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NORTHERN NSW COASTAL HAZARD ASSESSMENT

DESKTOP REVIEW

Hydrosphere

REPORT NO. 4063RMG02C

17 November 2023

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1. Introduction

This report presents the results of a summary desktop study to collate the available information relating to land instability issues for sites located at Pilot Hill and Convent Beach in Yamba and Cakora Point in Brooms Head in the Clarence Valley Council Area (CVC). This review is part of Stage 2 of the Clarence Valley Coastline and Estuaries Coastal Management Program. The sites are located on the Northern NSW coast as shown in Figure 1-1.

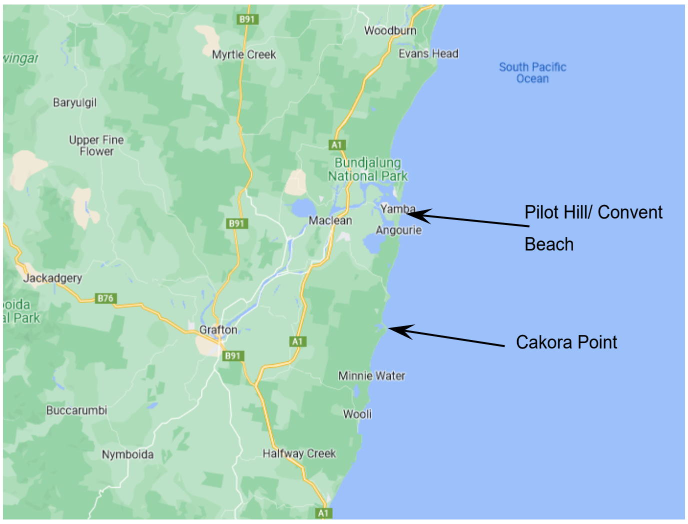


Figure 1-1 Site plan showing approximate location of subject areas (Google Maps 2022)

The scope of works for this desktop study comprises the following:

- Analysis of previous hazard assessments and recent available instability monitoring data to provide a contemporary understanding of the instability risk at Pilot Hill and Cakora Point, including:
    - Review of existing geotechnical reports and risk assessments.
    - Review of geological maps.
    - Review of aerial photography and geomorphology.
    - Development of geological and geomorphological models for cliff/slope instability.
    - Review of existing monitoring data including rainfall, groundwater and inclinometer data.
    - Identification of key geotechnical and geological hazards and processes and confirmation of landslide risk zones and mechanisms identified in previous reports.
- Identification of potential management options including ongoing monitoring, additional assessment, or remediation. Note that this review is high level only and does not involve any actual site inspections.
    - High level review of slope risk assessment undertaken using either RMS or AGS methodologies.
    - Review of existing slope stability management strategies and identify whether current mitigation measures are adequate and/or whether alternative options can be considered.
    - Identification if further studies or investigations are required and provide a road map for the next phase of the project.

1.1 Pilot Hill and Convent Beach, Yamba

1.1.1 Location and site summary

The Pilot Hill site of the study encompasses the section from Pilot Hill (Yamba Lighthouse) south to Yamba Ocean Pool including the Main Beach area adjacent to the Yamba township as shown in Figure 1-2. The Convent Beach site of the study encompasses the beach from the end of Marine Parade south-east to the end of Ocean Street.

The supplied information variously covers areas from the Clarence River mouth in the north, south to Pippi Beach.

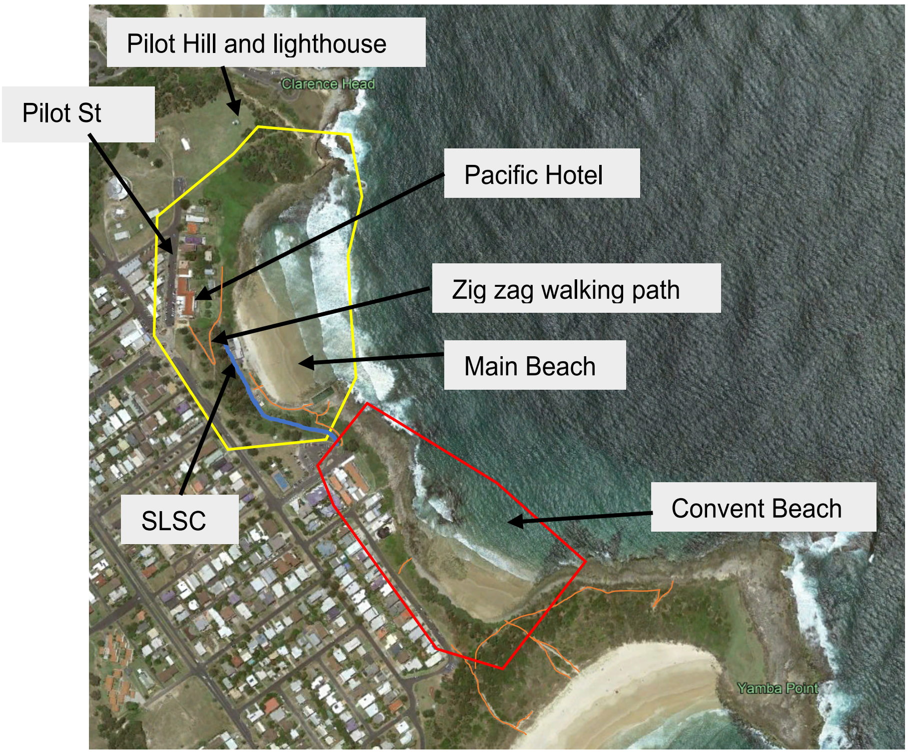


Figure 1-2 Main Beach, Pilot Hill and surrounding areas. Area of study for Pilot Hill is shown by yellow polygon, and for Convent Beach by red polygon. Marine Pde by a blue line and pedestrian walking paths in orange. (imagery from Google Earth)

1.1.2 Available Information

The following reports and data sets were made available for this review:

- Letter from JK Geotechnics (ref 19314L3 Let3, dated 23 December 2021) Geotechnical opinion on the Yamba Coastline interim emergency strategy, for Pilot Hill Yamba;
- Report from Hydrosphere Consulting (ref Job 20:038 Rev 2, dated 8 March 2021) Clarence Valley coastline and estuaries coastal management program: scoping study;

- Report from JK Geotechnics (ref 19314L3rptRev3, dated 22 December 2021) Addendum report to Clarence Valley Council: Geotechnical rainfall, groundwater, stability analyses and risk assessment for Pilot Hill, Yamba NSW;
- Report from Stephen P McElroy and Associates Pty Ltd (ref Job No 10/22, dated 31 December 2011) Yamba Coastline Management Plan, Stormwater audit of Pilot Hill Area;
- Report from JK Geotechnics (ref 19314L3rpt – Technical Report 3 Final, dated 30 August 2017) Technical Report 3, Risk Assessment and Stabilisation for Pilot Hill Yamba, NSW;
- Report from NSW Dept of Public Works and Services (DPWS) (ref MHL1045, dated May 2002) Yamba Coastline management study, Stages 1 and 2, Coastal Processes and hazard Definition;
- Hydrographs and groundwater monitoring data from Yamba Hill covering various dates, hydrographs from January 2005 to September 2021, and May 2022;
- Drone photographs of Main Beach and Convent Beach taken 10 February 2022, these photographs are oblique shots of a general nature;
- Plans and sections showing results of a Lidar survey undertaken on 10 February 2022 of Pilot Hill and Convent Beach;
- Chain of emails between Clarence Valley Council and JK Geotechnics regarding Main Beach risk assessment dated from 15 to 17 March 2022;
- Chain of emails between Clarence Valley Council and YSLSC regarding a landslide on Marine parage, Main Beach dated from 6 to 10 March 2022;
- A photograph taken on 16 September 2021 that geolocates to Marine Parade that appears to show an inclinometer and groundwater monitoring point.

It is noted that the JK Geotechnics report makes reference to several other reports that relate to the site but were not available for this study. These are noted to exist here but were not deemed to be able to provide any additional relevant information to this study. These are taken to include:

- JK Geotechnics – Technical Report 1: detailed rainfall analysis and historical search for known landslides within and around the study area, dated 21 September 2016;
- JK Geotechnics – Technical Report 2: analysis of groundwater monitoring conducted from May 2005 to about 2016, this report also contains borehole data and details of piezometers and inclinometers installed in 2005, dated 21 August 2017;
- Site investigation and installation of groundwater and inclinometers at the Pacific Hotel site by JK Geotechnics in 2005;
- Site investigation by Michael Samms and Associates (MSA) in 2000;
- Site investigations in 1999 and 1996 by Douglas Partners.

1.2 Cakora Point, Brooms Head

1.2.1 Location and site summary

This area comprises the rocky point to the east of the Brooms Head township, the site as covered by the report is shown in Figure 1-3.

Figure 1-3 General site plan of Cakora Point, area covered by SMEC report indicated by yellow polygon, distance to nearest public infrastructure shown

1.2.2 Available Information

The following reports and data sets were made available for this review:

- Report from Hydrosphere Consulting (ref Job 20:038 Rev 2, dated 8 March 2021) Clarence Valley coastline and estuaries coastal management program: scoping study;
- Report from SMEC (ref 30011071, dated 16 May 2012) Cakora Point Slope Stability Risks and Assessment.

2. Pilot Hill and Convent Beach General Information

2.1 Regional Geology and Geomorphological Context

The regional geology of the site is underlain by the Jurassic Age Marburg Subgroup which comprises fine to coarse grained, thin- to very thick- bedded, cross bedded, quartzose to lithofeldspathic sandstone, interbedded with pebbles and minor cobble conglomerate, siltstone, claystone, coal, basalt, fossil wood, and ferruginous oolite. This material is then overlain by Quaternary Age dunes and sand plains comprising calcareous and siliceous, locally shelly and/or cemented (beach rock), coastal sand dunes, beach sand, barrier beaches, foredune, and beach ridges. The material may be locally reworked.

Topsoil materials on these dune systems comprise giant podsoils whereby finely divided organic material is drawn down from the surface settling on the groundwater table. This organic material alters the redox chemistry of the groundwater resulting in the development of iron hydroxide minerals that would result in the development of brown colouration and localised cementing of the sand.

Based on the regional geological context, a sketched schematic cross section of what the local site geology is expected to comprise is given in Figure 2-1. The site is expected to comprise a dune with a seaward facing slope, with groundwater discharging from the toe of the slope from an unconfined groundwater table. The slope is defined by the dry angle of repose of the sand which is typically between 24° to 27° for fine quartz sand. The water table comprises a mound of water within the sand dune which forms an unconfined aquifer; the water table will typically fall towards the discharge point due to streaming effects. For Pilot Hill this will discharge towards the east and north-east, for Convent Beach to the north-east.

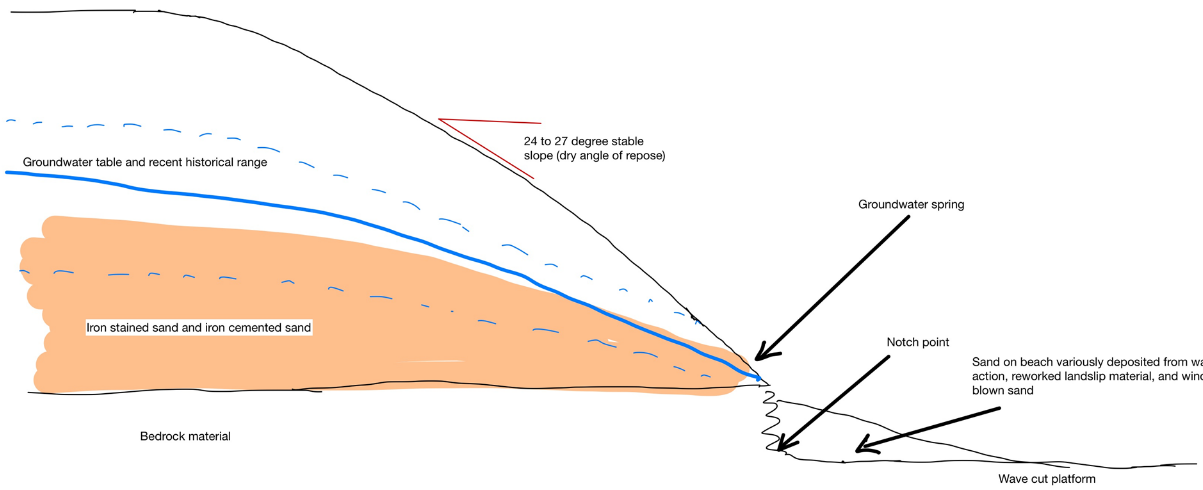


Figure 2-1 Schematic geological section of site based on typical features for this type of geological system

Anthropogenic changes affect both the natural processes and profile of the site through modifications to vegetation types, changes to drainage and groundwater infiltration, changes to slope gradients, introduction of fill materials and the removal of natural soil. These changes would have come about through the development of the site. It is understood that development of the area commenced in about the 1910's although the lighthouse was developed in the 1880's. A review of historical photographs (see Appendix D) show changes to the type and amount of vegetation present on the site as well as significant changes in the width of the sandy beach. It is understood that these changes to the beach width are in response to coastal engineering in other areas that have affected the replenishment/erosion cycle of sand on the beach.

2.2 Site Drainage Conditions

The Stephen McElroy report undertook an audit of the drainage in the area around Pilot Hill, the report looked at both surface drainage and infiltration of stormwater. The report found that drainage could be considered in relation to three main catchment areas comprising the water reservoir reserve and Pilot St, the residential properties, and Marine Parade and the land to the top of the cliff face.

Analysis showed that recharge of the unconfined aquifer differs in each catchment, with 67% of water coming from the water reservoir catchment, 22% from the residential property catchment and 11% from the Marine Parade catchment. The analysis also showed that the groundwater monitoring appears to be representative of the expected behaviour within the dune.

This report proposed the installation of sub-surface drainage to reduce the chance of an increased water table and it is understood that some of these works have been completed, but no information is given as to the extent of the works completed.

Interestingly the drainage report provides considerable background information on the site with reference to damage and to remediation of buildings in this area and information on proposed developments in the area.

2.3 Expected Instability and Geotechnical Issues

Based on the site geology there is an expected form of slope instability that would apply to both the Pilot Hill and Convent Beach sites. This instability is shown schematically in Figure 2-2. Failures would be expected to follow this progression:

- Minor failure at the toe of the slope, this may be caused by one or more of: localised scour, a tree falling over or other loss of vegetation, elevated streaming groundwater, or retreat of the wave cut platform;
- Material above this minor slip will calve off in small sections in durations of hours to weeks, note that the failure may also spread laterally from the initiation point;
- The basal plane of failures will comprise the angle of repose for the sand material and is expected to be between 24° and 27°, the failed slope will settle with a batter within this range.

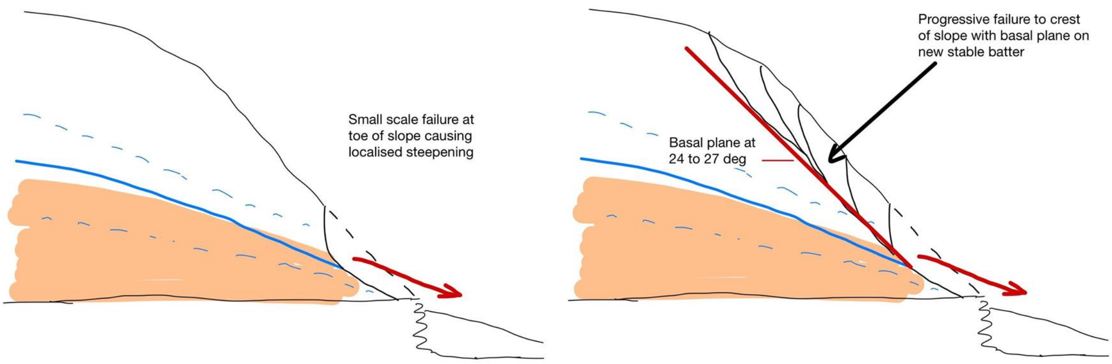


Figure 2-2 Schematic expected slope failure for beach facing dune slopes

Both sites are subject to ongoing geological processes and in the long term it is expected that the slope would continue to regress. Any rise in sea level is likely to accelerate this regression, particularly if waves are able to break directly onto the toe of the dune sand slope.

2.4 Development Controls Applicable to Site

The current development controls that are applicable to the Pilot Hill and Convent Beach sites has been reviewed regarding control for sites subject to landslides or other geotechnical hazards.

Part C General Development Controls for Residential Zones – Section C28 Sites Subject to Land Slip / Geotechnical Hazard requires a specific geotechnical report must be compiled where:

(a) land has a potential for landslip due to natural slope and/or soil conditions (geotechnical hazards) and/or

(b) Land has a potential for landslip due to coastal forces or river flow conditions; and/or

(c) Land is identified as being of particular concern due to geotechnical hazards; and/or

(d) Any developments that will or may generate a geotechnical hazard due to the work proposed, developments such as those involving excavation close to another property or near a large tree, deep excavations that may impact on adjoining property, deep filling or any other activity that will or may significantly increase the geotechnical risk to another property.

The above requirements are provided in broad terms, and it is recommended as part of the Site Analysis (Part J4) that steep land or land slip areas must be considered where relevant.

From a local context, the Yamba Hill Controls (Part W of the Residential DCP) cover development controls specific to this residential zone. The Yamba Hill Controls (Part W of the DCP) do not specifically address the risk of slope instability at Pilot Hill or Convent Beach.

3. Pilot Hill

3.1 Identified Instability

3.1.1 Historical Landslide Events

The JK Geotechnics report (2017) indicates that historical landslide events have been recorded around the Pacific Hotel since May 1921. The report does not postulate if instability may have been present at the site prior to this date. Figure 2-1 shows the location of some of these previous landslips. These historical landslips at the Pacific Hotel site appear to be reactivations of the same landslide during peak weather events.

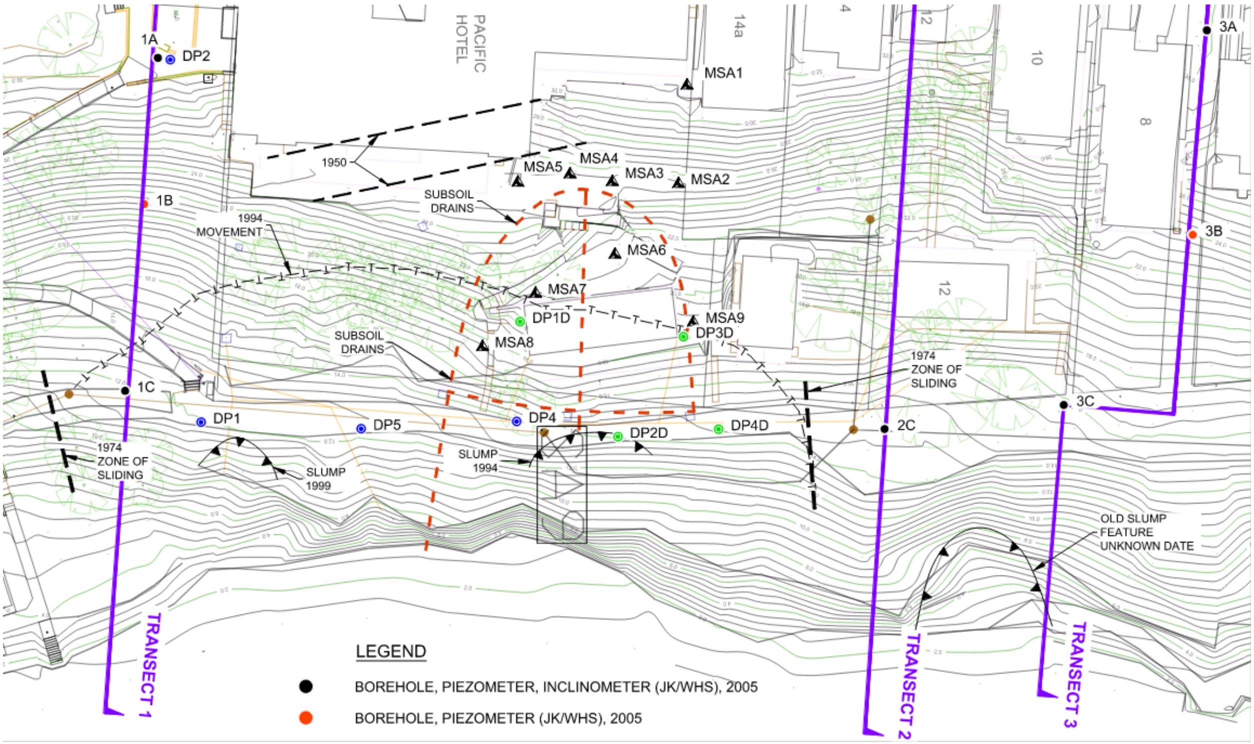


Figure 3-1 Exert from "Plan showing previous slips and subsoil drains" from 2017 JK Geotechnics report, shows several landslip features that have developed around the Pacific Hotel since construction as well as site investigation and monitoring points

The JK Geotechnics report summarise the types and occurrence of several type of landslides on the site:

- Scour events occurred following short duration high intensity rainfall events in May 1921, May 1938, March 1999 and June 2011;
- Earthslide events appear to occur following short and medium term critical rainfall periods and correspond with elevated groundwater levels within the soil profile. These types of events occurred in June/July 1950, April 1962, March 1974, May 1977, August 1989 and March 1994;
- Earthflow events were recorded in April 1988 and February 2002. The former event appears to be associated with similar circumstances as the Earthslide events, but the latter may have been triggered or made worse by a broken pipe.

An extended summary of the historical events and details of historical data is in Appendix B of the JK Geotechnical 2017 report and has not been reproduced here.

3.1.2 2022 Marine Parade Landslip

In March 2022 a landslip affected the Zig Zag walking path located on the slope above the Surf Life Saving Club (SLSC) and extending into the area below the Pacific Hotel affected by historical land sliding. A drone photograph of the site shows the location where the landslide occurred, other drone photographs of this site are included in Appendix C. Note that the landslide occurred after this photograph was taken, but the slip locations have been matched between the drone imagery and the provided slip photographs.

Figure 3-2 Drone imagery of Zig Zag path (taken 10 Feb 2022), an area of land sliding occurred in about the area of red polygon, with tension cracks below the Pacific Hotel shown by red dashed lines. Additional scour and tension cracks affected the road leading to the SLSC (below the photograph above)

In response to this event access to the SLSC and Marine Pde, the boardwalk construction and the walking path below the Pacific Hotel were closed for several weeks. Analysis of the rainfall data and groundwater levels by JK Geotechnics indicated that groundwater levels were at about peak historical levels when previous landslides had occurred. The closure was to reduce the risk to the public and allow time for the groundwater levels to dissipate. These small failures are indicative of the failure modes described in Figure 2-2.

3.2 Exposure to Landslides

3.2.1 Infrastructure/Buildings

JK Geotechnics (2017) indicate that the Pacific Hotel suffered extensive damage due to a historical landslide in 1950, with additional damage occurring on the slope below the building over the ensuing years. This report indicates that neighbouring buildings along Pilot St (#14) would have similar exposure but the risk to life is lower due to lower occupancy.

