LOCAL COASTAL SLOPE MONITORING ANALYSIS

Interpretation Report 11: June 2018 to November 2018

Prepared for

Scarborough Borough Council

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JACOBS

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Disclaimer

Jacobs Engineering Group UK Ltd (previously CH2M) has prepared this report in accordance with the instructions of our client Scarborough Borough Council (SBC) for the client's sole and specific use. Any other persons who use any information contained herein do so at their own risk. This report is a review of coastal slope monitoring data collected by JBA Consulting Ltd on behalf of SBC. The objective of this report is to analyse and interpret the slope monitoring data from specific locations in order to highlight any change in cliff instability risk. Halcrow has used reasonable skill, care and diligence in the interpretation of data provided to them and accepts no responsibility for the content, quality or accuracy of the monitoring data, third party reports, or further information provided either to them by SBC or, via SBC from a third party source, for analysis under this term contract.

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 June and November 2018 along the Scarborough Borough Council frontage. It is the eleventh in a series of six-monthly updates on the cliff instability risk of the frontage that began in 2014. The weather during summer 2018 was drier than average, but the autumn was marginally wetter than average, particularly in September and October. Overall, the monitoring period was slightly drier than average.

Boreholes show that water levels have remained at previous low levels or decreased slightly during the monitoring period, except for Scalby Ness (WS6 and B9), Filey Town (CPBH01a, CPBH02a, CPBH09a and CPBH10a) and Filey Flat Cliffs (B1) that are at atypically high levels. In situ monitoring using inclinometers does not indicate any significant 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 continue to remain steady at a low level. Piezometer BH1b, installed deeper in the in the same borehole, was dry and its integrity should be checked.
- At Scalby Ness, groundwater levels have fallen at most of the boreholes, including Sn2a, Sn2b and WS4, which were close to the historical high in the previous monitoring period. Piezometers located mid-slope at WS6 and B9 show groundwater levels have risen or remained elevated, close to or just above the historical high. Surface creep and minor displacement has been recorded as nearby inclinometer BH07. These sites should continue to be visually monitored, particularly following sustained periods of heavy rainfall. Automated piezometers in boreholes P1a, P1b, P2a, P2b, P3, P4a and P4b all had data logger communication errors and were sent for repair and data retrieval. No data was available for these piezometers during this monitoring period. Borehole B6 was dry, suggesting the piezometer may be damaged. This location should continue to be monitored. No significant movement has been recorded by inclinometers
- At The Holms, there was a problem downloading data from piezometer BH9a. This issue should be investigated and remedied by the monitoring contractor during the next visit.
- At Scarborough Spa Chalet, no data has been recorded since May 2016 at piezometer BH12. This site requires attention to fix or replace the piezometer and damaged cable.
- At Scarborough Spa, groundwater levels have fallen or remained steady at all piezometers where data has been retrieved. Inclinometers AA04 and BH14 show shallow positive and negative movements that are considered to be error. These sites should be visually monitored, particularly following sustained wet weather. Several boreholes were dry (G1b, BH106a, BH106b), suggesting the piezometer installations may be damaged. These locations require attention and should continue to be monitored. The borehole containing piezometers BH102a and BH102b have been reinstated with piezometers, having previously been inadvertently covered with tarmac. No data were available for BH1 Prom, G3 and BH102a. The loggers should be checked and repaired if necessary. No data were collected from monitoring wells 1 Spa, 2 Spa, 5 Spa, piezometer BH108b and inclinometer BH107 which were inaccessible at the time of the site visit due to ongoing works at the Spa.
- At the Clock Café, borehole BH15 remains dry. The integrity of the piezometer should be checked.

- At South Cliff Gardens, in boreholes D2b and BH3a there was a problem downloading data. The issue should be investigated and remedied by the monitoring contractor next time. The contractor noted Japanese knotweed present at inclinometer D3, which should be investigated and managed appropriately.
- At Holbeck Gardens there was a problem downloading groundwater data at borehole BH4a and BH4b. The issue should be investigated and remedied ahead of the monitoring contractor next time.
- At Filey Town, in boreholes CPBH01a and CPBH02a groundwater levels remain near historical highs. At CPBH09a and CPBH010a groundwater levels have continued to rise toward historical highs. Given the drier than average conditions, this suggests a supply of water from damaged water pipework or runoff from cliff top developments. These locations should be visually checked and reviewed in the next monitoring period. Boreholes CPBH02b 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 piezometers CPBH01b, CPBH04b, CPBH06b, CPBH08b and CPBH09b. This issue should be investigated and remedied by the monitoring contractor during the next visit. Access to inclinometer CPBH03 was not possible. Inclinometer CPBH05 shows no movement but requires a replacement cap material clogging the borehole.
- At Filey Flat Cliffs there was a problem downloading data at boreholes C4a, A3 and D1. The issue should be investigated and remedied by the monitoring contractor next time. Groundwater data show levels have risen in borehole B1, however remain within the historical range. Minor movement in borehole A2 should be monitored and the checked in the next monitoring period.

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, which are installed adjacent to conventional inclinometers, 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 the Council and a contract for regular data collection and monitoring reports was awarded that operated to spring 2012 (Mouchel 2012). SBC then commissioned Haskoning UK Ltd to undertake a review of the condition of boreholes and associated monitoring instruments (Haskoning, 2013), which highlighted locations of damaged or worn equipment that needed repair. In addition to routine repairs and maintenance of equipment the Council has upgraded piezometers with automatic dataloggers to ensure the best possible data are collected.

SBC invited tenders for a new phase of slope monitoring 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. A two-year extension to the project was awarded to the incumbent team in March 2016. A second extension was awarded in February 2018 that provides for an additional five reports extending the work to the monitoring period June to November 2020. Over this time, CH2M was purchased by Jacobs.

This report provides the eleventh set of data analysis and is presented as a stand-alone document to previous reports.

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 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			
Whitby West Cliff	1			
Robin Hood's Bay	2		4	
Scalby Ness	4		14	
Scarborough North Bay – Oasis Café	2		3	
Scarborough North Bay – The Holmes	2		5**	
Scarborough South Bay	17*	1	38*	1^
Filey Town	4		16†	
Filey, Flat Cliffs	4	1	4	1^^
TOTAL	40	2	93	2

*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.
** a single automated piezometer has been removed since this monitoring period
† Eight of these boreholes are inland of the coast and have a focus on flood risk. They are no longer included in the coastal instability monitoring programme.
^The Scarborough South Bay (Spa) weather station is being upgraded and there is a temporary rain gauge in place for this monitoring period.
^^the Filey, Flay Cliffs met station has not functioned reliably since 2016 and has recently been replaced with a permanent rain gauge. Rainfall data only partially covers this monitoring period.

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.

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 Jacobs (previously 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.

Table 1.2. Programme of data collection and reporting

JBA Monitoring Period	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: August 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 (CH2M 2016c)
Data set 7: June 2016 to November 2016	Report 7: January 2017 (CH2M 2017a)
Data set 8: December 2016 to May 2017	Report 8: October 2017 (CH2M 2017b)
Data set 9: June 2017 to November 2017	Report 9: February 2018 (CH2M 2018a)
Data set 10: December 2017 to May 2018	Report 10: August 2018 (CH2M 2018b)
Data set 11: June 2018 to November 2018	Report 11: February 2019 (this report)
Data set 12: December 2018 to May 2019	Report 12: August 2019
Data set 13: June 2019 to November 2019	Report 13: February 2020
Data set 14: December 2019 to May 2020	Report 14: August 2020
Data set 15: June 2020 to November 2020	Report 15: February 2021

The scope of 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 from 2016, and it has since been replaced with a permanent rain gauge collecting data since October 2018. Meteorological data from Scarborough Spa has been used from 2016, however in January 2018 the weather station became non-functional and it is currently being upgraded. A temporary rain gauge is in place for this monitoring period.
- 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

The project has a near-complete record of meteorological data from 2011 to the present day, allowing the response of groundwater to rainfall to be determined. Equipment upgrades and periodic outages mean that the sources of data have varied over this time.

A meteorological station that records wind speed and direction, air temperature, humidity, air pressure, rainfall and rainfall intensity every 15 minutes was in place at Flat Cliffs, central Filey Bay, between 29 September 2011 and March 2016. The device was inoperative from September 2014 to July 2015 and therefore supplemental MetOffice rainfall data were acquired from recording station Filey No 2 (54.20395, -0.30127), c. 3km north-northwest of Flat Cliffs. The Flat Cliffs weather station again failed in the period March to May 2016, however at this time a new weather station at Scarborough Spa had become operational and data from that site have been used from 11 January 2016 to present. The Scarborough Spa weather station became non-functional during January 2018, and rainfall data were acquired by the Met Office weather station at Scarborough to fill the gap. The weather station at Scarborough Spa is currently being upgraded and a temporary rain gauge is in place for this monitoring period. A permanent rain gauge was installed at Filey Flat Cliffs and has been collecting data since October 2018.

Data from all sources are summarised in Table 2.1 and Figure 2.1. The records for the last six months show that summer 2018 was drier when compared to past records but that autumn 2018 was marginally wetter on average, with September close to the long-term mean (upper range).

Daily rainfall totals recorded by the Scarborough Spa weather station are presented in Figure 2.2, which shows peaks on 27 July, 2 and 20 September and 14 October. The 20 September event was exceptional and a daily peak rainfall total of 43 mm was recorded. This event was Storm Bronagh, where an intense low-pressure system resulted in heavy rainfall and strong winds over Yorkshire on that day.

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 2018 was March, with 98.4 mm. This reflects the impact of the heavy rainfall event on 12 March.

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. The winter of 2016/17 and spring 2017 have been the driest on record. The summer of 2017 was relatively wetter than previous years, receiving 183mm of rainfall, whereas slightly drier conditions occurred through autumn 2017 and into the winter of 2017/2018. The spring of 2018 has been the wettest during this season on record, receiving a total of 195mm rainfall. However, the summer was especially dry. Autumn 2018 was relatively wet compared to past years.

Wind speed and air temperature records are presented in Figures 2.4 and 2.5. In both cases, the failure of the Scarborough Spa met station means there are no data for the current monitoring period.

Table 2.1. Monthly rainfall (mm) recorded at Flat Cliffs or Scarborough Spa met station

Month	Long-term mean (upper range)	2011	2012	2013	2014	2015	2016	2017	2018
January	80	No Data	31	41	113 (84.2)	No Data (13.4)	84 [part month]	14.5	22.8
February	60	No Data	8	38	96 (71.2)	No Data (44.8)	20.7	21.1	39.6
March	60	No Data	27	32	29 (40.4)	No Data (22.2)	53.9 [part month]	22.7	98.4
April	60	No Data	96	4	26 (33)	No Data (15.8)	43.4	17.8	73.2
May	60	No Data	34	37 [part month]	59 (50.8)	No Data (81.4)	15	22.4	23.6
June	80	No Data	104	No Data	34 (61)	No Data (41.2)	23	67.5	14.6
July	60	No Data	70	No Data	70 (93.2)	20	14.9	37.9	42.4
August	80	No Data	45	38 [part month]	No data (108.2)	17	69.7	78.7	17.2
September	80	0.14 (part month)	69	15	No data (17)	46	13.8	46.1	74
October	80	35	53	52	No Data (58)	29	15.4	22.9	62.4
November	80	15	78	25	No Data (70)	77.3	50.9	64.6	1.8 [part month]
December	80	72	132	6	No Data (27.2)	76.9	6.4	2.5	

Note: Data in brackets are from Filey No 2 station. Data from January 2016 to January 2018 are from Scarborough Spa. Data between January 2018 to May 2018 were provided by the Met Office Scarborough rainfall gauge. Data from June 2018 onwards are from the temporary rain gauge at Scarborough Spa.

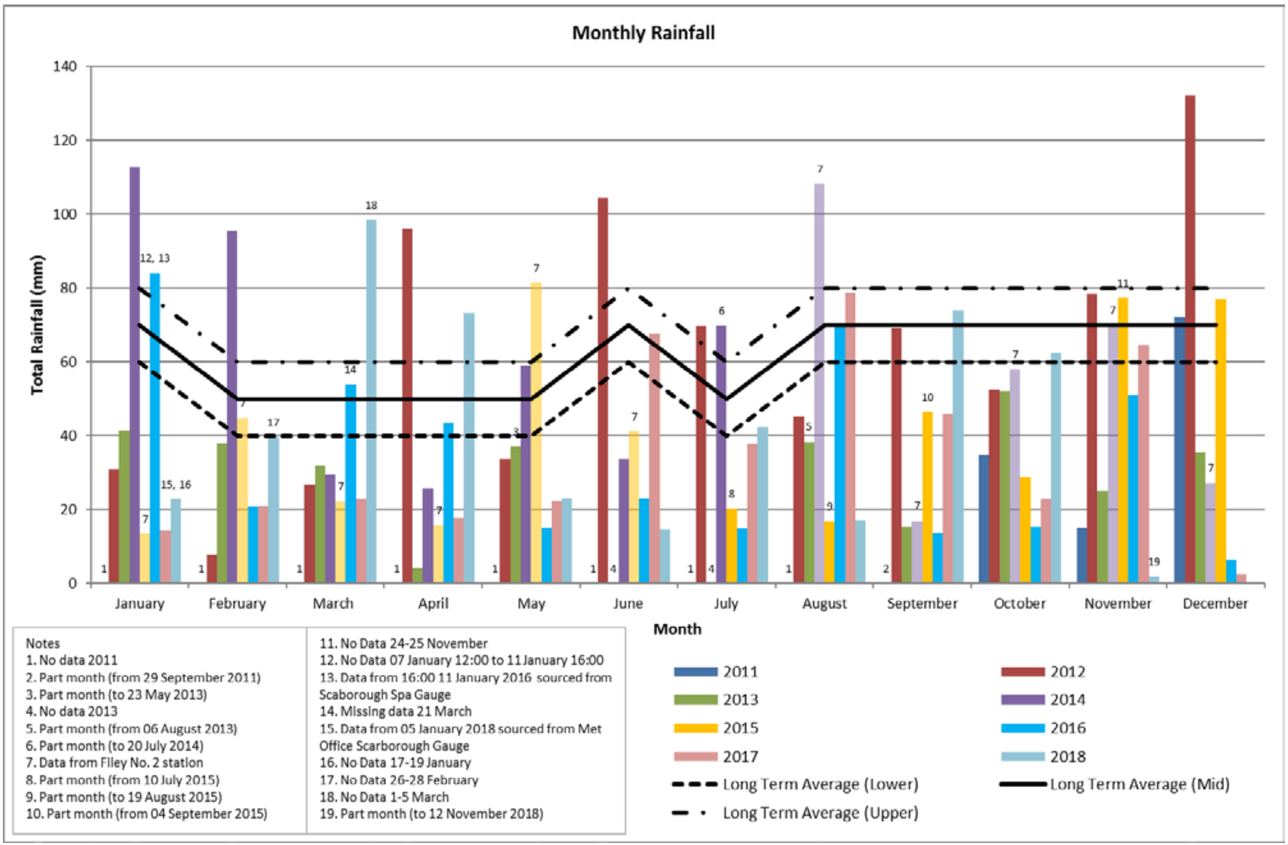

Figure 2.1 Comparison of monthly rainfall records (2011 to 2018).

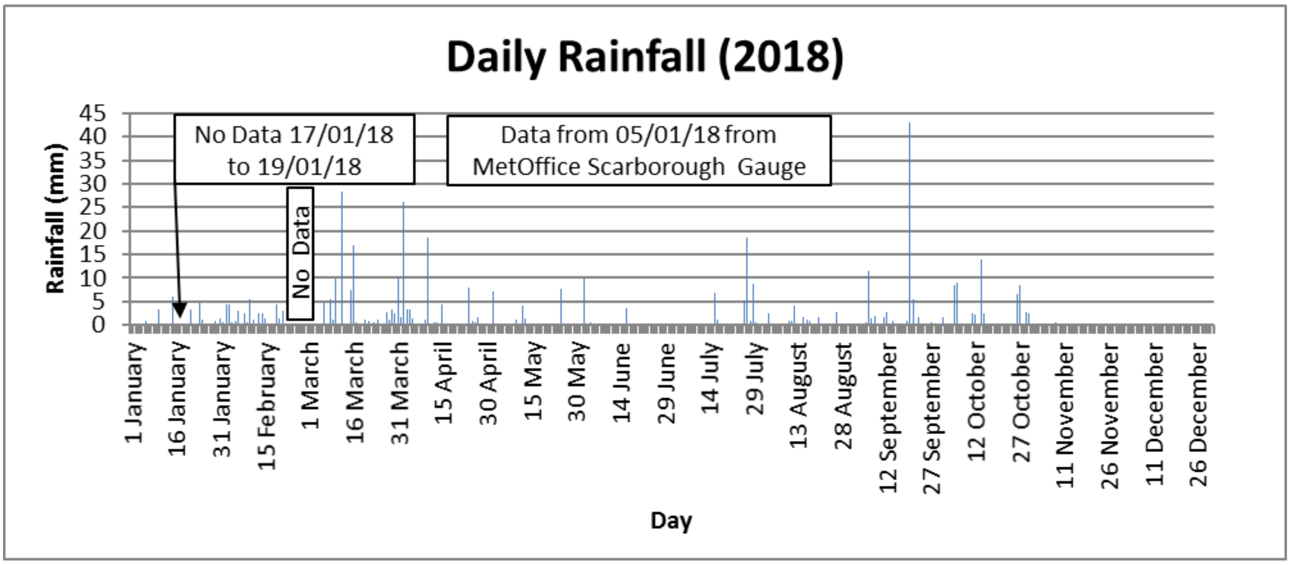

Figure 2.2 Daily rainfall recorded at Scarborough Spa during 2018.

