REPORT

Whakatāne District Council

Quantitative Landslide and Debris Flow Hazard Assessment Matatā Escarpment

Report prepared for:

Whakatāne District Council

Report prepared by:

Tonkin & Taylor Ltd

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Executive summary

On 18 May 2005, the town of Matatā was severely impacted by several large debris flows generated by intense rainfall within the adjacent hill country. Significant landsliding also occurred within the escarpment and hill country. Between May 2010 and June 2011, a series of high rainfall weather events passed over the eastern Bay of Plenty, triggering numerous landslides on the Matatā Escarpment and adjacent hills, although no debris flows were generated.

Whakatāne District Council (WDC) commissioned Tonkin & Taylor Ltd to undertake a quantitative landslide and debris flow assessment of the Matatā Escarpment in order to develop an understanding of the landslide and debris flow hazard within the vicinity of Matatā and the risks that future events of this type pose to residents and potential future developments.

The methodology of AGS (2007) has been adopted for this study, where considered appropriate.

The study area was defined in the WDC brief as: "...*the western end of the Awatarariki Stream debris fan to 71 Manawahe Rd to the east and Arawa [Street/SH2] to the north*.

The primary outputs from this study are a series of maps showing the nature and spatial distribution of these natural hazards. It is intended that these hazard maps, together with broad estimates of the personal and property risks associated with them, will aid the development of appropriate Council policies with respect to the ongoing occupancy and future development of Matatā and its immediate surrounds.

The hazard and risk assessments presented here are limited to landslides and debris flows. Risks associated with other natural hazards such as tsunami, flooding, coastal erosion etc do not form part of the scope of this report.

The main forms of slope instability observed on the Matatā Escarpment during the significant rainfall events of 2005 and 2010-2011 were debris avalanches originating on steep slopes, gullies and cliff faces. Despite the number of landslides generated during this period, no damage is known to have occurred as a result of direct landslide impact. Indeed, T&T have no records of any claims being made to the Earthquake Commission (EQC) for property or land damage as a result of any landslides originating from the Matatā Escarpment. This compares to over 150 claims for landslide damage to properties near the Whakatāne and Ōhope escarpments for the years 2004 to 2012.

Photographs from the early to mid-20th Century present an image of the Matatā Escarpment as being relatively well vegetated and largely devoid of significant landslide scaring. It is clear from aerial photographs that there were very few landslides on either the escarpment or the hills behind it prior to the 2005 debris flow event. Nevertheless, the presence of a significant debris or talus slope at the base of the escarpment clearly illustrates that a significant quantity of material has descended the escarpment in the form of landslides.

There is evidence for debris flows having occurred at Matatā prior to 2005, however neither the magnitude nor the recurrence interval of such events is known. Although topography of the lowlands area is subdued, there is geomorphologic evidence for the presence of debris fans extending out a considerable distance from the base of the escarpment. These fans are expected to be formed from both normal alluvial and debris flow depositional processes.

A landslide inventory developed for Matatā shows the escarpment is dominated by rainfall-triggered instability events. Strong seismic-shaking is potentially the source of the largest landslides that could occur on the escarpment, although the triggering event may have a much longer return period that rain storms. The triggering event for large debris flows may be about the same frequency as that for strong (MM9) earthquake shaking.

Through a process of developing the landslide inventory and mapping the extent of previous debris flows, a series of hazard maps have been developed that show the spatial distribution of landslide and debris flow hazards across the escarpment and flatlands of Matatā. A combined landslide initiation and inundation hazard map for Matatā is also presented.

Advantage was taken of numerical debris flow modelling undertaken by Tonkin & Taylor as part of the Matatā Regeneration Project to supplement the knowledge gained from the sole witnessed debris flow in 2005.

Estimates of loss of life risk and property loss risk have been assigned to the different landslide and debris flow hazard zones. The results indicate that the risks to some properties in Matatā are considered to be moderate to very high and therefore in excess of the level of risk commonly adopted as being tolerable. Despite the loss of life risk being considered high for some properties located near the base of the escarpment, a number of factors have contributed to a lack of previous landslide impacts. This distinguishes the Matatā Escarpment from the Whakatāne and Ōhope escarpments where many houses have been damaged or destroyed and several lives have been lost in the past 50 years or so.

The greatest instability-related risk to Matatā is considered to be from moderate to large debris flows rather than landslides on the escarpment. It is a certainty that debris flows will occur in the future (the 2005 event is thought to have a return period of between 200 and 500 years), with the Awatarariki and Waitepuru Streams providing the most likely sources.

Options for mitigation of the risks associated with landsliding and debris flows are limited as the higher hazard zones are already occupied. Suitable planning restrictions, together with an early warning system of unusually heavy rain are probability the most suitable responses to the identified risks.

A supplementary assessment of debris flow risk has been undertaken using numerical modelling methods (T&T, 2013c).

Definitions

Acceptable risk
A risk which society is prepared to accept without need for management or further expenditure to reduce the level of risk.

Annual exceedance probability
The probability that an event will occur or a certain value will be met or exceeded. Also known as the probability of occurrence.

Castlecliffian
New Zealand Stage from 1.1 million years to 11,000 years before present. Terminates near the end of the Younger Dryas cold spell.

Consequence analysis
The assessment of those elements at risk (people, property etc), the temporal probability of people or vehicles to be present and the vulnerability of the element with respect to loss of life or physical damage. One of the elements of Risk Estimation.

Debris
Loose unconsolidated mixture of silt, sand, gravel, cobbles and boulders with some clay.

Debris Avalanche
A very rapid shallow flow of partially or fully saturated debris on a steep slope independent of established channels.

Debris Flood
A very rapid surging flow of water heavily charged with debris.

Debris flow
A very rapid flow of water saturated, non-plastic soil, rock and vegetation debris that passes along established channels. Often deposits onto an open or unconfined fan.

Debris Flow Fan
Area of debris flow deposition beyond the main confined channel.

Digital Elevation Model (DEM)
Digital height data usually developed from LiDAR data

Earthquake Magnitude
A measure of the energy released by an earthquake (the rupture of a fault plane). Measured in terms of Moment Magnitude. Formerly measured in the Richter or Local Magnitude.

Elements at risk
Population, structures and infrastructure potentially affected by landslides.

Frequency
The number of events during a particular time period. In the case of landslides frequency is normally defined as number per annum.

Hazard
A condition with the potential to cause an undesirable consequence. In landslide studies, hazard represents the frequency and/or intensity of landslide occurrence and is therefore closely associated with probability of occurrence.

Holocene
A geological epoch which began at the end of the Pleistocene (around 12,000 to 11,500 years ago) and continues to the present. Meaning "entirely recent", it has been identified with the current climate.

Ignimbrite
The deposit of a pyroclastic density current, or pyroclastic flow which is a hot suspension of generally rhyolitic particles and gases.

Individual risk
The risk to a single person, usually the person considered most at risk. Differs to societal risk which considers the risk to a number of people.

Intolerable risk
Risk which cannot be justified except in extraordinary circumstances.

Jurassic
The Jurassic is a geologic period that extends from 201 million to 145 million years ago. The Jurassic is known as the Age of Reptiles.

Landslide
The down slope mass movement of soil and/or rock.

Landslide inventory
Database recording the location, classification, area/volume and spatial distribution of landslides that exist within an area. Can be in the form of tables and/or maps.

Landslide hazard
The potential for a landslide to cause an undesirable consequence.

Landslide susceptibility
The qualitative or quantitative assessment of an area's potential to generate and/or be inundated by landslides.

LiDAR
Light and Radar is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

Likelihood
Same as probability.

Loss of Life Risk
The annual probability that a person (usually the person most at risk) will be killed by the hazard being considered.

Person most at risk

The theoretical person who has the largest occupancy of a site.

Pleistocene

The geological epoch which lasted from about 2.6 million to 11,700 years ago, spanning the world's recent period of repeated glaciations.

Probability

The likelihood of a specific outcome, expressed as a number between 0 and 1.

Property Loss Risk

The annual probability that a structure such as a building will be damaged by a landslide.

Qualitative

Descriptions or distinctions based on some quality or characteristic rather than on some quantity or measured value.

Quantitative

A type of information based in quantities.

Quaternary

The most recent of the three periods of the Cenozoic Era, it spans from 2.6 million years ago to the present. It is characterized by a series of glaciations and by the appearance and expansion of modern humans.

Return Period

An estimate of the average time between occurrences of an event. It is the inverse of the expected number of occurrences in a year.

Recurrence Interval

The recurrence interval is the same as the return period.

Risk

A measure of the probability and the severity of an adverse outcome. Risk = Hazard x Consequence, or the expected loss.

Risk analysis

The use of available information to estimate the risk to individuals, populations or structures.

Risk assessment

The process of risk analysis and risk evaluation.

Risk estimation

The process used to produce a measure of the level of risk being analysed. Involves frequency analysis and consequence analysis.

Risk management

The complete process of risk analysis, evaluation and response implementation.

Risk mitigation
The process by which risk is reduced or eliminated through the undertaking of treatment options or risk transfer. Part of the risk management process.

Societal risk
The risk to society as a whole. Where the results of an event go beyond an individual.

Temporal-spatial probability
The probability that the element at risk is in the affected area at the time of the landslide.

Tephra
The fragmental material produced by a volcanic eruption regardless of composition, fragment size or emplacement mechanism.

Tolerable risk
A risk that society is willing to live with so as to secure certain benefits. Kept under review and further reduced as and when possible.

Unacceptable risk
Risk which cannot be justified except in extraordinary circumstances. Same as intolerable risk.

Vulnerability
The degree of loss for a given element affected by landslides. Expressed on a scale of 0 to 1. For a person, vulnerability is the probability that their life will be lost. For a property, vulnerability is expressed as a loss in value.

Zoning
The division of land into homogeneous areas or domains with a uniform assigned property such as hazard or risk rating.

1   Introduction

On 18 May 2005, the town of Matatā was severely impacted by several large debris flows generated by intense rainfall within the adjacent hill country. The largest and most destructive of these debris flows originated within the catchment of the Awatarariki Stream, although significant damage also occurred to properties to the east as a result of debris flows exiting the Waitepuru Stream. In addition to the debris flows, significant landsliding occurred on the escarpment and the hill country behind it.

Between May 2010 and June 2011, a series of high intensity rainfall weather events passed over the eastern Bay of Plenty, triggering numerous landslides on the Matatā Escarpment, although no debris flows were generated. Significant landsliding also occurred on the Whakatāne and Ōhope Escarpments.

Whakatāne District Council (WDC) commissioned Tonkin & Taylor Ltd (T&T) to undertake a quantitative landslide and debris flow hazard assessment of the Matatā Escarpment in order to develop an understanding of the landslide and debris flow hazard within the vicinity of Matatā and the risks that future events of this type pose to residents and potential future developments.

The primary outputs from this study are a series of maps showing the nature and spatial distribution of these natural hazards. It is intended that these hazard maps, together with broad estimates of the personal and property risks associated with them, will aid the development of appropriate Council policies with respect to the ongoing occupancy and future development of Matatā and its immediate surrounds.

This is the third project commissioned by WDC into understanding the landslide risk within the district's boundaries. The two previous studies undertaken by T&T were:

- *Project 1: Risk assessment of Whakatāne Escarpment (T&T, 2011);*
- *Project 2: Landslide risk assessment, Whakatāne and Ōhope Escarpments (T&T, 2013).*

Project 1 was a qualitative risk assessment of several specific properties affected by landsliding in 2010-2011, whereas Project 2 was a QLRA of the Whakatāne and Ōhope Escarpments as a whole. The Whakatāne and Ōhope study used the methodology of AGS 2007, regarded as international best practice for the susceptibility, hazard and risk assessments as a means of potentially controlling development through the requirements of the District Plan.

The intent of this third project is to apply similar processes used in the earlier projects to the identification and quantification of slope instability hazards within the Matatā Escarpment. An addition to the Matatā project is the assessment of debris flows risk.

The hazard and risk assessments presented here are limited to landslides and debris flows. Risks associated with other natural hazards such as tsunami, flooding, coastal erosion etc do not form part of the scope of this report. This assessment has been undertaken on the understanding that the methodology and findings of the Whakatāne and Ōhope Quantitative Landslide Risk Assessment (QLRA) would be used, where appropriate, to reduce the work required to be undertaken for this assessment.

A CD containing digital versions of the maps (Appendices A to G) is enclosed in this report.

2   Scope of Work

2.1   Purpose

The purpose of the Matatā Escarpment Landslide Risk Assessment Project was outlined in the brief provided to T&T by WDC:

> " An extensive assessment of the Matatā escarpment with a broad management focus that will input into the development of natural hazard objectives, rules and policies for the District Plan review project".

The required deliverable from the study would be:

> "A highly credible technical report that will be consistent with the Whakatāne and Ōhope landslide risk study... The report will inform development of District Plan objectives, policies and rules for landslide risk management of future developments above and below the Matatā escarpments."

2.2   Study Area

The study area was defined in the WDC brief as:

> "...the western end of the Awatarariki Stream debris fan to 71 Manawahe Rd to the east and Arawa [Street/SH2] to the north.

The study area is indicated on Figure 2.1. It extends far enough west to include the Clem Elliot Drive area.

2.3   Tasks

The QLRA was divided into a number of discrete but related tasks. There were:

- Data compilation and review;
- Base map preparation;
- Landslide inventory development;
- Field validation of data;
- Landslide mechanisms and control;
- Landslide and debris flow susceptibility assessments;
- Landslide and debris flow hazard assessments;
- Loss of Life and Property Loss risk assessments; and
- Review of landslide hazard mitigation and control measures

2.4   Limitations

The scope of this QLRA is limited to the broad-scale identification and characterisation of the landslide hazard and risk associated with the Matatā Escarpment. The results of the assessment are intended to be used as part of the WDC planning process. It is not appropriate for this study to be used to define risk levels for individual properties.

Lessons learnt from the Whakatāne and Ōhope QLRA have been used, where appropriate to reduce the time and expense of this study. No interviews with local residents have been undertaken to date to establish an historic account of landsliding on the Matatā Escarpment. It is recommended that additional efforts be made to establish a more detailed record of the landslide and debris flow history at Matatā prior to the finalisation of this study.

Figure 2.1:   *Location plan indicating the extent of the Matatā QLRA study*

Figure 2.2   *Matatā street layout (source: Terraview)*

3 Landslide Risk Assessment

3.1 Terminology

Risk assessments can take numerous forms depending upon the nature of the related hazard and the aims of the assessment. Preconceptions regarding the meaning of the terms "hazard" and "risk" can lead to significant confusion when communicating the results of a study such as this. The definitions applied in this report are those adopted by the Australian Geomechanics Society (AGS, 2007) as presented below. The definition of other terms used in landslide risk assessments are presented in the front of this report.

The primary distinction that needs to be made and understood is that hazard relates to the likelihood of a landslide occurring, whereas risk relates more to the outcomes of such an event, should it occur i.e. the expected loss.

Susceptibility, Hazard and Risk

Susceptibility:

The relative potential for a landslide event to occur

Example: an area has a high susceptibility to landsliding because of the soft geology and steep terrain

Hazard:

Probability or likelihood of a landslide occurring

Example: an area typically experiences 5 landslides/km^2/annum, thereby qualifying for a "high" landslide hazard rating according to AGS(2007).

Risk:

Hazard x consequence

Example: the annual Loss of Life Risk for the person most at risk in this area is 1×10^{-4} or in other words 1 chance in 10,000 per year.

3.2 General Risk Management Framework

The general principals, framework and process of risk management are defined by AS/NZS 31000:2009 *Risk management – Principals and Guidelines*. This Standard provides the following principals for effective risk management:

a) Risk management creates and protects value;
b) Risk management is an integral part of all organisational processes;
c) Risk management is part of decision making;
d) Risk management explicitly addresses uncertainty;
e) Risk management is systematic, structured and timely;
f) Risk management is based on the best available information;
g) Risk management is tailored;
h) Risk management takes human and cultural factors into account;
i) Risk management is transparent and inclusive;
j) Risk management is dynamic, iterative and responsive to change;
k) Risk management facilitated continual improvement of the organisation.

According to AS/NZS 31000:2009, risk management involves a step-wise process in which risks are identified, analysed, evaluated and then treated. The steps required for the management of specific risks such as landslides are not provided in AS/NZS 31000:2009.

3.3 Landslide Risk Management Framework

3.3.1 The New Zealand Context

New Zealand currently does not have its own formal system of assessing landslide risk. Although quantitative risk assessment methods were published by BRANZ (Riddolls & Grocott, 1999) and aspects of the risk assessment guidelines published by the Australian National Committee on Large Dams (ANCOLD, 2003) have previously been adopted for geotechnical risk assessments in New Zealand, it is the methodology published in 2007 by the AGS that is now generally followed in New Zealand when a quantitative assessment is required. The methodology of AGS (2007) has been adopted for this study, where considered appropriate.

3.3.2 AGS (2007) Risk Management Framework

The landslide risk management framework presented in AGS (2007) is reproduced in Figure 3.1. This divides the risk management process into the following three basic elements:

- *Risk analysis*: where the nature of the landsliding hazard is assessed and the numerical value of risk estimated;
- *Risk assessment*: where value judgements are made as to whether the calculated risks are acceptable, tolerable or intolerable/unacceptable;
- *Risk management*: where risk mitigation measures are assessed and implemented.

This study essentially covers the risk analysis portion of the framework only. The primary metric of risk used in this study is annual individual fatality risk, otherwise known as Loss of Life Risk (R_{LOL}). This is consistent with both AGS (2007) and the assessment methods of the British Health and Safety Executive (HSE). An assessment of property loss risk is also made, although this is a less commonly applied parameter.

Sometimes the risk to numerous people from a single rare event is adopted as a measure of risk (e.g. when considering the failure of a large dam). The applicability (or otherwise) of societal risk to the assessment of landslides and debris flows at Matatā is discussed further in Section 11.

The risk assessment component of the AGS (2007) framework is a process in which value judgements are made with regards to whether a calculated risk is considered acceptable, tolerable or intolerable/unacceptable. There are currently no formal definitions of these risk levels applied in New Zealand. As a consequence, this study specifically excludes risk assessment as an output i.e. this report does not classify the calculated landslide risks in terms of what is acceptable, tolerable or intolerable/unacceptable. This is for others (including the WDC) to decide. However a discussion on how the landslide and debris flow risks present at Matatā compare with a range of common activities is presented in Section 11.4.

Risk, together with many of its components, is reported here in terms of scientific notation. Translations between this notation and other forms are presented below.

