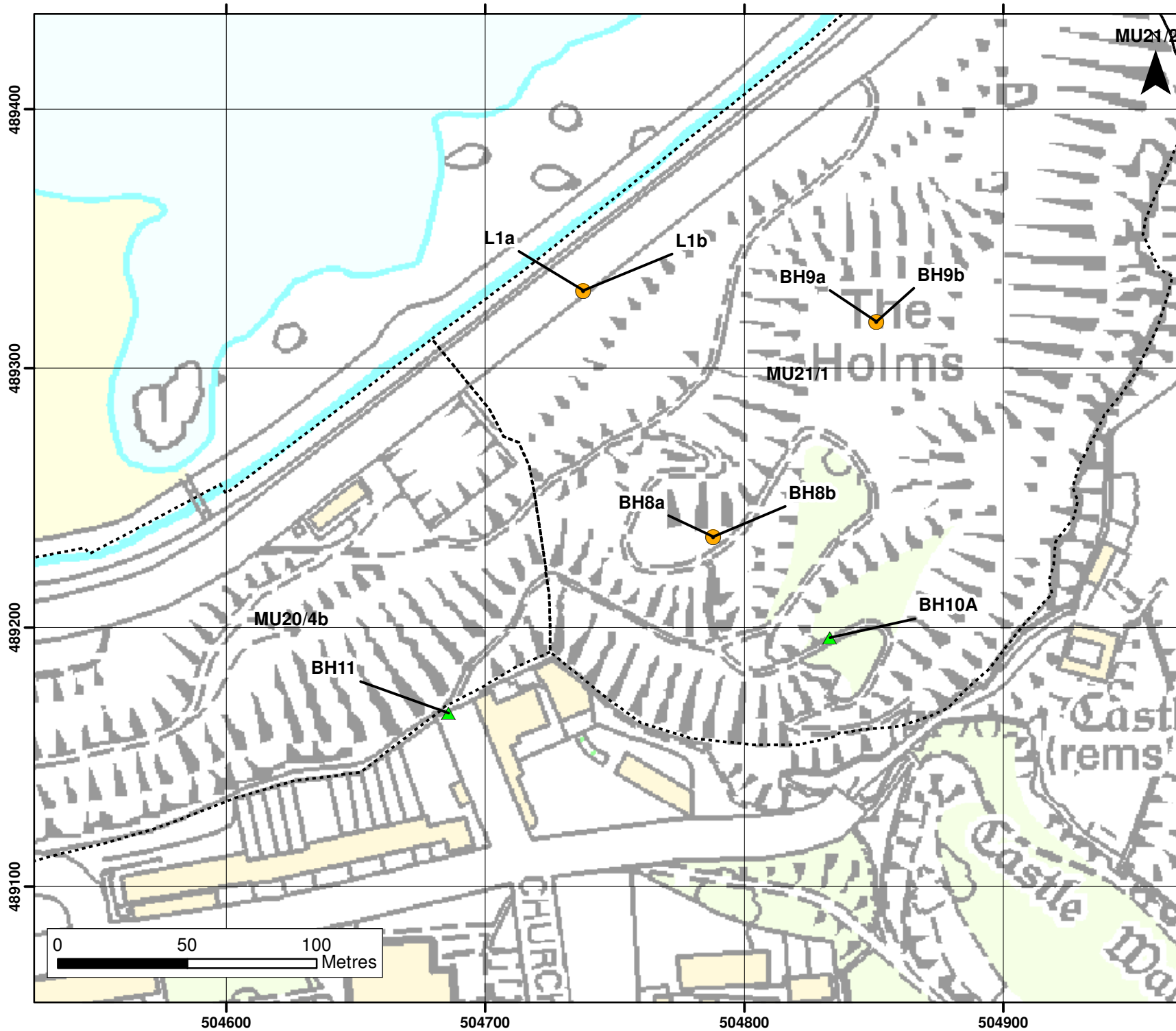
- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
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Figure 7.1 Location of slope monitoring at Scarborough North Bay –Oasis Cafe

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Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)
- Cliff behaviour unit