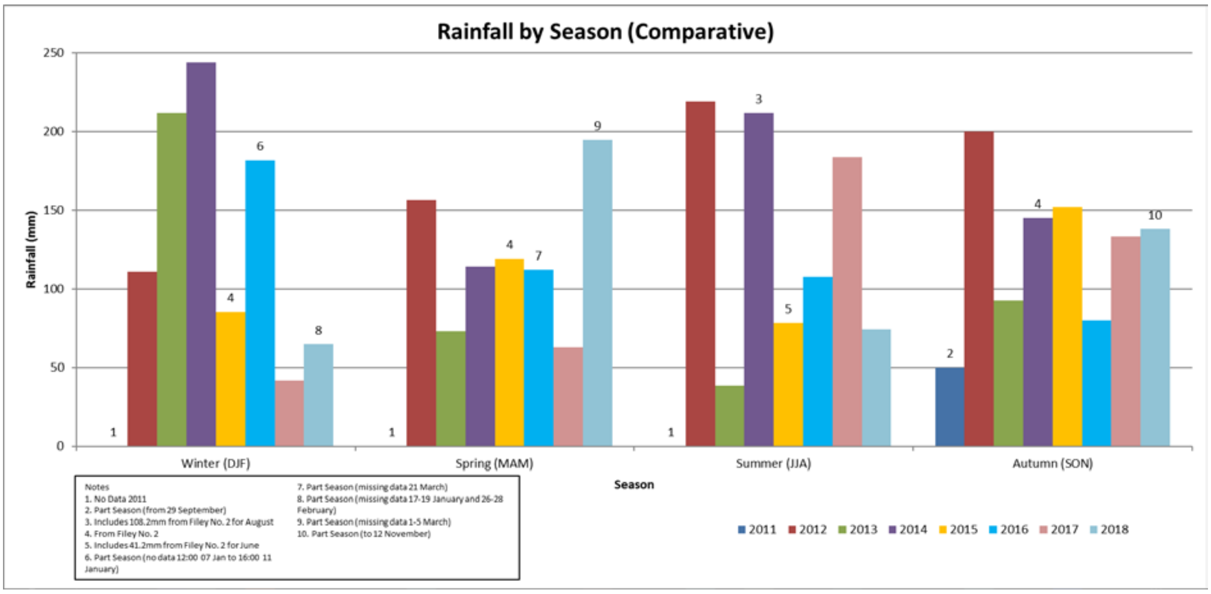

Figure 2.3 Seasonal rainfall comparison (2011-2018)

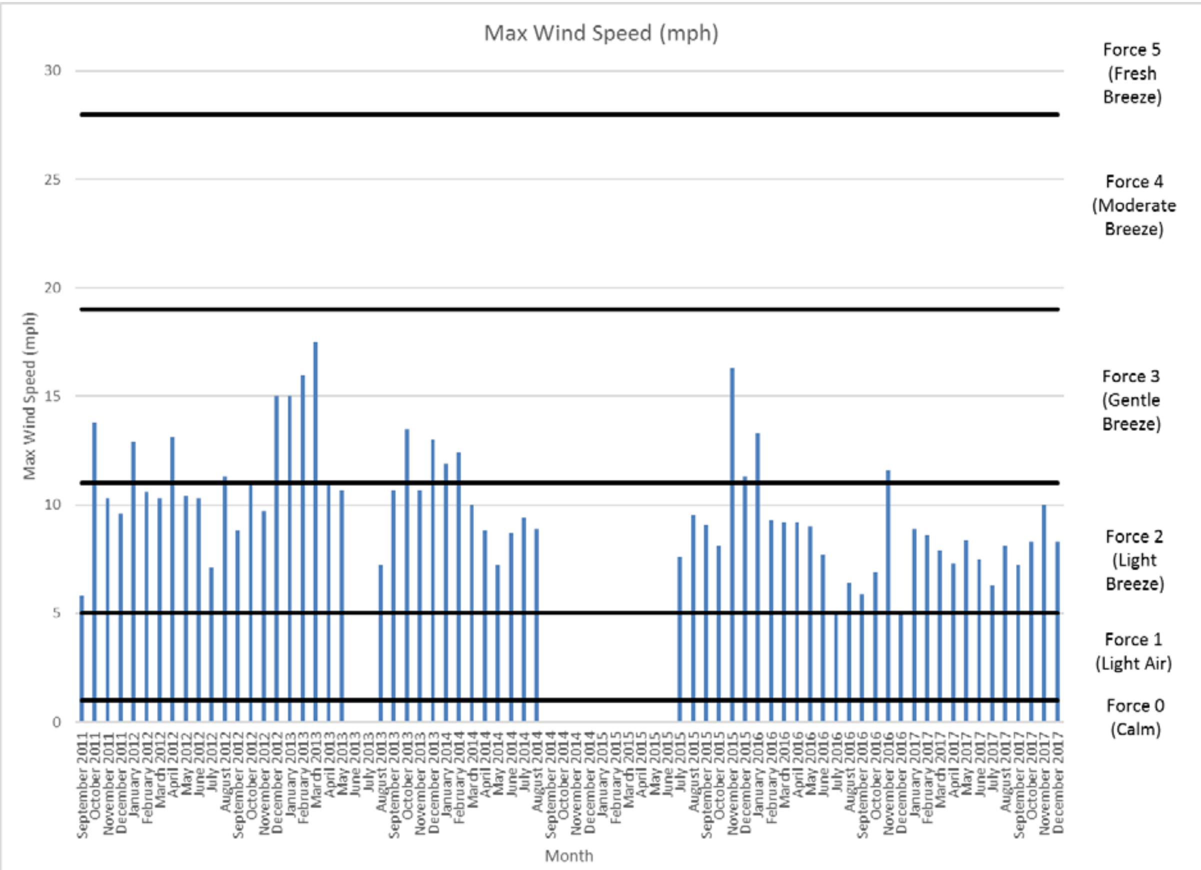

Figure 2.4 Maximum daily wind speed (2011 to 2017). Note there are no data for the current monitoring period.

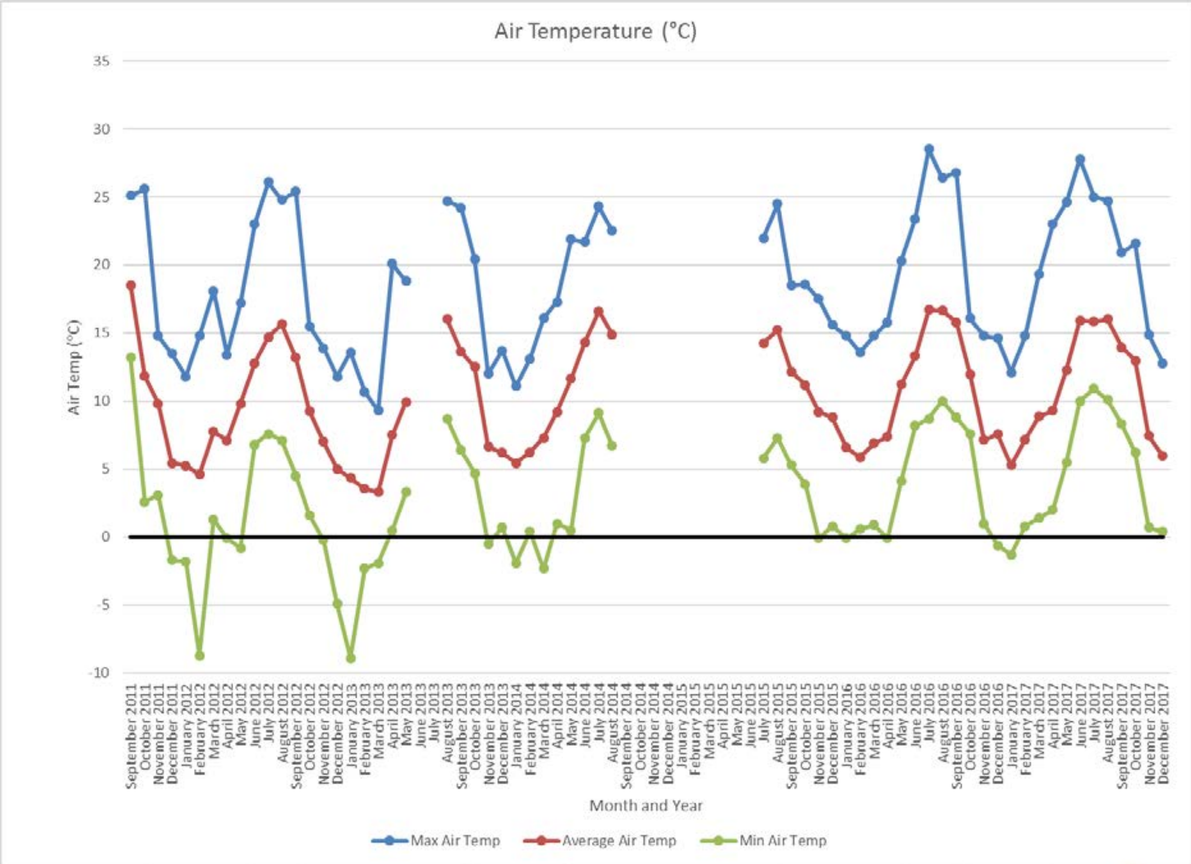

Figure 2.5 Air temperature variation (2011 to 2017). Note there are no data for the current monitoring period.

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. ‘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. Similarly, at Filey Flat Cliffs accelerated slope movement occurred following high antecedent rainfall levels in winter 2012/13. The inclinometer monitoring interval 17 January 2013 to 22 March 2013 showed c. 13 mm of resultant incremental shear surface deformation. Acoustic emission monitoring collected since 2011 was used to increase the temporal resolution of the inclinometer deformation information through conversion of measured acoustic emission rates to cumulative displacement (Smith et al., 2017). It showed a period of increased AE rates at the end of January 2013 which was interpreted to as the initiation of landslide movement. Periodic surges of accelerated slope movement were also identified at the end of February and middle of March 2013. Antecedent rainfall over the weeks and months prior caused the build-up of porewater pressures, which triggered the movement. The absence of movements elsewhere on the coast at that time suggests that the antecedent rainfall threshold levels are above this at other locations.

Antecedent rainfall over the current June-November monitoring period show peaks that are lower than that seen in December 2012, however a rapidly decreasing trend in antecedent rainfall over the monitoring period is evident, unlike the pattern to the previous June to November monitoring period which shows antecedent rainfall rises after June. Instead, antecedent rainfall increases in September. Antecedent rainfall totals do not reach those seen in December 2012 and it is therefore concluded there is a low likelihood of rainfall-induced landslides occurring in the monitoring period. However, the antecedent rainfall levels at the end of this monitoring period are increasing, which means if the winter of 2018/19 is wet, there may be an increased likelihood of ground movement in the next monitoring period.

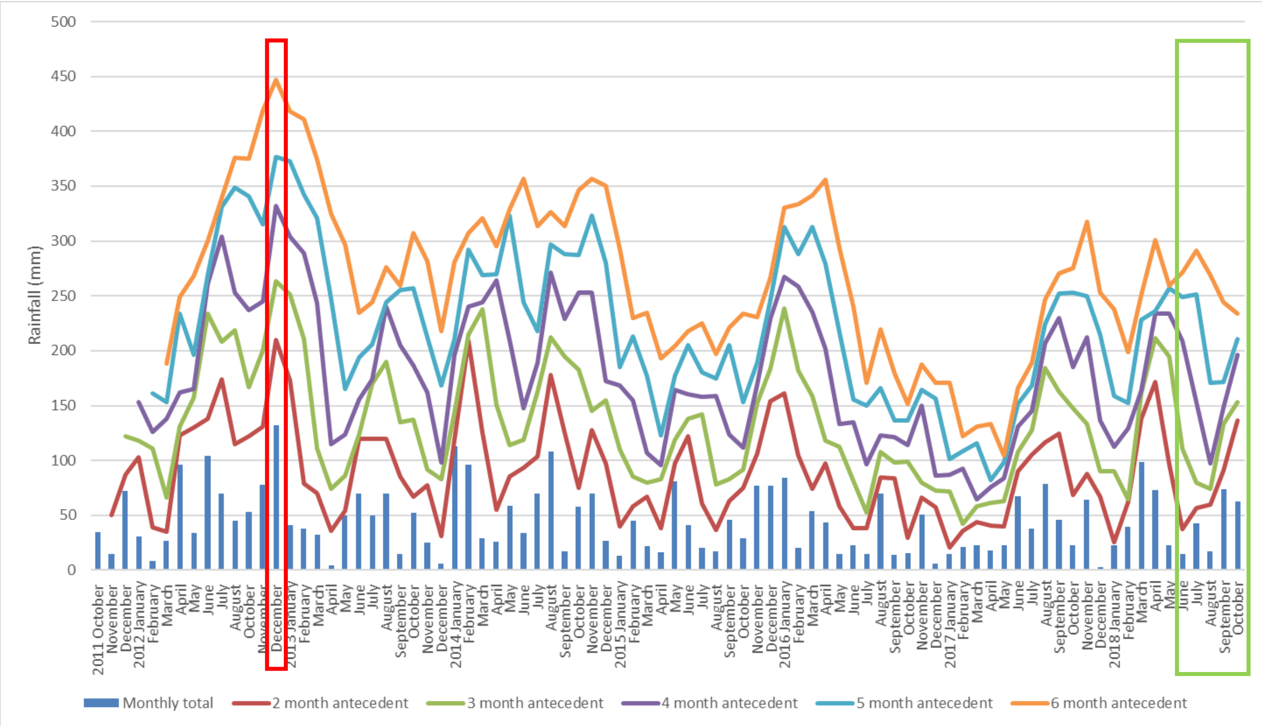

Figure 2.6. Monthly rainfall and two to six month antecedent totals (2011 to 2018). Ground movements were recorded at Scalby Mills during December 2012 (red box). Current monitoring period shown by green box.

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. This resulted in ground movement at Scalby Mills.
- 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.
- Between June and November 2016, rainfall has been lower than average apart from August where significant rainfall occurred on 4 and 25 August. Conditions over the 6-month period have been relatively dry and mild. Overall, data shows the 6-month period to have been relatively dry, with mild weather conditions suggesting a low likelihood of rainfall-induced landslides occurring.
- Summer 2017 has been wetter than the previous two summers, with rainfall above average during June. High daily rainfall totals were experienced 23 August, when an exceptional storm occurred. Overall, autumn 2017 experienced average conditions, whereby in November antecedent rainfall peaked.
- Winter 2017/18 has been drier than average, however spring experienced above average rainfall particularly during March and April where several heavy rainfall events occurred. Antecedent rainfall has risen early in spring compared to previous years.
- Summer 2018 has been drier than average, and antecedent rainfall declined rapidly in response. However, Autumn has been wetter than average, particularly during September. Exceptionally high daily rainfall totals were experience on 20 September when Storm Bronagh passed over the region. Antecedent rainfall increased to typical levels in Autumn.

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 Kettleness 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). A scheme to implement the recommendations of the strategy study was completed in summer 2018.

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 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 in the current phase of work as it was recognised that the data were of limited value to slope stability assessments and could be 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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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 been 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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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.	Negligible displacement of 1.2 mm downslope at 18.5 m depth in glacial till. Readings are potentially erroneous and are to be checked in the next monitoring period.

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 2018 is summarised in Tables 5.2 and 5.3.

Inclinometer data shows no significant movements recorded at boreholes BH2 and BH4.

The piezometer data show groundwater levels have remained relatively steady over the monitoring period. Bh1a, which is a shallow piezometer, was dry during this monitoring period and should be checked as equipment may be damaged and requires attention to determine whether it can be repaired. This borehole had shown steady groundwater levels near the historical low after mistakenly being covered with tarmac during an earlier monitoring period (CH2M, 2016c). Meanwhile, deeper piezometer BH1b shows steady groundwater levels during this monitoring period, having been dry in the previous two monitoring periods. Readings for piezometer BH3a and BH3b shows groundwater levels have decreased and increased slightly, respectively, with BH3a near the historical low.