Figure 2: Abbreviated flowchart for Landslide Risk Management.
Ref: AGS (2007a, 2007c)
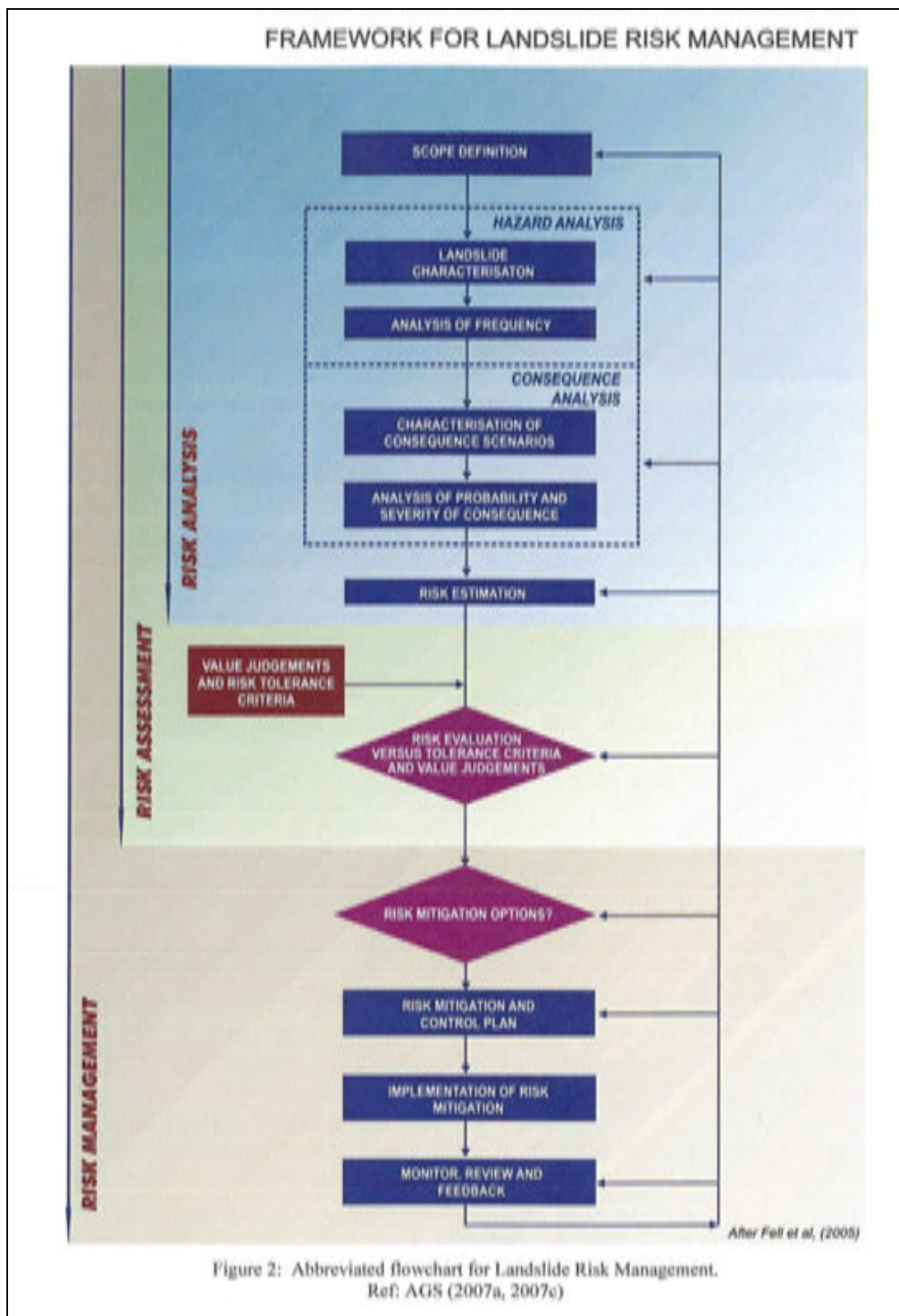
Figure 3.1:   *Landslide Risk Management Framework from AGS (2007).*

Numerical Terminology and Equivalents

Values of risk are generally too small to be written conveniently in terms of decimal points. For example, a one in ten thousand chance of occurring is, in normal decimal notation, 0.0001. It is typically more convenient to present such values in terms of scientific notion i.e. 1×10^{-4}, although other forms can be used. Four different notational forms for equivalent value are presented below.

Scientific Notation	Proportional Notation	Decimal Notation	Percentage Notation
10^{-1}	1 in 10	0.1	10%
10^{-2}	1 in 100	0.01	1%
10^{-3}	1 in 1,000	0.001	0.1%
10^{-4}	1 in 10,000	0.0001	0.01%
10^{-5}	1 in 100,000	0.00001	0.001%
10^{-6}	1 in 1,000,000	0.000001	0.0001%

4 Previous Work

A number of geotechnical and natural hazard studies have been undertaken at Matatā as a result of the 2005 debris flows. These include McSaveney *et al* (2005), Costello (2007), O'Leary (2007), Tonkin & Taylor (2009a) and Tonkin & Taylor (2009b).

The only hazard maps known to have previously been generated for the Matatā Escarpment are those recently prepared by GNS Science Ltd for the WDC (GNS, 2012). The following GNS Science maps were provided by WDC to T&T:

- Mapped extent of 2005 debris flows and debris avalanches (2 sheets);
- Geomorphic extent of past debris flows and debris avalanches (2 sheets);
- Mapped extent of
  - 2005 debris flows and debris avalanches
  - past geomorphic extent of debris flow and debris avalanche (1 sheet); and
- Mapped extent of
  - 2005 debris flows and debris avalanches
  - future inundation hazard extent of debris flow and debris avalanche (1 sheet).

These maps showed the extent of the deposits from previous instability events and possible future events. Whilst this implies areas of elevated hazard, the maps do not identify areas of different hazard level nor the recurrence intervals or magnitudes with these events.

T&T has previously undertaken a broadly similar QLRA for the Whakatāne and Ōhope escarpments for the WDC (T&T, 2013).

5 Setting

The town of Matatā is located on a narrow coastal strip between Awaateatua Beach and the dissected hilly terrain which rises to the south-west (Figures 2.1 and 5.1). The coastal strip opens out to the east, where it merges with the low-lying floodplain of the Tarawera and Rangitaiki rivers. The Matatā Escarpment comprises the steep slopes and cliffs marking the sharp transition from the elevated terrain down to the flatland areas.

Matatā is located between two significant streams that exit the escarpment: the Awatarariki Stream to the north-west and the Waitepuru Stream to the south-east (Figure 5.1). The smaller Waimea Stream, which consists of two branches, is located in between. North of the Awatarariki Stream, the escarpment consists of a line of former sea cliffs now set back some 300m from the coast (Figure 5.2). The escarpment reaches elevations of approximately 120m to 180m in this area.

The slopes located immediately behind the main Matatā township (i.e. between the Awatarariki and Waimea streams) are broadly similar in elevation and grade to those located west of the town (Figure 5.3), whereas those within the vicinity of the Waimea and Waitepuru streams are lower in elevation and significantly more dissected (Figure 5.4).

Figure 5.5 presents typical profiles of the escarpment slopes within the three areas described above.

It should be noted that at the turn of the 20th century, the Tarawera River passed through what is now the Matatā Lagoon before discharging to the sea in the vicinity of the present day Awatarariki Stream. A drainage scheme undertaken around the time of the First World War saw the Tarawera River realigned to its currently location some 2.5km to the east of the town. The geomorphology of the area around Matatā has been significantly affected by both these engineering works and earlier natural changes in course of the Tarawera River and the streams that feed into it.

Location and elevation maps of the study are presented as Figures A1 to A3 (Appendix A). Maps showing the gradient of the study area, as a series of slope classes, are presented as Figures B1 to B3 (Appendix B).
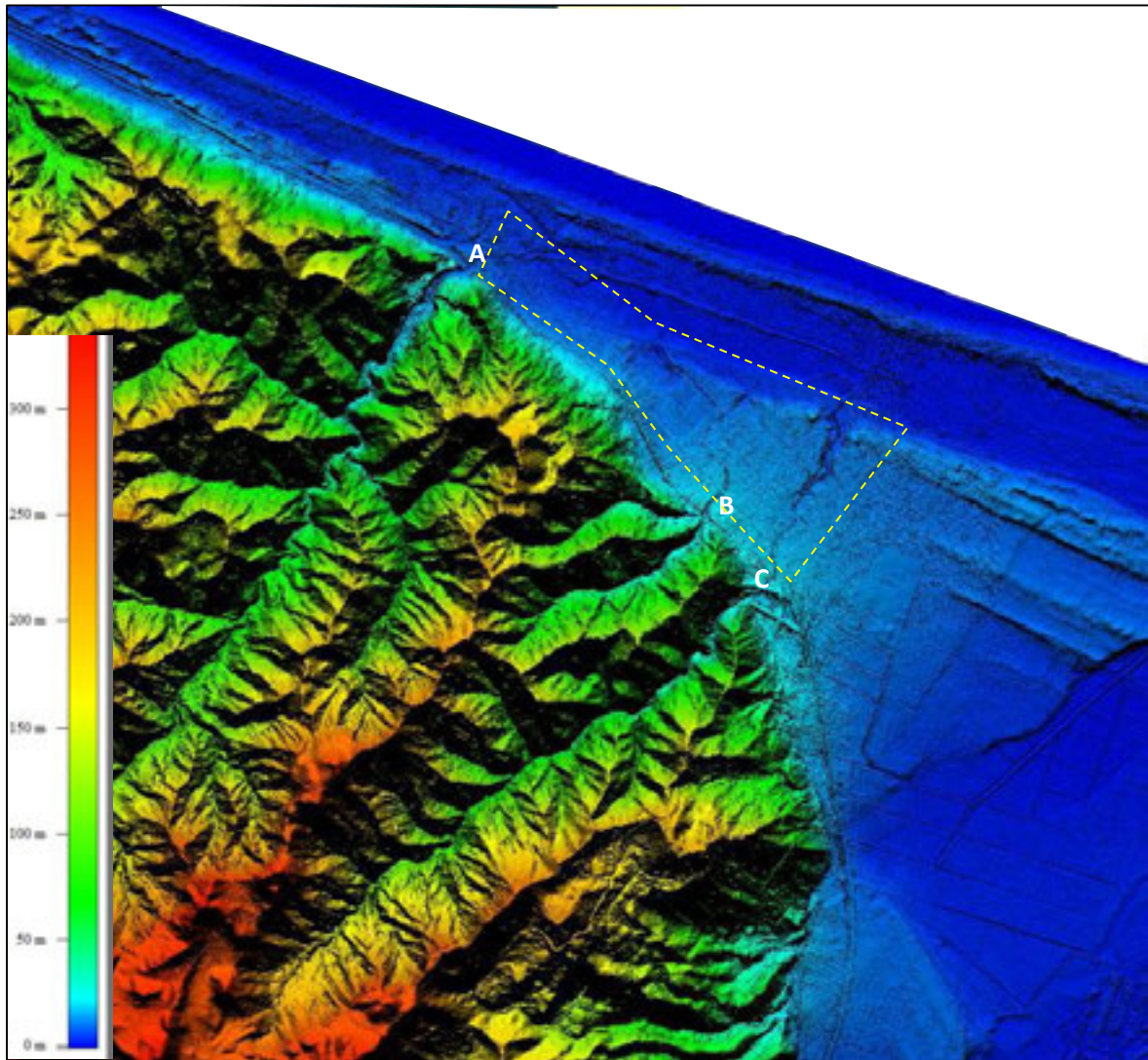
Figure 5.1:   Terrain map developed from LiDAR data showing the elevated and dissected terrain located behind Matatā. The locations of the Awatarariki (A), Waimea(B) and Waitepuru (C) streams are indicated. The main residential area of Matatā is indicated by the yellow line.

Figure 5.2:   *Abandoned sea cliffs forming the escarpment west of Matatā.*
View looking south from SH2.

Figure 5.3:   *View of the escarpment slopes east of the Awatarariki Stream.*
Photo taken in the immediate aftermath of the 2005 debris flows.

Figure 5.4:   View of the Matatā Escarpment to the south of Matatā looking north towards Waitepuru Stream.
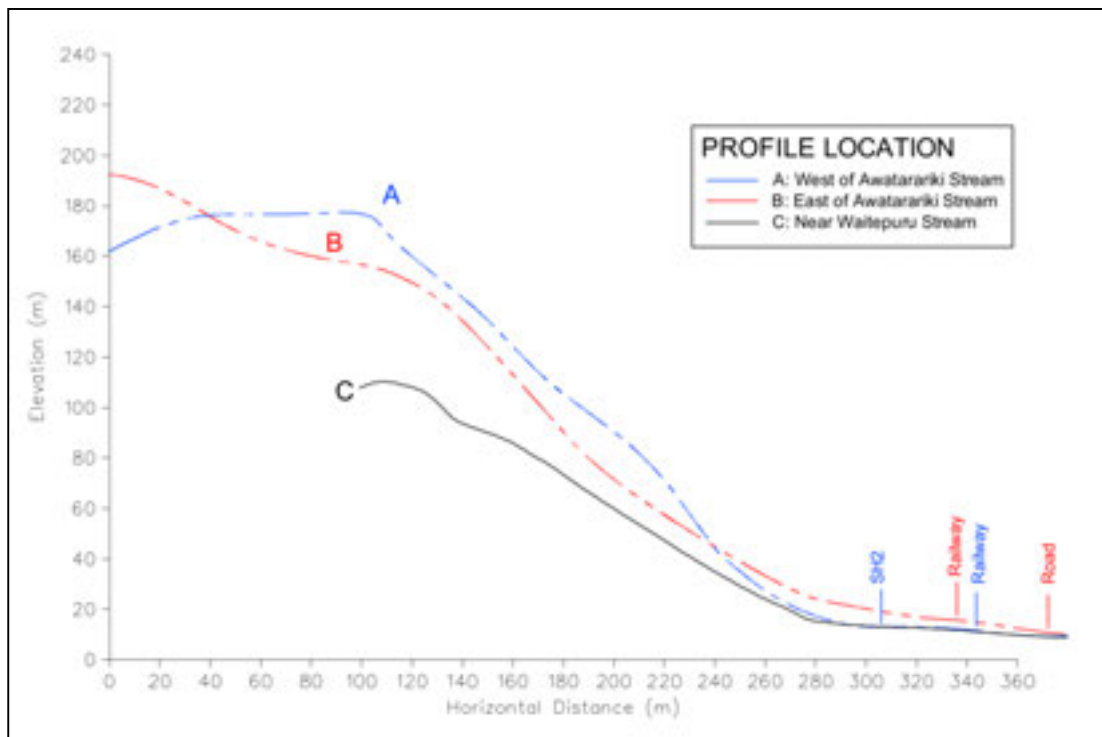
Figure 5.5   Representative slope profiles along the Matatā Escarpment

6 Geology

The geology of the Matatā area reflects its position between the Bay of Plenty coastline to the north, the Okataina Volcanic Centre to the south and the Whakatāne Graben located immediately to the east. The published geology for the area (Leonard *et al*, 2010), indicates that Matatā and the coastal region is underlain by Holocene-aged shallow marine, estuarine, alluvial and beach deposits. Alluvial and debris (talus) fan deposits have formed along the base of the escarpment.

The hills located to the south of Matatā are formed from early Quaternary-aged sediments of the Tauranga Group. These older sediments are formed from interbedded alluvial, estuarine and marine sediments with occasional volcanic airfall deposits (tephras). This sequence is capped further south by the Matahina Ignimbrite and younger volcanic deposits.

A general geological map of Matatā and its surrounds is presented as Figure 6.1. A stratigraphic column developed from Costello (2007), together with additional work undertaken by Tonkin & Taylor is presented as Figure 6.2.

6.1 Regional Basement

The regional geological basement is Jurassic-aged greywacke. The nearest exposures of greywacke are approximately 10km to the west of Matatā where they are worked at the Cameron Quarry Otamarakau. Greywacke will be present beneath Matatā at significant depth.

6.2 Early to Mid-Pleistocene Sediments

The oldest deposits exposed within the immediate vicinity of Matatā are a sequence of sediments deposited in the Early to Mid-Pleistocene[1]. The oldest of these are 700,000 to 2 million year old greywacke gravel conglomerates and an underlying siltstone of undetermined age. These are overlain by younger Castlecliffian (Pleistocene) sediments of the Tauranga Group (Costello 2007; Leonard *et al*., 2010). These consist of extremely weak to weak sandstones, siltstones and gravel conglomerates laid down in an estuarine to shallow marine environment some 300,000 to 700,000 years ago (McSaveney *et al*, 2005). Interbedded with these largely water-deposited sediments are rhyolitic airfall deposits originating from the Taupo Volcanic Zone. The former coastal cliffs located to the west of Matatā provide excellent exposures of this sedimentary sequence (Figure 5.2).

The only non-pyroclastic or sedimentary unit in the area of this age is the Manawahe Andesite, which was erupted approximately 620,000 years ago (McSaveney *et al*, 2005). It is exposed through younger volcanic cover rocks approximately 4km south-west of Matatā.

6.3 Late Pleistocene Volcanics

Eruptions within the Okataina Volcanic Centre started approximately 280,000 years ago. These eruptions resulted in a wide range of materials overlying the older estuarine and shallow marine sediments. The most significant of these materials exposed in the area is the Matahina Ignimbrite. Although this does not extend into the project site, it is exposed within the upper reaches of the Awatarariki Stream. Boulders of the Matahina Ignimbrite commonly occur within the Awatarariki Stream and were a major component of the 2005 debris flow deposits.

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[1] Pleistocene, which means "most recent", is the time period between approximately 2.6 million years ago and the end of the last glaciation ("ice age") approximately 10,000 years ago. It represents a period of major climate cycles and changes in sea level. The period between 10,000 years ago and the present is called the Holocene or Recent.
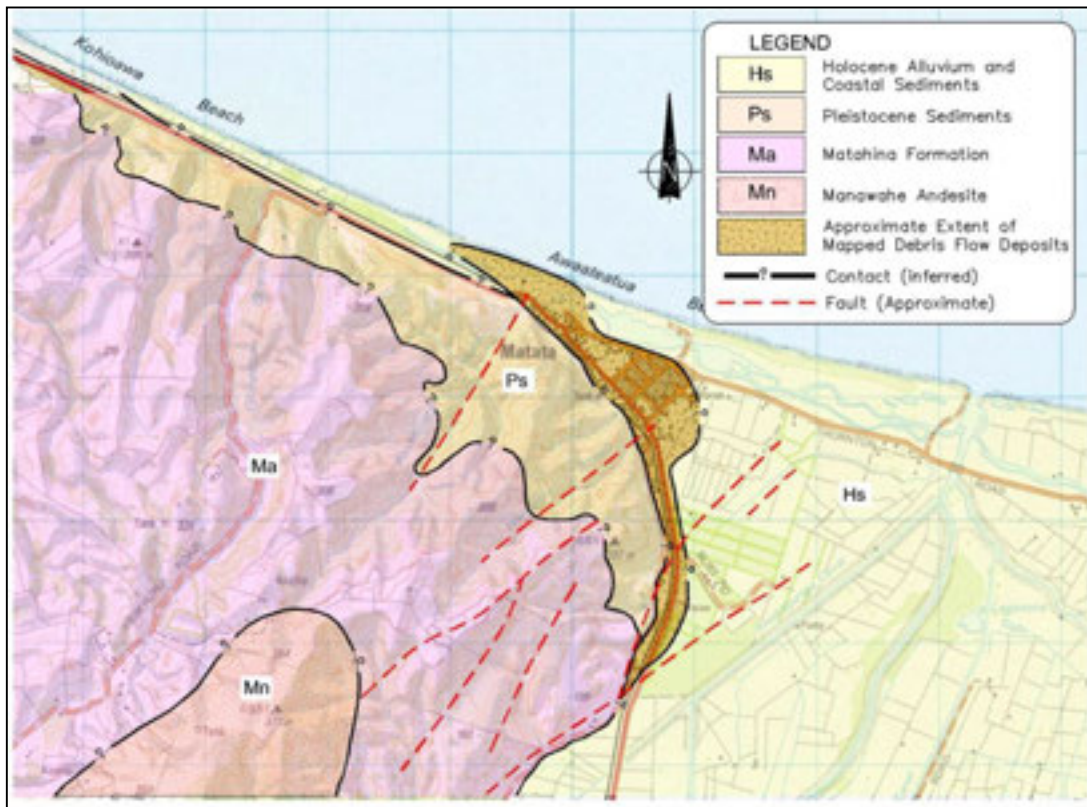
Figure 6.1: *General geology of the Matatā Area (modified from Leonard et al, 2010)*
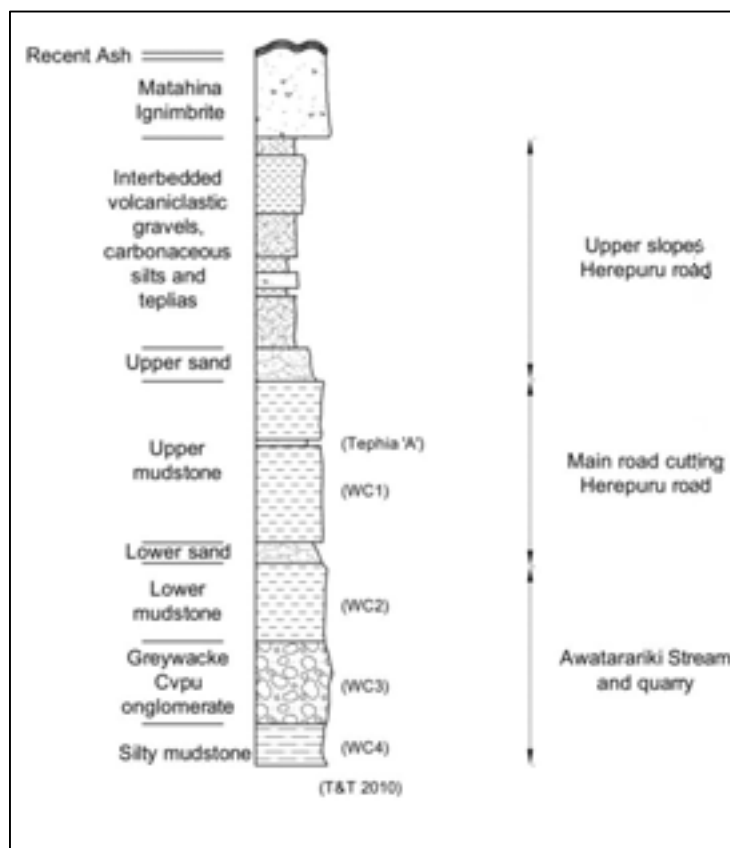
Figure 6.2: *Stratigraphic column for Matatā (modified from Costello, 2007)*

The stratigraphy is approximately horizontal, although faulting has resulted in numerous offsets of strata. A schematic geological section nominally located along the front of the Matatā Escarpment is presented in Figure 6.3.

