REPORT

Tonkin+Taylor

Maungatapu Landslide Advice

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Executive summary

Over 2022 and 2023, a number of large landslides occurred at several locations across Maungatapu which have caused property damage and social disruption. Tauranga City Council (TCC) is interested in understanding the factors that affect slope stability around Maungatapu and are considering what mitigation methods/processes could be applied to the peninsula to reduce the landslide risk. In this respect, TCC engaged Tonkin & Taylor Ltd (T+T) to help develop a greater understanding of the landslides occurring around Maungatapu Peninsula.

This report summarises publicly available geological, geotechnical and other relevant information associated with the peninsula including: ground elevation data, two theses and several reports associated with landslides in the Tauranga area, mapped relic landslide features, historic Toka Tū Ake Earthquake Commission (EQC) insurance claim information, historic rainfall records, and the TCC stormwater management zones.

It was found that there may be a number of factors influencing landslides across the Maungatapu Peninsula. Of these, rainfall and groundwater conditions along with slope steepness and height appear to exert the greatest influence. Literature and data reviewed as part of this report suggest that significant increases in landslide frequency across the peninsula are typically associated with prolonged periods of elevated rainfall which in turn leads to elevated groundwater conditions. Furthermore, extreme rainfall events in conjunction with previously elevated groundwater conditions also appear to result in an increased landslide frequency. In addition, the concentration of claims along the western and north-eastern edge of the peninsula is an evident trend observed when reviewing EQC insurance claim locations. The north-western and north-eastern slopes of the peninsula tend to be steeper than at other locations and this likely makes them more prone to instability.

Stormwater disposal via ground soakage may also be influencing groundwater dynamics across the peninsula and in turn, influencing the occurrence of landslides. However, the relationship between stormwater disposal methods, groundwater levels and landsliding remains difficult to quantify. More information is needed to assess the influence of stormwater disposal methods on groundwater levels across the peninsula.

To further understand the factors affecting landsliding across the Maungatapu Peninsula, we consider that it will be important to develop a greater appreciation of the underlying geology and groundwater dynamics. In addition, we are unaware of any long-term groundwater level monitoring stations across the Maungatapu. Developing a greater understanding of groundwater levels and their seasonal fluctuations and responses following rainfall would be beneficial to this understanding.

1 Introduction

Tonkin & Taylor Ltd (T+T) was engaged by Tauranga City Council (TCC) to help develop a greater understanding of the landslides occurring on the Maungatapu Peninsula (also described as the "Study Area", or "the peninsula" through the document). Over the past year, a number of large landslides have occurred in several locations across the peninsula which have caused property damage and social disruption. TCC is interested in understanding the factors that drive the landslides on the peninsula and are considering what mitigation methods/processes could be applied to the peninsula to reduce the impact of the landslides.

The Study Area associated with this project is shown in Figure 1.1.

Figure 1.1: Study area (dashed line) associated with this project.

1.1 Scope of work

To develop a greater understanding into the landslides occurring in the Study Area, we proposed a staged approach to TCC that comprised three tasks as follows:

- Task 1: Undertake a high-level desktop study of the landslides occurring in the Study Area.
- Task 2: Undertake geotechnical investigations and install monitoring equipment within the Study Area.
- Task 3: Investigate landslide management options for the Study Area and provide mitigation options for TCC to consider.

This report is only associated with Task 1. Task 2 and Task 3 may be undertaken at a later date.

The following scope of work was proposed for Task 1:

1 Undertake a literature review of historic EQC claims and TCC landslide information across the Study Area.
2 Undertake a literature review of academic research on the geology underlying the Study Area and on historic landslides.
3 Undertake a review of chronological aerial photographs to visually map historic landslides in the Study Area.
4 Geo-spatially analyse available LiDAR derived DEM datasets to assess ground surface elevation changes across the Study Area.
5 Develop a geomorphic map of the Study Area based on ground elevation data and recent aerial imagery.
6 Review available rainfall records that can be related to the Study Area and correlate to landslide inventory derived from historic EQC claims.
7 Undertake a review of available geotechnical investigations on the New Zealand Geotechnical Database (NZGD) and provide a high-level geological model of the Study Area.
8 Provide recommendations for further geotechnical investigations and/or monitoring equipment across the Study Area.

1.2 Site description

The Study Area covers the Maungatapu Peninsula, north of Welcome Bay Link Road. The majority of the peninsula is occupied by residential dwellings.

The Study Area is typically characterised by an elevated terrace, a landform that is common throughout the Western Bay of Plenty region (e.g., Ōmokoroa Peninsula, Te Papa Peninsula, Matua Peninsula etc). The upper ground surface of the terrace is gently undulating (slope angles typically less than 10°) and generally lies at an elevations between 20 and 30 m above sea level. The southern end of the peninsula generally increases in elevation, reaching a maximum height of approximately 38 m above sea level (Figure 1.2). The northern, eastern and western edges of the elevated terrace are characterised by steep slopes and coastal cliffs that typically terminate at the high tide mark associated with the Tauranga Harbour. However, it should be noted that in a few areas of the peninsula (e.g., Egret Avenue and Anchorage Grove), some of the steep slopes sit above low-lying land that has been developed and is occupied by residential dwellings. The steep slopes and coastal cliffs reach maximum heights of approximately 25 m (Figure 1.3) and are typically associated with slope angles greater than 45 degrees (Figure 1.4). The aspect of the steeply sloping land across the Study Area is variable, as shown in Figure 1.5.

Tidal mud flats surround the majority of the Study Area and are often exposed at low tide. However, one of the main channels associated with the harbour is positioned directly alongside the majority of the north western edge of the peninsula and constantly flows during low tide cycles (there are limited tidal flats between the peninsula and channel in this area).

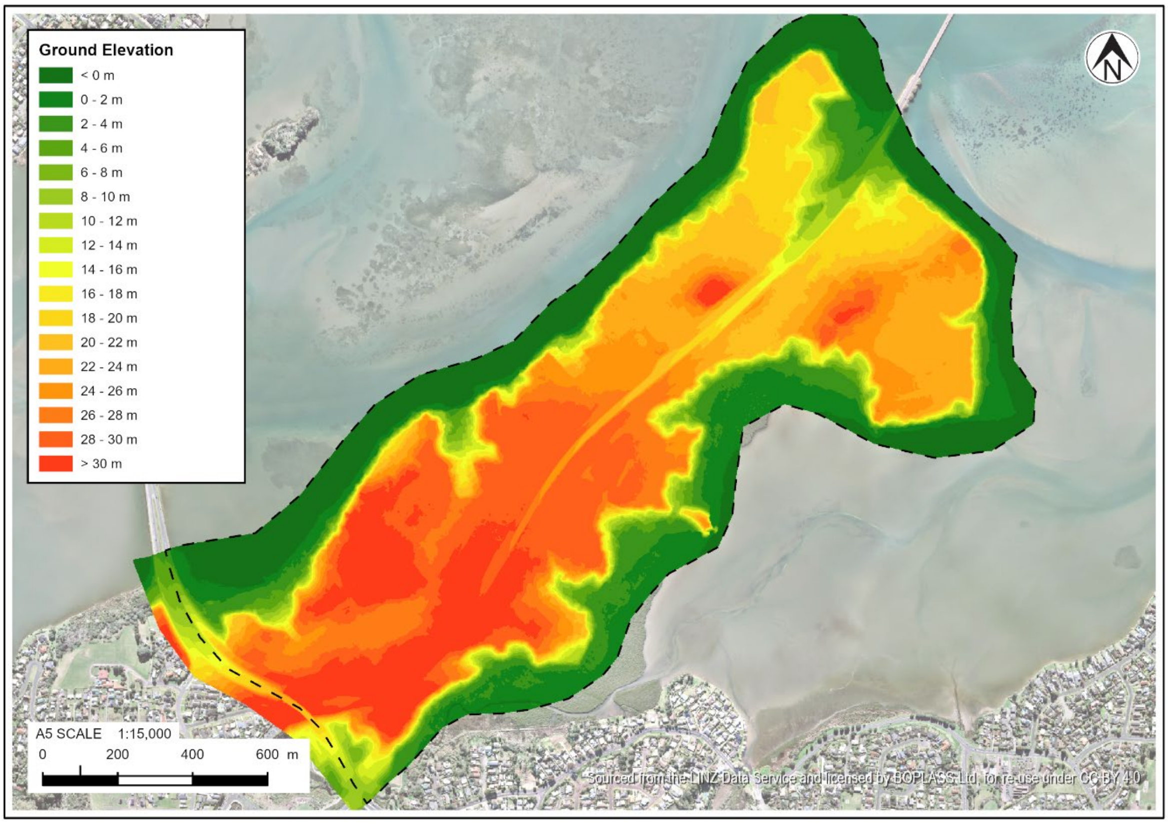

Figure 1.2: Ground elevation levels across the Study Area.

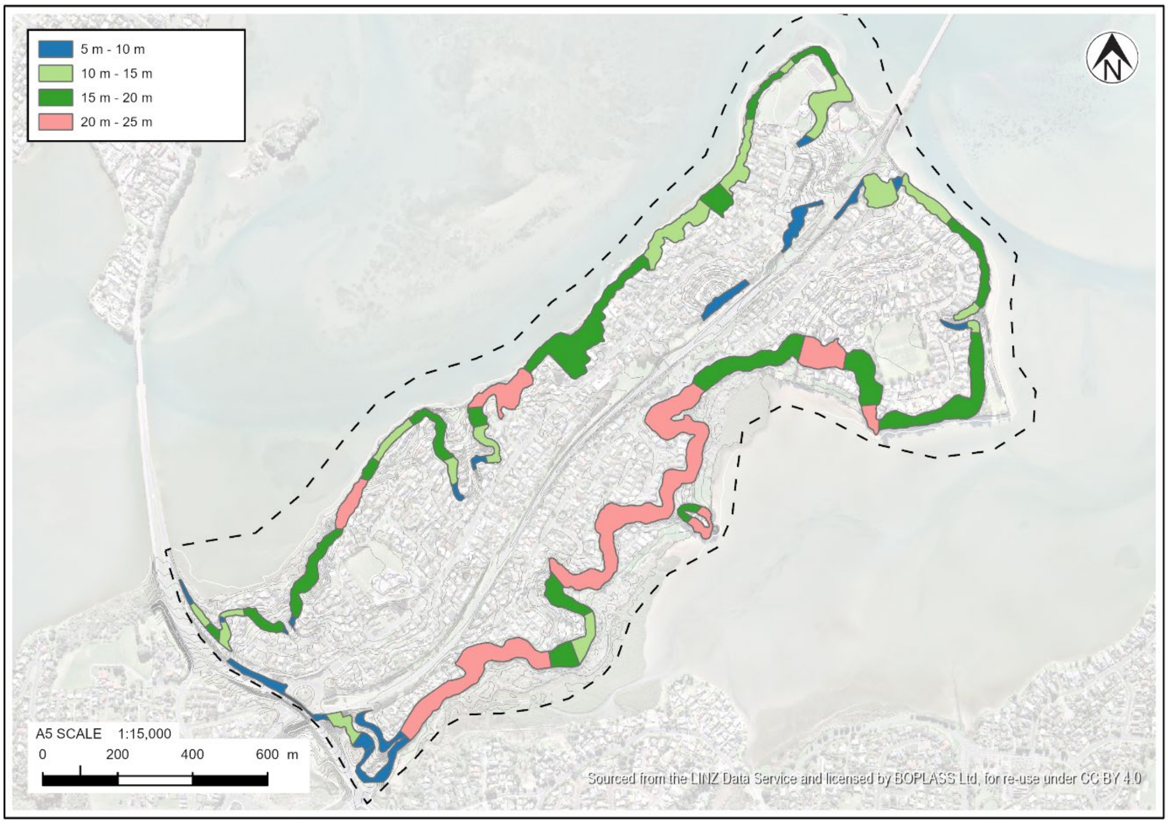

Figure 1.3: Generalised slope heights associated with the Study Area.

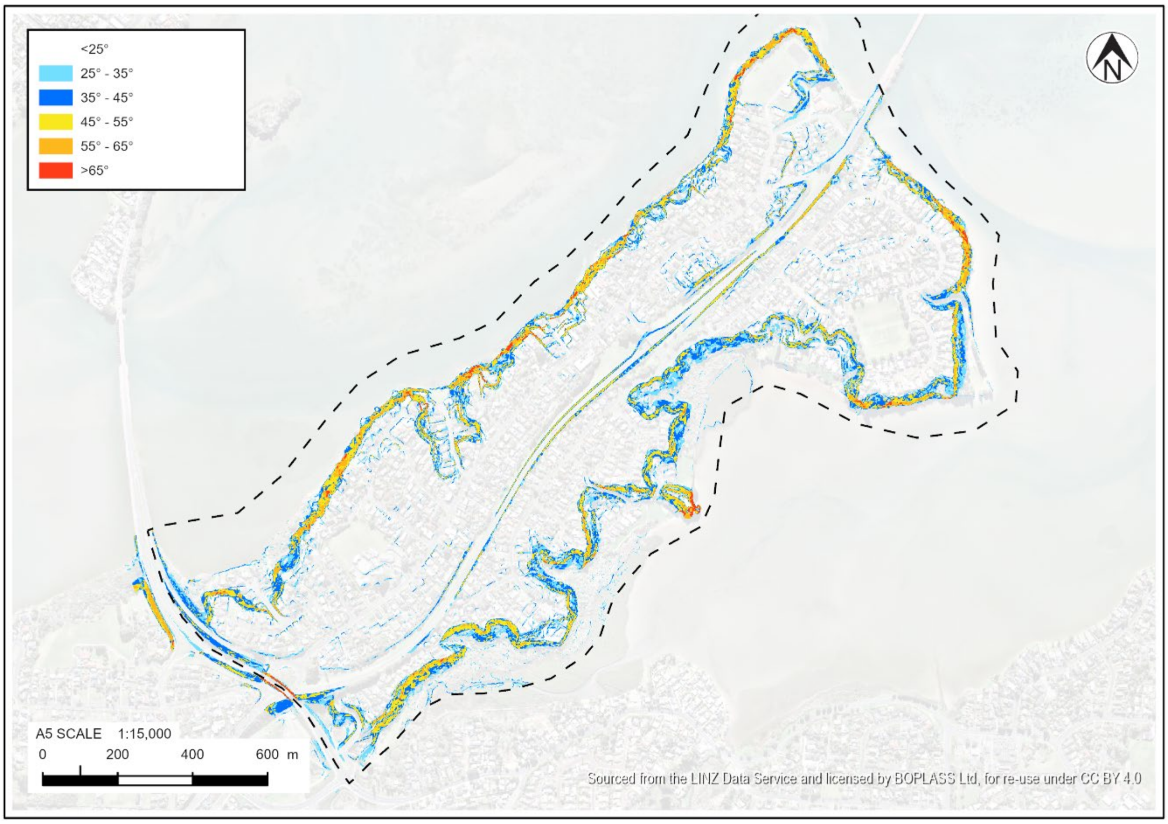

Figure 1.4: Sloping land and slope angles across the Study Area.

