REPORT

TO
CLARENCE VALLEY COUNCIL

TECHNICAL REPORT 3

RISK ASSESSMENT AND STABILISATION

FOR
PILOT HILL YAMBA, NSW

30 August 2017
Ref: 19314L3rpt – Technical Report 3 Final

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TABLE OF CONTENTS

1 INTRODUCTION

This Technical Report 3 presents the results of our geotechnical risk assessment, stabilisation options and future maintenance requirements. This report has been carried out at the request of Clarence Valley Council and will form part of the Pilot Hill Yamba Groundwater and Slope Stability Data Review and Action Plan. This geotechnical study has been carried out in conjunction with The University of New South Wales – Water Research Laboratory (WRL)

This report has utilised the results of our previous reports;

1. Technical Report 1 (Reference 19314L3 – Technical Report 1, dated 21 September 2016),
2. Technical Report 2 (Reference 19314L3 – Technical Report 2 Rev2, dated 21 August 2017).

Technical Report 1 included;

- A site visit on 23 August 2016 to meet with relevant stakeholders and Council to obtain information on any landslide events that have occurred since our last risk assessment in 2007.
- An extension of previous historical searches to identify relevant landslide events.
- Updating of the rainfall records, including daily and antecedent rainfall periods to identify relevant dates when rainfall was high.

Technical Report 2 included;

- A detailed review of all groundwater and inclinometer monitoring data from June 2005 to July 2016.
- Analysis and calibration of all groundwater data and rainfall records by WRL and provision of a predictive model of likely groundwater levels outside the monitoring period.
- Geotechnical slope stability modelling utilising the groundwater data.
- Review of Photogrammetry records for the study area.

2 PROJECT APPRECIATION

The study area which comprises Yamba Beach and the slopes leading up to Pilot Street, includes both private and public property at Pilot Hill in Yamba. In 2000, the former Maclean Shire Council engaged Manly Hydraulics Laboratory (now NSW Water Research Laboratory) to carry out studies for the purpose of preparing a Coastline Management Plan for Yamba. At that time, specialist geotechnical studies were also undertaken by JK Geotechnics and these included;

- Data review and historical searches, including rainfall assessment (now updated and presented in our recent Technical Report 1, dated September 2016).

- Geotechnical stability analysis, including an assessment of hydrogeological models (now updated and presented in our Technical Report 2, dated August 2017).
- A risk analysis, probability assessments for landsliding and development of landslide risk zones, and discussion of treatment options (to be presented in this Technical Report 3).

On the basis of that Coastline Management Plan, an Implementation Strategy was developed and this required groundwater monitoring within piezometers, and measurement of movement by the use of inclinometers. The inclinometer monitoring commenced in April 2005 and the groundwater monitoring commenced in May 2005. The plan required acquisition of data from antecedent rainfall and a 1 in 10 year average recurrence interval (ARI) or larger. The objective of the rainfall and monitoring data was to collect sufficient factual data for a re-assessment of the risks and for design of stabilisation measures. Council now wishes for a detailed review of all information to date to assess whether sufficient data has been obtained and to address its objectives.

2.1 <u>Current Study Area</u>

The current study area comprises Yamba Beach which is backed by steep foreshore slopes leading up to Pilot Street which is located on a Plateau area. The Pacific Hotel and various residential dwellings (No's 2 to 14) are located toward the crest of the foreshore slopes, with some minor structures located within the foreshore slopes south of No. 10, and below the Pacific Hotel. The attached Figure 1 shows a general location map showing the study area, while the attached Figure 2 shows a more detailed location plan including the current investigation locations by JK Geotechnics and WRL.

3 <u>SUMMARY OF TECHNICAL REPORT 1</u>

Technical Report 1 included a detailed rainfall analysis and a historical search for known landslides within and around the study area.

The rainfall analysis was based on rainfall data from a pluviometer located at Yamba Pilot Station, on Pilot Hill. Within Technical Report 1, the rainfall data was based on the period from 22 May 1887 to 21 June 2016, however since preparation of Technical Report 1, we have updated the data to include rainfall records up to 2 May 2017. The rainfall data was analysed and ranked for each daily and antecedent (2 day to 90 day) events. A summary table of the ranked rainfall was presented and the updated table (Table A) showing records up to 2 May 2017 has been included in Appendix A of this report. A Gumbel probability plot showing the predicted return period for daily and antecedent events was also prepared and an updated plot (including the data up to 2 May

2017) has been included within Appendix A as Table B. Tables D and E from our previous Technical Report 1 have also been updated and reproduced in the attached Appendix A, and these show a summary of the return periods for actual rainfall and antecedent rainfall for landslide events.

A summary of known or reported 'landslides' dating back to August 1889 was produced. The term 'landslides' was used generically to represent all events such as beach scour, rock revetment damage, earthflows, earth slides, scour and wave attack. Tables C and C1, summarising the known landslides and the historical data were presented within Technical Report 1. These tables have also been updated and presented within Appendix A of this Technical Report 3 for completeness.

4 SUMMARY OF TECHNICAL REPORT 2

Technical Report 2 produced an analysis of the groundwater monitoring conducted from May 2005. Based on the groundwater monitoring and review of existing subsurface information, geotechnical sections were developed to allow slope stability analysis to be undertaken. The rainfall data showed that there were a number of 'significant' rainfall events within the monitoring period. These included events in 2005, 2006, 2009, 2011 and 2013. A subsequent 'significant' rainfall event occurred in March 2017, however, although this rainfall data has been utilised to update the rainfall analysis (presented with the attached Appendix A), it was not analysed as part of Technical Report 2. Each of the rainfall events (apart from the event in 2013) had rainfall events which exceeded a 10 year return period. The peak groundwater levels recorded for these significant events were used as part of the slope stability modelling.

WRL undertook detailed modelling of the groundwater and rainfall data to develop a predictive model of groundwater levels for rainfall events beyond the period of monitoring. While the predictive model was not an exact fit, it was well within the accuracy expected for geotechnical purposes. As such, slope stability modelling was also undertaken for predicted peak groundwater levels.

The slope stability modelling assessed a number of different failures within the slopes (i.e. failures within the lower foreshore slopes, deep seated failures within the upper slopes and shallow failures within the upper slopes). Generally the slope stability analysis showed that factors of safety for circular failures were lower than would normally be considered acceptable when peak groundwater levels were adopted, and often also lower than would normally be considered acceptable even when 'average' groundwater levels were adopted.

5 TYPES OF LANDSLIDES

From review of the historical data, as summarised in Table C of Appendix A, we consider that there are essentially four different landslide types/events in relation to the hillside slopes, and these are discussed further below. In addition different landslide types/events occur at variable velocities. The following table provides a generalised summary of velocity scale for landslides.

Table 1 – Landslide Velocities and Significance

Description	Typical Velocity	Probable Destructive Significance
Extremely Rapid		Castastophe of major violence; buildings destroyed by impact of displaced material; many deaths escape unlikely
Very Rapid	5m/sec	Some lives lost: velocity too great to permit all persons to escape
Rapid	3m/min	Escape evacuation possible: structures, possession and equipment destroyed.
Moderate	1.8m/hr	Some temporary and insensitive structures can be temporarily maintained.
Slow	13m/month	Remedial construction can be undertaken during movement; in sensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
Very Slow	1.6m/year	Some permanent structures undamaged by movement
Extremely Slow	15mm/year	Imperceptible without instruments; construction possible with precautions

5.1 Scour

During periods of very high intensity rainfall, significant run-off would occur, even from permeable (landscaped) areas. The concentrated flow of surface run-off can lead to localised scour erosion which can cause significant local damage. This appears to have occurred on 1 and 2 March 1999 when the highest recorded daily rainfall of 300mm was recorded. The location of the scour is shown on the attached Figure 4 (termed 'slump 1999') below the Pacific Hotel and Marine Parade. The after effects of such scour are similar to a landslide in terms of the disruption and damage. There is also the potential for secondary landslides to occur around the scoured areas, thereby enlarging the effect. Scour events are most likely during the actual period of rainfall, or shortly thereafter, and ground movements would be expected to be Moderate to Very Rapid.

5.2 Earthslides

Most of the reported movements would be classified as “earthslides”, meaning that it is earth material rather than rock and that the form of movement is a slide rather than a flow, or a rockfall or similar. Other descriptive terms used could be a “slump failure”

For an Earthslide the earth moves downhill but does not move significantly from the source area. The surface evidence of such earthslides includes features such as a head scarp, or tension zone, and a depositional or bulge zone at the toe where the slide material is deposited over the existing ground levels. These failures are likely to occur relatively slowly often being preceded by creep movements. The rate of movement is expected to be Very Slow to Moderate.

The location of known earthslides within the study area are shown on Figure 3. These include the earthslides located at the toe of the slopes in 1994 and 1974.

5.3 Earthflows

There has been two reports of earthflows (1988 and 2002), on the west side of Yamba Hill in the slopes above the Calypso Caravan Park. In these cases the landslide debris has flowed in a “liquid like form” at least 30m across Harbour Street and into the Caravan Park. The significance of this type of movement is both the distance of travel of the landslide debris, and usually the rapidity with which it occurs being typically Rapid to Very Rapid. Such flows are usually in response to saturation effects in relatively weak and/or collapsing soils such as loose sands.

5.4 Wave Attack/Beach Scour

We have indicated on Table C in Appendix A some wave attack/beach scour events which were reported during public meetings and also documented in newspapers. These landslide events are relevant to coastal processes. However we note that from review of the photogrammetry records as part of Technical Report 2, it appears that while some loss of beach levels may occur during storm events, the relatively shallow depth to rock along the beach (particularly near the Yamba Surf Club) means that significant beach scour does not occur and beach levels are replenished over time. The photogrammetry records generally show no significant changes to beach levels since the first aerial photographs were taken in 1942.

6 RISK ANALYSIS

The risk analysis has included the following;

- A detailed rainfall analysis of daily and antecedent rainfalls from 22 May 1887 to 2 May 2017. This allowed an assessment of likely return periods for these rainfall events. These have been plotted on a Gumbel plot which is presented as Table B in Appendix A.
- Review of the FOS values from the slope stability analysis calculated as part of Technical Report 2. The summary slope stability results tables from Technical Report 2 are attached in Appendix C.
- A probability assessment, which included a historical search for known landslides and evaluation of return periods of actual rainfall and antecedent rainfall for landslide events. This summary is included as Table E in Appendix A.

These items were then used in combination with an assessment of the consequences of landsliding to calculate the risk to life and to assign landslide risk zones.

6.1 Slope Stability Factors of Safety

The slope stability analysis carried out as part of Technical Report 2 has shown that the stability would be marginal at the toe slopes under elevated groundwater conditions associated with wet weather, with FOS values close to 1.0. Also stability would be marginal (particularly at Transect 1) for deep seated failures of the upper slopes as a result of groundwater level rises.

The FOS values are generally less than the usually accepted values which are normally 1.5 for a 'reasonable design case'. Values as low as 1.25 may be tolerated for transient short term conditions.

6.2 Probability of Landslides

The probability assessment has included all known landslides and events as could reasonably be determined from the historical search, with the earliest known event occurring in May 1921 and the most recent event in June 2011.

A summary of rainfall return periods for the various landslide types is presented below. We have not included wave attack/beach scour as these are not considered to be a significant risk.

6.2.1 Scour

Scour events have occurred in June 2011, March 1999, May 1938 and May 1921. Typically the scour events have a critical rainfall period of relatively short duration (i.e. 1 to 2 days). The following summarises the rainfall and return periods for these events;

- The June 2011 scour event occurred after a higher intensity 1 in 20 year, 2 day rainfall event.
- The scour events of March 1999 and May 1921 have high short term rainfalls (1 to 5 day rainfalls). These rainfalls have an indicative return period of about 142 years.
- The May 1921 also had relatively high 15 to 30 day rainfalls with indicative return periods ranging from about 135 years. The high longer term rainfalls in May 1921 could also indicate that earthslides occurred as well as scour, however no details could be found during the historical searches.
- The 1938 scour event occurred when there was relatively low short term rainfall. Therefore it is possible that this scour event was actually a number of small earthslides rather than scour, or was the result of some other event rather than rainfall (such as a broken pipe).

6.2.2 Earthslides

Earthslide events have occurred in March 1994, May 1977, March 1974, April 1962, June/July 1950 and August 1989. These events seem to have critical rainfall periods which are both short term (1 to 5 days) and medium term (30 to 45 days). The corresponding return periods vary between about 9 years and 100 years. These types of failures generally seem to be driven by elevated groundwater levels within the soil profile. The short term rainfall probably results in a final driving groundwater force to an already elevated groundwater level.

6.2.3 Earthflow

The April 1988 earthflow had a similar pattern to the above Earthslide events, being a relatively low short term rainfall but higher long term rainfall, with a critical rainfall period of 60 days and a return period of about 24 years. In contrast, the February 2002 earthflow had very little short or long term rainfall. Our observations of photographs retrieved during our historical search and taken during this earthflow, indicated pipes within the failure area and therefore it is possible that a broken pipe may have exacerbated the failure.

6.2.4 Landslides within the Study Area

Some of the known landslide events discussed above were within the study area and have been plotted on Figure 3. We provide the following commentary on these events.

- In late June and early July 1950 significant damage occurred to the Pacific Hotel. The rainfall records indicate that 1950 had the highest recorded 45 day, 60 day and 90 day antecedent rainfall since rainfall records were commenced.
- A zone of sliding was recorded in 1974, and this also corresponded with a zone of movement within the slopes immediately below the Pacific Hotel which is believed to have occurred in about Easter 1994. The rainfall records indicate that March to June of 1974 represented one of the most significant rainfall periods since records commenced. The 1974 period of rainfall ranked 2 for 1, 2, 3, 5, and 8 day rainfalls and ranked between 3 and 7 for longer periods of rainfall.
- The 1994 rainfall ranked much lower than the 1974 rainfall with its highest ranking being 14 for a 30 day antecedent rainfall event. Further slumping within the lower foreshore slopes (below Marine Parade and the staff accommodation cottage) was also noted in 1994.
- A slump and scour occurred in 1999 following the most significant single day rainfall event in the history of rainfall records. We understand that this rainfall event was a very high intensity rainfall over a period of about 4 hours.

During our site visit on 23 August 2016, we also observed a slump feature within the lower foreshore slopes (below Marine Parade and below No.12 Pilot Street). The timing of this slump is unknown, however we suspect that it has most likely occurred within the last ten years or so, based on the lack of vegetation cover and the presence of soil material still at the toe of the slope.

6.2.5 Groundwater Level Responses

As part of Technical Report 2, the following table was produced which compared the maximum observed groundwater levels during the monitoring period with maximum predicted groundwater levels from 1945 to 2015.

Technical Report 2 provided a detailed analysis of the changes in groundwater levels with rainfall. A general trend is for the peak levels of groundwater at the crest of the slope to occur sometime (in the order of 3 to 15 days) after the highest 1 or 2 day rainfall events. In the mid to lower slopes, the peak groundwater occurs either during the highest 1 or 2 day rainfall event or very shortly after. This indicates that during periods of significant rainfall, the lower slopes essentially saturate quite quickly, due to the shallower depth of soil, while toward the top of the slope it takes some time for the rainfall to infiltrate through the deeper soils and impact the groundwater level. The top of the slope also takes longer to drain, while the mid to lower portions of the slope drain relatively quickly.

This is why the earthslides generally occur when longer term antecedent rainfall has occurred and then there is a more significant short term rainfall event at the same time.

Table 2 - Maximum Predicted Groundwater Levels from 1945 to 1915

Piezometer	Maximum Predicted Groundwater Level (mAHD) 1945-2015	Maximum Predicted Groundwater Levels (mAHD) 1950 Rainfall Event	Maximum Observed Groundwater Levels during Monitoring Period (mAHD) 2005 to 2016	Difference between Predicted Maximum Levels 1950 and Observed Maximum Levels 2005-2016
1A	23.58	23.58	22.52m	1.06
1B	19.11	19.11	18.75m	0.36
1C	10.82	10.82	10.22m	0.6
2A	26.09	26.09	25.44m	0.65
2C	14.77	14.65	14.47m	0.3
3A	27.04	26.57	26.61m	-0.04
3C	17.10	17.10	15.70m	1.4
MSA1	23.67	23.67	23.38m	0.29
MSA9	16.86	16.86	16.32m	0.54

6.2.6 Rainfall Events During the Monitoring Period

The following table provides a summary of the significant rainfall events and their return period during the monitoring period. We have also included the more recent March 2017 rainfall event. To our knowledge there has been no significant or recorded landslide events during the monitoring period, apart from two minor scours below Marine Parade and No. 2 and No. 4 Pilot Street in 2011.

Table 3 – Significant Rainfall Events During Monitoring Period (Return Period) in mm

Event Date	1-Day	2-Day	3-Day	5-Day	8-Day	30-Day	45-Day	60-Day	90-Day
30/6/2005–5/7/2005	250.4 (28.2)	323.4 (35.25)	360.4 (28.2)	376.3 (28.2)	385.1 (14.1)	405.5 (2.76)	572.8 (2.47)	572.8 (2.47)	645 (1.78)
30/8/2006–11/9/2006	155.8 (7.05)	181.4 (4.15)	194.8 (2.82)	213.4 (2.43)	215.6 (1.93)	299.4 (1.32)	349.7 (1.27)	422.5 (1.3)	581 (1.41)
31/3/2009-25/6/2009	145.6 (3.6)	192.6 (5.42)	215.8 (4.41)	242.6 (3.81)	244.6 (2.66)	438.4 (3.53)	510.8 (2.94)	763.8 (10.85)	946.4 (10.07)
17/3/2011-15/6/2011	160.8 (7.42)	308.8 (20.14)	356.4 (23.5)	358 (20.14)	358.6 (11.7)	476.8 (5.22)	554.6 (3.92)	726 (7.42)	997 (14.1)
28/1/2013-14/4/2013	113.8 (2.39)	170.8 (3.07)	222.8 (5.04)	230.3 (3.13)	232.6 (2.27)	477.3 (5.42)	604 (6.13)	630.3 (3.20)	777.4 (3.92)
14/3/2017-27/4/2017	261.4 (28.2)	276.8 (11.75)	304.8 (11.75)	365.4 (23.5)	379.6 (12.82)	740 (35.25)	798.6 (20.14)	817.2 (14.10)	1012.4 (17.63)

The event dates in the table above represent the period where the cumulative preceding rainfall for one of the days within the event date range totalled the values given in the table.

6.2.7 Indicative Annual Probabilities

From the above, and considering the known landslide events and groundwater responses to rainfall from the groundwater monitoring, we present below our indicative return periods and indicative annual probabilities for the different ‘landslides’. From the probability estimates we have produced Figure 5 showing our risk assessment calculations.