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

Borehole	Summary of past data	Report status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
BH2	The borehole is 41m deep but inclinometer records are only provided for the upper 22m. Ground level is c. 55.1m OD. The recorded pattern of movement is hard to explain and is likely to represent accumulated error.										Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.
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.										Incremental movements less than 1mm during the monitoring period, which is insignificant.	Incremental movements less than 1mm during the monitoring period, which is insignificant.

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 December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH1a	Ground level is 51.6m OD, the piezometer tip is targeting a shallower horizon. Water-levels have remained reasonably constant at c. 30m OD since installation.	22.7m OD 39.7m OD 17m										Borehole dry. **Check piezometer integrity.**	Groundwater level has fallen slightly to 29.2 m OD.
BH1b	Ground level is 51.6m OD, the piezometer tip is targeting a deeper horizon. Water levels in this elevation have been less variable, having remained at around 37.6m OD.	37.6m OD 39.9m OD 2.3m										Groundwater level remains steady at 38.8 m OD.	Groundwater level remains steady at 38.8 m OD.

Borehole	Summary of past data	Groundwater summary Min/Max/ Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH3a	Ground level is 60.4m OD. Piezometer targeting a shallower horizon. Water level between 44.3m and 44.8m OD between March 2010 and May 2012.	44.5m OD 56.1m OD 11.6m										Groundwater levels fall slightly to 45.4 m OD, close to the historical low.	Groundwater levels rise to 47.5 m OD, however remain well within historical range.
BH3b	Ground level is 60.4m OD. Piezometer targeting a deeper horizon. Water levels fluctuated by < 2m about a mean of c. 56m OD. Low levels occurred in May 2010 and highs in July 2010 and Nov 2011.	47.5m OD 56.7m OD 1.4m										Groundwater levels increase slightly to 56.3 m OD.	Borehole dry. **Check piezometer integrity.**

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 had fallen significantly in 2017 to their lowest since 2012, which may reflect the exceptionally dry conditions during winter 2016/17 and spring. 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. There is no clear response in the groundwater levels to wetter than average conditions during spring and autumn 2018.

5.6 Implications and recommendations

The groundwater data indicates a continuation of past patterns at Robin Hood’s Bay. BH1a and BH1b show groundwater level has remained steady at levels observed before the tarmac covering. BH3a indicates groundwater levels are low and increasingly slightly. These locations should be checked, and the next monitoring data reviewed, whether this trend continues. Borehole BH3b was dry should be checked 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.	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. 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.

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

Borehole	Summary of past data	Report status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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 less than 1 mm during the monitoring period, which is insignificant.	Displacements up to 2.7 mm recorded at 28 m to 30 m BGL in positive and negative directions on both A and B axes at contact between till and mudstone represent error and possible blockage near the base of the borehole.
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 less than 1 mm during the monitoring period, which is insignificant.	Incremental movements less than 1 mm during the monitoring period, which is insignificant. Minor upslope displacement of 2 mm is recorded at 21 m BGL and likely represents error.
L3(C004)	Borehole is ca. 17m deep, surface is 13.4m OD and borehole extends to c. -3.6m OD through 8.5m of glacial										No significant movement since last reading, Minor displacement that extends to ca. 2m	Incremental movements less than 1 mm during the monitoring period, which is insignificant.

	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.									BGL in clay is likely to be relatively shallow surface creep.	
BH07	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 in the downslope direction of 3 to 4 mm are evident at a depth of 3 m below ground level. This movement in the sand is associated with shallow surface creep. Minor upslope displacement of up to 2 mm is recorded at 6 to 8 m depth, and likely represents error. No further movement along shear surface at c. 11 to 12 m depth.	Incremental movement in the downslope direction of 3 mm evident in the upper 2m below ground level. This movement is associated with shallow surface creep in sandy and gravelly clay. **The trend will be reviewed in the next monitoring period.**

*Surface elevations and borehole depths calculated from digital elevation model

Table 6.3. Summary of groundwater data at Scalby Ness.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
P1a	Automated piezometer. Tip at appox.25.65m OD*. Surface elevation at c. 35.6m OD* (cliff top above CBU 1, co-located with P1b). Fluctuates between 27.5 and 28.5m OD, with rapidly rising and falling peaks linked to higher rainfall and subsequent dry periods.	27.1m OD 28.9m OD 1.8m										**No data available.** Data logger communication error. Logger removed and sent for repair. Data retrieval show no new data since October 2015.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**
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										**No data available for monitoring period.** Data logger communication error. Logger removed and sent for repair. Data retrieval for previous monitoring periods between October 2015 and July 2016 show groundwater level remained steady at 18.4 m OD.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**
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	27.3m OD 28.7m OD 1.4m										**No data available.** Data logger communication error. Logger removed and sent for repair.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**

	the Filey rainfall record.												
P2b	Automated piezometer. Tip at c. -0.6m OD*. Surface elevation at c. 34.7m OD* (co-located with P2a). Prior to Oct 2009, gound 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 2.6m										**No data available.** Data logger communication error. Logger removed and sent for repair.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**
P3	Automated piezometer. Tip at c. 10.5m OD*. Surface elevation at c. 30.7m OD. Steady at around 14.6-14.7m OD until Oct 200. Apparent recalibration between Oct 2009 and Mar 2010 after which groundwater levels are again steady at	14.2m OD 17.5m OD 3.3m										**No data available for monitoring period.** Data logger communication error. Logger removed and sent for repair. Data retrieval for previous monitoring periods between October 2016 and November 2016 show groundwater levels remained steady at about 17.3 m OD, peaking at 17.4 m OD.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**

	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 occur 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.	12.7m OD 15.1m OD 1.4m										**Logger removed and sent for repair.** Data retrieval for previous monitoring periods between May 2017 and November 2017 show groundwater levels remained steady at about 13.3 m OD until November where levels had risen to 13.7 m OD. During the current monitoring period, levels have continued to rise to ~14.6 m OD until mid-April, peaking on 18 and 20 March at 14.8 m OD. The pattern closely follows the lower piezometer at P4b.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**

P4b	Automated Piezometer. Tip at c. 6.35m OD*. Surface elevation at c. 18.6m OD (co-located with P4a). Fluctuating pattern btween 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	12.4m OD 14.8m OD 1.4m										**Logger removed and sent for repair.** Data retrieval for previous monitoring periods between May 2017 and November 2017 show groundwater levels remained steady at about 12.7 m OD until November where levels had risen to 13.6 m OD. During the current monitoring period, levels have continued to rise to ~14.3 m OD until mid-April, peaking on 18 March at 14.5 m OD. Levels fall by May to 13.6 m OD. The pattern closely follows the upper piezometer at P4a, slightly delayed peaks by hours.	**No data available.** Data logger communication error. **SBC to arrange for repair of equipment**
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										Groundwater levels increased by 2 m to 14.2 m OD.	Groundwater levels fell to 12.2 m OD.
WS5	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	6.5m OD 9.7m OD 3.2m										Borehole no longer functioning.	Borehole no longer functioning.

	autumn, high in winter).												
WS6	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.	10.0m OD 14.3m OD 4.3m										Groundwater levels increase to 13.7 m OD, close to historical high.	Groundwater levels remain elevated at 13.7 m OD.
B6	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).	9.9m OD 13.8m OD 3.8m										Borehole dry. Slumping of surrounding ground resulting in shortening of borehole depth. **Check piezometer integrity.** **SBC to investigate slumping ground around borehole.**	Borehole dry. **Check piezometer integrity.**

B9	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 May 2008 (13.4m OD).	9.8m OD 16.7m OD 6.9m											Following a fall in groundwater levels in the previous monitoring period to 14.5 m OD, groundwater increased to 15.2 m OD, still well below historical high.	Groundwater levels increase to 15.8 m OD, but remain below historical high.
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;groundwater elevations not possible for tip depth stated.	12.5m OD 13.7m OD 0.8m											Groundwater level increase to historical high of 13.7 m OD.	Groundwater level decreases to 12.5 m OD.
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 12.8m OD 2.5m											Groundwater increase to 12.2 m OD.	Groundwater level decreases to 10.7 m OD.

*Indicates approx. tip and surface elevations calculated from elevation from digital elevation model and known tip depth, rather than topographic survey

The new data indicate:

- No significant ground movements recorded in any of the inclinometers. Potentially erroneous readings in borehole L1 and L2 were recorded, indicating minor displacement in both downslope and upslope directions. The integrity of the inclinometer should be checked. Surface creep occurs mid-slope in glacial sediments at boreholes BH7 and there appears to be minor movement in sand at 11 to 12 m depth. The trend should be reviewed in the next monitoring period.

- Auto-piezometers in boreholes P1a, P1b, P2a, P2b, P3, P4a and P4b all had data logger communication errors. No data was available during this monitoring period.
- Piezometer data from B9 shows groundwater levels are increasing again following a significant fall in the past two monitoring periods. However, the groundwater level remains well below historical high.
- Groundwater levels have fallen in all other boreholes, except for midslope piezometer WS6 in which groundwater levels have remained elevated.
- Piezometer in boreholes B6 was dry and its integrity requires checking on next site visit.

6.5 Causal-response relationships

The majority of shallow piezometers at Scalby Ness closely reflect the pattern of rainfall. Following a dry start to 2012, the spring and summer were exceptionally wet and the latter half of 2012 was wet. Peaks in groundwater were recorded during April, May July and December 2012. Overall, 2013, 2014, 2015 were drier than average. Piezometers installed with data loggers recorded falling 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 2017, 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 followed and have either fallen or remained steady from May 2016 to November 2017, which includes a period of above average rainfall for summer 2017. Above average rainfall during spring 2018 is reflected by a rise in groundwater levels at all functioning boreholes at Scalby Ness, close to or beyond the historical highs. During this monitoring period, groundwater levels have fallen across most functioning boreholes during the relatively drier conditions in summer 2018.

Deeper piezometers have a longer lag between rainfall and groundwater response. Those with data loggers show a much more muted response.

The inclinometers in BH7 and L2 show significant periodic 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 precise 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, and spring 2018 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 decreased overall in the area, following sustained low rainfall totals over summer and autumn. Only piezometers located mid-slope at B9 and WS6 show groundwater levels have risen or remained elevated. This rise in groundwater level suggests a discharge from cliff top developments or a natural response to the localised movement at the slope toe, though no significant movements were recorded in adjacent inclinometers. However, inclinometer BH7 indicates surface creep mid-slope. It is recommended this trend in groundwater levels is monitored and reviewed in the next monitoring report, together with inclinometer readings.

In addition, auto-piezometers in boreholes P1a, P1b, P2a, P2b, P3, P4a and P4b all had data logger communication errors. The cable should be fixed by Cambertronics and the logger set up. Readings should be collected and reviewed on the next site visit. Piezometer in borehole B6 was dry and its integrity requires checking on 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 show a continuation or slight decrease, reflecting below average rainfall conditions in summer. Sub-weekly fluctuations are atypical during drier months and may reflect local sources of groundwater from cliff top properties. Peak in groundwater typically occur in July and September.

Table 7.2. Summary of inclinometer data at Oasis Café

Borehole	Summary of past data	Report status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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 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 into 2017. On 23 August 2017 extremely heavy rainfall occurred, coinciding with a spike in groundwater levels at borehole BH2p, however this occurs only once in the record during high rainfall events. For example, the response of groundwater level in this borehole to the extreme rainfall on 20 September 2018 was indistinguishable. Borehole BH2p has an unclear response to rainfall and/or tides. Shallow piezometer BH3p shows 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 and 27 August 2016, 12 March, 2 April, 27 July and 20 September 2018). Although a peak in groundwater in response to the 23 August 2017 rainfall event is evident, it is muted when compared to other high rainfall events. This piezometer showed a very clear response to the rainfall on 20 September 2018. 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.

Table 7.3. Summary of groundwater data at Oasis Café

Borehole	Summary of past data	Groundwater summary Min/Max/Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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 fluctuating weekly around an average of 8.2m OD, and increasing steadily to 8.3m OD from March onwards. Groundwater level spikes on 5 Jan, 2 & 26 Feb, 21 March close to 8.5 m OD. This is not coincident with heavy rainfall events and may represent ingress of water into the piezometer.	Continuation of past pattern fluctuating weekly around an average of 8.3 m OD, increasing to 8.4 m OD by July and falling again to 8.3 m OD by October. Groundwater levels fell briefly to 8 m DD on 21 September following extreme rainfall on the 21 September.
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										Groundwater levels rise slightly to an average of 14.7 m OD over the monitoring period. Large peaks up to 16.4 m OD occur on 12 March and 2 April, coinciding with particularly heavy rainfall events. Groundwater levels remain well below historical high.	Overall, groundwater levels fall during the monitoring period to an average of 13.8 m OD. Groundwater level peaks on 27 July 14.7 m OD and again on 20 September to 15.1 m OD, following particularly heavy rainfall events.
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 past cyclical pattern with sub-weekly variation. Groundwater levels have remained steady at an average of 19 m OD, falling briefly in early March.	Continuation past cyclical pattern with sub-weekly variation. Groundwater levels have decreased over the monitoring period to 18.8 m OD.

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 the elevated groundwater level over this period should be monitored. There is potential ingress of water from cliff top developments suggested by fluctuating groundwater levels during drier than average months in winter.

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 of glacial sediments overlies 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 landside 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 November 2018.

The new data indicate:

- No significant ground movements recorded in any of the inclinometers.
- Groundwater data shows a continuation of past patterns. Water levels fell in boreholes L1b and BH8a and increased slightly in others, all remaining well below historical high levels. Groundwater tended to peak in September. This may be a short-lagged response to rainfall in earlier in the month.
- Auto-piezometer in borehole BH9a had a data logger communication error. No data was available during this monitoring period.
- Piezometer BH9b is no longer functioning and the logger has been removed.

Table 8.2. Summary of inclinometer data at The Holms

Borehole	Summary of past data	Report Status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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.										Repeated minor displacements in sandstone bedrock at 16 m depth are error. Cumulative readings show no net direction to movement, suggesting inclinometer probe meets a small obstruction at this depth.	Repeated minor displacements in sandstone bedrock at 16 m depth are error. Cumulative readings show no net direction to movement, suggesting inclinometer probe meets a small obstruction at this depth.
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 13 m depth.	No change detected in sinusoidal pattern of deformation between 9 and 13 m 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 and wet June and August 2017. The piezometers at The Holms show a lagged response to these conditions with only BH8a showing a rapid response to May 2015, March and November 2016 rainfall. Levels fell during winter 2016/2017 following months of dry conditions then stabilised following a wet summer in 2017. Levels increased again over the drier than average winter 2017/18 and have stabilised at average levels following this. 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. There is no clear response in any of the boreholes to the extreme rainfall event experienced on 23 August 2017 or 20 September 2018.

8.6 Implications and recommendations

Auto-piezometer in borehole BH09a had a data logger communication error which should be checked and repaired. Readings should be collected and reviewed on the next site visit.

Table 8.3. Summary of groundwater data at The Holms

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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. 0.6 m during December and January. Groundwater levels show an average decrease throughout the monitoring period from c. 1m OD to 0.7 m OD. Groundwater levels peak in December to 1.2 m OD, and are lowest in April at 0.6 m OD.	Continuation of past cyclical patterns, with 2 to 3 week variations of up to c. 0.6 m from June to September. Groundwater levels show an average increase from mid-June from c. 0.5 m OD to c. 1.1 m in September, peaking on 24 September. Groundwater levels remain significantly below historical highs.
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.	3.6m OD 4.7m OD 1.1m										Continuation of 2 to 3-week cyclical pattern, with variations up to 0.5 m in January and February. Groundwater levels show a falling trend averaging 4.2 m OD, after rapidly rising to 4.6 m OD in January and February, peaking between the 29th January and 4th February.	Continuation of 2 to 3-week cyclical pattern, with variations up to 0.5 m from June to September. Groundwater levels show a falling trend averaging 3.8 m OD, reaching a new historical low at 3.6 m OD on 21 September before rising again.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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 following exceptional rainfall.	9.7m OD 10.7m OD 1.0m										Groundwater levels fall slightly over the monitoring period, around an average of 10.2m OD. Variation of up to 0.7m occurs during December where groundwater levels peak on 4 December and fall in mid-December, returning to more stable levels in March.	Groundwater levels fall slightly over the monitoring period, around an average of 10.1 m OD. Variation of up to 0.5 m occurs during September where groundwater levels fall to 9.9 m OD, rapidly rising to 10.4 m OD following heavy rainfall on 20 September.
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 similar rainfall-influenced pattern to BH8a.	9.4m OD 14.5m OD 5.1m										Groundwater levels continue a saw-tooth pattern, rising to 10.8 m OD by January, and rapidly falling and remaining stable around an average of 9.6 m OD over the remainder of the monitoring period.	Groundwater levels continue a saw-tooth pattern, rising in June to 10.5 m OD and rapidly falling in July to 9.6 m OD. Groundwater levels increase steadily over the remainder of the monitoring period to 10.4 m OD.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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 to 26.3m OD.	12.1m OD 26.2m OD 14.1m										Groundwater levels decreased to a new historical low of 12.1 m OD by November 2017. Groundwater levels increased rapidly during December peaking on 27 January to 18.8 m OD. Groundwater levels fell in February and stabilised averaging 15.6 m OD for the remainder of the monitoring period.	**No data available.** Data logger communication error. Logger removed and sent for repair.
BH9b	Tip depth at 0.49m OD, surface at 33.49m OD co-located with BH9a. Historical data showed similar pattern to BH9a, but contrary to that in BH8a and BH8b.	9.7m OD 30m OD 18.5m										Logger removed as piezometer no longer functioning.	Logger removed as piezometer no longer functioning.