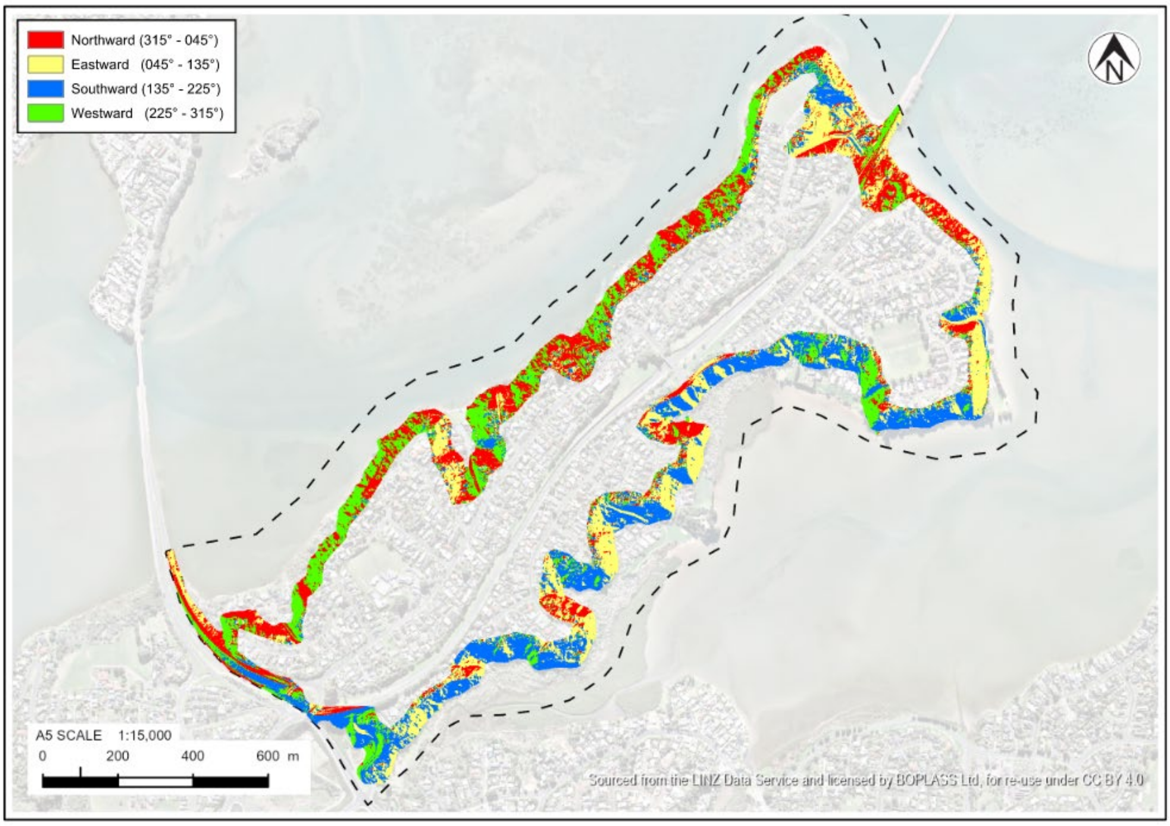

Figure 1.5: Aspect of steep slopes across Study Area.

2 Geological and geomorphic setting

2.1 Geological setting

The published geology of the Study Area (Briggs, et al., 1996) indicates that it is underlain by Matua Subgroup sediments (Early to Mid-Pleistocene-age) which are described as terrestrial and estuarine sedimentary deposits. These sediments comprise a wide variety of lithologies including fluvial pumiceous and rhyolitic silts, sands and gravels, lacustrine (diatomaceous) and estuarine muds, lignites and peats, interbedded with airfall tephras and thin distal ignimbrites. The depositional environments associated with these lithologies are known to be highly dynamic and spatially variable. As a result, the sediments comprising the Matua Subgroup do not often form continuous sedimentary layers, instead these sediments often vary both laterally and vertically (Briggs, et al., 1996).

A lithology of note within the Matua Subgroup is the Pahoia Tephra sequence. The Pahoia Tephra sequence, currently an active area of research for academia, is a series of primary and reworked rhyolitic volcaniclastic material that is known to be geotechnically problematic. The Pahoia Tephra sequence along with other layers is known to be highly sensitive and has been an influential factor in several large landslides across the Tauranga region. Similarly to the other Matua Subgroup lithologies, the Pahoia Tephra sequence is highly variable in both thickness and lateral extent (Moon, et al., 2013).

A series of unmapped volcanic ash deposits overly the Matua Subgroup sediments. These ash deposits have variable thicknesses and are known as the Hamilton Ash, Rotoehu Ash and post-Rotoehu Ash tephras (often referred to as “Younger Ashes”).

2.2 Geomorphic setting

The Study Area is characterised by an alluvial terrace that is mostly surrounded by the Tauranga Harbour. The outer edges of the terrace generally comprise steep slopes and coastal cliffs. The transition zone between the alluvial terrace and the steep edges is typically characterised by a sharp break in slope. In numerous areas across the Study Area, this break in slope is disrupted by relic landslide headscarps. These relic landslides are often associated with large, scalloped concave landforms that are frequently observed across the Maungatapu Peninsula. The top of slope and base of slope features within the Study Area is generalised in Figure 2.1.

2.3 Geotechnical investigations available within Study Area

Figure 2.2 shows the existing, publicly available geotechnical investigation data within the Study Area. As of 31 March 2023, there are 84 publicly available geotechnical investigation data points across the Study Area available on the New Zealand Geotechnical Database (NZGD). Table 2.1 summarises these geotechnical investigation data points.

Table 2.1: Geotechnical investigation data points available on NZGD (as of 31 March 2023)

Geotechnical investigation type	Number of investigation points within Study Area	Investigation depth range (m)
1 Machine drilled borehole	25	10 – 60
2 Cone Penetrometer Test (CPT)	31	7 – 33
3 Hand Auger borehole	10	3 – 5
4 Hand Auger borehole and Scala Penetrometer tests	6	1 – 3
5 Test pits	12	1 – 4

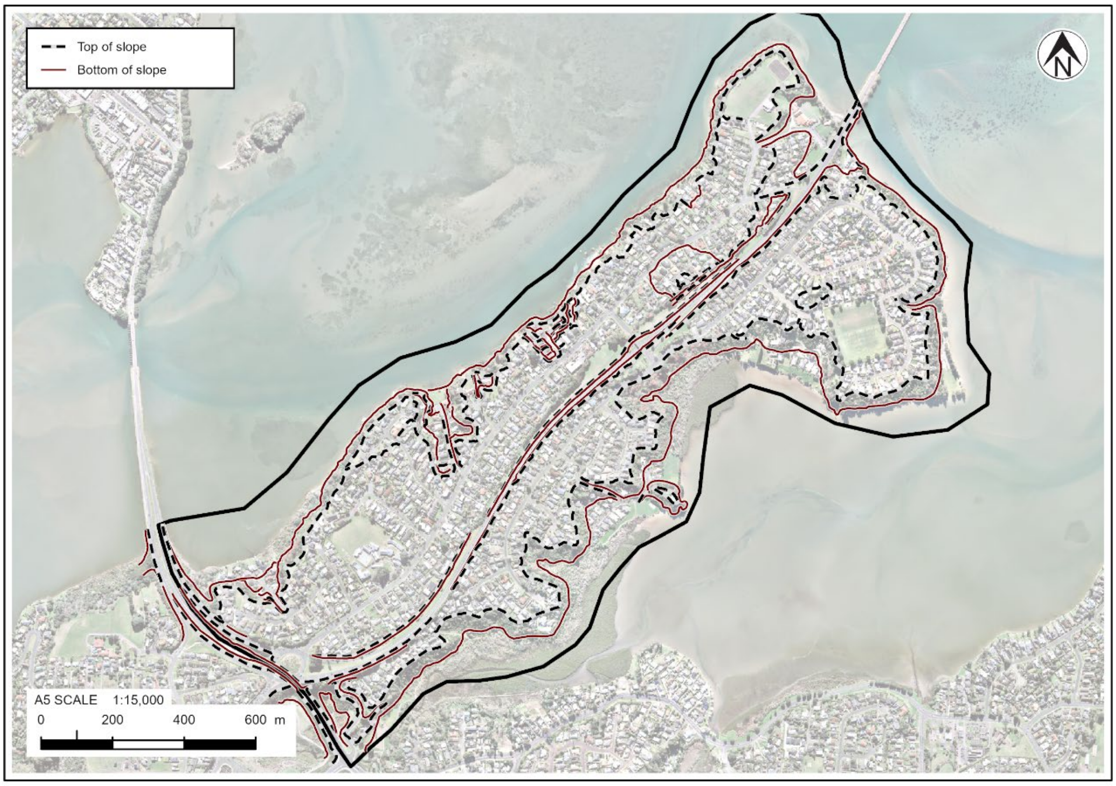

Figure 2.1: Generalised map showing top and bottom of slope within the Study Area.

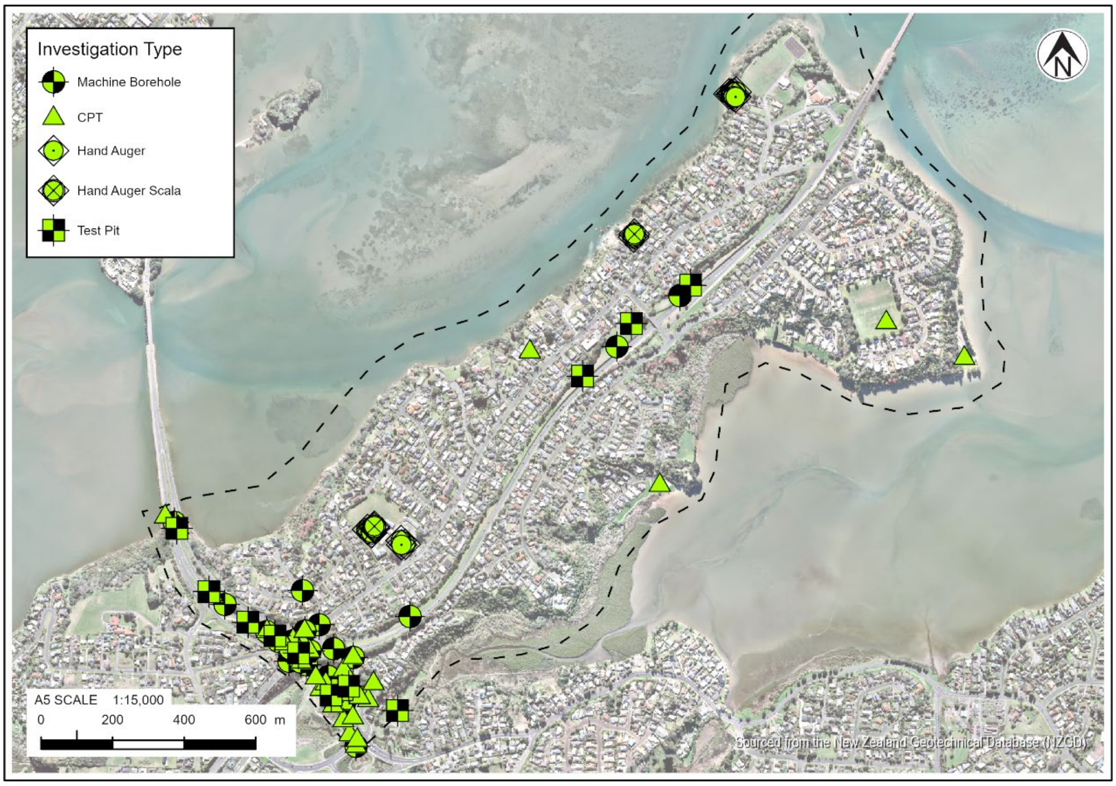

Figure 2.2: Publically available geotechnical investigations on the New Zealand Geotechnical Database (as of 31 March 2023).

The majority of the geotechnical investigations are located within the southern extent of the Study Area and are associated with Harini Link/Welcome Bay Link Road (Waka Kotahi New Zealand Transport Agency Project).

Several of the publicly available machine drilled boreholes and test pits were reviewed for this report to provide a general understanding of the ground conditions underlying the Study Area. A model has been developed to describe the sediments comprising the Study Area, from the elevated terrace surface down to the harbour margin (sea level). The generalised ground model based on the publicly available investigation datapoints is provided in Table 2.2. This schematic ground model is also illustrated in Figure 2.3.