6.4 Holocene Sediments and Debris Fans

The coastal strip is formed from a diverse mixture of alluvium, debris fan and coastal deposits, including fixed sand dunes. The sediments were deposited during the Holocene (and continue to do so) following the relative stabilisation of sea levels approximately 7,000 years ago. The sediments are dominated by sand with some silt, gravels and boulders.

The stratigraphy reflects the multiple sources of the sediments: coastal sands, sediments transported by the Tarawera and Rangitikei Rivers, alluvium and debris materials deposited onto alluvial fans (located where each of the streams exiting the escarpment) as well as material that has fallen directly from the escarpment itself.

As described above, prior to the First World War, the Tarawera River was located in the area now occupied by the Matatā Lagoon. The point where the river exited to sea was located approximately in the Clem Elliot Road/Awatarariki Stream area. The presence of the Tarawera River altered the geology and geomorphology of the township by eroding and truncating the debris fans that developed from the base of the Matatā Escarpment.

The approximate extent of debris fans near Matatā are indicated on Figure 6.1.

6.5 Recent Stream Alluvium

Investigations undertaken in the valley floor of the Awatarariki Stream (Tonkin & Taylor, 2006b) indicated that the stream is underlain by up to 8m of loose to medium dense alluvium containing boulders up to 3m in diameter and mixed organic material, including tree trunks, regarded as past debris flow and/or flood deposits. This alluvium typically comprises fine to coarse cobbles with frequent boulders in a sandy silt matrix. It is expected that the Waitepuru Stream is similarly underlain by a significant quality of debris. The Matahina Ignimbrite appears to be the predominant source of the boulder deposits that are present in the stream beds, although weaker siltstone boulders are also present.

Outcrops located between the Awatarariki and Waitepuru streams expose abundant bouldery deposits indicative of historic debris flows and debris avalanches. Evidence such as this indicates that slope instability processes have been part of the natural evolution of the landscape in this area.

6.6 Deposits from the 2005 Debris Flows

The May 2005 debris flows deposited a very large quantity of mud, sand, gravel and boulders within the lower reaches of the Awatarariki and Waitepuru streams, as well as significant parts of the flatlands. The debris had a very high proportion of sand and mud-sized particles compared to boulders, reflecting the fine grained and poorly consolidated nature of the materials that form the bulk of the catchments for these streams. Although the 2005 flows are likely to have been finer-grained than many described within the technical literature, they nevertheless contained many large boulders, including some several meters in diameter.
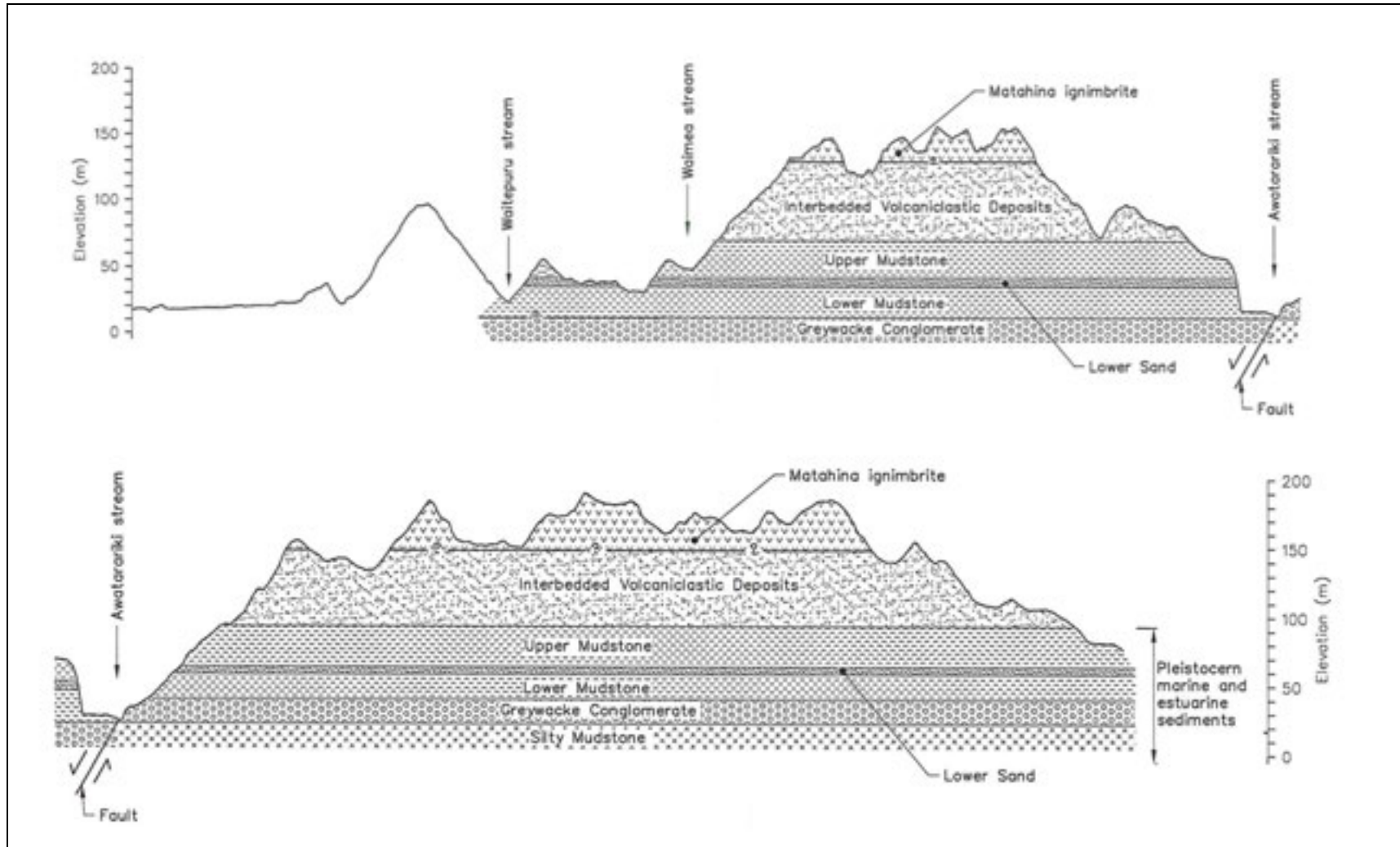
Figure 6.3:   Generalised geological section nominally along the front of the Matatā Escarpment. View from the flatlands to the hills

Test pits undertaken shortly after the 2005 event (Tonkin & Taylor, 2005c) indicated a debris flow thickness of between 1m and 2m on the Awatarariki Stream fanhead. However, as access difficulties restricted the testing locations to the northern part of Clem Elliot Drive, the debris thickness information obtained is expected to be more representative of the distal deposits. Deposit thicknesses on the upper fanhead are likely to have been closer to 3m or possibly 4m.

The 2005 debris flow event and its deposits are discussed further in Section 8.

6.7   Faulting

Matatā is located within the Taupo Volcanic Zone and on the western edge of the Whakatāne Graben. The graben is a regional-scale structure in which active tectonic extension has resulted in significant subsidence and subsequent alluvial infilling (Figure 6.4) . Central graben subsidence has created at least 550m of vertical offset in regional stratigraphy across the graben margins (Hockman, date unknown). Associated with the graben are numerous active north-east to south-west trending faults. These are typically downthrown on their eastern sides.

Figure 6.5 presents maps from the GNS Active Fault Database showing the location of active faults in the Matatā-Edgecumbe-Whakatāne area. This shows a significant number of faults have been mapped in and around Matatā and its immediate vicinity. The most significant of these is the Matatā Fault which, rather than being a single structure, is a complex series of related fault traces that strike SW-NE though the escarpment and township. This fault is included on the GNS Active Fault Database but is not included in those considered to have been historically active.

Other significant faults in the vicinity of Matatā are the Braemar, Awaiti and Edgecumbe faults. The GNS database indicates that both the Awaiti and Edgecumbe faults have been historically active. Significant faults also run along the Awatarariki and Ohinekoao streams. The unnamed fault in Awatarariki Stream dips at approximately 60° and has a throw of between 20 and 25m (Figure 6.6).

6.8   Seismicity

6.8.1   General

In discussing the magnitude and effects of earthquakes its necessary to consider two different concepts: the energy of the seismic event and the physical effects that such an event has. The rupture of a fault releases a quantum of energy into the ground, which attenuates with distance from the source. The energy associated with fault rupture is measured on the logarithmic Moment Magnitude or M_w scale. This has largely replaced the older Richter Magnitude scale (M_L) for characterising large earthquakes, although the Richter scale is often still used for local events. Each earthquake has a single M_w or M_L scale associated with it.

The physical effects of an earthquake depend not only on the magnitude of the event (M_w) but also on the distance of the observation location from the point of fault rupture. Seismic effects are described by the Modified Mercalli Intensity scale (MM). This twelve-step scale reflects the local effects of seismic shaking on people and structures as defined in Table 6.1.
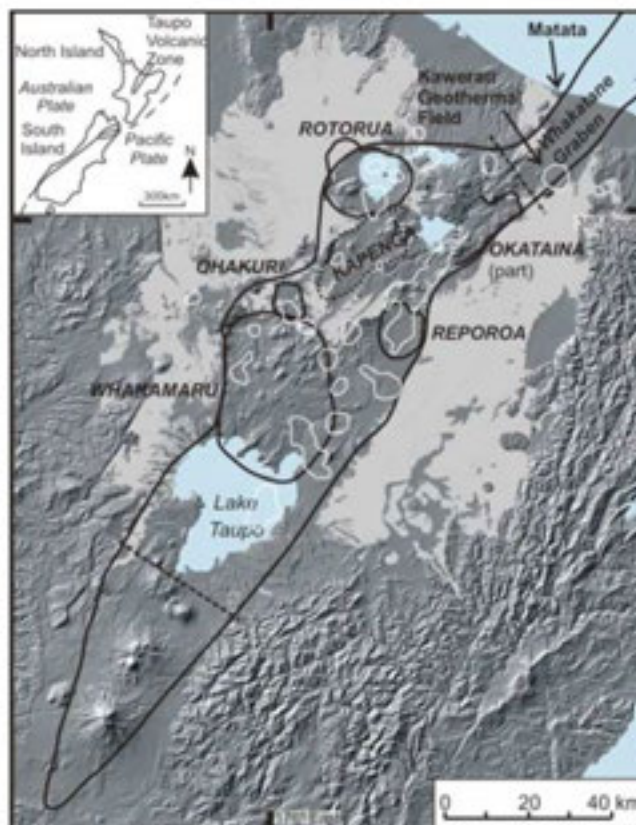
Figure 6.4: *The location of Matatā relative to the Taupo Volcanic Zone and Whakatāne Graben (Modified from Hochman, date unknown)*

6.8.2   Local Magnitude and Return Periods

The Eastern Bay of Plenty is a highly seismically active area. The Taupo Volcanic Zone is capable of generating earthquakes of Magnitude M_w 7, although the active faults located near Matatā are estimated to have potential magnitudes ranging from 6.3 to 6.5 (see Table 6.2). Several damaging earthquakes have occurred within the Bay of Plenty region over the past century, with the last large event being the 1987 Edgecumbe Earthquake. It is understood that this M_w 6.3 event generated ground shaking intensities of MM6 to MM8 in the Matatā area (Geonet.org.nz). Matatā was affected by several swarms of earthquakes between 2004 and 2007, although these were typically M_w 4 or less.

Tables 6.3 and 6.4 present estimated return periods for strong earthquake shaking and peak ground accelerations (PGA) for principal areas of settlement in the Bay of Plenty. Based on this information and the distribution of earthquake epicentres shown in Figure 6.5, Matatā could be expected to experience the approximate earthquake intensities and return periods presented in Table 6.5.
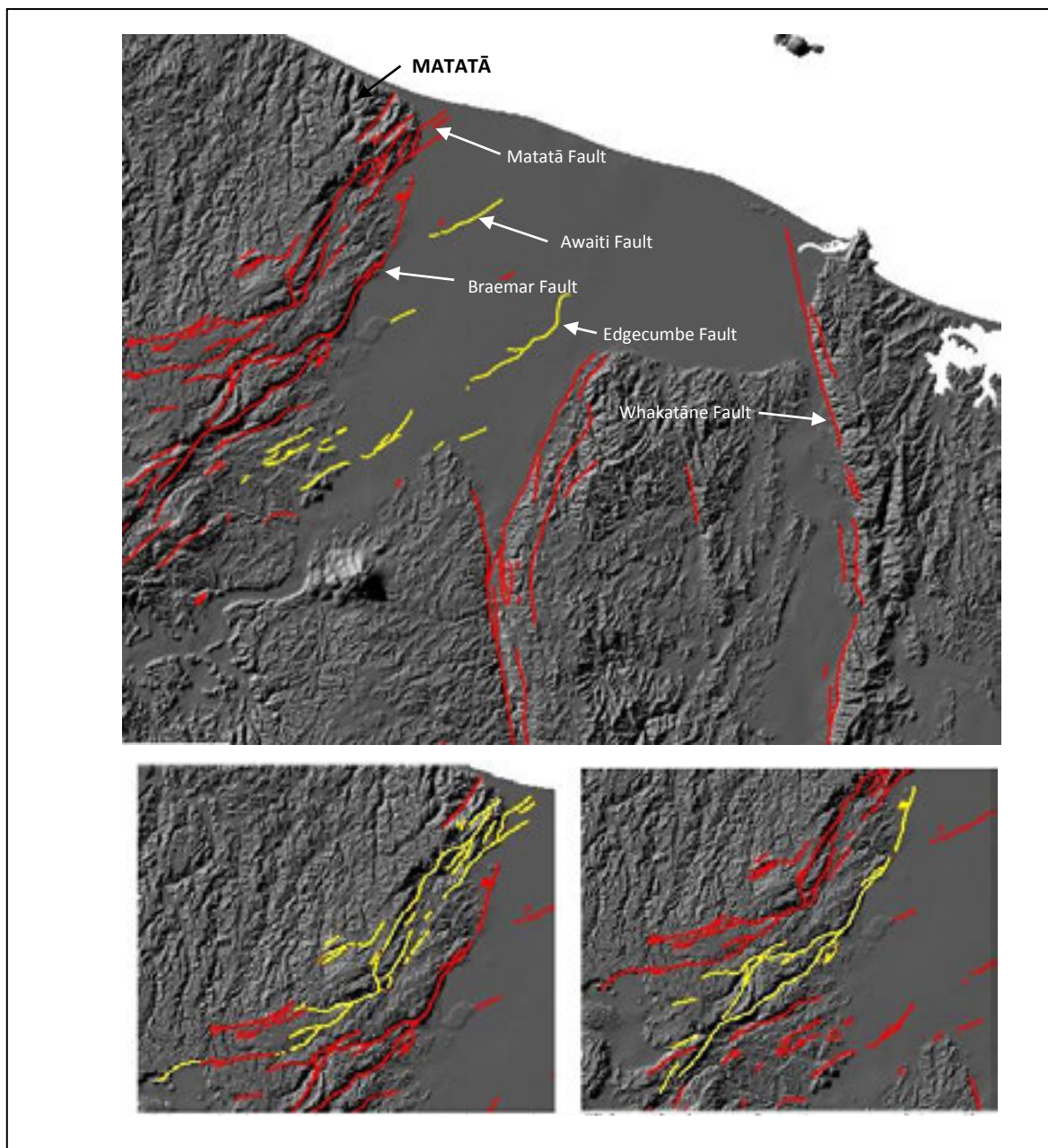
Figure 6.5:   Faults from GNS Active Fault Database
- *Main Figure – general area with historically active faults shown in yellow*
- *Left inset – Matatā Fault shown in yellow*
- *Right inset – Braemar Fault shown in yellow*
  (source: http://maps.gns.cri.nz/website/af/viewer.htm)
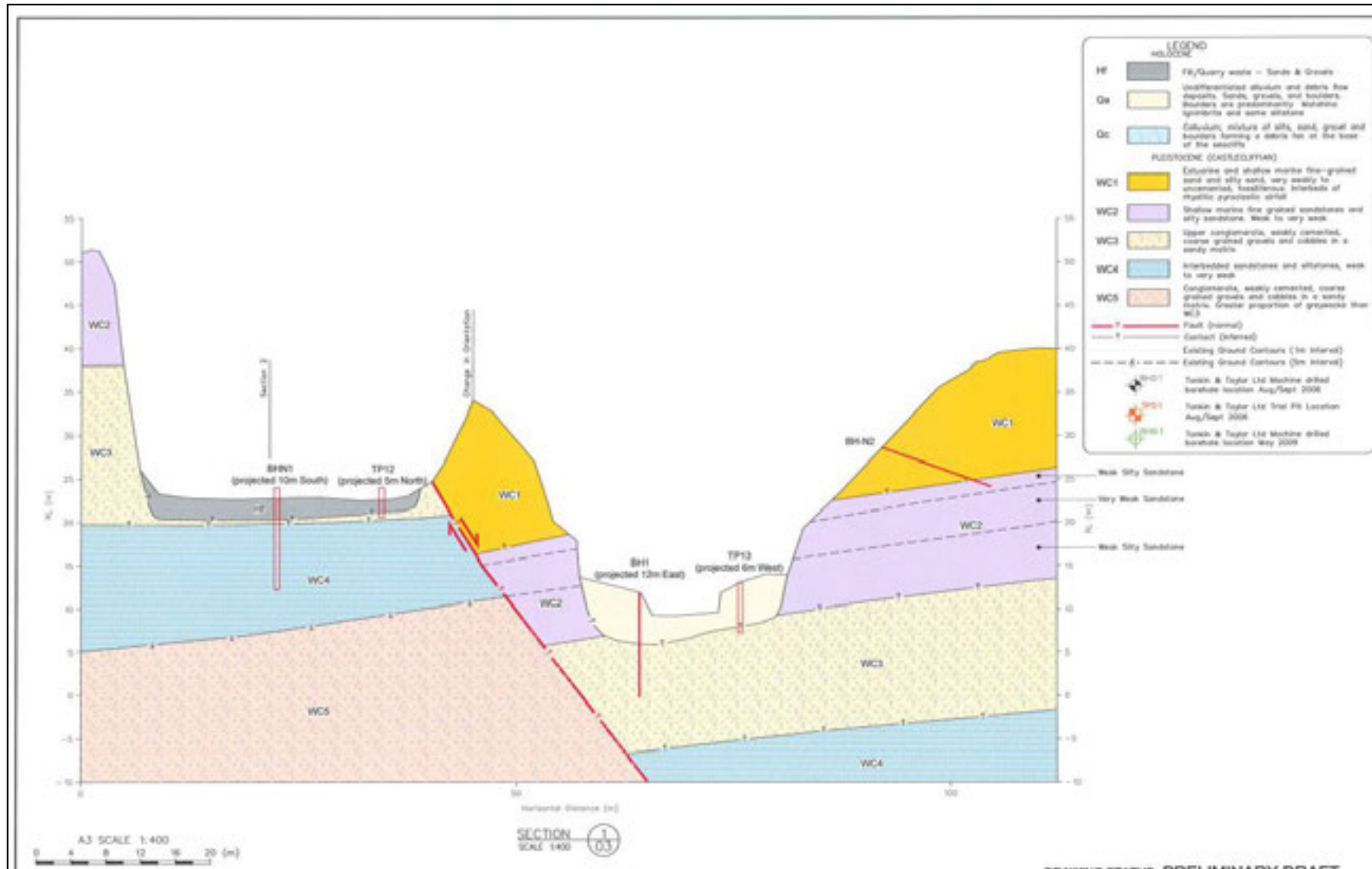
Figure 6.6: Geological section through the Awatarariki Stream showing the presence of a significant fault (source: Tonkin & Taylor, 2009a)