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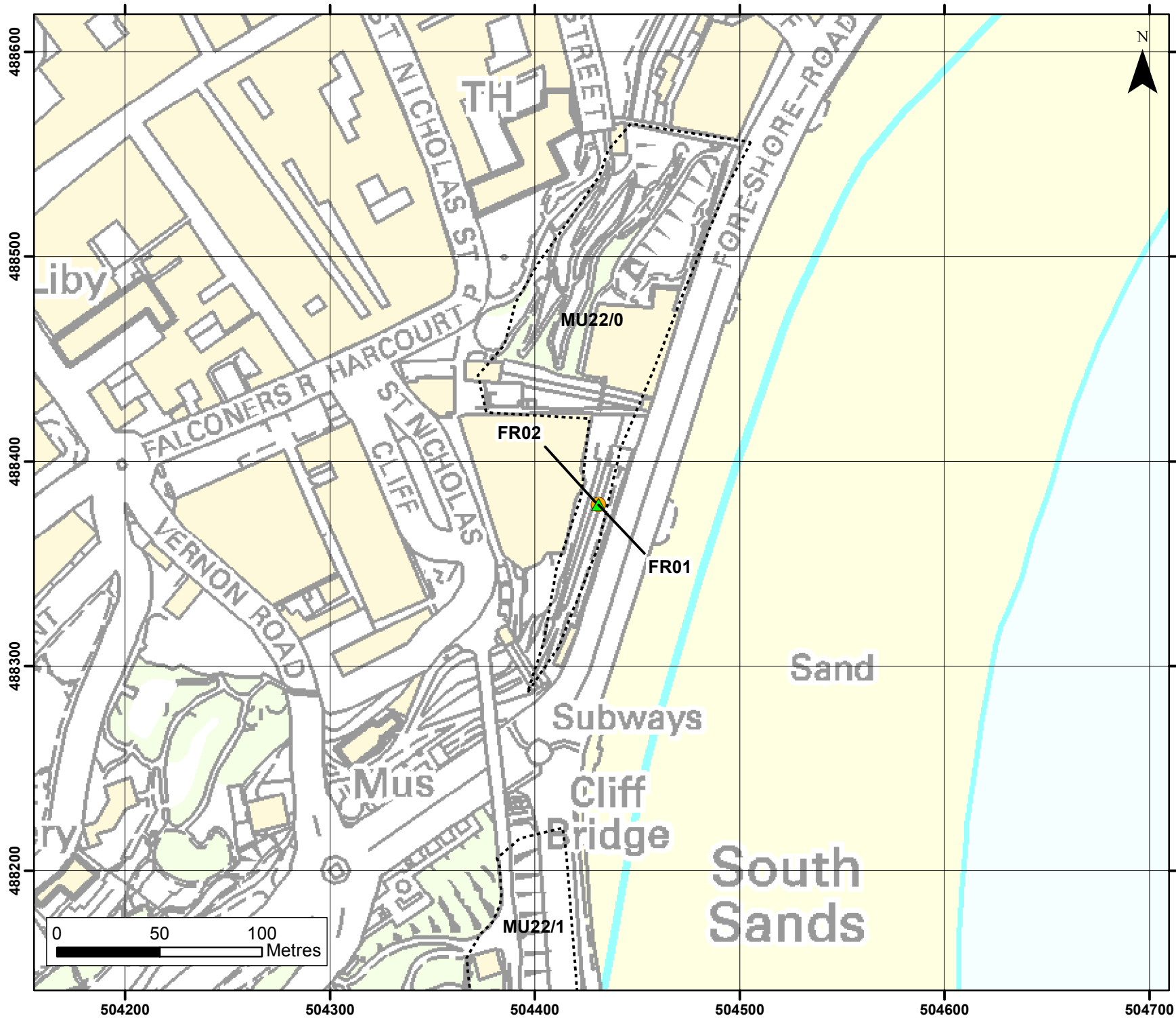
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Figure 8.1 Location of slope monitoring at Scarborough North Bay (The Holms)

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Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