Table 2.2: Generalised ground model for Study Area

Geological unit		Description
Younger Ash		Where earthworks or large landslides haven't occurred in the Study Area (on the elevated terrace surface), the near surface soils are typically associated with volcanic airfall deposits that commonly form fine grained soils (SILT and sandy SILT). These soils are generally brown to brownish orange and several metres thick.
Rotoehu Ash		This ash unit is generally coarser grained than the Younger Ashes and is usually described as SAND or silty SAND. This unit is typically whitish-grey and directly overlies the Hamilton Ash. The thickness of the Rotoehu Ash layer varies across the Tauranga region with 0.3 to 2.4 m documented.
Hamilton Ash		The Hamilton Ash unit represents a series of older volcanic airfall deposits that generally underlie the Rotoehu Ash. This unit is characterised by fine grained soils (SILT) often with a higher clay content compared to the Younger Ash. The Hamilton Ash is easily identified by a paleosol which has formed at its upper surface (this unit is often described as the "chocolate brown" layer). The thickness of this unit is variable but generally less than 2.5 m.
Matua Subgroup	Upper Matua Subgroup	The Matua Subgroup forms the majority of the Study Area and can be observed within the steep slopes and coastal cliffs surrounding the Study Area. For the purposes of this report Matua Subgroup has been differentiated into 'Upper' and 'Lower'. The Upper Matua Subgroup sediments that underly the Hamilton Ash are characterised by variable fine grained and coarse-grained sediments. The sedimentary layers within Upper Matua Subgroup comprise alternating layers of sand and silt with varying clay contents. Upper Matua Subgroup also includes the Pahoia Tephra sequence described in Section 2.1. Upper Matua Subgroup generally makes greater than 50% of the slope profiles comprising the steep land and coastal cliffs.
	Lower Matua Subgroup	In the Study Area, Lower Matua Subgroup is predominantly characterised by granular sediments. Based on the publicly available geotechnical investigation data, the lower sections of the steeply sloping land and coastal cliffs across the Study Area comprise thick, coarse-grained sediments that extend below high tide mark. The main difference between this unit and Upper Matua Subgroup is the absence of extensive fine-grained sediments and the Pahoia Tephras.

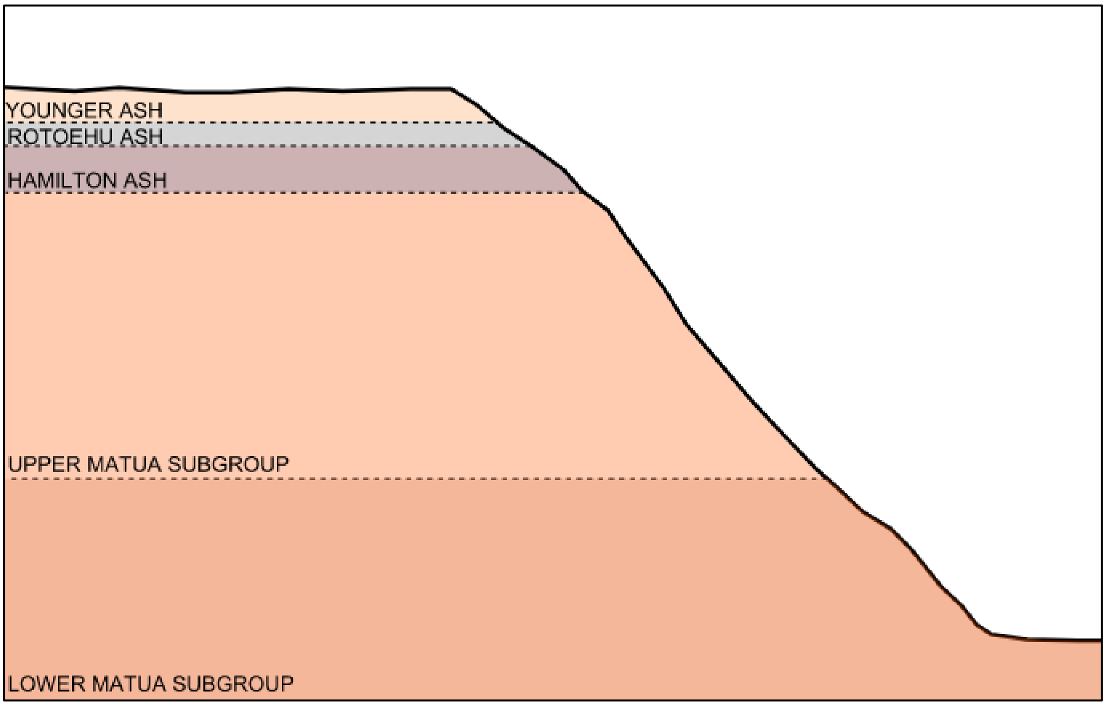

Figure 2.3: Schematic ground model for sloping land associated within the Study Area.

3 Literature review

3.1 General

Two theses and several reports were reviewed as part of this project to provide a better understanding of the geology and landslides occurring across the Maungatapu Peninsula. The following documents were reviewed:

- A geotechnical characterisation of volcanic soils in relation to coastal landsliding on the Maungatapu Peninsula (Oliver, 1997).
- The nature and causes of coastal landsliding on the Maungatapu Peninsula (Bird, 1981).
- Tauranga Storm event of 18 May 2005: Landslip issues (Hegan and Wesley, 2005)
- Study into the decommissioning of soak-holes in the Otumoetai Area (T+T, 2006)
- Maungatapu Road Slips: The present status of the slips below 310, 312A, 320, 326 and 330 (Ice Geo & Civil, 2023).
- Egret Avenue Landslides – Conceptual Remedial Options (T+T, 2023).
- Inspection of observed Slope Instability – 190 Te Hono Street (Aurecon, 2023).
- Inspection of observed Slope Instability – 3 Te Hono Street (Aurecon, 2023).
- Inspection of observed Slope Instability – 15 & 16 Mersea Place (Aurecon, 2023).

Relevant information from each of these documents is summarised in the following subsections.

3.2 A geotechnical characterisation of volcanic soils in relation to coastal landsliding on the Maungatapu Peninsula

A Master of Science thesis completed by Robert Oliver in 1997 titled "A geotechnical characterisation of volcanic soils in relation to coastal landsliding on the Maungatapu Peninsula, Tauranga, New Zealand" provides valuable information regarding the land instability across the Study Area. This thesis was reviewed as part of this project.

The Oliver thesis was funded by the Tauranga District Council following three landslides that occurred on Te Hono Street in May 1995 after a prolonged period of heavy rain. Rainfall records from the NIWA weather station at the Tauranga Aero AWS (Tauranga Airport, 5.5 km north of the site) were analysed as part of the thesis and were correlated with the landslides that occurred on Te Hono Street in 1995. Oliver stated that the average yearly rainfall between 1898 to 1978 was 1,342 mm and during this time period, the maximum recorded annual rainfall was 1,897 mm in 1916. The annual rainfall for 1995 (year of the Te Hono landslides) was 1,620 mm which was approximately 20% above the average annual rainfall.

During 1995, there were three separate periods of higher than average rainfall (March to April, July and November). Of note was the significant rainfall volume in April, which recorded a total of 312 mm (approximately 260% above average). Oliver looked into the daily rainfall magnitudes for March 1995, April 1995 and May 1995 and concluded that there were no daily rainfall events that exceeded the 1 in 2 year recurrence interval rainfall events (equivalent to a daily rainfall total of 101 mm). Oliver then concluded that, the landslides that occurred on Te Hono Street in May 1995 were not driven by singular extreme rainfall events, rather that they occurred following several months of above average rainfall. Oliver also observed this same trend in rainfall data from 1979 which was associated with a large number of landslides that were recorded across the Maungatapu Peninsula. One of the conclusions from the Oliver thesis was that "*…it takes approximately two months of double the average rainfall to produce adverse pore water conditions at the cliff edges where a rainfall event can trigger a piping-triggered block side…*".

Oliver's thesis also discussed the relationship between elevated porewater pressures and a series of aquifers and aquitards underlying the Maungatapu Peninsula. Geotechnical field investigations undertaken as part of the thesis suggested that there is a continuous hydraulic connection of the aquifer systems from the northern end of the peninsula back towards the southern end. The aquitards described by Oliver are believed to be one of the more influential factors causing instability across the Study Area, with groundwater infiltrating down to these layers and then flowing towards the free faces (steep slopes and coastal cliffs) around the outer edge of the peninsula. When the peninsula experiences significant rainfall events or prolonged periods of wet weather, these aquitards cause excessive porewater pressures to build within the subsoil profile, resulting in further instability on the outer edges. Oliver also suggested that this phenomenon is exacerbated by the disposal of stormwater via soakage across the Study Area.

Oliver described the Study Area as a "progressively eroding headland" that has experienced an extensive landsliding history. Initially, during the Late Pleistocene (126,000 – 781,000 years ago) when sea-levels were significantly lower than present, evidence suggests that the Tauranga area was being incised by large, braided river systems. It is thought that these river systems could have produced the larger scale landslides seen across the Maungatapu Peninsula (such as the relic headscarps at Fantail Drive and Egret Avenue) due to toe erosion by river channels. As sea level increased during the Holocene period (the last 12,000 years), the braided rivers were submerged and the frequency of the large-scale landslides decreased. Smaller scale landslides around relic headscarps and coastal cliffs then became more common within the Study Area. Urbanisation of the peninsula then began in the late 1960s which led to a greater frequency of recorded coastal landslides. Oliver suggests that most of the failures across the peninsula have become more prominent as vegetation density and size has increased. This theory is based on the increased root mass associated with the vegetation impeding drainage from the slopes across the peninsula and in turn increasing porewater pressures within the sediments (increased porewater pressures increase driving forces for landslides to occur). It is also likely that, before urbanisation, Tangata Whenua and/or farmers did not report landslides that were occurring across the peninsula.

Oliver used the terminology of Cruden and Varnes (1996) to describe the types of landslides and failure mechanisms across the Maungatapu Peninsula. From field investigations undertaken during the thesis, four major landslide failure types were delineated: larger scale block failures, piping-triggered block failures, wave erosion triggered block failures, and colluvium/topsoil failures. These failures are described in Table 3.1.

Table 3.1: Summary of landslide failure mechanisms across Maungatapu Peninsula (Oliver, 1997)

Failure type	Description
Larger scale block failure	Large landslides identified from existing headscarp geomorphology (Fantail Drive and Egret Avenue). Possibly driven by historic braided river systems during lower stand sea-levels. Geomorphic features suggest that these landslides were retrogressive in nature and often increase in size due to downcutting of streams draining off the peninsula surface.
Piping-triggered block failure	Erosional structures (such as exfoliation defects, fractures, bioturbation and buried stream channels) within the soil structure underlying the peninsula allow rainfall to permeate through various soil units. The influx of rainwater into the soil profile increases porewater pressures in confined layers due to variable permeability. Increasing porewater pressures within sensitive soil layers can result in piping-type failure that can quickly expand laterally, removing support from the soil mass. Loss of support due to piping erosion can result in block sliding downwards then outwards along circular paths.

Failure type	Description
Wave erosion triggered block failure	An uncommon failure on the peninsula, typically associated with the north eastern edge of the peninsula where wave energy is the greatest. This failure type often starts as a small colluvium/topsoil failure at the base of a slope/cliff. Vegetation root clumps cause cavities to form as wave erosion removes toe support from slope/cliff. Cavities form as a result of erosion causing overhanging soil to fail. In most cases, cavities can result in colluvium/topsoil or shallow block failures occurring.
Colluvium/topsoil failure	The most common failure type on the peninsula that can involve all or part of the slope/cliff face. Involves shallow failures incorporating topsoil and shallow soil profile, most often mobilised by root mass associated with vegetation. Failures can be driven by toe erosion or overland stormwater flow from the slope above.

Schematic representations of these failure types sourced from the Oliver thesis are provided in Appendix A of this report.

Oliver's theory on successive months of above average rainfall influencing landslides on the Maungatapu Peninsula was also suggested in a report produced by T+T in 1980. This T+T report, titled "Omokoroa Point Land Stability Investigation", also provided evidence to suggest that at least two months of above average rainfall caused an increase in landsliding on the Omokoroa Peninsula (the Omokoroa Peninsula comprises the same geological units as the Study Area).

3.3 The nature and causes of coastal landsliding on the Maungatapu Peninsula

An earlier Master of Science thesis completed by Bird in 1981 titled "The nature and causes of coastal landsliding on the Maungatapu Peninsula" also provided findings that aligned with the findings of Oliver's thesis (1997). The two following statements have been sourced from the Bird (1981) thesis:

- "*Stability analyses showed that individual failures are triggered largely by the occurrence of high pore water pressures in the lensoidal silt sands/sandy muds above the clay maker bed*".
- "*In summary, the pore water pressure rises appear to be generate after long wet periods, which culminate in short, intense rainfalls*".

3.4 Tauranga Storm event of 18 May 2005: Landslip issues

Hegan and Wesley (2005) published a report on landslides that occurred in the Tauranga area following an intense storm in May 2005. The following text has been sourced from the report that supports the theories raised by previous academics/engineers:

"*The prime cause of the slips was (rather obviously) the extreme rainfall event of 18th May. Our understanding of this event is that it was approximately a 100 year event, which is a very severe event. We have been informed that there was also a period of heavy rain early in May, which was probably a significant contributing factor. Recent preceding rain would tend to saturate the ground and raise water levels, and thus increase the likelihood of slips during the storm that followed on 18th May. Many verbal reports of local residents who observed the storm from their properties speak of large "rivers" and "waterfalls" on their properties, which appear to confirm the very extreme nature of the rainfall at the time*".

3.5 Study into the decommissioning of soak-holes in the Ōtūmoetai Area

Another report of note that was commissioned by TCC in 2006 that is also relevant to this project/Study Area is the T+T report titled "Study into the Decommissioning of Soak-holes in the Ōtūmoetai Area". T+T was tasked with studying the effects of stormwater disposal via soak-holes on the stability of slopes in Bellevue, Brookfield, Judea and Ōtūmoetai following a storm event in May 2005. It is important to note that the geological setting of these suburbs in Tauranga is very similar to the Maungatapu Peninsula.