Earthslides and Scour at the Toe of the Slopes

Earthslides and scour at the toe of the slopes, such as the 1994 and 1999 slumps below Marine Parade typically involve shorter term ‘critical’ rainfall periods (say 1 to 5 day events), the typical return period ranges from about 1 in 10 years to 1 in 142 years. The historical data also suggests that ‘landslides’ only occur about 50% of the time that a ‘critical’ rainfall level is reached. Based on this data the probability of such failures would range from $5x10^{-2}$ to $3.5x10^{-3}$ per annum. The rainfall records (Table 3 above) show that we have had a 1 to 5 day rainfall with a return period of about 35 years within the monitoring period. Three of these events also had return periods of greater than 10 years. Stephen P McElroy and Associates Pty Ltd produced a report for Clarence valley Council titled “Yamba Coastline Management Plan Stormwater Audit of Pilot Hill Area”, Report Number 10/22 and Report date 31 December 2011. That report by Stephen P McElroy, identifies two small earthslides/scours which occurred during the 2011 rainfall event. To our knowledge there have been no other earthslides or scour within the subject site during the monitoring period. Therefore the historical data which suggests that landslides only occur about 50% of the time that a ‘trigger’ event occurs seems to be reasonable in this instance.

- Recommended probability for earthslides and scour at the toe of the slopes;
  $5x10^{-2}$ to $3.5x10^{-3}$ per annum.

Larger Earthslides Encompassing the Steeper Hillside Slopes

Larger earthslides encompassing the steeper slopes in and around the Pacific Hotel have occurred in 1950, 1974 and 1994 within the study area. These types of landslides are typically more deep seated and are driven by rises in the groundwater level. Therefore they require a longer term critical rainfall period (more like antecedent rainfall of 30 days and longer), although the actual failure will still probably occur after a ‘top up’ of rainfall from a higher intensity 1 or 2 day rainfall event. The typical return period for these landslides is 1 in 10 years to 1 in 100 years. As discussed above, the historical data also suggests that ‘landslides’ only occur about 50% of the time that a ‘critical’ rainfall event is reached. So based on this data the probability of such failures would range from

$5x10^{-2}$ to $5x10^{-3}$ per annum. The rainfall records (Table 3 above) show that we have had a 30 day rainfall with a return period of about 35 years within the monitoring period. In 2009 we also had 60 day and 90 day events with a return period of greater than 10 years, while in 2011 we had a 90 day event with a return period of about 14 years. The latest 2017 event had return periods of greater than 10 for 30 day, 45 day, 60 day and 90 day periods. Although, to our knowledge, there have been no earthslides or scour within the steeper hillside slopes on the subject site during the monitoring period, we do not consider that we have had sufficient 'significant' 30 day and longer rainfall events to justify any further reduction in the probabilities.

- Recommended probability for earthslides encompassing the Steeper Hillside Slopes; $5x10^{-2}$ to $5x10^{-3}$ per annum.

We note that there have been no reported larger landslides within the steeper hillside slopes North of No.14 Pilot Street. However there has been evidence of very slow to slow creep movements as evidenced by the inclinometer movements and minor cracking in some of the structures. Nevertheless we have reduced the probability of landsliding in this area to 10^{-2} to 10^{-3} per annum.

We note that the historical data extends back to 1889 and there has obviously been changes to contributory factors affecting groundwater levels, such as landforms and development (including house roofs, paving around houses, roadways, and changes from absorption tanks to mains sewer etc). These items are likely to have resulted in a reduction in groundwater level responses. Thus it would be logical to expect that the probability of larger earthslides in the vicinity of the Pacific Hotel to have decreased. Unfortunately this is not borne out in the 1994 zone of movement and we have not had any major long term rainfall events within the monitoring period to match some of the historical significant long term events (such as 1921 and 1950). Therefore at this stage we consider that the above probability values should be adopted.

6.3 Landslide Risk Zones

To nominate risk, it is necessary to consider a nominated 'Element at Risk'. For the purposes of this study, risk has been evaluated in terms of loss of life rather than property. This has required assumptions as to typical occupancy, or temporal probability, for users of the area.

The hillside slopes within the study area have been subdivided into Landslide Risk Zones (LRZ) as shown on the attached Figure 4. The subdivisions have been made on the basis of;

- History of past landsliding.
- Similarity of hillside forms and inferred likely subsurface profiles.

- The nature of the elements at risk, both in terms of the current property development, or possible future property development based on zoning, and likely occupancy patterns.

Where considered reasonable the LRZ boundaries have been aligned with lot boundaries for administrative ease.

6.4 Risk Analysis Results

The general principal in risk analysis is that the RISK is a product of the PROBABILITY that the event will occur and the CONSEQUENCES if the event does occur. In this instance, where we are assessing the risk to life, the Consequences are loss of life, however the probability can be further broken down to some partial probabilities such as;

- If the event occurs will it impact an element (e.g. a structure or person). This is called a Spatial Probability. The probability of Spatial Impact has also been modified by two further factors;
  - (i) Firstly there has been consideration of the likely rate of movement by either Very Slow to Moderate moving landslides, or Rapid to Very Rapid Landslides.
  - (ii) Secondly there is a conditional probability for landslides at a particular location causing significant structural damage, which is a prerequisite to the Vulnerability of persons.
- If the event occurs and the element is impacted, what is the probability that people will be within or using the element at the time of the event occurring. This is called the Temporal Probability.
- If people are impacted by the event, what is the probability that there will be loss of life. This is called Vulnerability.

These partial probabilities have been taken into consideration in our risk analysis shown on Figure 5.

The following risk estimates have been considered in relation to the suggested criteria given in AGS2007 Risk Management Guidelines which are;

For an existing slope: **Tolerable Risk of 10^{-4}** for loss of life for the person most at risk.
Acceptable Risk of 10^{-5} for loss of life for the person most at risk.

It will be up to the owners and regulators to decide whether these values are appropriate and the conclusions regarding risk estimates reasonable. The risk estimates should also be considered in the light of the FOS values for the stability models analysed as part of Technical Report 2.

Landslide Risk Zone 1a

The highest risk values are associated with Landslide Risk Zone 1a (LRZ1a), which encompasses the Pacific Hotel, where slopes are steepest, the history of movement most evident, occupancy is expected to be high and the possibility of a larger scale failure affecting the Pacific Hotel (Spatial probability) is higher. The specific results of the risk assessment are shown in the attached Figure 5. However in summary the results obtained for LRZ1a are;

For	a) Very Slow to Moderate Movements	$7.5x10^{-5}$ to $1.5x10^{-5}$	TOLERABLE
For	b) Rapid to Very Rapid Movements	$2x10^{-3}$ to $4x10^{-4}$	UNACCEPTABLE

The above risk values are also consistent with the slope stability factor of safety values produced in Table 11 of Technical Report 2, which show a FOS value of only about 1.09 for a deep seated failure of the upper slopes when using the actual highest rainfall level from the 2011 rainfall event and Transect 1. For the predicted groundwater level during the 1950 rainfall event the FOS is assessed to be close to 1.0. The tables summarising the Slope Stability Results from Technical Report 2 have been reproduced in Appendix C.

Landslide Risk Zone 1b

LRZ1b includes residential dwellings in the area close to the Pacific Hotel. This zone also generally includes the area where the subsoil drains have been installed. The specific results of the risk assessment are shown in the attached Figure 5. However in summary the results obtained for LRZ1b are;

For	a) Very Slow to Moderate Movements	$2.1x10^{-5}$ to $2.1x10^{-6}$	TOLERABLE TO ACCEPTABLE
For	b) Rapid to Very Rapid Movements	$7.2x10^{-4}$ to $7.2x10^{-5}$	UNACCEPTABLE

The slightly reduced risk for this zone compared to LRZ1a is essentially as a result of the reduced likelihood of a failure affecting an individual dwelling. The FOS values for a deep seated failure are also expected to be closer to the results for Transect 2, which showed a FOS of 1.46 for a deep seated slope failure and 1.21 for a shallow slope failure within the upper slopes. Consideration has also been given to the existing subsoil drains within the slope and its impact on risk to LRZ1b. The current groundwater monitoring indicates that while there may be some localised improvement (i.e. lowering of groundwater levels and more rapid decline in groundwater level rises) immediately adjacent to the drains, the drains are not having a significant effect on the global groundwater levels in the area.

Landslide Risk Zone 1c

LRZ1c includes all the toe slope areas, including the grass area immediately below the Pacific Hotel. While the probability of landsliding in these areas is still high, and the FOS values for toe failures is low, the consequences to life are low due to the low occupancy. Therefore based on the risk analysis this zone is considered to have a risk to life of less than $1x10^{-6}$ which would be considered ACCEPTABLE.

Landslide Risk Zone 2

LRZ2 includes the residential properties north of No. 14 Pilot Street (i.e. Property No.'s 2, 4, 6, 8 and 12). These areas have flatter slopes than LZR1a and LRZ1b and have no historical evidence of large deep seated slides, although there is evidence (such as inclinometer results and minor cracking in structures) to indicate that soil creep movements are occurring. The specific results of the risk assessment are shown in the attached Figure 5. However in summary the results obtained for LRZ2 are;

For	a) Very Slow to Moderate Movements	$5x10^{-7}$ to $5x10^{-8}$	ACCEPTABLE
For	b) Rapid to Very Rapid Movements	$1.8x10^{-5}$ to $1.8x10^{-6}$	ACCEPTABLE (Just)

We also consider that the above risk assessment is reasonable on the basis of the FOS values calculated from the slope stability analysis. Deep seated failures of the upper slopes have been shown to have a FOS ranging from 1.39 (Transect 3) to 1.46 (Transect 2) for a groundwater level equivalent to the actual highest groundwater level during the 2011 rainfall event. For the predicted groundwater level during the 1950 rainfall event, the FOS varies from 1.33 (Transect 3) to 1.38 (Transect 2). At Transect 2, there is a lower FOS for shallow surface failures within the upper slopes (FOS=1.21), however these types of failures would be more associated with slower moving creep type failures as they are not driven by rises in groundwater level.

7 TREATMENT AND STABILISATION OPTIONS

7.1 Treatment and Stabilisation Principles

The general risk treatment principles which can be considered for implementation are as follows;

- **Reduce the Likelihood:** This requires implementation of stabilisation measures that would control the initiating circumstances. Possible options would include, groundwater control (including surface and subsurface drainage), re-profiling of the surface slopes, and structural solutions such as anchored walls or similar.

- **Reduce the Consequences:** This requires measures such as changing the behaviour of the landslide, provision of defensive stabilisation measures (such as design of structures to minimise consequences) or relocation of the development to a more favourable location.
- **Monitoring and Warning Systems:** This treatment option is essentially designed to reduce the consequences (in particular loss of life), by providing a warning of potential or imminent failure and therefore opportunity for evacuation. Such systems are likely to be sophisticated and extensive. They may include the monitoring of groundwater levels or monitoring for movements. Such systems can be automated to include real–time monitoring such that any pre-set trigger level can be instantly communicated to those at risk and an overriding authority.

We consider that the only real feasible treatment/stabilisation principle for this site is to reduce the likelihood, probably in combination with monitoring and warning systems. Reducing the consequences is likely to be cost prohibitive, although some measures may be able to be introduced progressively with any new development applications.

7.2 Stabilisation Options

The following section provides further comment on possible stabilisation options.

7.2.1 Groundwater Control

Measures associates with groundwater and surface water drainage are aimed at reducing the likelihood of landslides being initiated, by reducing the risk of potential future rises in groundwater levels. Possible measures include;

a) Audit all Drainage

Auditing all drainage within the catchment area would involve checking of all drainage from roof and paved areas and connections to appropriate surface water disposal systems. As a result, all absorption systems would be eliminated as a means of disposing roof or other surface water. Connection of downpipes to the stormwater system, rather than allowing discharge to landscaped areas, would also reduce infiltration. The audit would include initial and then regular (say 5 yearly) checking of all stormwater and effluent pipes for leakage by static head testing. Any leaking systems would need to be rectified or replaced. These measures would reduce potential groundwater level rises, although probably marginally.

b) Improve Surface Water Drainage

This would be carried out by provision of lined surface water drains in the slope catchment area, including provision of controlled discharge routes via lined drains or sealed pipes. This would include provision of adequate surface water drains in landscaped areas at the crest and toe of batters and along access pathways. The drainage design should be such that it can function effectively for high return period rainfall events (i.e. at least a 1:100 year event) to reduce the risk of initiating scour events. This option is likely to require considerable upgrading of existing surface water drainage, much of which is within private property.

c) Install Subsurface Drains

Subsurface drains would be designed to control groundwater levels. We expect that a combination of deep trench drains at the toe of the slope with inclined buried subsoil drains extending back into the hillside to be required. Further specific analysis would be required to enable an evaluation of likely drain spacing, but our experience suggests that the spacing is likely to be in the order of 10m. The effective implementation of subsoil drainage will reduce groundwater levels and hence the probability of landslides.

7.2.2 Re-profiling Surface Slopes

These types of stabilisation options are aimed at reducing the driving forces, typically being in the steeper upper slopes and increasing the resisting forces, by provision of additional load and shear resistance at the toe.

a) Flatten Steeper Slopes

While theoretically flattening the steeper upper slopes would provide some improvement in stability and a reduced probability of landsliding, practically we consider that such a system is unlikely to be feasible, unless it was carried out during any redevelopment works. The improvement in overall stability is still likely to be relatively small for large deep seated failures but may be more significant for reducing the probability of rapid near surface failures.

b) Provide Toe Berm

Provision of a toe weighted berm is often used to stabilise deep seated instability. However such a berm would have to be located at about the alignment of the Marine Parade access track. Any fill placed in this area would require a toe retaining wall since failures have already occurred along the toe and even without any additional surcharge loading from a berm the FOS values for failures is very low. Therefore we expect that such a system will be quite costly and would still not reduce the probability of shallow surface failures within the upper slopes, unless the berm also extended further up the slope to flatten the slopes. Such a system is unlikely to be practical or aesthetically appealing where existing structures are already located close to the Marine Parade access track.

7.2.3 Slope Reinforcement

Provision of slope reinforcement structures/elements could be designed to improve stability to acceptable levels. However as the earth forces are relatively large, the cost and difficulty of construction is likely to render them uneconomic. Schemes that could be considered include;

a) Anchored Walls/Piers

Deep walls could be constructed by use of contiguous piles socketed into the underlying bedrock. Lateral stability would be provided by the use of permanent anchors bonded into the underlying bedrock. However construction access is limited and is likely to require such walls constructed on or close to Marine Parade. This will require extension of the wall system above current ground surface levels to enable the steep slopes above to be flattened to acceptable batters. This scheme would be very costly.

b) Toe Retaining Walls

Provision of properly engineered toe retaining walls would be possible. Typical wall forms would include gabion or precast gravity walls, reinforced concrete cantilever walls or anchored bored piers. The wall would have to be located back from the existing toe cliff line for bearing and stability considerations. The potential earth forces on the wall would be significantly higher than for a normal retaining wall due to the surcharge effect of the steep slope above. Temporary stability during construction would have to be carefully managed and may require staged construction or provision of temporary retaining systems. Therefore such a wall would again be very costly

c) Soil Nails

The use of soil nails would be a possible stabilisation measure for the steep upper slopes. They may not address the potential large scale deep seated instability but would certainly provide a sound stabilisation technique for shallow surface failures. This option would be more feasible where flattening of the existing upper slopes is not feasible due to the existing development. Soil nailing involves installing a grid of reinforcing bars into the slope (typically at 1.5m to 2m centres) to provide additional shear resistance for slope failures. Such a scheme would require detailed design and analysis and would be limited by access considerations. This would also be quite a costly solution.

7.2.4 Stabilisation Overview and Conclusions

The extent of stabilisation will need to consider;

(i) The current risk for the particular area of the site,

(ii) The level of risk which can be accepted following stabilisation works,

(iii) Cost implications of any stabilisation methodology adopted, and

(iv) Practicality and aesthetics of any particular stabilisation system.

LRZ1a and LRZ1b

These landslide risk zones have risk assessments which essentially range from Tolerable to Unacceptable and therefore we consider that stabilisation measures are necessary for these zones. While the structural solutions provide sound stabilisation methodologies, they will generally be impractical in and around the existing structures and would also be of high cost. Such systems would be more applicable if redevelopment in these areas was to be carried out. Therefore it is our opinion that the most suitable option at this stage for these landslide risk zones would be for a formalised groundwater drainage stabilisation scheme. We envisage that this system would involve;

- Trench drains through the lower foreshore slopes to keep the toe of the slope well drained,
- Subsoil drains drilled back into the hillside to reduce the risk of groundwater level rises.
- Auditing of all drainage, and
- Improvements to subsurface water drainage.

It is important to note however that lowering the groundwater table alone will not provide Acceptable FOS values for shallow or deep slope failures of the upper slopes, particularly at Transect 1.

The following table summarises the FOS values for the various slope failures at Transect 1 and 2 for the actual average groundwater level recorded during the monitoring period. We would be confident that a well designed groundwater drainage system would at least be able to keep groundwater levels to below such levels and hopefully lower.

Table 4 – Summary of FOS Values for Slope Failures

Subsurface Model	Groundwater Level	Factor of Safety (FOS)	Failure Form (Appendix B - Figure Number)
Transect 1	Actual Average Groundwater Level During Monitoring Period	1.68 (Acceptable)	Lower Foreshore Slope Failure
		1.51 (Acceptable – Just)	Deep Mid Slope Failure
		1.24 (Tolerable – Just)	Shallow Failure Upper Slopes
		1.22 (Tolerable – Marginal)	Deep Slope Failure Upper Slopes
Transect 2	Actual Average Groundwater Level During Monitoring Period	1.56 (Acceptable)	Lower Foreshore Slope Failure
		1.21 (Tolerable to Unacceptable)	Shallow Failure Upper Slopes
		1.56 (Acceptable))	Deep Slope Failure Upper Slopes

Based on these results, maintaining the groundwater levels no higher than the actual average levels recorded during the groundwater monitoring period, will produce acceptable FOS values for failures in the lower foreshore slopes and for a deep seated failure in the upper slopes at Transect 2. However FOS values for failures in the upper slopes for Transect 1 would still be only just Tolerable, and similarly shallow surface failures in the upper slopes for both Transect 1 and 2 would still also be marginally Tolerable to Unacceptable. Therefore a groundwater drainage stabilisation scheme alone will still not be sufficient to produce Acceptable factors of safety. Further structural solutions would be required for this to be achievable, although the cost to achieve a stabilisation scheme which provides stability FOS values which are Acceptable is likely to be cost prohibitive and impractical in and around the current site structures. Soil nailing of the upper slopes would likely enable acceptable FOS values for the shallow failures of the upper slopes but such a scheme is unlikely to assist with the deep seated failures in the upper slopes.

Considering the above, there will probably need to be a ‘trade off’ between cost and risk. The risk to life can also be improved by continued monitoring and warning systems, some of which could be automated.

LRZ1c and LRZ2

The risk assessment for these zones generally showed that the risk to life was Acceptable to Just Acceptable. However the lower foreshore slopes still had low factor of safety values for slope failures. Failures in these lower foreshore slopes will ultimately lead to continued creep type movements and possibly large scale slope failures in the upper slopes. Therefore we consider that as a minimum it would be wise to construct trench drains through the lower foreshore slopes, as well as auditing of drainage and surface water drainage improvements. The slope stability analysis gave FOS values of 1.39 and 1.33 for deep seated failures where the groundwater level was at the highest recorded during the monitoring period and the predicted level during the 1950 rainfall event respectively. While this FOS would only be deemed Tolerable from a slope stability perspective, it may be that the additional cost to install subsoil drains back into the slope to improve the FOS and reduce the risk further in this area cannot be justified.