Other buildings that have a lower exposure to landslides include the other buildings along Pilot St (#2 to #8 and #12), the SLSC, Zig Zag walkway, Marine Pde and subsoil drainage installed to relieve groundwater pressure from the slope.

3.2.2 Site Traffic

Pedestrian traffic occurs on both formed and informal paths. Formed paths include the public boardwalk and paths associated with the Zig Zag walkway, access along Marine Pde and beach access points. Additional private walkways extend from properties on Pilot St to the extended Marine Pde road reserve. These formed paths are generally constructed with a paving surface and are delineated with edging or rails to keep pedestrians on the path. The informal paths comprise walking tracks formed by repeated short cuts by pedestrians across the site. These break down vegetation cover and are prone to erosion.

Vehicle traffic into the site is along Marine Pde comprising a combination of sealed and brick paved roadway between Queen St and the SLSC, to the north of the SLSC an unsealed vehicle access is present to 12 Pilot St. Photographs of this area show that the pavement is not fitted with a kerb on the downhill side meaning that stormwater can overtop the slope from the edge of the pavement. It would appear that some of the photographs of the 2022 landslide damage may include scour damage and undermining of the pavement to Marine Pde.

3.3 Monitoring Regime

3.3.1 Rainfall Monitoring

JK Geotechnics have undertaken several analyses of rainfall data collected from the nearby Yamba Pilot Station on Pilot Hill. This station has continuous rainfall records from 22 May 1887 to present, with a gap between 27 January to 28 February 2017. This report includes plots of expected return periods of significant rainfall events.

3.3.2 Existing Instrumental Monitoring

Instrument monitoring has been installed around the Pacific Hotel site and recent historical landslips along three transects as shown in Figure 2-3, below. In total the instrumental monitoring comprises 11 piezometers and 6 inclinometers.

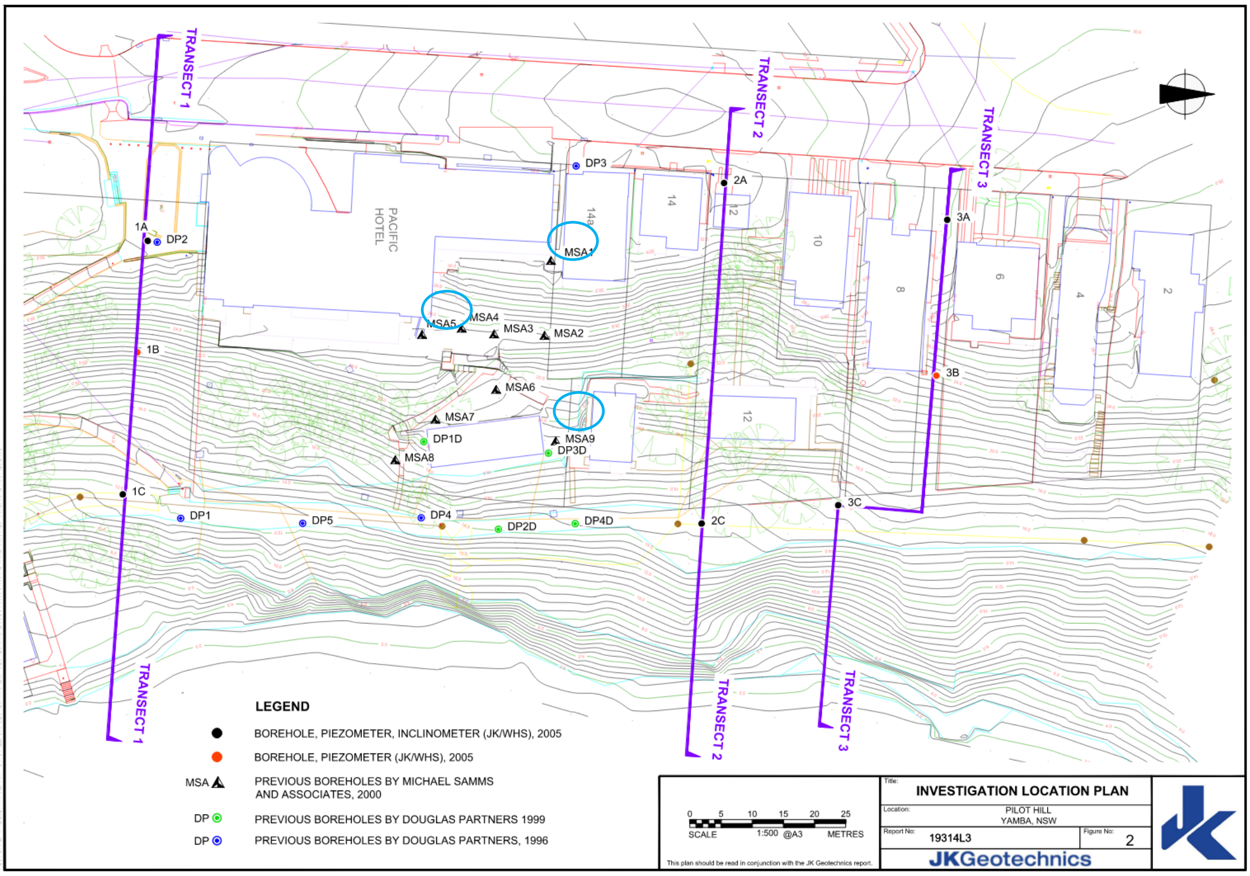


Figure 3-3 Plan from 2017 JK Geotechnics report showing the location of monitoring points. The three Michael Sam and Associates (MSA) boreholes with piezometers installed are indicated by blue ellipses

The piezometers comprise eight 50mm PVC standpipes with a 0.75m long screened section at the toe of the borehole installed by JK Geotechnics in 2005. A further three standpipes from the MSA investigation have had piezometers installed, although the details of construction of these boreholes is unknown. CVC have engaged an external contractor (Groundwater Data Collection Services) to undertake the collection of groundwater data on a 30-minute interval since 2005. Generally, the continuity of data collection is good with minor time gaps present in all piezometers, but there are large time gaps in the records for YAM3B (Borehole 3B on Transect 3) with only a handful of readings available for YAMMSA5. A copy of groundwater level plots from the Groundwater Data Collection Services report for each of the piezometers is included in Appendix A. The McElroy report indicated that through comparison to groundwater modelling the data from the piezometers appears to accurately reflect the groundwater conditions within the slope.

Six 70mm PVC inclinometers were installed by JK Geotechnics in 2005 that were drilled through the sand dune materials and socketed into the underlying sandstone bedrock. Monitoring of these inclinometers is infrequent with three readings in 2005, one each in 2006, 2007, 2014, 2016 and 2021; however, it appears that not all the inclinometers have been read at the same time. Copies of the inclinometer data from the JK Geotechnics report are included in Appendix A. It is noted that only inclinometers 2C and 3C show any indication of long-term slope displacement of about 15mm to 20mm over the monitoring period. This movement is occurring within the upper 2m to 3m of the subsurface profile and at the interface between the silty sand and sandy clay layer. Over the period of time that these measurements were recorded, these movements are evidence of very slow to slow creep movement occurring at these locations. It was noted during the last set of measurements that readings could no longer be undertaken in 1A and 2C due to possible blockages. This report attributes the inability to read the instruments to movement within the slope and possible surface damage, but does not indicated how they arrived at this conclusion. The single large movement in 3A in 2016 before a return to previous values in the most recent test is probably the result of a bad reading (usually caused by not allowing the inclinometer to settle in the hole).

3.3.3 Existing Inspection Monitoring

No records have been given that indicate that regular periodic inspections are undertaken on the site. The records appear to indicate that inspections are only undertaken in reaction to landslide events.

3.3.4 LiDAR Survey of Site

A LiDAR survey was undertaken of the site in February 2022 with slope sections provided at four locations. It is noted that the position and topography of the slope underlying thick vegetation is interpolated rather than directly measured. The angle of the slope of the vulnerable toe parts of these sections were calculated and are summarised as:

- Align 1 – This section is across part of Marine Pde south of the SLSC where the slope has been modified for the installation of a carpark, this section is not representative of the natural conditions;
- Align 2 – Toe slope angle of 32.2° over a vertical height of 6.3m, this section of the slope failed three months after the LiDAR survey;
- Align 3 – Toe slope angle of 29.9° over a vertical height of 8.6m, this section corresponds to Transect 2;
- Align 4 – Toe slope angle of 26.6° over a vertical height pf 10m, this section corresponds to Transect 3.

The LiDAR survey cross sections are included in Appendix C.

3.4 Slope Risk Assessments

3.4.1 Site Investigation Data

Due to the landslip history of the slope below the Pacific Hotel there has been several penetrative site investigations undertaken, based on the provided information borehole data for this part of the site should be available from the following sources:

- Five boreholes by Douglas Partners in 1996, these comprised two near Pilot St on the north and south sides of the Pacific Hotel, with three other holes along the Marine Pde road reserve below the hotel;
- Four boreholes by Douglas Partners in 1999, these were located along the Marine Pde road reserve and around the staff quarters building;
- Nine boreholes by Michael Samms and Associates in 2000, these were located between the hotel and the staff quarters building. Three of these boreholes have piezometers fitted and are monitored for groundwater levels;
- Eight boreholes by JK Geotechnics in 2000 with the boreholes finished with either piezometers or inclinometers, where both are installed two boreholes were installed within a metre of each other. These boreholes were drilled on slope sections between Pilot St and the beach, Transect 1 is on the southern side of the Pacific Hotel, Transect 2 is between #12 and #14 Pilot St, and Transect 3 is between #6 and #8 Pilot St.

Details of where these site investigation points are located, and the sections (transects) is given in Figure 3-3. No borehole logs were in any of the reports provided for this study.

Note that the Australian Standard that details how soil and rock materials are to be logged changed in May 2017. Although most soil materials logged to both the previous version (AS1726 – 1993) and the current version (AS1726 – 2017) of the standard will have the same definition. Some soils, particularly admixtures of clay/silt and sand/gravel, will have differing definitions depending on the standard that they are logged to. This should be considered when comparing the historical drilling results with any future site investigations.

3.4.2 Numerical Modelling

The reports refer to three types of numerical modelling on data obtained from the site, these comprise:

- Modelling of the rainfall from the Pilot Hill station to assess the rainfall intensity/duration and return periods for the site. The AEP plot for the site for data between 22 May 1887 and 15 July 2021 is given in Appendix A of JK Geotechnics (2021) Addendum report;
- Groundwater modelling with respect to rainfall was referred to in the JK Geotechnics 2017 report. This indicated a peak in groundwater at the crest between 3 and 15 days after the highest 1 or 2 day rainfall events. The mid and lower parts of the slope saw peaks during the highest 1 or 2 day rainfall events. It was also noted that the mid and lower parts of the slope drain relatively quickly whereas the crest takes longer. The groundwater modelling allowed the selection of a rainfall trigger value that would result in elevated groundwater levels that would result in an increased likelihood of a landslip;
- Stormwater modelling was undertaken by Stephen P McElroy and Associates to check on the likely sources of groundwater, ie run-off versus infiltration. This study found that 67% of the rainfall on the ground west of Pilot St, about 22% of the rainfall on Pilot St and about 11% of the rainfall onto the slope east of Pilot St infiltrates the ground to recharge the groundwater table. This study also found that the piezometer data provides a robust correlation to rainfall events;
- Slope stability modelling was undertaken by JK Geotechnics in the 2017 report. This modelling considered various scenarios of groundwater levels, types of failures and locations of failures. This showed that increased groundwater levels directly reduce the factor of safety of the slope, with historically high levels resulting in problematic factors of safety. This modelling and the results of the groundwater analysis were used to inform the slope risk assessment and provide indicative values of probability for different types of events.

3.4.3 Slope Risk Assessment

The AGS 2007 slope risk assessment method is a probabilistic approach to the assessment of landslide risk and hazard. It uses utilises an assessment of likelihood and consequences to property and/or life to provide a consequence assessed between Very Low to Very High.

The slope risk assessment is contained within the JK Geotechnics 2017 and 2021 report and uses this AGS 2007 methodology. The report notes that the analysis was based on risk to life only and does not include the risk of damage or destruction of infrastructure, amenity, or buildings. The analysis broke the slope below Pilot St into four zones as shown in Figure 2-4. No analysis was undertaken on the slope south of the Pacific Hotel or other slopes along Main Beach.

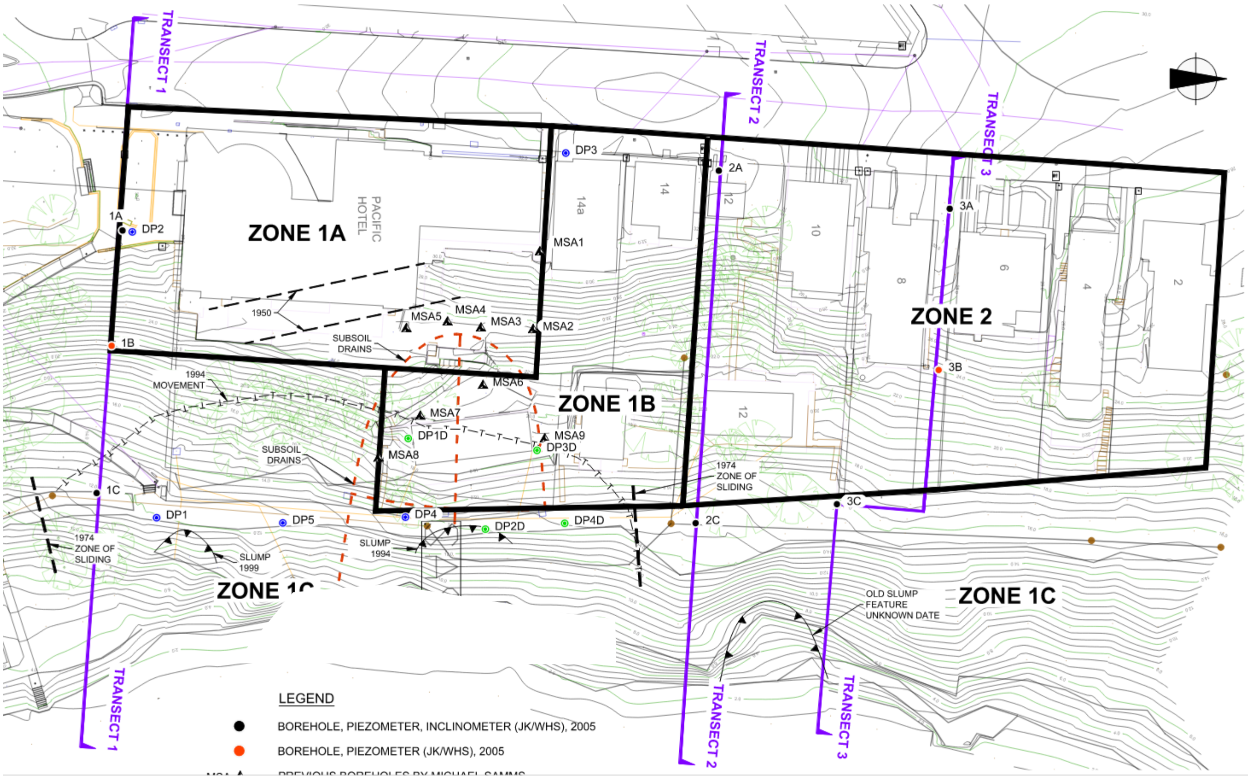


Figure 3-4 Landslide risk zones used for slope risk assessment by JK Geotechnics (2017)

The analysis used the following risk estimates for the Indicative Value of Approximate Annual Probability:

- Tolerable risk of 10^{-4} (0.01%) for loss of life for the person most at risk;
- Acceptable risk of 10^{-5} (0.001%) for loss of life for the person most at risk.

The calculation of risk is a product of the probability that the event (slope failure) will occur and the consequences if the event does occur. For a loss of life assessment, the consequences are loss of life. The probability is a product of the following partial probabilities:

(a) Spatial probability – if the event occurs, will it impact an element (structure or person). This is dependent on the speed of the landslide (whether there is sufficient warning) and is categorised as either “very slow to moderate” or “rapid to very rapid” movement and whether the landslide causes significant structural damage

(b) Temporal probability – if the event occurs and the element is impact, what is the probability that people will be within the element (house, hotel etc) at the time of the event

(c) Vulnerability – if the people are impacted, what is the probability that there will be a loss of life

The JK Geotechnics 2017 and 2021 reports considers each of the above probabilities for each landslide zone. The results of the most recent (2021) slope risk assessment are summarised in Table 2-1.

Table 3-1 Summary of Slope Risk Assessment for slope east of Pilot St (JK Geotechnics 2021)

Landslide Risk Zone	Very Slow to Moderate Movements		Rapid to Very Rapid Movements	
	Annual Probability	Risk Estimate	Annual Probability	Risk Estimate
Zone 1A	$2.1x10^{-5}$ to $1.0x10^{-5}$	TOLERABLE to ACCEPTABLE	$5.6x10^{-4}$ to $2.7x10^{-4}$	UNACCEPTABLE
Zone 1B	$5.9X10^{-6}$ to $1.4x10^{-6}$	ACCEPTABLE	$2x10^{-4}$ to $4.9x10^{-5}$	UNACCEPTABLE to TOLERABLE
Zone 1C	$<1x10^{-6}$	ACCEPTABLE	$<1x10^{-6}$	ACCEPTABLE
Zone 2	$5x10^{-7}$ to $5x10^{-8}$	ACCEPTABLE	$1.8x10^{-5}$ to $1.8x10^{-6}$	ACCEPTABLE (just)

The slope stability analysis showed that the likelihood of a landslip in Zone 1C is significantly higher than elsewhere, but due to the low occupancy of this area the probability of a loss of life is significantly reduced.

For each landslide zone, the “rapid to very rapid movement” is only considered plausible or possible for the near surface materials. The more likely land sliding scenario is the “very slow to moderate movement”, which has been observed both physically and historically. Given the “rapid to very rapid movement” scenario is governing the landslide risk for Zone 1A, 1B and 2 further review of whether the failure of near surface materials is able to impact the elements at risk, should be undertaken.

This slope risk assessment is based on the assumption of global slope failure as shown in the slope stability analysis contained in the JK Geotechnics (2017 and 2021) report/s. These failure models are typically circular in nature and may not represent the geological and failure model shown in Figure 2-2. As the “rapid to very rapid movement” land slide speed governs the risk assessment, further investigation should be given to the failure geometries in these slopes stability models to assist in refining the Slope Risk Assessment. Consideration should also be given to better defining the failure geometry and potential variability in material strengths, which could further guide probabilistic slope stability analyses as inputs into the Risk Assessment.

Furthermore, it does not appear to account for the effect of subsoil drainage works, or remediation undertaken on the Pacific Hotel to underpin the foundations. Since the analysis only accounted for loss of life it has been skewed by the higher population density contained in the Pacific Hotel (Zone 1A). It would be expected that the results of the analysis would change if the risk to property was considered, if slope failure is based around the progressive slip mechanism contained in Figure 2-2, and if the effects of slope and foundation remediation were considered.

3.5 Emergency Management Plan

In accordance with recommendations in MHL (2002), McElroy (2011) and JK Geotechnics (2017), Council currently implements a strategy to respond to the risks associated with rainfall events, which is aimed at identifying possible rainfall conditions that may trigger a landslide event. Rainfall is monitored to identify conditions that may give rise to an emergency as follows:

1. A period of prolonged high rainfall, up to periods of 90 days.
2. A period of high daily rainfall after previous wet periods.
3. High intensity rainfall over short periods of say 1 day or less.

Emergency rainfall warning levels were set up based on analysis of historic rainfall data. Two warning levels are assigned - an Orange Alert Level which was based on a 1 in 3 year rainfall event, and a Red Alert Level which is based on a 1 in 10 year rainfall. The levels are revised based on actual rainfall. At its meeting of 26 April 2022 Council adopted (Resolution 07.22.084) revised “orange” and “red” alert antecedent rainfall levels as recommended in the JK Geotechnics (2021) review of the Interim Emergency Management Plan. The current warning levels are shown in Table 2-2.

Antecedent Rainfall Period (days)	Orange Alert Level (mm)	Red Alert Level (mm)
1	180	200
2	200	280
5	215	325
8	250	370
15	310	425
30	425	560
45	500	675
60	600	800
90	740	955

Table 3-2 Rainfall Warning Levels (Source: JK Geotechnics (2021))

The warning levels apply to land within Landslide Risk Zones (LRZ) 1a, 1b, 2 and 3 shown in Figure 2-5 extending from 2 Pilot Street south to the Pacific Hotel.

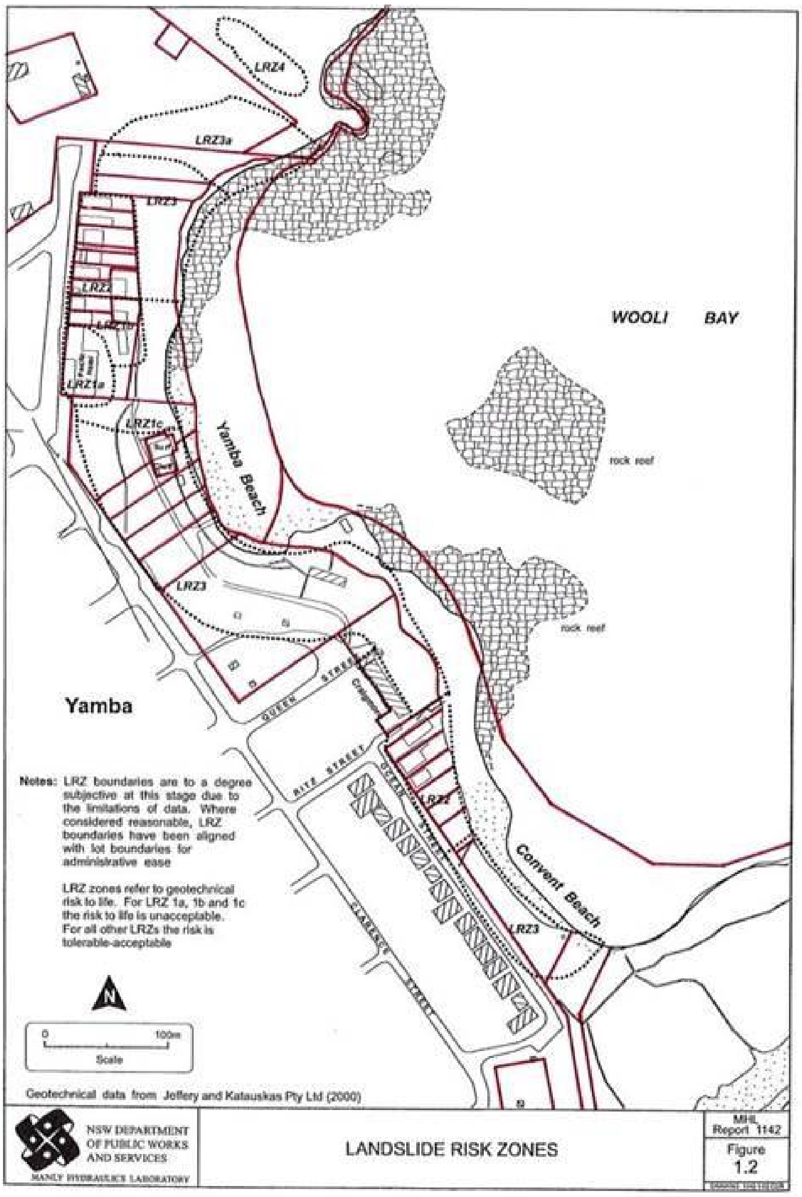


Figure 3-5 Landslide risk zones subject to emergency alert levels

Council monitors the rainfall and alerts landowners and occupants if rainfall levels meeting the orange or red levels are experienced or expected. It is the landowners' responsibility to monitor their premises for any evidence of movement once an alert advice has been notified and based on those observations and their own assessment of their building's structural design, make their own assessments as to whether further action is necessary. Council also advises emergency service representatives who are responsible for evacuation advice. If the orange or red levels are reached, Council will inspect drainage infrastructure to ensure that it is functioning properly. If the red alert level is reached, Marine Parade will be closed to vehicular traffic, the zig zag path will be closed to pedestrians and the Yamba SLSC will also be closed.