The T+T soak-hole decommissioning report found that the major factor on the stability of slopes in the Ōtūmoetai was their height and gradient. The report also noted that the near surface geology capping the Ōtūmoetai peninsula generally followed the ground surface topography and that any water supplied into the ground would likely flow sub-parallel to surface water flows. T+T found that slopes greater than 5 m high with gradients greater than 25° were generally vulnerable to instability. These vulnerable slopes were further differentiated into major (greater than or equal to 15 m) and minor slopes (less than 15 m).

As part of the project, T+T mapped soil exposures in landslide headscarps related to the May 2005 event, drilled geotechnical boreholes to examine the variability of the shallow geology, analysed the geomorphology of the subject area, determined catchment boundaries for vulnerable slopes and investigated the storage capacity of the Rotoehu Ash later in relation to soak-hole discharge during major storm events. One of the main conclusions from the report issued by T+T was that the primary contributor to the porewater pressures in the areas of landsliding in Ōtūmoetai was overland stormwater flow. Soak-holes were not considered the primary contributor, however, they still had a detrimental effect on slope stability. As a result, the report outlined zones in Ōtūmoetai where decommissioning of soak-holes was recommended (including areas where groundwater was likely to flow towards vulnerable slopes).

3.6 Numerous recent landslide reports associated with the Study Area

As mentioned in Section 1, several large landslides have occurred within the Study Area over the past year. Reports have been commissioned by TCC to address some of the larger landslides that have occurred, with the intention of providing information on building safety and some guidance on risk mitigation. Table 3.2 summarises the key points from these recent landslide reports.

Table 3.2: Summary of recent landslide reports associated with the Study Area

Report Title	Company	Date of landslide event(s)	Summary
Maungatapu Road Slips: The present status of the slips below 310, 312A, 320, 326 and 330.	Ice Geo & Civil	320 and 326: 29/07/2022 326 and 330: 07/08/2022 312A: 02/2023 310: 11/2021, 08/2022 and 02/2023	First landslide (Landslide 1) occurred on 29 July 2022 affecting 320 Maungatapu Road. Landslide was 10 m wide and came within 6 m of dwelling located on the site. Landslide extended into neighbouring property (326). By 7 August 2022, the landslide at 320 regressed closer to the dwelling and undermined recently constructed deck. Landslide extended further into 326. During this time, another landslide (Landslide 2) occurred between 326 and 330. Landslide 1 and 2 have continued to move in a sporadic manor with both landslides widening and headscarps regressing. A third landslide occurred at 310. Started as a small failure in November 2021. Landslide increased in size dramatically in August 2022. Landslide was approximately 6 m from the top of the slope at this time and was described as having a steady water

Report Title	Company	Date of landslide event(s)	Summary
			flow from the landslide scarp. A large hole with “milky” water discharge was observed in August 2022. Hole extended in size resulting in soil above collapsing (cyclic process). Author of report considered that supply of groundwater to the landslide was controlling enlargement and collapse cycle. Owners of neighbouring property (304) noted “*Two springs in the slope below their property that flowed clear water continuously, stopped flowing after the August 2022 failures below 302 and 310*”, author of report suggests that groundwater flow paths have changed since the August landslide. A fourth landslide (Landslide 4) occurred at 312A in February 2023. It comprises a very active 10 m high slip face, headscarp is approximately 9.3 m from the dwelling. Arcuate failure observed in lower portion of landslide, feature appeared to be growing in size and could be related to subsurface flow. Cause of landslides considered to be high rainfall. Report relates back to Oliver thesis (1997) and the theory of two successive months of above average rainfall driving the landslides.
Egret Avenue Landslides – Conceptual Remedial Options	Tonkin + Taylor	28/01/2023	Two landslides occurred above Egret Avenue affecting 8 properties (3 properties above the landslide and 5 below): • 9 Egret Avenue. • 11 Egret Avenue. • 15 Egret Avenue. • 16 Egret Avenue. • 18 Egret Avenue. • 19 Te Mutu Crescent • 21 Te Mutu Crescent • 23A Te Mutu Crescent Landslides occurred on night of 28 January. Both landslides were suggested to be “piping triggered block failure” in accordance with the categorisation developed by Oliver (1997). Large debris flow generated from Landslide 1. There is an erosional cavity associated with Landslide 1 that extends back into the headscarp. Turbid groundwater observed flowing from landslide.
Inspection of observed Slope Instability – 190 Te Hono Street	Aurecon	28/01/2023 – 30/01/2023	Landslide occurred on 15 m high slope with the headscarp being approximately 10 – 12 m from dwelling on site. Headscarp was described as near vertical and approximately 6 m high. Ponded water and uncontrolled stormwater runoff from the dwelling on site observed near headscarp.

Report Title	Company	Date of landslide event(s)	Summary
			Stormwater was flowing down and adjacent to affected slope.
Inspection of observed Slope Instability – 3 Te Hono Street	Aurecon	28/01/2023 – 30/01/2023	Landslide occurred approximately 7 m away from deck associated with dwelling on property. Tension cracks were observed between landslide headscarp and dwelling. No dimensions were given for the landslide size.
Inspection of observed Slope Instability – 15 & 16 Mersea Place	Aurecon	28/01/2023 – 30/01/2023	Majority of landslide positioned on 15 Mersea. 16 Mersea located immediately adjacent to landslide. Headscarp was approximately 1 – 2 m from the deck associated with dwelling. No dimensions were given of landslide size. Water seepage and small erosional tomos were observed 2 – 3 m below headscarp. Dwelling at 15 Mersea Place approximately 17 m away from headscarp. Deck associated with dwelling at 16 Mersea directly above landslide. No evidence was observed to suggest evacuating residents.
Inspection of observed Slope Instability – 16 Mersea Place	Aurecon	24/02/2023	This report was issued following continued landslide movement and signs of wider instability at the subject site. Additional landslides had occurred on the slope below the dwelling on the property and some property damage was observed. It was concluded that there was active instability at the subject property and that "*given the sensitive nature of the soils and their tendency to fail with no warning, the risk to life is not considered acceptable for occupancy within the property*." The report also recommended that a pool positioned adjacent to the house be drained immediately to reduce the load on the slope and eliminate the risk of pool water leakage affecting the slope stability.

4 Mapped relic landslide features within the Study Area

The Tauranga City Council GIS MAPI platform provides a publicly available relic landslide feature dataset that extends across the Tauranga City Council area. These relic landslides were mapped by Houghton and Hegan in 1979, and Bell, Richards and Thomson in 2001. Figure 4.1 shows the mapped relic landslides within the Study Area.

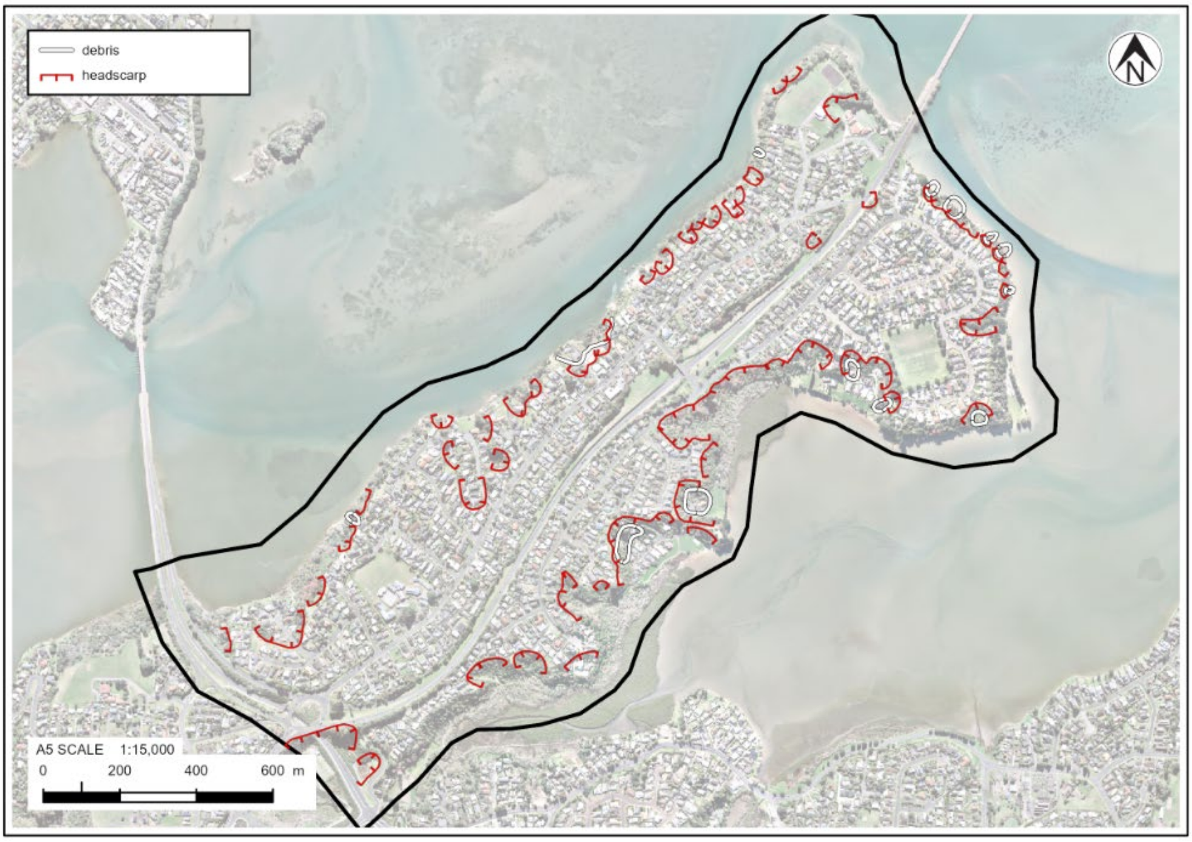

Figure 4.1: Relic landslides mapped within the Study Area (sourced from TCC MAPI platform).

5 Toka Tū Ake Earthquake Commision insurance claims within the Study Area

In New Zealand, if a landslide damages private property and the private property is insured, the land damage may be covered by Toka Tū Ake Earthquake Commission (EQC). EQC has provided T+T with a record of all EQC insurance claims that have occurred within the Study Area between April 2000 and September 2022. During this 22-year period there have been 190 no. EQC claims for landslides within the Study Area. There have been no documented accounts of earthquake-induced landslides occurring within the Tauranga area over the past 23 years so we assume that these EQC claims are associated with rainfall-induced instability. A colour coded density map of the 190 no. EQC claims within the Study Area is provided in Figure 5.1.

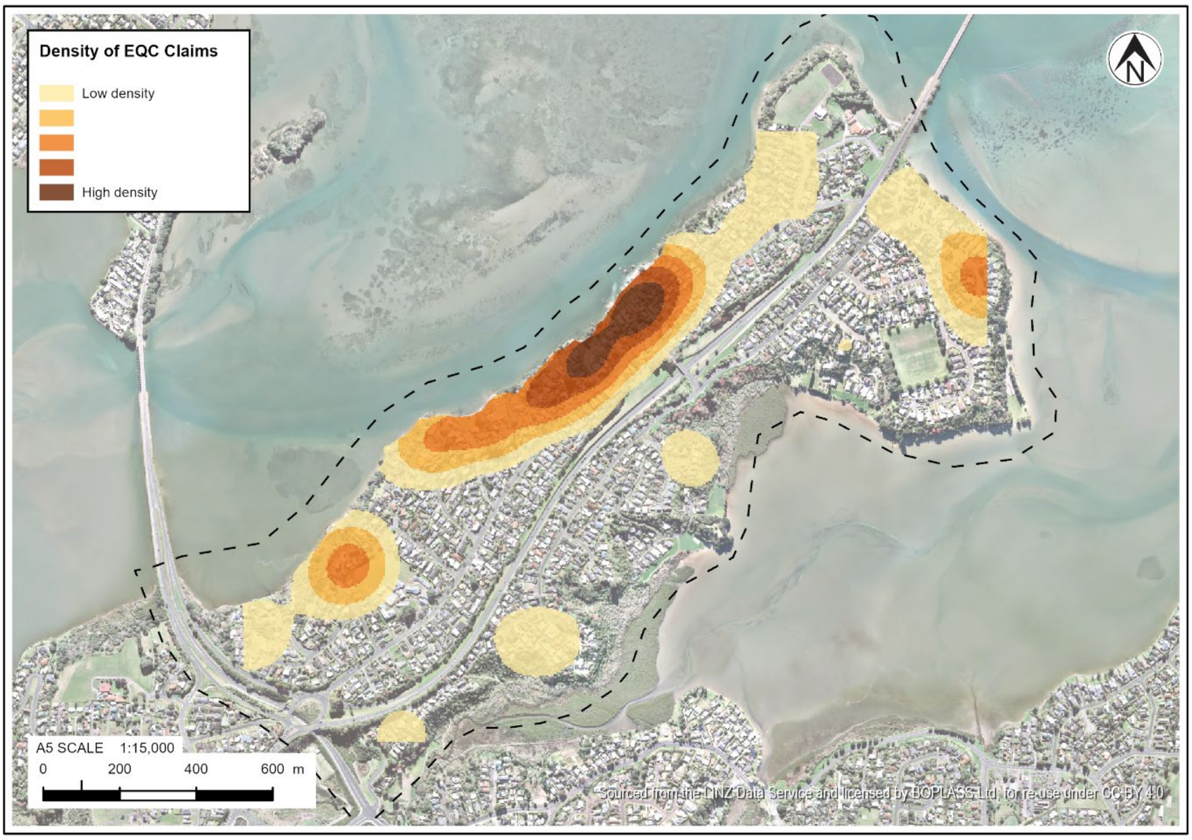

Figure 5.1: Spatial density of EQC claims within Study Area (note that areas that are not coloured represent no claims).

It is likely that there were more landslides within the Study Area over the past 23 years, but they would not have been recorded if either a claim wasn't made, or if they affected areas that were not covered by EQC.