7.2.5 Design of Stabilisation Systems

Groundwater monitoring has been undertaken for some 12 years (commencing in 2005). Therefore we believe that there is currently sufficient data to be able to commence more detailed design of stabilisation schemes. Some additional boreholes on the site to define more definitively the boundary between the upper sands and lower clayey soils would be beneficial for groundwater drainage designs. If significant structural improvements are to be undertaken, then it is likely that more specific geotechnical subsurface investigations, involving deeper boreholes would be necessary.

Where a groundwater drainage system is to be utilised it would still be necessary to maintain groundwater monitoring so that verification of the system and its capability to keep groundwater levels below required levels can be confirmed. Some additional groundwater monitoring wells would also likely need to be installed to provide a better coverage of the site for validation purposes. Verification of the system by continued monitoring would need to be carried out until a significant rainfall event (at least a 1 in 20 year event and possibly higher) occurred and the monitoring confirmed that the drainage was effective. Long term maintenance of the drainage would also need to be allowed for including flushing of subsoil drains to prevent clogging. Flushing would need to be carried out on about 5 yearly intervals of if monitoring indicates that the drainage is becoming less effective.

7.2.6 Design of New Developments

We recommend that any new developments within the study area be designed to have an acceptable risk against the potential slope failure mechanisms identified as part of this study. This will involve provision of adequate drainage, and properly engineered retention and footing systems. A peer review process may be warranted for any new development proposals.

8 FUTURE MONITORING AND MAINTENANCE

8.1 Monitoring Prior to Implementation of Stabilisation Measures

Prior to any stabilisation options being carried out, we recommend the following monitoring and maintenance measures. Most of the monitoring would be a continuation of what is already being completed.

8.1.1 Inclinometers

Currently there are six (6) inclinometers installed within the study area, the inclinometers at the crest of the slope (inclinometers 1A, 2A and 3A) generally have shown little or no movement during the monitoring period. However the inclinometers along Marine Parade have all shown some movement with time. The last set of readings was in August 2016, when the inclinometer probe could no longer be lowered to the base of Inclinometer 1C, indicating that significant movement had occurred. Therefore Inclinometer 1C should be replaced. Ongoing Inclinometer monitoring is recommended on at least a yearly basis, and if a rainfall event greater than a 1 in 10 year event for any period occurs.

As discussed above the inclinometers installed along Marine Parade have shown ongoing movement. There is also a wide gap between Inclinometers 1C and 2C. Therefore we consider that it would also be beneficial to install an additional inclinometer along Marine Parade between 1C and 2C.

The current Inclinometer monitoring provides discrete readings at a given time. If the inclinometer shows movement, there is no record of when the movement may have occurred (such as during a specific rainfall event, or when groundwater levels reached a certain level). Therefore consideration could be given to the use of real time inclinometer monitoring (even if it was only used in a few of the inclinometers). This monitoring is reasonably costly, but it has the advantage that any movement can be directly related to groundwater levels and rainfall at the time of movement. This would be extremely useful in allowing a true assessment of what groundwater levels or rainfall triggers movement. It would be even more beneficial if it was also linked in with real time monitoring of the groundwater levels. Such systems can be linked to mobile devices and would be far superior for early warning of failures.

8.1.2 Groundwater Monitoring

Groundwater monitoring should continue and we suggest that the current period of three months for downloading of the data be continued. The groundwater data plots with respect to rainfall should be kept up to date. As discussed above consideration could be given to the use of real time groundwater data logging systems, which would be more beneficial to alert levels than simply rainfall records. In other words the Alert Level could be based on groundwater levels as well as rainfall, with the groundwater levels linked to warnings on mobile devices.

8.1.3 Rainfall Analysis

We suggest that rainfall analysis be continued on at least an annual basis to update probabilities for rainfall events, so that these can be assessed in relation to slope performance. While the probabilities of certain rainfall events is not likely to change significantly, the cost for maintaining the rainfall records and updating plots is relatively low.

8.1.4 Lot Drainage

We recommend that all individual lots upgrade their surface and subsurface drainage.

- Absorption trenches should be made redundant and all stormwater should be directed to sealed pipes for controlled discharge. This will likely require a formalised drainage easement along Marine Parade with a defined and controlled stormwater outlet structure which discharges stormwater in a controlled manner without erosion.
- Individual lots should have their effluent and stormwater pipes checked for leaks (such as by pressure head testing). Any leaks should be repaired. Checking of drainage on each lot should be carried out at a frequency of not greater than 5 yearly. Flexible pipe connections should be considered where repairs are required due to leaks.
- Surface drainage should also be formalised to reduce overland flows and erosion during high intensity rainfall events.

8.1.5 Structural Appraisals

There has been no appraisal of existing slope retention measures within existing developments as part of this study. It is recommended that an audit be carried out by a qualified engineer on each lot to identify any individual cut or fill batters or retaining walls. For batters the audit should include, batter height and angle, nature of material, surface and subsurface drainage, and evidence of past instability. For walls the audit should include wall height, wall construction, design details (if known), surface and subsurface drainage measures, any evidence of wall movement and cracking. In addition, all structures on the site should be assessed for evidence of possible movement and/or settlement. The stability and adequacy of batters and retaining walls should be assessed and recommendations given for any remedial measures or for further investigations. Photographic records with clearly measured and recorded items is recommended.

8.1.6 Alert Levels

A management strategy has already been put in place to manage the risks associated with rainfall events. The management strategy was aimed at identifying possible rainfall conditions that may trigger a landslide event. It was considered that conditions that may give rise to an emergency are any of the following;

a) A period of prolonged high rainfall, say over 30 days to 90 days.

b) A period of high daily rainfall after previous wet periods

c) High intensity rainfall over short periods of say 1 day or less.

From examination of the data, emergency rainfall warning levels were set up. Two warning levels were assigned; an Orange level which was based on a 1 in 3 year rainfall event, and a Red level which is based on a 1 in 10 year rainfall. The relevant rainfall warning levels are given in the table below. We note that the table below has been amended from the previous warning levels as a result of more recent rainfall records. We recommend that Council adopt these revised warning levels.

Table 5 - Relevant Rainfall Warning Levels

Antecedent Rainfall Period (days)	Orange Level (mm)	Red Level (mm)
1	125	190
2	170	250
5	230	320
8	260	365
15	300	425
30	420	540
45	515	650
60	630	775
90	775	955

8.2 Monitoring After Implication of Stabilisation Measures

Depending on the stabilisation methodology adopted, long term monitoring may still be required or may still be recommended to ensure that the stabilisation is performing as expected. For example where a drainage solution is adopted, some groundwater monitoring will still need to be carried out to confirm that the drainage is effective in maintaining groundwater to the desired levels. Structural solutions are less likely to require long term monitoring.

9 MAIN BEACH AND NORTHERN CONVENT BEACH RISK ASSESSMENTS

The following presents our proposed scope of works for a detailed risk assessment at Main Beach and Northern Convent Beach. We have assumed that the Main Beach study area would range from the southern end of the current study area through to Queen Street, while the Northern Convent Beach study area would extend from the Craigmore Headland through to about 50m past the sewer pump station on Convent Beach.

9.1 Review of Available Data and Detailed Walkover Assessment

As a first stage of our risk assessment for Main Beach and Northern Convent Beach at Yamba, we would review the previously available data, which includes;

- The rainfall analysis completed as part of this current study.
- Some previous boreholes by Douglas Partners at Main Beach and some borehole data by EJ Armstrong and Australian Soil and Concrete testing at Northern Convent Beach.
- Review and plotting of surface monitoring data for Marine Parade.
- Review of information from previous landslips (such as the 1999 Landslips along Marine Parade and Craigmore Headland).
- Conduct a detailed walkover assessment and geotechnical mapping. The mapping would be aimed a defining the geotechnical features of the area as a basis for preliminary slope stability analysis and risk assessment.

9.2 Installation of Monitoring Equipment

To supplement the preliminary risk assessments, it would be necessary to drill additional boreholes and install monitoring equipment, including piezometers and inclinometers. The precise number would be determined following the data review, the detailed walkover assessment, access considerations and budgetary constraints. The equipment would need to be monitored for a defined time period so that a better understanding of groundwater and soil movements can be undertaken.

We expect that the monitoring would need to be carried out until at least a 1:10 year rainfall event occurred.

9.3 Updated Slope Stability and Risk Assessments

Once a satisfactory period of monitoring was carried out, more detailed slope stability analysis and risk assessments could be undertaken, similar to the procedures carried out for this current study.

AERIAL IMAGE SOURCE: GOOGLE EARTH PRO 7.1.5.1557
AERIAL IMAGE ©: 2015 GOOGLE INC.

This plan should be read in conjunction with the JK Geotechnics report.

Title:	**STUDY AREA**
Location:	PILOT HILL YAMBA, NSW
Report No: 19314L3	Figure No: 1

JK Geotechnics

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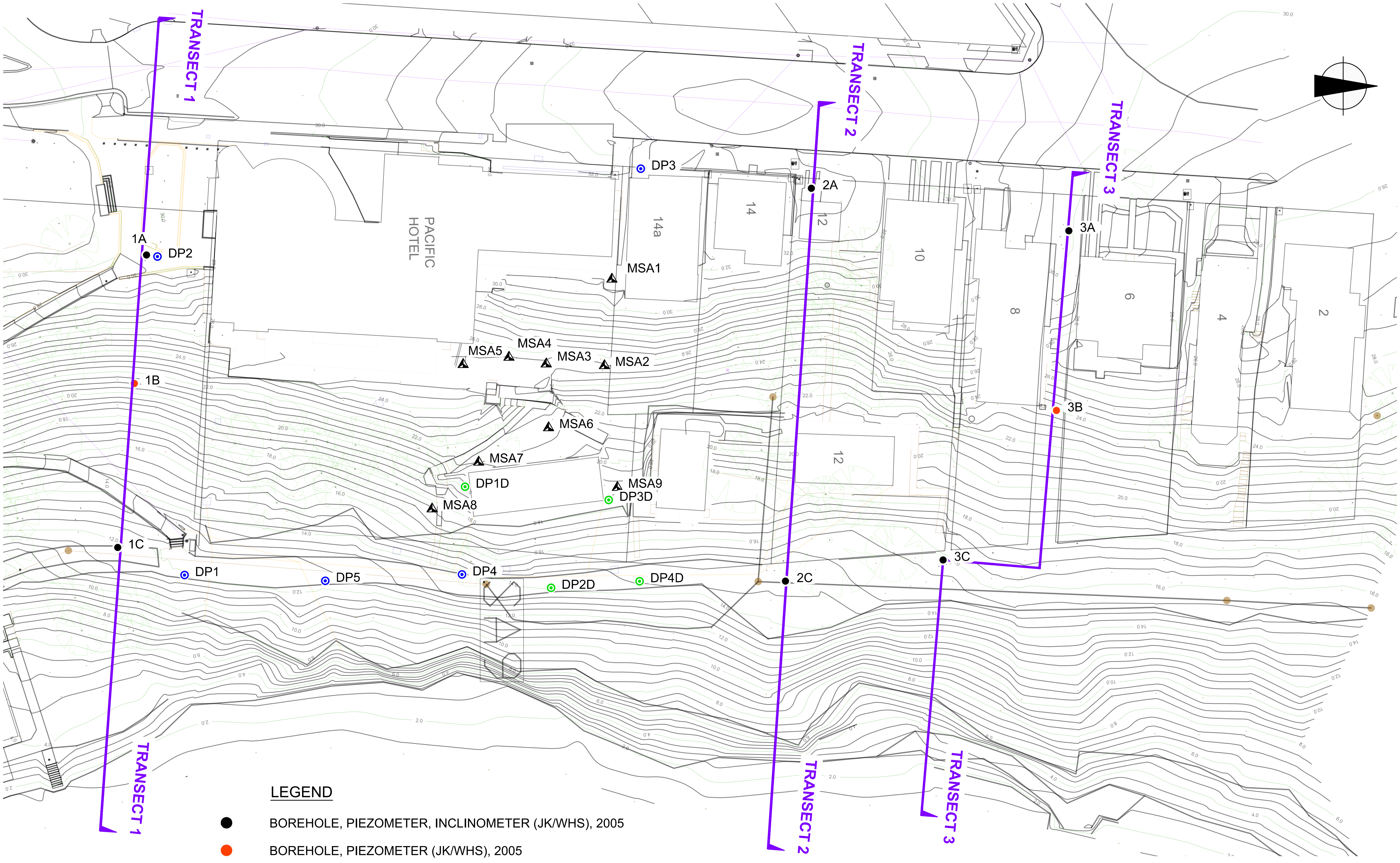

LEGEND

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● BOREHOLE, PIEZOMETER (JK/WHS), 2005

MSA ▲ PREVIOUS BOREHOLES BY MICHAEL SAMMS AND ASSOCIATES, 2000

DP ◉ PREVIOUS BOREHOLES BY DOUGLAS PARTNERS 1999

DP ◉ PREVIOUS BOREHOLES BY DOUGLAS PARTNERS, 1996

0 5 10 15 20 25
SCALE 1:500 @A3 METRES

This plan should be read in conjunction with the JK Geotechnics report.

Title: **INVESTIGATION LOCATION PLAN**

Location: PILOT HILL
YAMBA, NSW

Report No: 19314L3

Figure No: 2

JK Geotechnics

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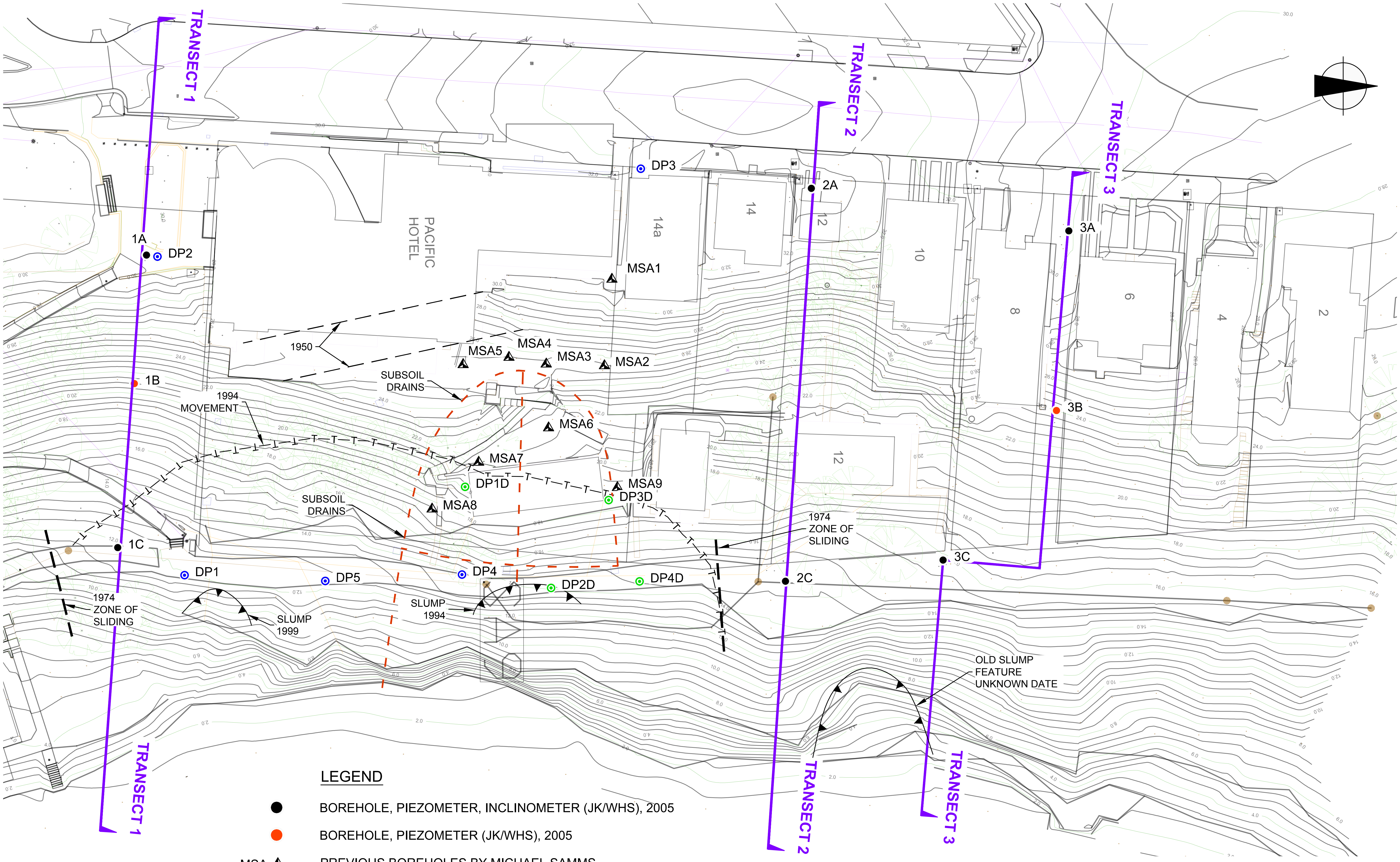

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- ● BOREHOLE, PIEZOMETER, INCLINOMETER (JK/WHS), 2005
- ● BOREHOLE, PIEZOMETER (JK/WHS), 2005
- MSA PREVIOUS BOREHOLES BY MICHAEL SAMMS AND ASSOCIATES, 2000
- DP PREVIOUS BOREHOLES BY DOUGLAS PARTNERS 1999
- DP PREVIOUS BOREHOLES BY DOUGLAS PARTNERS, 1996

SCALE 0 5 10 15 20 25 METRES 1:500 @A3

This plan should be read in conjunction with the JK Geotechnics report.