3.6 Recommendations for Future Work

3.6.1 Overview

The ongoing failures or movement that is being observed is a combination of superficial scouring and oversteepening due to concentrated stormwater flows, saturation, and failure of the upper sand materials due to perched water tables and slow creep movement of the entire sand dune mass, most likely on the interface with either the silty sand or sandy clay layer. The more recent failures appear to be due to the first two mechanisms.

The failure mechanisms are expected to be ongoing, and while the current slope stability management strategies (rainfall monitoring) serves to provide prior warning of slope failures (albeit not in real time), it does not provide resolution for CVC or stakeholders on how the slope can ultimately be stabilised or managed. It is recommended that short term (< 1 year) and long-term (> 1 year) management strategies are weighted equally towards minimising the slope risk and while determining the long-term stabilisation requirements.

Each report that has assessed the conditions at Pilot Hill have made recommendations regarding methods of stabilising the slope and/or reducing the risk of landslides on the slope. These included:

- Establishment of subsurface drainage to draw down the groundwater table faster;
- Changes to surface drainage to reduce the amount of rainwater infiltration;
- Further monitoring of groundwater and slope movement;
- Modifications to the foundations of structures in the study area to reduce the impact of landslide events;
- Reprofiling of the slope;
- Installation of structural elements such as a toe berm, piles or soil nails to strengthen the slope.

Regardless of these options above the following recommendations are made for further work on the site. Any infrastructure maintenance or improvements would only be recommended if they are expected to result in reduced risks at the site.

To assist Council with planning and decision making, these recommendations have been split between short-term and long-term recommendations:

3.6.2 Short-term Recommendations (< 1 year)

The focus of the short-term recommendations should be focussed on ensuring that the geotechnical information and monitoring data is sufficient and suitable to allow further review of the slope stability analysis and AGS 2007 Risk Assessment. The following is recommended:

- **Emergency management strategy:**
    - Continue the existing emergency management strategy involving rainfall monitoring and alerts until other short-term recommendations are completed. Based on the results of the monitoring program review, additional geotechnical investigations, updated slope stability analysis and risk assessment and the status of remediation measures described below, the emergency management strategy (alert levels and application area) should be reviewed and updated to reflect the revised risk information.
- **Review and repair existing instrumentation**
    - A review of the condition of the inclinometers be made using a small diameter pipe camera to assess whether the blockage within the inclinometers is the result of deflection, sedimentation and/or vandalism. For the inclinometer casing to have moved to the point of blocking passage of the inclinometer probe the casing would need to be sheared or crushed due to excessive bending, however, the displacements indicated for the site are insufficient to expect this sort of damage to the inclinometers. It is common with inclinometers installed in public places to have inquisitive individuals drop items down them causing blockages, these items can be removed and the instrument rehabilitated;
    - Approximate costs for review and repair of instrumentation are $5k to $10k.
- **Review monitoring program:**
    - The current reading interval for the piezometers is satisfactory, but the inclinometers should be read at least annually and following a peak rainfall event.
    - While the piezometer readings have provided a robust correlation with the rainfall events, a correlation with slope movement is still uncertain. This is largely due to the infrequent, manual, readings of the inclinometer locations. Repair of the existing inclinometers should be attempted, however, if this is not successful, then new devices should be installed. If CVC doesn't want to manual hire cost of reading the inclinometers, then the installation of automated In-Place Inclinometer (IPI's) linked to a cloud database may be a worthwhile investment. There is a high initial investment in these systems, however, they become more cost effective for long-term monitoring programs, as limited manual intervention is required.
    - The piezometers could also be remotely linked to the same cloud system as the IPIs, whereby, the piezometer measurements could be directly linked to slope movement, providing a more rigorous trigger limit system. The trigger limit system would also work in real time, with messages sent to relevant parties once triggers are breached.
    - Remotely monitored GPS sensors can also be considered to monitor structure movements or surface movements at critical locations on the slope surface. These sensors have the ability to measure to an accuracy of +/-3mm and relay data to a cloud-based database and user nominated intervals.
    - Approximate costs for new monitoring are:
        - Supply and install inclinometer (manual) - $20k to $25k per inclinometer (manual) plus $5k per visit for manual equipment hire and readings ex Brisbane
        - Supply and install inclinometer (in-place) - $60k to $75k per inclinometer (in-place)
        - Supply and install vibrating wire piezometer (in place) - $10k per piezometer
        - Cloud based monitoring system (in place only) - $0.5k to $1k per month depending on number of sensors and supplier.

- **Plan and undertake additional geotechnical investigations**
    - The existing slope stability models use circular failure mechanisms to model non-circular failure modes. Furthermore, the interface of the larger-scale failure mechanism requires further review.
    - Additional geotechnical investigations targeting the location and strength of this interface should be undertaken. These can be undertaken in conjunction with any additional inclinometer installations. Recommended investigations include borehole and dilatometer testing (DMT). The boreholes can be used to collect samples of the interface materials for further laboratory testing, while the DMT can be used to determine in situ strength properties and zones of historical movement.
    - Approximate costs for additional investigations are:
        - 2 days of DMTs with laboratory testing and reporting - $30k to $40k.
- **Update Slope Stability Analysis and Risk Assessment**
    - Following further geotechnical investigations, slope stability analysis should be reviewed for updated subsurface profiles, strength and considering non-circular failure mechanisms.
    - The slope risk assessment should be updated with:
        - Consideration of slope drainage improvements and remediation works undertaken to underpin the Pacific Hotel
        - Consideration of any available geotechnical information (e.g. bore logs) available for the study area.
        - Feedback from property owners regarding property information, any specialist advice received and improvements implemented.
        - Damage to property and infrastructure in the study area, Appendix C of AGS 2007 includes tables of consequences to property as a result of landslide activity.
    - The slope stability analysis and slope risk assessment should consider whether the rapid failure mechanism has sufficient thickness and extent to impact persons or property.
    - The required modifications to the Emergency Management Plan should be identified based on the updated risk assessment.
    - Approximate costs for updates to slope stability analyses and risk assessments are: $30k $50k
- **Undertake Short Term Slope Remediation Measures to Manage Stormwater Flows**
    - Damage from the recent (2022) rain events appear to be largely due to scour resulting from concentrated flows. Due to the sandy nature of the subsurface materials (and lack of cohesion) concentrated flows from stormwater pipes or roadways can rapidly eroded the subgrade, resulting in the shallow slope failures that have been observed. The following maintenance works should be undertaken:

    - Sources of concentrated flows need to be identified. Stormwater outlets and drainage paths should be lined and outlet to appropriate locations at the base of the slope
    - There is currently no provision to capture and divert surface water drainage along Marine Parade and associated walking tracks. Surface water is concentrated along these alignments leading to scour of the subgrade and adjacent batter slopes. Kerbs directed to lined stormwater drains could be considered to minimise the risk of scouring and infiltration into the slope

- **Review Landscaping on Dunes to Improve Surface Stability**
  - Historical photos of Pilot Hill show dense native vegetation covering the sand dunes. Over time these trees have been cleared for development and this has been a likely contributor to the slope instability that has been observed.
  - For slope stability purposes, the vegetation provides two important benefits, firstly provides a degree of cohesion to the upper 0.5m to 1.0m of the slope profile, where the roots are present and secondly provides protection to instability caused by surface scouring
  - In the short term the existing vegetation cover should be maintained as far as reasonably practicable, but in the long term, advice should be sought on suitable, deep root species, to repopulate the dune system and improve the surface stability.

3.6.3 Long-term Recommendations (> 1 year)

Following completion of the short-term recommendations (within 1 year) the following long-term strategies should be considered:

- **Undertake Periodic Drone Photography and LiDAR Survey**
  - A drone flight and photogrammetry survey were undertaken as part of this current commission. It is recommended that similar flights are undertaken initially 3 monthly and following a peak rainfall event to catalogue changes in the slope geometry and also potentially identify areas that may not be immediately noticeable by manual/visual means. The use of drones with set flight paths and photo locations (with the same orientation) for each flight would allow detailed assessment of the coastal processes, slope regression and movement to be studied.
- **Review and Update Planning and Development Controls**
  - Landslide hazard mapping has been undertaken for a number of regional councils in Queensland. For example, the Sunshine Coast Regional Council (SCRC) has developed Landslide Hazard and Steel Land Overlay Maps to help Stakeholders identify whether their property resides in a landslide hazard area and steep lane (slopes of 15% of greater). This applies to existing and proposed developments.
  - Once a landslide hazard area is identified the Code provides guidance on the minimum geotechnical investigation, assessment and sign-off requirements, including clear conclusions about the overall suitability of the land for the proposed development with clear statements on whether the land is presently stable, whether it will remain stable in the long-term and whether conditions are required on the proposed development to maintain long-term stability. Relevant parts of the SCRC planning scheme and performance-based requirements are included in Appendix E for reference.
  - CVC could consider implementing a similar scheme as noted above across the council area or specifically for Yamba Hill. The former approach would remove the direct pressure on the Pilot Hill properties and would place an emphasis on to all property owners to ensure that they keep their property internally and externally stable. This would also allow residents to undertake individual risk assessments for their properties to allow future development.

4. Convent Beach

The slope stability assessment for Convent Beach is limited to Letter 3 from JK Geotechnics (2021) and LiDAR survey undertaken in February 2022. Although the geology of this site is similar to Pilot Hill and Main Beach, the dune height is significantly less.

4.1 Identified Instability

The JK Geotechnics Letter indicated that a large historical landslide occurred in the slope infront of the Craigmore Appartments in 1999, but provides no other detail. The site walkover did identify that the entire section of the slope would be subject to ongoing hillside erosion processes that may lead to localised or more significant instability.

4.2 Exposure to Landslides

4.2.1 Infrastructure/Buildings

The JK Geotechnics Letter indicates that most of the structures adjacent to the beach comprise modern 3 to 4 level homes, it was assumed that these buildings are founded onto the underlying rock. A small weatherboard home and the Craigmore Apartments are set sufficiently back from the crest of the slope that they are unlikely to be affected.

4.2.2 Site Traffic

Pedestrian traffic comprises both formal and informal paths, with a greater proliferation of informal paths in the southern part of the beach. The presence of private properties between Ocean St and the beach in the northern part of the site has limited the development of informal paths.

Ocean St is directly exposed to the seaward slope of the dune south of 8 Ocean St, in this area the dune slope varies from about 25° in the north to about 37° in the south, but the road is further set back from the crest of the slope in the southern part of the site. There is no vehicular traffic directly to the beach.

4.3 Monitoring Regime

No instrumentation or monitoring is installed along this site.

One of the questions posed to JK Geotechnics in the Letter was if the rainfall trigger levels for Pilot St were relevant to this site. The conclusion given was that there was no need to extend the trigger zones to homes along Convent Beach.

4.4 Slope Risk Assessments

4.4.1 Site Investigation Data

No previous site investigation data is available for this site, but the Letter does surmise that some form of geotechnical investigation was undertaken for the recent homes in the site.

4.4.2 Numerical Modelling

No numerical modelling has been undertaken on the slope.

4.4.3 Slope Risk Assessment

The slope risk assessment contained within the letter comprised the opinion of the author that no significant slope risk is present along this section of the site. The letter does not contain any formal or qualitative analysis of slope risk.

4.5 Recommendations for Future Work

The following long-term recommendations are made with respect to future work at this site:

- Drone Photography and Survey
  - A drone flight and LiDAR survey were undertaken as part of this current commission. It is recommended that similar flights are undertaken initially 3 monthly and following a peak rainfall event to catalogue changes in the slope geometry and also potentially identify areas that may not be immediately noticeable by manual/visual means. The use of drones with set flight paths and photo locations (with the same orientation) for each flight would allow detailed assessment of the coastal processes, slope regression and movement to be studied.
- Slope Risk Assessment
  - The slope risk assessment should be updated for damage to property and infrastructure in the study area, Appendix C of AGS 2007 includes tables of consequences to property as a result of landslide activity;
- Planning and Development
  - Refer to recommendations for Pilot Hill.
  - Changes should be considered to the planning scheme for this site to ensure that future construction conforms with the site requirements and that any new structures contain elements that will resist damage to the structure from earth movements in the slope.

5. Cakora Point

5.1 Regional Geology and Geomorphological Context

This site is underlain by Carboniferous sediments of the Coramba Beds which comprises lithofeldspathic wacke, minor siltstone, siliceous siltstone, mudstone, metabasalt, chert and jasper, rare calcareous siltstone and felsic volcanics. These rocks formed in a trench wedge as part of a tectonic subduction zone that was present along the coast at the time. During subduction the material was accumulated against the frontal accretion as sediments were scraped off the subducting plate. This resulted in folded and imbricated sediments that are largely tilted to vertical and have intermixed rock of various types and ages.

Cakora Point comprises mainly high strength rock such as greywacke and sandstone and the orientation of the headland has been affected by the orientation of bedding in the rock.

The headland is exposed to ongoing geological processes from direct wave attack. This has resulted in the development of an extensive wave cut platform with cliffs and coves through the erosion of the headland. This method of erosion is the result of wave action on the rock that is concentrated on the tidal range resulting in undercutting of the slope which subsequently results in toppling failures and rock falls that develop along natural fractures.

Longshore drift of sandy sediments results in accumulation on the south of the headland and depletion on the north, but it does appear that sandy sediments do pass the headland.

5.2 Identified Instability

5.2.1 Historical Landslide Events

The SMEC report identified that previous rockfall events had occurred at the site as evidenced by scree material accumulated at the toe of the slope, but no specific landslide events were identified.

5.2.2 Landslide Features

The SMEC report observed several mechanisms of failure on the site which are summarised below, the landslide risk assessment was based on the impact of these mechanisms on the site.

- Mechanism 1 Receding Cove: consisted of a cove in the northern part of the headland. Failures comprised rock falls and toppling of blocks from intersecting joint sets in siltstone and sandstone. It was noted that a 3m high build up of debris was present at the toe of the slope;
- Mechanism 2 Undermining: consisted of an overhanging slope in the northern part of the site with bedding and orthogonal joint sets resulting in toppling and rock fall events in siltstone and sandstone with failed material present on the beach below. Groundwater seepage appears within the slope and it is postulated that this is caused by rainfall and site drainage;
- Mechanism 3 Crest Fretting and Block Toppling: Weathered siltstone material is fretting away from the crest of the slope aided by informal public access tracks. This slope is mainly siltstone and sandstone with a sandstone wave cut platform at the toe of the slope. Rock falls from blocks and toppling rocks occur from orthogonal joints and the bedding planes, fallen blocks are strewn across the wave cut platform. This mechanism was reported at three locations within the report.

Copies of the site sketches showing typical details of these mechanisms are given in Appendix B.

5.3 Exposure to Landslides

5.3.1 Infrastructure/Buildings

The SMEC report notes that the nearest private property to the location is 140m, so any landslides at this site is unlikely to affect these properties. The site however has paths owned and maintained by CVC, so the report was limited to risks to this infrastructure only. The main item of CVC infrastructure was a carpark and lookout area seen in Figure 1-3.

5.3.2 Site Traffic

Pedestrian traffic in the study area uses a combination of defined paths that were constructed by and are maintained by CVC. The remainder of the pedestrian traffic in the area uses informal paths to access the cliffs, coves and wavecut platform.

Vehicular traffic is limited to the look out access road and is separated from the cliff tops by fencing. There is no vehicular access to the beach below the cliffs.

5.4 Monitoring Regime

5.4.1 Existing Instrumental Monitoring

There is currently no instrumental monitoring on this site.

5.4.2 Existing Inspection Monitoring

The SMEC report recommended that periodic inspections be undertaken of the site on a minimum 5-year interval. No information has been provided that indicates that these inspections have been undertaken.

5.5 Slope Risk Assessments

5.5.1 Site Investigation Data

The only site investigation data provided comprises the site mapping undertaken by SMEC. Note that due to the nature of the site and failures it would be unnecessary for a drilling investigation to be undertaken at this site.

It is noted that the sections given within the document are stated as typical rather than actual site sections.

5.5.2 Numerical Modelling

The SMEC report does not appear to contain any numerical modelling.

5.5.3 Slope Risk Assessment

The slope risk assessment contained within the SMEC report is based on descriptors for likelihood and consequences contained in Appendix C of AGS 2007, and the selection of the most suitable descriptors appears to be based on site observations. Numerical values of probability have been taken from typical values contained within these tables. Table 4 from the SMEC report that summarises the results of the slope risk assessment is given in Figure 5-1 below.

Table 4 – Summary of Risk Assessments for Hazards.

Hazard		Crest Failure up to 2m^3	Block Toppling (up to 1m side length)	Collapse of Overhanging Ledges (300m^3)	Minor Rock Falls from Overhangs (<0.2m side length)
Probability $P_{(H)}$	Descriptor	Possible	Almost Certain	Possible	Almost Certain
	Level	C	A	C	A
	Rate	$1x10^{-3}$	$1x10^{-1}$	$1x10^{-3}$	$1x10^{-1}$
Consequence	Level	Medium	Medium	Significant	Insignificant
	Descriptor	3	3	2	5
Risk To Property		**Moderate**	**Very Low**	**Low**	**Very Low**
Probability of Spatial Impact $P_{(S:H)}$		$5x10^{-2}$ (2m length of failure on 40m long section)	$5x10^{-3}$ (1m block over 200m section of cliff)	$5x10^{-1}$ (5m wide failure over 10m overhang)	$4x10^{-3}$ (0.2m block over 50m section of overhang)
Probability of Temporal Impact $P_{(T:S)}$		0.17 (assumes lookout is used for 4 hours a day)	$2.08x10^{-2}$ (areas below overhangs very seldom accessed, 0.5hrs/day)	$2.08x10^{-2}$ (areas below overhangs very seldom accessed, 0.5hrs/day)	$2.08x10^{-2}$ (areas below overhangs very seldom accessed, 0.5hrs/day)
Vulnerability of an Individual $V_{(D:T)}$		1.0 (person killed) $1x10^{-1}$ (person injured)	1.0 (person killed)	1.0 (person killed)	1.0 (person killed) $1x10^{-1}$ (person injured)
Risk (loss of life)		**Death $8.5x10^{-6}$ or 0.00085%** **Injury $8.5x10^{-7}$ or 0.000085%**	**$1.0x10^{-5}$ or 0.001%**	**$1.0x10^{-5}$ or 0.001%**	**Death $8.3x10^{-6}$ or 0.00083%** **Injury $8.3x10^{-7}$ or 0.000083%**

Figure 5-1 Table 4 showing the summary of the slope risk assessment for Cakora Point from SMEC report

5.6 Recommendations for Future Work

The SMEC report made the following recommendations to reduce the risk to the site. Based on information contained in the client brief some of these recommendations have been implemented. The recommendations were:

- Installation of signage to warn of the danger associated with rock falls. These were to be installed at the crest of slopes, at entry points at the base of slopes and at the base of slopes where it is considered accessible;
- Installation of walkway barriers or to remove walking tracks from the proximity to crests/cliff faces. The main recommendation for barriers was to reduce the incidence of informal tracks that have formed within 2m of the crest of the slope;
- Inspection, monitoring and maintenance, comprising a minimum 5 year frequency of inspections to assess the degree and extent of slope degradation, identify specific hazards such as unstable blocks, allow for timely implementation of remedial actions.

The following long-term recommendations are given for future work at the site:

- Undertake a desktop study using geo-located historical aerial photographs to assess and estimate the rate of slope regression, rock falls, and erosion of scree material at the toe of the slope when exposed to wave action. This will provide a better estimation of the probability of these events. Due to the nature of these images it will only be applicable to regression of the crest as the toe regression will be hidden from view;

- Undertake detailed mapping of the site and the creation of a catalogue of specific hazards on the site. Once specific hazards are identified any progression towards failure can be tracked through periodic inspections so that a proactive approach can be made towards management of hazards;
- Undertake regular periodic inspections of the site to assess the progression of any previously identified slope hazards and to identify any new hazards. Inspections should be undertaken on an interval of between 2 and 5 years based on the results of the slope regression analysis, ie if the slope is regressing quickly with scree rapidly eroded from the toe of the slope then a shorter inspection period would be warranted, and visa versa;
- It is recommended that a drone survey is undertaken initially 3 monthly and following a peak rainfall event to catalogue changes in the slope geometry and also potentially identify areas that may not be immediately noticeable by manual/visual means. The use of drones with set flight paths and photo locations (with the same orientation) for each flight would allow detailed assessment of the coastal processes and historical rock fall that has occurred between flights. A drone-based survey methodology may need to be developed that captures the undercut areas of the cliff in a repeatable and quantifiable way.
- Revise the slope risk assessment with actual failure rates identified through the regression analysis and site inspections. This may either increase or decrease the consequences of any slope failures.

6. Closure

Finally, we draw your attention to the attached Important Information about your FSG report.

Please contact the undersigned if any further information or clarification is required.

Regards,

pp

Michael Grinceri
Senior Geotechnical Engineer

Adam Kemp
Principal Geotechnical Engineer

Important Information about your FSG Report

Deep foundation and geotechnical engineering problems are a principal cause of construction delays, cost overruns, claims and disputes. The following information is provided to help you to understand this report and its limitations and manage your risks.

Scope and Applicability of this Report

This report has been prepared for a specific purpose and scope and its applicability is limited. FSG cannot accept any responsibility for the use of this report outside of the stated scope and purpose. If a service has not been explicitly included in the scope, it must be assumed that it has not been provided. Assessment of soil or groundwater contamination does not form part of this geotechnical report and any reference to any potential site contamination is for information only. If you are uncertain about the applicability of the results for any particular purpose, you should consult FSG to avoid any misunderstanding or miss-application.

This report has been prepared for the nominated Client and project only and should not be relied upon by other parties, or for other purposes, without consulting FSG. Any party relying on this report beyond its specific purpose and scope does so entirely at their own risk and responsibility. FSG does not take responsibility for the use of this document by any other person or party than the Client.