 Cliff behaviour unit

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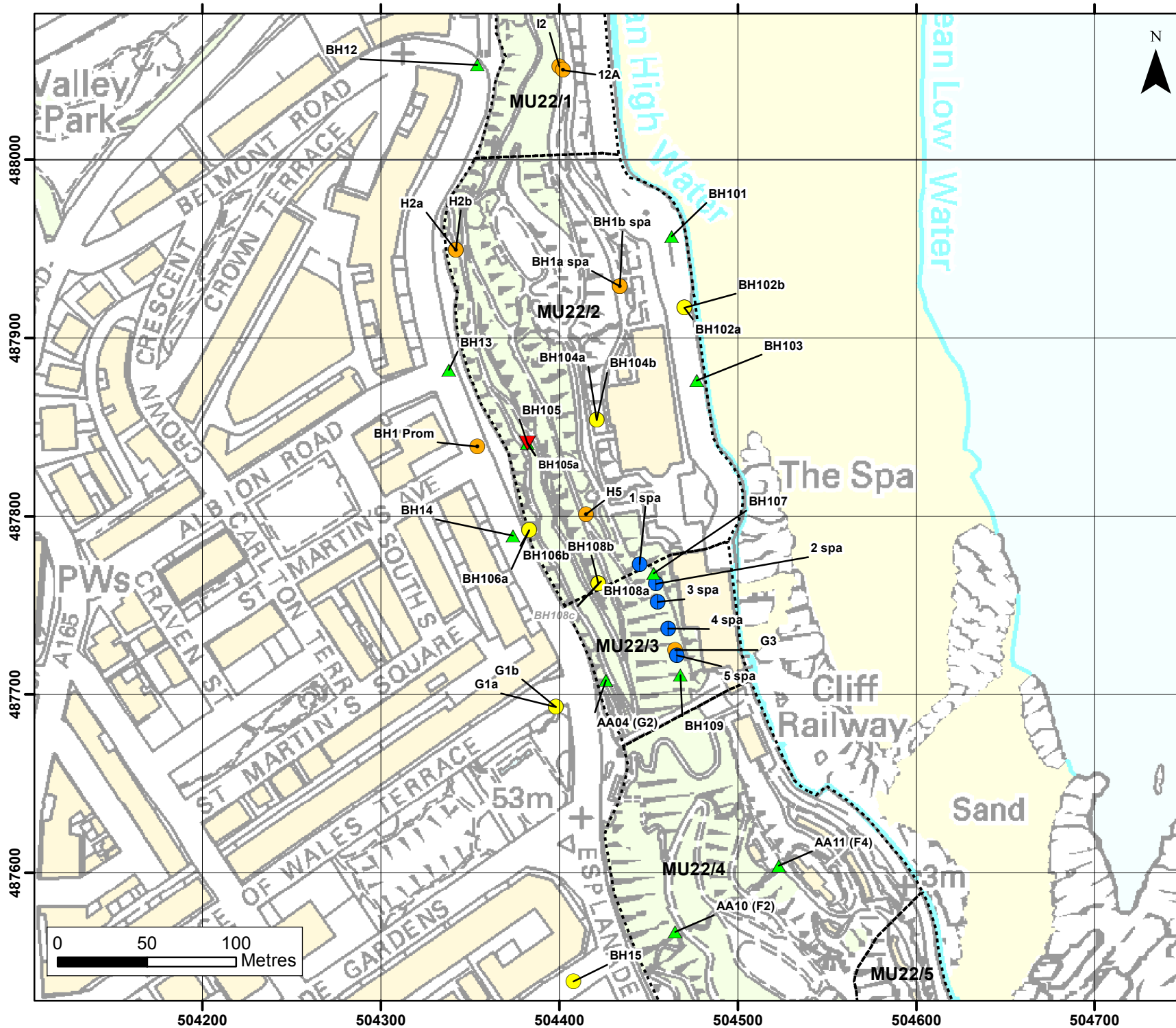
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Figure 9.1A Location of monitoring at Scarborough South Bay

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Legend

Active

- ▼ Acoustic inclinometer
- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)

Inactive

- △ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
- ⋯ Cliff behaviour unit