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 at 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 on by Mouchel.

Table 9.2 Summary of inclinometer data at St Nicholas Cliff

Borehole	Summary of past data	Report Status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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.										Readings show less than 1mm movement and are not significant.	Readings show less than 1mm movement and are not significant.

Table 9.3 Summary of groundwater data at St Nicholas Cliff

Borehole	Summary of past data	Groundwater summary Min/Max/ Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
FR02	FR02 has been monitored since 21 May 2014. Tip is at 18.0m depth (c.-6.5m OD). Variation may reflects term tidal cycles.	6.6m OD 8.4m OD 9m										Continuation of past cyclical pattern, with groundwater levels remaining steady averaging 6.9 m OD. Groundwater levels are greatest between January and February, and lowest late-March suggesting levels respond to several months' antecedent rainfall.	Continuation of past cyclical pattern, with groundwater levels remaining steady averaging 6.9 m OD. Groundwater levels are lowest from June to August, and greatest in September suggesting levels respond to several months' antecedent rainfall.

No ground movement is recorded at this site and water levels remain near the historical low.

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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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.										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 December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH12	Tip at -8.4 OD. Cyclical pattern with c. two-week frequency between peaks. Max. levels are between 1.25 and 1.5m above OD and min. between 0.3 and 0.5m above OD. May be influenced by tides.	0.0m OD 2.3m OD 2.3m										No data recorded for monitoring period, unable to connect to data logger. Last data recorded in May 2016. This site requires attention.	No data recorded for monitoring period, unable to connect to data logger. Last data recorded in May 2016. This site requires attention.
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 OD and min levels are c. 3.3m OD.	3.2m OD 3.9m OD 0.7m										Range of fluctuations within past limits and linked to tidal cycles. Groundwater levels remain steady. Fluctuation ranges from 3.2 to 3.9 m OD, averaging 3.6 m OD. Large cyclical variations occur between December and February, close to the historical low.	Range of fluctuations within past limits and linked to tidal cycles. Groundwater levels remain steady. Fluctuation ranges from 3.3 to 3.9 m OD, averaging 3.6 m OD. Large cyclical variations occur during September when conditions are wetter.

No ground movement has been recorded and fluctuations in groundwater levels are within the ranges previously observed. The piezometer in borehole BH12 requires attention to fix or replace faulty equipment.

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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
AA04 (G2)	40.5m deep borehole penetrating 34.5m of glacial sediments and 6m of sandstone/siltstone bedrock. Ground level is 47.6m OD, base of hole is 7.1m OD.										No significant movement.	Downslope movement of up to 5 mm, in upper 11m of borehole within till. Pattern of movement shows negative and positive deflection, which suggests error.

												Inspect site and take careful readings next time.
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.										No significant movement.	No significant movement.
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 movement.	Up to 8 mm positive and negative displacement on both A and B axes in the upper 20m of the borehole reflects blockages in the upper borehole and/or careless reading.
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.										Minor displacement of 2 mm downslope at 12 m depth within clay. No other significant movement.	Minor displacement of 2 mm downslope at 12 m depth within clay.
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 20.4m OD, base of hole at 2.4m 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. Very minor downslope movement at 11 m depth within clay.	No access to site. Readings to be taken on next site visit.
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 installation in Oct 2012 and Dec 2012 are <1mm.										No significant movement.	No significant movement.
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 movement.	No significant movement.
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 September 2017 and August 2018 do not show significant slope movements. As seen previously, periods of elevated AE activity are thought to be a response to rainfall events generating seepage in the gravel beds. It is also possible that extraneous noise generated at Scarborough could be due to ongoing construction activities to stabilise the slope.	AE measurements between June and November 2018 do not show significant slope movements. As seen previously, periods of elevated AE activity are thought to be a response to rainfall events generating seepage in the gravel beds. It is also possible that extraneous noise generated at Scarborough could be due to ongoing construction activities to stabilise the slope.

Table 9.7. Summary of groundwater data at the Spa

Borehole	**Long-term Pattern**	**Groundwater summary** **Min/Max/ Range**	**Report status**									**Change December 2017 to May 2018**	**Change June to November 2018**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
H2a	Located near the headscarp of the Spa landslide. Tip at 17.3m OD. 3 to 5 day frequency fluctuation around mean of c. 17.3m OD with amplitude of c. 0.5m. No clear long-term trend or temporal pattern.	16.7m OD 17.6m OD 0.9m										Groundwater levels remain steady averaging 17.2 m OD. There is a cyclical sub-weekly pattern, where groundwater varies up to 0.7 m, falling to 16.8 m OD in late-December, which coincides with below average rainfall for the month.	Groundwater levels remain steady averaging 17.2 m OD. Cyclical sub-weekly pattern, with variation of up to 0.5 m. Falls in late-September coincide with low antecedent rainfall. Groundwater rapidly increases after the heavy rainfall of 20 September.
H2b	Located near the headscarp of the Spa landslide. Tip at 11.1m OD. 3 to 7 day frequency fluctuation around mean of c. 12.7m OD with amplitude of c. 0.3m. Highs and low reflect antecedent rainfall	12.0m OD 13.0m OD 1.0m										Groundwater level decreased over the previous and current monitoring period from 12.5 m OD in June 2017 to 12 m OD in May 2018. Groundwater fluctuated more greatly between December and February by 0.5 m.	Groundwater level continues to decrease over the monitoring period to an average of 11.9 m OD in Oct. Levels fluctuated by 0.4m following extreme rainfall on 20 Sept.
H5	Located near the base of the cliff behind the Spa building. Tip at 15.5m OD.	17.0m OD 23.01m OD 6.01m										Groundwater levels continue to show a saw-tooth pattern, with a sharp rise and fall, although changes of 0.7m are more muted during this monitoring period. Groundwater levels peak on 29 December at 22.4 m OD, and fall during May to 22 m OD in response to several months' antecedent rainfall.	Groundwater levels continue to follow a saw-tooth pattern, with a sharp rise and fall, with more muted variation of 0.6m Levels peak in late July and decrease throughout the remainder of the monitoring period in response to several months' antecedent rainfall.
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	6.7m OD 11.9m OD 5.2m										Borehole dry. **Check piezometer integrity.**	No access to site. Readings to be taken on next site visit.

	historical low of c.7m OD between Aug 2008 and Aug 2009.												
2 spa	Located near the base of the cliff. Tip at 6.4m OD. Water levels fluctuated between c. 10m and c. 12m OD between Jan 2003 and Aug 2009. Thereafter, fluctuations increase.	7.2m OD 12.1m OD 4.9m										Groundwater levels fall slightly to 10.3 m OD.	No access to site. Readings to be taken on next site visit.
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.	7.1m OD 13.0m OD 5.9m										Groundwater levels increase to 12.3 m OD, which is close to the historical peak.	Groundwater levels decrease to 11.9 m OD.
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.	6.1m OD 12.6m OD 6.5m										Groundwater levels increase to 12.2 m OD, which is very close to the historical peak.	Groundwater levels decrease to 11.7 m OD.
G3	Located near the base of the cliff. Tip at 13.6m OD. Complex pattern comprising c. 7 month variation in water level with sub-weekly fluctuations.	13.2m OD 14.4m OD 1.2m										Groundwater levels continue to rise from December, rapidly peaking on 18 March at 14.4 m OD, at the historical high, coinciding with heavy rainfall. Groundwater levels decline to 14.1 m OD by May and remain elevated.	Groundwater levels fluctuate rapidly between 14.7 m and 16.2 m OD until Aug, where a sustained peak of 15.9 m OD is maintained. The pattern appears erroneous. **The integrity of the piezometer should be checked.**
5 spa	Located near the base of the cliff. Tip at 9.4m OD.	8.5m OD 9.6m OD										Borehole dry.	No access to site.

	No correlation with the upper tip in this well. Data only recorded between Sep 2006 and May 2012, after which the hole is dry.	1.1m									**Check piezometer integrity.**	Borehole is in exclusion zone of Spa stabilisation construction site.
BH1a spa	Located at the toe of the Spa landslide. Tip at 2m OD. Sub-weekly fluctuation about mean c. 4.4m OD.	3.9m OD 5.0m OD 1.1m									Continuation of previous pattern during the monitoring period. Fluctuations within past range, peaking to the historical high of 5m OD on 21 March, following heavy rainfall on the 12 and 16 March. Levels average 4.7 m OD for the remainder of the monitoring period.	Groundwater levels fall throughout the monitoring period to c. 4.4 m OD, fluctuating within 0.4 m. Levels peaks at 4.7 m OD on 25 Sept following extreme rainfall on 20 Sept.
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.	11.8m OD 12.8m OD 1.0m									Continuing cyclical pattern, a falling groundwater levels from December to April, to an average of 12.2 m OD. Levels peak several times, the greatest on 26 February. On 2 April groundwater reaches a new historical low of 11.9 m OD and following this, increases to 12.5 m OD by May.	Continuing cyclical pattern around a falling trend with levels reaching a new low of 11.8 m OD in Sept. Levels peak on 25 Sept at 12.5 m OD and return to the average 12.2 m OD.
BH1 Prom	Located inland of the cliff top. Tip at 41.4m OD. 5 month period of rising water level 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 is a sub-weekly fluctuation of c. 0.3m.	41.2m OD 43.7m OD 1.4m									**No telemetry data available at present.** Data to be collected at the next site visit.	**No telemetry data available at present.** Data to be collected at the next site visit.
G1a	Located inland of the cliff top. Dipped piezometer that shows consistent water levels of c.	53.4m OD 53.9m OD 0.3m									Groundwater levels steady at 53.4 m OD.	Groundwater levels steady at 53.4 m OD.

	53.5m OD since late 1997.												
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.	19.2m OD 51.1m OD 31.9m										Borehole dry. **Check piezometer integrity.**	Borehole dry. **Check piezometer integrity.**
BH108a	Deep piezometer tip located mid-slope. Solinst data logger replaced by telemetry system in 2018. Record begins on 18 Dec 2012 and shows several sharp fluctuations of uncertain cause.	20.7m OD 31.4m OD 10.7m										Groundwater levels continue to fall over monitoring period to 21 m OD, falling rapidly in early March by 1.3 m.	Groundwater levels continue to fall over monitoring period to a new low of 20.7 m OD.
BH108b	Shallow piezometer tip co-located with deeper BH108a. Dry between Sept 2012 and Jan 2013.	25.6m OD 31.6m OD 6m										Borehole dry. **Check piezometer integrity**	No access to site. Data to be collected at the next site visit.
BH106a	Located at the cliff top. Solinst data logger. BH 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. BH 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. Solinst data logger replaced by telemetry system in 2018.	4.30m OD 20.0m OD 15.7m										Groundwater levels rise slightly to 4.4 m OD. No fluctuation.	Groundwater is steady around 4.3 m OD.

BH104b	Located near the base of the slope. Manual piezometer tube. BH dry between Sept 2012 and Jan 2013.	4.3m OD 11.2m OD 6.8m										Groundwater level rises to 11.2 m OD, a new historical high.	Groundwater levels fall to 10.3 m OD.
BH102a	Located at the base of the slope behind the seawall. Solinst data logger.	0m OD 2.6m OD 2.6m										No data downloaded. Borehole filled with tarmac.	No data downloaded.
BH102b	Located at the base of the slope behind the seawall. Manual piezometer.	1.0m OD 2.1m OD 1.1m										No data downloaded. Borehole filled with tarmac.	Groundwater level at 1 m OD.

These data indicate:

- Inclinometers show no significant movement in the monitoring period, with the exception of borehole AA04 and BH14 that show potentially erroneous readings. During data collection the logger experienced connection issues. It is also possible the inclinometer has been affected by nearby construction activities on the coastal slope. The inclinometers should be checked and data reviewed for the next monitoring period.
- Most locations show continuation of past patterns, and groundwater remaining steady or decreasing over the monitoring period. Piezometers which recorded historical high groundwater levels have now receded to average levels and no ground movement was detected at nearby inclinometers.
- Piezometer data from H5 are now collected via telemetry and show water levels follow the same saw-tooth pattern recorded previously. Sharp increases in groundwater level tend to occur in response to two months antecedent peak rainfall events. This trend should be reviewed in the next report.
- Piezometers G1b, BH106a and BH106b should be checked because they were dry. This equipment may be damaged and required attention to determine whether they can be repaired.
- Boreholes BH102a and BH102b that has previously been mistakenly covered with tarmac have been reinstated. No data are available for BH102a for this monitoring period due to temporary logger problems. The data should be downloaded and reviewed for the next monitoring period.
- No data were available for BH1 Prom and data from G3 appears erroneous. Both loggers should be checked/repaired and data collected for the next monitoring period.
- Access to piezometers 1 spa, 2 spa and 5 spa was not possible during this monitoring period due to on-going works at the Spa. The data should be downloaded and reviewed for the next monitoring period.
- 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). It is also possible that extraneous noise generated at Scarborough could be due to ongoing construction activities to stabilise the slope.

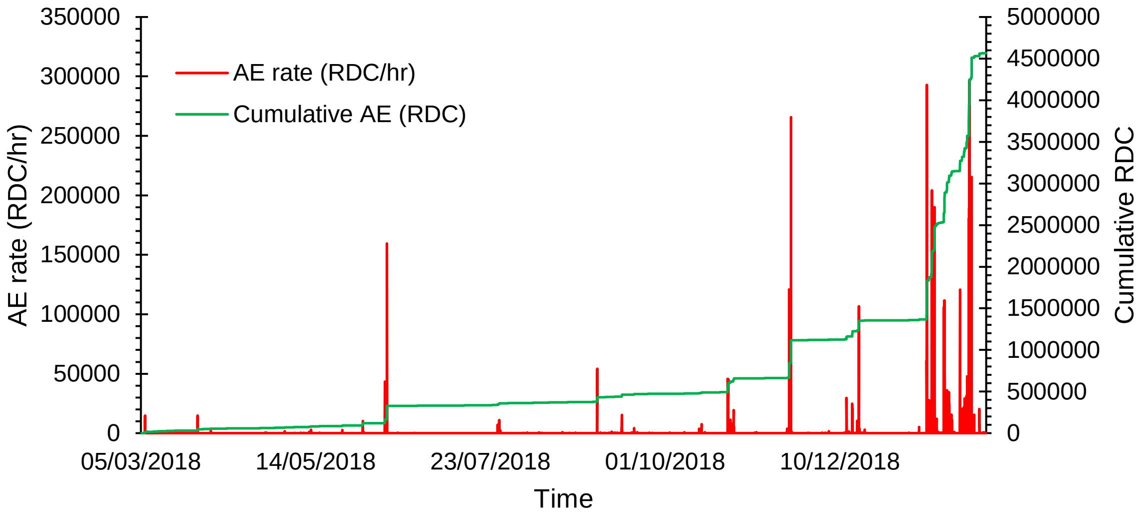

Figure 9.2. Cumulative AE (RDC) and AE rate (RDC/hr) time series at Scarborough Spa for the period March 2018 to January 2019.

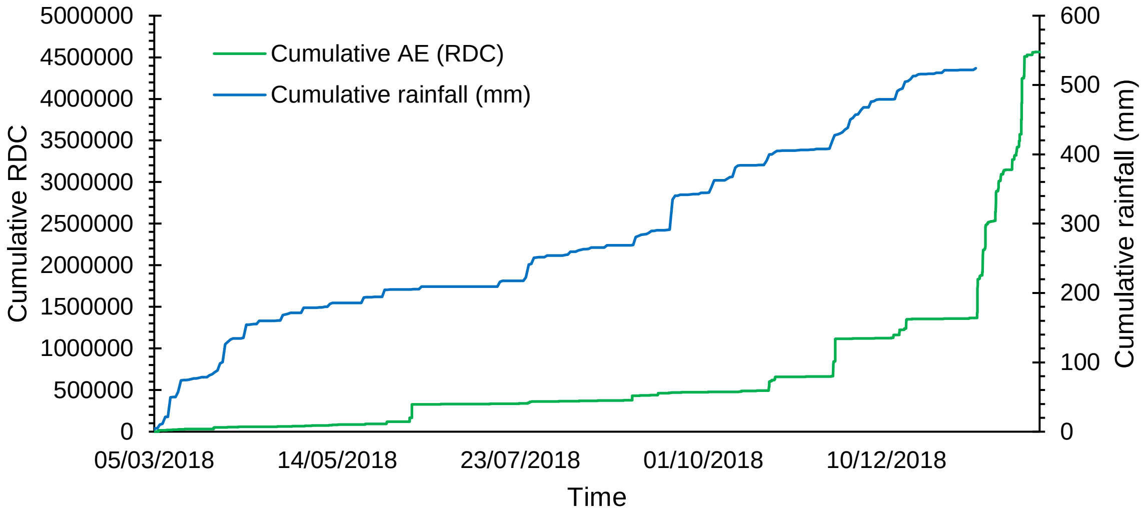

Figure 9.3. Cumulative AE (RDC) and cumulative rainfall time series at Scarborough Spa for the period March 2018 to January 2019.