Table 6.1: Modified Mercalli Intensity Scale

MM Scale	Description
MM 1 - imperceptible	Barely sensed only by a very few people.
MM 2 - scarcely felt	Felt only by a few people at rest in houses or on upper floors.
MM 3 - weak	Felt indoors as a light vibration. Hanging objects may swing slightly.
MM 4 - light	Generally noticed indoors, but not outside, as a moderate vibration or jolt. Light sleepers may be awakened. Walls may creak, and glassware, crockery, doors or windows rattle.
MM 5 - moderate	Generally felt outside and by almost everyone indoors. Most sleepers are awakened and a few people alarmed. Small objects are shifted or overturned, and pictures knock against the wall. Some glassware and crockery may break, and loosely secured doors may swing open and shut.
MM 6 - strong	Felt by all. People and animals are alarmed, and many run outside. Walking steadily is difficult. Furniture and appliances may move on smooth surfaces, and objects fall from walls and shelves. Glassware and crockery break. Slight non-structural damage to buildings may occur.
MM 7 - damaging	General alarm. People experience difficulty standing. Furniture and appliances are shifted. Substantial damage to fragile or unsecured objects. A few weak buildings are damaged.
MM 8 - heavily damaging	Alarm may approach panic. A few buildings are damaged and some weak buildings are destroyed.
MM 9 - destructive	Some buildings are damaged and many weak buildings are destroyed.
MM 10 - very destructive	Many buildings are damaged and most weak buildings are destroyed.
MM 11 - devastating	Most buildings are damaged and many buildings are destroyed.
MM 12 - completely devastating	All buildings are damaged and most buildings are destroyed.
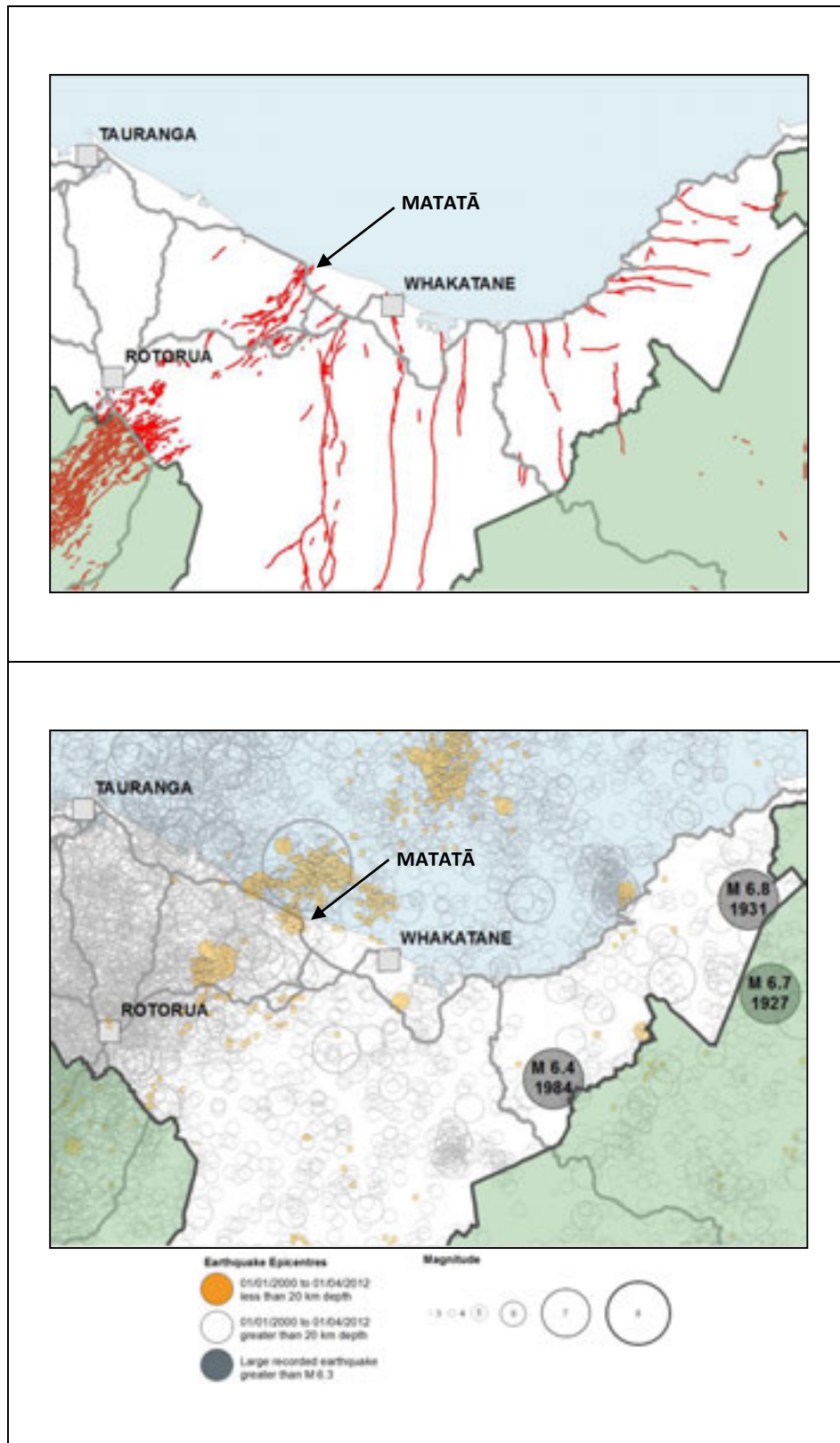
Figure 6.5:   Mapped active faults (top) and earthquake epicentres (bottom) for Bay of Plenty between 2000 and 2012 (Source: http://www.shakeout.govt.nz/bayofplenty/)

Table 6.2: Data for Seismic Sources near Matatā (Perrin, 1999)

Fault	Slip Rate (mm/year)	Estimated Earthquake (M_w)	Average Recurrence (years)
Matatā	2.0	6.3	<2000[1]
Braemar	1.0	6.3	<2000
Edgecumbe	2.5	6.5	550
Whakatāne	1.0	6.5	1000

1: Trenching of the Matatā Fault has revealed approximately four earthquakes post-dating 4800 years and probably 3300 years, with the most recent having occurred post-Kaharoa Ash (800 yrs) and is probably in the last 250 years (Perrin, 1999).

Table 6.3: Return Periods for Strong Earthquakes for Principal Bay of Plenty Settlements (Modified Mercalli Intensity Scale)

Location	MM>6	MM>7	MM>8
Tauranga	10	42	180
Rotorua	8	42	180
Whakatāne	5	36	150

Source: http://www.boprc.govt.nz/council/civil-defence/regional-hazards/earthquake/

Table 6.4:   Peak Ground Acceleration

Location	PGA (g) at 10% probability in 50 years	Approximate equivalent Modified Mercalli Intensity
Tauranga	0.40	8 – 9
Rotorua	0.45	8 – 9
Kawerau	0.50	9
Edgecumbe	0.55	9
Whakatāne	0.50	9

Source: Stirling *et al* (1998) In: Perrin (1999)

Table 6.5:   Approximate Shaking Intensity and Return Periods for Matatā

Modified Mercalli Intensity	Approximate Return Period (years)
MM6	5
MM7	35
MM8	150
MM9	475

7   Landslide Type and Triggers

7.1   Type

Landslides occur in many different forms depending upon, amongst other things, geology, topography, climate and triggering mechanism. The major types of landslide are presented in Figure 7.1. As this indicates, debris flows are one of the major types of landslides.

7.2   Trigger Events

Although factors such as geology and topography are the primary factors dictating whether slope instability can occur, it usually takes a triggering event, such as extreme rainfall or seismic shaking, in order for a landslide to be initiated. In the case of debris flows, extreme rainfall is a prerequisite for formation.

7.2.1   Rainfall

The relationship between high intensity rainfall and the occurrence of landslides on steep terrain is clear. Although there is no rainfall quantum that can be considered to be the single trigger point for landslides, it is clear that the greater the quantity and intensity of rainfall, the greater the probability of landslide or debris flow generation.

Three different, yet related factors control the potential for any single storm to result in landslides. These factors are:

- The amount of antecedent rainfall in the previous months, days and hours;
- The total amount of rainfall that falls during the storm event;
- The intensity of the rainfall, particularly the maximum intensity and its duration.

McSaveney *et al* (2005) describe research in the Southern Alps by GNS which indicated that few landslides occur when intensities are 1mm/minute or less. Larger landslides occur with rainfall intensities of approximately 1.5mm/min, however it takes intensities of approximately 2mm/min before landslides and debris avalanches occur widely. The critical rainfall intensity thresholds at which landsliding of various intensity occur will necessarily depend on both geology and terrain. Few intensity records of this type exist however, compared to the hourly or daily rainfall records ordinarily compiled.

Work undertaken by T&T as part of the Whakatāne and Ōhope escarpment QLRA provides a valuable insight into the triggering of landslides in these soft Quaternary materials (T&T, 2013). This is discussed in Section 9.2.1.

 High rainfall is a necessity in order for a debris flow to be generated. A number of authors have attempted to link rainfall intensity to debris flow initiation. However, given the recognised importance of local topographic, climatic and geological controls on debris flow initiation, there is probably limited applicability of such an approach to the derivation of a recurrence interval for debris flows. This is particularly the case when assessing the return period of debris flows with different magnitudes. Even temporal variations in material availability mean that equivalent rainfall events within the same catchment may well have very different results in terms of initiation and flow volume.
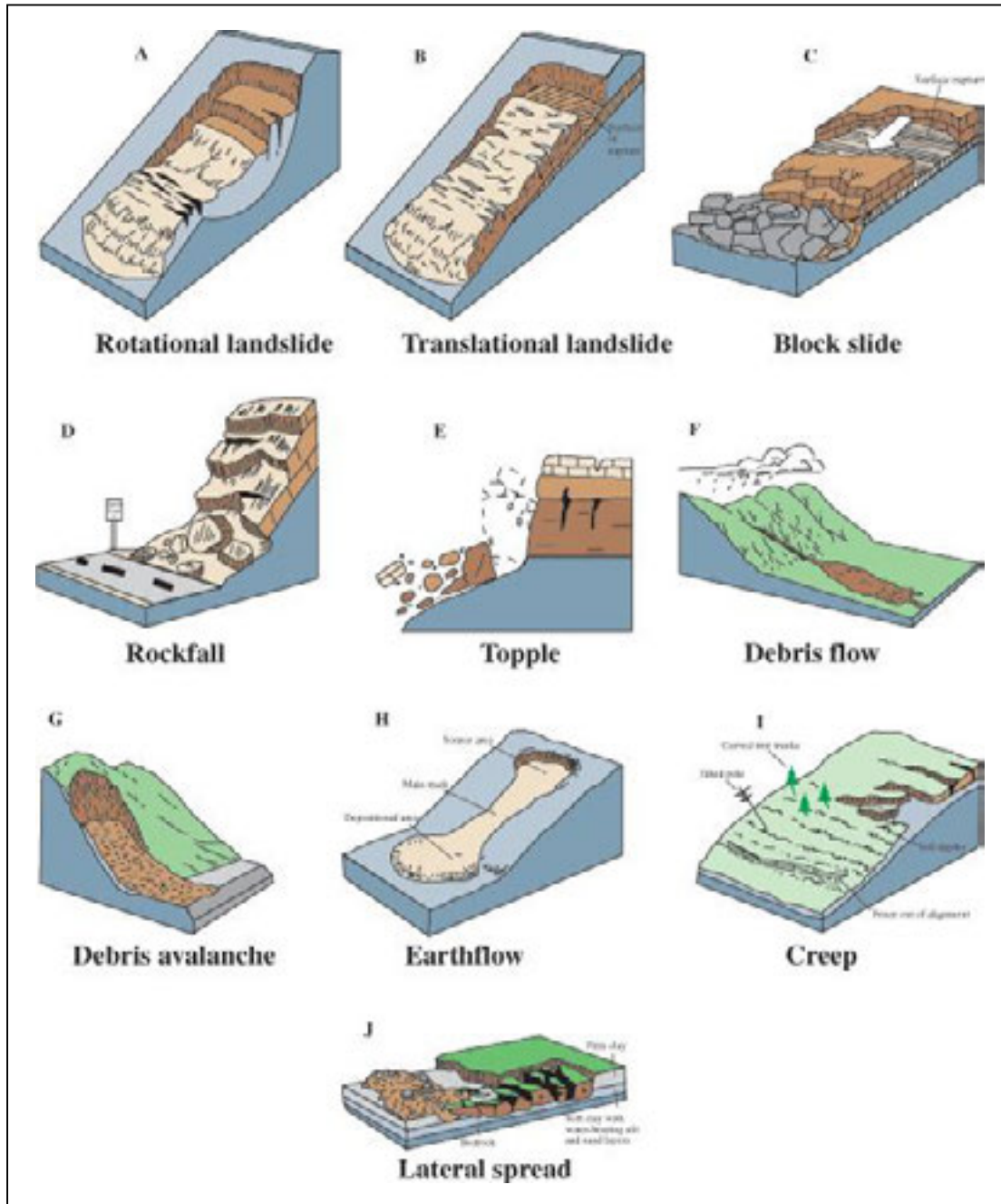
Figure 7.1:   Major landslide types (US Geological Survey Fact Sheet 2004-3072, July 2004).

7.2.2   Earthquakes

Seismic shaking can be a significant trigger of landslides. Although rainfall is the most common and more frequent trigger for landsliding in New Zealand, earthquake-induced landslides tend to be bigger (or at least have the capability to be) and are therefore potentially capable of greater impact. Landslide size is strongly dependant on earthquake magnitude, intensity and distance from the source (Hancox *et al*, 1997), although topography, rock and soil types and degree of ground saturation are also factors.

Given the highly seismic nature of the Matatā area (Section 6.8), it can be expected that seismically-triggered landslides have and will continue to occur periodically on the Matatā Escarpment. Some of the larger arcuate landforms shown on the landslide inventory may represent significant seismic-induced landslides, although this cannot be known for sure.

From a study of 22 historic earthquakes in New Zealand that are known to have produced damaging landslides, Hancox *et al* (2002) concluded that the minimum magnitude for earthquake-triggered landsliding was approximately M_w5, with significant landsliding only occurring at M_w6 or greater. Most earthquake-induced landslides occur on slopes of 20° to 50°. Attenuation of the seismic waves means that shaking intensity, and therefore the occurrence of landsliding, drops off significantly with distance from the point of rupture. With respect to location-specific shaking intensity, Hancox *et al* (2002) found the minimum intensity for landslide occurrence was MM6, although significant landsliding only occurred was shaking intensity reaches MM7 to MM8. Very large landslides were found to occur primarily at intensities of MM9 and MM10. Rock avalanches could be generated on high narrow slopes by earthquakes of M6.5 or greater.

Hancox *et al* (1997) compiled data on landslides resulting from the Edgecumbe Earthquake of 1987. All occurred within the MM7 isoseismal and the majority were enclosed by the MM9 isoseismal. The landslides that occurred as a result of the Edgecumbe Earthquake affected many slopes steeper than 40° but were mainly small and shallow (Perrin, 1999), with the majority being cut slopes steeper than 50°. Failures were more common in tephras and pumice materials. It is thought that some minor landsliding occurred on the Matatā Escarpment as a result of the 1987 Edgecumbe Earthquake, however the location, nature and extent of this landsliding is currently unknown.

A significant amount of landsliding occurred in the Western Bay of Plenty in July 2004 as a result of the M_w 5.4 Rotoma Earthquake, the epicentre of which was only 20km from Matatā. The ground shaking, which reached a maximum value of MM8, resulted in hundreds of EQC claims.

It should be noted that earthquake triggered landslides are typically debris avalanches and rockfalls and not earthflows or debris flows, which require a high volume of water within the debris in order to be generated

8   Instability at Matatā

8.1   General

The potential for slope instability on the Matatā Escarpment to materially affect the residents of Matatā was clearly demonstrated by the 2005 debris flow event. The debris flows, and their associated flood waters, destroyed 27 homes and damaged a further 87 properties. The most significant impacts were on the fan heads of the Awatarariki and Waitepuru streams (Figures 8.1 and 8.2 respectively). The heavy rainfall that generated the debris flows also triggered a large number of debris avalanche landslides on the Matatā Escarpment (Figure 8.3) and the steep terrain located behind it (Figure 8.4). Similar landsliding occurred in the summer of 2010-2011, although no debris flows are known to have been generated.

The main forms of slope instability observed on the Matatā Escarpment during the significant rainfall events of 2005 and 2010-2011 were debris avalanches originating on steep slopes, gullies and cliff faces. Despite the number of landslides generated during this period, no damage is known to have occurred as a result of direct landslide impact. Indeed, T&T have no records of any claims being made to the Earthquake Commission (EQC) for property or land damage as a result of any landslides originating from the Matatā Escarpment. This compares to over 150 claims for landslide damage to properties near the Whakatāne and Ōhope escarpments just for the years 2004 to 2012.

A distinction is made in the latter sections of this report between landslides and debris flows. Although debris flows are one of the major forms of landsliding (Figure 7.1) their transportation and depositional characteristics are sufficiently different to other landslide types, including debris avalanches, that the hazard and risk associated with them needs to be considered separately.

8.2   Relationship to Whakatāne and Ōhope Escarpments

The sequence of shallow marine, alluvial and pyroclastic deposits that make up the stratigraphic column of Matatā (Figure 6.2) is essentially the same as that occurring in the Ōhope area and what are known colloquially as the Ōhope Beds. Extensive observations made of the nature and behaviour of the Ōhope Beds with respect to slope instability are expected to be applicable to Matatā.

8.3   Previous Landslides

As noted above, T&T is unaware of any EQC claims related to landslide damage for any property at Matatā (as opposed to those claims associated with the 2005 debris flows). The primary sources of information regarding the location of historic landsliding at Matatā are aerial photographs, supplemented with limited geomorphologic mapping undertaken recently by T&T. Although such evidence allows the physical location of landslide sources to be estimated, considerable uncertainty remains with respect to the debris run-out distance and recurrence interval or return period of those historic events.

Figure 8.1:   View of the 18 May 2005 debris flow deposits, Awatarariki Stream

Figure 8.2:   View of the 18 May 2005 debris flow deposits, Waitepuru Stream

Figure 8.3:   View of debris avalanche landslides on the Matatā Escarpment as a result of the rain that generated the 18 May 2005 debris flow event

Figure 8.4:   View of the debris avalanche landslides typical of those that occurred within the hills behind Matatā in May 2005

Photographs from the early to mid 20th Century (Figures 8.5 to 8.8) present an image of the Matatā Escarpment as being relatively well vegetated and largely devoid of significant landslide scaring. Nevertheless, the presence of a significant debris or talus slope at the base of the escarpment, particularly west of the Awatarariki Stream (Figure 8.5), clearly illustrates that a significant quantity of material has descended the escarpment in the form of landslides since the ocean retreated from the base of the cliffs during the Holocene[2].

Figure 8.9 presents aerial photos of the study area taken in 2002, 2007 and 2011 respectively. It is clear that there were very few landslides on either the escarpment or the hills behind it prior to the 2005 debris flow event. Although taken some time after the debris flow event, the 2007 aerial photograph shows the significant landsliding that occurred within the hills and on the escarpment, particularly to the west of Matatā. A similar pattern of landsliding appears to have occurred as a result of the series of large rainfall events that affected the Eastern Bay of Plenty in 2010 and 2011. In contrast, there is a clear lack of significant landsliding within the rectangular block located between the Awatarariki and Waitepuru streams.

A number of arcuate features of varying scales were noticed on the crest of ridges from aerial photographs and during our field work. These are likely to represent the source areas of older, larger and possibly seismically triggered landslides. Accompanying many of these features are accumulations of debris in the form of talus or debris fans (Figure 8.10).

T&T has heard an anecdotal account of debris from a landslide originating on the slopes above (unformed) Simpson Street reaching Matatā lagoon in the early 1900s. If true, this debris travelled some 300m from its point of origin. The collation of additional anecdotal information of this type would assist in the development of understanding of natural hazards in the Matatā area.

All of the landslides identified within the study area from photographic evidence are considered to be the result of intense rainfall events, as was the case for the Whakatāne and Ōhope escarpment (T&T, 2013).