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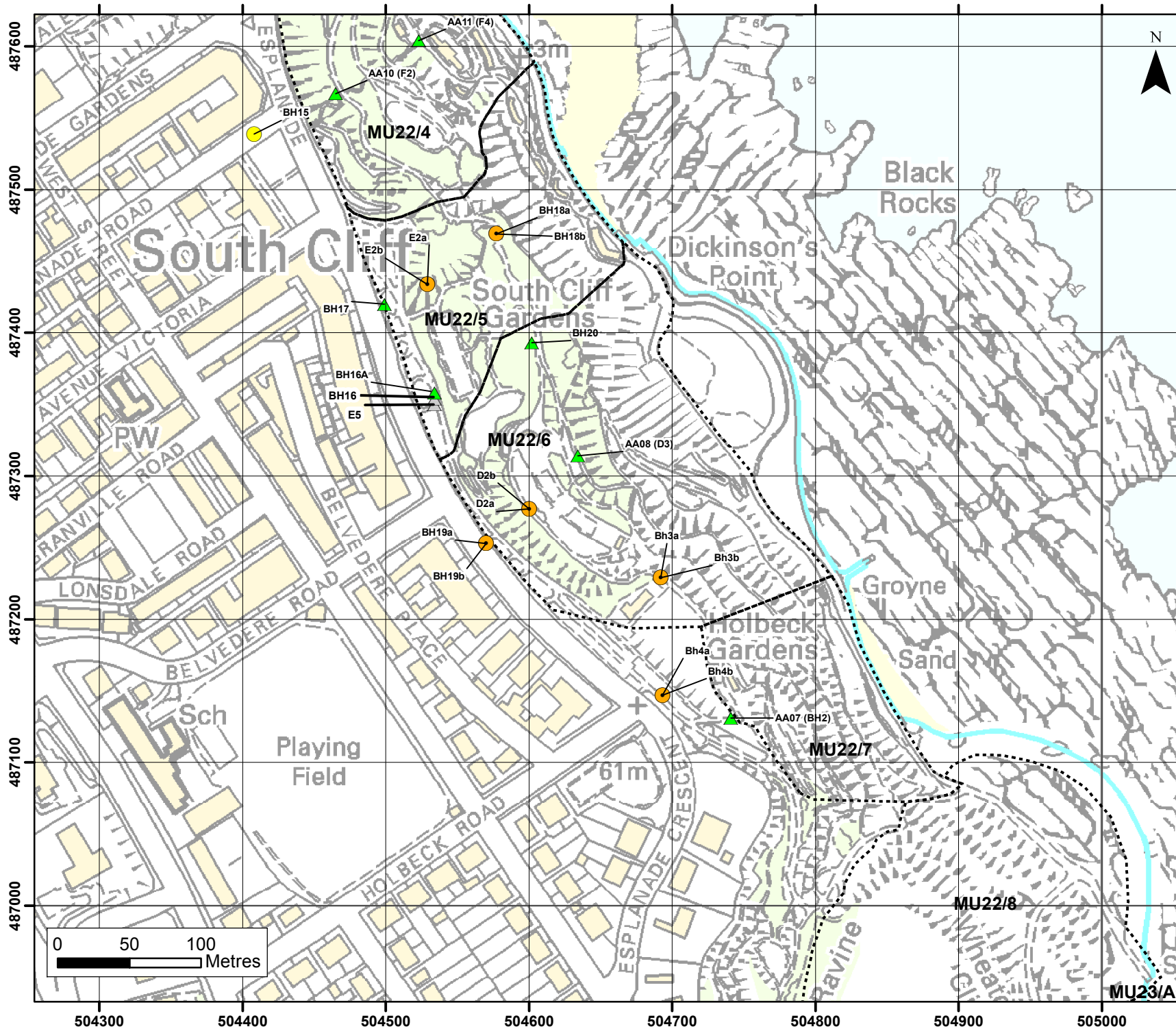
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Figure 9.1B Location of monitoring at Scarborough South Bay