Title: **PLAN SHOWING PREVIOUS SLIPS & SUBSOIL DRAINS**

Location: PILOT HILL YAMBA, NSW

Report No: 19314L3

Figure No: 3

JK Geotechnics

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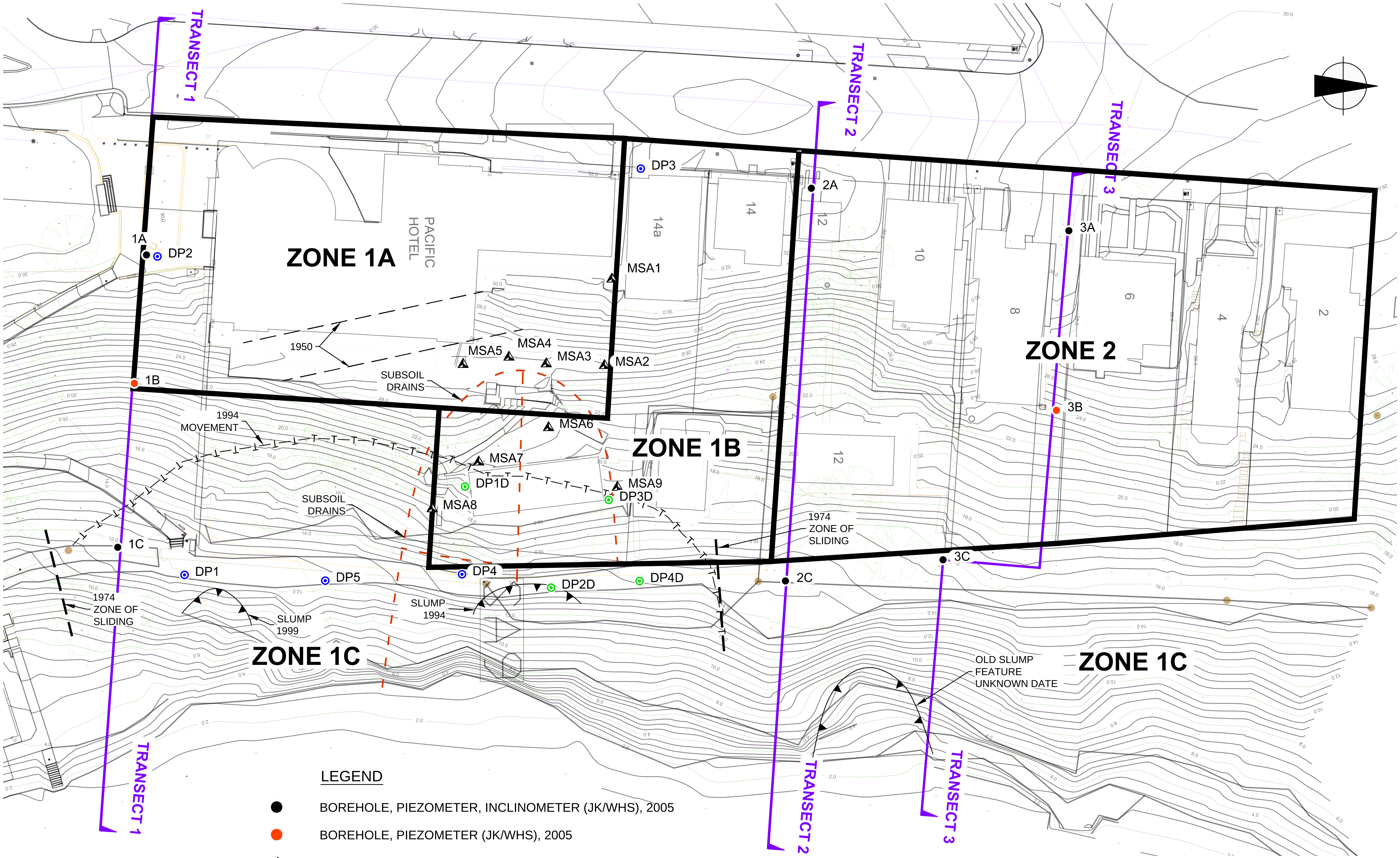

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- MSA PREVIOUS BOREHOLES BY MICHAEL SAMMS AND ASSOCIATES, 2000
- DP PREVIOUS BOREHOLES BY DOUGLAS PARTNERS 1999
- DP PREVIOUS BOREHOLES BY DOUGLAS PARTNERS, 1996

SCALE 0 5 10 15 20 25 METRES 1:500 @A3

This plan should be read in conjunction with the JK Geotechnics report.

Title: **PLAN SHOWING PREVIOUS SLIPS & SUBSOIL DRAINS**

Location: PILOT HILL YAMBA, NSW

Report No: 19314L3-Technical Report 3

Figure No: 4

JK **Geotechnics**

PLOT DATE: 28/08/2017 5:33:15 PM DWG FILE: S:\6 GEOTECHNICAL\6F GEOTECHNICAL JOBS\19000'S\19314L3 YAMBA\CAD\19314L3-TECHNICAL REPORT 3.DWG

FIGURE 5
RISK ASSESSMENT FOR LOSS OF LIFE

No	Consideration / Conditional Probability	LANDSLIDE RISK ZONE							
		1a		1b		2		1c	
		Values	Comment	Values	Comment	Values	Comment	Values	Comment
I	Probability of Landsliding	$5x10^{-2}$ to $5x10^{-3}$	From rainfall and historical data	$5x10^{-2}$ to $5x10^{-3}$	From rainfall and historical data	10^{-2} to 10^{-3}	As not within area of reported slides but some creep effects evident.	$5x10^{-2}$ to $3.5x10^{-3}$	From rainfall and historical data
II	Element at Risk	Pacific Hotel		Residential dwelling in area close to hotel		Residential dwellings in area of no known landslides		Undeveloped toe slopes above outcrop or foot of main hillside	
III	Probability of affecting Element at Risk	0.5 to 1.0 respectively	Assumes lower prob event likely to be larger, plus cumulative effects of upslope regression	0.2	Assumes 10m to 20m wide landslide over about 70m of slope, say 3 to 7 potential slides, on average 5, each about width of dwelling	0.1	Similar to 1b, but dwellings on flatter crest slopes	No. of potential slides = $^{500}/_{20}$ = 25. Probability of person at slide site = $^{1}/_{25}$ = $4x10^{-2}$	For person at landslide site, assumes about 20m wide landslides over 500m length of slope; non over-lapping, all equally likely.
IV	Likely rate of Movement and Probability	(a) Very Slow to Moderate 1.0 (b) Rapid to Very Rapid 0.1	Physical and Historical evidence Possible, but may be only near surface	(a) Very Slow to Moderate 1.0 (b) Rapid to Very Rapid 0.1	Physical and Historical evidence. Possible, but may be only near surface.	(a) Very Slow to Moderate 1.0 (b) Rapid to Very Rapid 0.05	Physical and inclinometer evidence. Less likely than 1b since further from instability.	(a) Very Slow to Moderate 1.0 (b) Rapid to Very Rapid, 1.0	Area likely to be affected by both scour and earthslides
V	Probability of significant structural damage	(a) 0.2 to 0.5, say 0.3 (b) 0.5 to 1.0, say 0.8		(a) 0.2 to 0.5, say 0.3 (b) 0.5 to 1.0, say 0.8		(a) 0.1 to 0.4, say 0.2 (b) 0.4 to 0.8, say 0.7	Reduced from 1b due to flatter crest slopes. May not affect much of dwelling.	N/A	
VI	Affect on Element	for (a) for (b)	Cracking and distortion, with time becomes unsafe/unusable. Rapid cracking, possible collapse.	for (a) and for (b)	As 1a Rapid cracking, possible collapse. For dwellings at lower elevation, possible impact from above.	for (a) for (b)	As for 1a As for 1a	N/A	
VII	Vulnerability to Persons in area affected	for (a) 0.01 for (b) 0.8 to 1.0, say 1.0	Escape due to warning by cracking likely, some may be "unlucky" Escape may not be possible.	for (a) 0.01 for (b) 0.8 to 1.0, say 1.0	Escape due to warning by cracking likely, some may be "unlucky". Escape may not be possible, may be buried.	for (a) 0.01 for (b) 1.0	As for 1a As for 1a	for (a) 0.01 for (b) 0.5	As for 1a Assumes 50% chance of not being buried.

Ref: 19314L3 Figure 5 Risk Table
Page 2

FIGURE 5 (continued)

No	Consideration / Conditional Probability	LANDSLIDE RISK ZONE							
		1a		1b		2		1c	
		Values	**Comment**	**Values**	**Comment**	**Values**	**Comment**	**Values**	**Comment**

VIII	Occupancy/ Temporal Probability for person most at risk	0.7 to 1.0,
		say 1.0
			For person staying in Hotel accommodation and using bar & restaurant.
			Failure more likely during inclement weather therefore prolonged occupancy.
				for (a) 0.7
				
				for (b) 0.9
					Assumes persons absent on average ≈8 hours/day.
					
					Assumes persons more likely to be present during inclement weather.
						for (a) 0.25
						
						for (b) 0.5
							Assumes area affected not bedrooms, living area occupied about 6 hours/day.
							Assumes person more likely to be present during inclement weather, but bedrooms not affected.
								$^{0.5}/_{24}$ to $^{1}/_{24}$
								= 0.02
									Assumes person is regular user, walking through area every day.
									Occupancy assumed for 0.5 hours per day.

IX	Risk Estimate for person most at risk	for (a) $5x10^{-2}$ x 0.5x 0.3 x 1.0 x 0.01 x 1.0 = **$7.5 x 10^{-5}$** to $5x10^{-3}$ x 1.0 x 0.3 x 1.0 x 0.01 x 1.0 = **$1.5 x 10^{-5}$**	Very Slow to Moderate movements	for (a) $5x10^{-2}$ x 0.2 x 1.0 x 0.3 x 0.01 x 0.7 = **$2.1 x 10^{-5}$** to $5x10^{-3}$ x 0.2 x 1.0 x 0.3 x 0.01 x 0.7 = **$2.1 x 10^{-6}$**	Very Slow to Moderate movements	for (a) 10^{-2} x 0.1 x 1.0 x 0.2 x 0.01 x 0.25 = **$5 x 10^{-7}$** to 10^{-3} x 0.1 x 1.0 x 0.2 x 0.01 x 0.25 = **$5 x 10^{-8}$**	Very Slow to Moderate movements	For (a) $5x10^{-2}$ x $4x10^{-2}$x 1.0 x 0.01 x 0.02 = **$4x10^{-7}$** to $3.5x10^{-3}$ x $4x10^{-2}$ x 1.0 x 0.01 x 0.02 = **$2.8x10^{-8}$**	Very Slow to Moderate movements
		for (b) $5x10^{-2}$x 0.5 x 0.8 x 0.1 x 1.0 x 1.0 = **$2 x 10^{-3}$** to $5x10^{-3}$ x 1.0 x 0.8 x 0.1 x 1.0 x 1.0 = **$4 x 10^{-4}$**	Rapid to Very Rapid movements	for (b) $5x10^{-2}$ x 0.2 x 0.1 x 0.8 x 1.0 x 0.9 = **$7.2 x 10^{-4}$** to $5x10^{-3}$ x 0.2 x 0.1 x 0.8 x 1.0 x 0.9 = **$7.2 x 10^{-5}$**	Rapid to Very Rapid movements	for (b) 10^{-2} x 0.1 x 0.05 x 0.7 x 1.0 x 0.5 = **$1.8 x 10^{-5}$** to 10^{-3} x 0.1 x 0.05 x 0.7 x 1.0 x 0.5 = **$1.8 x 10^{-6}$**	Rapid to Very Rapid movements	For (b) $5x10^{-2}$ x $4x10^{-2}$ x 1.0 x0.5 x 0.02 = **$2x10^{-5}$** to $3.5x10^{-3}$ x $4x10^{-2}$ x 1.0 x 0.5 x 0.02 = **$1.4x10^{-6}$**	Rapid to Very Rapid movements