Project Details and Information Provided

This report has been based on project details as provided to us at the time of the commission. We have assumed that the information supplied to FSG by the client or other external sources on behalf of the client, is correct unless explicitly stated so. FSG does not accept any responsibility for incomplete or inaccurate data provided by others.

If any project details change during the course of the project or observed conditions are considered to differ from those expected or assumed, FSG should be notified in order to investigate if and how changes in project details affect the conclusions and recommendations in our report. If FSG is not consulted when changes are made to the initial project details, we cannot accept any responsibility for problems arising from these changes.

Geotechnical Information and Interpretation

Site investigations only sample discrete parts of the ground, and that extrapolation and interpolation of collected information can be used with varying degrees of risk and uncertainty depending on the extent and quality of the site investigation, the variability of the subsurface conditions and the consequences to the proposed works.

The analyses and recommendations in this report rely on the results of site investigation information, and other reported geotechnical information that is relevant to the works. This may include the results of pile load testing, other geotechnical testing, and inspections and observations from studies that have been performed as part of the works or in the vicinity of the works previously.

We have endeavoured to incorporate the available information into an appropriate geotechnical model based on our interpretation of the likely subsurface conditions. This process, and the geotechnical analysis and interpretation based on that model, is an inexact science, as a model is but a simplification of reality to derive a geotechnical solution. While we endeavour to incorporate realistic model parameters, our models, interpretations and the outcomes or our work generally may differ from reality for a range of reasons including:

- Spatial Variability: Geotechnical and geological variability across the site which may not have been captured in the site investigation works that have been used in our works. Geotechnical site investigations are very limited in the extent of physical investigation compared to the size of the entire site. No site investigation, no matter how comprehensive, can reveal all subsurface details and anomalies and conditions that differ from those observed in the site investigation will occur;
- Temporal Variability: Subsurface conditions can change with time due to man-made events such as cutting or filling or any construction works on or adjacent to the site which can also affect the site drainage and hence underlying properties; or by natural events such as floods or groundwater fluctuations.
- Variability in Mechanical Properties: Normal geotechnical variability in the inferred properties of materials represented in the boreholes, the performance of foundations or other elements that are tested or observed, and the performance of structures that are in contact with the ground in general. The data collected is only directly relevant to the exact location where the investigation was undertaken. The subsurface conditions between test locations have been inferred based on judgement and experience with the facts available at that time and related to the relative position of the proposed works;
- Testing Limitations: Uncertainty associated with geotechnical testing, design correlations associated with those tests or material descriptions, and case histories from which geotechnical parameters may have been inferred or in design and/or analysis methods that have been adopted;
- Construction Effects: Variability in the performance of construction equipment, such as hammers, cushions, guides and associated equipment for piling, construction effects that may influence the way structures interact with the ground, as well as inaccuracies in data measurement and testing methods that may have been used to record construction processes.

The results provided should be considered as indicative of the best estimate of likely outcomes (or range thereof), and should not be considered to be definitive or absolute, or represent the full range of possible outcomes at this site. Caution and prudence should be exercised when making decisions with significant implications for your project. The limitations of this report as outlined herein should be incorporated in decision making, and appropriate contingencies should be put in place to accommodate unexpected variability in relation to the works

Geotechnical Modelling

Model parameters that are used may vary in nature depending on the purpose of the analysis. Where it is necessary to make a realistic evaluation of the soil model, we would normally describe this as a 'best estimate' (BE). Depending on the particular application, it may be important to understand the sensitivity of the solution to soil model changes. We may then also define an 'upper-bound' (UB) soil model and a 'lower-bound' soil model, being estimates of the likely, strongest and weakest soil conditions which are anticipated based on the available geotechnical information and inferred geotechnical parameters. In certain circumstances, such as cases where the ground conditions appear to extremely uncertain or variable, we may also define 'extreme upper bound' (XUB) and 'extreme lower bound' (XLB) parameters which are intended to represent the likely extremes of the site conditions. In all cases, these models are inferred using engineering judgement from the available information and actual conditions and associated outcomes may differ from those assumed or given in our report, due to the inherent unpredictability of the ground, as outlined in the preceding section.

It should be noted that depending on the particular application either upper-bound or lower-bound analyses could be deemed conservative.

Disclaimer

The results, opinions, conclusions and any recommendations in this report are based on assumptions made by FSG in order to carry out the work. FSG specifically disclaims responsibility: arising from, or in connection with, any change to the site conditions or the nature of the proposed works including change in position of the structure or proposed works relative to the available data; to update this report if the site conditions or project details change or if the report is used after a protracted delay; and for liability arising from any of the assumptions that have been made or information provided being incorrect, incomplete or inaccurate.

Subject to the terms of an Agreement for Professional Services between FSG and the client, and to the maximum extent permitted by law, all implied warranties and conditions in relation to the services provided by FSG and this report are excluded.

Closure

Unless otherwise documented by way of a signed agreement for the services provided, all services in preparing this report have been provided under FSG's standard Terms and Conditions which are referenced in our fee proposal. The report is specific to the brief provided with its associated time and cost constraints.

Should you require any further information or clarification in relation to this report, please contact FSG.

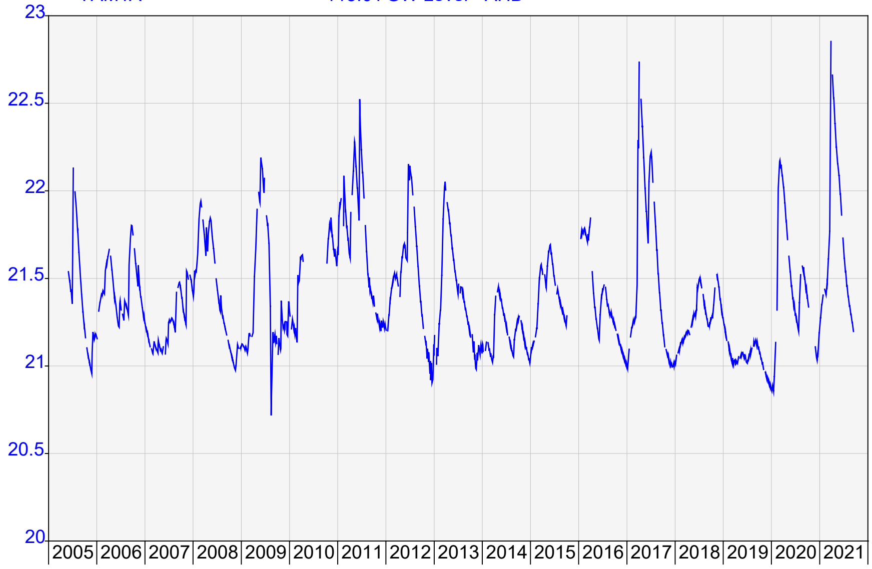
Appendix A
Monitoring Data from Pilot Hill

Groundwater Data Collection Services

HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 2005-21

— YAM1A 115.01 GW Level - AHD

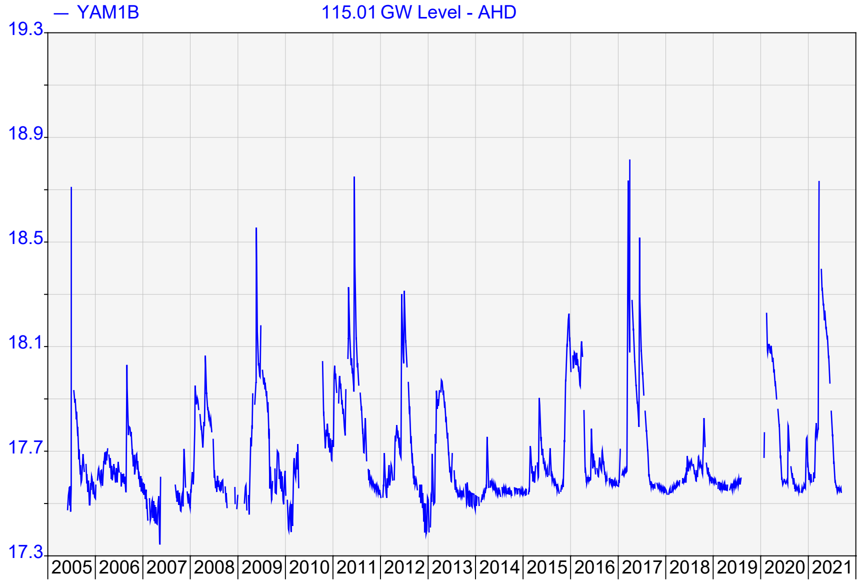


Groundwater Data Collection Services

HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 2005-21

— YAM1B 115.01 GW Level - AHD

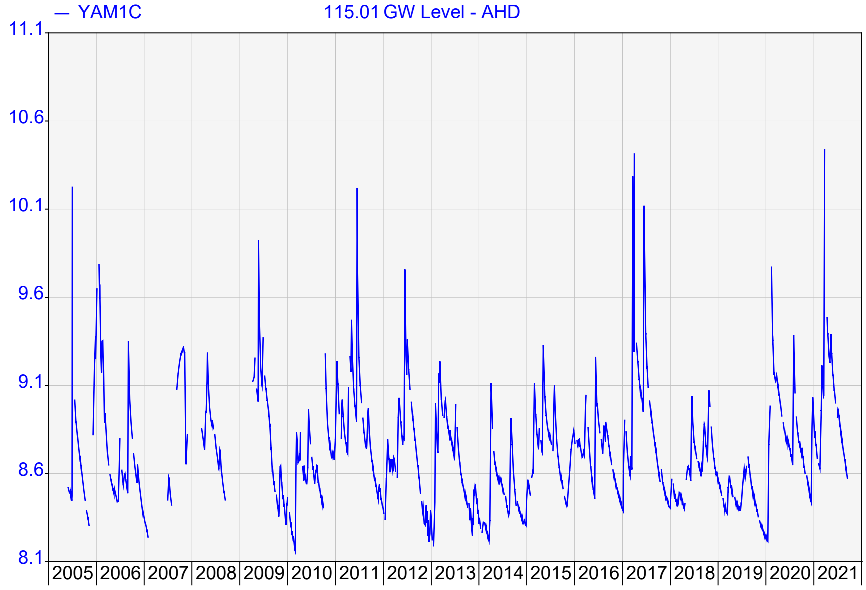


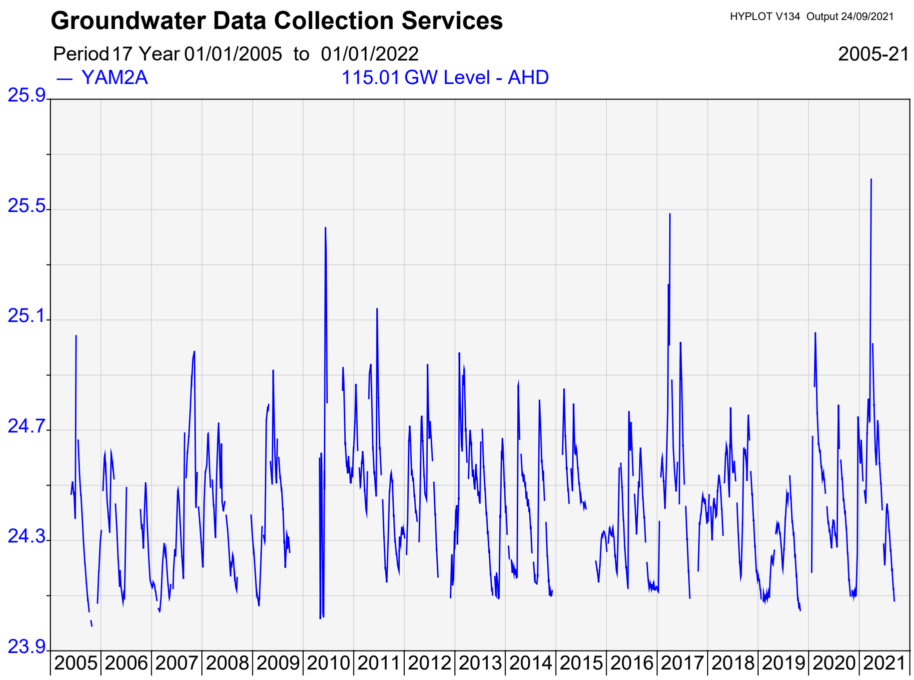
Groundwater Data Collection Services

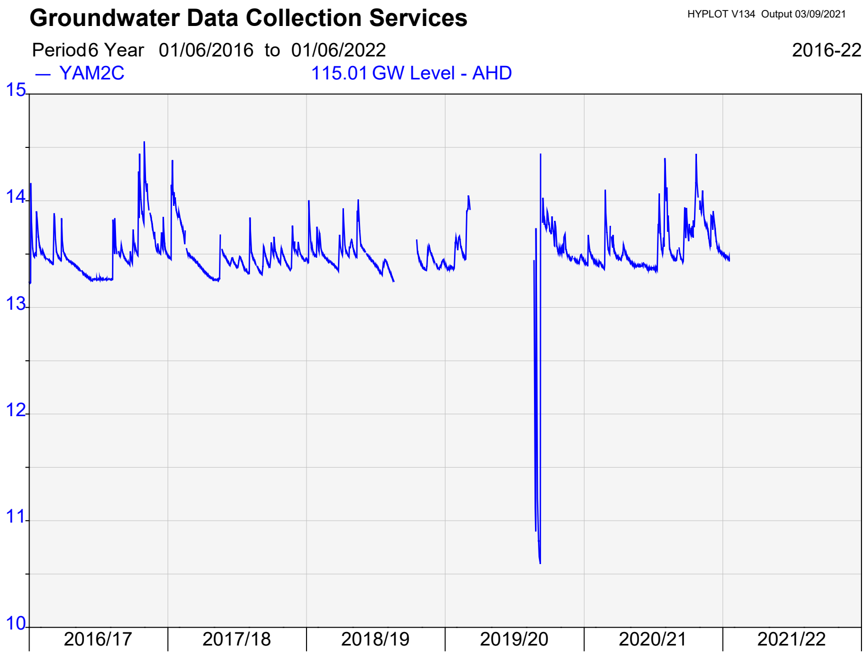
HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 2005-21

— YAM1C 115.01 GW Level - AHD





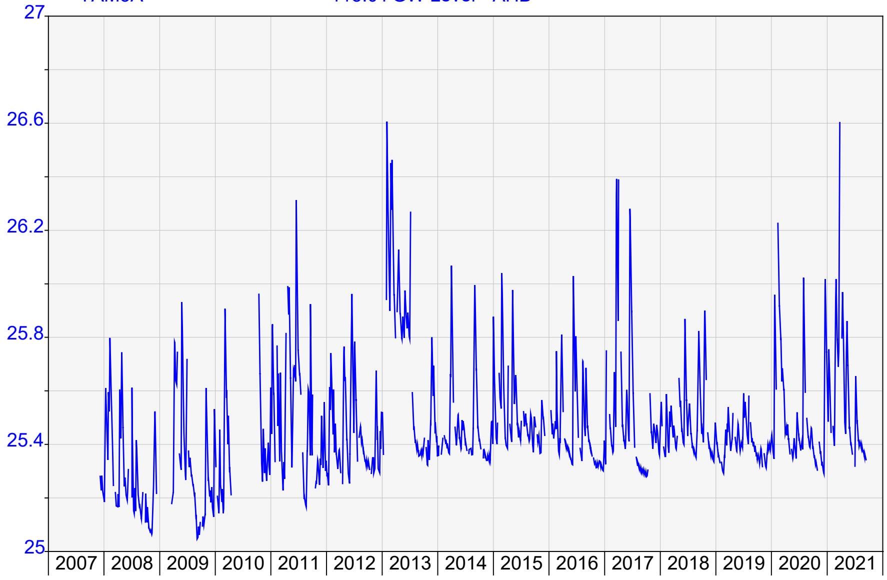


Note that the main report had a duplicate of the YAM2A piezometer and no data for YAM2C, the above plot has been taken from the May 2022 report

Groundwater Data Collection Services HYPLOT V134 Output 24/09/2021

Period 15 Year 01/01/2007 to 01/01/2022 2007-21

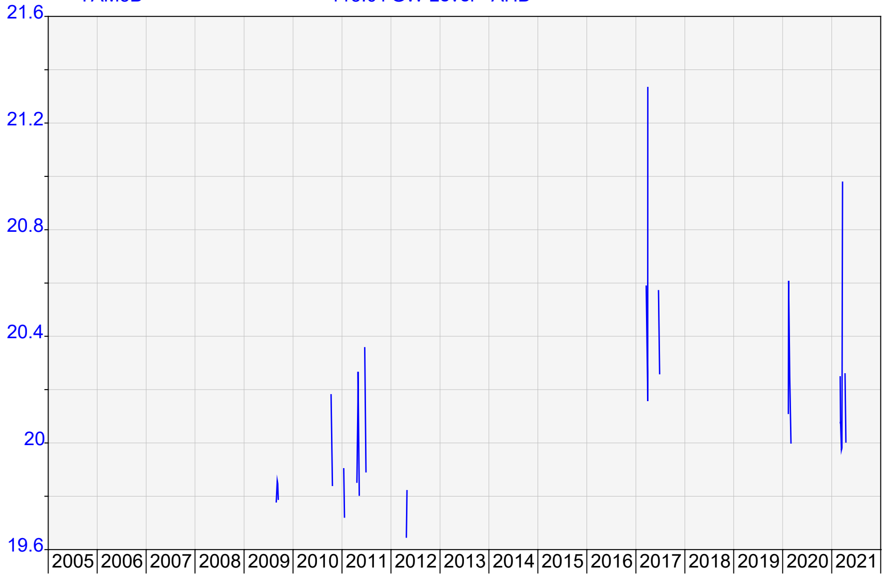
— YAM3A 115.01 GW Level - AHD



Groundwater Data Collection Services HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 2005-21

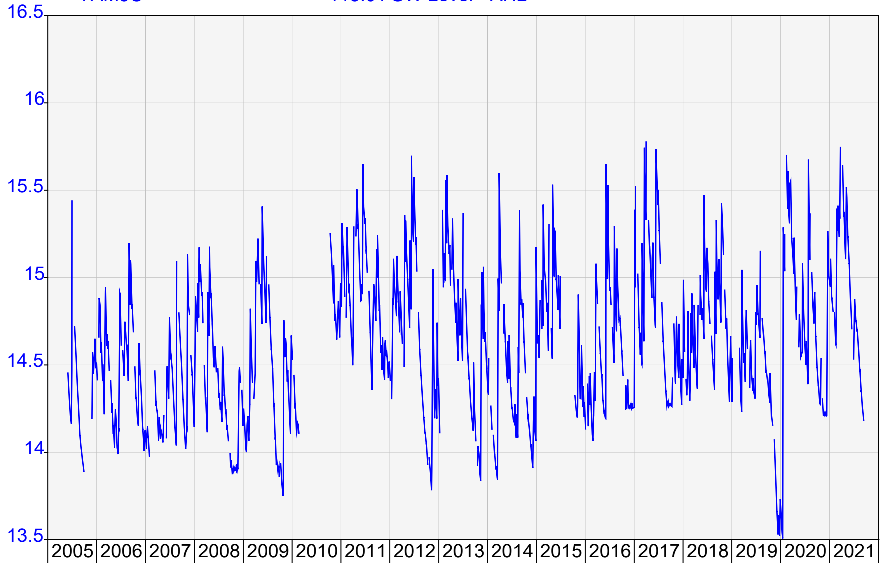
— YAM3B 115.01 GW Level - AHD



Groundwater Data Collection Services HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 2005-21