Table 5.1: Frequency of EQC claims since 01/01/2000

Year	Number of EQC claims
2000	11
2001	3
2002	0
2003	0
2004	21
2005	65
2006	13
2007	5
2008	4
2009	1
2010	9
2011	14
2012	1
2013	4
2014	2
2015	0
2016	0
2017	20
2018	4
2019	2
2020	4
2021	1
2022[1]	6
2023[2]	14

[1]Data only available up until September 2022.

[2]Data from 2023 only related to claims T+T has worked on between January and March 2023 (these claims are not included in the density Figure 5.1).

Table 5.1 shows that the number of claims across the peninsula in 2005 is a significant outlier to the dataset. In 2005, there were 65 EQC claims within the Study Area. However, 51 of these claims are associated with the extreme weather event that caused significant flooding and landslides across the western Bay of Plenty Region (including the Matata Debris flows) on 18 May 2005.

6 Historic rainfall

Two rainfall datasets have been interpreted and related to the Study Area to identify significant rainfall events. One of the datasets is associated with a NIWA weather station located at the Tauranga Airport (Tauranga Aero Aws) and the other is a Tauranga City Council owned weather station at Ila Place, Hairini. Monthly rainfall data was retrieved from the Tauranga Airport station for the past 32 years (Table 6.1) and from the Ila Place station for the past 15 years (Table 6.2).

Table 6.1: Monthly rainfall totals since June 1990 (Tauranga Aero Aws Station)

Year	Rainfall (mm)												
	JAN *70.8[1]*	FEB *82.6[1]*	MAR *95.1[1]*	APR *128.5[1]*	MAY *116.6[1]*	JUN *126.1[1]*	JUL *132.3[1]*	AUG *110.4[1]*	SEP *88.7[1]*	OCT *84.7[1]*	NOV *68.1[1]*	DEC *101.9[1]*	Total
1990	-	-	-	-	-	145.4	158	178.8	59.6	122	92.7	22.2	> 778.7
1991	63	95.6	58.4	122	43.6	105.2	102	129	187.2	75.8	55	42	1078.8
1992	167.4	68.4	47.2	52.4	108.2	104	124.6	128	97	139.6	43.8	189.4	1270
1993	13.8	71.8	77	65.8	50.2	125.2	32.6	85.4	38.2	21.7	84.4	63	729.1
1994	53.8	138.8	48.2	128.6	45.6	95.4	170	112.2	125	135.2	19.8	15.6	1088.2
1995	52.8	70.6	157.6	296	141.6	135	183.8	116.2	57.4	95.2	204.2	111.8	1622.2
1996	36.8	48.4	122	183.8	92	125.8	196.2	169	128.8	44.2	38.4	262.6	1448
1997	35.8	74.2	138.2	49	-	210	41.4	57	163.6	81.8	23.6	35.8	> 910.4
1998	46.8	70.6	114.2	49.4	101	111.4	314.8	93	54.6	85.6	86.6	131	1259
1999	119.4	11.4	72.4	103.4	32.2	99	136.8	88.8	63.6	46.6	160.2	68.8	1002.6
2000	69.2	11.6	68.6	311.2	87	79.2	67.9	190.4	75.6	64	85.2	40.4	1150.3
2001	36.4	267.8	60	-	194.8	39.4	38.4	95.4	91.2	102.4	100.2	208	> 1234
2002	72.2	30.2	35.4	105	55.4	109.8	107.2	46.8	64.6	41	33.8	45.6	747
2003	98.6	100.8	132.4	105.6	80.8	104.8	52.6	74.6	-	108.8	48	72.6	> 979.6
2004	35.4	237.2	15	229.2	192.4	114.4	178	65	81.7	93.8	51.8	136.3	1430.2
2005	23.2	55.6	103.2	14	633.8	89.6	161.6	76	73	192.6	70	188.6	1681.2
2006	98.6	66	109.4	203.4	77.4	51.4	80	125.9	50.4	77.2	60.2	49.6	1049.5
2007	105.8	100	191	86	26.6	101.2	231.1	83.2	51.9	75.6	38.8	61.6	1152.8
2008	40.6	69.4	94.8	146.4	116	147.6	224	145.2	54.8	72.4	39	85.4	1235.6
2009	40.6	190.2	130.3	57.4	71.4	171.2	145.4	96.6	93.2	152.4	11.8	72.2	1232.7
2010	178.2	10	16.8	26.6	254.2	201.5	51.8	274.4	139.5	23.4	35.8	113.2	1325.4
2011	347.2	9.2	156.4	225	173.2	160.8	94.4	71.4	37.2	134.1	13.2	275.8	1697.9
2012	62	77.6	157.6	47	114.2	36.2	327.6	148	68.3	57.6	26.8	79.3	1202.2
2013	4	30.8	20.2	284.2	118.8	140.2	61.4	69.8	93.2	15	65.2	149	1051.8
2014	50	64	43	224.8	28.4	229	-	-	-	37.8	35.4	145.2	> 857.6
2015	8.4	43.8	77.4	116.2	95.4	35.2	91	150.8	92	27.8	88	18.2	844.2
2016	104.2	144.6	144.6	87.4	88.6	-	153.6	75.4	166.2	54.8	77.8	44.4	> 1141.6
2017	36.4	154	275.2	293.4	153.8	66.4	124	159	184.6	162	49	28.8	1686.6
2018	136	153	85	119	70.8	195.8	93.4	-	33.4	78.8	112.8	278.2	> 1356.2
2019	15.6	19	53.2	91.6	47.4	51.8	151.8	73.6	96.4	91	38.2	57.4	787
2020	-	11.2	41	16.4	57	262.4	85	-	28	23.8	106	18.8	> 649.6
2021	17.4	63.4	35	45.2	112.8	135.8	122	42.2	109.8	125.6	-	116.2	> 925.4
2022	26.2	82.7	163	97	151.4	256.3	-	91.4	-	134.7	182.2	137.2	> 1332.1

[1]Average monthly rainfall (past 23 years).

[2]Red cells indicate above average rainfall, yellow cells indicate more than double the average rainfall.

[3]Cells with (-) represent months where there was either no rainfall or an error with the data.

Table 6.2: Monthly rainfall totals since March 2008 (Ila Place Station)

Year	Rainfall (mm)												
	JAN 82.2[1]	FEB 147.6[1]	MAR 118.8[1]	APR 133.7[1]	MAY 117.5[1]	JUN 160.9[1]	JUL 133.9[1]	AUG 129.7[1]	SEP 128.5[1]	OCT 95.0[1]	NOV 63.8[1]	DEC 108.8[1]	Total
2008	-	-	97.4	215.6	74.6	176.6	246.6	154.6	69.6	65.8	37.8	99.8	1238.4
2009	48.0	147.6	194.6	57.8	82.4	196.6	143.2	101.4	104.0	144.2	17.8	63.6	1301.2
2010	165.2	17.4	21.4	25.4	233.8	179.2	69.6	364.6	324.8	42.4	30.4	62.4	1536.6
2011	313.6	15.0	188.0	45.4	219.2	206.2	76.0	58.6	48.2	178.2	22.8	318.0	1689.2
2012	81.0	124.0	190.4	57.8	132.2	46.0	217.0	171.6	81.0	94.4	31.4	108.6	1335.4
2013	11.4	43.8	38.8	283.8	142.4	175.6	55.0	93.6	122.2	42.6	100.2	74.8	1184.2
2014	35.6	75.2	49.2	232.0	56.6	288.0	72.4	90.4	126.0	40.8	49.2	114.6	1230
2015	25.2	48.8	75.4	147.6	90.6	77.8	125.0	159.4	136.4	30.0	93.4	30.2	1039.8
2016	126.6	223.8	174.6	122.2	103.8	180.0	158.0	86.8	187.8	84.4	98.4	35.6	1582
2017	47.0	168.8	385.6	335.0	206.2	80.0	126.8	201.2	195.4	196.6	32.8	51.4	2026.8
2018	198.6	200.2	96.0	193.4	91.6	191.6	115.8	148.6	43.8	91.6	109.4	299.4	1780
2019	18.6	38.0	39.6	100.2	68.2	77.4	188.4	63.2	126.8	85.8	52.2	100.0	958.4
2020	15.2	9.4	56.8	47.2	64.0	275.2	48.8	86.4	30.2	31.0	56.8	19.0	740
2021	23.8	67.2	48.2	56.2	71.4	30.0	89.0	47.6	119.0	143.4	38.6	110.8	845.2
2022	40.4	72.4	125.6	85.8	126.0	233.4	276.2	117.0	212.8	154.2	185.4	144.0	1773.2
2023	385.4	141.4	-	-	-	-	-	-	-	-	-	-	-

[1]Average monthly rainfall (past 15 years).

[2]Red cells indicate above average rainfall, yellow cells indicate more than double the average rainfall.

[3]Cells with (-) represent months where there was either no rainfall or an error with the data.

Both of these rainfall datasets have been graphed to visually show successive months of above average rainfall and are shown in Figure B1 and Figure B2 in Appendix B.

7 Tauranga City Council stormwater management zones within Study Area

Tauranga City Council has categorised the Study Area into two stormwater management zone types. These are stormwater reticulation zones and stormwater specific design zones (Figure 7.1). These areas relate to how stormwater is disposed of within the Study Area, predominantly from residential properties. Descriptions of each of these management zones are as follows:

- **Stormwater reticulation area**: This stormwater management zone shows properties that have stormwater reticulation connections available. These properties have systems that were either developed during subdivision or provided by council at some point in time.
- **Stormwater specific design area**: This stormwater management zone allows private properties to discharge stormwater by ground soakage methods. Tauranga City Council Development Standard 5 (DS-5) outlines the requirements for ground soakage methods in this zone, in particular, the requirement for these methods to be designed by a Chartered Professional Engineer. Section 5.7.2 of DS-5 states that "*Disposal of stormwater by ground soakage or ground water recharge is only suitable in some areas of Tauranga (i.e., areas not located near relic slips or plateau edges) and most areas of Mount Maunganui and Papamoa*".

Figure 7.1: Stormwater management zones within the Study Area (sourced from TCC MAPI).

8 Discussion

Landslides across the Study Area have occurred throughout its history and will occur in the future. As suggested by T+T (1980), Bird (1981) and Oliver (1997), it appears that successive months of above average rainfall influence the frequency and timing of landslides within the Study Area. This is partially corroborated by figures B1 and B2 in Appendix B. For example, during 2017, there were 20 EQC claims and both the Tauranga Aero and Ila Place weather stations recorded seven months of above average rainfall. The highest total annual rainfall recorded across both weather stations was also in 2017.

An outlier to this trend occurred in 2005, when 65 EQC claims were recorded but, the majority of these claims were not preceded by several successive months of above average rainfall. The reason for the 2005 spike in claims was the extreme rainfall event that occurred on 18 May 2005 (267 mm of rainfall was recorded over 24 hours at the Airport weather station, i.e. more than twice the average total May rainfall). This followed a period of heavy rain earlier in the month. The 18 May 2005 event resulted in significant landsliding across the Tauranga area. As outlined in Section 3 of this report, Hegan and Wesley (2005) suggested that it was not the single extreme rainfall event that caused the landslides across the Tauranga area rather a combination of previously elevated rainfall conditions followed by the extreme rainfall event (554.8 mm of rainfall was recorded between 1 May and 18 May 2005 at the Tauranga Airport weather station, approximately five times the average rainfall for the month). Figure 8.1 presents a graph showing the daily rainfall totals for April and May 2005 from the Tauranga Aero Aws weather station (for reference to the May 2005 extreme weather event).

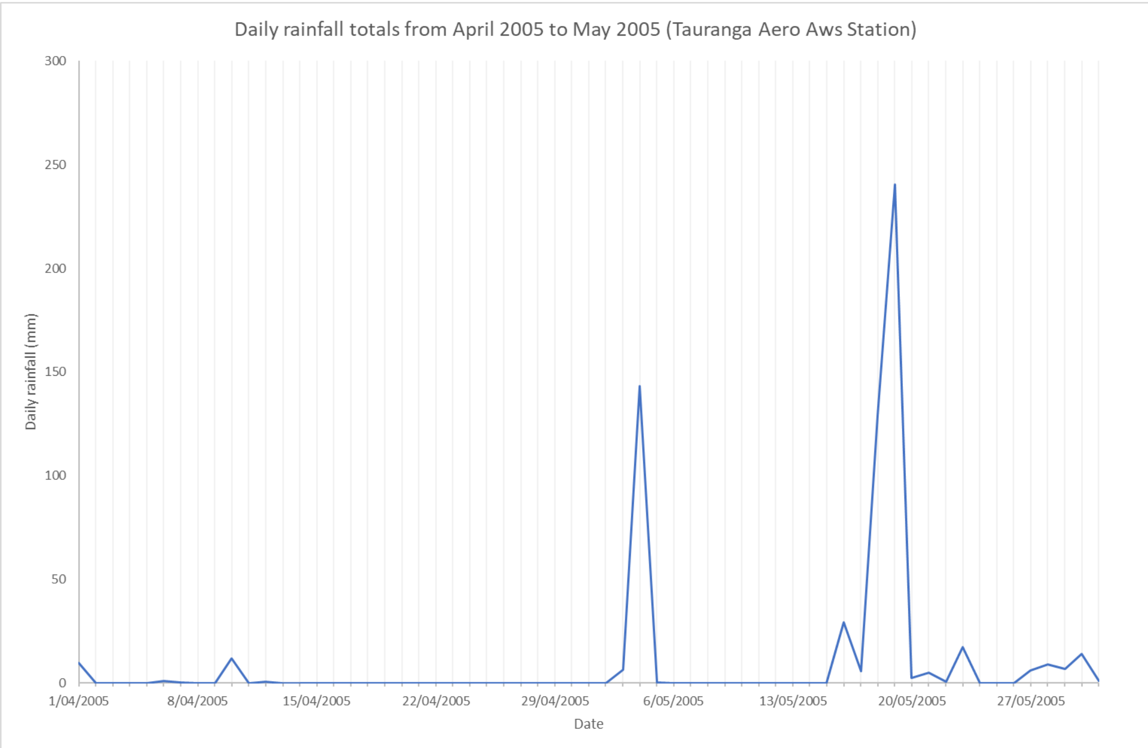

Figure 8.1: Graph showing daily rainfall amounts from April to May 2005 (sourced from Tauranga Aero AWS weather station).