APPENDIX A

TABLE A
SUMMARY OF ANNUAL RAINFALL ANALYSIS
YAMBA PILOT STATION FROM 22 MAY 1887 TO 2 MAY 2017

RANK	DAILY RAINFALL		2 DAY ROLLING TOTAL		3 DAY ROLLING TOTAL		5 DAY ROLLING TOTAL		8 DAY ROLLING TOTAL		15 DAY ROLLING TOTAL		30 DAY ROLLING TOTAL		45 DAY ROLLING TOTAL		60 DAY ROLLING TOTAL		90 DAY ROLLING TOTAL	
	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	Date	60 Day	Date	90 Day
1	02/03/1999	300	16/05/1921	460.6	16/05/1921	594.2	16/05/1921	599.3	16/05/1921	622.4	18/05/1921	707.3	18/05/1921	840.5	31/07/1950	1130.9	12/08/1950	1203.6	30/08/1950	1305.3
2	11/03/1974	287.2	11/03/1974	460.2	12/03/1974	506.6	14/03/1974	549.7	17/03/1974	562.1	08/05/1963	611.5	8/08/1889	811.3	16/05/1921	943.2	13/04/1988	1039.5	25/07/1921	1238.1
3	15/05/1921	273.1	02/03/1999	379.6	02/03/1999	430.6	7/08/1889	494	04/03/1999	499	23/03/1974	604.3	14/04/1988	794.6	18/04/1988	916.9	10/05/1963	1026.1	14/04/1988	1212.7
4	21/02/1954	270.5	01/07/2005	323.4	7/08/1889	409.9	04/03/1999	471.8	8/08/1889	498.6	06/03/1999	541.6	08/04/2017	740	23/04/1974	858.6	17/05/1921	985.2	05/06/1974	1180.3
5	31/03/2017	261.4	7/08/1889	322.3	01/07/2005	360.4	01/07/2005	376.3	09/05/1980	447.4	14/04/1988	532.6	02/08/1950	711.8	8/08/1889	837.7	08/05/1974	953.5	31/05/1963	1133.6
6	30/06/2005	250.4	08/04/1962	317.2	14/06/2011	356.4	18/03/2017	365.4	08/04/1962	417.6	8/08/1889	499.6	10/05/1963	696.7	11/05/1963	808.6	31/08/1889	898.9	6/04/1890	1076.7
7	6/08/1889	231.1	14/06/2011	308.8	08/04/1962	345.6	10/04/1962	359.3	25/06/1950	414	16/05/1980	497.8	04/03/1999	671	13/04/2017	798.6	17/04/1964	841.5	18/05/1964	1074.8
8	30/06/1929	205.2	21/02/1954	306.3	29/02/1976	325.6	16/06/2011	358.4	29/02/1976	387.7	30/07/1950	485.6	22/03/1974	631.3	13/03/1999	784.2	10/03/1999	829.8	05/04/2017	1012.4
9	29/02/1976	202.2	30/06/1929	303	19/05/1977	323.2	03/05/1983	346.2	08/04/1988	385.2	21/02/1954	483.8	28/02/1954	615.4	25/03/1976	688.7	31/03/1890	821.9	08/04/1962	1000.8
10	07/04/1962	199.6	08/05/1963	283.8	01/07/1929	314.4	20/05/1977	337	02/07/2005	385.1	31/03/2017	466.4	29/04/1923	593.1	15/06/1996	682.6	27/04/2017	817.2	20/04/1999	999
11	20/12/1892	195.6	29/02/1976	283.2	21/02/1954	307.1	02/07/1929	328.6	21/03/2017	379.6	15/04/1962	464.1	10/04/1962	588.8	15/04/1962	671.9	14/01/1962	789.2	15/06/2011	997
12	09/03/2001	191.4	31/03/2017	276.8	18/03/2017	304.8	02/03/1976	326.6	03/05/1983	363.7	23/06/1967	463.9	04/03/1976	578.5	04/03/1954	668.4	22/06/1996	771.8	17/05/2003	978
13	08/05/1963	188	14/06/1967	234.9	08/05/1963	292.9	07/05/1980	324.9	17/06/2011	358.6	16/05/1996	432.6	29/05/1980	554.5	28/03/1890	651.6	24/06/1983	764	10/05/1976	957.1
14	16/02/1995	186	22/07/1914	228.1	14/06/1967	276.8	08/05/1963	317.6	20/05/1977	351.8	2/02/1895	431.4	16/03/1964	553.4	26/04/1892	650.6	24/05/2009	763.8	28/04/1887	955.7
15	21/07/1914	185.4	21/03/1972	223.5	22/03/1972	269	14/06/1967	312.4	03/03/1975	347.8	13/06/1945	416.6	01/04/1994	549.6	01/04/1964	643.4	08/06/1919	739.6	25/06/2009	946.4
16	20/03/1972	177	16/02/1995	219.2	12/06/1945	267.9	17/05/2003	311.4	27/02/1954	347	8/01/1883	412.7	29/06/1967	548.4	04/04/1994	641.4	31/05/1990	731.2	8/08/1889	937.4
17	11/03/1909	175.3	30/07/1950	218	13/06/1900	254.5	21/02/1954	307.6	09/05/1996	346.2	07/03/1976	411.9	4/04/1890	525.1	27/03/1953	640.9	22/03/1972	727.9	02/05/1956	931.2
18	05/06/2016	172.4	09/03/2001	218	23/07/1914	252.2	12/06/1945	305	14/06/1945	345.4	09/03/1964	393.1	15/06/1945	521.9	27/04/1887	623.7	11/03/1956	727.9	18/04/1929	923.5
19	09/03/1964	169.9	12/06/1945	217.9	16/02/1995	245.2	6/01/1883	299.7	14/06/1967	342.9	02/07/2005	388.4	6/04/1892	517.5	12/03/1956	621.7	02/04/1976	726.9	16/05/1985	921.1
20	14/06/2011	160.8	19/05/1977	216.2	31/07/1950	242.1	22/03/1972	288	11/05/1963	334.4	09/03/1975	388.1	23/05/1996	515.6	28/04/1923	616.3	14/06/2011	726	16/03/1893	911.6
21	30/08/2006	155.8	29/04/1949	212.6	10/03/2001	240.2	16/02/1995	282.8	8/01/1883	329.4	15/06/2011	385.4	08/06/1919	503.5	04/06/1985	610.6	03/03/1954	723.1	01/07/1930	902.5
22	13/06/1967	155.4	05/06/2016	205.2	16/05/2003	236.9	10/03/2001	276.4	05/07/1929	329.1	16/05/2003	381.9	13/06/1900	501.1	30/01/1959	609.7	22/03/1953	707.7	18/03/1959	902.5
23	29/04/1983	154.6	12/06/2012	204	20/02/1961	236.5	10/12/1970	275.6	31/03/1994	328.2	22/04/1923	381.6	2/02/1895	500.4	6/02/1883	608.8	30/04/1892	703.7	04/04/1972	900.3
24	13/06/1897	152.4	21/12/1892	198.1	07/05/1980	231.4	03/06/1903	273.9	24/02/1953	321.3	12/05/1983	374.6	21/05/1985	500.1	05/03/2013	604	27/04/1887	696.4	20/05/1977	882.2
25	07/04/1926	151.1	20/02/1961	197.1	03/06/1903	229.4	07/05/1996	271.6	16/05/2003	313.5	01/08/1912	373.9	17/05/2003	495.8	29/05/1980	593.8	05/04/1929	696.1	05/08/1914	878.8
26	3/01/1883	147.1	03/05/1996	195.8	30/04/1949	228.6	07/04/1988	266.6	11/03/2001	311.8	26/02/1953	372.1	28/05/1983	487.3	1/02/1895	591.4	26/07/1886	694.5	20/05/1949	875.7
27	31/03/2009	145.6	16/05/2003	192.7	05/06/2016	226.6	21/12/1892	265.9	10/03/1964	306.8	05/04/1994	366.2	25/02/2013	477.3	22/08/1899	585.2	05/07/1900	692.7	24/06/1983	866.8
28	09/11/1917	145.3	22/05/2009	192.6	13/06/2012	223	23/07/1914	262.9	25/03/1972	294.2	20/05/1977	363.6	30/04/2011	476.8	08/06/1919	584.4	14/02/1893	686.5	05/02/1944	862.6
29	22/08/2007	144.1	09/11/1917	191	29/01/2013	222.8	28/03/1890	262.2	17/02/1995	286.2	10/06/1919	359	18/03/1956	475	03/05/1983	580.5	02/08/1914	684.9	10/06/1919	862.1
30	04/10/2010	143.4	13/06/1900	188	4/01/1883	222	14/06/1900	259.6	09/04/1990	285.8	05/05/1985	348.2	26/04/1887	467.4	3/03/1896	580.1	29/06/1930	684.5	24/08/1899	861.4
31	13/06/1900	143.3	3/01/1883	187.7	09/03/1964	218.9	08/04/1990	257.4	27/05/1938	281.4	26/05/1938	346.9	15/03/1953	462.2	12/03/2001	575.6	24/08/1899	678	11/03/1896	858.6
32	09/05/1934	141	09/05/1934	184.2	3/04/1892	216.9	26/04/1985	254.2	30/03/1890	280.4	13/06/1897	343.4	29/01/1883	459.5	11/05/1990	574.8	29/04/1923	678	27/03/1953	852
33	28/03/1890	140.2	11/10/1888	183.6	23/05/2009	215.8	01/08/1950	251.5	10/12/1970	277.6	30/10/1972	341.5	28/05/1938	455.9	24/02/1893	565.7	01/04/1994	675.8	20/06/1990	846.8
34	27/02/1916	139.7	30/04/1983	182.8	11/04/1958	213.7	30/01/1944	249.8	18/06/1900	276.1	6/04/1892	336.5	28/02/1896	453.7	27/07/1914	564.7	17/04/1975	667.7	06/03/1971	838.9
35	22/01/1933	138.9	30/08/2006	181.4	11/08/1925	211.8	21/02/1961	248.4	03/06/1903	273.9	12/07/1929	335.2	23/07/1914	453.1	29/06/1967	563.1	15/02/1895	665.8	24/07/1900	834.4
36	10/10/1888	137.4	20/12/1958	180.1	10/12/1970	210.3	24/02/1953	244	11/10/2010	272.4	12/06/2012	328.8	18/02/1893	450.7	02/03/1929	555.8	21/03/1959	659.8	22/04/1947	832.3
37	29/09/1899	137.2	09/03/1964	179.8	10/04/1923	208.6	07/03/1987	243.2	27/07/1914	271.3	6/04/1890	325.4	10/05/1884	450.5	01/05/2011	554.6	29/06/1967	659.7	14/04/2013	829.5
38	07/04/1988	137	09/04/1923	179.4	06/04/1990	205.8	23/05/2009	242.6	15/04/1923	268.7	03/03/1956	319	19/05/1977	448.2	05/07/1900	553.5	22/02/1883	657.8	28/07/1996	827.2
39	29/07/1950	136.7	12/03/1909	178.3	02/05/1956	204.5	08/02/1931	241	06/03/1987	267.6	12/10/2010	317	20/03/1975	446.6	9/06/1891	544.8	22/03/1894	657.6	28/04/1954	821.4
40	19/05/1977	134.4	18/11/1943	178.3	07/04/1988	203.8	12/04/1923	240.7	21/12/1892	265.9	16/03/2001	316.8	15/11/1972	438.7	04/06/2003	537	18/07/1945	646.3	10/07/2012	819.8
41	09/04/1923	133.9	28/02/1896	177.9	04/05/1996	203.6	13/07/1899	240.3	20/02/1961	264.2	17/03/1937	311.3	23/04/2009	438.4	13/05/1884	534.6	31/03/2001	640.4	26/05/1892	814.1
42	22/01/1959	133.6	26/02/1906	175.2	10/05/1934	203.3	14/06/2012	234.2	26/12/1958	262.4	10/12/1970	307.1	18/02/1959	436.7	16/06/1945	533.1	07/04/1981	636.6	4/04/1894	795.8
43	28/02/1896	133.4	10/05/1990	175	05/10/2010	203.2	27/01/1927	232.6	10/04/1916	262	04/03/2013	304	28/06/2012	432.4	16/06/1938	532.5	19/06/1985	633.8	03/05/1981	784.2
44	03/05/1996	132.2	28/03/1890	174	11/07/1899	202.7	02/05/1949	230.4	27/04/1985	259.6	14/04/2009	302.6	21/05/1949	430.2	12/07/2012	529.6	28/06/1980	631.8	7/07/1884	778.5
45	18/11/1943	132.1	04/10/2010	173.4	01/05/1983	202.2	11/03/1964	230.4	30/01/1927	257.5	11/07/1924	301.5	20/06/1897	429.9	30/11/1972	522.7	25/03/2013	630.3	29/06/1967	777.4
46	14/08/1968	128	31/01/1899	172.2	18/11/1943	201.9	29/01/2013	230.2	17/03/1937	256.8	11/04/1916	299	10/06/1891	426.6	10/04/1916	521.9	13/06/2012	625.8	13/03/1927	773
47	20/02/1985	125	28/01/2013	170.8	22/08/2007	200.5	05/06/2016	228.8	11/11/1917	256.3	20/02/1995	298.6	20/04/1904	415.8	20/03/1937	516.4	22/05/1949	622.1	14/05/1994	770.4
48	21/12/1895	124.5	10/07/1985	169	09/11/1917	199.1	2/02/1895	227.6	31/01/1944	255.6	29/03/2014	298.5	21/02/1947	410.9	11/05/1930	513.9	3/06/1884	621.1	10/04/1916	769.1
49	12/02/1992	123.6	02/06/1903	164.6	29/01/1944	195.9	09/05/1934	227.4	12/05/1934	253.6	11/04/1990	297.6	12/05/1930	408.8	23/04/2009	510.8	27/05/1938	615.7	30/05/1904	768.8
50	16/05/2003	123.5	03/03/1975	164.4	28/03/1890	195.6	25/05/1938	225.5	2/02/1895	247.4	09/02/1931	296.7	24/06/1886	407.6	24/04/1910	510.2	17/03/1896	611.6	16/06/1938	765.9
51	25/02/1906	123.4	07/04/1926	163.5	31/08/2006	194.8	10/07/1924	222.8	09/02/1931	245.8	01/04/1904	293.6	16/08/1912	405.8	31/01/1944	507.8	09/03/1927	608.4	23/02/1898	762.3
52	19/02/1961	123.2	22/01/1959	162.8	07/02/1931	194.5	23/01/1933	222.5	16/07/1899	245.6	17/06/1951	292.8	05/07/2005	405.5	13/02/2008	507.6	16/05/2003	596.2	27/02/1895	759.2
53	15/04/1911	122.7	13/06/1897	161	05/03/1987	193.4	1/06/1887	221.8	15/08/1925	245.1	14/06/1900	291.5	30/04/1958	403.7	30/01/1927	505.6	09/04/1916	591.7	30/04/2001	756.4
54	25/04/1966	121.7	06/05/1980	160.8	10/07/1924	192	11/08/1925	220.9	24/05/2009	244.6	30/12/1958	291.4	18/02/1929	401.4	24/12/1975	504.8	1/02/1898	590.1	29/06/1958	749.9
55	15/11/1975	117.6	25/07/1922	160.5	11/10/1888	191.5	13/04/1958	220.8	22/11/1943	242.6	03/08/1914	290.6	03/06/1903	400.6	8/07/1886	502.2	05/04/1946	583.9	18/07/1945	745.8
56	12/06/2012	117.6	02/05/1956	160.3	2/02/1895	187.9	02/05/1956	216.7	22/01/1933	241.6	15/03/1894	289.6	28/01/1927	400.2	30/12/1970	502	17/05/1904	581.8	12/08/1886	743.8
57	14/06/1952	117.3	26/03/1946	159.7	21/07/1965	185.9	18/11/1943	216.4	02/05/1956	240.1	06/04/1905	289	11/07/1924	398.8	17/01/1898	500.8	11/06/1891	574.8	10/05/1975	738
58	24/08/1944	116.1	27/02/1916	159.5	23/01/1959	183.4	08/06/1951	215.5	03/05/1948	239.6	12/09/2006	287.6	26/03/1906	398.5	03/08/1912	499.8	02/07/2005	572.8	24/03/1883	734.1
59	12/06/1945	113.8	07/04/1988	159	26/04/1985	181.8	01/09/2006	213.4	14/06/2012	238.2	12/05/1930	286.9	10/12/1970	396.9	20/05/1977	498.8	05/01/1944	570.2	24/03/1907	733.6
60	28/01/2013	113.8	30/05/1919	158	30/05/1919	180.9	31/05/1919	213	07/04/1926	236.4	18/02/1893	286.7	17/03/2001	395.4	08/03/1947	498.4	04/02/1971	561.9	27/04/1989	721.6
61	29/01/1989	113.6	23/01/1933	157.2	12/10/1982	178.4	11/11/2007	212.6	13/07/1924	234.2	21/02/1961	285.8	06/06/1990	394.2	06/04/1981	496.2	23/03/1947	561.6	21/04/1910	721
62	23/01/1953	112.8	13/12/1991	157	12/03/1909	178.3	04/03/1975	211.1	05/05/1949	232.7	3/03/1896	285.5	13/10/1982	392.7	01/01/1971	494.1	11/04/1937	560.8	09/05/1923	716.5
63	27/06/1940	112.3	1/02/1895	154.9	26/03/1946	178	23/01/1959	210.3	29/01/2013	232.6	09/02/1944	285.5	21/03/1894	390.5	09/03/1917	488.3	04/05/1901	556.1	18/02/1992	706.8
64	03/12/1946	110.5	21/07/1965	151.6	28/02/1896	177.9	06/10/2010	207.8	2/08/1884	231.6	10/04/1926	285.4	20/03/1937	387.5	02/05/1904	481.1	29/02/2008	553.5	05/04/1946	702.8
65	21/06/1979	110.3	06/03/1987	149	15/11/1975	177.6	11/11/1917	205.5	30/07/1912	229.1	22/11/1943	283.8	01/01/1971	385.7	25/07/1924	476.4	30/12/1970	549	16/05/1901	702.4
66	29/04/1949	108.7	29/01/1989	147.8	27/02/1906	175.7	31/07/1884	204.9	05/06/2016	228.8	12/07/1899	282.8	1/01/1898	382.6	8/03/1894	470.4	11/04/1992	544.5	17/05/1987	701.6
67	16/02/1879	107.7	28/01/1944	146.1	22/02/1953	173.4	28/03/1994	199.3	2/06/1887	226.6	29/01/1933	282.4	13/04/1926	382	04/05/1905	470.1	02/05/1955	538.7	05/02/2008	700.5
68	30/05/1919	107.7	14/08/1968	145.5	09/04/1916	168.6	7/12/1897	197.4	09/06/1951	225.5	13/03/1987	281.4	08/03/1995	381.2	11/06/1949	468.1	18/03/1917	537.2	28/12/2010	700.4
69	02/05/2015	107.4	25/04/1966	145.3	09/10/1978	168.4	26/03/1946	194.5	01/04/1904	225.2	10/04/1955	280.1	02/03/1981	375.3	25/06/1897	450	24/02/2015	536.3	20/03/1937	689.8
70	11/06/1893	106.7	18/02/1971	144.8	19/02/1966	166.1	12/10/1888	192.5	26/08/2007	222.3	02/02/1927	279.6	16/10/2010	375.2	02/05/1955	446.3	08/05/1910	534.3	13/07/1924	688.6
71	27/01/1927	104.6	10/11/2007	144.8	16/06/1952	165	01/03/1916	190.5	28/02/1896	220.3	01/01/1959	274.7	05/04/1946	373.6	07/04/1906	444.5	11/06/1977	534.2	02/07/1980	679.2
72	05/03/1987	103.8	15/06/1952	144.7	01/04/1904	163.8	31/07/1912	189.5	25/01/1959	220	03/06/1903	273.9	13/04/1955	373.1	26/03/1961	443.9	01/08/1912	533.3	26/04/1879	678
73	22/11/1937	102.9	28/06/1940	144.3	07/04/1926	163.5	01/03/1906	189.4	13/06/1897	216.9	05/04/1946	271.5	30/01/1944	372.8	11/05/1934	443.8	21/05/1905	531.4	23/04/1917	668.7
74	02/05/1956	102.9	29/03/1955	144.1	02/05/2015	161.2	14/10/1982	189.2	03/09/2006	215.6	25/03/1907	268.9	15/03/1961	366.3	18/04/1926	441.2	20/03/1961	522.2	19/05/1925	667.4
75	21/02/1981	102.4	03/03/1912	143.3	13/06/1897	161	4/11/1896	188	03/06/1919	215	18/11/1917	267.5	10/01/1992	363.2	03/06/1903	438.2	06/05/1925	518.3	18/06/1948	661
76	01/04/1904	101.6	08/11/1925	142.5	24/05/1938	160.8	21/07/1965	185.9	09/04/1981	214.1	20/04/1884	266.8	27/07/1899	360.4	18/06/1987	438	11/07/1924	516.3	03/04/1961	658.8
77	31/03/1994	101	08/12/1970	141.8	25/07/1922	160.5	27/04/1966	185.7	13/03/1901	212.6	12/11/2007	266.2	03/12/1917	352.3	15/04/1978	436.9	08/03/1951	509	21/03/1951	657.5
78	15/03/1894	100.8	07/02/1931	141.7	23/01/1933	160.2	09/03/1935	182.6	04/03/1906	212.5	08/03/1906	262.7	06/03/1987	351.8	22/04/1909	433.6	25/03/1907	508.3	29/07/1913	657.3
79	20/12/1958	100.6	10/07/1924	140.2	17/03/1937	158.2	03/05/2015	181.8	01/01/1922	212.4	10/05/1934	262.5	10/03/1935	350.6	19/01/1992	429.8	23/06/1948	506	30/05/1891	655.1
80	6/07/1884	100.3	14/02/1947	138.9	13/12/1991	157.2	12/03/1909	181.6	30/01/1894	209.4	20/03/1901	262.4	24/04/1910	347.6	25/03/1946	428.4	26/07/1897	505.2	02/07/2005	645
81	05/05/1980	100.2	23/01/1953	134.6	04/03/1912	156.5	10/10/1978	181.2	29/01/1989	206.2	30/04/1949	260.9	01/03/1916	347	20/03/1995	427.6	22/04/1909	505.1	12/08/1897	643.2
82	05/04/1990	99.8	12/10/1982	133.6	15/08/1887	156.3	10/06/1991	179.4	03/04/1992	202.5	10/04/1992	259.9	17/06/1951	343.9	01/07/2005	426.9	19/11/2010	503.2	20/04/1955	640.4
83	26/03/1905	99.3	16/06/1948	131	14/02/1992	156.2	01/01/1922	178.6	17/03/1909	201.9	10/04/1981	259.7	15/04/2014	343.2	18/04/1925	426.3	21/01/2006	496.2	31/01/1918	631.6
84	06/02/2002	98.4	01/04/1904	129.5	08/06/1951	155	11/06/1893	176.6	12/03/1935	200.4	10/04/1887	255.4	27/03/1909	341.6	12/11/2010	424.6	27/04/1989	493.2	28/07/1903	630.6