A landslide inventory has been developed for Matatā Escarpment based primarily on photographic evidence, supplemented with limited field mapping. This is presented as Figures C1 to C3 (Appendix C).

8.4 Previous Debris Flows

There is anecdotal and geomorphologic evidence for debris flows having occurred at Matatā prior to 2005, however neither the magnitude nor the recurrence interval of such events is known. McSaveney *et al* (2005) describe accounts of possible debris flows in the Awatarariki Stream in 1869 and the Waitepuru Stream in 1950. McSaveney *et al* (2005) also describe the presence of large boulders on the seafloor near Matatā being a possible indication of major debris flows having occurred prior to European settlement. Shearer (2005a,b) provides a detailed review of past flood and possible debris flow events based on an extensive review of historical records and interviews with residents.

Although topography of the lowlands area is subdued, there is geomorphologic evidence for the presence of debris fans extending out a considerable distance from the base of the escarpment. Although debris fans are a characteristic of regular alluvial processes, the size of the boulders that have been observed indicate that debris flows have at least contributed to the formation of the flatlands. An example of such a deposit away from the major streams is the debris fan near Clarke Street. This fan was reported in McSaveney *et al* (2005) as a debris flow deposit. The inferred

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[2] The Holocene is a geological epoch that extends from approximately 12,000 years ago to the present day. It represents the period of temperature and sea level rise that accompanied the end of the last major glaciation.

extent of potential debris flow deposits is indicated in Figure 6.1. Maps showing the extent of deposition from the 2005 event are presented as Figures D1 to D3 (Appendix D). A map showing the detailed distribution of debris on the Awatarariki Stream fanhead is presented as Figure 8.11.

Figure 8.5:   *View of the former Matatā railway station in 1924. The station was located approximately where the current oversize load bypass rejoins SH2. Note the numerous areas devoid of vegetation and the significant talus slope developed at the base of the escarpment (reproduced with permission of Alexander Turnbull Library)*

Figure 8.6:   *View of Matatā in 1953. Awatarariki Stream (A). Note how the former alignment of SH2 goes up and around a debris fan (B). (reproduced with permission of Alexander Turnbull Library).*

Figure 8.7:   View of eastern and central Matatā in 1951 (reproduced with permission of Alexander Turnbull Library)

Figure 8.8:   View of Eastern & central Matatā in 1965: Waitepuru Stream (A): Division Street (B); Debris Fan (C). Note the limited elevation of the escarpment compared to that west of the town (reproduced with permission of Alexander Turnbull Library)

Figure 8.9:   Aerial photos showing the density of landslides in the general study area (top) and Awatarariki Stream (bottom between 2002 and 2011). Note the much lower density of landslides in the area between the Awatarariki and Waitepuru streams (yellow box, top middle photo)

Figure 8.10: Debris fan formed at the base of the Matatā Escarpment in the general vicinity of Clarke Street.
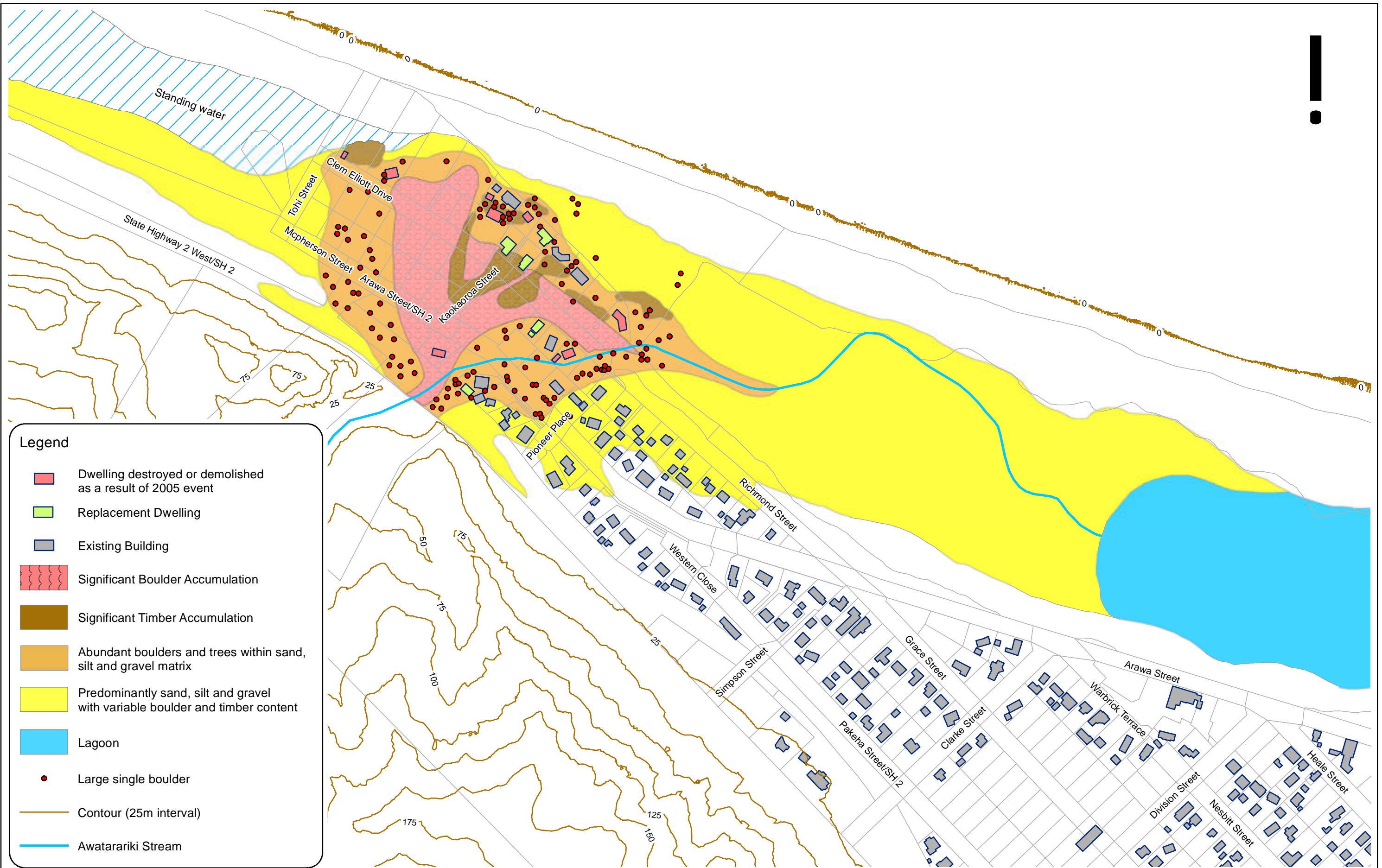
Legend

▱ (pink)	Dwelling destroyed or demolished as a result of 2005 event
▱ (green)	Replacement Dwelling
▱ (grey)	Existing Building
▨ (pink pattern)	Significant Boulder Accumulation
▨ (brown)	Significant Timber Accumulation
▨ (orange)	Abundant boulders and trees within sand, silt and gravel matrix
▨ (yellow)	Predominantly sand, silt and gravel with variable boulder and timber content
▨ (blue)	Lagoon
• (red dot)	Large single boulder
⌒ (brown line)	Contour (25m interval)
⌒ (blue line)	Awatarariki Stream

Standing water

Clem Elliott Drive

Tohi Street

Mcpherson Street

State Highway 2 West/SH 2

Arawa Street/SH 2

Kaokaoroa Street

Pioneer Place

Richmond Street

Western Close

Simpson Street

Grace Street

Clarke Street

Pakeha Street/SH 2

Warbrick Terrace

Arawa Street

Heale Street

Division Street

Nesbitt Street

A3 SCALE 1:4,000

0   50   100   150   200   (m)

Location Plan
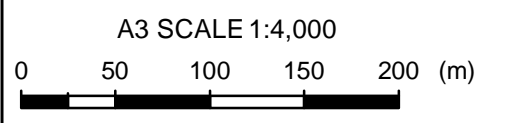
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
www.tonkin.co.nz

DRAWN	JC	Nov.13
CHECKED		
APPROVED		

ARCFILE
29115-F8.11.mxd

SCALE (AT A3 SIZE)
1:4,000

PROJECT No.
29115

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris from 2005 Event

FIGURE No.
Figure 8.11

Rev.
0

9 Estimation and Reliability of Event Occurrence

Landslide susceptibility maps are an acknowledgement that, for various reasons, some locations have a greater (or lesser) propensity for landsliding to occur than others. The concept of landslide hazard is similar, except the probability of occurrence is implicitly considered. Be it expressed as an exceedance probability, recurrence interval, return period or frequency, the relative abundance of landslides affecting an area each year lies at the heart of both landslide hazard and risk assessments.

Aside from being critical to such assessments, the frequency at which landsliding occurs is also one of the most difficult parameters to determine with any degree of certainty. This is because its estimation requires an extensive knowledge of past events, including their location, magnitude, age and trigger mechanism.

An assessment of landslide probability requires an assessment not only of the past events (i.e. landslide inventory) but consideration also needs to be given to the return periods of likely trigger events such as rainstorms and earthquakes.

9.1 Landslide Inventory

Unlike the Whakatāne and Ōhope escarpment, where a relatively large and reasonably well documented record of landslides exists, the Matatā Escarpment landslide inventory is deficient in data concerning the frequency of past landsliding events.

Some 70 landslides are represented on the landslide inventory (Appendix C). The majority of these (approximately 50) occurred within the past decade, predominantly in the 2004, 2005 and 2010-2011 storm events. A further 25 presumably much older landslides have been recognised from geomorphological considerations. Some of these features are likely to be the cumulated effect of several landslides rather than a single large event.

The landslide inventory for Matatā (Appendix C) encompasses the following data:

- Recent landslides of known age and known trigger (i.e. those that occurred on 17 – 18 May, 2005 due to a high rainfall event);
- Recent landslides of approximate age and known trigger (i.e. those that occurred during 2010-2011 as a result of an extensive wet period with a number of high intensity rainfall events);
- Old landslides of unknown age and uncertain trigger (i.e. landslides observable in historic photographs that were probably rainfall-induced); and
- Ancient landslides of unknown age and unknown trigger (i.e. arcuate features within the landscape indicative of large landslides of significant age. Some are possibly of seismic origin)

A clear pattern exists in the distribution and intensity of landsliding on the Matatā Escarpment. These, which can be seen in the aerial photographs of Figure 9.9, are:

- The greatest density of landslides occurs on the steep and tall escarpment west of the Awatarariki Stream;
- Almost all of the large landslides that travelled a significant distance from the base of the escarpment occurred west of the Awatarariki Stream;
- There are significantly fewer mapped landslides on the escarpment located behind the township. The majority of these features occur on the slopes located between the Awatarariki Stream and Clarke St (see Figure 2.2 for the location of roads and streets). A small number of landslides reached the talus slope;

- South of Clarke St, landslides are relatively rare and small in size. This section of escarpment is typically lower in both elevation and gradient than those with more landslides.

Although the location of existing landslides can be determined with some degree of accuracy from aerial photographs and field observations, the date of occurrence for any feature other than the most recent, is typically poorly known or even completely unknown.

Assigning a frequency or annual probability of occurrence to such events is not only problematic, any uncertainty associated with these parameters will have a direct and profound effect on any subsequent Loss of Life or Property Loss risk calculations. The following section describes the methods by which design event probabilities have been derived.

9.2 Rainfall-Triggered Landslides

9.2.1 Frequency of Triggering Events

Whether landsliding is triggered by a rainfall event such as a cyclonic storm depends not only on the total rainfall produced, but also the intensity of the rain and antecedent rain, possible for several months before the storm. There is therefore no unique set of circumstances that can be considered to represent the trigger point at which landsliding will occur. Nevertheless the QLRA undertaken by T&T for the Ōhope escarpment (T&T, 2013) indentified a number of factors that can aid the identification of landslide-inducing rain events:

- A very high daily rainfall will always produce landslides in areas with weak geology. The threshold for widespread landslide occurrence was approximately 120mm per day. It appeared that once daily rainfall reaches this level, landsliding occurred regardless of other factors;
- Landsliding may or may not occur when daily rainfall exceeds 100mm. It appears that at a level below 120mm, factors such as rainfall intensity or the amount of antecedent rainfall play a significant part in determining whether landsliding actually occurs;
- Extensive antecedent rains can allow landsliding to occur during an event that delivers significantly less than 100mm of rain. Landsliding was observed on some occasions at Ōhope as a result of rains as low as 40mm/day, the rate of rainfall that ordinarily would not produce landslides, however extensive rain in the preceding weeks clearly lowered the triggering level significantly.

These observations are similar to those made by Glade (1998) who, in analysing records of rainfall and landslides in the Wairarapa since 1880, found that:

- Landslides always occurred when daily(24 hour) rainfall exceeded 120mm;
- Daily rainfall of between 40 and 120mm sometimes produced landslides if preceded by wet weather
- The 3 day (72 hour) antecedent rainfall associated with landsliding usually exceeded 120mm.

General experience suggests that an hourly rainfall intensity of approximately 25mm can result in significant landsliding.

Daily rainfall records have been obtained from the Bay of Plenty Regional Council for automatic raingauges installed at Awakaponga and Ohinekoao, located some 4 to 5km from Matatā. The locations of the raingauges are indicated on Figure 9.1 whereas the daily rainfall data is shown on Figure 9.2. The Ohinekoao raingauge is located closer to Matatā and is within the escarpment terrain, however its length of operation is substantially less than that of the Awakaponga raingauge.

It is evident from the data that higher total daily rainfall events have become increasingly common in the Matatā area since the mid-2000's. Prior to the storm of 18 May 2005, rainfall in excess of 100mm had only been recorded twice in the preceding 16 years, yet it occurred 11 times in the subsequent 6 years between 2011 and 2005, a 13 fold increase in annual rate. Figure 9.2 clearly illustrates the exceptionally high rainfall that occurred during the 18 May 2005 storm event. Data recorded at Awakaponga include:

- 15 minute rainfall of 30.5mm
- One hour rainfall of 95.5mm
- 24 hour rainfall of 302mm

These are some of the highest intensity rainfall records ever recorded in New Zealand. Both the 1 hour and 24hr rainfall were estimated to be some 30% greater than the respective 1%-annual-exceedance-probability (AEP) or 100 year return period, which equates potentially with a 500 year return period (McSaveney *et al*, 2005). The exceptional nature of the May 2005 event is indicated by the fact that the 1 hr, 12hr, 24hr, 48hr and 72hr rainfall records for Awakaponga were all set at this time.

Figure 9.3 presents the daily rainfall records for Awakaponga and Ōhope together with indications of when landsliding occurred. The record of landsliding at Ōhope is very detailed thanks to the abundance of EQC claims for this area (T&T, 2013). The records for Matatā are much less complete. It is quite possible that some landsliding took place on the Matatā Escarpment on days of heavy rainfall other than those indicated. Even though the data is incomplete, it does support the observations presented above that landsliding is commonly associated with:

- Effectively all one-off rainfall events of 120mm or more;
- some 100mm events; and
- some events less than 100mm if the preceding weeks and days had been wet.

Figure 9.3 also shows the significant increase in landsliding at Ōhope between 2010 and 2011 at rainfall levels typically not associated with landslide occurrence. The experience from Ōhope is that unusually high rainfall events are ordinarily required to trigger landsliding, however the threshold reduces the longer a wet spell continues, and the ground becomes saturated.

With a total of 8 days over the past 24 years having delivered rainfall of 120mm or greater, the storm associated with landsliding can be inferred to have an approximate return period of 3.0 years. The long-term return period is probably longer than this as many of the 120mm or greater events have occurred in the past 6 years. The return period for such events prior to 2010-2011 was approximately 5 years.

The storm event that delivers 100mm or more of rain occurs on average every 1.8 years. In such cases, landsliding may or may not occur depending upon other factors. It can be concluded that, based on rainfall data and previous landsliding history, landsliding can be expected to occur on the Matatā Escarpment every 2 to 3 years on average. Given that the data is skewed by recent events, a design return period for a landslide-triggering rainstorm of 5 years appears reasonable i.e. an annual probability of exceedance of 0.2. The actual annual probability of a landslide occurring depends not only on the return period of the triggering event but also the number of landslides generated by it. If we assume two potentially destructive landslides each storm, the annual return period for landslide occurrence is 0.4.

In reality, these landsliding events are likely to be unevenly spread, with more than one landslide event occurring in one year, whereas possibly nearly a decade or more could pass without landsliding occurring.

A probability of occurrence of 0.40 has been adopted as the annual probability of occurrence for rainfall-triggered landslides on the escarpment west of Awatarariki Stream which is the part most vulnerable to landslides, as per the aerial photos.

Figure 9.1:   Location of the Awakaponga (A) and Ohinekoao (O) raingauges

9.2.2   Probability of Rainfall-Triggered Landslide Occurrence

Using just the data available for the landsliding that occurred between 2005 and 2011, it could be concluded that a few large debris avalanche landslides could be expected to occur on the escarpment every year or so on average, particularly west of the Awatarariki Stream. Such an approach to estimating landslide frequency would however be profoundly conservative, as the intensity of landsliding between 2005 and 2011 cannot be considered typical of the long-term. This view is supported by historic photographs dating back several decades (Section 8.3) which show a general lack of landslides on the escarpment, other than the small features one would expect in such terrain.

Nevertheless, the abundance of debris (talus) at the base of the escarpment is an indicator that landsliding is an integral part of the natural processes affecting the escarpment as a whole. This should be expected given the steep nature of the terrain and the very weak geology.

Because no properties or dwellings are located on the escarpment slopes themselves, only those landslides large enough or fluidised enough to travel onto, or beyond, the talus slopes located at the base of the escarpment need to be considered. Based on available information, it is reasonable to expect that such landslides occur only every few years at most. It is important to note that although the event that triggers a landslide event (be it rainfall or earthquake) may not occur very often, they typically result in several landslides occurring at about the same time. The

return period of the landsliding (i.e. number of years / number of landslides that occurred in that time) will therefore be less than the return period of the triggering event.

From a purely qualitatively perspective, one would expect that a large landslide would occur less than once per year west of the Awatarariki Stream, and on a significantly less frequent basis for the other parts of the escarpment.

Given the lack of dated landslides on the Matatā Escarpment, consideration has been given to the landslide frequency estimates developed for the Ōhope Escarpment behind West End Road. This section of escarpment is considered to be relevant as it exhibits a very similar geology, terrain and recent landslide history to the Matatā escarpment west of the Awatarariki Stream.

The landslide inventory for West End Road includes 49 landslides covering a period of 70 years, giving a recurrence interval or return period of 1.43 years i.e. we can expect, on average, one landslide to occur approximately every one and half years. The annual probability of landslide occurrence is the inverse of the return period i.e. 0.7 or 70%.

Note that the annual probability of occurrence is effectively the long-term average. The probability that a landslide will occur in any single given year is less than the average annual probability. In the case of West End Road, the probability of a landslide occurring in a given one year period is $1 - e^{-1/T} = 0.5$, or 50%. With each passing year, the probability of a landslide occurring increases with the lengthening observation period (Table 9.1). This should not be mistaken for an increasing probability of occurrence per annum as time passes without an event happening.

Note that these estimates relate only to rainfall-triggered landslides, as this was the basis of the frequency estimation at Ōhope.

If it is assumed that the escarpment west of Awatarariki Stream has a landslide frequency similar to that at West End Road, an annual probability of occurrence of 0.7 could be adopted. Rainfall data however suggests a return period of approximately 5 years, and an annual probability of landslide occurrence[3] of 0.4 (see Section 9.2.1).

This is in line with the qualitative assessment above in that significant landsliding can be expected to occur on somewhat less than annual frequency. Based on changes in topography and the number of landslides present further to the south, reduced probabilities of occurrence have been adopted for those sections of escarpment located further to the east and south. The design probabilities of rainfall-induced landslides are presented in Table 9.2.