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Legend

Active

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

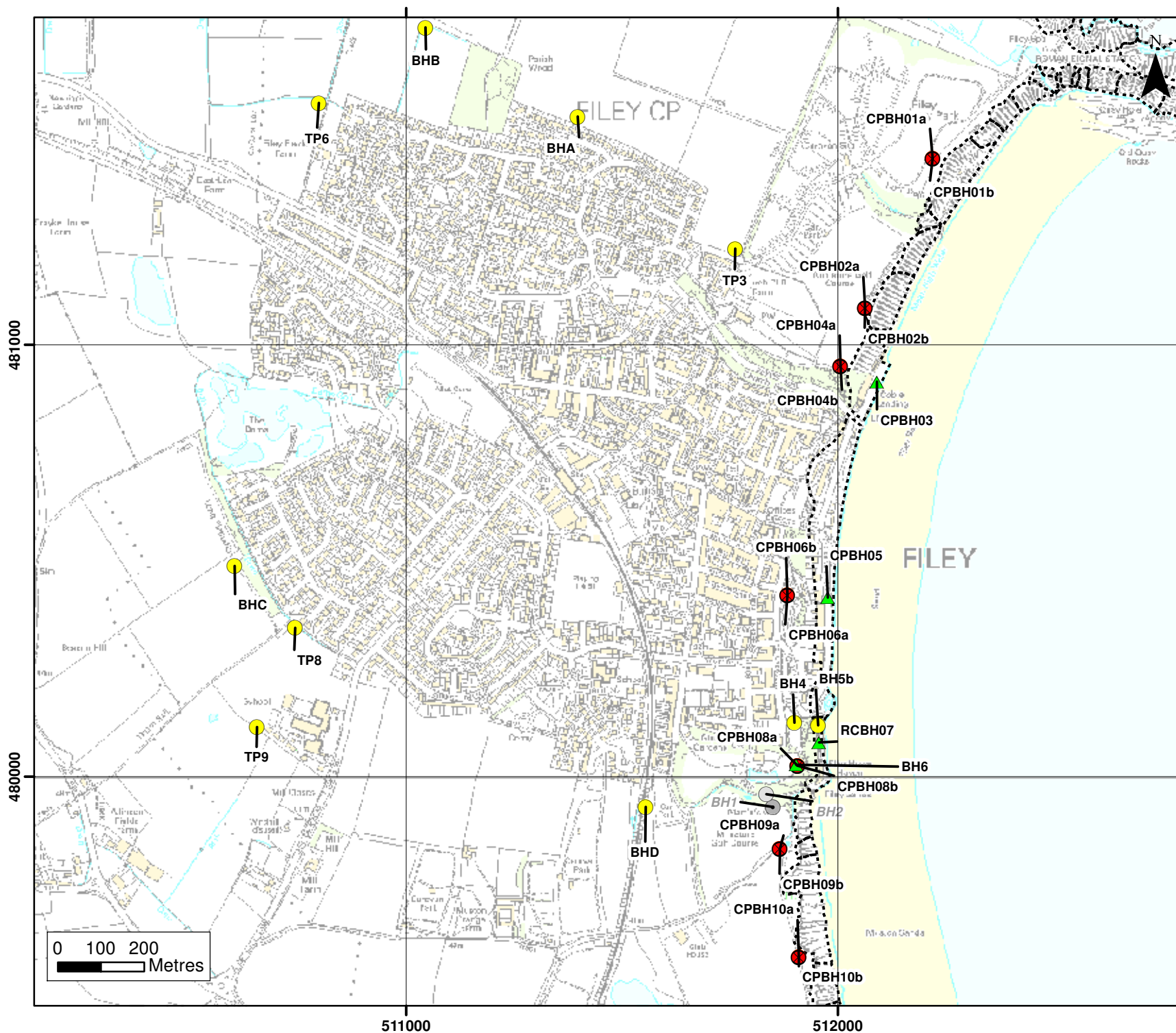
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- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
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Figure 9.1C Location of monitoring at Scarborough South Bay

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Active

- ▲ Inclinometer
- Monitoring well
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- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