We are aware of 12 EQC claims within the Study Area that relate to landslide events that occurred between January 2023 and March 2023 (there may be more EQC claims than noted that have been assessed by other consultancies). Furthermore, as discussed in Section 3, a number of reports have been issued to TCC addressing several landslides that have occurred within the Study Area during the same time period (some of these landslides will be associated with the 12 EQC claims for 2023).

The 2023 landslide events followed four months of above average rainfall. As shown on Figure 8.2, January 2023 experienced approximately four times the average rainfall which included three days throughout the month which exceeded daily rainfall totals of 50 mm (56.8 mm on 5/01/2023, 73.4 mm on 27/01/2023 and 103.2 mm on 28/01/2023). The combination of both the above average rainfall conditions and high daily rainfall events meet the conditions described by T+T (1980), Bird (1981), Oliver (1997), and Hegan and Wesley (2005) that generate landslides within the Study Area.

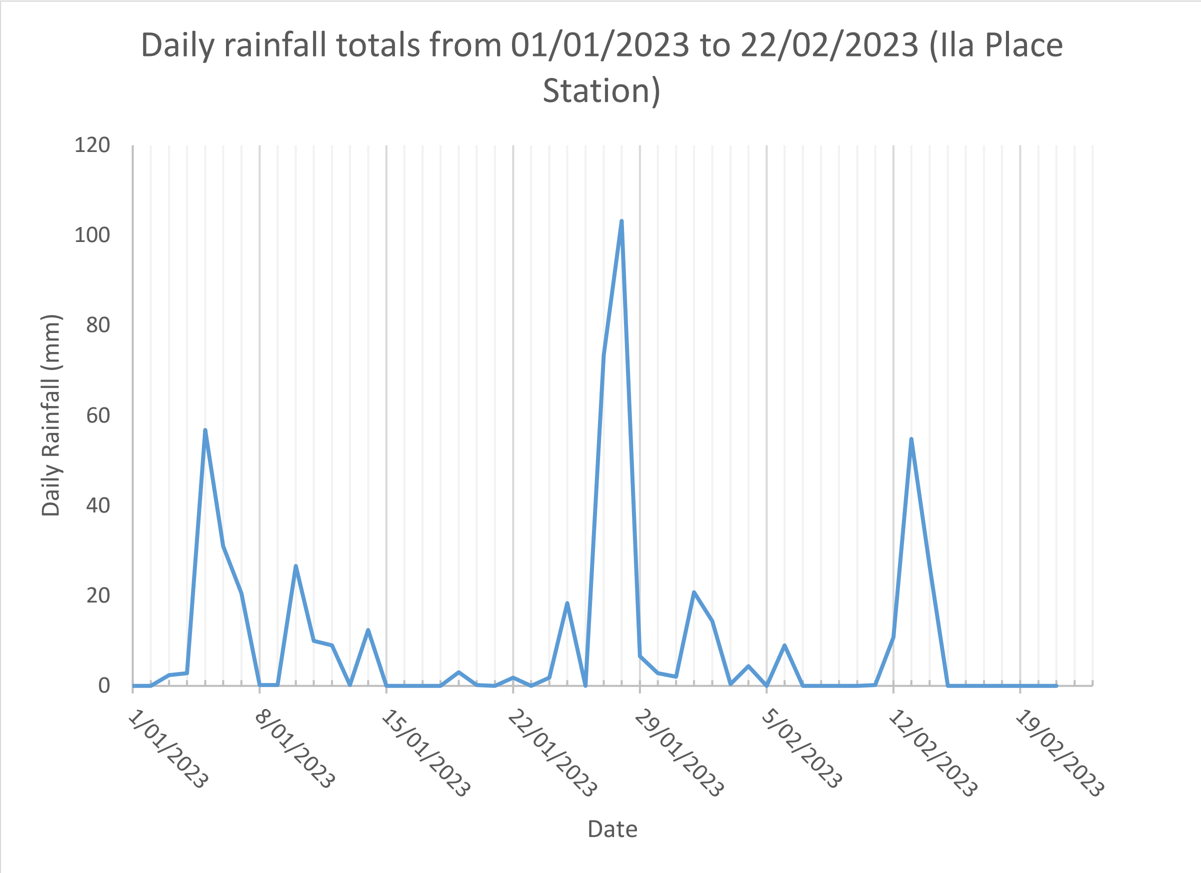

Figure 8.2: Graph showing daily rainfall amounts from January 01 to February 19 2023 (sourced from Ila Place weather station).

The spatial density of the EQC claims show some trends, noting that these claims do not represent all of the landslides that have occurred within the Study Area over the past 22 years. One of the most evident trends is the concentration of EQC claims along the western and north-eastern edges of the Study Area (refer to Figure 5.1). Many factors influence slope stability including:

- Morphology (slope height and gradient)
- Geology
- Weathering
- Vegetation type and cover
- Groundwater regime (including buried topography)
- Overland flow regime
- Concentration of rainfall
- Seismicity
- Erosion regime
- Human activities

A number of these factors are difficult to assess, however, T+T (2006) found that slopes steeper than 25° and higher than 5 m were generally more vulnerable to instability than other areas in Ōtūmoetai. Figure 1.4 is a colour coded map of slope gradients around Maungatapu Peninsula. It shows that the north-western and north-eastern slopes of the peninsula tend to be steeper than at other locations and this likely makes them more prone to instability. The highest concentrations of EQC 'landslip' claims are also coincident with these steeper north-western and north-eastern slopes.

The reasons that the overall slope gradients are steeper in north-western and north-eastern areas of the Study Area has not been determined, but they may include slope aspect and the location of harbour channels. There are limited tidal flats on the north-western and north-eastern sides of the peninsula and harbour channels flow in closer proximity to the peninsula slopes in these areas than elsewhere. The locations of the channels in these areas may have had the effect of keeping the peninsula slopes in these areas generally steeper than in other areas. The currents associated with the channels may also have eroded debris more quickly at these locations compared to other areas.

In addition to the above, storms that appear to cause the greatest effect in Tauranga (in terms of rainfall and slope instability) seem to predominantly come from a northern direction (NIWA, 2013). Although toe erosion is not considered to be a major control of instability observed in north-western and north-eastern areas of the Study Area, wave action associated with these storms may also have contributed to the steepness of slopes during their development.

Groundwater dynamics and flows paths are also likely to be important factors in relation to the spatial variability of landsliding across the Study Area. For example, a comment from a resident detailed in the Ice Geo & Civil report "*Maungatapu Road Slips: The present status of the slips below 310, 312A, 320, 326 and 330*" provides evidence to suggest that groundwater flowpaths within the peninsula can change following landslides occurring (as discussed in Section 3). The reason for this is unclear however, landslides may remove low permeability colluvium from the coastal slopes opening new paths and creating preferential flow towards areas of recent instability. Undulations and lateral variations in soil layers may also create preferential groundwater flow paths.

There is also some uncertainty about the relationship between stormwater disposal methods and groundwater dynamics across the Study Area. As suggested by Oliver (1997), the disposal of stormwater via soakage may be increasing the frequency of landslides occurring within the Study Area. However, the report published by T+T in 2006 following the 18 May 2005 storm event noted that that the primary contributor to instability in Ōtūmoetai during the storm was overland stormwater flow and that soak-holes were considered secondary. The report stated that soak-holes still had a detrimental effect on slope stability. There are likely to be many soak-holes across the Maungatapu Peninsula that could be affecting groundwater dynamics and in-turn, landslide frequency. However, further information will need to be gathered to provide a greater understanding about the influence of these soak-holes on groundwater dynamics.

To further understand landsliding across the Study Area it will be important to develop a greater understanding about the underlying geology and groundwater dynamics. Currently, there are very few deep geotechnical investigations (mainly machine drilled boreholes) in the majority of the Study Area. There are numerous geotechnical investigations in the southern extent of the Study Area however, these are primarily associated with the Hairini Link project and it would be prudent to obtain a greater spread of information. In addition, we are unaware of any long-term groundwater level monitoring stations across the Study Area. Developing a greater understanding of groundwater levels and their response following rainfall would be beneficial in understanding their relationship to landsliding here.

9 Further work recommendations

Factors controlling slope stability can be complex, however TCC may want to consider undertaking the following actions to develop a greater understanding about the ground beneath the Study Area:

1. Complete several deep cored machine drilled boreholes across the Study Area, particularly in the central and northern extents to better understand the spatial variability of the upper Matua Subgroup sediments. The boreholes should be logged by a suitably qualified geotechnical engineer or engineering geologist. Cone penetration testing could also be undertaken to augment the drilling.
2. Install piezometers with continuous groundwater monitoring equipment across the Study Area within the machine drilled boreholes. This will allow groundwater trends to be observed across the Study Area following significant rainfall events. Ideally, these piezometers would be nested (multi-level) and located in contrasting locations across the Study Area. For example, it would be beneficial to have piezometers in densely and sparsely populated areas to see if the groundwater is influenced by soakage and other stormwater disposal activities.
3. Assessment of stormwater disposal methods. Gathering data on disposal via soakage and via TCC reticulation would be useful to correlate with Item 2. This would require input from private property owners or an extensive review of council owned property files.

10 Applicability

This report has been prepared for the exclusive use of our client Tauranga City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by: by:	Reviewed by and authorised for Tonkin & Taylor Ltd
....	....
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Appendix A Schematic representations of failure types

- **Figure 1 – Large scale block failure**
- **Figure 2 – Piping triggered block failure**
- **Figure 3 – Wave erosion triggered block failure**
- **Figure 4 – Colluvium/topsoil failure**

Figure A1: Large scale block failure (Oliver, 1997)

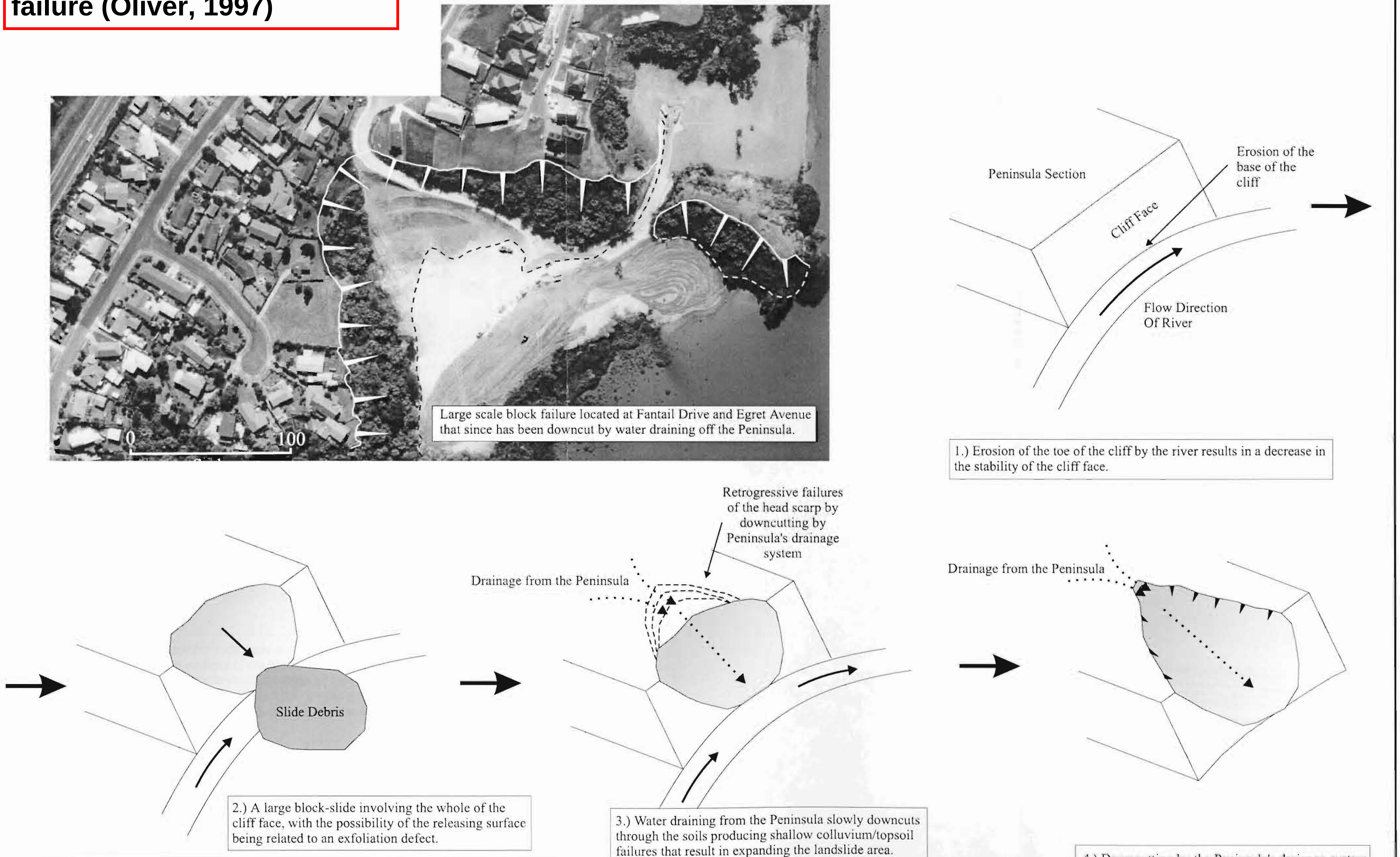


Figure 2.7 Developmental stages of the "probable larger scale landslides" seen around the Maungatapu Peninsula with an example located at Fantail Drive and Egret Avenue (grid reference 704350 274850).