— YAM3C 115.01 GW Level - AHD

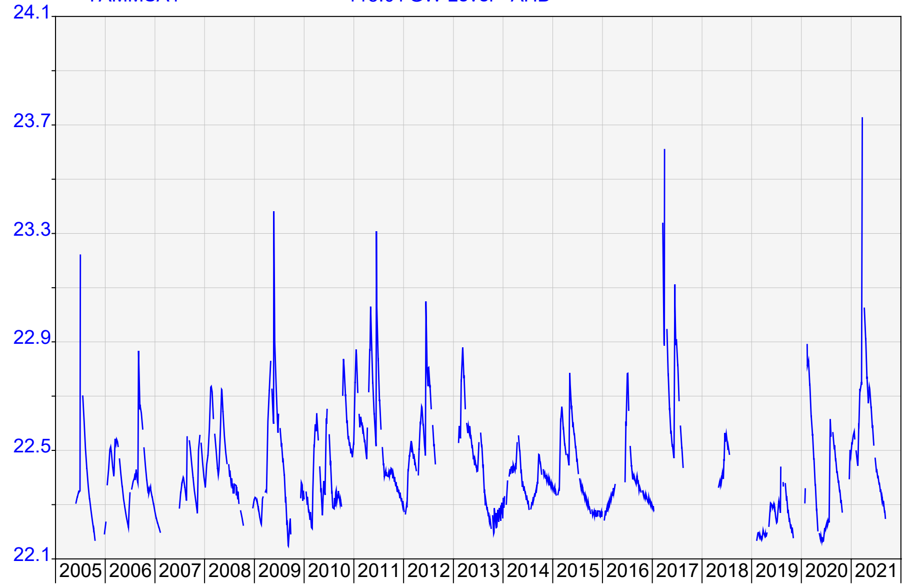


Groundwater Data Collection Services

HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 — 2005-21

— YAMMSA1 — 115.01 GW Level - AHD

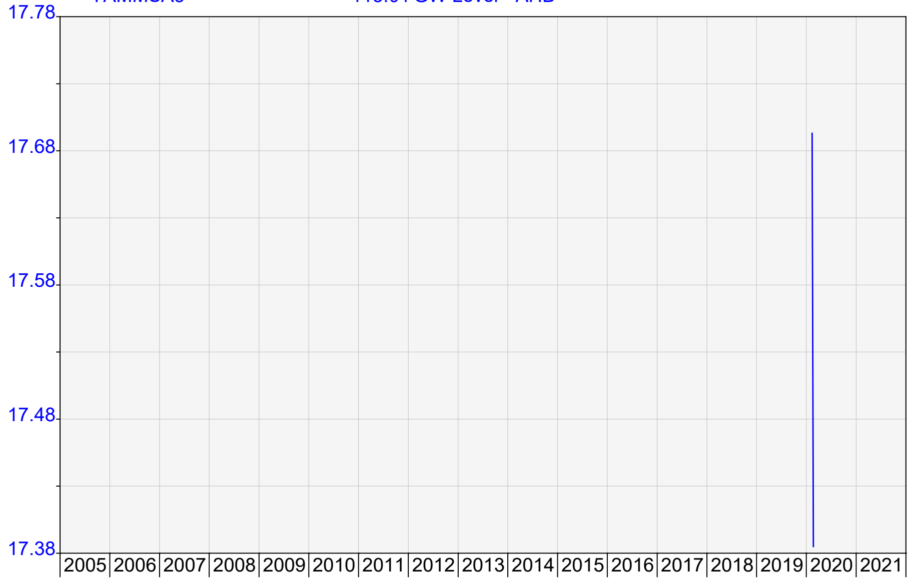


Groundwater Data Collection Services

HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 — 2005-21

— YAMMSA5 — 115.01 GW Level - AHD

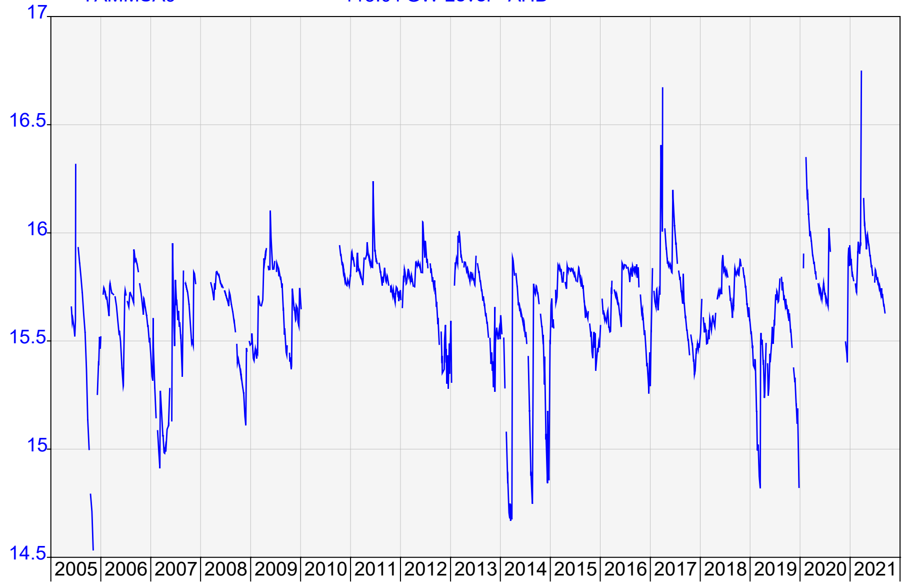


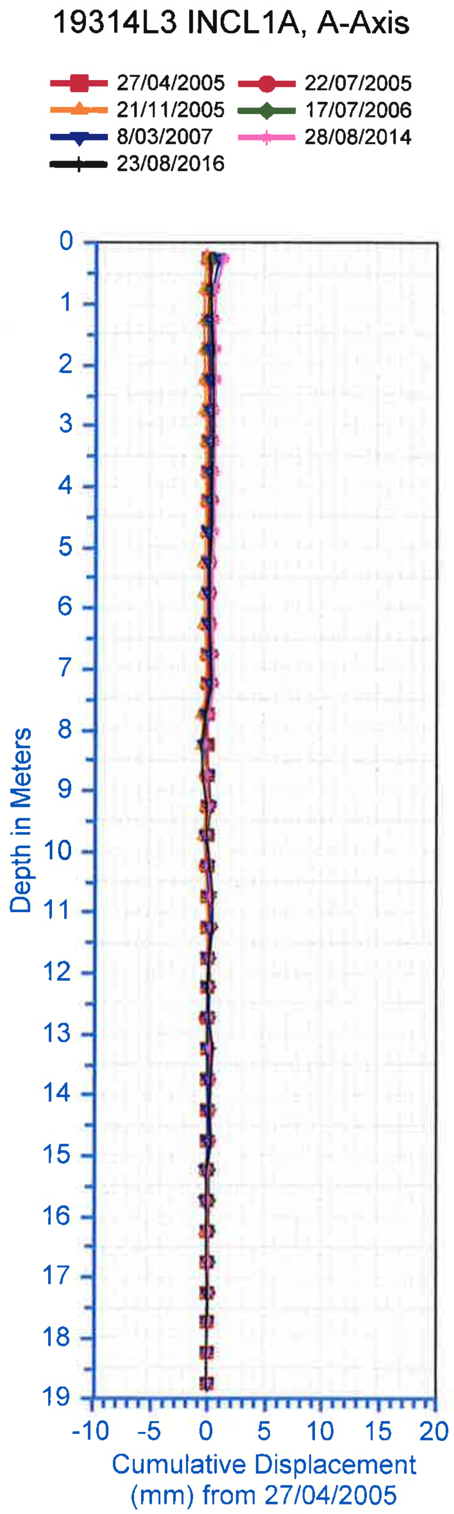
Groundwater Data Collection Services

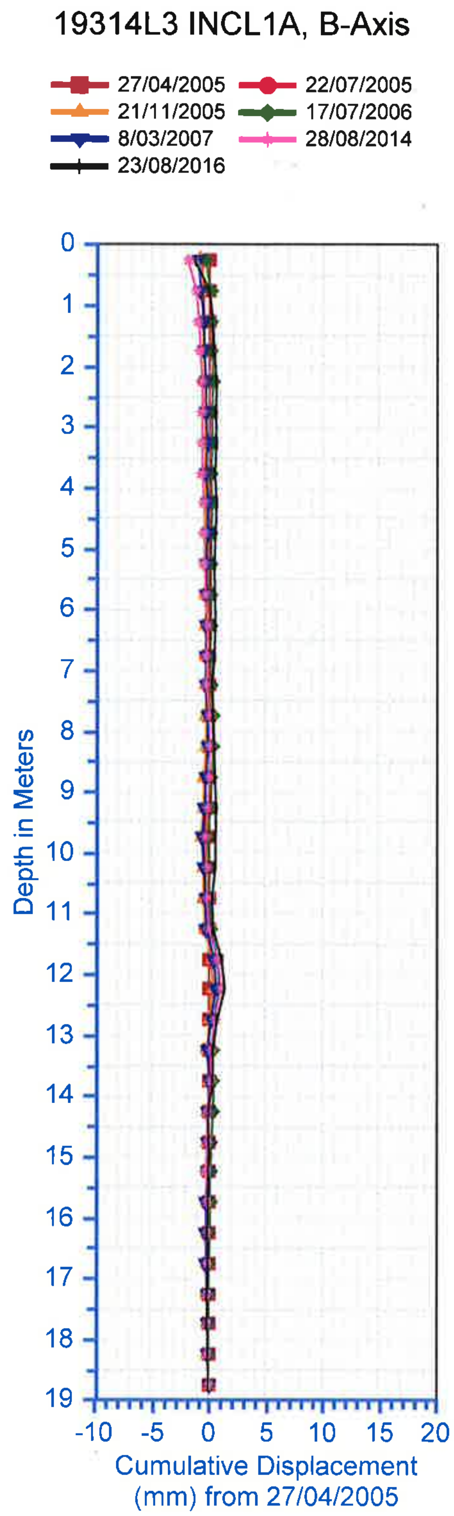
HYPLOT V134 Output 24/09/2021

Period 17 Year 01/01/2005 to 01/01/2022 — 2005-21

— YAMMSA9 — 115.01 GW Level - AHD





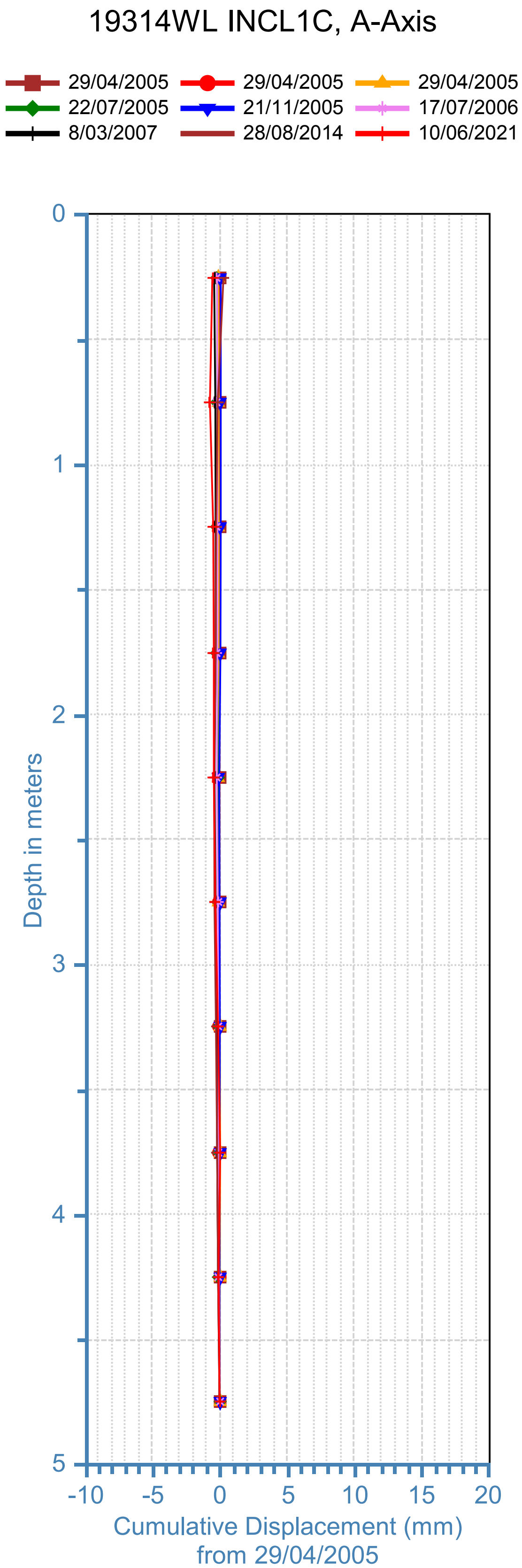


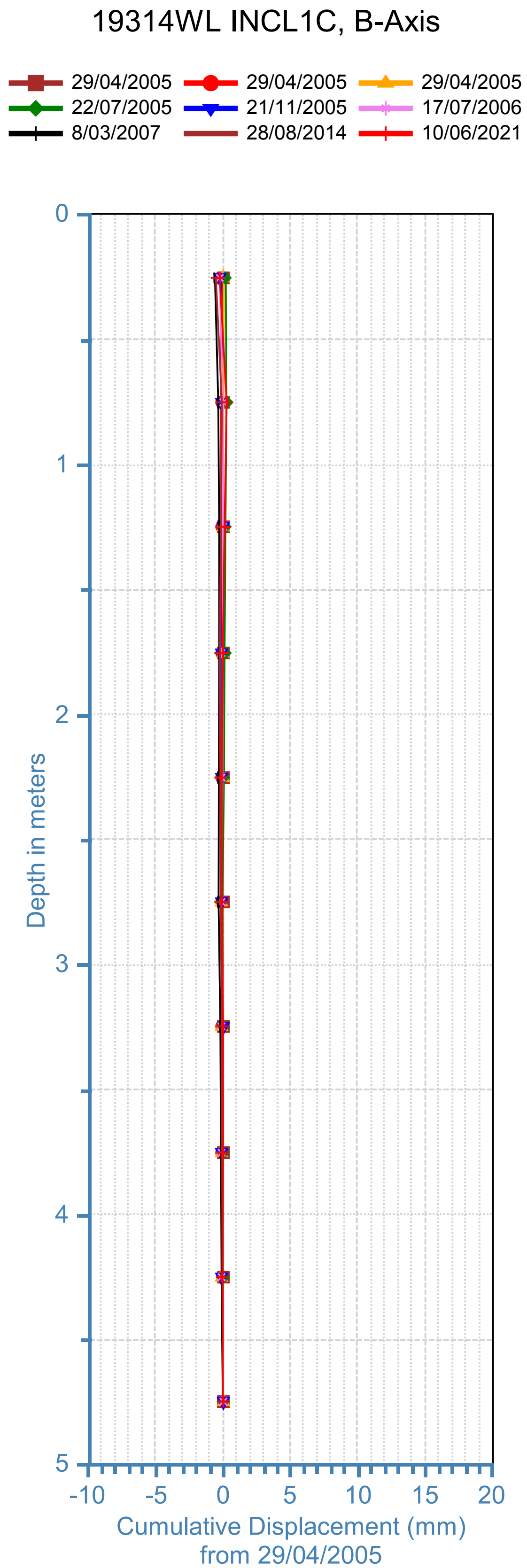
JK GEOTECHNICS

CLIENT: Clarence Valley Council
PROJECT: Inclinometer Monitoring
LOCATION: Pilot Hill, Yamba, NSW