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[3] Annual probability of landslide occurrence, not occurrence of the triggering rain storm
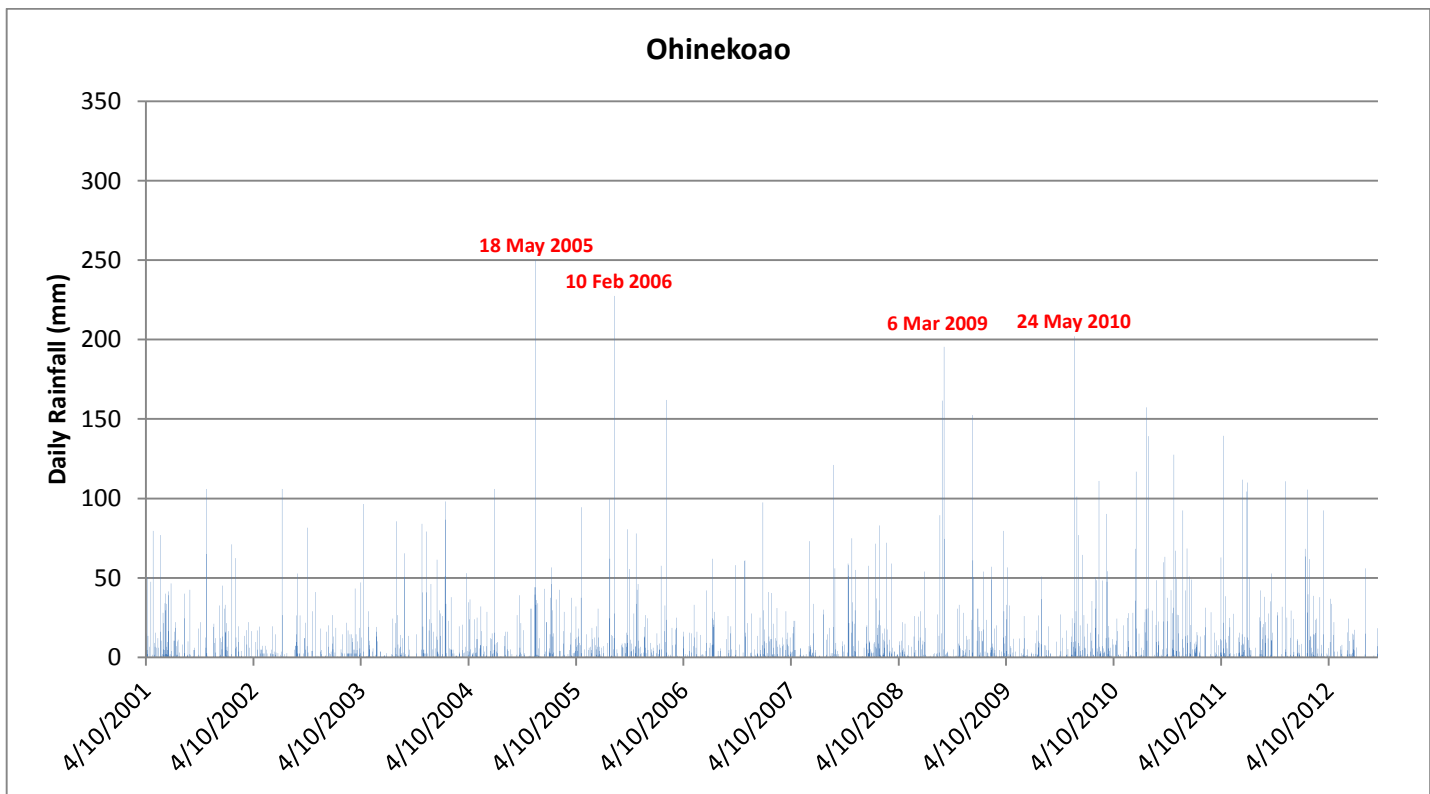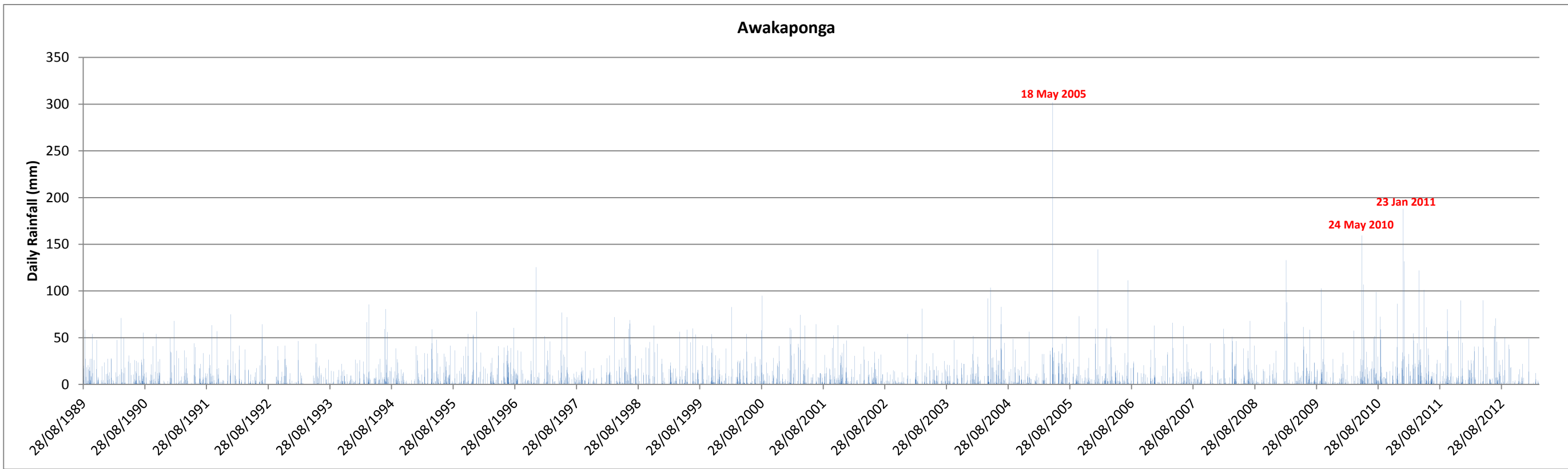
Figure 9.2:   Daily rainfall records for raingauge No. 769701 "Tarawera" at Awakaponga and No. 769705 "Ohinekoao" at Harris Saddle, Herepuru Road. Dates of major rainfall events are indicated
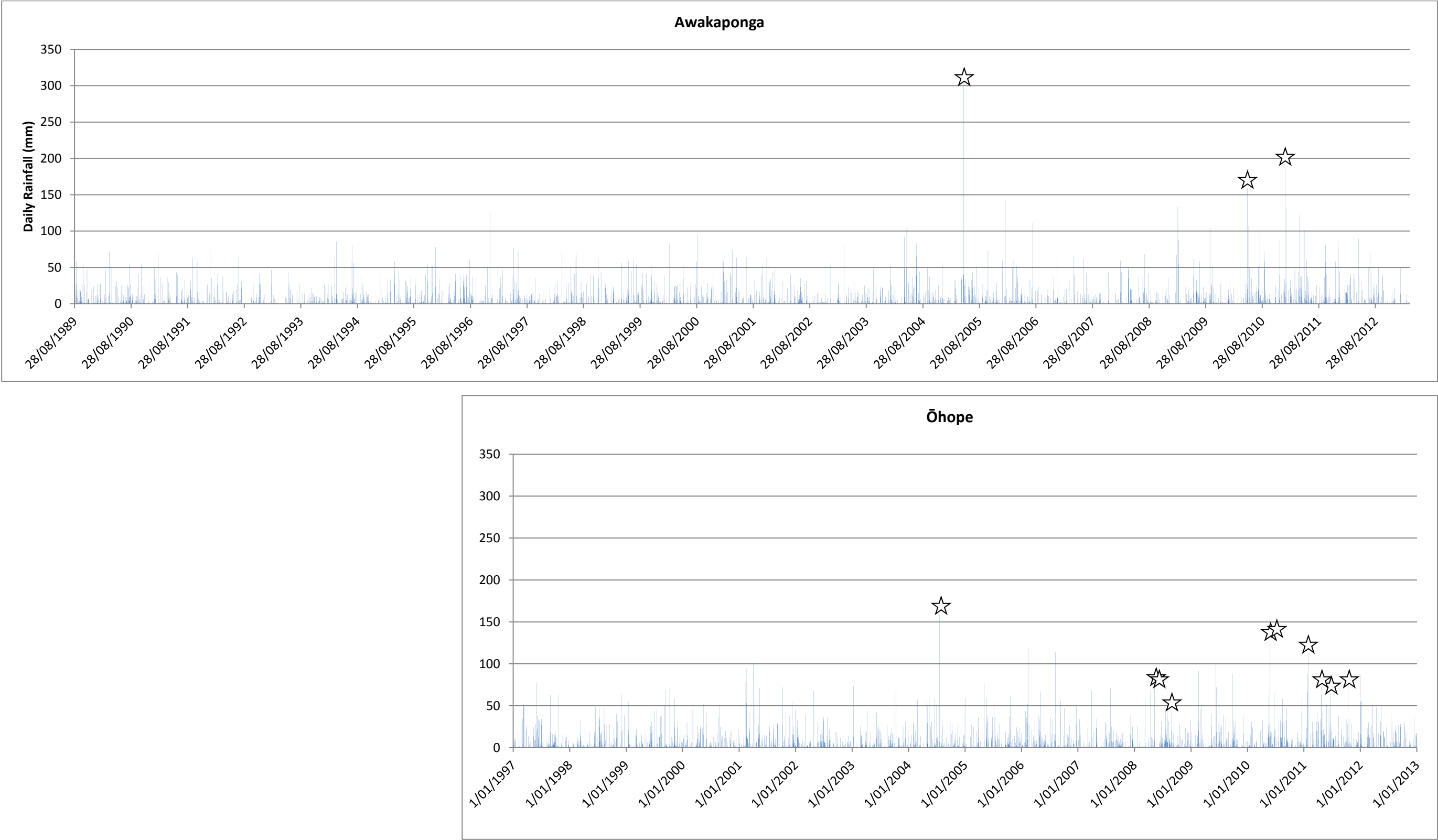
Figure 9.3: Daily rainfall data for Awakaponga and Ōhope. Significant landslide events are indicated by a star.

Table 9.1: Probability of Landslide Occurrence, West End Road, Ōhope

Time Period (T) (years)	Probability of a Landslide with a 1.43 year return period occurring in time (T)
1	0.50
2	0.75
3	0.88
4	0.94
5	0.97
10	0.999

Table 9.2: Design Probability of Occurrence, Rainfall-Triggered Landslides

Escarpment Section	Annual Probability of Occurrence
West of Awatarariki Stream	0.40
Awatarariki Stream to Division St	0.14
South of Division St	0.10

9.3 Debris Flows

9.3.1 Frequency of Triggering Events

A prerequisite for a debris flow to occur is high rainfall event. An unusually high rainfall is required to generate debris flows in areas such as Matatā where debris flows are an infrequent or indeed rare event. There are no rigorous methods by which the probability of debris flow occurrence can be estimated (Fuchs *et al*, 2008). Information on past debris flow events is typically the most reliable indication of future debris flow occurrence and magnitude. Unfortunately at Matatā, our understanding of past debris flows is effectively limited to observations made of the 2005 event and the mapping of debris from past, possibly ancient events.

As described above, the return period of the rainfall event that triggered the 18 May 2005 debris flows has been estimated to be in the order of 200 to 500 years. Debris flows are expected to be less frequent than potentially damaging earthquakes and many times less frequent than potentially damaging rainstorms.

9.3.2 Probability of Debris Flow Occurrence

The database of historic debris flows within the Awatarariki Stream is insufficiently detailed to define a reliable return period for the 2005 event. T&T (2009a) assumed that the 2005 debris flow event had a return period of somewhere between 200 and 500 years, although there was considerable uncertainty around this estimate. Although debris flow frequencies do not generally coincide with precipitation patterns (Hungr *et al*, 1984), the very large size of the flows suggests that the return period of the 2005 event is likely to be hundreds of years rather than decades.

9.4 Earthquake-Triggered Landslides

9.4.1 Frequency of Triggering Events

After rainfall, earthquakes are the second most common trigger mechanism for landslides in New Zealand. Strong earthquakes may occur on a less frequent basis than heavy rainfall events, although when they do occur, strong earthquakes can be responsible for triggering a great many landslides. Strong earthquakes are also more likely to generate large to very large landslides than rainfall, but not debris flows. It is also noted that the recurrence interval of the heavy rainfall at Awakaponga that was responsible for the 2005 debris flows at Matatā is approximately 500 years, which is comparable to the recurrence interval for MM9 intensity shaking (475 years, Table 9.3).

From a consideration of strong earthquake return periods (Table 6.5), some instability could potentially be triggered by seismic events with a return period as short as 35 years, although with a shaking intensity of MM7, this would be expected to be of relatively limited extent and associated with steep cutting or marginally stable cliffs. Significant landslides would only be expected to occur on natural slopes during an earthquake with an intensity of MM8 or MM9, which have estimated return periods in the order of 150 and 475 years respectively. The estimated return periods and physical effects of earthquakes with different local intensity values are presented in Table 9.3. For the purposes of hazard and risk assessment, it is assumed that the return period of significant seismic-trigger landsliding on the Matatā Escarpment is 150 years.

Although rainfall and earthquakes are considered here to be separate triggers, they are not entirely independent variables, as rainfall before an earthquake can substantially increase the number and size of landslides caused by an earthquake (Hancox *et al*, 2004; Dowrick *et al*, 2008).

9.4.2   Probability of Earthquake-Triggered Landslide Occurrence

Using experience grained from past earthquakes, including the 1987 Edgecumbe event, it has been assumed that significant landsliding would only occur on the Matatā Escarpment once seismic shaking reached or exceeded an intensity of MM8. The recurrence interval of such an event is estimated to be 150 years or more (Table 6.5). Although the probability of exceedance for such as event is only 0.006, this is the probability that one or more _earthquakes_ will occur, not the number of landslides, as was the case with the rainfall-triggered events. In order to derive an equivalent annual probability of seismic landsliding, it is necessary to estimate the number of landslides generated from an MM8 or greater event. The larger the number of landslides generated, the greater is the equivalent annual probability of landslide occurrence.

To illustrate this, a range of possible landslide numbers for both the MM8 and MM9 intensity events is presented in Table 9.4. It can be seen that if the number of landslides generated is small, the equivalent annual probability is significantly smaller than the equivalent for rainfall-triggered landslides. If however the number of landslides number, say, 25 or more for a 150 year return period event, then the equivalent annual probability becomes significant, and possibly similar in magnitude to the rainfall-triggered landslides.

There is no way of knowing how many landslides would be generated by an MM8 or greater level of shaking. It is conceivable however that one or two dozen large landslides could eventuate. These could be expected to occur primarily on the escarpment west of Awatarariki Stream and probably to a much lesser extent for the slopes to the east. The lower and flatter slopes south of Clarke St would be expected to be much less susceptible to seismic-triggered landslides than the escarpment to the north.

Assuming that 10 large seismic-triggered landslides occurred in a 150 year event, this would be an annual landslide occurrence rate equivalent to only 15% of the equivalent rainfall-induced landsliding. Obviously if lower or higher numbers of landslides are assumed then the relative proportion will similarly decrease or increase. Unless many dozens of major landslides occurred, the seismic landslide hazard is only a fraction of that represented by rainfall-triggered landslide. For the purposes of this assessment, it has been assumed that the seismic-triggered landslide probability is 15% that of the rainfall-triggered value. This has been applied uniformly over the escarpment to reflect the observable variation in susceptibility of the slopes.

Design landslide occurrence (exceedance) probabilities are presented in Table 9.5.

Table 9.3:   Estimate of Seismic Landslide Occurrence for Matatā

Modified Mercalli Intensity Scale	Relative Occurrence of Landslides[1]	Approximate Return Period (years)
MM6	Very minor, if at all. Essentially limited to marginally stable to unstable areas such cliffs etc. Loose material may be dislodged from existing failures, talus slopes etc. A few very small ($<10^3$m^3) soil and regolith slides from steep banks and cuts.	5
MM7	Limited primarily to steep cuttings and cliffs of low stability. A few small to moderate (10^3-10^5m^3) landslides, mainly rock falls on steep slopes, cliffs and cuts. Small discontinuous areas of shallow sliding.	35
MM8	Many small to moderate slides (10^3-10^5m^3), many on cuttings, cliffs etc. Significant landsliding in susceptible areas, with some reactivation of scree slopes. A few large (10^5-10^6m^3) landslides from coastal cliffs and possibly debris avalanches from steep mountain slopes.	150
MM9	Widespread occurrence on general steep slopes. Very large landslides on coastal cliffs. Large rockfalls/debris avalanches on steep mountain slopes. Moderate to large failures of road cuts and slumping of road edge fills. Many small to large (10^3-10^6m^3) failures in regolith and bedrock and some very large landslides ($>10^6$m^3) on steep susceptible slopes	475

Modified from Dowrick *et al* (2008)

Table 9.4:   Probability of Exceedance for Seismic-Triggered Landslides

Earthquake Recurrence Interval (Intensity)	No. of Landslides Generated	Equivalent Annual Probability of Occurrence
150 years (MM8)	1	0.007
	10	0.06
	25	0.15
	50	0.28
475 years (MM9)	1	0.002
	10	0.02
	25	0.05
	50	0.10
	100	0.18

Table 9.5:   **Estimated Annual Probability of Significant Landslides Occurring on the Matatā Escarpment**

Section	Typical Hazard Rating[2]	Annual Probability of Landsliding		
		Rainfall-Triggered	Seismic-Triggered[1]	Total Events
West of Awatarariki Stream	High	0.4	0.060	0.46
Awatarariki Stream to Division St	High	0.14	0.020	0.16
South of Division St	Moderate	0.10	0.015	0.12

Notes:

1) Based on 15% of rainfall triggered events

2) Refer to Figures E1 to E3, Appendix E

10 Hazard Assessment

10.1 Landslide Susceptibility

Landslide susceptibility is a measure of a particular area's propensity to either generate or be inundated by landsliding. The assessment of susceptibility is based on the following two axioms;

- Areas that have experienced landslides or debris flows in the past are likely to experience such events in the future.
- If an area has similar geomorphology, topography and geology to areas that have experienced landslides, then it too is likely to experience such events in the future.

Given that there is limited variation in the macro-geology across the landslide source area, susceptibility to landslide initiation is most closely related to the steepness of the terrain. The susceptibility to landslide debris inundation is a function primarily of slope height and orientation relative to the base of the escarpment. The result is that historically, landsliding on the Matatā Escarpment has occurred primarily on the steep north-facing coastal cliffs located west of the Awatarariki Stream (Figure 10.1). Some landsliding occurs on the slopes located behind the main town but to a significantly lesser extent.

The reason for the apparent reduction in susceptibility to the east of the Awatarariki Stream is not clear, as both sections of escarpment have broadly similar gradients (Figure 5.5) and geology. The western escarpment does however have a number of short cliff sections that are more likely to contribute to landslide initiation than the generally uniformly graded and vegetated eastern slopes.

Table 10.1 presents the landslide initiation classification developed for the Matatā Escarpment on the basis of slope gradient. This is the same susceptibility classification developed from a detailed assessment of slopes formed in similar geology at Ōhope (T&T, 2013). Using this as a starting point, a landslide initiation and inundation susceptibility map has been developed for the Matatā Escarpment This is presented in Figure 10.2. The process used to delineate the different susceptibility zones is outlined in Table 10.2.

The susceptibility of an area to impact by a debris flow is very different to more typical landslide events, as the travel distances and potential for damaging impact are so much greater. For debris flows, the issue of susceptibility is entirely one around the potential for inundation, not initiation. Whilst debris flow susceptibility is also related to the potential for high intensity rainfall, it remains independent of an areas potential for be affected by significant earthquakes. This is a function of the frequency and magnitude of the debris flows that could be generated within nearby streams and most importantly, the distance from the source of the debris flow. In the case of Matatā, this is the distance and orientation relative to the point where the debris exits the escarpment and begins to travel across the fanhead and lowlands.