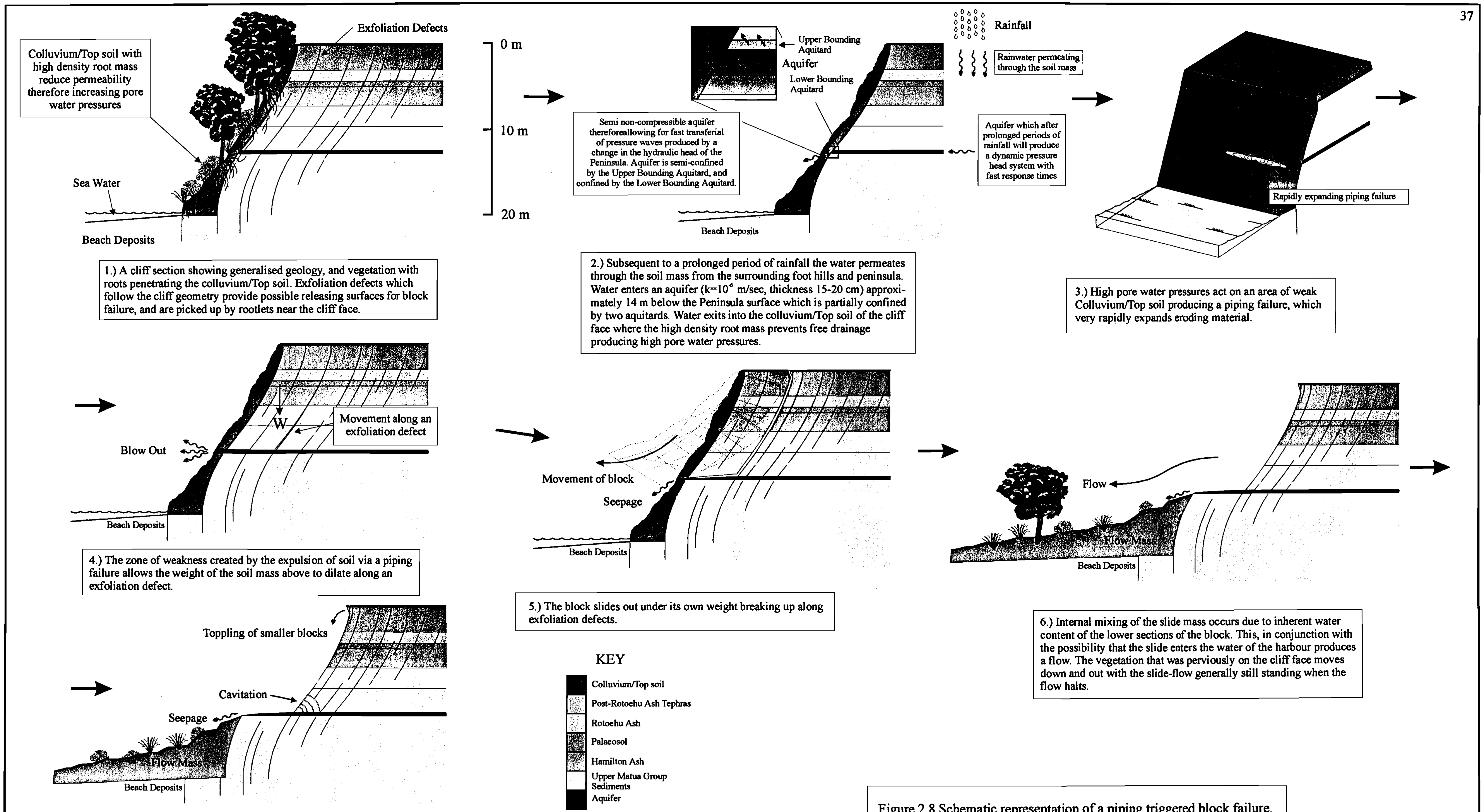
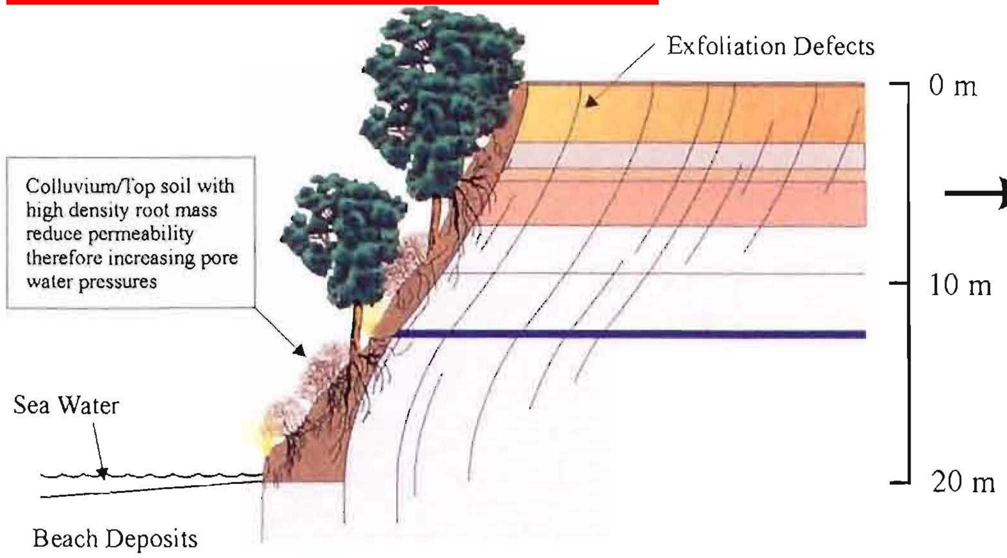
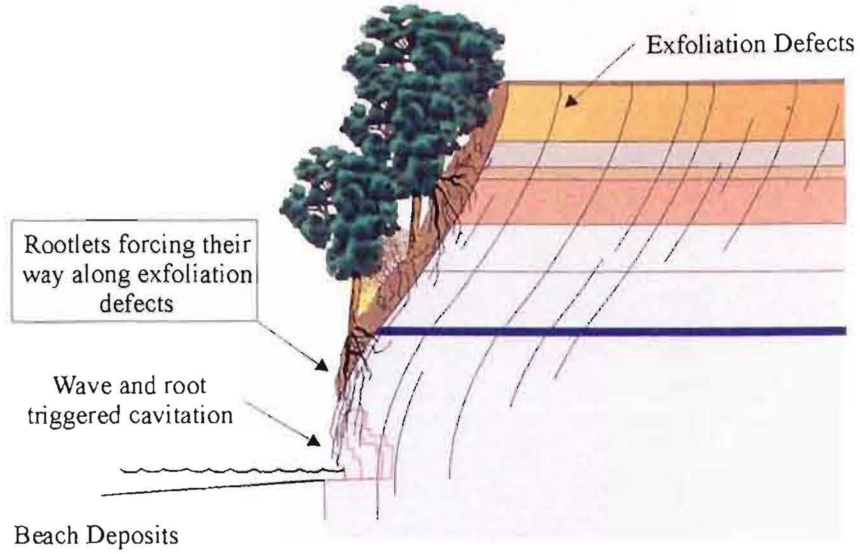


Figure A2: Piping triggered block failure (Oliver, 1997)

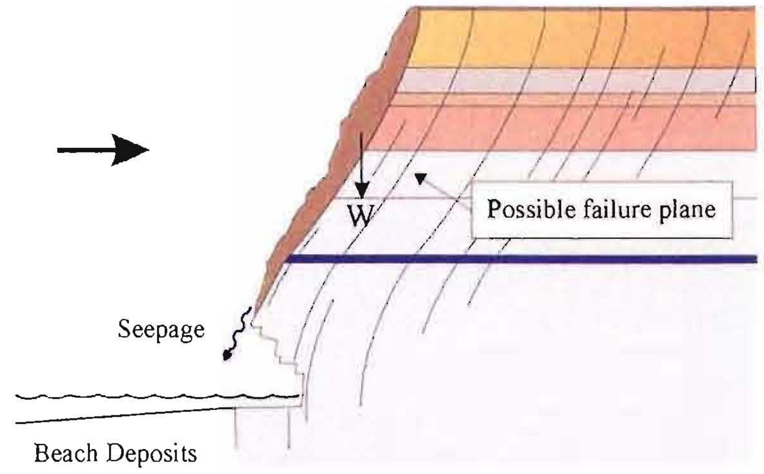
Figure A3: Wave erosion triggered block failure (Oliver, 1997)



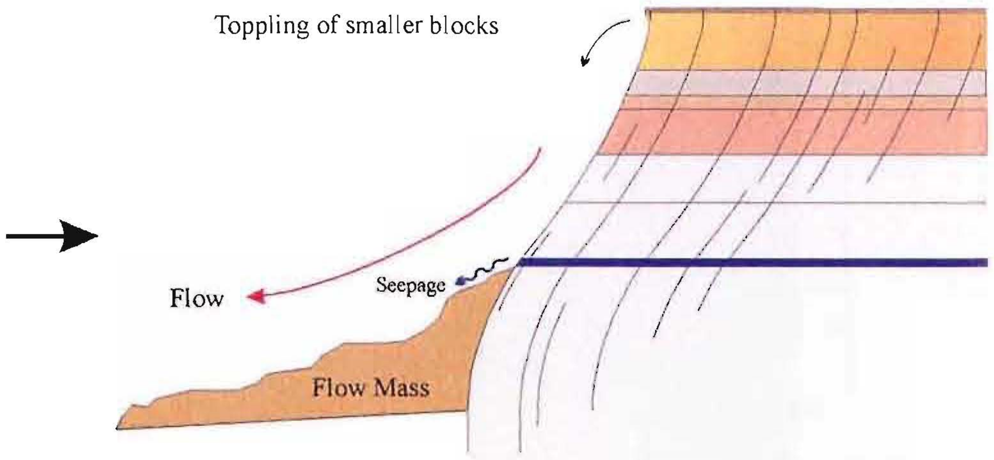
1.) A cliff section showing generalised geology, and vegetation with roots penetrating the colluvium/Top soil. Exfoliation defects which follow the cliff geometry provide possible releasing surfaces for block failure, and are picked up by rootlets near the cliff face.



2.) Toe erosion cause initially by a small Colluvium top soil failure at the base of the cliff, producing a fresh surface. Cavitation is caused by a combination of toe erosion by wave action during storm events, and failure along exfoliation fefects by the above vegetation's root mass.



3.)The weight of the above soil mass becomes to great and slides away from the cliff along an exfoliation defect.



4.) As the block fails internal defects help to break it up as it hits the cliff bottom. With high water content as in aquifer triggered failures or on entering sea water will produce a flow instead of a slide as in the second phase of movement.

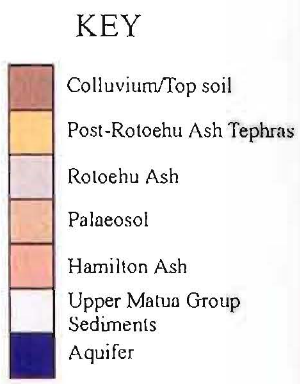
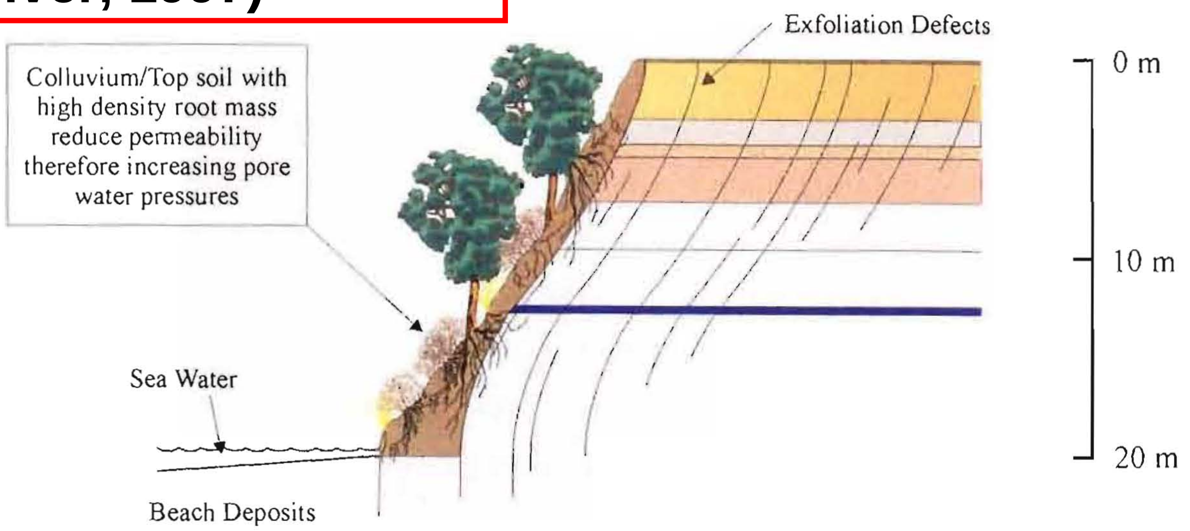


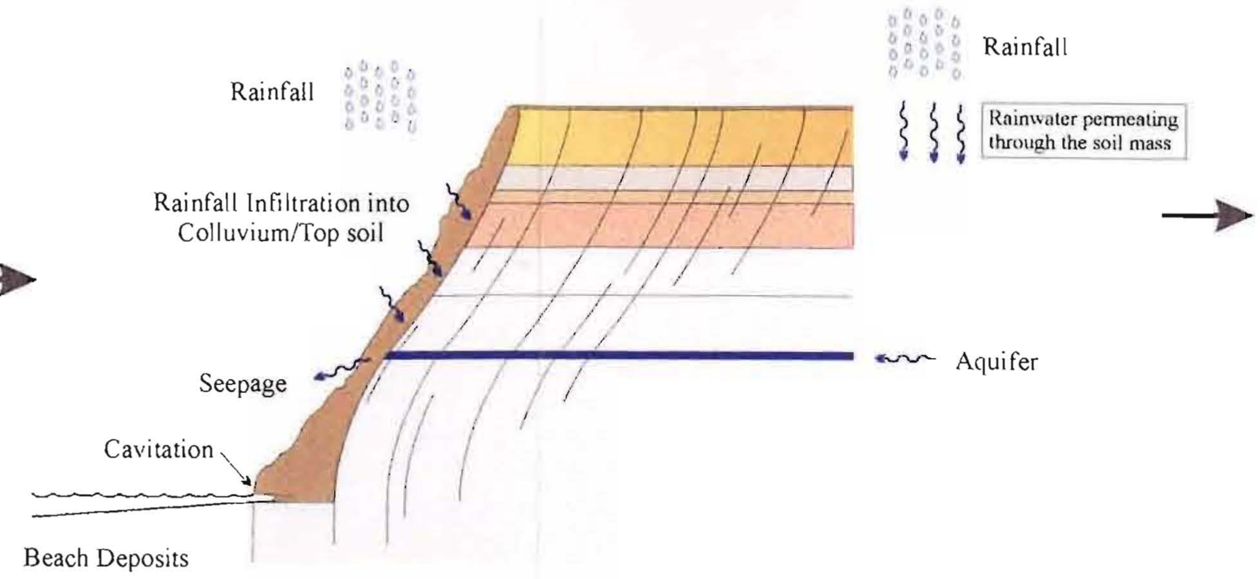
Figure 2.9 Schematic representation for a wave erosion triggered block failure. Failure occurs where the toe of the cliff has been removed by erosion producing either a colluvium/top soil failure or a larger block failure. The later stages of failure can be dramatically influences by water content of the soil mass. From Cruden and Varnes (1996) terminology the failure can be defined as a "Retrogressive, complex; very slow-extremely slow, dry-moist, debris, fall; very rapid-extremely rapid, moist-very wet, debris, slide-flow".