JOB No. 19314L3
INCL No. 1A

FIGURE No. ______



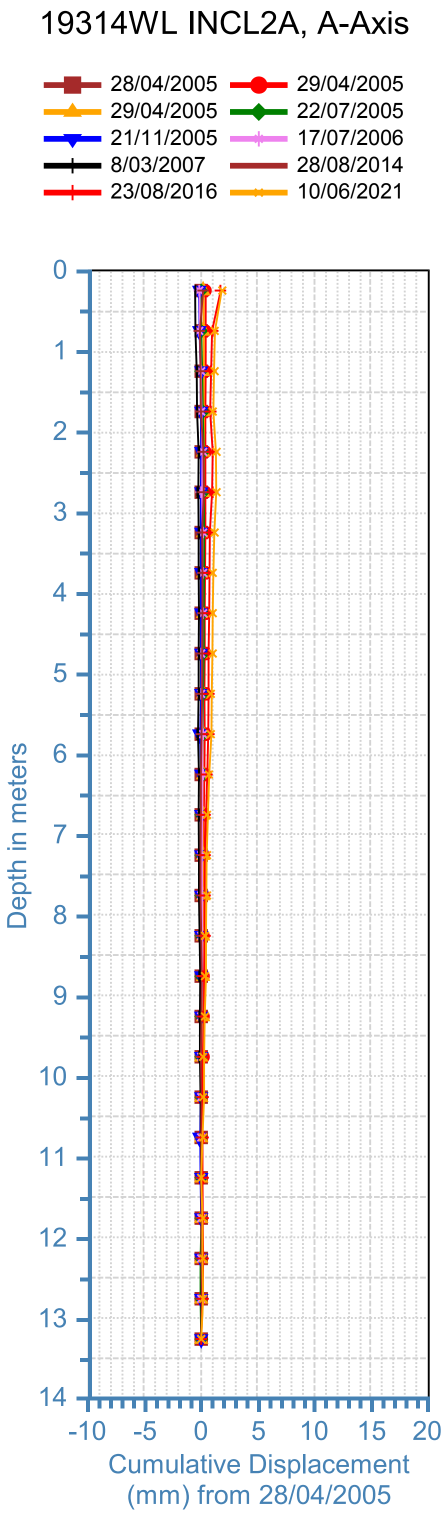


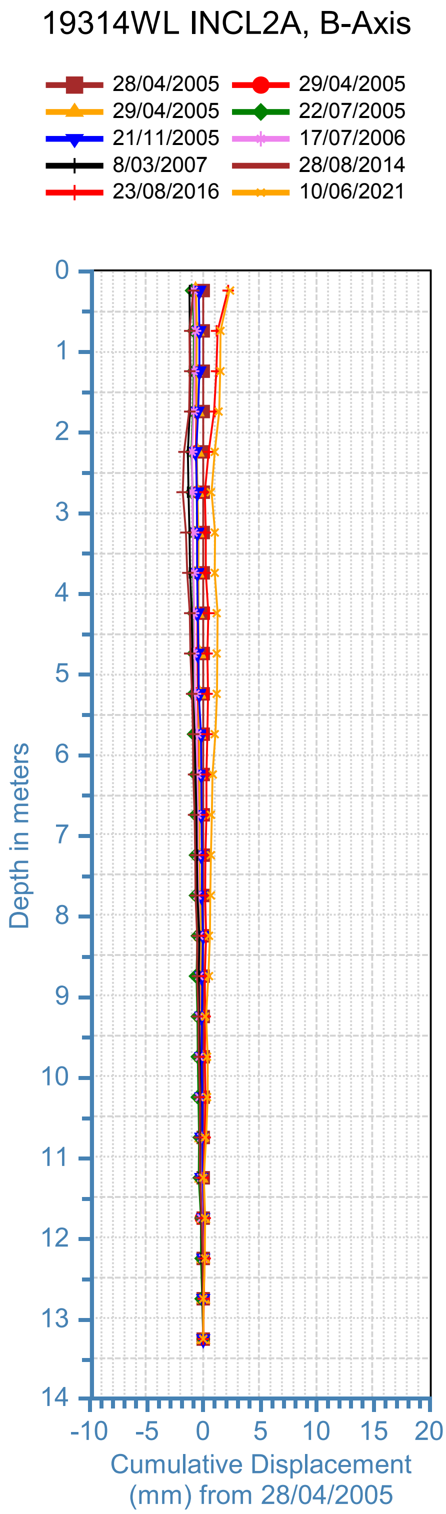
INCLINOMETER SURVEY RESULTS

CLIENT: Clarence Valley Council — **Job No: 19314L3**

PROJECT: Inclinometer Monitoring — **BH/INCL No: INCL1C**

LOCATION: Pilot Hill, Yamba, NSW — **Figure No:**



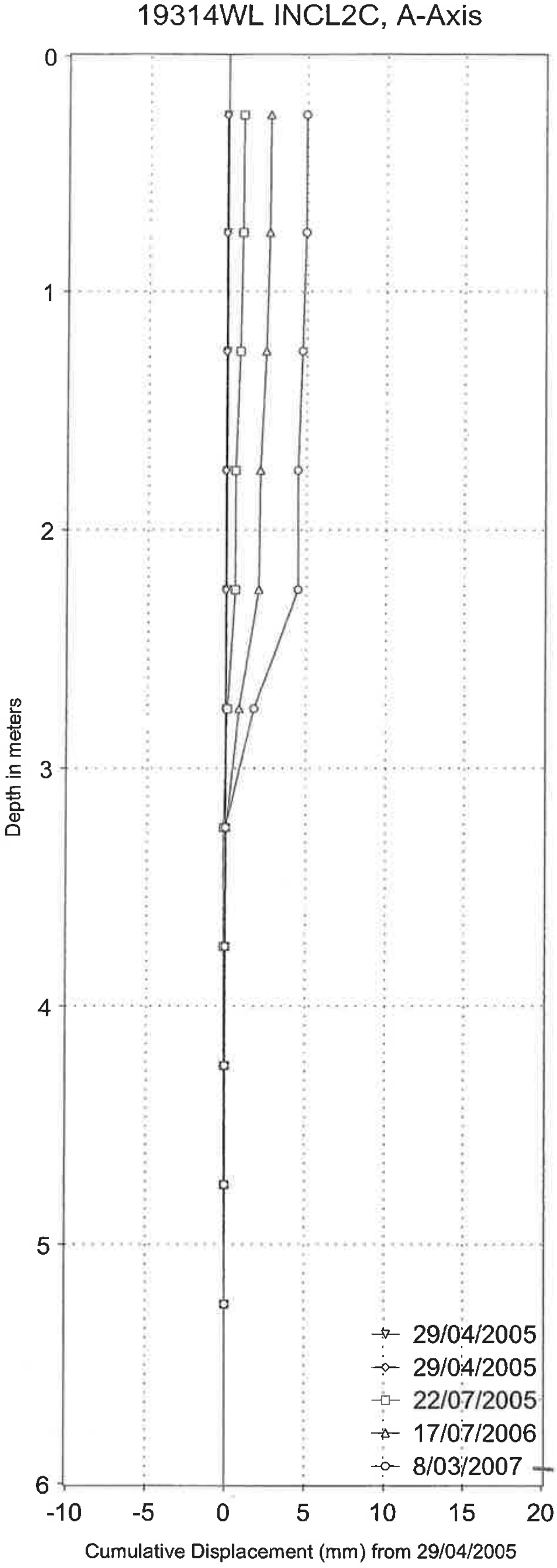


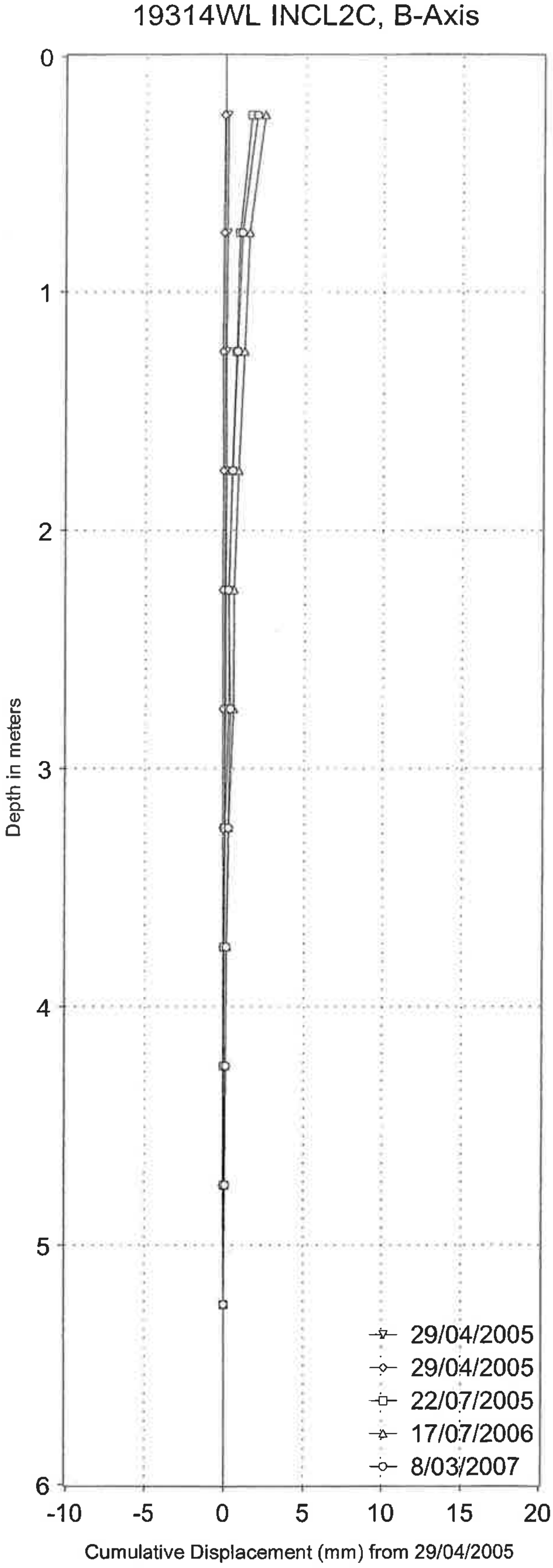
INCLINOMETER SURVEY RESULTS

CLIENT: Clarence Valley Council **JOB No. 19314L3**

PROJECT: Inclinometer Montoring **INCL No. 2A**

LOCATION: Pilot Hill, Yamba, NSW **FIGURE No. ______**





Jeffery and Katauskas Pty Ltd

CLIENT: Water Research Laboratory UNSW

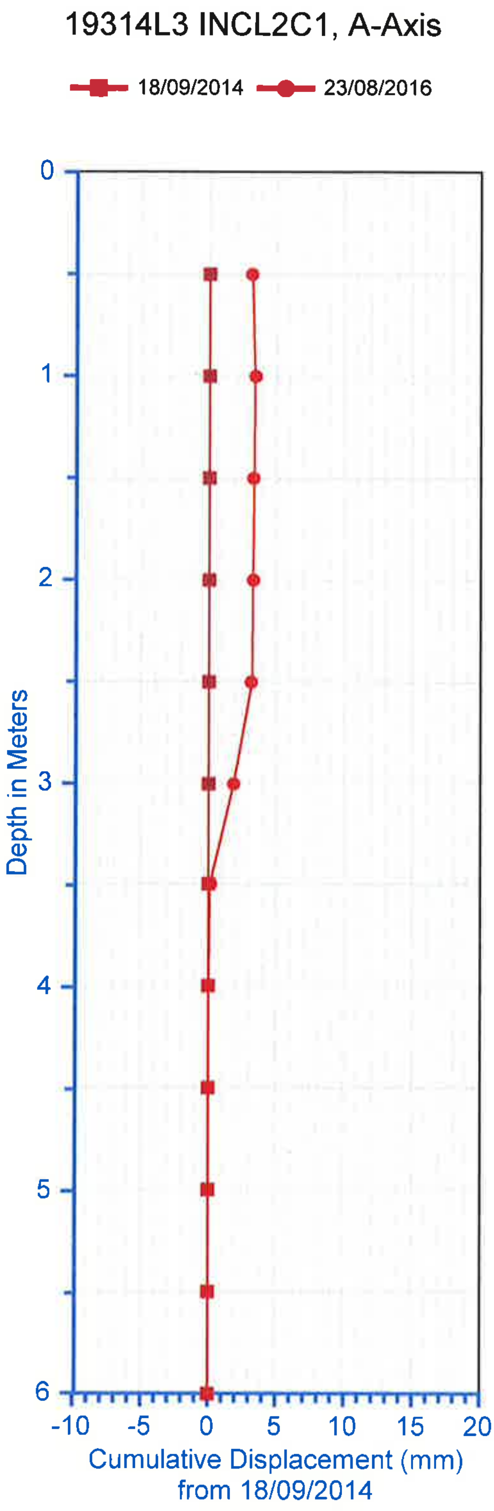
PROJECT: Inclinometer Monitoring

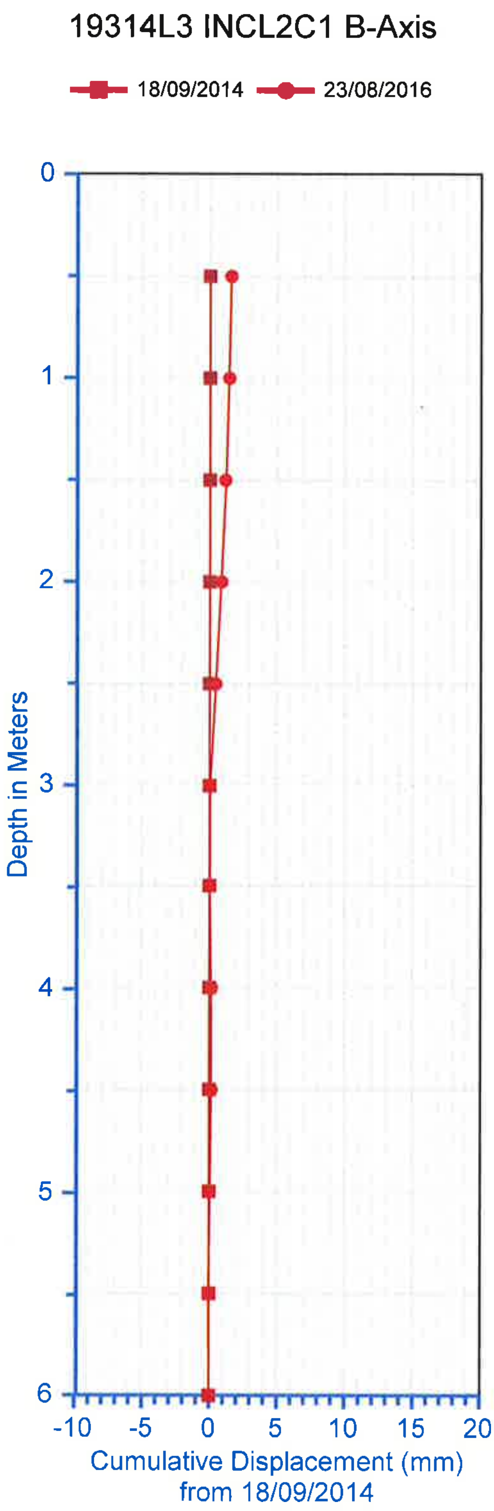
LOCATION: Pilot Hill, Yamba, NSW

Job No: 19314WL

BH/INCL No: INCL2C

Figure No:



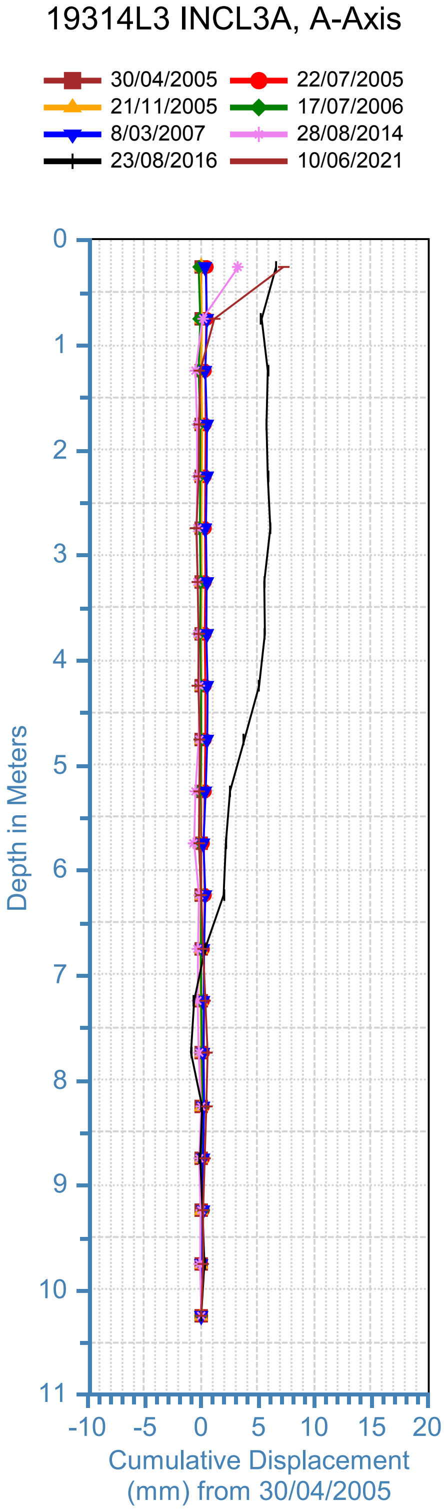


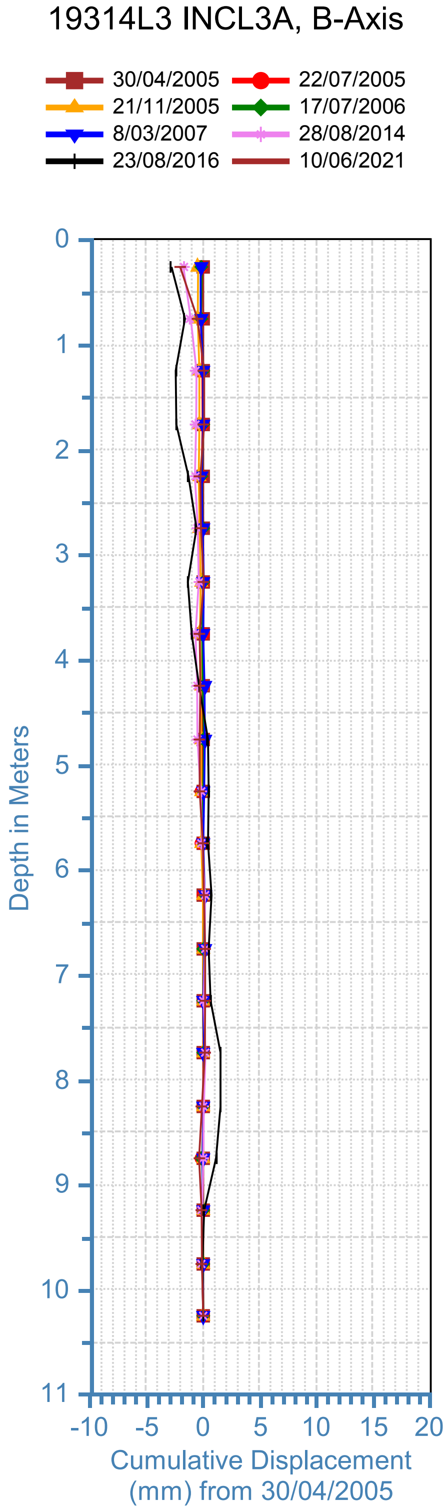
JK GEOTECHNICS

CLIENT: Clarence Valley Council
PROJECT: Inclinometer Monitoring
LOCATION: Pilot Hill, Yamba, NSW

JOB No. 19314L3
INCL No. 2C1

FIGURE No. ______



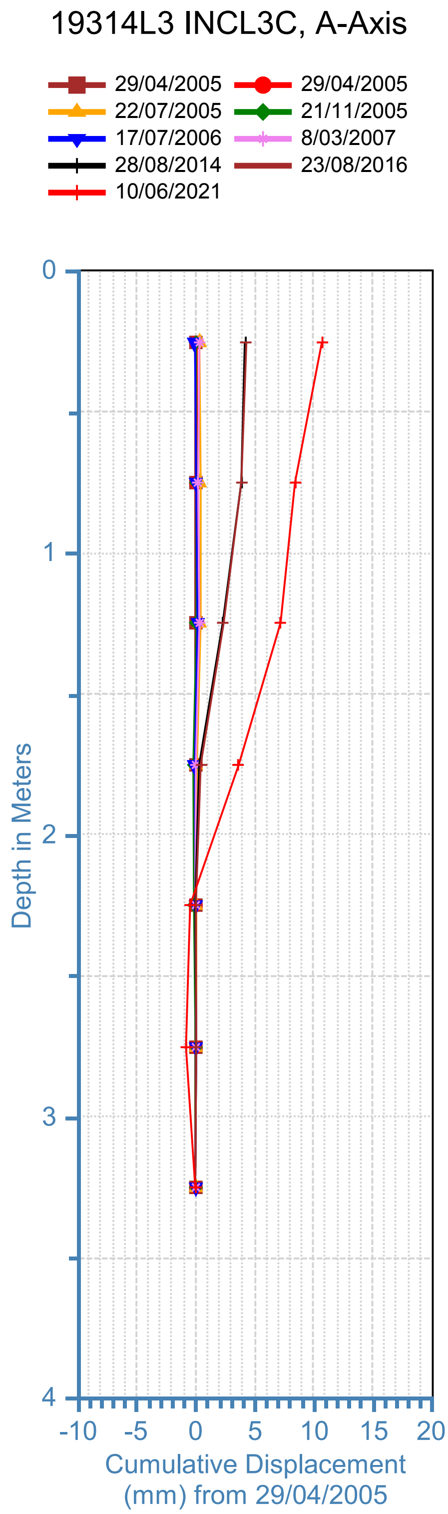


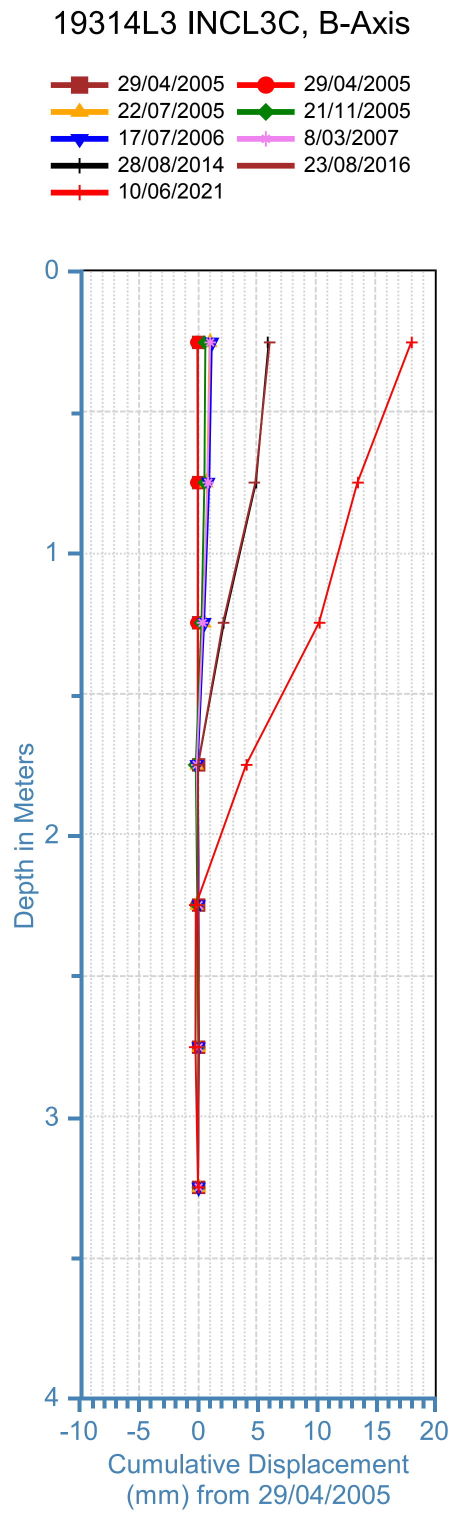
INCLINOMETER SURVEY RESULTS

CLIENT: Clarence Valley Council **JOB No. 19314L3**

PROJECT: Inclinomter Monitoring **INCL No. 3A**

LOCATION: Pilot Hill, Yamba, NSW **FIGURE No. ______**





INCLINOMETER SURVEY RESULTS

CLIENT: Clarence Valley Council **JOB No. 19314L3**

PROJECT: Inclinometer Monitoring **INCL No. 3C**

LOCATION: Pilot Hill, Yamba, NSW **FIGURE No.**

Appendix B
Section sketches from Cakora Point

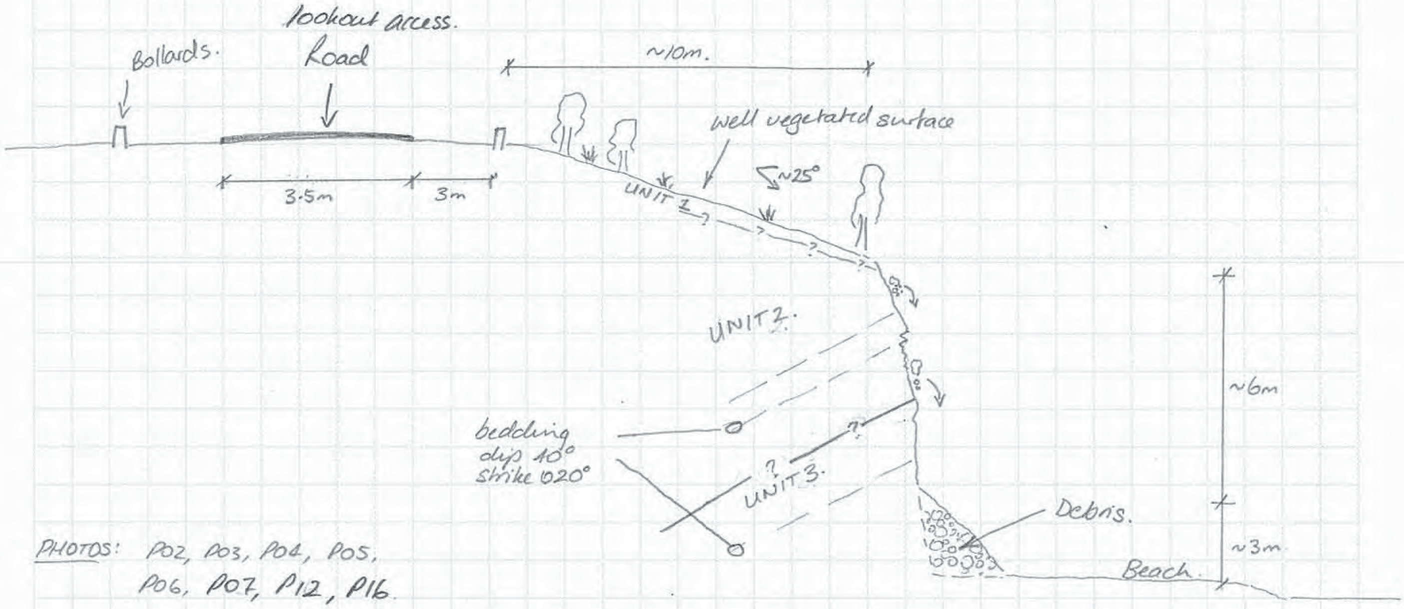

Bedding dip 40° strike 020°
Mechanism 3A
Mechanism 1
Mechanism 2
Bedding dip 60° strike 000°
Fold
Mechanism 3B
Mechanism 3C

SMEC

COMPUTATION SHEET

Project: BROOMS HEAD | Page No.:
Project No.: 30011071 | Date: 2/3/12
Feature/Structure: SLOPE STABILITY RISK ASSESSMENT | Calcs By: BLM.
Details: MECHANISM 1 : RECEEDING COVE. | Checked By:

SECTION (Not to Scale).



PHOTOS: P02, P03, P04, P05, P06, P07, P12, P16.

SMEC

COMPUTATION SHEET

Project: BROOMS HEAD

Page No.

Project No.: 30011071

Date: 2/3/12

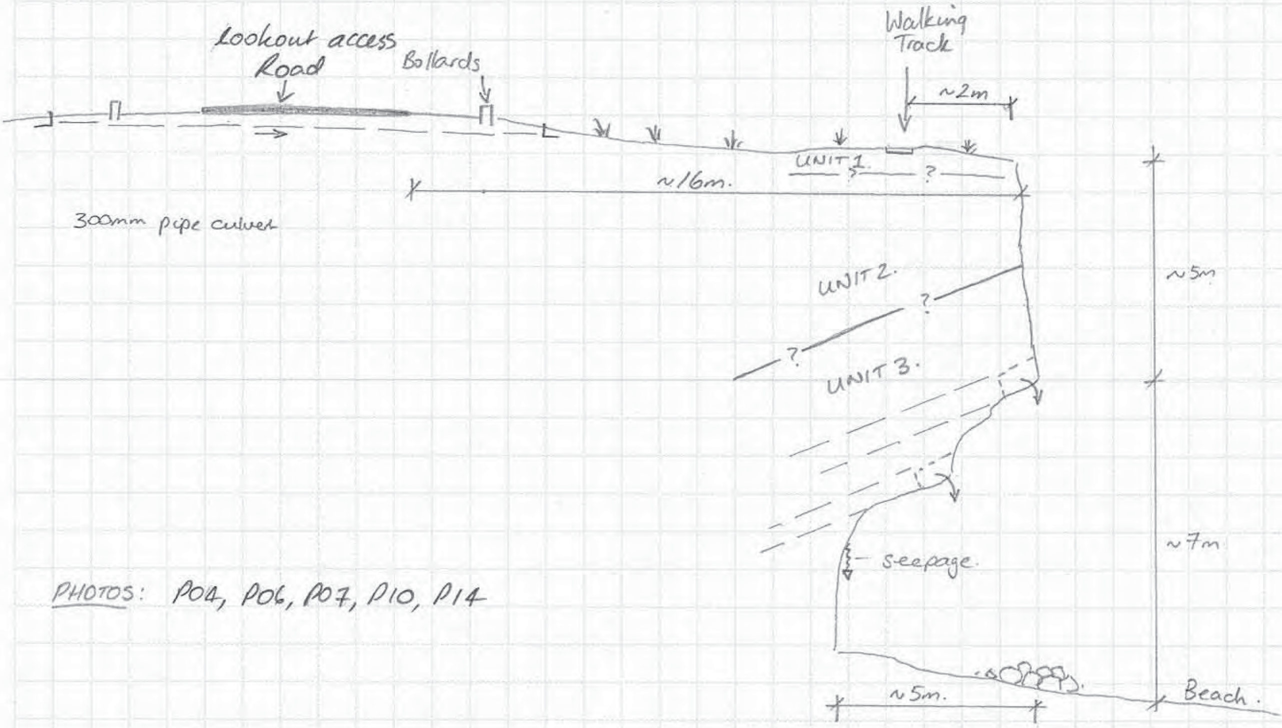
Feature/Structure: SLOPE STABILITY RISK ASSESSMENT

Calcs By: BLM

Details: MECHANISM 2: UNDERMINING.

Checked By

SECTION (Not to Scale)



PHOTOS: P04, P06, P07, P10, P14

SMEC

COMPUTATION SHEET

Project: BROOMS HEAD

Page No.

Project No.: 30011071

Date: 2/3/12

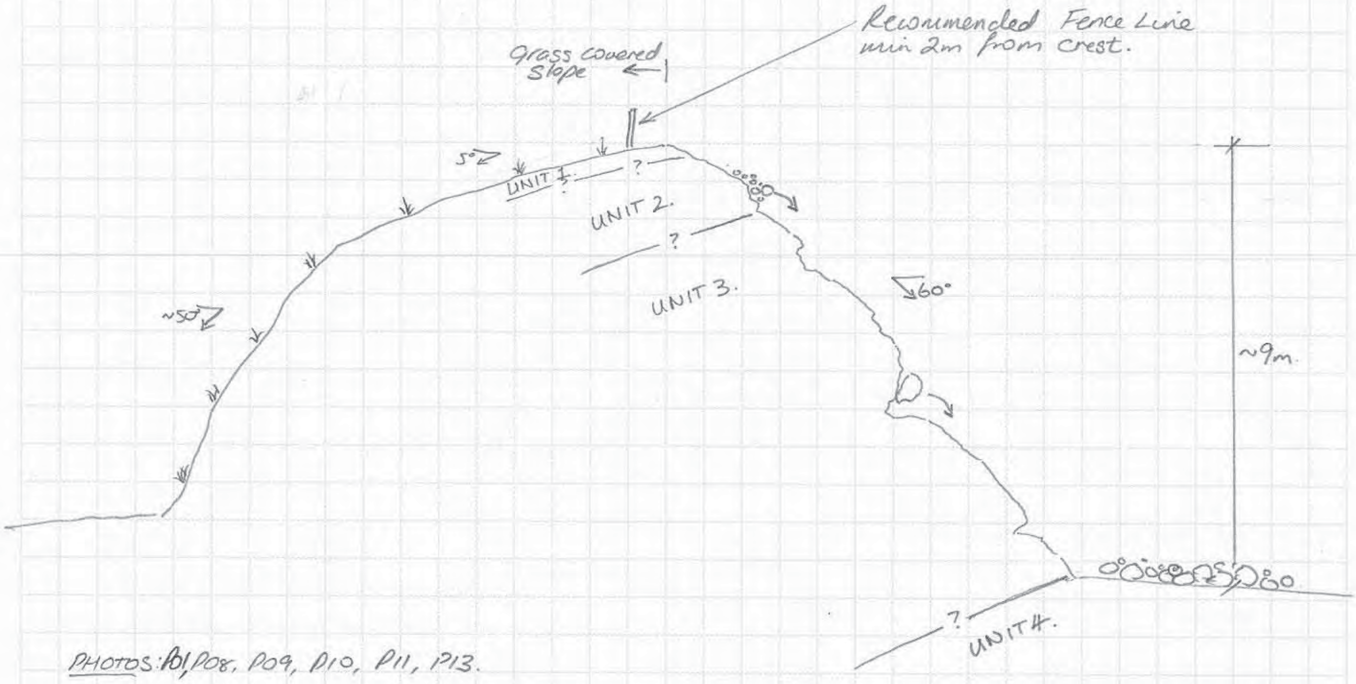
Feature/Structure: SLOPE STABILITY RISK ASSESSMENT

Calcs By: BLM.