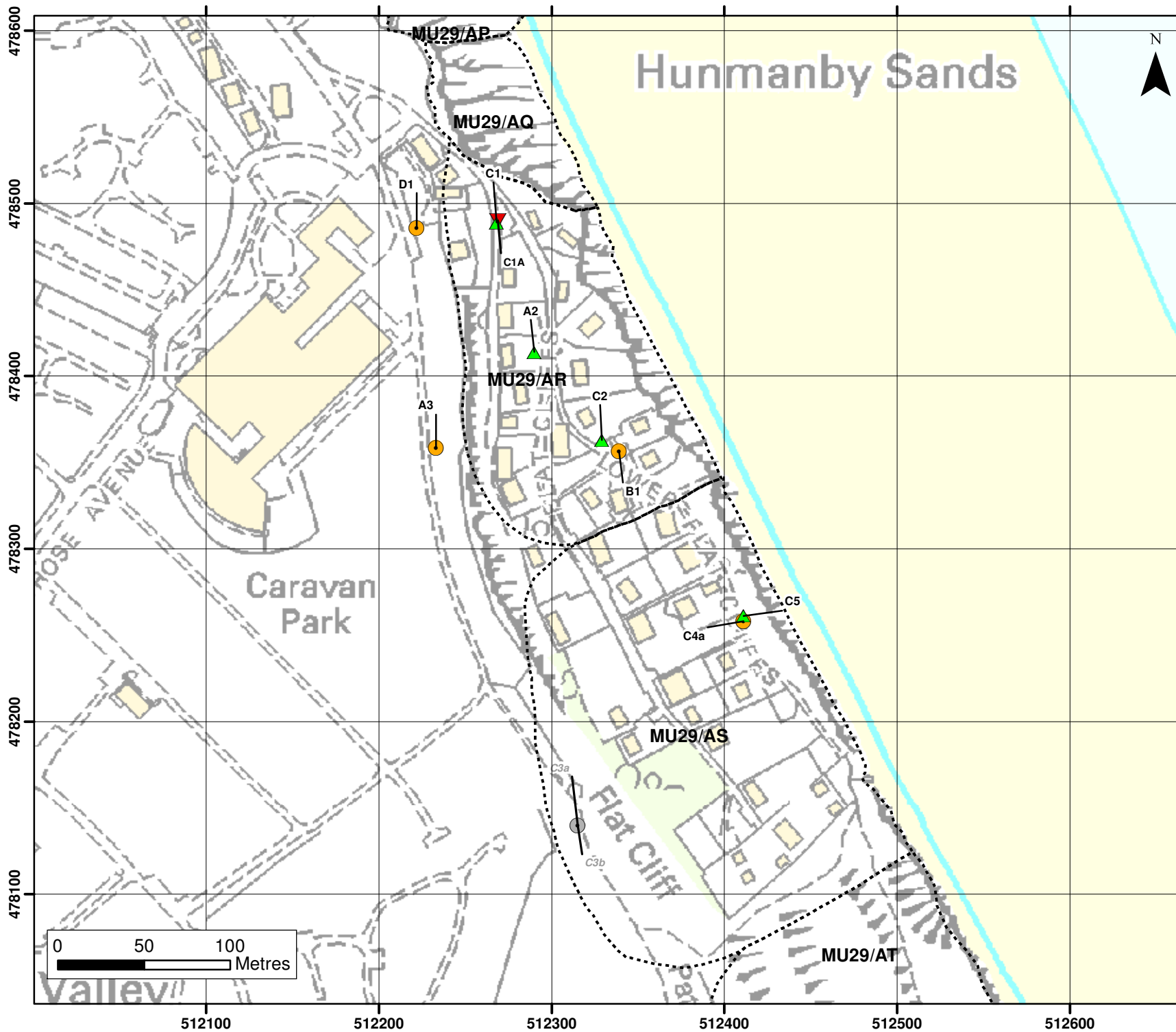
- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
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Figure 10.1. Location of slope monitoring at Filey

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Active

- ▼ Acoustic inclinometer
- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

- ▲ Inclinometer
- Monitoring well
- Piezometer (not automated)
- Piezometer (with data logger)
- ⊗ Piezometer (with diver)
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Figure 11.1 Location of slope monitoring at Filey Flat Cliffs

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