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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
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 35.0m OD, base of hole is 5.0m OD. Very low creep indicated in the upper 5m.										Readings are less than 1mm and not significant.	Readings are less than 1mm and not significant.
AA11 (F4)	20m deep borehole penetrating 8m of glacial sediment and 12m of siltstone/sandstone bedrock near the toe of the Clock Café landslide.										Readings are less than 1mm and not significant.	Readings are less than 1mm and not significant.

Table 9.9. Summary of groundwater data at the Clock Café

Borehole	Summary of past data	Groundwater summary Min/Max/ Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH15	Located inland of the landslide headscarp. No historical data	n/a										Borehole dry. **Check piezometer integrity**	Borehole dry. **Check piezometer integrity**

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 and/or should continue to be read.

In mid-March 2018, a retaining wall behind chalets south of the Clock Café failed, resulting in significant cracks forming on the footpath behind the chalets. There are no inclinometers or piezometers in the vicinity of the wall failure, however adjacent data do not indicate any movement nearby. A ground investigation concluded that bedrock was at shallow depth and the failure results to collapse of the retaining wall structure rather than ground movement. High antecedent groundwater levels due to heavy rainfall in early spring 2018 were probably a trigger of the failure.

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 Cliff Gardens

Borehole	Summary of past data	Report status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
AA08 (D3)	24m deep borehole that penetrates 12m of glacial sediment and 12m of interbedded bedrock. Ground level is 38.4m OD, base of hole is at 14.4m OD. Data indicate slight progressive creep along the whole length of the borehole,										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
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 57.5m OD, base of hole at 7.5m OD.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
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 62.9m OD, base of hole is 8.9m OD.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
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 5.9m OD, base of borehole is 18.0m OD.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

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

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH18a	Tip at 26.8m OD near the base of the cliff and Rose Garden landslide. Complex pattern, with sub-weekly peaks much higher than base readings.	34.4m OD 42.6m OD 6.1m										Groundwater levels spike several times between mid-March and early April, to 42.6 m OD at the historical high, following above average rainfall over these months. Groundwater levels are declining from an average of 39.9 to 37.3 m OD by May.	Groundwater levels fall gradually over the monitoring period to 35.3 m OD by October. Groundwater only peaks on the 21 September at 36 m OD, shortly after the extreme rainfall which occurred on the 20 September.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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										Groundwater levels are steady around 35.3 m OD. Peaks at 36.6 m OD several times between late Dec, early Feb, and in early April. On 12 March, groundwater peaks to 37.4 m OD, coinciding with the high daily rainfall total.	Groundwater levels fall steadily over the monitoring period to an average of 34.2 m OD by Oct. Levels peaks on 20 Sept at 34.8 m OD, following extreme rainfall that day.
BH19a	Tip at 53.8m OD inland of the headscarp of the South Bay Pool landslide. This piezometer has been dry since installation.	52.3m OD 62.4m OD 10.1m OD										Cyclical pattern with magnitude of variation ranging 0.7m averaging 52.6m OD. Groundwater level is greatest during late February and falls, remaining steady thereafter.	Cyclical pattern with magnitude of variation ranging 0.5 m averaging 52.6 m OD. Level is greatest in late June at 52.8 m OD, decreasing at its lowest to 52.3 m OD in Sept. No response to peak rainfall on 20 September.
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 53.4m OD 6.3m										Continuation past patterns. Groundwater levels increase from a historical low in December, peaking at 48.2 m OD on 22 February, before declining slightly to an average of 47.7 m OD in May. This suggests levels respond to several months' antecedent rainfall	Continuation past patterns. Level falls over the monitoring period to an average of 47.5 m OD. Lowest level of 47.5 m OD reached in Aug. Peaks on 30 July at 48.0 m OD and 20 September at 48.6 m OD in response to peak rainfall.
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, following which no data has been recorded.	31.1m OD 40.9m OD 9.8m										Groundwater levels increase slightly to an average of 31.7 m OD with sub-weekly fluctuations of up to 0.5 m. Groundwater peaks on 20 March at 32 m OD, following high daily rainfall totals several days earlier.	Groundwater levels fell over the monitoring period to an average of 31.5 m OD and remained steady from September onwards. Levels peaked on 24 Sept at 31.70 m OD after heavy rainfall on 20 September.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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.											No data, logger to be checked.	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 is drops to c. 44m AOD.	Original logger: 43.6 44.8 1.2 Replacement logger: 45.6m OD 50.0m OD 4.4m										No data, logger to be checked.	No data, 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 (Bh3a), but typical level of 10.5m OD is interrupted by frequent short-duration (1 day) peaks up to 8m higher.	10.3m OD 18.6m OD 8.3m										Levels remain steady around 10.6m OD with sub-weekly fluctuations of up to 0.6 m. Groundwater levels peak in late February at 10.9 m OD.	Levels steady around 10.6 m OD with sub-weekly fluctuations of up to 0.6 m. Peaks of 10.9 m OD on 24 Sept after heavy rain on 20 Sept. Level then increased slightly to an c. 10.7 m OD.
E2a	Tip at 31.4m OD below the headscarp of the mudslide embayment. Cyclical long-term pattern with sub-metre fluctuations superimposed.	43.3m OD 46.5m OD 3.2m										Groundwater increases during the monitoring period from an average of 43.5 to 44.5 m OD. Between December and February there is up to 0.5 m variation in groundwater level.	Groundwater levels fell over the monitoring period to an average of 44 m OD in October. Groundwater levels briefly peaked on 24 September to 44.3 m OD.
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 levels remain steady averaging c. 50.4 m OD and varies by up to 0.8 m during February. Levels rise to 50.5 m OD by May.	Levels steady at c. 50.5 m OD, varying up to 0.5 m during September. Levels briefly peak on 24 September to 50.8 m OD following peak rainfall on 20 Sept.

These data indicate:

- No movement has been recorded in any boreholes at South Cliff Gardens.

- Overall, groundwater levels have mostly remained steady or fallen during the monitoring period; however, a number of piezometers exhibit a rapid response to high daily rainfall totals, specifically on 20 September. Groundwater spikes rapidly within deep boreholes BH18b and BH19b. In other boreholes, however, groundwater levels peaked days later. These included BH18a, D2a, BH3b, E2a and E2b.
- Peaks in groundwater level in response to high daily rainfall were not as prominent when compared with lesser rainfall events. This suggests surface water ingress and the contractor should ensure that plastic caps are in place and that water cannot collect at the top of the boreholes. In addition, groundwater level has risen in borehole E2a over the monitoring period. These piezometer data should be reviewed during the next monitoring period. There are no significant ground movement in nearby boreholes.
- Borehole piezometers D2b and BH3a should be checked and repaired.

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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
AA07 (BH2)	60m deep borehole penetrating 31m of glacial sediments and 29m of siltstone/sandstone bedrock. Ground level is 56.3m OD, base of hole is -3.7m 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.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

Table 9.13. Summary of groundwater data at Holbeck Gardens

Borehole	Summary of past data	Groundwater summary Min/Max/ Range	Report status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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										Unable to download logger data. **Check integrity of piezometer.**	Unable to download logger data. **Check integrity of piezometer.**

The data logger was at fault for Bh4a and Bh4b, and data were not downloaded. The integrity of the piezometers should be checked. No evidence of movement is shown in the current inclinometer data.

9.5 Causal-response relationships

Groundwater levels in South Cliff tend to show a decrease in groundwater levels or remain steady. Some piezometers with data loggers show a response to the peak rainfall event on 20 September 2018 event, however, the most common response is for steady or falling groundwater levels, which suggests a lagged response to the drier conditions over summer, and/or a relationship to the 5 or 6-month antecedent rainfall (Figure 2.6). There is little evidence of movement in the inclinometers and no critical groundwater level thresholds have been identified during this period.

9.6 Implications and recommendations

None of the inclinometers indicate ground movement. Boreholes AA04 and BH14 have readings that are interpreted as error due to blockages in the shallow borehole, careless readings or potentially the nearby construction activities on the coastal slope at the Spa. The inclinometers and surrounding land should be checked and data reviewed for the next monitoring period.

The majority of piezometers show groundwater levels have either remained steady or decreased. Several show short-lived peaks in water level that suggests ingress of surface water during heavy rainfall. Checks should be made at these locations to ensure water-proof caps are in place. Elevated groundwater levels experienced during the previous monitoring period at South Cliff Gardens in BH18a and at Scarborough Spa in G3 have receded well within the range of historical highs.

No data were collected at a number of piezometers including BH12 (Spa Chalet), BH1 Prom and BH102a (Spa), D2b, BH3a (South Cliff Gardens), and BH4a and BH4b (Holbeck Gardens) due to data logger communication errors. Boreholes BH102a and BH102b at the Spa have been reinstated with piezometers. Boreholes G1b, BH106a, BH106b (Spa) and BH15 (Clock Café) are recorded as dry, and borehole G3 (Spa) recorded erroneous data. The integrity of piezometer tips should be checked and the next monitoring data reviewed, whether these trends continue.

Access to piezometers 1 spa, 2 spa and 5 spa at Scarborough Spa was not possible during this monitoring period, partly due to the construction site zone for the Spa Stabilisation works. The data should be downloaded and reviewed for the next monitoring period.

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
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.	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.

10.4 New data

Tables 10.2 and 10.3 summarise the inclinometer and piezometer data from Filey Town to June 2017.

These data indicate:

- No movement has been recorded in any boreholes at Filey Town
- Inclinometer in borehole CPBH03 was not accessible at the time of data collection.
- Water levels are generally stable or increasing slightly in most boreholes.
- Groundwater levels remain elevated in borehole CPBH01a near to the historical high, following a previous fall to lower levels. It is possible the borehole was flooded by surface water flows. Groundwater level also remains elevated in CPBH02a and CPBH09a.
- Groundwater levels continue to increase steadily CPBH10a, rising to a new historical high. However, manual dip meter readings suggest water level has not increased significantly from earlier low levels.
- Boreholes CPBH02b and CPBH10b were dry.

- Data logger communication errors occurred at boreholes CPBH01b, CPBH04b, CPBH06b and CPBH08b, and data was not downloaded for this monitoring period.
- The data logger for borehole CPBH09b should be checked and recalibrated as dip meter readings and diver readings are discordant.

Note boreholes BHA, BHB, BHC, BHD, TP3, TP6, TP8 and TP9, which are inland of the coast and have a focus on flood risk, are no longer included in the coastal instability monitoring programme.

Table 10.2. Summary of inclinometer data at Filey Town.

Borehole	Summary of past data	Report status									Change December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
CPBH03	CPBH03 is 10m deep. Surface elevation is c. 6m OD and the base of the borehole is at -4.0m OD*, extending through 4.4m of made ground and 5.6m of glacial sediment.										Readings are less than 1mm and therefore not significant. Minor displacement at 1 m depth due to soil creep.	No access to site. Readings to be taken on next site visit.
CPBH05	CPBH05 is 10m deep. Surface elevation is c.6.5m OD and the borehole extends to c. -3.5m OD* through glacial sediments.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
CPBH07	CPBH07 is 20m deep. Surface elevation is at c. 5m OD* and the borehole extends to c. -15m OD through glacial sediments.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
BH6	BH6 is 30m deep. Surface elevation is c.27.4m OD* and the base of the hole is c. -2.6m OD. The borehole extends through glacial sediment.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

Note: *Surface elevation and borehole depth calculated from digital elevation model.

Table 10.3. Summary of groundwater data at Filey Town

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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										Groundwater levels decline slightly to 1.4 m OD.	Groundwater levels increase slightly to 1.5 m OD.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
BH4	Tip at 18.1m OD. Major fluctuations (>7m) in groundwater elevation between Dec 2009 and June 2011. reported as 'erratic' (Mouchel 2012). Levels more settled 2011 albeit showing an increase to 20.2m OD in May 2012.	19.7m OD 27.1m OD 7.4m										Groundwater level increases slightly to 21.1 m OD.	Groundwater levels decrease slightly to 20.8 m OD
CPBH01a	Readings sporadic and hole often dry. Mean level is 17.2m	16.9m OD 26.2m OD 8.3m										Groundwater levels remain steady at 26 m OD, remaining close to the historical high.	Groundwater levels decline slightly to 25.9m OD, remaining close to the historical high.
CPBH01b (Diver)	Tip at 32.6m 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 36.0m OD 3.0m										Data logger communication error. **Repair/collect on next site visit.** Manual dip readings at 36 m OD, which suggests levels have risen to a new historical high.	No data available. Dip meter to be repaired following vandalism.
CPBH02a	Tip at 1.6m OD. Mean groundwater elevation at c. 5m OD with minor fluctuations. Short lived drop to 3.6m in Sept 2012. Max level 5.3m OD on 19/04/2012.	3.6m OD 5.2m OD 1.6m										Groundwater levels decline slightly to 4.9 m OD, remaining at an elevated position.	Groundwater levels remain at 4.9 m OD, at an elevated position.
CPBH02b (Diver)	Tip at 8.2m 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 8.6m OD, which is credible and reflects past records, but manual dip readings indicate borehole is dry. **Recommend installation integrity is checked.**	Water level steady at 8.6m OD, which is credible and reflects past records, but manual dip readings indicate borehole is dry. **Recommend installation integrity is checked.**

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
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										Groundwater levels remain steady at 7.2 m OD.	Groundwater levels remain steady at 7.2 m OD.
CPBH04b (Diver)	Tip at 9.9m OD. Steady around 13.5m OD until Dec 2012 although dip in Dec 2012 reads significantly higher (16.3m OD).	13.2m OD 13.7m OD 0.5m										Data logger communication error. **Repair/collect on next site visit.** Manual dip readings at 13.2 m OD suggest levels declined slightly and are within the range of previous records.	Data logger communication error. **Repair/collect on next site visit.** Manual dip readings at 13.7 m OD suggest levels increased to a new historical high.
CPBH06a	Tip depth at 0.13m OD. Mean groundwater elevation at 19.9m OD. Range between 18.9m OD (27/02/12) and 20.1 (20/12/12). Rises to highest level in Dec 2012 after very wet year.	18.9m OD 20.0m OD 1.1m										Groundwater levels decline slightly to 19.3 m OD.	Groundwater declines to 18.8 m 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 20/03/12 and 06/09/12 and sudden drop on 19/04/12 followed by a prolonged steady period at c. 15m OD before sudden recovery on 24/05/12 to 18m OD.	9.2m OD 19.3m OD 10.1m										Data logger communication error. **Repair/collect on next site visit.** Manual dip readings at 19.1m OD, which suggests levels have risen slightly and are within the range of previous records.	Data logger communication error. **Repair/collect on next site visit.** Manual dip readings at 19.3m OD suggests levels have risen slightly and are at a new historical high.