AGS (2007) does not present a susceptibility classification system suitable for debris flows. No alternative susceptibility system has been developed for this study as it is the debris flow hazard that is considered to be of greater importance. A qualitative assessment of debris flow susceptibility can however be gained from the spatial extent of debris from past events (Appendix D and Figure 6.1).
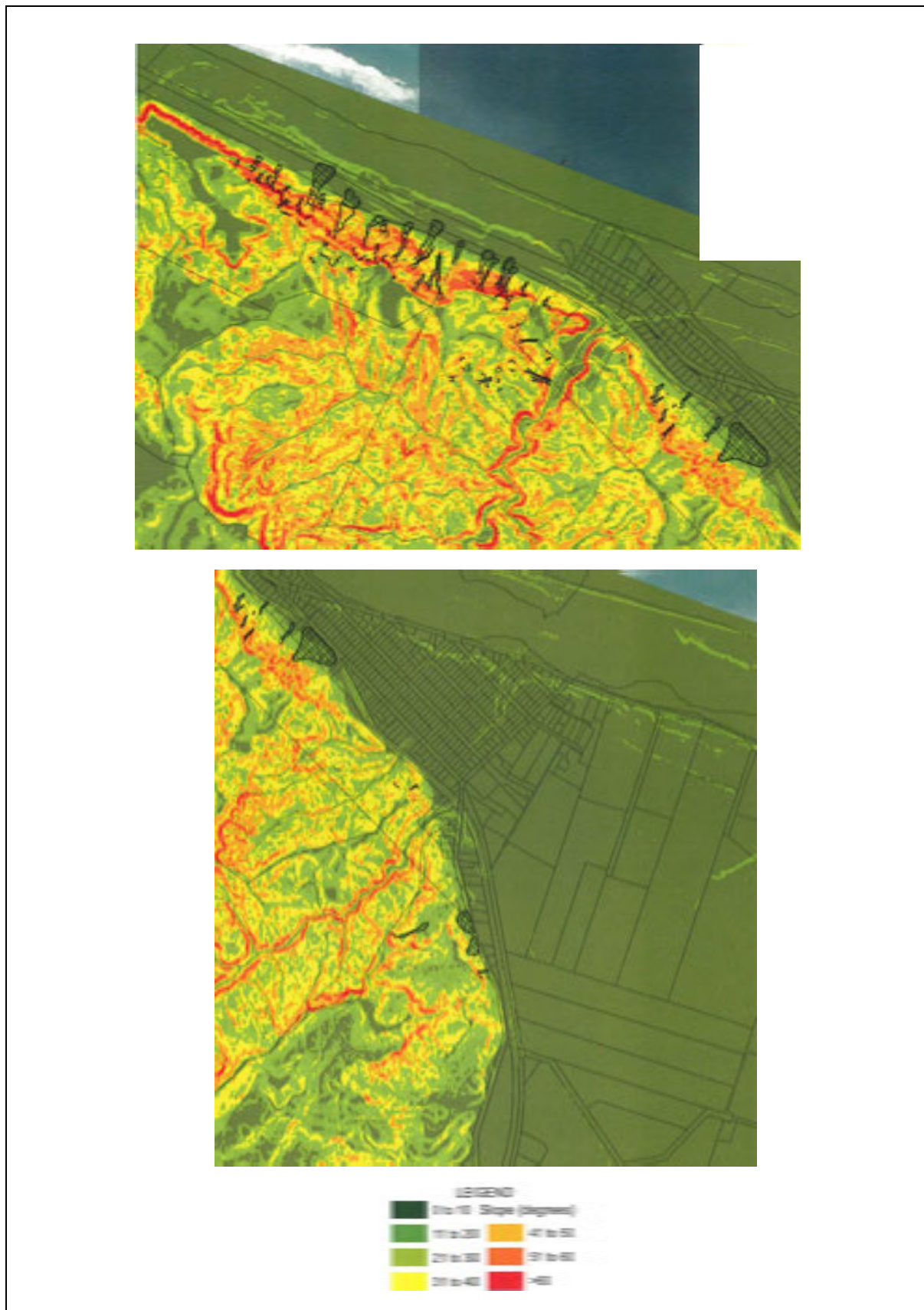
*Figure 10.1:   Slope class map with landslide inventory overlain. Note the predominance of
landslides west of the Awatarariki Stream*

Table 10.1: Landslide Susceptibility Classification

Slope Class	Slope Angle (deg)	Susceptibility Descriptor
I	0 – 10	Very Low
II	11 – 20	Very Low
III	21 – 30	Low
IV	31 – 40	Moderate
V	41 – 50	High
VI	51 – 60	High
VII	60+	High

Table 10.2: Susceptibility Mapping Criteria

Location or Parameter	Basis of mapping
Escarpment initiation susceptibility	Based on a consideration of slope class, abundance of landslides and the classification system of Table 10.1.
Escarpment inundation susceptibility	Escarpment slopes are assigned the same susceptibility rating for inundation as for initiation.
Inundation susceptibility beyond the escarpment	High susceptibility zones were extended out from the base of the escarpment to include those areas known to have been inundated by significant landslides
	Moderate susceptibility zones were extended out to enclose those areas beyond recent landsliding but are underlain by debris deposits.
	Moderate inundation susceptibility was assumed to extend 50m out from similarly classified escarpment in the absence of mapped landslides and debris deposits.
	Those areas located beyond recognised debris deposits were given a low to very low susceptibility of inundation. No distinction was made between low and very low susceptibility as there is no reliable metric to base such a distinction on.
Physical barriers	Where necessary, the susceptibility rating was modified based on engineering judgement to account for significant physical barriers such as the railway embankment.

Figure 10.2   Landslide initiation and inundation susceptibility

10.2 Landslide Hazard

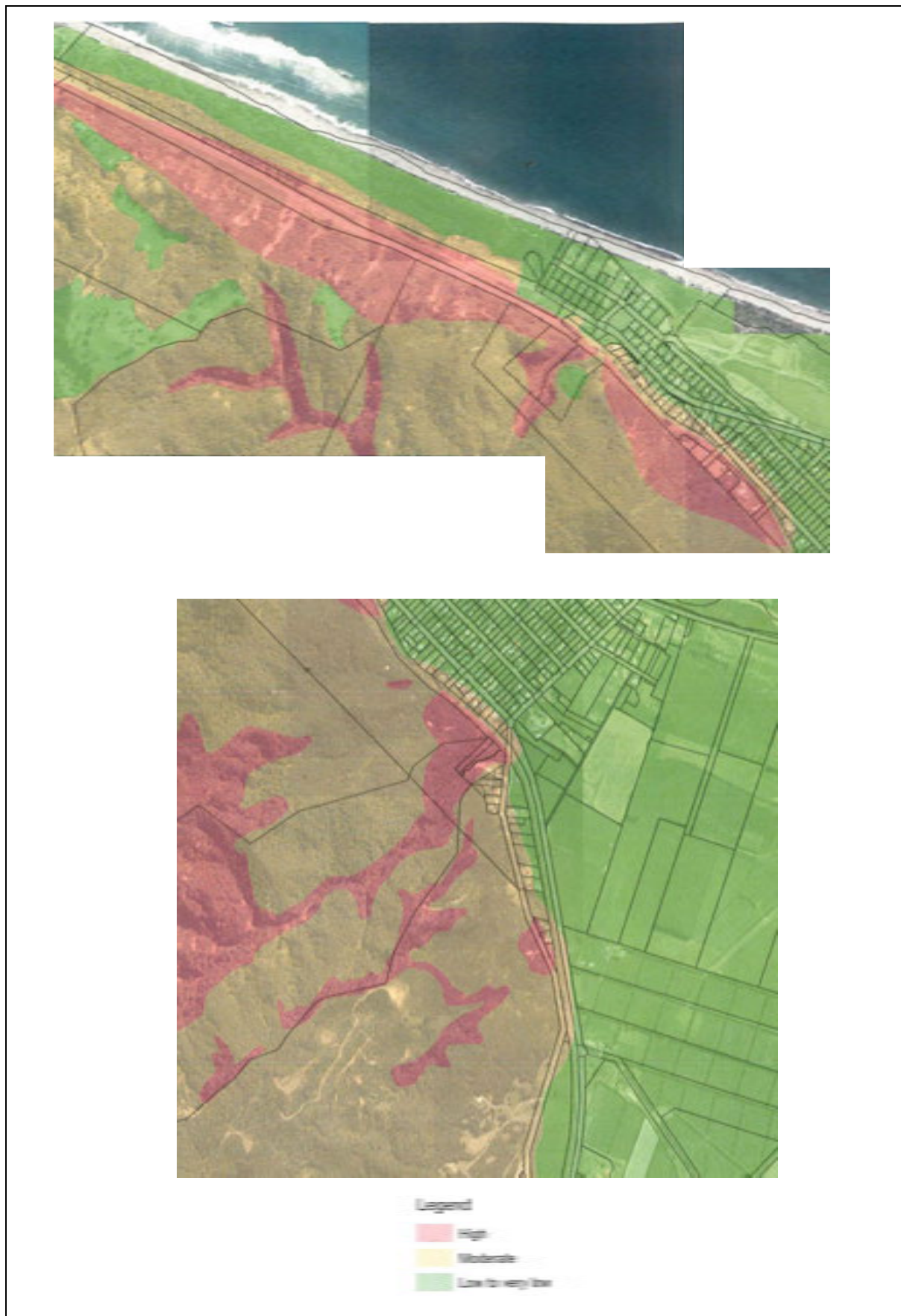In the following discussion, a distinction is made between landslide and debris flow hazard. Although debris flows are one of the major forms of landsliding (Figure 7.1) their transportation and depositional characteristics are sufficiently different to other landslide types the hazard associated with them to be considered separately.

10.2.1 Initiation vs. Inundation

Hazard mapping provides a quantitative means of describing the probability that a landslide of a given magnitude will occur within a certain time frame. The hazard descriptors recommended by AGS (2007) are presented in Table 10.3. The hazard definition for small landslides (i.e. No./km²/yr) is the appropriate measure of landslide hazard for the Matatā Escarpment.

Landslide hazard is formed from two components: landslide initiation and landslide debris inundation. The landslide inventory is critical in developing an understanding of landslide hazard, as this shows not only the location and size of previous landslides, but it also provides an insight into the areas down slope that have previously been impacted.

Landslide-initiation hazard has been assessed from a consideration of the inferred susceptibly of the various sections of escarpment (Figure 10.2), the density of landslides as indicated by the inventory (Appendix C) and the estimated frequency of both landslides and their triggering events (see Section 9).

In areas such as Matatā, where the population resides entirely within the area of debris inundation rather than initiation, debris travel distance is a critical parameter in determining the degree of hazard present at any particular location. Thus reducing the debris travel distance is a viable mitigation option.

Landslide hazard, as reported below, relates to both the initiation and inundation hazard.

10.2.2 Travel or Run-Out Distances

The distance that the debris from a landslide will travel from the source area depends upon a number of factors including the nature of the debris, the vertical distance between the point of initiation and deposition (and therefore the potential velocity), slope gradient, degree of channelisation, the presence and density of significant vegetation etc.

Three methods have been used to estimate landslide debris travel distances:

- Mapping of the debris paths and deposits of recent landslides;
- Mapping the extent of historic landslide debris; and
- Determining a theoretical height-travel distance relationship.

When an area such as the Matatā Escarpment has been subject to a significant number of landslides in recent times, then the mapping of the flow paths and depositional areas of these landslides is an effective means of developing a practical understanding of what areas may be similarly impacted in the future. This has been achieved through the development of the landslide inventory (Appendix C).

On a more theoretical basis, Hunter and Fell (2003) provide empirical relationships between the height of landslide initiation (H), the travel distance (L) and the gradient of the travel path (α) for "rapid" landslides (Figure 10.3). They found that:

- The ratio H/L decreased with increasing debris volume i.e. larger landslides tend to travel further not only in absolute terms but also relative to their initiation elevation;

- H/L decreased for increasing slope angles;
- Travel distances are significantly greater for confined travel paths than for unconfined;
- Smaller slides (<500m³) with unconfined paths on steep slopes (such as at Matatā) tend to deposit material along these paths and so terminate on the slopes; and
- For small volume failures and unconfined travel, an H/L ratio of approximately 0.75 could be expected
- Wet deposits can travel further, although "dry" rock avalanches above a certain large volume can have excessive run-out distances.

By interrogating the landslide inventory and topographic data for Matatā, the travel distance ratio (H/L) was found to range from 0.47 to 0.87, with a mean value of 0.70. This is equivalent to a shadow angle of 35°. This mean value correlates well with the estimate of Hunter and Fell (2003) and has been used to estimate the distance that a landslide could reasonably be expected to travel.

10.2.3   Landslide Hazard Mapping

The hazard rating is based on the estimated number of landslides per km² per annum based on the inventory, estimated frequency etc from Section 9.2.2. The specific rules used to derive the maps are presented in Table 10.4.

A combined landslide initiation and inundation hazard map for Matatā is presented as Figures E1 to E3 (Appendix E). A description of the process used to develop these maps is presented in Table 10.4

Although sharp boundaries are necessarily drawn between the different hazard zones on these maps, it needs to be appreciated that, in reality, the estimation of numerical values of hazard and the transition from one hazard zone to another carries with it considerable uncertainty and need for judgment.

It should also be noted that the lowest landslide risk in the AGS (2007). For this reason, the lowest classification available for mapping is very low. There has been no attempt on these maps to identify any credible outer limit of landslide risk i.e. were the risk is effectively zero.

Table 10.3: Definition of Landslide Hazard (modified from AGS, 2007)

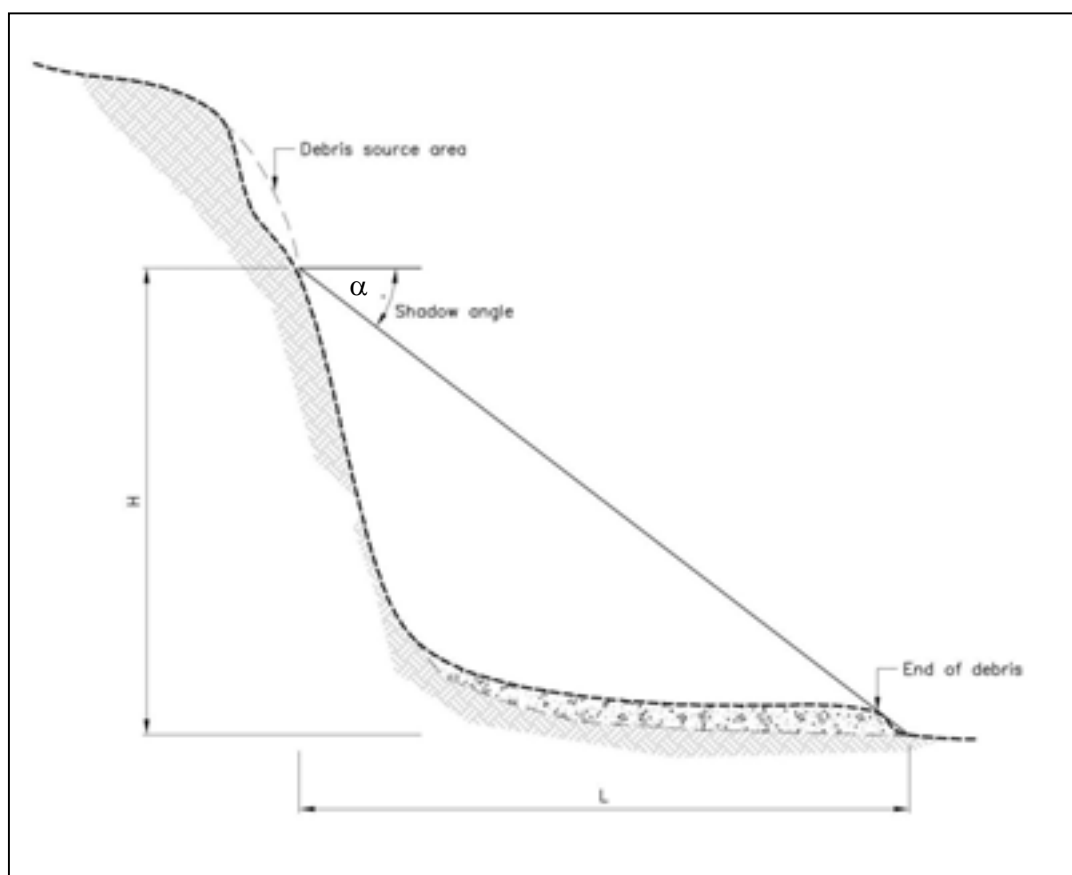| Hazard Descriptor	Small Landslides No./km²/yr	Individual Landslides (Annual probability of active sliding)
Very High	>10	10^{-1}
High	1 to 10	10^{-2}
Moderate	0.1 to 1	10^{-3} to 10^{-4}
Low	0.01 to 0.1	10^{-5}
Very Low	<0.01	$<10^{-6}$

Figure 10.3:   Debris travel distance expressed as an H/L ratio. The shadow angle is equivalent to the α angle of Hunter and Fell (2003)

Table 10.4: Basis of Landslide Hazard Mapping

Location	Basis of Hazard Classification
West of Awatarariki Stream to Division Street	
Escarpment	The vast majority escarpment is classified as high hazard based on a number of landslides that have occurred in the period of 2004 to 2013. The classification would remain high if the observation period is extended out to 28 years without further landslides being incorporated into the inventory. The hazard rating has been based on the estimated frequency of landslides and their trigger events (Section 9).
	Although the slopes both west and east of the Awatarariki Stream are classified as high hazard, the frequency of landsliding and hence the associated hazard is significantly greater on the western side. Indeed the area from the Awatarariki Stream to Division St is close to being classified as moderate hazard.
	This area is considered to also be the most susceptible to seismic induced landslides because of the steep slopes and narrow ridges. A significant number of seismic-induced landslides could conceivably be generated in this high hazard zone, although on a less frequent basis than rainfall-induced landslides.
Talus slope	The talus slope is given the same hazard rating as the escarpment located immediately behind it.
Flatlands	The high hazard rating extends out to a point defined by a travel distance ratio of 0.7. This encapsulates all of the mapped landslides.
	The hazard rating is reduced from high to moderate to cover the mapped or inferred extent of historic landslide debris. Areas mapped as being beyond the extent of inferred historic landslide debris are given a low to very low hazard rating. There is insufficient data to distinguish low from very low areas.
South of Division Street	
Escarpment	The escarpment is given a moderate hazard rating on the basis of the landslide inventory. The occurrence of landsliding in this area is clearly significantly less than in the area to the north. Some areas of high hazard have been identified within the drainage channels within the dissected hill country.
Talus slope	The talus slope located immediately adjacent to the escarpment is given the same moderate hazard rating as the escarpment. The moderate hazard zone in the vicinity of Waitepuru Stream extends further out from the escarpment than some other areas to account for the steeper slopes and number of small landslides mapped in this area.
Flatlands	In the absence of landslide travel data in this area, the moderate hazard zone has been extended out a distance of 50m from the base of the escarpment. The basis for this is the behaviour of landslides formed in similar materials in Ōhope. In some locations the railway embankment effectively provides a limit to landslide debris travel distance.

10.3   Debris Flow Hazard

10.3.1   General

The hazard associated with debris flows emerging from the escarpment streams is essentially one of inundation within a particular time interval. Because the potential area of impact depends on the magnitude (i.e. volume) of the debris flow, and that this in turn reflects recurrence interval (i.e. larger debris flows occur less often than small debris flows), debris flow hazard is more analogous to flood hazards than landslide hazards. As a result, the landslide hazard classification system of AGS (2007) is not applicable to debris flows.

Rickenmann (1995)[4] proposed a two stage method for debris flow hazard analysis:

- Determine the occurrence probability of a debris flow event;
- Quantitatively estimate the event magnitude, travel distance (runout) and deposition area.

10.3.2   Event Probability

The probability of debris flows at Matatā has been considered in Section 9.3.2. For the purposes of this assessment, the return period of 200 to 500 years adopted by T&T (2009a) for the 18 May 2005 event has been retained. This is based on the expectation that the 2005 event had a return period of centuries, rather than decades or millennia. There is no inference here than the return period of the triggering rainstorm and the return period of the debris flow are directly related.

10.3.3   Magnitude and Spatial Extent

The magnitude of the 2005 debris flows within the Awatarariki and Waitepuru Streams were estimated by T&T (2009a) to be approximately 300,000m^3 and 100,000m^3 respectively. These estimates have been retained.

10.3.3.1   Travel Distance

Compared to landslides, debris flows have very high travel or runout distances. Although this travel distance is a function of many interrelated parameters, ultimately it is event magnitude (i.e. volume) that determines the extent of inundation. The area of inundation from the 2005 debris flows is shown on maps presented in Figures D1 to D3 (Appendix D). A more detailed map for the Awatarariki Stream fanhead is presented as Figure 8.11. Although this was a very large debris flow event, we know from the extent of debris flow deposits that pre-date the settlement of modern Matatā (Figure 6.1) that debris flows have extended out even further than what was observed in 2005. It is logical to also expect that debris flows smaller than the 2005 event have occurred and that their debris fields did not extend as far.