Details: MECHANISM 3A: CREST FRETTING & BLOCK TOPPLING.

Checked By

SECTION (Not to Scale).



PHOTOS: P01, P08, P09, P10, P11, P13.

SMEC

COMPUTATION SHEET

Project: BROOMS HEAD

Page No.:

Project No.: 30011071

Date: 2/3/12

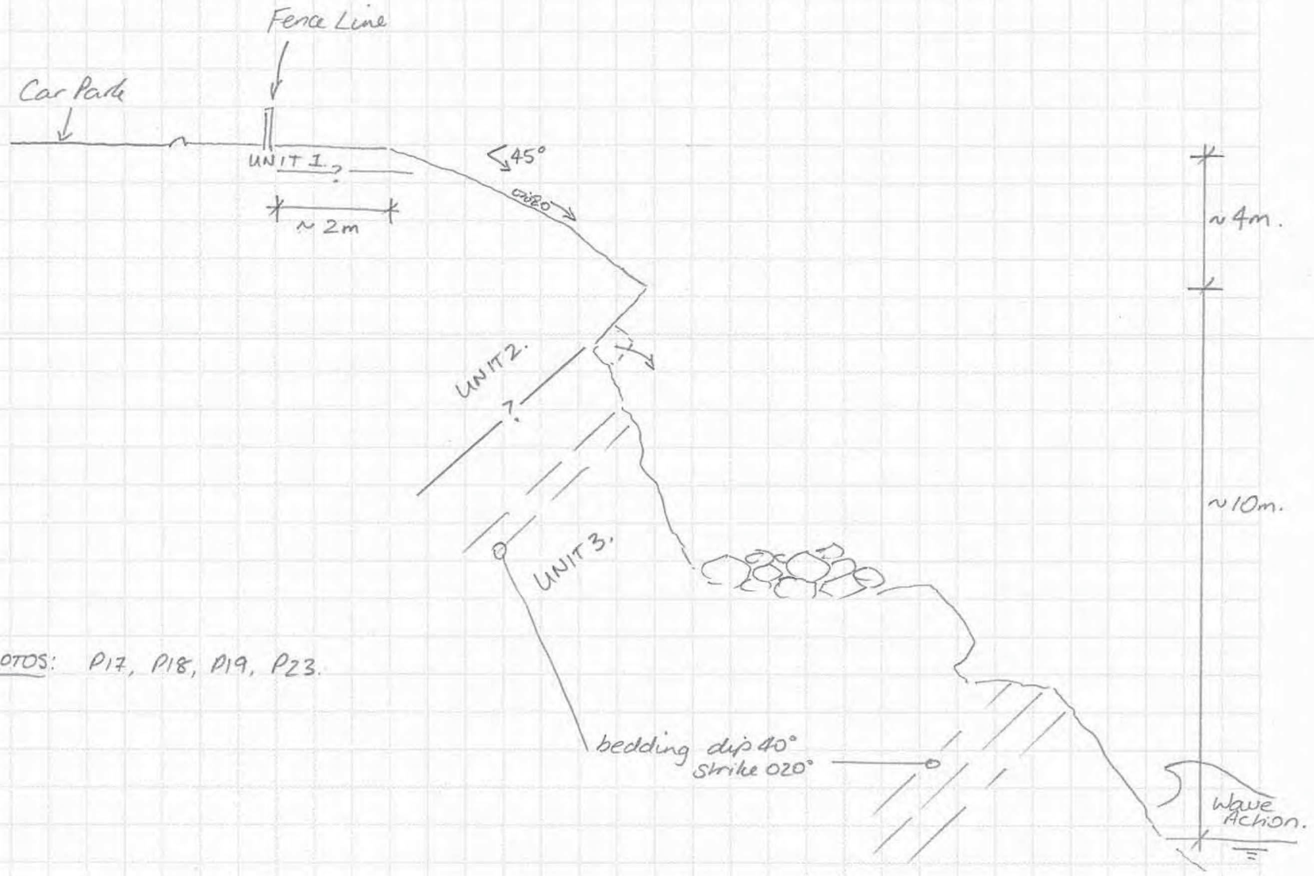
Feature/Structure: SLOPE STABILITY RISK ASSESSMENT

Calcs By: BLM.

Details: MECHANISM 3B: CREST FRETTING & BLOCK TOPPLING.

Checked By:

SECTION (Not to Scale).



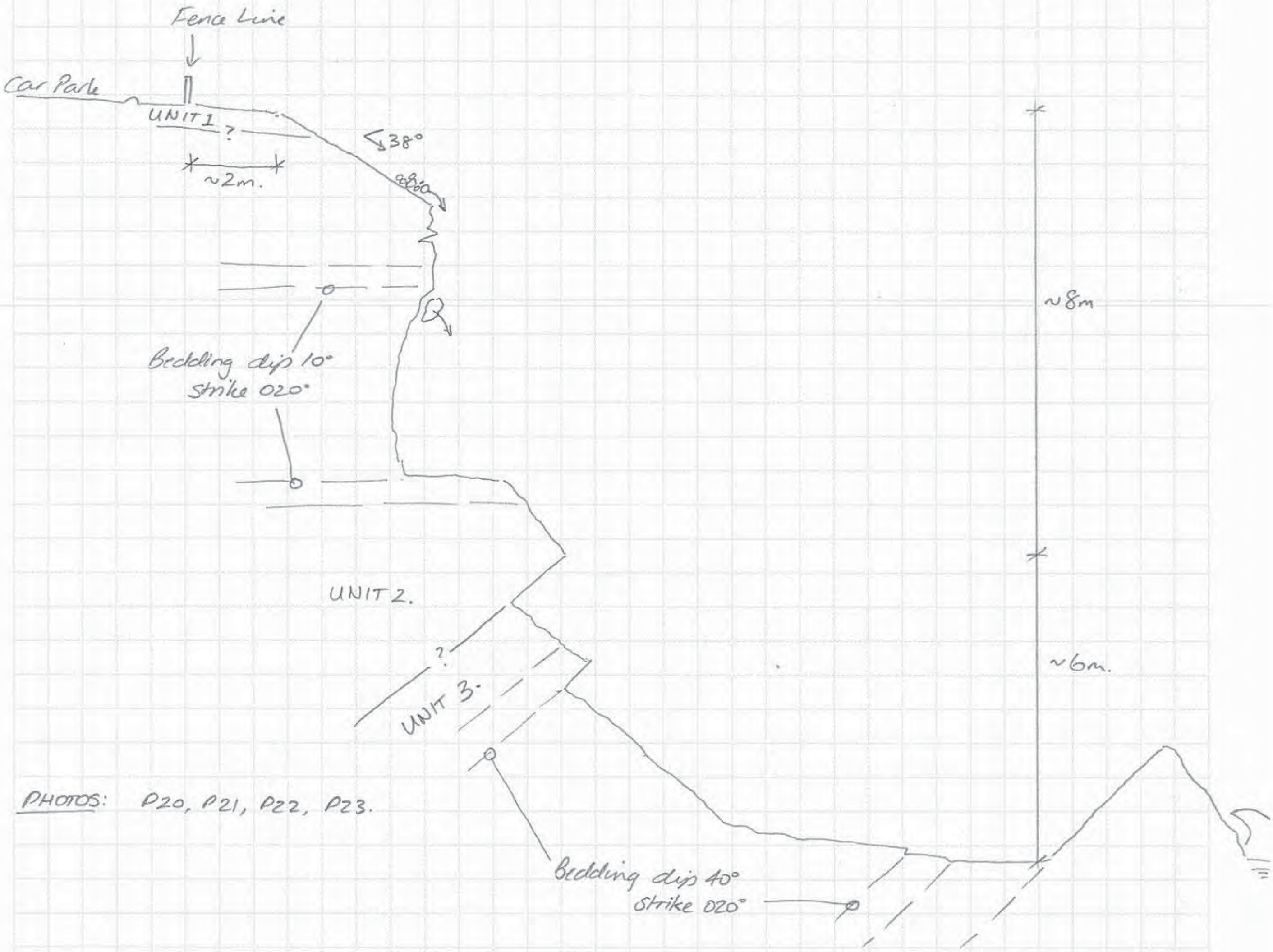
PHOTOS: P17, P18, P19, P23.

SMEC

COMPUTATION SHEET

Project: BROOMS HEAD | Page No.:
Project No.: 30011071 | Date: 2/3/12
Feature/Structure: SLOPE STABILITY RISK ASSESSMENT | Calcs By: BLM.
Details: MECHANISM 3C: CREST FRETTING & BLOCK TOPPLING | Checked By:

SECTION (Not to Scale).



PHOTOS: P20, P21, P22, P23.

Appendix C
Lidar Sections

Notes:

1. UAV Lidar survey undertaken 10/02/2022 by Hydrosphere Consulting.
2. Aerial photography supplied by Nearmaps Imagery dated 28/05/2016.
3. All vertical levels relative to AHD.
4. Refer Figure 4 for vertical profiles.
5. Survey referenced to CORSnet-NSW.
6. Survey elevation accuracy assessed against Yraygir2018-C3-AHD_5356743_56_0001_0001 Lidar dataset .

DRAWING PRODUCED BY: HYDROSPHERE CONSULTING P.O. BOX 7059 BALLINA NSW 2478 WWW.HYDROSPHERE.COM.AU	Hydrosphere Consulting Strategy in Water & Environment	SCALES 0 20 40 Metres	CLIENT Clarence Valley Council Pilot Hill Profile locations Yamba	JOB NUMBER 22-009	DRAWING NUMBER FIGURE 3

REVISION	DATE	DESCRIPTION	DRAWN
	2022-02-27	REV 0	JF

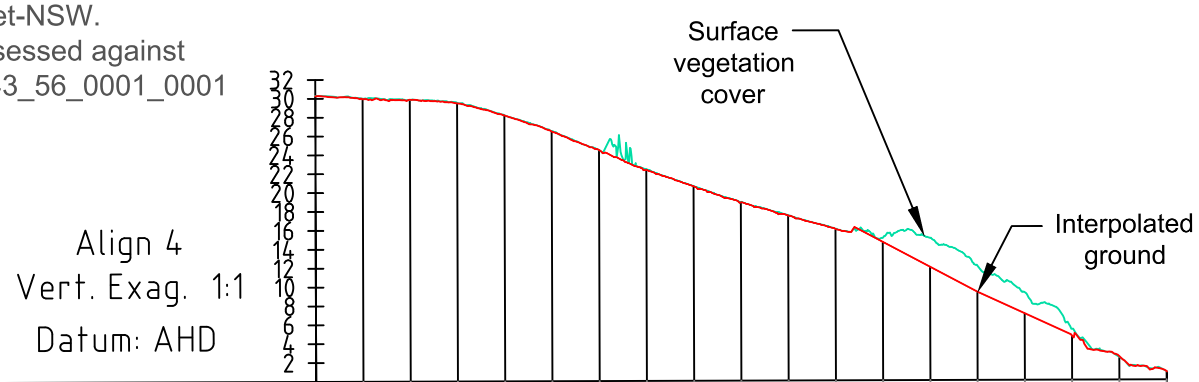
Y:\22-009 Clarence coastline CMP stage 2-4\Drawings\Pilot Hill sections.dwg

Notes:

1. UAV Lidar survey undertaken 10/02/2022 by Hydrosphere Consulting.
2. Aerial photography supplied by Nearmaps Imagery dated 28/05/2016.
3. All vertical levels relative to AHD.
4. Horizontal datum used MGA.
5. Refer Figure 4 for vertical profiles.
6. Survey referenced to CORSnet-NSW.
7. Survey elevation accuracy assessed against Yraygir2018-C3-AHD_5356743_56_0001_0001 Lidar dataset .

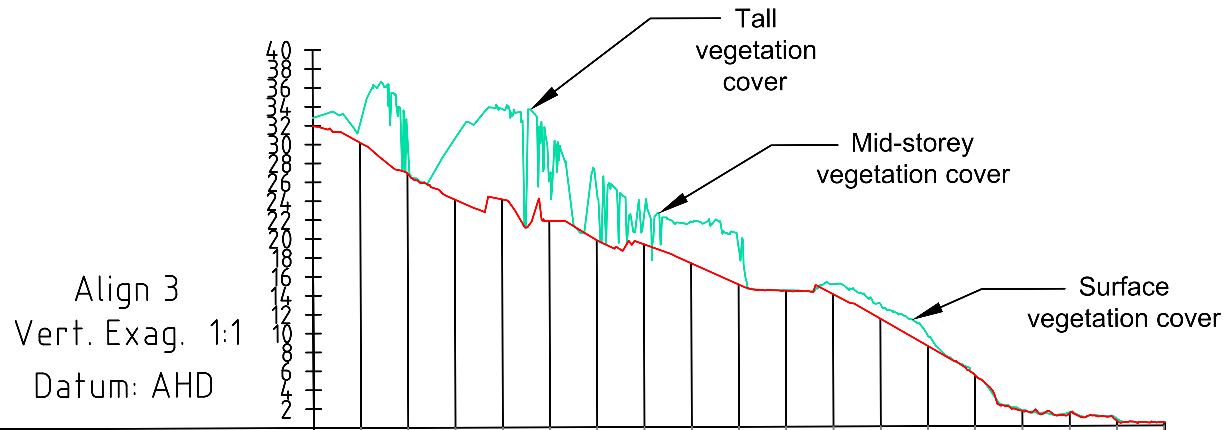
Lidar sub-sampled ground level (unedited)

Lidar edited interpolated minimum values for ground level (approximate)



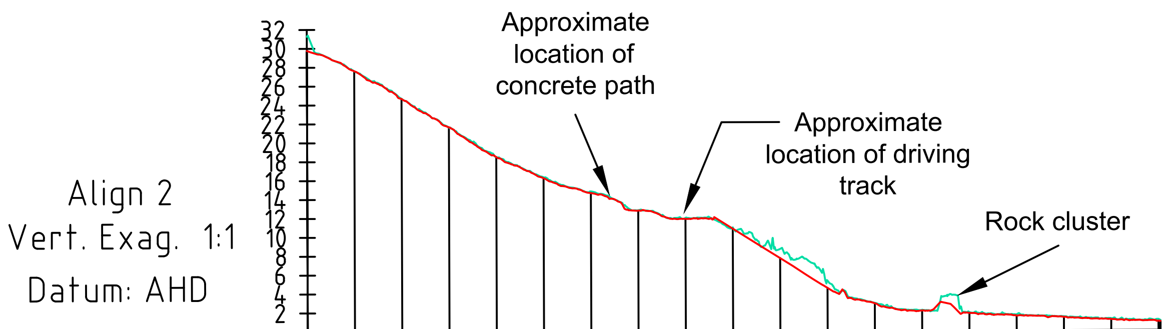
EXISTING LEVELS	29.933	29.870	29.460	28.178	26.461	24.478	22.365	20.603	18.883	17.490	16.048	14.663	12.007	9.351	7.052	4.660	2.465	0.862
CHAINAGE	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90

ALIGN 4



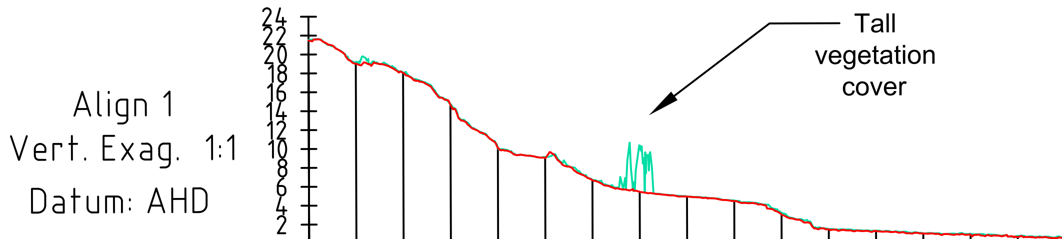
EXISTING LEVELS	30.173	26.946	24.134	24.136	21.814	19.798	19.340	17.316	15.061	14.392	14.001	11.393	8.496	5.378	1.591	1.321	0.525	0.334
CHAINAGE	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90

ALIGN 3



EXISTING LEVELS	27.615	24.669	21.650	18.488	16.235	14.648	12.778	11.884	10.832	7.705	4.536	2.896	2.112	1.846	1.541	1.392	1.165	0.977
CHAINAGE	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90

ALIGN 2



EXISTING LEVELS	19.018	18.034	14.627	10.043	8.978	6.601	5.361	4.838	4.346	2.923	1.327	1.135	0.855	0.709	0.458	0.302
CHAINAGE	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80

ALIGN 1


PACIFIC HOTEL


PACIFIC HOTEL

DRAWING PRODUCED BY:		SCALES	CLIENT	JOB NUMBER		DATE	DESCRIPTION	DRAWN	DRAWING NUMBER
HYDROSPHERE CONSULTING P.O. BOX 7059 BALLINA NSW 2478	Hydrosphere Consulting	0 20 40 Metres	Clarence Valley Council	22-009	REVISION	2022-02-27	REV 0	JF	FIGURE 1
WWW.HYDROSPHERE.COM.AU	Strategy in Water & Environment		Convent Beach Profile locations Yamba						

Y:\22-009 Clarence coastline CMP stage 2-4\Drawings\Convent beach sections.dwg

Notes:

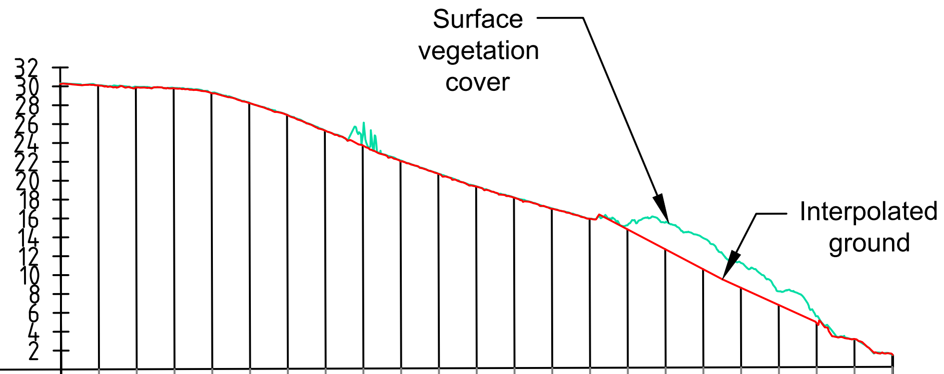
1. UAV Lidar survey undertaken 10/02/2022 by Hydrosphere Consulting.
2. Aerial photography supplied by Nearmaps Imagery dated 28/05/2016.
3. All vertical levels relative to AHD.
4. Refer Figure 4 for vertical profiles.
5. Survey referenced to CORSnet-NSW.
6. Survey elevation accuracy assessed against Yraygir2018-C3-AHD_5356743_56_0001_0001 Lidar dataset .

Lidar near-ground features (unedited)

Lidar edited interpolated minimum values for ground level (approximate)

N

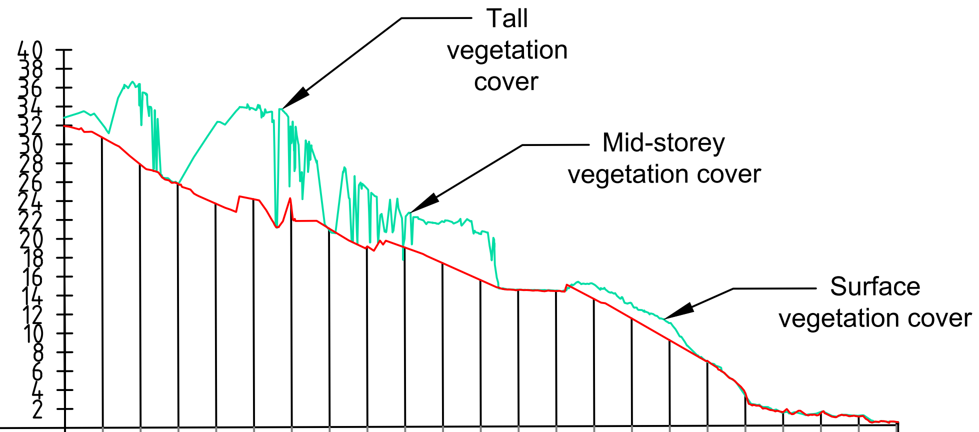
Align 4
Vert. Exag. 1:1
Datum: AHD



EXISTING LEVELS	30.094	29.869	29.769	29.235	28.178	26.902	25.237	23.648	21.941	20.603	19.252	18.059	16.864	15.798	14.663	12.538	10.413	8.429	6.593	4.660	2.957	1.317
CHAINAGE	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88

ALIGN 4

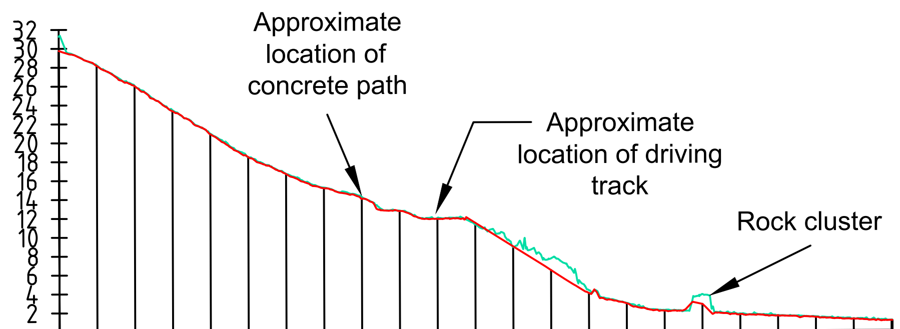
Align 3
Vert. Exag. 1:1
Datum: AHD



EXISTING LEVELS	30.734	27.893	25.830	23.690	24.136	23.541	21.010	19.048	18.979	17.316	15.512	14.441	14.311	13.473	11.393	9.075	6.865	3.445	1.436	1.321	0.930	0.341
CHAINAGE	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88

ALIGN 3

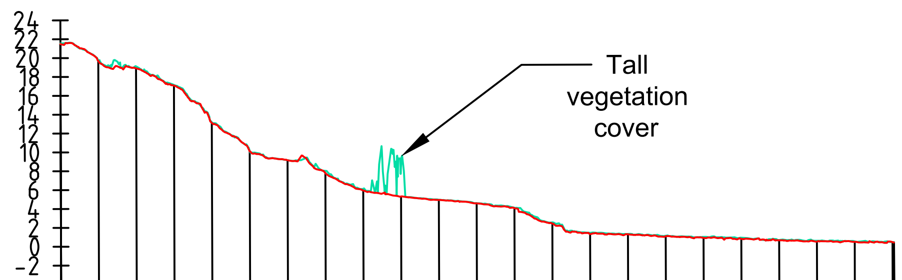
Align 2
Vert. Exag. 1:1
Datum: AHD



EXISTING LEVELS	28.189	26.026	23.362	20.923	18.488	16.686	15.161	14.034	12.737	11.884	11.458	8.956	6.432	3.995	2.896	2.111	2.804	1.713	1.582	1.392	1.203	1.056
CHAINAGE	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88

ALIGN 2

Align 1
Vert. Exag. 1:1
Datum: AHD



EXISTING LEVELS	19.694	18.897	17.052	13.083	10.043	9.092	7.724	5.864	5.215	4.838	4.463	3.939	2.300	1.168	1.135	0.912	0.725	0.610	0.445	0.302	0.250	0.208
CHAINAGE	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88

ALIGN 1

Y:\22-009 Clarence coastline CMP stage 2-4\Drawings\Pilot Hill sections.dwg

DRAWING PRODUCED BY:
HYDROSPHERE CONSULTING
P.O. BOX 7059
BALLINA NSW 2478
WWW.HYDROSPHERE.COM.AU

Hydrosphere Consulting
Strategy in Water & Environment

SCALES
0 20 40
Metres

CLIENT
Clarence Valley Council

JOB NUMBER
22-009

Pilot Hill Profile Sections
Yamba

REVISION	DATE	DESCRIPTION	DRAWN
	2022-02-27	REV 0	JF

DRAWING NUMBER
FIGURE 4

Appendix D
Historical Photos

Historical Photographs of Main Beach and Slope Near Pacific Hotel

These photographs are from the Yamba Museum Facebook page, accessed May 2022

Main Beach circa 1910, looking towards where the Pacific Hotel would be constructed

Main Beach circa 1911, looking towards where the Pacific Hotel would be constructed

Picture of Main Beach circa 1911, photograph taken from what is now Flinders Park

Main Beach circa late 1930’s showing the surf life saving club and Pacific Hotel

Main Beach circa late 1930's showing surf life saving club and Pacific Hotel

Main Beach circa mid 1940's showing surf life saving club and Pacific Hotel

Main Beach and surrounds circa 1950

Surf life saving club and Pacific Hotel, photograph taken between 1950 and 1954, prior to slope failure

Main Beach on New Year's Day 1963 following from cyclonic swells

Main Beach circa 1983

Looking up at Ocean Street from the rocks with Convent Beach to the left, circa Late 1940’s

Appendix E
SCRC Landslide Planning Guidelines

SC6.11 Planning scheme policy for the landslide hazard and steep land overlay code

SC6.11.1 Purpose

The purpose of this planning scheme policy is to:-

(a) provide advice about achieving outcomes in the **Landslide hazard and steep land overlay code**;

(b) identify and provide guidance about information that may be required to support a development application where subject to the **Landslide hazard and steep land overlay code**; and

(c) identify guidelines that may be relevant to achieving outcomes in the **Landslide hazard and steep land overlay code**.