TABLE A
SUMMARY OF ANNUAL RAINFALL ANALYSIS
YAMBA PILOT STATION FROM 22 MAY 1887 TO 2 MAY 2017

RANK	DAILY RAINFALL		2 DAY ROLLING TOTAL		3 DAY ROLLING TOTAL		5 DAY ROLLING TOTAL		8 DAY ROLLING TOTAL		15 DAY ROLLING TOTAL		30 DAY ROLLING TOTAL		45 DAY ROLLING TOTAL		60 DAY ROLLING TOTAL		90 DAY ROLLING TOTAL	
	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	DATE	AMOUNT	Date	60 Day	Date	90 Day
85	08/11/1925	98	12/02/1969	128.5	30/03/1955	153	29/07/1957	176.5	26/03/1946	199.4	24/03/1909	254.7	06/12/1943	329.7	30/12/1943	420.5	22/02/1922	489.6	29/04/1909	629
86	13/12/1991	97.6	29/03/2014	128.2	15/02/1947	151.9	01/04/1904	175.7	12/06/1893	199.2	17/03/1939	251.9	22/03/1901	328.1	15/05/1958	417.2	31/12/1943	483.1	06/04/1933	628.4
87	20/05/1908	97.5	27/01/1927	128	27/01/1927	151.1	03/04/1992	175.6	7/05/1881	195.5	16/08/1925	247.9	07/05/1979	326.8	06/02/1922	415.9	28/07/1903	482.8	03/05/2015	627.2
88	06/03/1935	97.5	08/06/1951	127.8	17/02/1973	151.1	2/03/1886	173.2	16/10/1982	193	9/06/1891	247.8	09/04/1978	324.4	01/04/1901	415	05/01/1926	482.1	14/01/1973	623.5
89	17/02/1971	95	09/10/1978	126.4	26/03/1994	151.1	07/04/1926	172.9	5/03/1886	192.5	21/04/2008	245.7	11/05/1934	323.2	27/04/1989	415	08/03/1911	481.6	30/12/1970	622.7
90	12/08/1891	93.5	11/06/1893	125.8	19/02/1971	150.4	29/03/2014	172.6	12/10/1888	192.5	29/04/1979	244.9	21/02/2015	322.6	03/05/1948	412.3	04/06/1958	481.4	14/05/1905	621.2
91	03/03/1920	91.9	16/04/1911	125	29/01/1989	150.2	06/04/1981	172.3	19/02/1973	192.2	15/06/2016	241.6	13/03/1997	320.4	02/11/1982	412.3	18/06/1987	481.2	25/06/1979	613.2
92	22/05/1938	91.9	4/09/1894	124.8	20/05/1908	150.1	5/05/1881	171.4	07/05/1915	190.4	03/05/1948	240.6	29/08/1879	320	25/03/1907	411.5	12/05/1934	477.6	01/03/1922	612.5
93	20/10/1882	91.4	12/02/1992	123.6	17/04/1911	149.1	18/06/1948	168.8	04/04/1947	190.3	29/01/1989	240.2	25/04/2008	318.9	16/03/1935	409.4	08/04/1935	471.3	12/05/1934	606.7
94	13/02/1947	91.4	14/08/1887	123.5	28/06/1940	147.1	16/06/1952	168.8	27/04/1966	189	15/02/1947	239.2	06/03/1931	318.8	25/06/1913	407.3	16/04/1978	470.7	09/05/1935	605.5
95	16/06/1948	91.4	07/03/1935	123.4	15/08/1968	147	17/02/1973	167.1	21/07/1965	185.9	15/05/1915	235.3	10/04/1905	317	17/06/1951	404.9	02/01/1918	470.4	09/05/1997	602.4
96	20/07/1965	89.4	03/05/2015	123.4	13/02/1969	146.3	04/04/1947	165.9	17/01/1891	185.9	19/10/1978	234	14/03/1957	316.1	11/03/1931	404.2	25/06/1979	467.5	12/04/1982	601.1
97	13/02/1887	88.9	21/06/1979	122.5	30/12/2014	143.8	29/07/1913	163.4	27/08/1879	184.4	09/01/1922	233.8	27/03/1907	315.1	24/05/1979	390.3	14/10/1982	466.7	20/01/1926	600.4
98	10/12/1970	87.6	20/05/1908	122.4	12/06/1893	143.6	17/03/1937	163.3	19/12/1991	184.2	17/04/1910	232.5	10/06/1991	314.8	07/09/1957	387.9	26/03/1931	465.7	15/04/1978	593.1
99	15/02/1973	87.1	03/12/1994	121.4	08/03/1935	143.2	08/03/1939	162.1	10/03/1939	183.8	12/03/1997	229.6	20/06/2016	311.2	11/05/1879	387.9	29/08/1957	464.8	28/05/1939	592.8
100	26/07/1886	86.9	16/02/1879	120.4	07/03/1957	143.2	30/03/1955	159.6	10/10/1978	183.3	11/06/1886	229.3	19/05/1966	305.2	10/01/1928	385.5	03/04/1906	461.5	24/02/1928	583.8
101	02/06/1903	86.4	22/05/1938	119.3	17/06/1948	142.9	20/06/1971	158.3	06/03/1997	183	5/03/1880	229.1	13/02/1933	304.8	16/04/1939	383.6	29/07/1913	455.8	11/09/2006	581
102	17/01/1951	86.4	06/05/1915	116.4	2/05/1884	141.7	17/08/1968	158.2	05/05/2015	182	16/03/1935	227.6	22/01/1922	304.7	10/03/1997	383.2	20/03/1995	452.2	08/03/1911	579.9
103	12/02/1969	86.1	7/07/1884	115.3	25/03/1907	139.4	16/01/2004	157.2	17/12/1955	178.4	01/03/1973	226	19/12/1965	304.6	03/01/1984	377	23/04/1939	450	20/05/1908	577.5
104	18/03/1998	85.9	17/03/1937	113.5	03/05/1901	136.4	29/01/1989	157	05/03/1960	178.2	3/07/1898	221.7	22/02/1878	304.4	10/03/1878	374.3	28/04/1879	449.9	16/08/1912	577.2
105	27/02/1960	85.3	02/05/1901	111.5	21/06/1979	133.9	04/05/1901	155.7	29/07/1957	176.5	7/05/1881	220.9	23/06/1913	304	25/02/1911	371.1	13/04/1973	447.4	11/05/1995	575.8
106	25/07/1922	83.8	24/03/1907	111.5	06/03/1939	130.3	07/05/1986	155	29/03/2014	176.4	13/12/1965	220.8	05/06/1969	303.4	25/02/2015	370.5	27/07/1933	446.7	25/04/1931	570
107	06/03/1997	83.8	17/07/1882	111	06/05/1915	129.1	06/05/1915	153.8	11/05/1930	175.7	22/12/1991	220.6	03/04/1925	300.2	6/05/1881	365.9	12/06/1966	438.7	09/04/2004	567
108	15/04/1924	82.6	06/03/1939	110	9/06/1891	128.2	18/04/1911	153.7	06/11/1984	174.4	29/08/1879	219.2	26/09/2006	299.4	20/05/1908	364.5	25/01/1928	430.4	29/03/1906	564.6
109	19/03/2014	82	1/03/1886	109.7	23/02/1981	125.6	30/06/1940	152.7	24/02/1971	174.3	03/03/1971	216.4	17/02/1989	297.2	16/04/2014	364	19/04/1952	429.5	12/11/2007	554.3
110	08/10/1978	81.6	07/03/1997	108	4/09/1894	124.8	6/03/1894	152.4	06/02/2002	172	25/06/1913	215.2	03/05/1948	292.9	13/06/1969	358.3	01/01/1984	419.2	31/12/1943	553.8
111	15/04/1930	81.5	16/01/1891	107.7	23/02/1880	124.7	20/05/1908	150.1	02/04/1905	171.6	12/03/1960	213.8	29/03/1939	290.4	28/03/1973	358	11/03/2004	419.2	14/04/1878	552.9
112	27/08/1957	81	23/02/1880	104.4	29/07/1913	124.5	10/04/2008	149.6	16/06/1952	168.8	06/05/1966	212.8	24/11/2007	287.3	03/09/2006	349.7	09/05/2014	418.7	30/01/1984	552.4
113	22/02/1880	80.8	11/05/1930	104.2	10/02/1882	123.9	14/02/1969	149.1	11/04/1910	167.5	21/02/1878	211.7	7/05/1881	278.8	25/02/2004	345.2	16/05/1998	416.2	24/04/1941	548.3
114	21/06/1898	80	06/02/2002	104	05/02/2008	123.7	25/03/1907	144.9	29/07/1913	167.5	12/05/1986	210.8	18/03/1960	278.1	18/02/1933	344.2	25/03/1878	413.6	11/05/1952	532.6
115	02/03/1912	79.8	04/02/2008	103.9	05/05/1986	122	22/06/1979	143.1	28/08/1969	166	30/08/1957	208	06/02/1911	275.6	12/06/1991	342.2	26/03/1997	405.4	6/05/1881	524.3
116	06/04/1955	79.5	22/02/1981	102.6	17/02/1879	121.7	23/02/1880	141.2	26/08/1911	165	23/09/1982	207.7	26/06/1984	273.5	16/04/1936	338.2	12/06/1969	396.4	30/08/2016	520.8
117	09/01/1993	79.4	29/07/1913	101.6	28/02/1886	120.9	27/03/1905	134.7	18/01/2004	164.2	27/06/1984	201.4	07/02/2004	273.2	13/03/1880	337.7	7/05/1881	394.3	06/05/1966	518.6
118	12/03/1901	79.2	27/03/1905	101.1	04/05/1905	114.8	20/07/1882	132.1	07/05/1986	163.6	08/02/2002	197.4	26/03/1936	272.3	01/09/1965	337.6	19/03/1960	382.4	28/05/1936	517.6
119	24/03/1907	78	04/03/1920	99.5	10/04/1984	113.8	11/06/1891	129.5	08/01/2008	162.8	12/10/1888	195.8	14/03/1973	271.8	22/02/1941	333	08/04/1908	380.7	09/09/1965	515.3
120	09/02/1913	77.5	09/04/1984	98	12/05/1930	112.8	15/10/1942	129.1	19/08/1968	161.3	03/05/2015	195.6	20/03/1880	266.5	11/04/1960	332.5	28/03/1880	380	30/08/1957	506.4
121	06/02/1931	76.2	16/02/1973	97.5	13/10/1942	111.3	24/08/1879	126.8	30/06/1940	153.5	24/04/1998	189.2	12/10/1888	266.5	04/04/1952	329.3	10/07/1991	379	31/05/1920	498.4
122	28/01/1984	76.2	09/12/1993	95.6	08/03/1997	109.2	19/06/1984	126.2	26/02/1880	150.6	05/03/1911	184.5	07/02/1941	260.7	11/05/1918	328.9	17/07/1882	375.1	26/04/1880	493.4
123	09/11/1941	74.9	07/03/1957	93.9	07/02/2002	107.4	06/02/2002	125.6	25/05/1908	150.6	26/01/2004	181	08/03/1908	253.1	12/12/2007	321.2	14/09/1965	371.6	11/06/2014	484
124	05/05/1915	73.2	16/01/2004	92.2	04/03/1920	106.1	27/05/1936	120.8	27/03/1907	148.7	16/05/1969	175.6	06/05/1918	252.5	05/01/1966	320.9	16/04/1936	370.6	15/03/1960	471.4
125	12/10/1982	70	10/11/1941	91.2	3/05/1881	105.4	23/02/1898	118.6	25/06/1979	147.5	05/03/1952	175.3	08/12/1986	252.4	16/05/1998	320.5	02/06/1941	367.8	16/01/2000	468.8
126	26/01/2008	69	21/06/1898	90.4	09/12/1993	104.4	05/05/1930	118.3	21/07/1882	147.3	21/08/1968	174.8	16/05/1915	250	09/07/2016	320	14/06/1920	359.6	05/07/1991	455.6
127	03/03/1936	66.3	2/05/1881	90.2	10/01/1928	101.9	10/03/1997	117.2	28/05/1936	147.3	30/06/1940	174.8	14/05/1998	245.2	21/07/1882	315.6	20/06/2016	334.6	31/12/1942	451.2
128	08/04/1918	66	28/02/1960	89.1	22/02/1898	101.3	16/01/2000	115.2	17/10/1942	134.9	07/02/1941	169.8	27/01/1920	245.1	12/06/1986	298.4	15/01/2000	334.2	10/04/1940	450.7
129	12/01/2004	64	26/04/1902	86.8	15/01/2000	98	21/02/1878	114.9	1/01/1898	134.4	23/10/1942	169.7	23/03/1952	241.4	03/03/1940	293.7	24/12/2007	334.1	22/07/1969	445.4
130	6/12/1878	62.7	18/03/1998	85.9	17/01/2004	97.4	02/06/1941	114.5	22/02/1878	129.1	24/02/1908	169	16/01/2000	233.4	11/02/1920	287.8	12/06/1986	332	21/07/1882	436
131	03/05/1986	62.4	04/05/1986	85.2	29/02/1960	96.7	08/04/1910	112.7	03/07/1928	127.8	26/03/1936	167.6	08/11/1942	228.3	11/10/1888	284.3	19/03/1940	317.4	05/05/2002	436
132	26/06/1928	59.4	13/10/1942	84.6	10/11/1941	96.3	09/12/1993	112.4	26/04/1902	126.9	21/02/1882	159.7	13/06/1882	212.5	05/05/2002	284.3	10/01/1993	313.5	17/05/1998	431.2
133	21/10/1910	58.9	27/06/1928	82.8	16/05/1998	94.6	11/01/1928	111.1	18/04/1998	126.6	10/01/1920	157.1	15/02/2002	207.8	16/03/1942	283.7	17/03/1942	309	02/01/1915	427.2
134	1/05/1881	58.4	21/04/1910	82.1	26/04/1902	91.9	02/03/1960	110.4	15/11/1941	117.7	09/03/1918	148.4	16/08/1968	196.8	09/01/1993	280.3	15/01/1932	304	18/06/1986	418.6
135	06/03/1939	55.9	08/04/1918	81.2	06/04/1910	88.8	04/03/1920	106.1	19/01/2000	117.6	03/05/1902	143.7	21/05/1902	192	16/05/1915	279.3	11/05/2002	294.9	24/01/1993	412.5
136	25/04/1902	52.8	27/02/1885	78	28/05/1936	86.9	11/04/1918	97.7	12/12/1993	112.8	21/02/1928	141.9	08/02/1940	190.3	14/01/1932	279.2	16/05/1915	291.6	16/01/1932	387.5
137	31/12/1942	48.8	04/03/1936	77.5	27/01/1878	85.1	16/06/1885	97.4	2/03/1885	108	13/07/1993	127.6	19/01/1928	189.4	31/01/2000	264.2	31/10/1888	289.1	28/03/1888	364.2
138	26/02/1885	48.3	15/01/2000	76.8	09/04/1918	83.7	18/05/1998	96.8	23/04/1920	107.1	3/03/1885	126.8	30/07/1993	184.8	21/05/1902	230	09/06/1902	247.5	15/01/1968	334.5
139	14/01/2000	46.4	29/06/1932	72.7	30/06/1932	82.9	26/04/1902	91.9	13/04/1918	103.8	25/01/2000	126.4	01/01/1932	164.9	18/08/1968	227.5	27/08/1968	237.3	15/07/1902	320.2
140	30/08/1877	40.1	26/01/1878	71.1	27/02/1885	81.6	02/07/1932	86.2	03/07/1932	89	12/07/1932	112.7	26/03/1885	145.8	26/03/1885	184.1	23/04/1885	226.1	27/04/1885	286.3
141	29/06/1932	37.6	31/08/1877	63	31/08/1877	65.5	2/09/1877	72.6	2/09/1877	72.6	26/07/1877	99.1	26/07/1877	130.9	26/07/1877	154.8	22/10/1877	195.1	28/09/1877	267.8

TABLE B
Probability Plot of Actual Rainfall and Antecedent Rainfall for Yamba
22 May 1887 to 2 May 2017

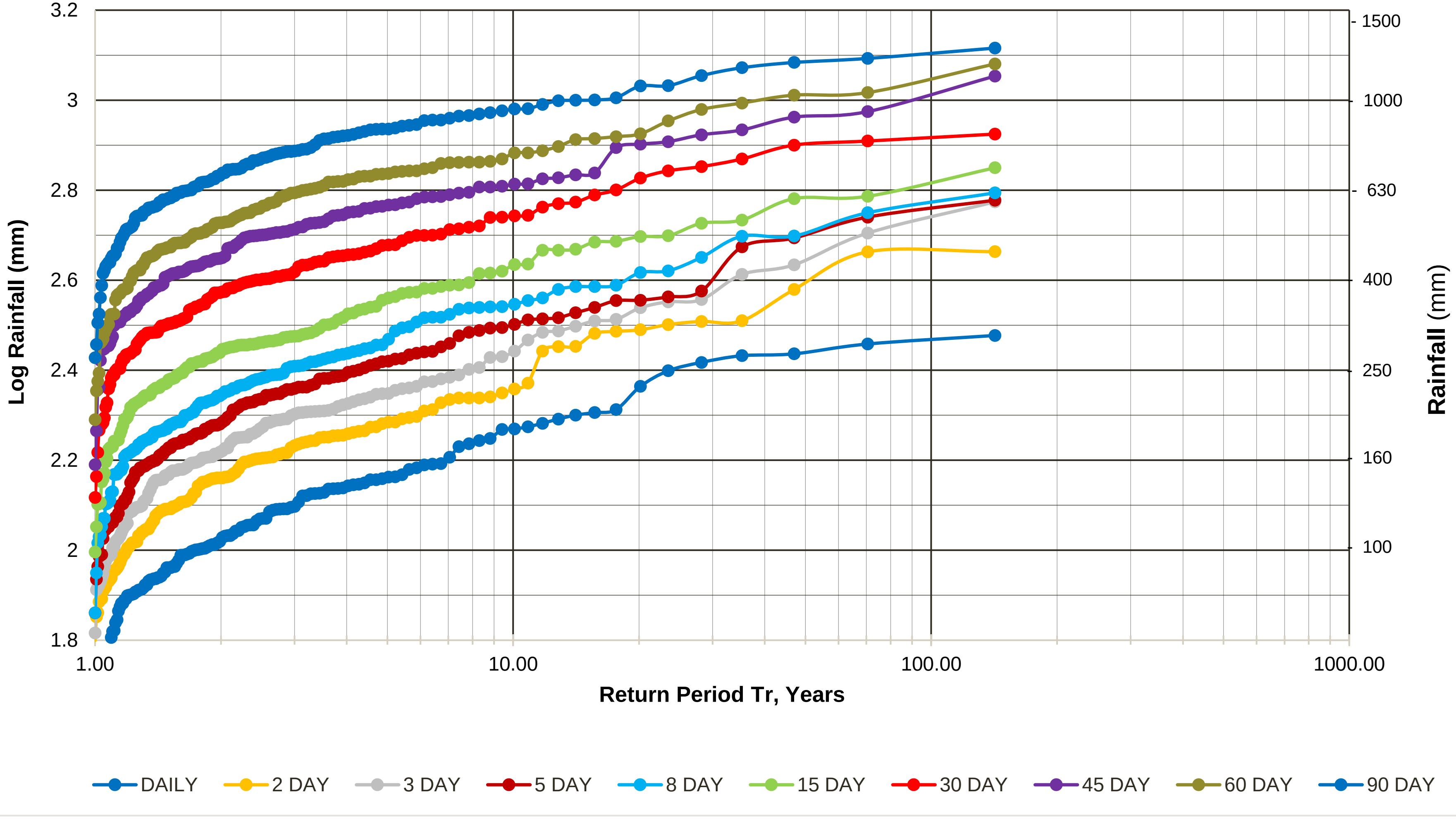

TABLE C
SUMMARY OF KNOWN LANDSLIDES AND EVENTS

DATE	LOCATION	TYPE
13 or 14 June 2011	Downslope of Marine Parade, below No.2 and No. 4 Pilot Street	2No. Minor Earthslide/Scours
22 May 2009	Yamba Surf Life Saving Club (YSLSC)	Beach Scour Rock Revetment Damage
5 or 6 February 2002	Clarence Street to Harbour Street (West Side Yamba Hill)	Earthflow
12 and 13 April 2001	(YSLSC)	Beach Scour
24 May 1999	(YSLSC)	Beach Scour
1& 2 March 1999	Downhill of Pacific Hotel. Access Road to Yamba Beach. Craigmore Headland	Earthslide and Scour Earthslide Earthslide
?/?/1996	(YSLSC)	Wave Attack
About 1 April 1994	Pacific Hotel	Earthslide
7 April 1988	Calypso Caravan Park (West Side Yamba Hill	Earthflow
Early 1977	Beer garden of Pacific Hotel Craigmore Headland	Earthslide (creep movement) Earthslide
March 1974	Pacific Hotel / North of YSLSC	Earthslide
6 February 1974	YSLSC	Beach Scour and Wave Attack
7 or 8 April 1962	Hillside on Drive to Yamba Beach	Earthslide
Late June and early July 1950	Pacific Hotel (destroyed) following after cyclone of 23 June 1950	Earthslide
? July 1950	West side Yamba Hill	Earthslide
28 July 1950	Craigmore Guesthouse	Earthslide/Scour
15 June 1945	YSLSC	Wave Attack
About 25 or 26 May 1938	Yamba Beach Hillside	Scour
14 and 15 May 1921	Yamba Beach Hillside	Scour and/or Earthslide
About 6 August 1889	Flood damage to River Walls	Not Known

TABLE C1
SUMMARY OF HISTORICAL DATA

Date	Origin/Source	Location & Comment
13 or 14 June 2011	Stephen P McElroy Report 31 December 2011	On 13 or 14 June 2011, two small localised scours occurred downslope of Marine Parade below No.2 and No.4 Pilot Street after three days of heavy rainfall.
22 May 2009	CN	Beach Scour and Rock Revetment Damage "The Yamba Surf Club may have survived the pounding of last months storm, but the cracks are beginning to show. The massive seas during the flood, combined with last weeks king tides, have eroded Main Beach to such an extent that cracks have appeared along the length of the rock wall. The worst of it can be seen in front of the clubhouse where the ramp has snapped in two and a large hole has formed underneath YSLSC." DE July 1 2009.
5 or 6 February 2002	DE	Earthflow at Clarence Street on west side of Yamba Hill, flowed down over Harbour street and into the Calypso Caravan Park. "An embankment fringing the northern end of Clarence Street gave way around 2pm on Tuesday causing a large quantity of sand to spill down the hillside across Harbour Street and about 20m into Easts Calypso Caravan Park" DE 8 February 2002.
12 and 13 April 2001	DE	Beach Scour at Yamba Beaches "Local beaches have suffered as a result of cyclonic type weather conditions north and south of Yamba…YSLSC president Jim Dougherty said erosion at main beach was a problem. He said much of the sand had been washed away" DE 14 April 2001
24 May 1999	DE	Beach Scour at Main Beach due to storms "The Yamba Surf Life saving Club complex on Yamba's Main Beach to a hammering in four to five metre seas that pounded the Clarence Coast…club members and volunteers cleared the lower levels of the complex and sandbagged the main clubhouse entrance as the seas built up during the morning and early afternoon…Witnesses in the clubhouses said metres of sand had been ripped from the beach by the wave action." DE 24 May 1999
February 1999	DP (1999) Publican, PH Mrs Garven Public meeting Public meeting	South-east corner of Pacific Hotel slope, Marine Parade, Craigmore Headland. Scour below hotel and access road due to stormwater concentration and blockage or broken stormwater pipes. Scour on northern headland of main beach. Scour adjacent to footings of dwelling of Convent Beach. Craigmore Headland, washout due to drainage concentration.
1 March 1999 to 2 March 1999	DE & CN	Landslides on slope east of Pacific Hotel, Marine Parade and east of Craigmore units. Yamba SES Controller Allan Garven reported "most of last night's (1/3-2/3) torrential rain in Yamba fell in four hours" DE 3/3/99.
Mid 1990's	Deborah Fisher	Corner of Kiosk at YSLSC washed away.
1996	CMC	Wave run-up at main beach past completely through YSLSC - could be photos in PYHS album, undated.
May 1996	MSC	Slump above Yamba Beach amenities block.