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
CPBH08a	Mean groundwater elevation is 8.7m OD ranging between 8.5m OD (19/04/2012) and 9.5m OD (20/12/2012), suggesting a greater lag time or less responsiveness to antecedent rainfall conditions.	8.5m OD 11.4m OD 1.9m										Groundwater levels rise slightly to 9.8 m OD, remaining well within the historical range.	Groundwater levels rise to 10.7 m OD, remaining well within the historical range.
CPBH08b (Diver)	Very steady with fluctuations over whole period only between 17.9m OD and 18.0m OD.	17.7m OD 19.3m OD 1.6m										Data logger communication error. **Repair/collect on next site visit.** Dip meter data indicates borehole is dry.	Data logger communication error. **Repair/collect on next site visit.** Dip meter data indicates borehole is dry.
CPBH09a	Tip depth at 0.6m OD. Mean groundwater elevation is 20.3m OD with variation of c. 1m.	19.9m OD 21.0m OD 1.1m										Groundwater level rises to 20.5 m OD, close to the historical high.	Groundwater level remains elevated at 20.5 m OD, close to the historical high.
CPBH09b (Diver)	Tip depth at 17.7m OD. .	18.8m OD 21.1m OD 2.3m										Data logger indicates water level is at 3m OD, however manual dip readings are at 20.4 m OD, suggesting a data logger communication error. **Repair/collect on next site visit.**	Data logger indicates water level is at 3.2 m OD, however manual dip readings are at 20.4 m OD, suggesting a data logger communication error. **Repair/collect on next site visit.**

Borehole	Long-term Pattern	Groundwater summary Min/Max/ Range	Report Status									Change December 2017 to May 2018	Change June to November 2018
			1	2	3	4	5	6	7	8	9		
CPBH10a (Diver)	Tip depth at 23.8m 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 flashy response to rainfall	24.6m OD 37.5m OD 13.7m										Diver data indicates groundwater level continues to rise throughout the monitoring period to a new historical high. Monthly variation in groundwater levels ranges up to 4.4 m. Groundwater levels peaked on 4 April at 34.8 m OD, and remained elevated in May. Manual dip meter readings, however, indicate groundwater levels are at 28.8 m OD. **Check diver calibration**	Diver data indicates levels stabilised at an elevated level averaging 37.5 m OD, reaching a new historical high. Monthly variation in groundwater levels ranges up to 2.9 m. Groundwater levels peaked on 21 Sept at 37.6 m OD. Dipped readings indicate groundwater levels are 9.3m lower at 28.3 m OD. **Check diver calibration**
CPBH10b	Tip depth at 11.9m. 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.**

10.5 Causal-response relationships

Most piezometers show a weak response to rainfall, with the exception of shallow piezometers CPBH01a and CPBH10a that respond rapidly, within a month, to peaks in rainfall. Muted antecedent rainfall responses are also noted in CPBH06a and CPBH09a. There is no clear response in groundwater level following the extreme rainfall event on 20 September in any of the boreholes. Most of the piezometers show steady groundwater levels, reflecting the relatively dry summer and wetter autumn and mild conditions during the monitoring period. There has not been movement in inclinometers and therefore no relationships between groundwater and ground movement have been identified.

10.6 Implications and recommendations

No data are available for boreholes CPBH01b, CPBH04b, CPBH06b, CPBH08b and CPBH09b and require readings to be re-taken on the next site visit. Boreholes CPBH02b and CPBH10b were dry and require investigation and repair work where necessary. The elevated groundwater levels towards the historical high in CPBH09a and CHBH10a should be monitored and reviewed in the next monitoring report. Data from manual readings in CPBH10a show different results to the diver data and is it is suggested the diver calibration is checked to ensure accuracy. Groundwater levels in CPBH01a and CPBH02a remain elevated and should also be reviewed in the next report to see whether this trend continues. Inclinometer in borehole CPBH03 was not accessible at the time of data collection, and data should be downloaded at the next data collection visit.

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 November 2018.

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 December 2017 to May 2018	Change June to November 2018
		1	2	3	4	5	6	7	8	9		
A2	A2 is 27.5m deep (surface elevation at 17.9m OD) and extends through glacial sediment. Moderate movements (<5mm cumulative) recorded between c. 6m - 7m OD										Readings are less than 1mm and therefore not significant.	c. 2 mm ground movement at 13 m BGL in both A and B axes probably relates to a blockage in the inclinometer tracking
C1	25m deep. Surface elevation is 25.7m OD* the base of the hole is c. 0.7m OD.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
C2	21m deep. Surface elevation is at 16.5m* and the borehole extends to -4.5m OD through glacial sediments.										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.
C5	16m deep. Surface elevation is 12.0m OD* and the borehole extends to -4.0m OD passing through variable glacial sediments. Very minor displacement in the uppermost 1.5m										Readings are less than 1mm and therefore not significant.	Readings are less than 1mm and therefore not significant.

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 September 2017 and August 2018 do not appear to show significant slope movements. The periods of elevated AE activity could be indicative of deformations but of a very slow rate and magnitude. It is more likely that this increased AE activity was caused by extraneous noise (e.g. interference with the surface cover).	AE measurements between June and November 2018 do not appear to show significant slope movements. The periods of elevated AE activity could be indicative of deformations but of a very slow rate and magnitude. It is more likely that this increased AE activity was caused by extraneous noise (e.g. interference with the surface cover).

Table 11.3. Summary of groundwater data at Flat Cliffs

Borehole	**Summary of past data**	**Groundwater summary Min/Max/ Range**	**Report status**									**Change December 2017 to May 2018**	**Change June to November 2018**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
B1	Tip Depth at -7.6m OD. Monitored since July 2001. Fluctuates between c. 11.2 m OD and 15.6m OD.	11.2m OD 15.6m OD 4.4m										Groundwater level rises to 14 m OD.	Groundwater level rises to 14.4 m OD.

D1	Tip depth at 15.61m OD. Monitored with data loggers since 2011. Levels show large fluctuations between 15.7 m OD (Sept 2008) and 38.4m OD (Mar 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									No data available. **Data logger memory full. Repair/collect on next site visit.**	No data available. **Data logger communication error. Repair/collect on next site visit.**
A3	Tip depth at 6.4m OD. Monitored since 2001. Dipped readings show static ground water level at c. 18.8m OD with for peaks up to c. 2m higher. Vibrating wire piezometer installed in Sept 2011 shows static groundwater level of c. 18.0m OD with minor fluctuations.	17.7m OD 18.2m OD 5.0m									No data available. **Data logger communication error. Repair/collect on next site visit.**	No data available. **Data logger communication error. Repair/collect on next site visit.**
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 data available. **Data logger communication error. Repair/collect on next site visit.**	No data available. **Data logger communication error. Repair/collect on next site visit.**

The new data indicate:

- No evidence for ground movements is shown by inclinometers, with the exception of minor movement in borehole A2 within mudstone.
- AE measurements between June and November 2018 do not show significant slope movements. The periods of elevated AE activity, which are shown by periods of increased gradient of the cumulative RDC record, could be indicative of deformations but of a very slow rate and small magnitude. However, it is more likely that this increased AE activity was caused by extraneous noise (e.g. interference with the surface cover).
- Groundwater data show levels have risen in borehole B1, however remain within the historical range.
- No data collected at piezometer in borehole C4a, A3 and D1, requires readings to be retaken.

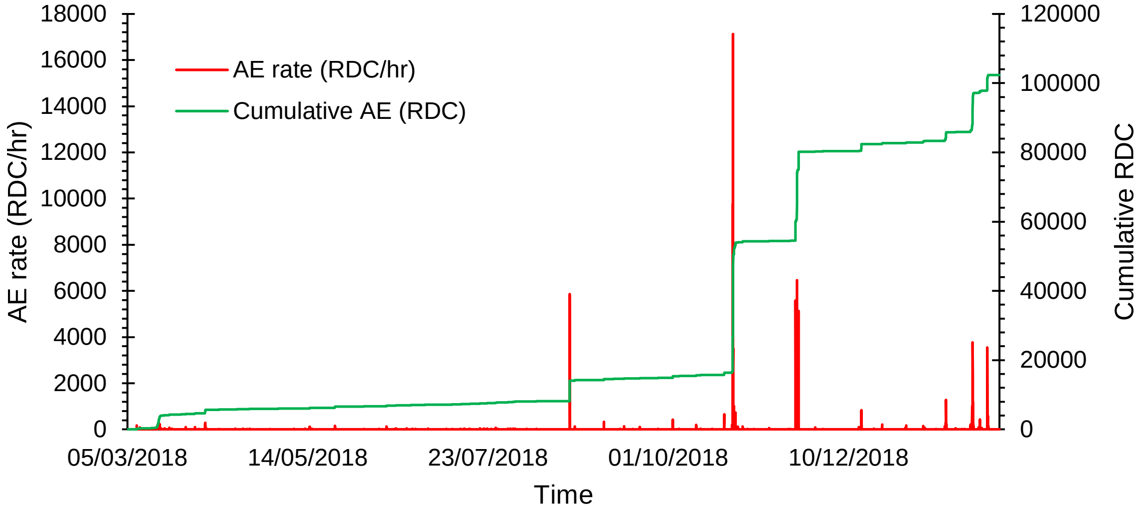

Figure 11.2 Cumulative AE (RDC) and AE rate (RDC/hr) time series at Flat Cliffs, Filey for the March 2018 to January 2019.

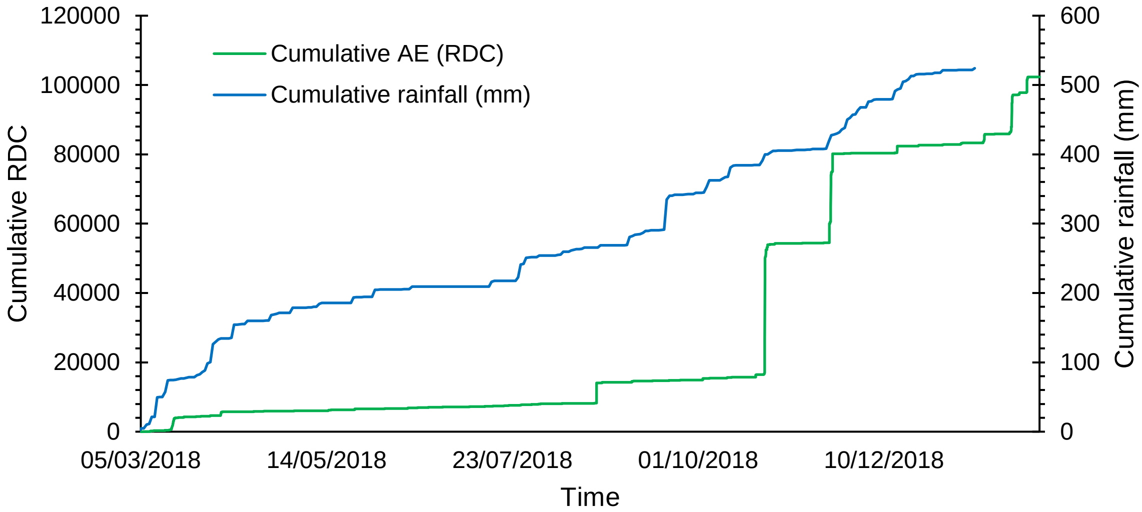

Figure 11.3 Cumulative AE (RDC) and cumulative rainfall time series at Flat Cliffs, Filey for the period March 2018 to January 2019.

11.5 Causal-response relationships

No relationship is identifiable between ground movements and rainfall as no substantial ground movements have occurred. Acoustic emissions data indicates low rate and slow magnitude movement in borehole C1a at the end of November 2017 lasting for 5 days coincident with a period of high rainfall. However, there was no significant movement recorded during the extreme rainfall event on 23 August 2017. 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. B1 gradual increase in groundwater level follows a month antecedent rainfall. There is no clear response in groundwater levels to the extreme rainfall event on 23 August 2017, or heavy rainfall event on 12 March 2018.

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. Piezometers in borehole A3, C1a and D1 require attention and should be repaired for data collection on the next site visit.

The publicly accessible location of the acoustic inclinometer means it has become a target for vandalism, with youths seen by residents kicking the equipment. This has resulted in spurious data being recorded. It is recommended that any future acoustic installations are placed well-away from public accessible land to mitigate the risk of vandalism.

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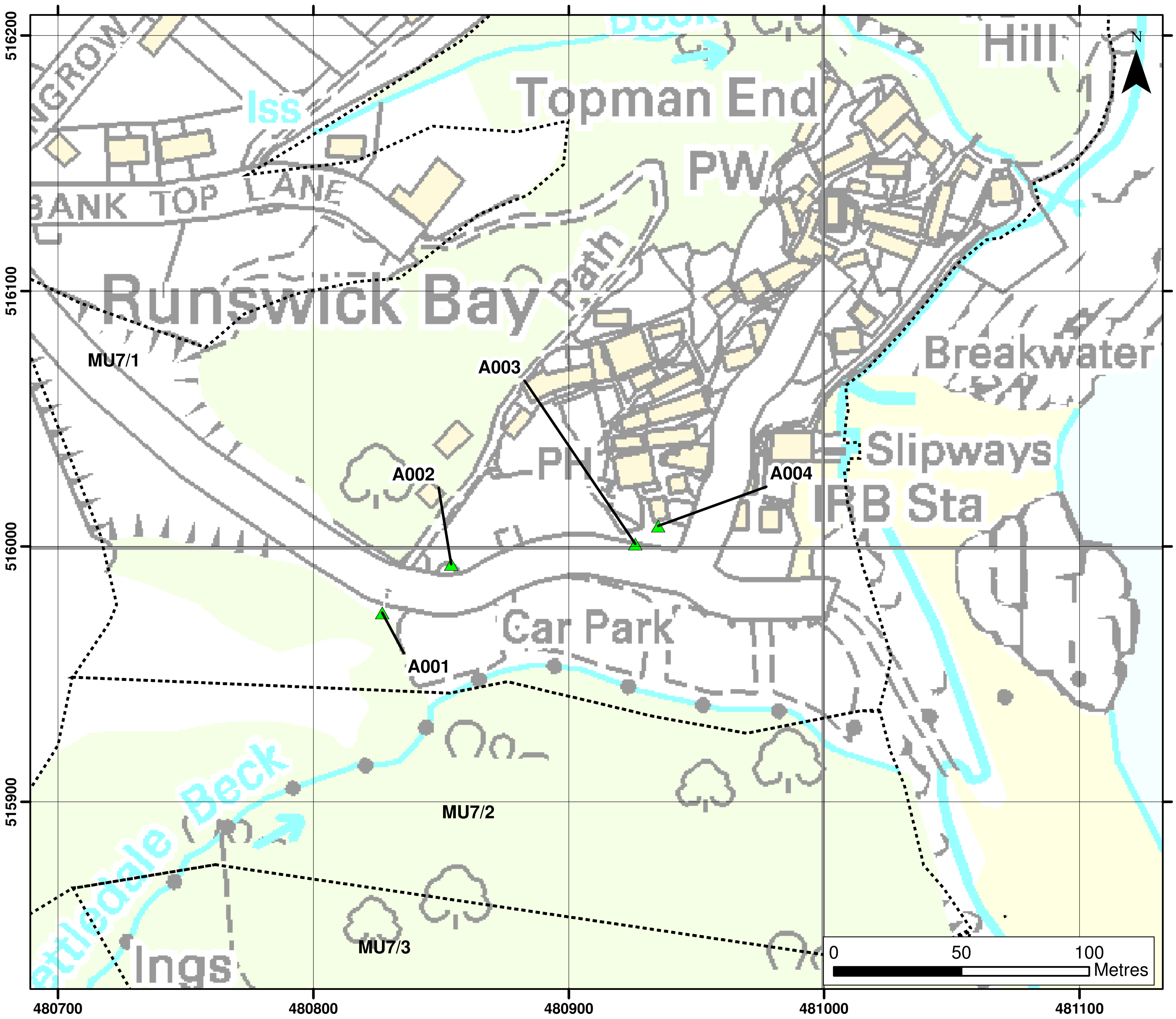
Appendix A
Digital data



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

Client: Scarborough Borough Council

Project: Scarborough Borough Council Geotechnical Monitoring

Figure 3.1 Location of slope monitoring at Runswick Bay

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Legend

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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)
- Cliff behaviour unit

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Figure 4.1 Location of slope monitoring at Whitby West Cliff