Note—nothing in this planning scheme policy limits Council's discretion to request other relevant information under the Development Assessment Rules made under section 68(1) of the Act.

SC6.11.2 Application

This planning scheme policy applies to development which requires assessment against the **Landslide hazard and steep land overlay code**.

SC6.11.3 Advice for landslide hazard and steep land outcomes

The following is advice for achieving outcomes in the **Landslide hazard and steep land overlay code** relating to landslide hazard and steep land:-

(a) compliance with Performance Outcomes PO1 and PO2 of **Table 8.2.10.3.1 (Requirements for accepted development and performance outcomes and acceptable outcomes for assessable development)** and PO1 to PO5 of **Table 8.2.10.3.2 (Additional performance outcomes and acceptable outcomes for assessable development)** of the **Landslide hazard and steep land overlay code** may be demonstrated in part or aided by the submission of a geotechnical assessment report prepared by a competent person in accordance with **Section SC6.11.4 (Guidance for the preparation of a geotechnical assessment report)**.

Note—for the purposes of this planning scheme policy, a competent person is a qualified registered professional engineer (RPEQ) with appropriate and proven technical experience in geotechnical engineering or engineering geology.

SC6.11.4 Guidance for the preparation of a geotechnical assessment report

(1) The extent and detail of investigations required to be incorporated in a geotechnical assessment report will depend upon the particular site characteristics and the nature of the development proposed. Council will require each report to demonstrate a method and scope of work appropriate to the subject site and the proposed development.

(2) **Table SC6.11A (Indicative scope of work for geotechnical investigations)** provides an indication of the scope of work for geotechnical investigations that may be required to be undertaken for different levels of identified landslide hazard.

Table SC6.11A Indicative scope of work for geotechnical investigations

Level of identified hazard	Scope of geotechnical investigation
Very high/High	• Investigation of existing conditions (including groundwater conditions) and soil strength. • Classification testing. • Walk over survey. • Review of aerial photography. • Site survey. • Numerical modelling such as slip circle analysis to determine the probability of global slip failure.
Moderate	• Walk over survey. • Subsurface investigation.

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Level of identified hazard	Scope of geotechnical investigation
Low/Very low	• Walk over survey where slopes exceed 15%. • Subsurface investigation where slopes exceed 15%.

(3) The extent of work actually required should be determined by the geotechnical engineer preparing the geotechnical assessment report, provided that the conclusion of the report is that the lot, site, building or other feature under assessment has a Factor of Safety of at least 1.5.

(4) The following detailed guidance for geotechnical assessment reports may therefore be adjusted (particularly in respect to investigation of existing conditions) having regard to the scope of work determined to be appropriate in the circumstances.

(5) A geotechnical assessment report is to:-

(a) describe the subject land and the proposed development;

(b) describe the method and scope of investigations;

(c) describe the existing conditions of the development site, including an assessment of land suitability and geotechnical constraints to development in accordance with **Section SC6.11.5 (Investigation of existing conditions for geotechnical assessment reports)**;

(d) assess the suitability of the site for the proposed development, having regard to the prevailing geological and topographic conditions, including an assessment of the likely effects or impacts of the development upon slope stability and landslip potential;

(e) recommend measures to mitigate impacts, including siting, engineering and other measures required to ensure a satisfactory form of development that does not involve high whole of life cycle costs such as deep sub-soil drainage within single residential lots or public land;

(f) incorporate conclusions and recommendations in accordance with **Section SC6.11.6 (Conclusions and recommendations for geotechnical assessment reports)**;

(g) use contour plans showing 1 metre contours developed from site survey or low level aerial photographs using objective photogrammetric techniques;

(h) have regard and refer to the *Landslide Risk Management and Concepts Guidelines (Australian Geomechanics Society) 2007*;

(i) utilise the preferred format outlined in **Appendix SC6.11A (Preferred format for a geotechnical assessment report)**; and

(j) be illustrated by photographs and sketches as appropriate.

(6) Where a geotechnical assessment report has already been prepared for the site and provided as supporting documentation to Council as part of a previous development application (i.e. reconfiguring a lot or material change of use of premises), these documents are to be clearly referenced in the geotechnical assessment report prepared as supporting documentation for the subsequent development application (i.e. operational work or building work).

Note—the guidance provided in this planning scheme policy outlines all matters to be addressed in a geotechnical assessment report, on the basis that such supporting documentation (i.e. earlier geotechnical reports) are not available. In the event that geotechnical assessment reports and certifications for the previous development applications are available, items already covered in these earlier reports/certifications may be referenced and covered in less detail.

SC6.11.5 Investigation of existing conditions for geotechnical assessment reports

(1) A geotechnical assessment report is to include an investigation of existing site conditions comprising an assessment of the existing stability of the subject land and details of geotechnical constraints on building and/or other development works on the site.

(2) The investigation of existing conditions is to include:-

(a) a description of existing geology (surface and subsurface materials, soil/rock stratigraphy) and geomorphology (slopes, ground contours, natural features, terrain analysis, landslip features) both locally and regionally, including review of published materials;

(b) the results of field investigations to assess the following factors:-

(i) depth of soil overburden within proposed works areas (including roads, infrastructure, building sites, potential swimming pools, tennis courts, garage, access driveways and the like);
(ii) classification of surface and subsurface materials to determine:-
(A) erosion potential;
(B) foundation conditions that could affect structural performance;
(C) suitability for wastewater disposal;
(D) any other relevant characteristics;

(c) the results of any numerical modelling/slip circle analysis to determine the probability of global slip failure;

(d) evidence of previous instability (i.e. irregular contours, hummocky topography, scarp faces in area of tension cracks, curved and/or non-vertical tree trunks, broken kerb and gutters, cracked or uneven roadway surfaces, distressed houses or other buildings);

(e) a description of the extent and type of any existing occurrences of erosion;

(f) an assessment of sub-surface drainage characteristics (i.e. presence of water table, springs, swampy areas, wet grass types, presence/depth to/ special conditions (artesian) of groundwater, and possible presence of confined aquifer beneath site;

(g) a description of existing vegetation cover; and

(h) a description of any existing site improvements (i.e. buildings, structures and earth works).

(3) The results of all field and laboratory tests should be included in the geotechnical assessment report, including the location and level (including datum) of field investigations such as boreholes, trench pits and cone penetrometer results.

SC6.11.6 Conclusions and recommendations for geotechnical assessment reports

(1) The geotechnical assessment report is to include conclusions about the overall suitability of the land for the proposed development, including clear statements about:-

(a) whether all existing/proposed lots are presently stable;

(b) whether all lots, and associated completed buildings (i.e. dwelling houses) and infrastructure, will remain stable in the long term – that is, has a factor of safety against failure of at least 1.5; and

(c) whether any conditions need to be placed on the development of lot/s to maintain long term stability.

(2) The geotechnical assessment report is to include recommendations that clearly outline the following:-

(a) whether the site has a history of landslip;

(b) whether the proposed development (including all lots and buildings where applicable) will alter the present state of stability of the subject land;

(c) whether any portion of the subject land should be excluded from the development and included in natural, undisturbed or rehabilitated areas;

(d) whether the proposed development (including all lots and buildings where applicable) will adversely affect the current state of stability of adjoining land;

(e) whether the proposed development (including all lots and buildings where applicable) should allow cuts and fills and if so, to what depth;

(f) whether retaining structures are required and if so, provide necessary foundations design parameters, including drainage requirements;

(g) whether any special design features are required to stabilise or maintain the stability of the subject land, or portions of the subject land (including each lot where applicable);

(h) whether any special surface and/or subsurface drainage measures need to be taken to improve or maintain the stability of the subject land, or portions of the subject land (including each lot where applicable);

(i) whether on site disposal of liquids should be allowed; and

(j) whether any follow up inspections are required by the geotechnical engineer during construction.

(3) The recommendations of the geotechnical assessment report should also provide guidance on appropriate measures required to make the site suitable for the proposed development, including:-

(a) preferred locations for buildings, other structures, driveways, etc.;

(b) foundation requirements such as bearing pressures, piling parameters, special techniques for expansive clays;

(c) pavement type and design;

(d) construction methods to avoid problem areas associated with loose materials and groundwater seepage;

(e) preferred excavation/retention/stabilisation techniques and suitability of excavated materials for use in on-site earthworks;

(f) surface and subsurface drainage requirements;

(g) preferred methods of wastewater disposal (deep soil drainage within single residential lots or public land is not acceptable to Council; and

(h) vegetation protection and revegetation requirements.

SC6.11.7 Guidelines for achieving landslide hazard and steep land overlay outcomes

For the purposes of the performance outcomes and acceptable outcomes in the **Landslide hazard and steep land overlay code**, the following are relevant guidelines:-

(a) *Landslide Risk Concepts and Guidelines* (Journal and News of the Australian Geomechanics Society, 2007).

Appendix SC6.11A Preferred format for a geotechnical assessment report

1. Introduction

1.1 Details of development
1.2 Site location and description (including survey co-ordinates/co-ordinate system)
1.3 Method and scope of investigation
1.4 Qualifications of company and competent person(s) to prepare report

2. Description of existing conditions

2.1 Geology (local and regional)
2.2 Topography
2.3 Groundwater
2.4 Surface drainage
2.5 Vegetation
2.6 Buildings, other structures

3. Assessment of land stability

3.1 Existing conditions
3.2 Geotechnical constraints to development

4. Description of proposed development

4.1 Site layout
4.2 Proposed development components
4.3 Potential geotechnical effects

5. Assessment of development impacts

5.1 Site layout
5.2 Roadworks, driveways and other pavements
5.3 Earthworks (excavation, materials usage)
5.4 Foundations
5.5 Surface drainage
5.6 Wastewater treatment and disposal
5.7 Overall effect of development on stability

6. Recommendations and measures to mitigate impacts

7. Summary and conclusions

8. Site plan

APPENDIX – Field and laboratory test results and modelling results

8.2.10 Landslide hazard and steep land overlay code[36] [37]

8.2.10.1 Application

(1) This code applies to accepted development and assessable development:-

(a) subject to the landslide hazard and steep land overlay shown on the overlay maps contained within **Schedule 2 (Mapping)**; and

(b) identified as requiring assessment against the Landslide hazard and steep land overlay code by the tables of assessment in **Part 5 (Tables of assessment)**.

(2) The acceptable outcomes in **Table 8.2.10.3.1 (Requirements for accepted development and performance outcomes and acceptable outcomes for assessable development)** are requirements for applicable accepted development.

(3) All provisions in this code are assessment benchmarks for applicable assessable development.

8.2.10.2 Purpose and overall outcomes

(1) The purpose of the Landslide hazard and steep land overlay code is to ensure:-

(a) development avoids or mitigates the potential adverse impacts of landslide hazard on people, property, economic activity and the environment; and

(b) development on *steep land* is avoided or otherwise limited in scale and intensity, and is sensitively located and designed to minimise adverse impacts on scenic amenity, the environment and public safety.

(2) The overall outcomes sought for the Landslide hazard and steep land overlay code are the following:-

(a) development in areas at risk from landslide hazard is compatible with the nature of the hazard;

(b) the risk to people, property and the natural environment from landslide hazard is minimised;

(c) development does not result in a material increase in the extent or severity of landslide hazard; and

(d) development on *steep land* occurs only where the scenic and environmental quality and integrity of the landscape is maintained and safe and efficient *access* can be provided.

8.2.10.3 Performance outcomes and acceptable outcomes

Table 8.2.10.3.1 Requirements for accepted development and performance outcomes and acceptable outcomes for assessable development

Performance Outcomes		Acceptable Outcomes	
Landslide Hazard Areas			
Risk of Harm to People and Property			
PO1	Development does not increase the risk of harm to people and property as a result of landslide by either:- (a) avoiding development in a landslide hazard area; or (b) undertaking development in a landslide hazard area only	**AO1**	Development, including associated *access*, is not located on land identified as a landslide hazard area on a Landslide Hazard and Steep Land Overlay Map. **OR**

[36] Editor's note—landslide hazard areas and *steep land* (slopes of 15% or greater) are identified on the Landslide Hazard and Steep Land Overlay Maps in **Schedule 2 (Mapping)**. Landslide hazard may also be a risk in other areas and warrant further assessment.
[37] Editor's note—the **Planning scheme policy for the landslide hazard and steep land overlay code** and the **Planning scheme policy for development works** provide advice and guidance for achieving certain outcomes of this code, including guidance for the preparation of a site-specific geotechnical assessment report.

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Performance Outcomes		Acceptable Outcomes	
	where strictly in accordance with *best practice* geotechnical principles.		Development, including associated *access*, is located in a low or very low landslide hazard area, as determined by a geotechnical investigation prepared by a competent person. Note—a site-specific geotechnical assessment may be used to demonstrate that although the proposed development is shown on a Landslide Hazard and Steep Land Overlay Map as being located within a landslide hazard area, the landslide hazard risk is in fact low or very low. **OR** Where development is located on land identified as a landslide hazard area[38]:- (a) a competent person has certified that:- (i) the stability of the *site*, including associated buildings and *infrastructure*, will be maintained during the course of the development and will remain stable for the life of the development; (ii) development of the *site* will not increase the risk of landslide activity on other land, including land above the *site*; and (iii) the *site* is not subject to the risk of landslide activity originating from other land; and (b) any measures identified in a site-specific geotechnical assessment for stabilising the *site* or development have been fully implemented.
Steep Land			
Risk of Harm to People and Property			
PO2	Development, including associated *access*, does not increase the risk of harm to people and property by:- (a) avoiding development on *steep land*; or (b) undertaking development on *steep land* only where strictly in accordance with best-practice geotechnical principles.	**AO2**	Development, including associated *access*, is not located on *steep land* as identified on a Landslide Hazard and Steep Land Overlay Map. **OR** Development, including associated *access*, is located on land with less than 15% *slope*, as determined by a site-specific *slope analysis* prepared by a competent person. **OR** Where development is located on steep land[39], a site-specific geotechnical assessment prepared by a competent person certifies that:- (a) the stability of the *site*, including associated buildings and *infrastructure*, will be maintained during both the construction and operational life of the development; and (b) the *site* is not subject to risk of landslide activity originating from other land.

[38] As specified on a Landslide Hazard and Steep Land Overlay Map or as determined by a site-specific geotechnical assessment.
[39] As specified on a Landslide Hazard and Steep Land Overlay Map or as determined by a *slope analysis*.

Performance Outcomes		Acceptable Outcomes	
Additional requirements for accepted development and performance outcomes and acceptable outcomes for assessable development where for a Dwelling House			
PO3	Where for a *dwelling house*, the development:- (a) is responsive to the natural topography of the *site* and minimises the need for cut and fill; (b) does not visually dominate the hill slope or interrupt the skyline; and (c) is visually integrated with natural site characteristics including *vegetation*.	**AO3.1**	Where for a *dwelling house* and located on land having a *slope* exceeding 15%, as identified on a Landslide Hazard and Steep Land Overlay Map:- (a) buildings are of a split level design that steps down the slope or incorporates a suspended floor construction that avoids filling and/or excavation; **OR** (b) any *filling or excavation* associated with buildings, structures or driveways is confined to the driveway and plan area of the *dwelling house*, with ground level being retained around the driveway and the external walls of the building(s); **OR** (c) any *filling or excavation* associated with buildings, structures or driveways:- (i) is not more than 2 metres relative to ground level or 1.0 metre relative to ground level where within 1.5 metres of any property boundary; and (ii) does not necessitate the construction of a retaining wall exceeding 2 metres in height relative to ground level.
		AO3.2	Any *filling or excavation* associated with buildings, structures or driveways provides for the stabilisation of any cut or fill batter through the use of landscapes and/or retaining walls.
		AO3.3	Driveways are not steeper than 20% for more than 20 metres or one quarter of their length, whichever is the lesser, and not more than 25% in any location.
		AO3.4	Parts of a driveway steeper than 20% are provided with a slip-resistant surface.

Table 8.2.10.3.2 Additional performance outcomes and acceptable outcomes for assessable development

Performance Outcomes		Acceptable Outcomes	
Landslide Hazard and Steep Land			
Essential Community Infrastructure			
PO1	*Essential community infrastructure* is able to function effectively during and immediately after landslide events.	**AO1**	Development involving *essential community infrastructure* is not located within a landslide hazard area, or on *steep land*, as identified on the applicable Landslide Hazard and Steep Land Overlay Map. **OR**

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Performance Outcomes		Acceptable Outcomes	
			Development involving *essential community infrastructure* is located in a low or very low landslide hazard area, as determined by a site-specific geotechnical assessment prepared by a competent person. **OR** Development involving *essential community infrastructure*:- (a) does not result in any new building work, other than an addition to an existing building; (b) does not involve *vegetation clearing*; and (c) does not alter ground levels or stormwater conditions. **OR** Development involving *essential community infrastructure* includes measures identified by a site-specific geotechnical assessment, prepared by a competent person, that ensure:- (a) the long term stability of the *site*, including associated buildings and *infrastructure*; (b) *access* to the *site* will not be impeded by a landslide event; and (c) the community *infrastructure* will not be adversely affected by landslides originating from other land, including land above the *site*.
Storage of Hazardous Materials			
PO2	Development ensures that public safety and the environment are not adversely affected by the detrimental impacts of landslide on hazardous materials manufactured or stored in bulk.	**AO2**	Development involving the manufacture or storage of hazardous materials in bulk is not located within a landslide hazard area, or on *steep land*, as identified on a Landslide Hazard and Steep Land Overlay Map. **OR** Development involving the manufacture or storage of hazardous materials in bulk is located in a low or very low landslide hazard area, as determined by a site-specific geotechnical assessment prepared by a competent person. **OR** Where development is located in a landslide hazard area[40], a site-specific geotechnical assessment prepared by a competent person certifies that:- (a) the stability of the *site*, including associated buildings and *infrastructure*, will be maintained during both the construction and operational life of the development; and

[40] As specified on a Landslide Hazard and Steep Land Overlay Map or as determined by a site-specific geotechnical assessment.

Performance Outcomes		Acceptable Outcomes	
			(b) the *site* is not subject to risk of landslide activity originating from other land.
Steep Land			
Site Responsive Design			
PO3	Development, including associated *access*, is designed and constructed to:- (a) sensitively respond to the constraints imposed by slope; (b) minimise impacts on the natural landform and landscape character; and (c) avoid any potential instability and associated problems, including long term stability of the *site* and long term stability of the development and adjoining properties.	**AO3.1** **AO3.2** **AO3.3**	No additional lot which includes a house site is created on land with a *slope* of 25% or greater. Development avoids or minimises *filling or excavation* by using elevated construction or stepped (split level) building forms. Development provides for cut and fill batters to be stabilised and protected from erosion by measures such as grassing, dense landscapes, retaining walls or other suitable stabilisation/protective methods.
PO4[41]	Development is sensitively designed, sited and erected to respect and be visually integrated into the *streetscape* and the natural surroundings by ensuring:- (a) adequate screening of the underneath of buildings; (b) retention, where possible, of natural landforms, drainage lines and *vegetation*; and (c) buildings and structures are not visually intrusive, particularly from ridge lines, public open spaces, scenic routes and other critical vantage points, outside of the *site*.	**AO4.1** **AO4.2**	Any building, including any associated car parking structure:- (a) has a maximum undercroft height at the perimeter of the building of 3 metres above ground level; or (b) incorporates undercroft skirting or screening (such as timber battens) to the full height of any undercroft higher than 3 metres above ground level at the perimeter of the building; or (c) incorporates landscape screening for the full height of any undercroft higher than 3 metres above ground level at the perimeter of the building. The extent of *filling or excavation* is revegetated immediately following completion of the works.
Safe and Efficient Access			
PO5	Development provides safe and efficient *access* for vehicles and pedestrians.	**AO5.1** **AO5.2** **AO5.3** **AO5.4**	Road grades comply with the standards specified in the **Planning scheme policy for development works.** Driveways are not steeper than 20% for more than 20 metres or one quarter of their length, whichever is the lesser, and not steeper than 25% in any location. Vehicle turning areas are provided at the end of driveways so that it is not necessary to reverse up or down driveways. Where a driveway is steeper than 20% in any part, it is provided with a slip-resistant surface.

[41] Editor's note—the acceptable outcomes corresponding to this performance outcome represent only partial fulfilment of the performance outcome. In order to adequately address this performance outcome, other measures are also likely to be necessary.