Date	Origin/Source	Location & Comment
1994	Publican, PH	Landslide in front of managers residence due to stormwater drainage pipes problem.
Easter 1994	DP(1994) DE	Zone 2 and Zone 3 sliding on east slope of Pacific Hotel. (Note: Good Friday was on 1 April 1994) "Yamba was worst-hit town in the valley yesterday with 195mm of rain recorded in the 30 hours to 3pm. The deluge caused local flooding in many parts of the town." DE 1 April 1994.
About 7 April 1988	DE	Earthflow from Yamba Hill: "Residents in Calypso Caravan Park in Yamba had a narrow escape when a mudslide on Yamba Hill dumped tonnes of debris into the park. The debris spewed three metre deep across Harbour Street through the park fence and more than 30m into the park". DE 8 April 1988. "A mudslide at the Calypso Caravan Park is particularly dangerous because the bank is still slipping…". DE 11 April 1988.
1985	Public meeting	No details
1980's	Mrs Garven	Settlement of paving and steps at the property adjoining No 8 (presumably No 10) Pilot Street. Vertical cracking in brickwork below deck area of No 8. Photos dated 18 August 1985 but cracking and movement known to have occurred prior to that.
1977	DP (1994)	Damage to beer garden structure of Pacific Hotel.
July 1977	Anthony Tod & Partners	Comments on work required to relevel external timber Beer Garden Terrace considered "unsafe". Also erosion due to stormwater run-off (dated 20 July 1977)
Early 1977	Craigmore Home Units	Letter to MSC in relation to March 1999 landslides refers to "… also a previous but not so severe land slip in Early 1977." "… our property at No 1 Queen Street, Yamba was subjected to a land slippage and an area of our front lawn collapsed down the hillside." Letter dated 1 June 1999 from Mr J E McCulloch, Chairman, Craigmore Home Units, SP4356.
1975	DP (1994)	Damage to hotel managers residence as detailed in letter by John W Campbell Consultants letter of 20/2/75.
1974	DP (1994)	Damage to Pacific Hotel on east side as given in letter from Antony Tod and Partners letter dated 30 August 1974.
1974	DP (1994)	MSC (?) drawing shows landslides on northern side of YSLSC.
1974	Public meeting	Erosion of Whiting Beach due to storms.
1974	DE of 20/11/81	YSLSC almost demolished. Erosion along the front (east side of building) shows pier supports about 2m exposed.

Date	Origin/Source	Location & Comment
6 February 1974	DE	Yamba beach scour: "With the scheduled high tides and heavy swell caused by Cyclone Pam, severe sand and beach erosion was being caused along the Yamba beach front. The high tides and swell had washed in the Yamba Surf Life Saving Club's surf boat shed and had also smashed in the two roller doors of the boat shed. Steps leading to the surf club had also been washed away. The concrete paths that lead to the public dressing sheds on the southern end of the beach had been washed out of alignment and the beach heavily scarred and exposed. Heavy seas had eroded a hole about four feet deep in front of the boat shed and had washed away the boat ramp". DE 7 February 1974. "The Yamba Surf Life Saving Club which appeared at one time on Wednesday (6/2/74) to be in imminent danger of being washed away was spared further punishment yesterday as the waves did not break on it. However the foundations were exposed. On Yamba beach itself hundreds of tons of sand have been eroded". DE 8 February 1974. Refer Photographs A4 & A5.
1974	Publican, PH	Pacific Hotel connected to main sewer, septic tank disconnected.
1974	MSC S58 Certificate	The rear wall and floors of the building which are affected by subsidence, in the building situated Lot 1, Pilot Street, Yamba and being the Pacific Hotel … is unfit for human habitation or occupation and is dangerous to the public." MSC 9 September 1974.
1970's	Mrs Garven	Erosion in front of the middle house on downhill side of Ocean Street/Convent Beach.
1970	Public meeting	No detail.
About 7 or 8 April 1962	DE	"A landslide occurred on the drive leading down to the (Yamba) beach". DE 9 April 1962.
1960's	CMC	Landslides in area north of YSLSC due to high rainfall. Landslides on rock face at old quarry now Turner's Beach car park.
1960's	CMC	Wave run-up through YSLSC.
1950	DP (1994)	Zone 1 area damage to Pacific Hotel inferred from evidence of cracking and movement.
June-July 1950	PYHS	Photos of damage to Pacific Hotel. Damage appears to be worse towards north-east corner. Photos show settlement on east face and shear cracking of transverse walls, particularly the outer north-east corner wall, indicative of settlement.
6 July 1950	DE	“Subsidence Damages Hotel. A number of rooms at the Hotel Pacific, Yamba have been temporarily closed following a subsidence which has caused cracks to appear in the walls of the hotel.” DE 6 July 1950.

Date	Origin/Source	Location & Comment
8 July 1950	DE	"Rooms closed at Hotel Pacific. Twelve bedrooms, the dining room, kitchen, bathrooms and toilet have been closed at the Hotel Pacific, Yamba as a safety precaution pending repairs. The closed portion is on the northern and north-eastern side. The southern part of the hotel where the bar is situated is still in use. ***Foundation subsidence at the hotel has been causing concern for some months. It was aggravated by the recent cyclone and heavy rain, cracks have appeared in the walls. Some walls have been strengthened with bars and rods until major repairs can be effected."*** DE 8 July 1950.
July 1950	DE	"Exceptionally heavy rain during the past month had been responsible for many washaways and blocks drains…". "The resealing of the roadway near Pacific Hotel would be carried out, provided…… such work would not be interfered with by operations now going on in connection with the reconstruction of the hotel". "…. a new drain had to be opened up in Yamba Street – from Mr C J Masen's property to High Street. It was to arrest the overflow and seepage from the hill and carry it to a sump at High Street. At the same time it relieved flooding in Beach and Yamba Streets during heavy rain". DE 21 July 1950.
26 July 1950	DE	"The Hotel Pacific ….. is to be demolished. That decision was made after further subsidence occurred as a result of the heavy rain of the past week. Serious subsidence took place after the cyclone of June 23." DE 26 July 1950.
28 July 1950	DE	"A sudden subsidence beneath 'Craigmore' guest house, Yamba, on Friday morning, left one corner of the two storey part of the building suspended over a large hole. The proprietor, Mr J McDonald ….. said that apparently consistent rains had caused a body of water to accumulate beneath the building. On Friday morning, without warning, between 50 and 60 tons of earth slid down the hill, taking with it concrete slabs weighing a couple of tons and a large part of the grass lawn. The subsidence smashed the sewerage system pipes and left a large hole beneath the corner of the building". DE 31 July 1950.
1950	PYHS	Landslides in front of Craigmore Guest House.
1950	PYHS	Landslide at east end of Harbour Street, being at the foot of the western slope of Yamba hill. (Location now adjacent to Caravan Park).
7 August 1950	DE	"At a public meeting ….. a working bee was formed to repair damaged portions of Yamba Road. ….. the Shire Council was not in a position to carry out the repairs. It had ….. no funds for this work and trucks were unavailable. It was therefore, necessary that they should help themselves.
15 June 1945	DE	"The Yamba Surf Life Saving Club('s) …… shed on the beach had been badly damaged by the high seas. The seas were the highest seen at Yamba, at times washing the first floor of the shed. Three out of four of the boat gates below the shed had been smashed and the latticework destroyed. The concrete retaining wall at the end of the shed had been damaged". DE 16 June 1945.
25 or 26 May 1938	DE	"Serious erosions have occurred in many parts of the town. Possibly the zig-zag pathway leading to the beach suffered most damage, and the civic fathers are faced with considerable expense in repairing damage occasioned by raging torrents caused by the recent heavy rains. It is evident that only pathways of a permanent nature will withstand further assaults by nature". DE 27 May 1938.

Date	Origin/Source	Location & Comment
14 & 15 May 1921	DE	"Yamba: The wind and rain storm worked great havoc at the seaside village over the weekend. The hill leading from the township to the beach has had the surface washed away. A large channel has been cut under Bond's boarding house ….". DE 17 May 1921 (Tuesday).
About 6 August 1889	CRE	Reports on floods and "The late flood has devastated 26 years labour on the Harbour and Rivers Department at Clarence River Heads." CRE 6 August 1889.

Abbreviations:

CMC	Coastal Management Committee
CN	Coastal News
CRE	Clarence & Richmond Examiner
DE	Daily Examiner
DP	Douglas Partners
MSC	MacLean Shire Council
PH	Pacific Hotel
PYHS	Port Yamba Historical Society
YSLSC	Yamba Surf Life Saving Club

TABLE D
ACTUAL RAINFALL AND ANTECEDENT RAINFALLS (mm) FOR KNOWN LANDSLIDES AND EVENTS

DATE	Daily	2 DAY	5 DAY	8 DAY	15 DAY	30 DAY	45 DAY	60 DAY	90 DAY
14 June 2011	160.8	308.8	356.4	356.4	384.2	422	441	726	995.4
22 May 2009	135.6	192.6	219.4	219.4	253.2	312	485	738.6	821
5 February 2002	5.6	5.8	45.4	75.6	94.6	107.6	138	171.2	327.2
6 February 2002	98.4	104	125.6	172	193	206	236.4	253.6	405.8
12 April 2001	0	0.8	6.8	7.2	74.6	104	419.8	497.6	740.8
13 April 2001	2.2	2.2	3	9	65.8	106.2	422	499.8	743
24 May 1999	3.6	6.8	55.4	82.4	151.6	224.6	299.2	396.4	964.6
1 March 1999	79.6	130.6	157.8	184.6	200.2	361.4	421.8	486.8	585.4
2 March 1999	300	379.6	444.4	473	500.2	656	721.8	786.8	870.2
6 June 1996	32.2	32.8	51.2	53.8	58	204	573.4	582.4	685
31 March 1994	101	106.9	177.1	328.2	348	548.8	617.4	665.8	705.6
1 April 1994	16.8	117.8	167.9	297.6	364.8	549.6	632.2	675.8	722.4
7 April 1988	137	159	266.6	383.8	462.6	648.4	762.3	916.3	1064.3
22 February 1977	122	133	133	133.4	160.8	234.1	252.5	312.8	406.3
3 March 1977	82.4	85.3	122.8	144.3	287	388.1	388.1	426.1	515.9
19 May 1977	134.4	216.2	335	340.4	354	448.2	494.5	508.4	870.8
1 February 1974	35.4	38.6	46.2	95.4	99.9	225.2	314.6	396	476.2
6 February 1974	12.6	12.8	12.9	51.8	108.3	170.3	257.4	346.9	448.6
10 March 1974	173	173	175.6	176.8	187.6	240.6	358.9	418.3	592.1
11 March 1974	287.2	460.2	462.8	462.8	474.8	527.1	639.8	683.1	878.5
12 March 1974	46.4	333.6	507	509.2	521.2	573.3	660.3	727.1	923.4
7 April 1962	199.6	228	260.3	300.5	311.4	473.5	530.1	571.1	995.7
8 April 1962	117.6	317.2	352.2	417.6	426.7	586.8	647.7	683.9	1000.8
23 June 1950	29.2	68.8	176.5	261.4	284	298.5	322.2	442.6	776
24 June 1950	95.5	124.7	203.2	352.8	379.5	391.2	411.3	538.1	865.4
25 June 1950	67.6	163.1	238.3	414	447.1	458.8	478.9	605.7	931

10 July 1950	103.6	104.4	104.4	104.4	107.4	554.5	566.2	586.3	972.8
DATE	**Daily**	**2 DAY**	**5 DAY**	**8 DAY**	**15 DAY**	**30 DAY**	**45 DAY**	**60 DAY**	**90 DAY**
28 July 1950	6.4	6.4	27	107.5	336.4	465.4	915.5	927.2	1056.3
29 July 1950	136.7	143.1	163.7	179.2	450	602.1	1046.6	1063.9	1184.4
30 July 1950	81.3	218	225.7	259.2	485.6	683.4	1110.9	1145.2	1264.4
15 June 1945	9.1	11.6	231.8	318.9	403.3	521.9	532.8	613.8	730.9
22 May 1938	91.9	119.3	137.1	149.8	236.4	311.6	422.9	491.2	567.3
23 May 1938	26.7	118.6	163.8	174.5	257.8	338.3	430.3	514.1	583.6
24 May 1938	42.2	68.9	206	214.9	299.2	380.5	459.8	549.2	625.8
25 May 1938	37.3	79.5	225.5	243.3	332.7	417.8	450.1	585.2	663.1
26 May 1938	14.2	51.5	212.3	257.5	346.9	432	456.2	596.9	676.8
27 May 1938	23.9	38.1	144.3	281.4	343.4	454.9	479.3	615.7	700.7
14 July 1938	20.3	39.6	71.9	114.6	152.2	185.7	252.1	545.2	732.4
14 May 1921	133.6	135.9	151.1	190.8	279	380.4	491.8	526.4	620.9
15 May 1921	273.1	406.7	411.8	463.9	531.5	653.5	761.3	799.5	894
16 May 1921	187.5	460.6	599.3	622.4	706.3	839.5	943.2	984.7	1081.5
5 August 1889	87.6	148.6	172	172	178.1	484.7	511.1	513.6	630.6
6 August 1889	231.1	318.7	403.1	403.1	408.9	715.8	742.2	744.7	842.4
7 August 1889	91.2	322.3	494	494.3	495.3	807	833.4	835.9	933.1

TABLE E
SUMMARY OF RETURN PERIODS OF ACTUAL RAINFALL AND ANTECENDENT RAINFALL FOR LANDSLIDE EVENTS

DATE	Return Period (years) for rainfall over						Comments
	1 day to 2 day	5 day to 15 day	30 day to 45 day	60 day to 90 day	Critical Rainfall Period	Indicative Return Period (years)	
A. SCOUR EVENTS							
14 June 2011	7 to 20	20 to 6	3 to 2	7 to 15	2 and 5 day	20	
2 March 1999	142 to 47	32 to 24	20 to 18	14 to 6	1 day	142	1999 - Most rainfall reported over about 4 hours.
26 May 1938	~1	2 to 5	3 to 2	3 to 2	15 day	5	
15 May 1921	47 to 55	33 to 28	22 to 20	14 to 6	2 day	55	
16 May 1921	12 to 142	142 to 135	135 to 70	35 to 32	2,5 & 8 days	142	
B. EARTH SLIDE EVENTS							
31 March 1994	2 to 1	2 to 6	9 to 7	4 to 2	30 day	9	
19 May 1977	4 to 7	15 to 5	4 to 2	3 to 6	5 day	15	
11 March 1974	70 to 70	34 to 15	9	5 to 6	1 & 2 day	70	
7 April 1962	16 to 11	5 to 4	5 to 3	2 to 14	1 day	16	
8 April 1962	3 to 24	24 to 11	14 to 11	5 to 18	2 & 8 day	24	
25 June 1950	1 to 3	4 to 20	4 to 2	3 to 9	8 day	20	
10 July 1950	2 to 1	~1	12 to 4	3 to 12	30 & 90 day	12	
29 July 1950	4 to 2	1 to 12	16 to 100	90 to 35	45 day	100	
6 August 1889	24	30 to 9	35 to 18	10 to 4	30 day	35	
7 August 1889	2 to 28	47 to 20	65 to 28	18 to 9	30 day	65	

DATE	Return Period (years) for rainfall over						Comments
	1 day to 2 day	5 day to 15 day	30 day to 45 day	60 day to 90 day	Critical Rainfall Period	Indicative Return Period (years)	
C. <u>EARTHFLOWS</u>							
5 and 6 February 2002	2 to 1	~1	~1	~1	1 day	2	
7 April 1988	4 to 2	6 to 14	22 to 19	24 to 18	60 day	24	

APPENDIX B

LANDSLIDE RISK

MANAGEMENT

TERMINOLOGY

APPENDIX B
LANDSLIDE RISK MANAGEMENT

Definition of Terms and Landslide Risk

Risk Terminology	Description
Acceptable Risk	A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.
Annual Exceedance Probability (AEP)	The estimated probability that an event of specified magnitude will be exceeded in any year.
Consequence	The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
Elements at Risk	The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.
Frequency	A measure of likelihood expressed as the number of occurrences of an event in a given time. See also 'Likelihood' and 'Probability'.
Hazard	A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.
Individual Risk to Life	The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.
Landslide Activity	The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (eg. seasonal) or continuous (in which case the slide is 'active').
Landslide Intensity	A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, or kinetic energy per unit area.
Landslide Risk	The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.
Landslide Susceptibility	The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
Likelihood	Used as a qualitative description of probability or frequency.
Probability	A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event. These are two main interpretations: (i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an 'objective' or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.
Probability *(continued)*	(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation,

Risk Terminology	Description
	or the quality and quantity of information. It may change over time as the state of knowledge changes.
Qualitative Risk Analysis	An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.
Quantitative Risk Analysis	An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.
Risk	A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
Risk Analysis	The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.
Risk Assessment	The process of risk analysis and risk evaluation.
Risk Control or Risk Treatment	The process of decision-making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.
Risk Estimation	The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.
Risk Evaluation	The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.
Risk Management	The complete process of risk assessment and risk control (or risk treatment).
Societal Risk	The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.
Susceptibility	See 'Landslide Susceptibility'.
Temporal Spatial Probability	The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.
Tolerable Risk	A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
Vulnerability	The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

NOTE: Reference should be made to Figure B1 which shows the inter-relationship of many of these terms and the relevant portion of Landslide Risk Management.

Reference should also be made to the paper referenced below for Landslide Terminology and more detailed discussion of the above terminology.

This appendix is an extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

TABLE B1: LANDSLIDE RISK ASSESSMENT
QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}		100 years		The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-3}$	1000 years	200 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-4}$	10,000 years	2000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-5}$	100,000 years	20,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}	$5x10^{-6}$	1,000,000 years	200,000 years	The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	**Notional Boundary**			
200%		Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	100%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	40%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	10%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%	1%	Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa.

Extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

TABLE B1: LANDSLIDE RISK ASSESSMENT
QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (continued)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) Cell A5 may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		**Example Implications** (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

Extract from PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT as presented in Australian Geomechanics, Vol 42, No 1, March 2007, which discusses the matter more fully.

AUSTRALIAN GEOGUIDE LR2 (LANDSLIDES)

What is a Landslide?

Any movement of a mass of rock, debris, or earth, down a slope, constitutes a "landslide". Landslides take many forms, some of which are illustrated. More information can be obtained from Geoscience Australia, or by visiting its Australian landslide Database at www.ga.gov.au/urban/factsheets/landslide.jsp. Aspects of the impact of landslides on buildings are dealt with in the book "Guideline Document Landslide Hazards" published by the Australian Building Codes Board and referenced in the Building Code of Australia. This document can be purchased over the internet at the Australian Building Codes Board's website www.abcb.gov.au.

Landslides vary in size. They can be small and localised or very large, sometimes extending for kilometres and involving millions of tonnes of soil or rock. It is important to realise that even a 1 cubic metre boulder of soil, or rock, weighs at least 2 tonnes. If it falls, or slides, it is large enough to kill a person, crush a car, or cause serious structural damage to a house. The material in a landslide may travel downhill well beyond the point where the failure first occurred, leaving destruction in its wake. It may also leave an unstable slope in the ground behind it, which has the potential to fall again, causing the landslide to extend (regress) uphill, or expand sideways. For all these reasons, both "potential" and "actual" landslides must be taken very seriously. The present a real threat to life and property and require proper management.

Identification of landslide risk is a complex task and must be undertaken by a geotechnical practitioner (GeoGuide LR1) with specialist experience in slope stability assessment and slope stabilisation.

What Causes a Landslide?

Landslides occur as a result of local geological and groundwater conditions, but can be exacerbated by inappropriate development (GeoGuide LR8), exceptional weather, earthquakes and other factors. Some slopes and cliffs never seem to change, but are actually on the verge of failing. Others, often moderate slopes (Table 1), move continuously, but so slowly that it is not apparent to a casual observer. In both cases, small changes in conditions can trigger a landslide with series consequences. Wetting up of the ground (which may involve a rise in groundwater table) is the single most important cause of landslides (GeoGuide LR5). This is why they often occur during, or soon after, heavy rain. Inappropriate development often results in small scale landslides which are very expensive in human terms because of the proximity of housing and people.

Does a Landslide Affect You?

Any slope, cliff, cutting, or fill embankment may be a hazard which has the potential to impact on people, property, roads and services. Some tell-tale signs that might indicate that a landslide is occurring are listed below:

- Open cracks, or steps, along contours
- Groundwater seepage, or springs
- Bulging in the lower part of the slope
- Hummocky ground
- trees leaning down slope, or with exposed roots
- debris/fallen rocks at the foot of a cliff
- tilted power poles, or fences
- cracked or distorted structures

These indications of instability may be seen on almost any slope and are not necessarily confined to the steeper ones (Table 1). Advice should be sought from a geotechnical practitioner if any of them are observed. Landslides do not respect property boundaries. As mentioned above they can "run-out" from above, "regress" from below, or expand sideways, so a landslide hazard affecting your property may actually exist on someone else's land.

Local councils are usually aware of slope instability problems within their jurisdiction and often have specific development and maintenance requirements. **<u>Your local council is the first place to make enquiries if you are responsible for any sort of development or own or occupy property on or near sloping land or a cliff.</u>**

TABLE 1 – Slope Descriptions

Appearance	Slope Angle	Maximum Gradient	Slope Characteristics
Gentle	0° - 10°	1 on 6	Easy walking.
Moderate	10° - 18°	1 on 3	Walkable. Can drive and manoeuvre a car on driveway.
Steep	18° - 27°	1 on 2	Walkable with effort. Possible to drive straight up or down roughened concrete driveway, but cannot practically manoeuvre a car.
Very Steep	27° - 45°	1 on 1	Can only climb slope by clutching at vegetation, rocks, etc.
Extreme	45° - 64°	1 on 0.5	Need rope access to climb slope.
Cliff	64° - 84°	1 on 0.1	Appears vertical. Can abseil down.
Vertical or Overhang	84° - 90±°	Infinite	Appears to overhang. Abseiler likely to lose contact with the face.

Some typical landslides which could affect residential housing are illustrated below:

Rotational or circular slip failures (Figure 1) - can occur on moderate to very steep soil and weathered rock slopes (Table 1). The sliding surface of the moving mass tends to be deep seated. Tension cracks may open at the top of the slope and bulging may occur at the toe. The ground may move in discrete "steps" separated by long periods without movement. More rapid movement may occur after heavy rain.

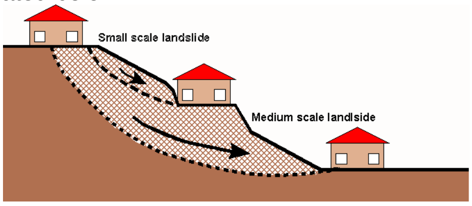

Figure 1

Translational slip failures (Figure 2) - tend to occur on moderate to very steep slopes (Table 1) where soil, or weak rock, overlies stronger strata. The sliding mass is often relatively shallow. It can move, or deform slowly (creep) over long periods of time. Extensive linear cracks and hummocks sometimes form along the contours. The sliding mass may accelerate after heavy rain.

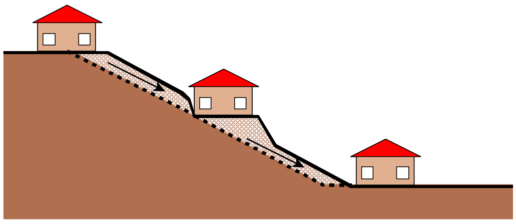

Figure 2

Wedge failures (Figure 3) - normally only occur on extreme slopes, or cliffs (Table 1), where discontinuities in the rock are inclined steeply downwards out of the face.

Rock falls (Figure 3) - tend to occur from cliffs and overhangs (Table 1).

Cliffs may remain, apparently unchanged, for hundreds of years. Collections of boulders at the foot of a cliff may indicate that rock falls are ongoing. Wedge failures and rock falls do not "creep". Familiarity with a particular local situation can instil a false sense of security since failure, when it occurs, is usually sudden and catastrophic.

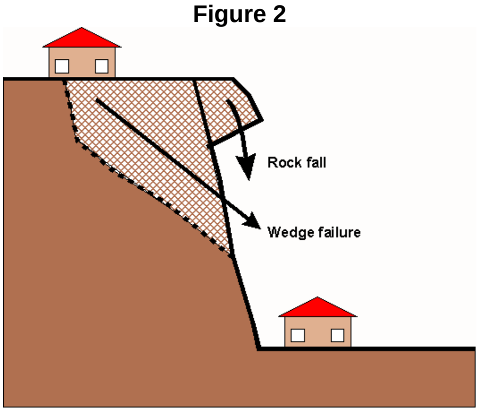

Figure 3

Debris flows and mud slides (Figure 4) - may occur in the foothills of ranges, where erosion has formed valleys which slope down to the plains below. The valley bottoms are often lined with loose eroded material (debris) which can "flow" if it becomes saturated during and after heavy rain. Debris flows are likely to occur with little warning; they travel a long way and often involve large volumes of soil. The consequences can be devastating.

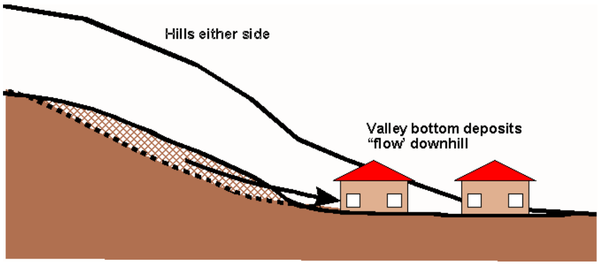

Figure 4

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR3 - Soil Slopes
- GeoGuide LR4 - Rock Slopes
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

AUSTRALIAN GEOGUIDE LR7 (LANDSLIDE RISK)

Concept of Risk

Risk is a familiar term, but what does it really mean? It can be defined as *"a measure of the probability and severity of an adverse effect to health, property, or the environment."* This definition may seem a bit complicated. In relation to landslides, geotechnical practitioners (see GeoGuide LR1) are required to assess risk in terms of the likelihood that a particular landslide will occur and the possible consequences. This is called landslide risk assessment. The consequences of a landslide are many and varied, but our concerns normally focus on loss of, or damage to, property and loss of life.

Landslide Risk Assessment

Some local councils in Australia are aware of the potential for landslides within their jurisdiction and have responded by designating specific "landslide hazard zones". Development in these areas is normally covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, then go first for information to your local council. If you have any concern that you could be dealing with a landslide hazard that your local council is not aware of you should seek advice from a geotechnical practitioner.

Landslide risk assessment must be undertaken by a geotechnical practitioner. It may involve visual inspection, geological mapping, geotechnical investigation and monitoring to identify:

- potential landslides (there may be more than one that could impact on your site);
- the likelihood that they will occur;
- the damage that could result;
- the cost of disruption and repairs; and
- the extent to which lives could be lost.

Risk assessment is a predictive exercise, but since the ground and the processes involved are complex, prediction inevitably lacks precision. If you commission a landslide risk assessment for a particular site you should expect to receive a report prepared in accordance with current professional guidelines and in a form that is acceptable to your local council, or planning authority.

Risk to Property

Table 1 indicates the terms used to describe risk to property. Each risk level depends on an assessment of how likely a landslide is to occur and its consequences in dollar terms. Likelihood is the chance of it happening in any one year, as indicated in Table 2. Consequences are related to the cost of the repairs and perhaps temporary loss of use. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

TABLE 1 – RISK TO PROPERTY

Qualitative Risk		Significance - Geotechnical engineering requirements
Very high	VH	**Unacceptable** without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low. May be too expensive and not practical. Work likely to cost more than the value of the property.
High	H	**Unacceptable** without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable level. Work would cost a substantial sum in relation to the value of the property.
Moderate	M	**May be tolerated** in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as possible.
Low	L	**Usually acceptable** to regulators. Where treatment has been needed to reduce the risk to this level, ongoing maintenance is required.
Very Low	VL	**Acceptable**. Manage by normal slope maintenance procedures.

TABLE 2 – LIKELIHOOD

Likelihood	Annual Probability
Almost Certain	1:10
Likely	1:100
Possible	1:1,000
Unlikely	1:10,000
Rare	1:100,000
Barely credible	1:1,000,000

The terms "unacceptable", "tolerable" etc. in Table 1 indicate how most people react to an assessed risk level. However, some people will always be more prepared, or better able, to tolerate a higher risk level than others. Some local councils and planning authorities stipulate a maximum tolerable risk level. This may be lower than you feel is reasonable for your block but it is, nonetheless, a pre-requisite for development. Reasons for this include the fact that a landslide on your block may pose a risk to neighbours and passers-by and that , should you sell, subsequent owners of the block may be more risk averse than you.

Risk to Life

Most of us have some difficulty grappling with the concept of risk and deciding whether, or not, we are prepared to accept it. However, without doing any sort of analysis, or commissioning a report from an "expert", we all take risks every day. One of them is the risk of being killed in an accident. This is worth thinking about, because it tells us a lot about ourselves and can help to put an assessed risk into a meaningful context. By identifying activities that we either are, or are not, prepared to engage in, we can get some indication of the maximum level of risk that we are prepared to take. This knowledge can help us to decide whether we really are able to accept a particular risk, or to tolerate a particular likelihood of loss, or damage, to our property (Table 2).

In Table 3, data from NSW for the years 1998 to 2002, and other sources, is presented. A risk of 1 in 100,000 means that, in any one year, 1 person is killed for every 100,000 people undertaking that particular activity. The NSW data assumes that the whole population undertakes the activity. That is, we are all at risk of being killed in a fire, or of choking on our food, but it is reasonable to assume that only people who go deep sea fishing run a risk of being killed while doing it.

It can be seen that the risks of dying as a result of falling, using a motor vehicle, or engaging in water-related activities (including bathing) are all greater than 1:100,000 and yet few people actively avoid situations where these risks are present. Some people are averse to flying and yet it represents a lower risk than choking to death on food. The data also indicate that, even when the risk of dying as a consequence of a particular event is very small, it could still happen to any one of us today. If this were not so, there would be no risk at all and clearly that is not the case.

In NSW, the planning authorities consider that 1:1,000,000 is the maximum tolerable risk for domestic housing built near an obvious hazard, such as a chemical factory. Although not specifically considered in the NSW guidelines there is little difference between the hazard presented by a neighbouring factory and a landslide: both have the capacity to destroy life and property and both are always present.

TABLE 3 – RISK TO LIFE

Risk (deaths per participant per year)	**Activity/Event Leading to Death** (NSW data unless noted)
1:1,000	Deep sea fishing (UK)
1:1,000 to 1:10,000	Motor cycling, horse riding , ultra-light flying (Canada)
1:23,000	Motor vehicle use
1:30,000	Fall
1:70,000	Drowning
1:180,000	Fire/burn
1:660,000	Choking on food
1:1,000,000	Scheduled airlines (Canada)
1:2,300,000	Train travel
1:32,000,000	Lightning strike

More information relevant to your particular situation may be found in other AUSTRALIAN GEOGUIDES:

- GeoGuide LR1 - Introduction
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- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
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The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

APPENDIX C

Table 11 - Transect 1 – Summary Slope Stability Results

Subsurface Model	Groundwater Level	Factor of Safety (FOS)	Failure Form (Appendix B - Figure Number)
Transect 1	Actual Lowest Groundwater Level During Monitoring Period	1.81	Lower Foreshore Slope Failure (Fig B4)
		1.24	Shallow Failure Upper Slopes (Fig B5)
		1.25	Deep Slope Failure Upper Slopes (Fig B6)
Transect 1	Actual Average Groundwater Level During Monitoring Period	1.68	Lower Foreshore Slope Failure (Fig B7)
		1.51	Deep Mid Slope Failure (Fig B8)
		1.24	Shallow Failure Upper Slopes
		1.22	Deep Slope Failure Upper Slopes (Fig B9)
Transect 1	Groundwater Level Equivalent to Actual 2011 Rainfall Event	1.23	Lower Foreshore Slope Failure (Fig B10)
		1.26	Deep Mid Slope Failure (Fig B11)
		1.24	Shallow Failure Upper Slopes
		1.09	Deep Slope Failure Upper Slopes (Fig B12)
Transect 1	Groundwater Level Equivalent to Predicted 1950 Rainfall Event	0.97	Lower Foreshore Slope Failure (Fig B13)
		1.15	Deep Mid Slope Failure (Fig B14)
		1.24	Shallow Failure Upper Slope
		1.02	Deep Slope Failure Upper Slopes (Fig B15)
MSA Transect 1	MSA Groundwater Levels Equivalent to Actual 2011 Rainfall Event	1.29	Lower Foreshore Slope Failure (Fig B16)
		1.29	Deep Slope Failure Upper Slopes (Fig B17)
		1.46	Deep Mid Slope failure (Fig B18)
Transect 1 Loose Sand at Toe of Slope	Actual Average Groundwater Level During Monitoring Period	1.49	Lower Foreshore Slope Failure (Fig B19)
		1.44	Deep Mid Slope Failure (Fig B20)
Transect 1 Loose Sand at Toe of Slope	Groundwater Level Equivalent to Actual 2011 Rainfall Event	1.07	Lower Foreshore Slope Failure (Fig B21)
		1.20	Deep Mid Slope Failure (Fig B22)
Transect 1 Loose Sand at Toe of Slope	Groundwater Level Equivalent to Predicted 1950 Rainfall Event	0.82	Lower Foreshore Slope Failure (Fig B23)
		1.10	Deep Mid Slope Failure (Fig B24)
Transect 1 Upper Bound Soil Strengths	Actual Lowest Groundwater Level During Monitoring Period	1.33	Deep Slope Failure Upper Slopes (Fig B25)
Transect 1 Upper Bound Soil Strengths	Actual Average Groundwater Level During Monitoring Period	1.30	Deep Slope Failure Upper Slopes (Fig B26)
Transect 1 Upper Bound Soil Strengths	Groundwater Level Equivalent to Actual 2011 Rainfall Event	1.17	Deep Slope Failure Upper Slopes (Fig B27)
Transect 1 Upper Bound Soil Strengths	Groundwater Level Equivalent to Predicted 1950 Rainfall Event	1.09	Deep Slope Failure Upper Slopes (Fig B28)

Table 12 - Transect 2 – Summary Slope Stability Results

Subsurface Model	Groundwater Level	Factor of Safety (FOS)	Failure Form
Transect 2	Actual Lowest Groundwater Level During Monitoring Period	1.59	Lower Foreshore Slope Failure (Fig B30)
		1.21	Shallow Failure Upper Slopes (Fig B31)
		1.62	Deep Slope Failure Upper Slopes (Fig B32)
Transect 2	Actual Average Groundwater Level During Monitoring Period	1.56	Lower Foreshore Slope Failure (Fig B33)
		1.21	Shallow Failure Upper Slopes
		1.56	Deep Slope Failure Upper Slopes (Fig B34)
Transect 2	Groundwater Level Equivalent to Actual 2011 Rainfall Event	1.05	Lower Foreshore Slope Failure (Fig B35)
		1.21	Shallow Failure Upper Slopes
		1.46	Deep Slope Failure Upper Slopes (Fig B36)
Transect 2	Groundwater Level Equivalent to Predicted 1950 Rainfall Event	1.05	Lower Foreshore Slope Failure (Fig B37
		1.21	Shallow Failure Upper Slope
		1.38	Deep Slope Failure Upper Slopes (Fig B38)

Table 13 - Transect 3 Summary Slope Stability Results

Subsurface Model	Groundwater Level	Factor of Safety (FOS)	Failure Form
Transect 3	Actual Lowest Groundwater Level During Monitoring Period	1.48	Lower Foreshore Slope Failure (Fig B40)
		1.69	Shallow Failure Upper Slopes (Fig B41)
		1.71	Deep Slope Failure Upper and Lower Slopes (Fig B42)
Transect 3	Actual Average Groundwater Level During Monitoring Period	1.07	Lower Foreshore Slope Failure (Fig B43)
		1.69	Shallow Failure Upper Slopes
		1.55	Deep Slope Failure Upper and Lower Slopes (Fig B44)
Transect 3	Groundwater Level Equivalent to Actual 2011 Rainfall Event	0.92	Lower Foreshore Slope Failure (Fig B45)
		1.69	Shallow Failure Upper Slopes
		1.39	Deep Slope Failure Upper and Lower Slopes (Fig B46)
Transect 3	Groundwater Level Equivalent to Predicted 1950 Rainfall Event	0.92	Lower Foreshore Slope Failure (Fig B47)
		1.69	Shallow Failure Upper Slope
		1.33	Deep Slope Failure Upper and Lower Slopes (Fig B48)
		0.82	Small Slope Failure Immediately Above Marine Parade (Fig B49)