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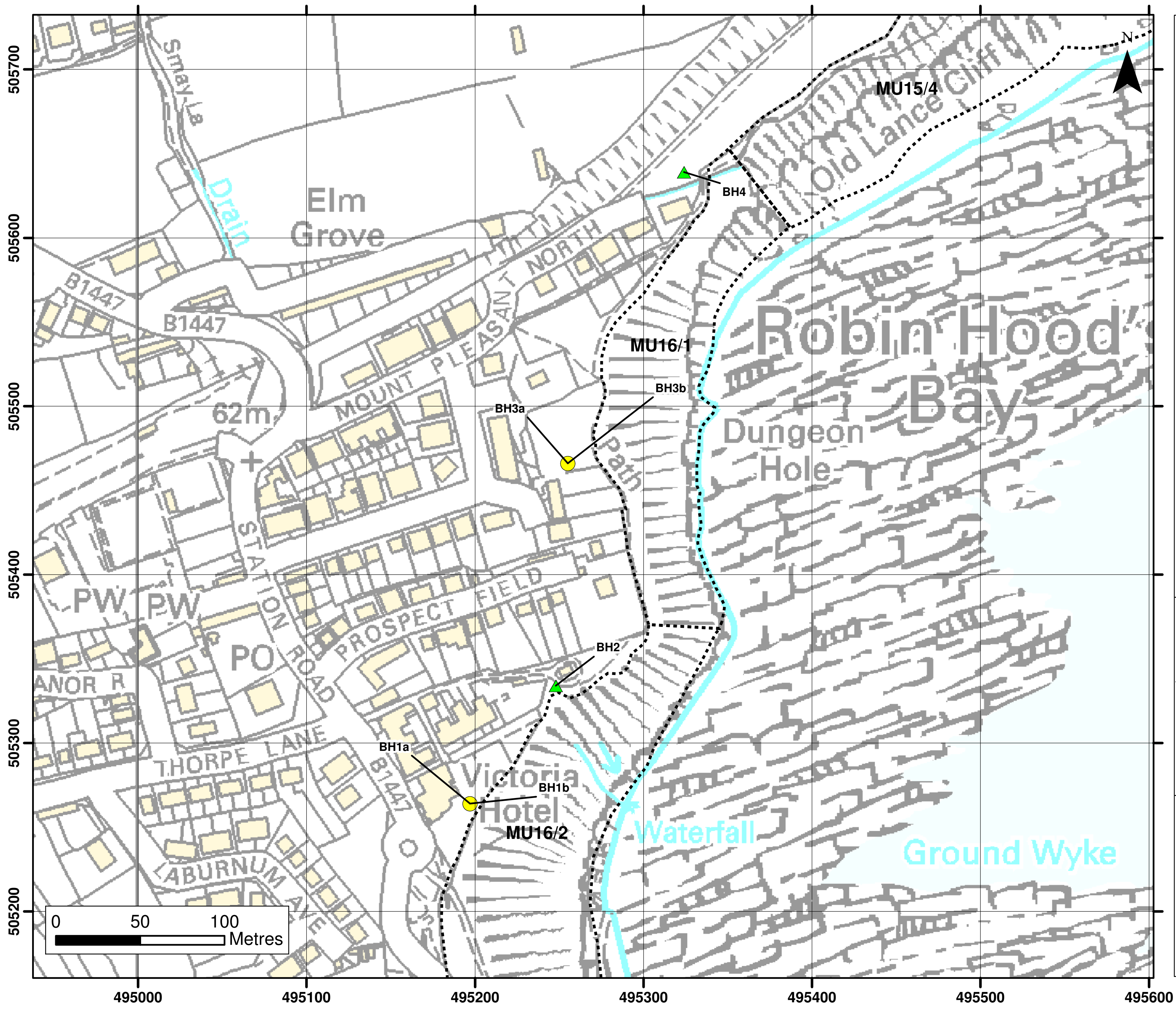

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- Piezometer (with diver)

Inactive

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

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

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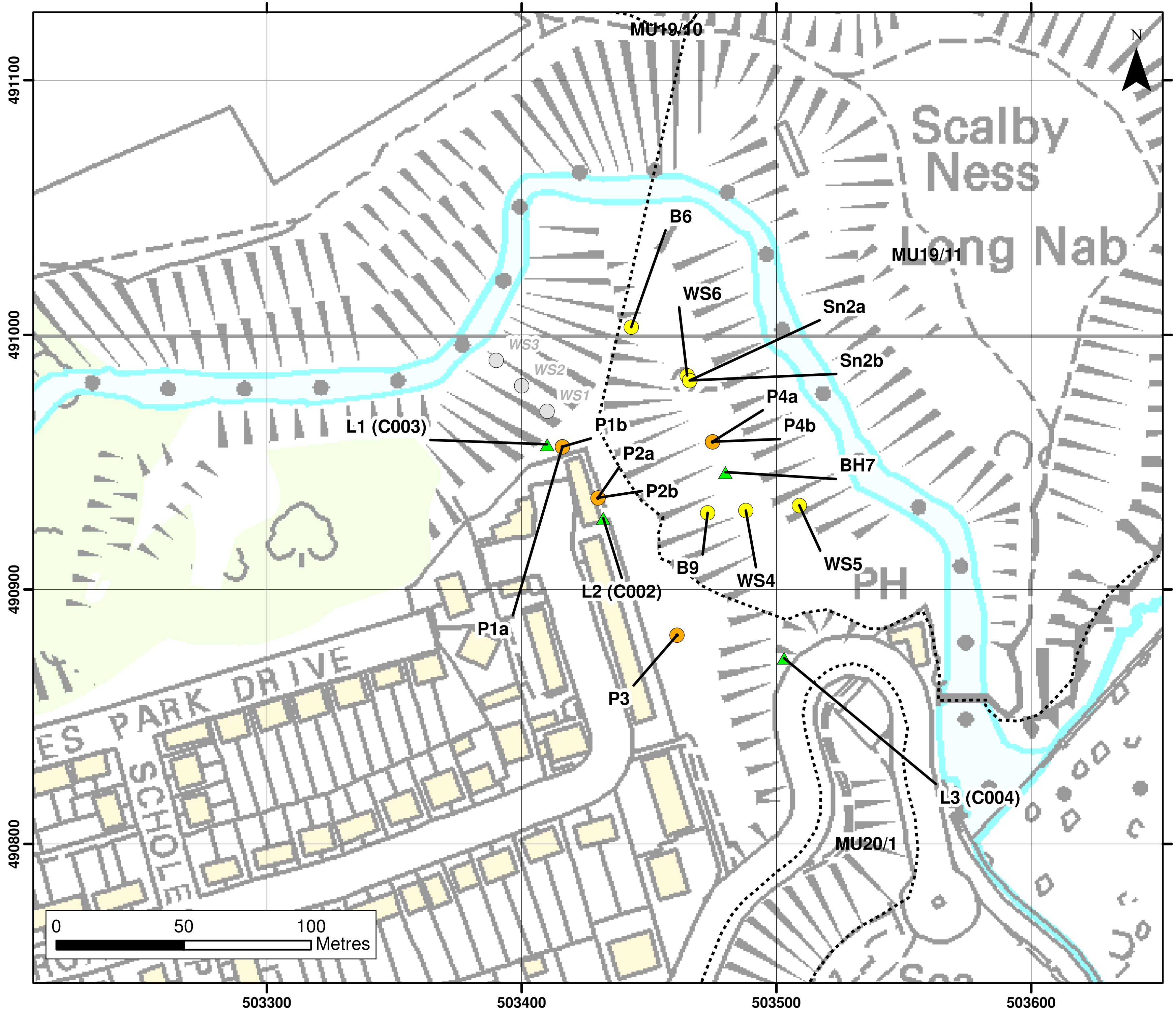

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Inactive

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- Monitoring well
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- Piezometer (with data logger)
- Piezometer (with diver)
- Cliff behaviour unit

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Figure 6.1 Location of slope monitoring at Scalby Ness

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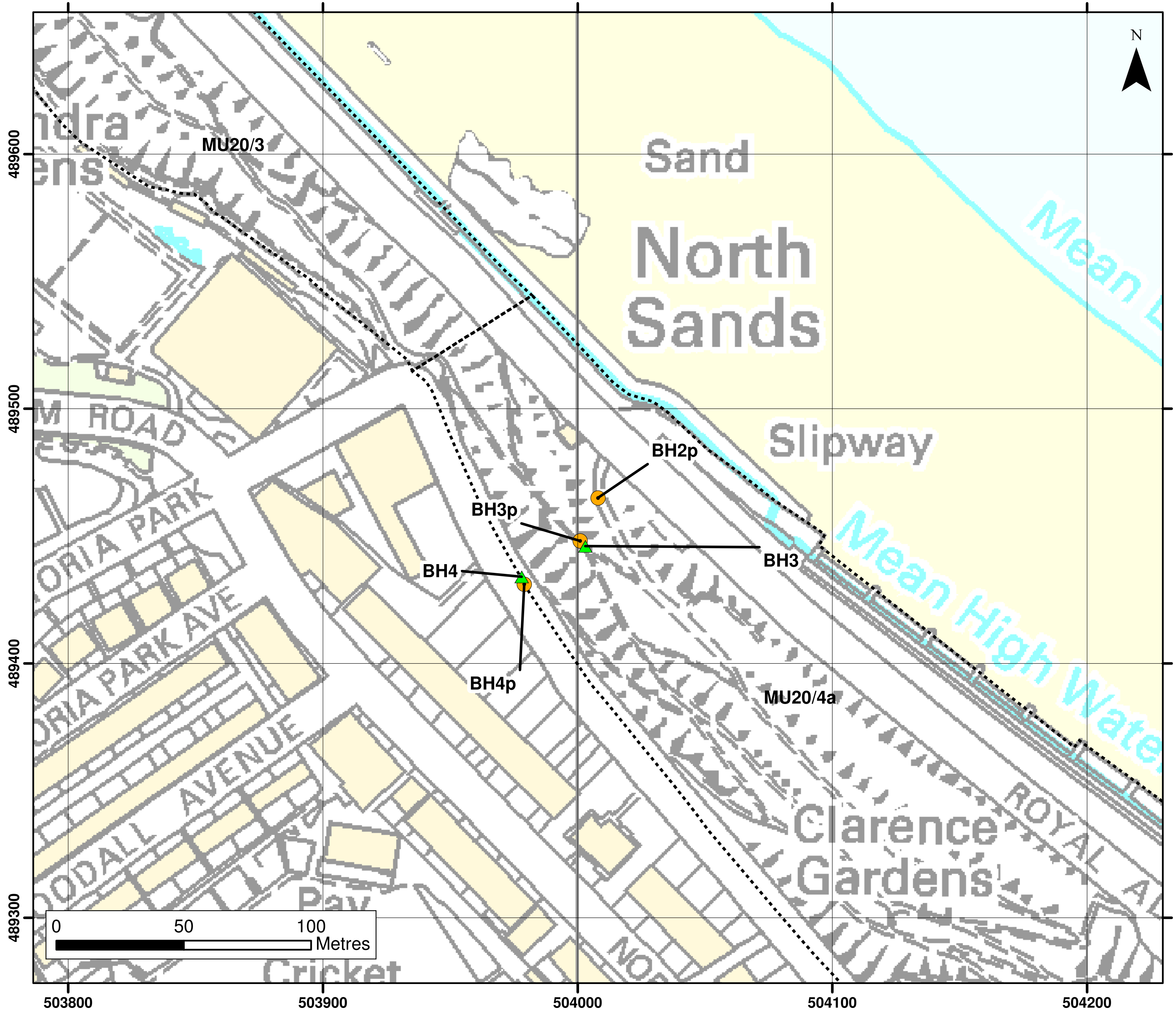

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Inactive

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

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Figure 7.1 Location of slope monitoring at Scarborough North Bay –Oasis Cafe

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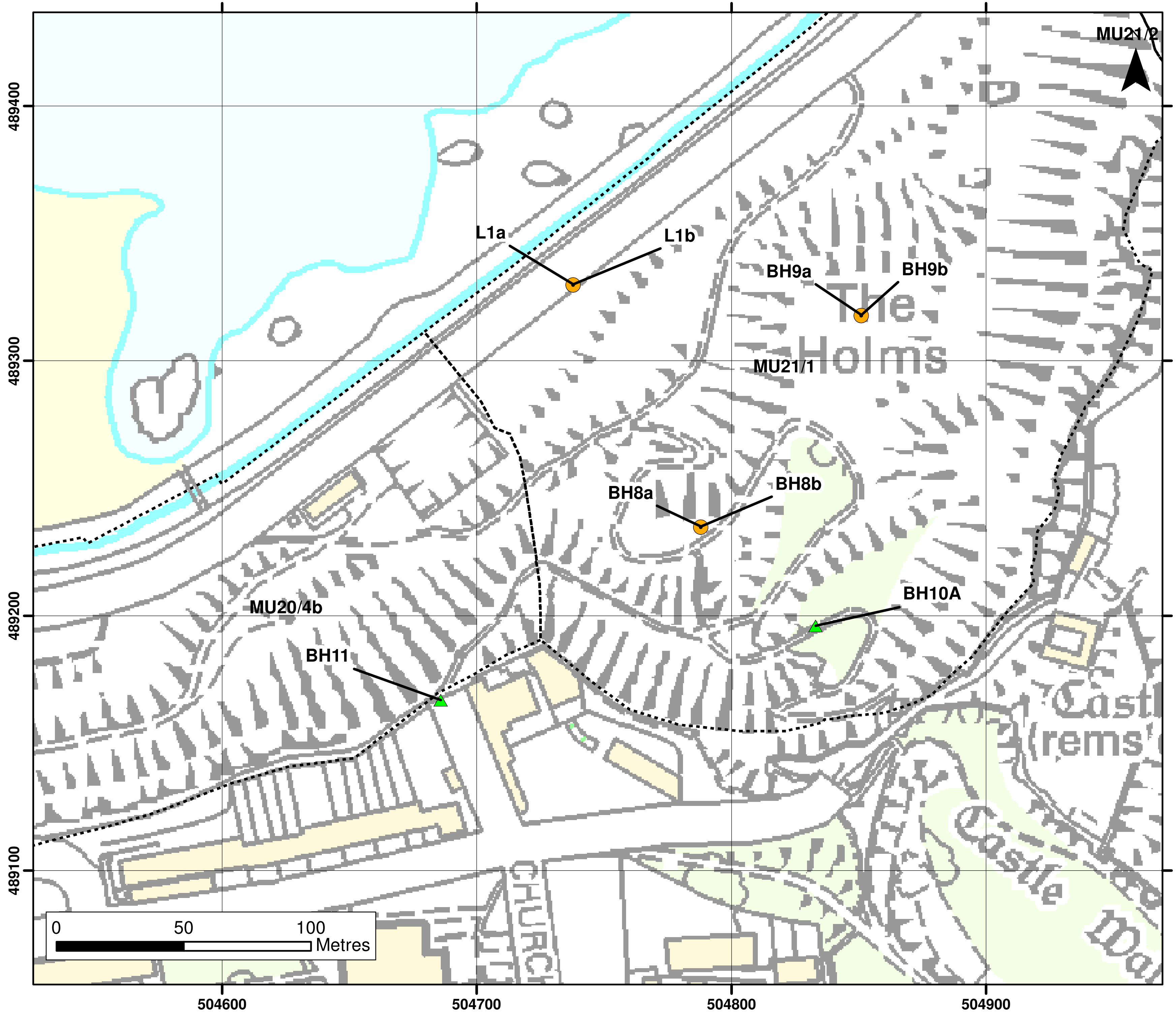

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- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

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

Client: Scarborough Borough Council

Project: Scarborough Borough Council Geotechnical Monitoring

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

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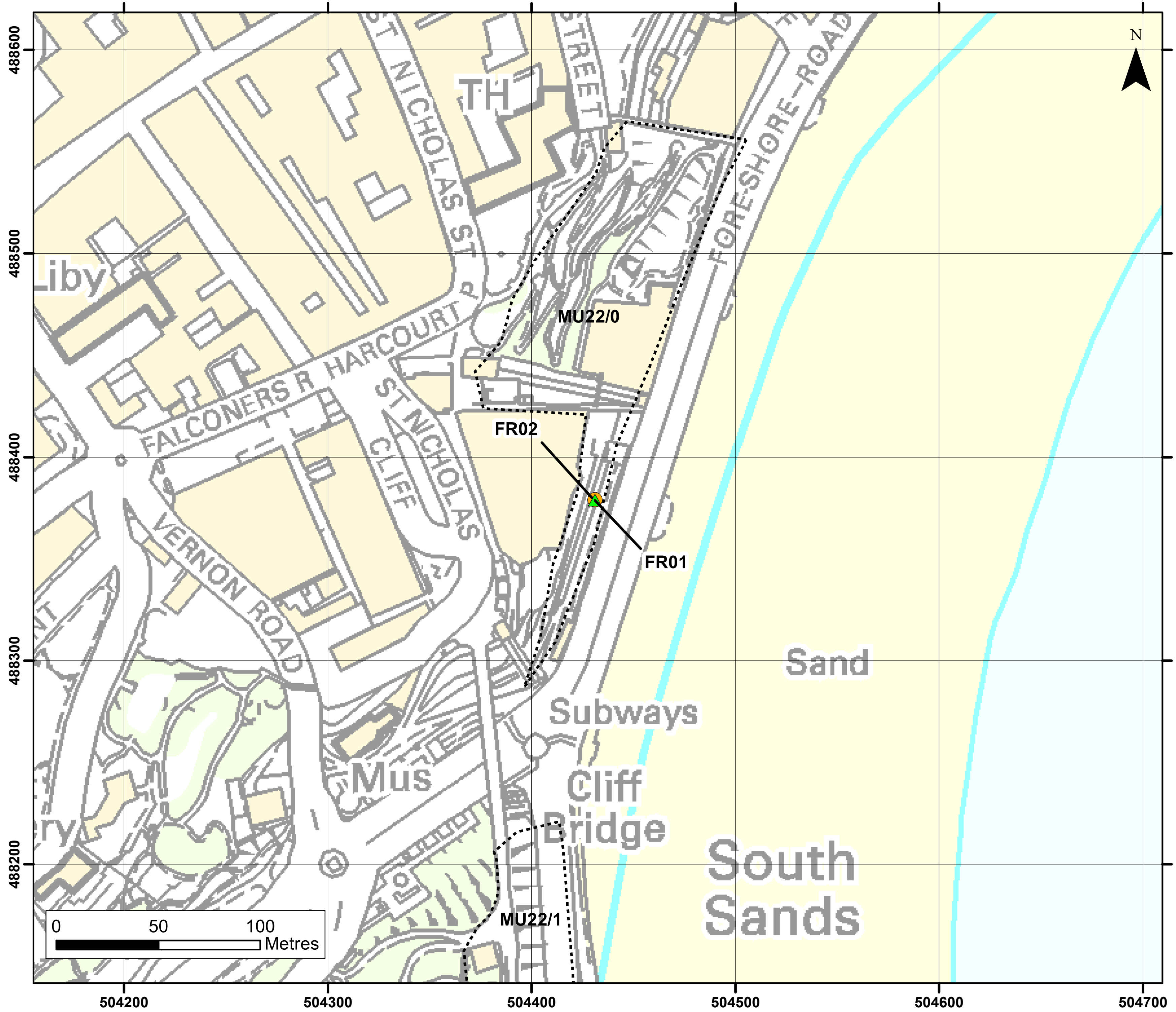