The Photograph depicts how the root mass from vegetation above pushes its way through the soil mass along exfoliation defects creating a root mat. This provides a surface on which the soil can fail after it has been undercut by wave action. Failure in this case tends to occur more as falls with debris easily seen accumulated at the bottom of the cliff.

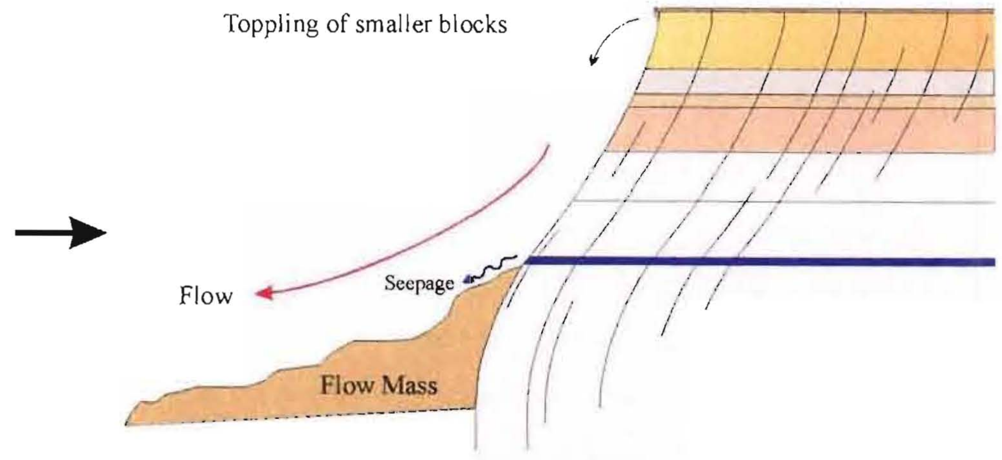
Figure A4: Colluvium/ topsoil failure (Oliver, 1997)



1.) A cliff section showing generalised geology, and vegetation with roots penetrating the Colluvium/Top soil. Exfoliation defects which follows the cliff geometry provide possible releasing surfaces for block failure, and are picked up by rootlets near the cliff face.



2.) Rainfall entering the soil mass from the surrounding hinterland and Peninsula is transferred to the aquifer which exits at the cliff face. In Addition, rainfall can help to saturate the Colluvium/Top soil mass adding extra weight and increasing pore water pressures. Also erosion by wave action at the base of the cliff can increase the possibility that failure will occur.



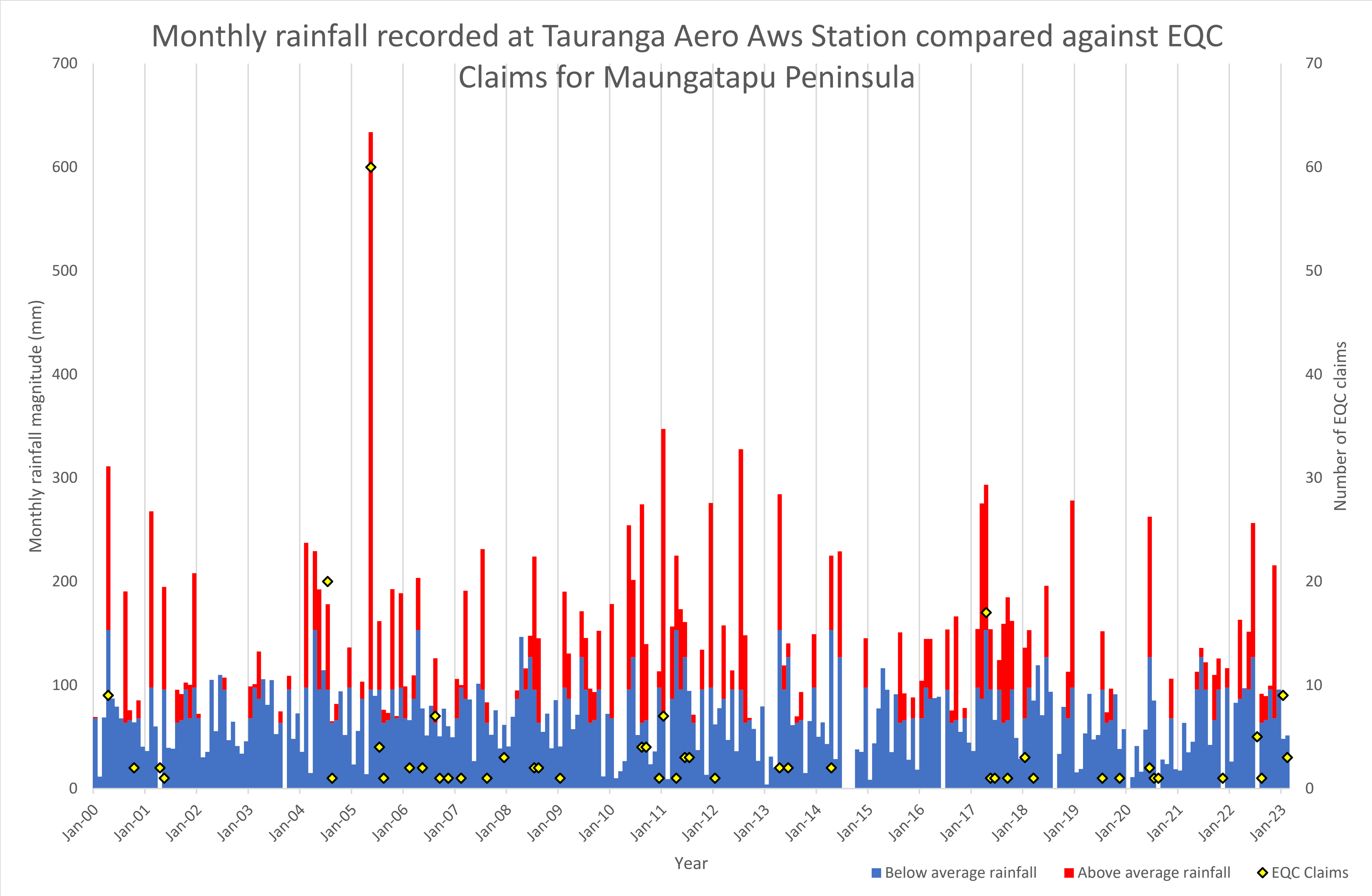
3.) The boundary between the Colluvium/Top soil and underlying geologic units can provide a surface on which a top soil failure may occur. As the top soil slides internal mixing of the soil mass due to the high water content produces a flow. If the flow enters sea water this will increase the effects of the internal mixing and how far the flow will travel. Most of the vegetation tends to survive the failure remaining in a semi-vertical position as on the cliff face.

The Photograph show vegetation root mass in conjunction with Colluvium/ Top soil produces a surface on which failure may occur. Vegetation weight especially larger trees results in a torque placed on the soil mass aiding in production of instability. Sliding has occurred along the interface between the vegetation root mass-Colluvium/Top soil and a shallow exfoliation defect. The debris has subsequently been eroded away by wave action.

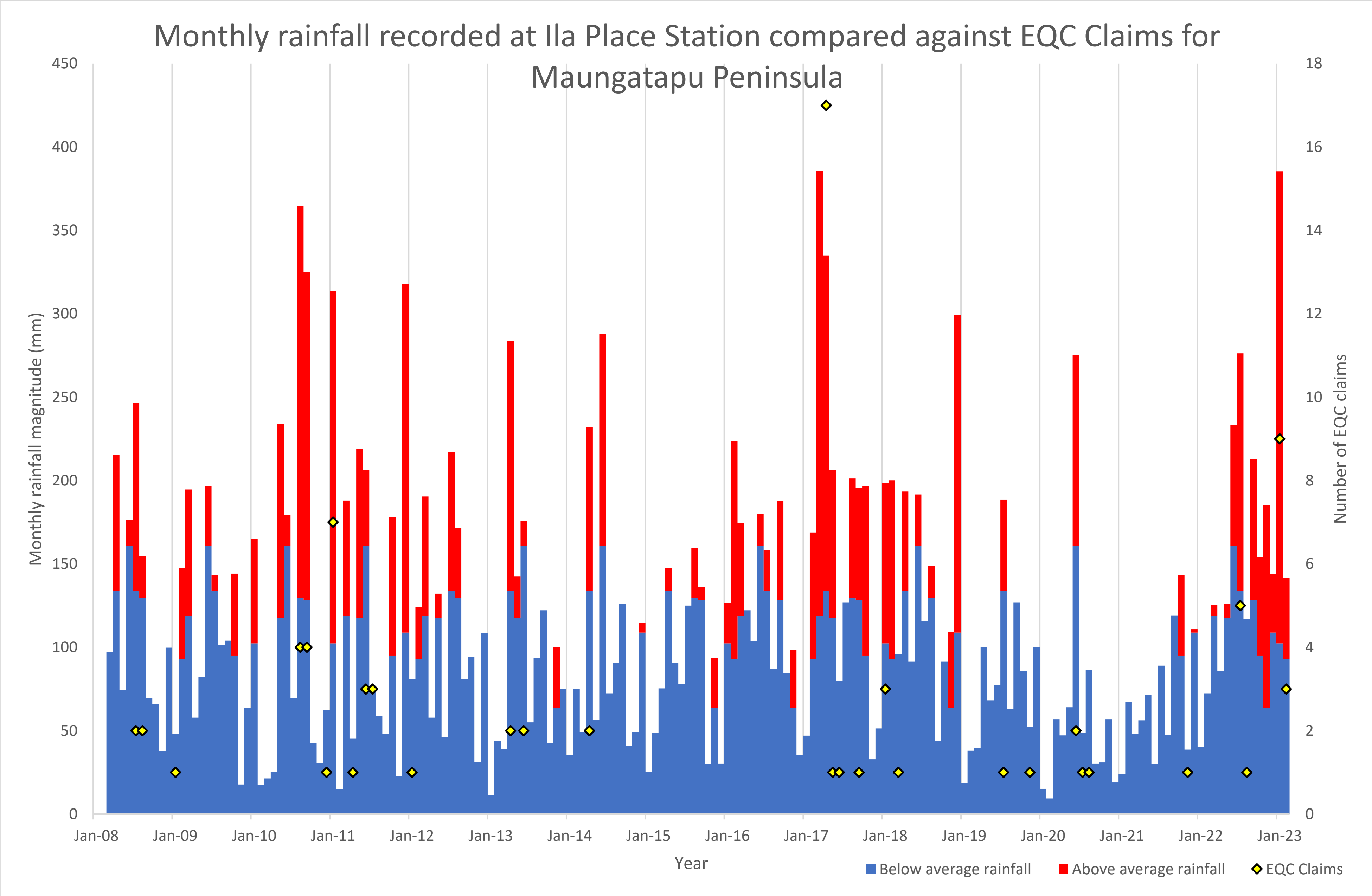
Figure 2.10 Schematic representation of a Colluvium/Top soil failure. From Cruden and Varnes (1996) terminology the failure can be identified as a "Retrogressive, complex, very slow-very rapid, dry-wet, debris, slide-flow".

Appendix B Rainfall events in relation to EQC claims

- **Figure B1: Graph showing rainfall events from Tauranga Aero Aws weather station compared with EQC claims within the Study Area.**
- **Figure B2: Graph showing rainfall events from Ila Place weather station compared with EQC claims within the Study Area.**



Monthly rainfall recorded at Tauranga Aero Aws Station compared against EQC Claims for Maungatapu Peninsula
Monthly rainfall magnitude (mm)
Number of EQC claims
Year
0
100
200
300
400
500
600
700
0
10
20
30
40
50
60
70
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Below average rainfall
Above average rainfall
EQC Claims


Monthly rainfall recorded at Ila Place Station compared against EQC Claims for Maungatapu Peninsula
Monthly rainfall magnitude (mm)
Number of EQC claims
Year
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Below average rainfall
Above average rainfall
EQC Claims

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