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Inactive

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

Client: Scarborough Borough Council

Project: Scarborough Borough Council Geotechnical Monitoring

Figure 9.1A Location of monitoring at Scarborough South Bay

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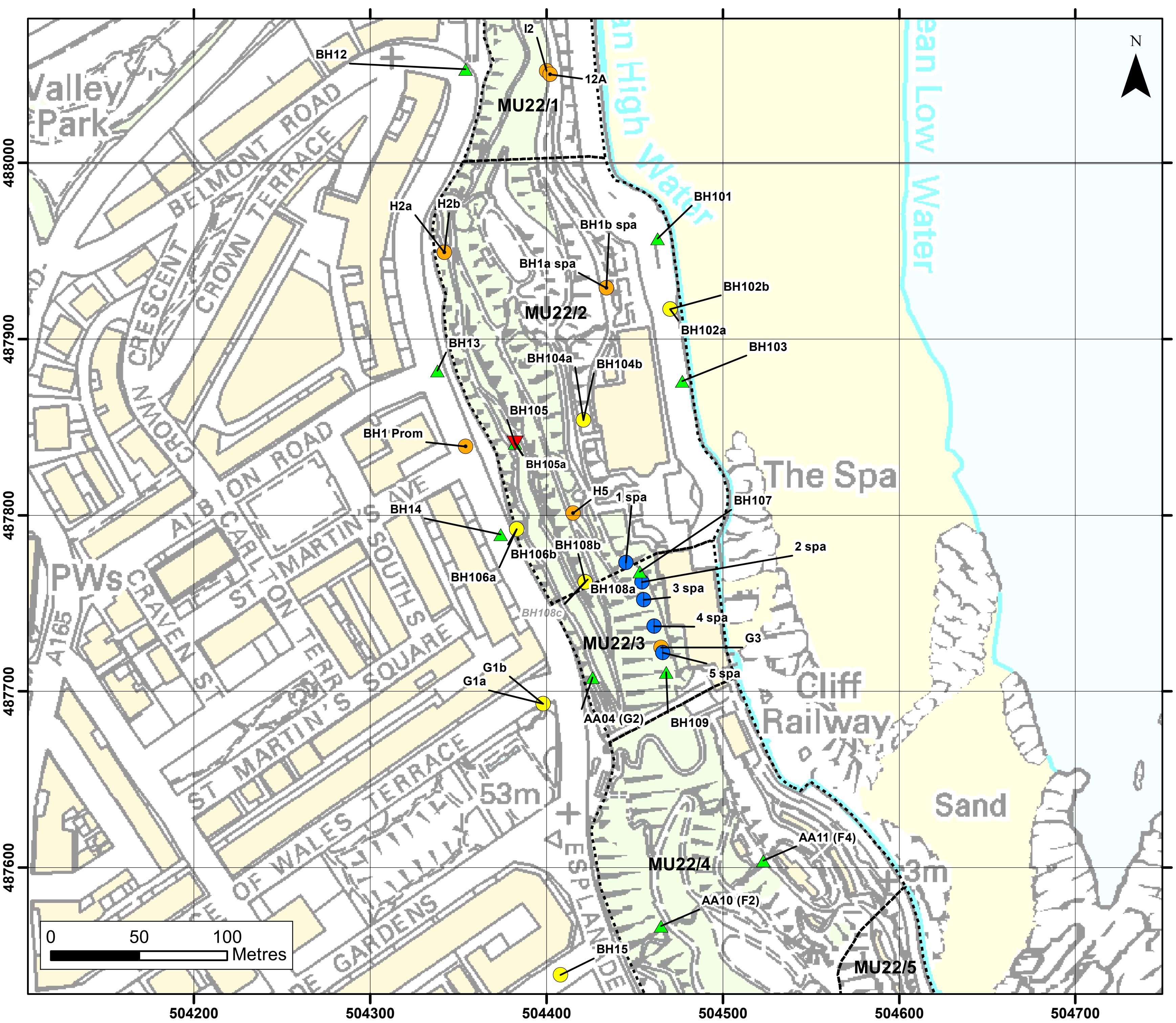

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- Piezometer (with diver)

Inactive

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

Client: Scarborough Borough Council

Project: Scarborough Borough Council Geotechnical Monitoring

Figure 9.1B Location of monitoring at Scarborough South Bay

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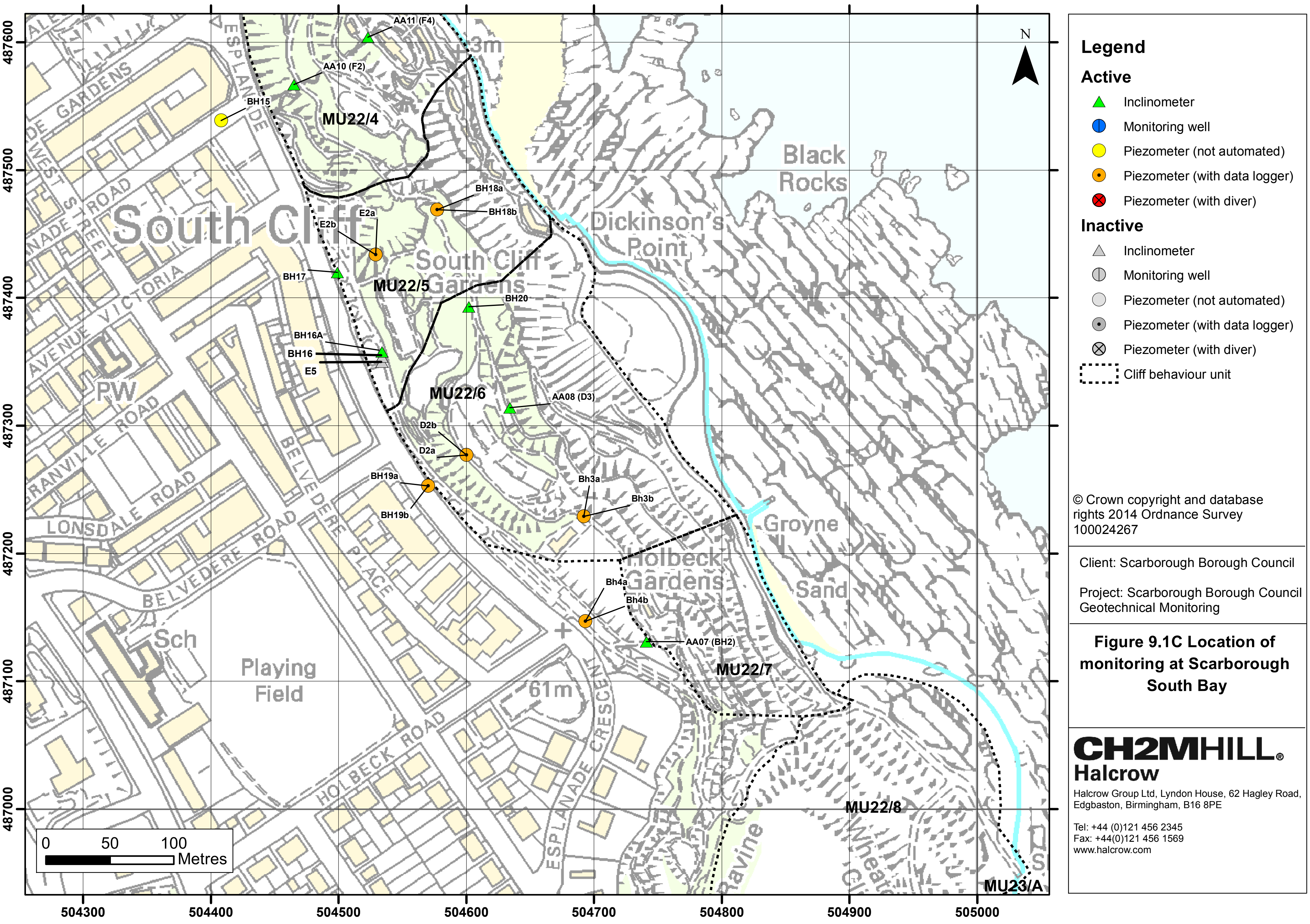

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Project: Scarborough Borough Council Geotechnical Monitoring

Figure 9.1C Location of monitoring at Scarborough South Bay

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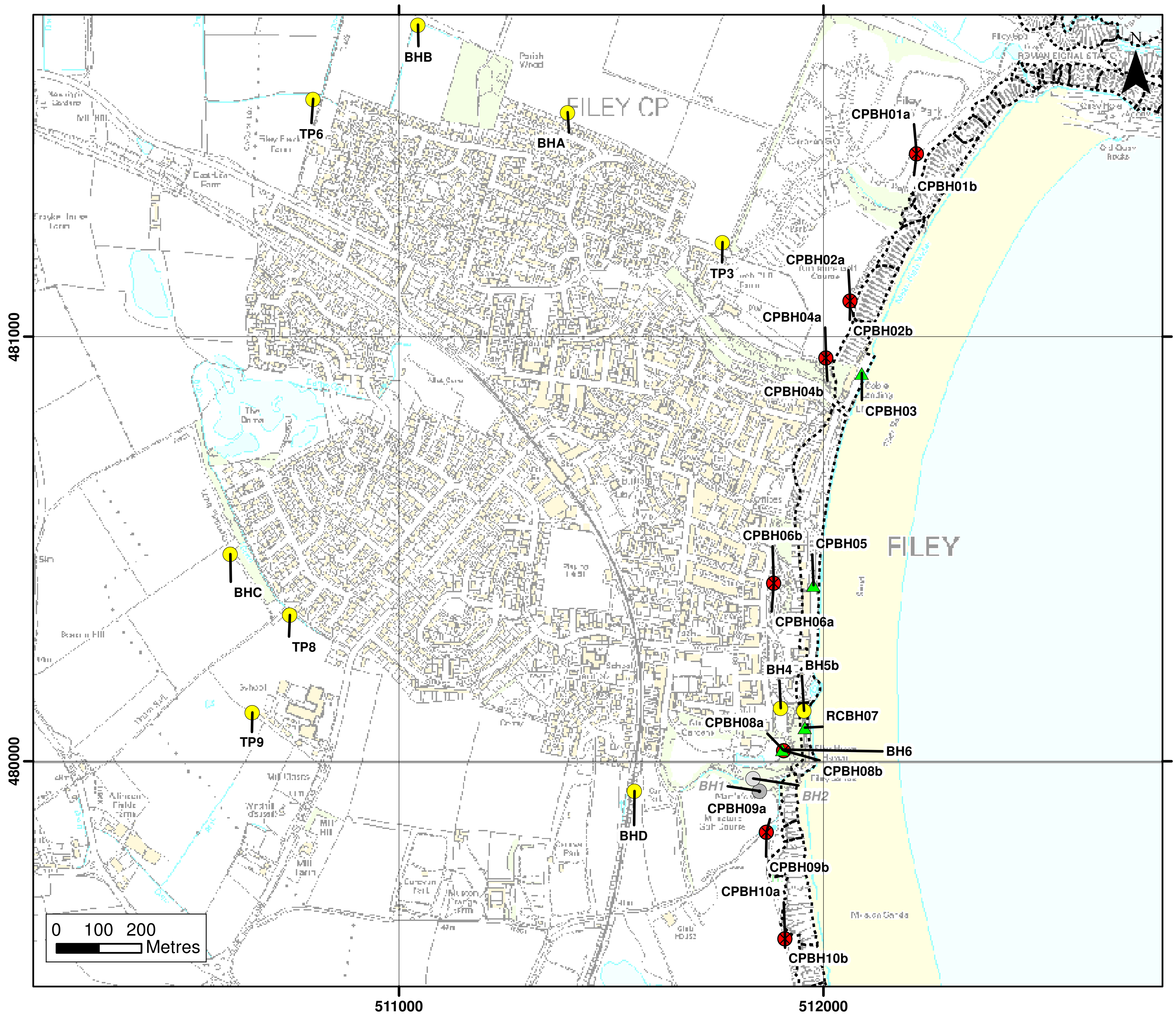

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Inactive

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

Client: Scarborough Borough Council

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Figure 10.1. Location of slope monitoring at Filey

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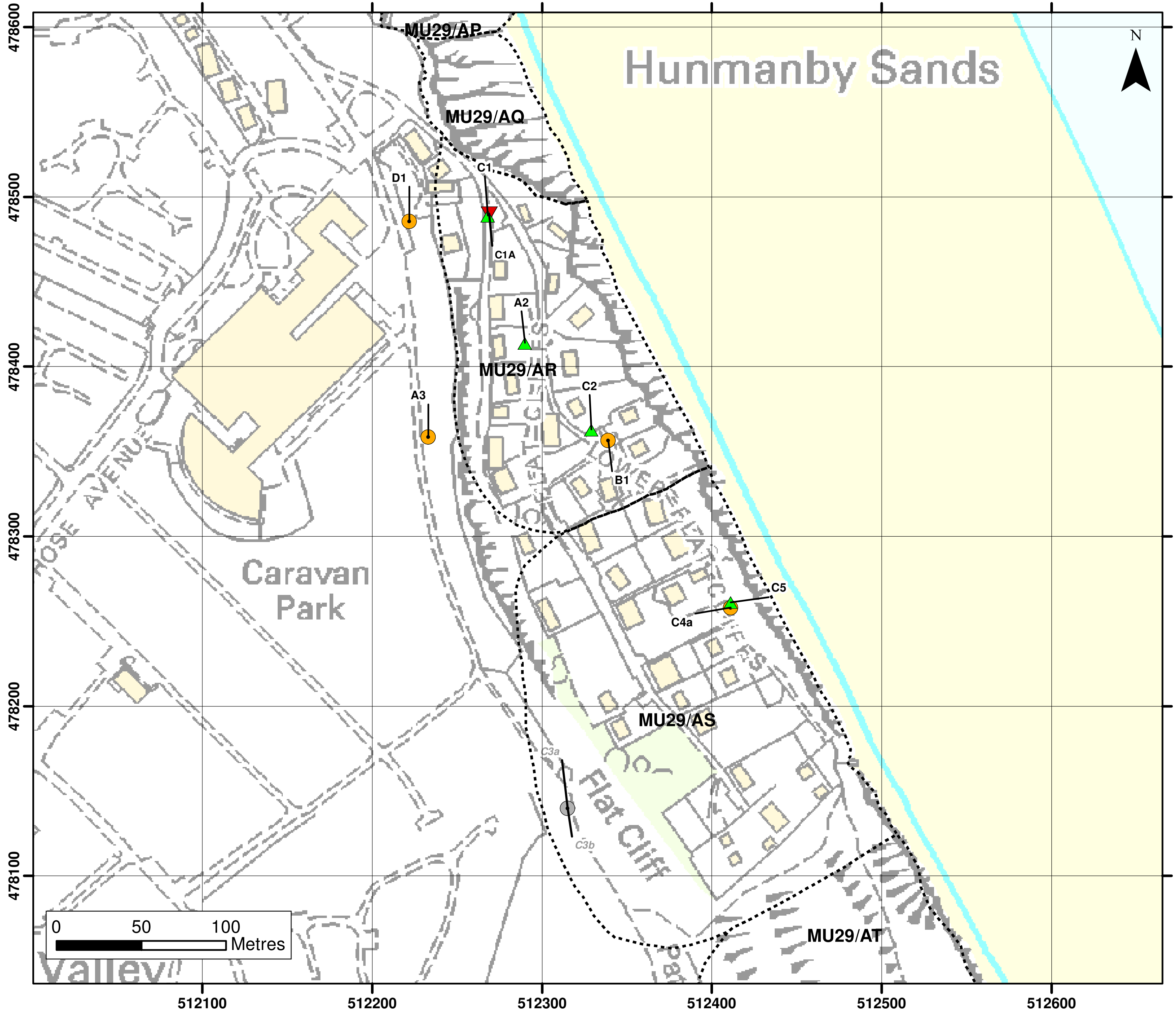

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- Piezometer (with data logger)
- Piezometer (with diver)

Inactive

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

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