10.3.4   Debris Flow Hazard Mapping

A debris flow hazard map is one which, ideally, shows the extent of debris flows with different magnitudes and return periods. Those areas located close enough to be affected by both small (more frequent) and large (less frequent) debris flows will have the highest hazard. More distal locations will have a lower hazard rating on account of their susceptibility being limited to only the largest and less frequent events.

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[4] In Fuchs *et al* (2008)

In the case of Matatā however, we have only one data point (18 May 2005) with only a very approximate return period estimate available. The only other information is the possible extent of the debris field from much older events (Figure 6.1).

An alternative approach is to use numerical modelling methods to estimate the spatial extent of debris flows of different volumes. No numerical modelling has been commissioned as part of this study, however the results of debris flow modelling undertaken by T&T as part of the Matatā Regeneration Project are available. It should be noted that the modelling reported in T&T (2009a) was undertaken for very different purposes and provides only some guidance as to the potential spatial extent of debris flows of different magnitudes, particularly near the Waitepuru Stream.

Note that debris flow modelling has been used extensively in a supplementary debris flow risk assessment for the Awatarariki Stream fanhead area (T&T, 2013c). This latter report should be referred to when assessing debris flow risk in the Matatā area.

Back analysis of the 2005 debris flows in the Awatarariki and Waitepuru streams using the numerical modelling program RAMMS (Figure 10.4) allowed calibration of the model's various flow parameters to those conditions relevant to Matatā. By modelling debris flows with substantially smaller and substantially larger debris volumes (half and double the 2005 volumes respectively) estimates of debris distribution for debris flows of very different magnitude have been able to be made[5].

Assuming a return period of 200 to 500 years, the annual probability of occurrence for the 18 May 2005 debris flows is between 2.0×10^{-3} (0.2%) and 5.0×10^{-3} (0.5%). An alternative to the annual probability assessment is to consider the likelihood of a debris flow event occurring during the lifetime of a resident or the design life of a building. By adopting 50 years as the assessment period, an event with a 200 to 500 year return period can be expected to have a probability of occurrence of between 10% and 25%. Such an event would be considered "possible". Debris flows that are much smaller or much larger than the 18 May 2005 event will have correspondingly higher or lower likelihoods of occurrence.

Table 10.5 presents the qualitative assessment of event likelihood used to develop the debris flow hazard classification. The estimated spatial extent of the debris flow hazard zones are presented in Figures F1 to F3 (Appendix F). The variation in hazard with distance reflects both the longer return period of larger events as well as the reduced destructive capacity of the flows with distance. Some judgement has been necessary in the assessment of the hazard for the Waitepuru Stream post-construction of the diversion berms. It should not in inferred from the maps that the hazard in the vicinity of Waitepuru Stream is equal to or greater than it was in 2005.

It should be noted that following the completion of the analysis presented in this report, a supplementary debris flow risk assessment was undertaken using numerical modelling methods. This is reported in T&T (2013).

No specific debris flow hazard zones have been determined for the Waimea Stream or other small drainage channels on the escarpment. Although debris fans are present in areas other than the Awatarariki and Waitepuru streams, these drainage systems did not produce debris flows in 2005. As such, these areas have been assigned a low hazard rating.

10.4   Combined Inundation Hazard

It is clear from the hazard maps presented in Appendices E and F that different areas of Matatā have quite different hazard ratings with respect to landslide and debris flow inundation. As these

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[5] The assessment of debris distribution for the larger flow at the Waitepuru Stream is limited by the fact that the 2009 modelling was focussed on the performance of the then proposed debris control bunds, not the wider area.

hazards are additive, a combined hazard map representing total inundation hazard has been developed. Presented in Appendix G, the combined hazard map (Figures G1 to G3) represents a basis for evaluating total hazard.

The combined hazard map has been developed from a consideration of how the landslide and debris flow inundation hazards overlap. Any particular area will have a specific combination of landslide hazard (high, moderate, low to very low) and debris flow hazard (high, moderate, low). A hazard matrix, presented at Table 10.6, is used to define each of the combined hazard zones shown on the maps in Appendix G. Areas outside of the mapped hazard zones are assigned a "no credible hazard" rating.
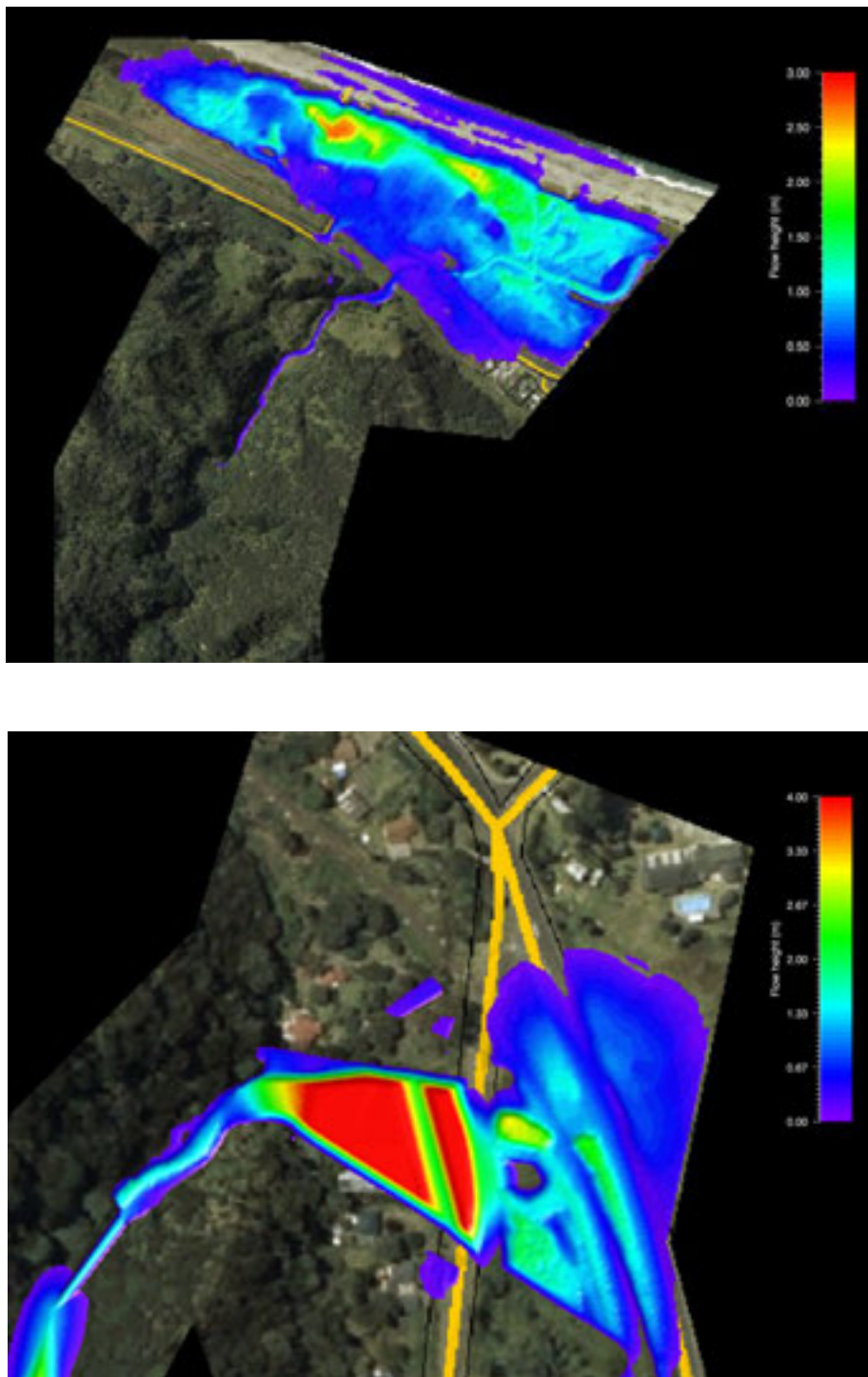
Figure 10.4: Example output from 2009 RAMMS debris flow simulation for the Awatarariki Stream (top) and Waitepuru Stream (bottom)

Table 10.5: Probability of Occurrence in 50 years and Debris Flow Hazard Rating

Event Relative Magnitude	Return Period (years)	Probability of Occurrence in 50 years (%)	Description of Likelihood in 50 years	Hazard Rating
Half 2005	<200	>25	Likely	High
2005	200 - 500	10 – 25	Possible	Moderate
Twice 2005	>>500	<<25	Unlikely	Low

Notes: The design return period of the 2005 event has been estimated as being somewhere in the order of 200 to 500 years. For the purposes of this assessment, it has been assumed that an event that has half the volume of the 2005 event would have a return period less than this (say less than 200 years) but no value has be assumed. IT has been assumed that given the very large size of the 2005 event, a future event that is twice this size would be a very rare event, if indeed it is even possible. The return period is unspecified but is assumed to be much greater than 500 years.

Table 10.6: Combined Inundation Hazard Matrix

		Debris Flow Hazard		
		Low	Moderate	High
Landslide Hazard	High	H3	H2	H1
	Moderate	M1	M3	H5
	Low to V. Low	L1	M2	H4

11   Risk Assessment

11.1   General Concepts

Risk is often mistaken for the likelihood or probability that some adverse event may occur, when this is the definition of hazard. Risk is in fact the product of likelihood (hazard) and consequence of occurrence. It can be assessed either qualitatively or quantitatively for people (Loss of Life Risk) or property (Property Loss Risk).

It is important to note that risk can vary significantly with time, even though the underlying hazard has not. For example, if no people or structures are present within an area of hazard, then the risk is low. However should people or property subsequently occupy that site, the risk will increase accordingly, even though the hazard stays the same. Risk is a much more dynamic parameter than hazard. It is also considerably more difficult to estimate and evaluate in a meaningful way than is hazard.

This section provides an introduction to the criteria used to define risk for landslide studies. It then provides a description of the risk analyses undertaken for Matatā. The risks associated with landslides and debris flows are considered separately as were the hazards.

11.1.1   Qualitative Risk Matrix

With risk being defined as the product of likelihood and consequence, a useful means of representing risk is through a qualitative risk matrix. An example of such a risk matrix is presented below as Table 11.1. Qualitative assessments such as this are valuable for undertaking risk assessments where there is insufficient information available with which to make quantitative calculations.

11.1.2   Loss of Life Risk

Loss of life risk ($R_{(LOL)}$) is the annual probability of a person being killed by either a landslide or debris flow. It is a function of several factors including the probability of a landslide or debris flow occurring, the probability of a person being impacted and their vulnerability to impact.

Loss of Life Risk for a residential community can be represented in the following form:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

$R_{(LOL)}$ - the annual loss of life risk

$P_{(H)}$ - the annual probability of a landslide occurring

$P_{(S:H)}$ - the probability of spatial impact. This has two components:

$P_{(S:H-1)}$ - the probability that a dwelling is located below the landslide

$P_{(S:H-2)}$ - the probability that the landslide can travel as far at the dwelling

$P_{(T:S)}$ - the temporal spatial probability. This has two components:

$P_{(T:S-1)}$ - the probability that someone is home

$P_{(T:S-2)}$ - the probability that the person home is in a position that allows them to be physically impacted either by the landslide or building debris

$V_{(D:T)}$ is the vulnerability of the individual to impact.

AGS (2007) provides a classification of loss of life risk for landslides based on the "person most at risk". This is reproduced as Table 11.2. Note that the acceptability, tolerability or otherwise of these terms is not implied.

11.1.3   Property Loss Risk

The evaluation of property loss risk is based around on a consideration of the likelihood of an impact occurring during the lifetime of the structure (assumed to be 50 years) and the physical consequences should the impact occur.

AGS (2007) present a property loss risk matrix that is essentially a general qualitative risk matrix (e.g. Table 11.1) but with the percentage cost of damage being associated with each of the consequence categories. The AGS (2007) property loss risk matrix is reproduced below as Table 11.3.

Two additional tables are presented below as an aid to interpreting the AGS (2007) property loss risk matrix:

- Qualitative terms used to describe likelihood (Table 11.4);
- Qualitative measures of consequences to property (Table 11.5);

The measure of the consequence of landslide impact on property is simply the extent of damage brought about by the occurrence of the landslide. AGS (2007) define consequence to property arising from landslides in two forms:

- the estimated extent of damage likely to arise from each landslide;
- the estimated cost of rebuilding and slope remedial works.

Damage is defined in AGS (2007) as the direct cost of the landslide, not in dollar terms, but as a percentage of the improved value of the unaffected property. The improved value includes both the land and any affected structures. The costs that need to be considered include the direct costs of reinstatement, possible stabilisation works and necessary professional fees. As a result, the consequential cost may be greater than 100% of the property value.

Assigning a property loss risk to a particular location is problematic as in order to estimate the likely consequences, the magnitude of impacting debris (both velocity and volume) needs to be assumed. Evaluation of the consequences also requires an understanding of the impacted structure. The vulnerability of a structure to a landslide is highly dependent on the characteristics of both the landslide and the building. The consequence of this is that property loss risk cannot be defined spatially. For example, two structures located adjacent to each other in the same landslide hazard zone can have quite different property loss risk on account of their layouts, construction materials etc. This is in effect analogous to the different vulnerabilities that affect Loss of Life calculations.

Table 11.1: Qualitative Risk Matrix (modified from AGS, 2007)

Relative Likelihood	Consequences				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost Certain	VH	VH	VH	H	L
Likely	VH	VH	H	M	L
Possible	VH	H	M	M	VL
Unlikely	H	M	L	L	VL
Rare	M	L	L	VL	VL

Table 11.2: Descriptors for Risk Zoning Using Loss of Life Criteria (AGS, 2007)

Risk Zone Descriptor	Annual Probability of Death of the Person Most at Risk in the Zone
Very High	$>10^{-3}$/annum
High	10^{-4} to 10^{-3} /annum
Moderate	10^{-5} to 10^{-4} /annum
Low	10^{-6} to 10^{-5} /annum
Very Low	$<10^{-6}$ /annum

Table 11.3: Property Loss Risk Matrix (AGS, 2007)

Likelihood		Consequences to Property (with indicative approximate value of damage)				
(over lifetime of the building)	Indicative Value of Approximate Annual Probability	Catastrophic (200%)	Major (60%)	Medium (20%)	Minor (5%)	Insignificant (0.5%)
Almost Certain	10^{-1}	VH	VH	VH	H	M or L
Likely	10^{-2}	VH	VH	H	M	L
Possible	10^{-3}	VH	H	M	M	VL
Unlikely	10^{-4}	H	M	L	L	VL
Rare	10^{-5}	M	L	L	VL	VL
Barely Credible	10^{-6}	L	VL	VL	VL	VL

Table 11.4: **Risk to Property - Qualitative Measures of Likelihood (modified from AGS, 2007)**

Approximate Annual Probability Indicative Value (Notional Range)	Implied Indicative Landslide Recurrence Interval Indicative Value (Notional Range)	Description Occurrence over design life	Descriptor	Level
10^{-1} (5×10^{-2} to $>1 \times 10^{-1}$)	10 years (<20 yr)	The event *is expected* to occur	Almost certain	A
10^{-2} (5×10^{-3} to 5×10^{-2})	100 years (20 – 200 yr)	The event *will probably* occur under adverse conditions	Likely	B
10^{-3} (5×10^{-4} to 5×10^{-3})	1000 years (200 – 2,000 yr)	The event *could* occur under adverse conditions	Possible	C
10^{-4} (5×10^{-5} to 5×10^{-4})	10,000 years (2,000 – 20,000 yr)	The event *might* occur under very adverse circumstances	Unlikely	D
10^{-5} (5×10^{-6} to 5×10^{-5})	100,000 years (20,000 – 200,000 yr)	The event *is conceivable* but only under exceptional circumstance	Rare	E
10^{-6} ($<1 \times 10^{-6}$ to 5×10^{-6})	1,000,000 years (>200,000 yr)	The event *is inconceivable* or fanciful	Barely credible	F

Table 11.5:   Risk to Property - Qualitative Measures of Consequence to Property (modified from AGS, 2007)

Approximate Cost of Damage Indicative Value (Notional Range)	Description	Descriptor	Level
200% (100% to >200%)	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequential damage	Catastrophic	1
60% (40% to 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% (10% to 40%)	Moderate damage to some of the structure, and/or significant part of site requiring large stabilisation works. Could cause at least some adjacent property minor consequence damage.	Medium	3
5% (1% to 10%)	Limited damage to part of the structure, and/or part of site requiring some reinstatement stabilisation works.	Minor	4
0.5% (0% to 1%)	Little damage[1]	Insignificant	5

Note:

1: For high probability events (i.e. almost certain), this category may be subdivided at a notional boundary of 0.1%

11.2   Assessment of Landslide Risk for Matatā

The objective of the assessment presented here is to determine the broad-scale risks associated with landslides occurring on the Matatā Escarpment and any associated debris flows. The objective has not been, and the available data does not support, assessments of individual properties, buildings or persons.

11.2.1   Loss of Life Risk

Annual loss of life risk is calculated from a number of variables, but primarily:

- The annual probability of landslide occurrence;
- The probability that the landslide can reach the location of interest; and
- The presence of a person at that location and their vulnerability to an impact.

The first and third parameters are effectively fixed for all locations being considered. The probability that debris from a landslide will reach a particular site depends upon where that site is located with respect to travel or runout distance of the debris. As a result, loss of life risk drops significantly with distance from the escarpment i.e. it varies in response to the inundation hazard.

Loss of life risk has been calculated for the same three escarpment sectors identified as having significantly different landslide occurrence: west of Awatarariki Stream, Awatarariki Stream to Division Street and south of Division Street. The annual loss of life risk calculations are presented in Table 11.6, together with notes explaining the development of the input parameters.

Individual calculations have been undertaken to characterise the annual loss of life risk for the moderate and high hazard zones. There is insufficient data with which to calculate the loss of life risk for the low to very low hazard zone, although based on the results obtained for the moderate hazard zones, it would appear to be less than 10^{-4} per annum.

It should be noted that this procedure is based on a person occupying a dwelling. The risk of being impacted by a landslide is greater if the person at risk is outside. However, given that there is a much greater likelihood that a resident would be indoors than in the rear of their properties, the risk estimates have not be adjusted to account for this.

The loss of life risk values classify the assessed areas as very high to high risk, with the low to very low hazard areas having an estimated risk ranging from very low to moderate depending upon the distance from the escarpment. These classifications may at first appear to be at odds with the fact that there have been no known injuries or EQC claims, let alone fatalities, from landslides originating on the escarpment. However aerial photographs reveal that several landslides have inundated the area west of SH2. These properties have either been undeveloped or have been protected to some extent by the presence of the railway embankment. It is possible that even just in the period 2010-2011, one or more properties could have been impacted had circumstances been a little different. It is also worth noting the difference between what people generally consider to be a significant risk with the very small annual probabilities used by the AGS (2007) classification to define a low or very low risk.

11.2.2   Property Loss

Property loss risk has been estimated for the same hazard zones assessed for loss of life risk. The results are presented in Table 11.7. Property loss risk is highly dependent on the nature of the building impacted and is therefore property specific. The risk ratings presented in Table 11.7 should only serve as a guide as to how one area compares to another. It should not be used in absolute terms to estimate the potential financial implications of a landslide impact, should one occur.

Table 11.6: Annual Loss of Life Risk for Landslides for Moderate to High Hazard Zones

Location	Landslide Hazard Zone[a]	Risk Factors						$R_{(LOL)}$	AGS (2007) Classification
		$P_{(H)}$[b]	$P_{(S:H-1)}$ [c]	$P_{(S:H-2)}$	$P_{(T:S-1)}$[f]	$P_{(T:S-2)}$[g]	$V_{(D:T)}$[h]		
West of Awatarariki Stream	High	4.6×10^{-1}	-	-	-	-	-	N/A[d]	-
	Moderate	4.6×10^{-1}	-	-	-	-	-	N/A[d]	-
Awatarariki Stream to Division Street	High	1.6×10^{-1}	9.0×10^{-2}	1.0×10^{0} [e]	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	2.0×10^{-3}	Very High
	Moderate	1.6×10^{-1}	3.0×10^{-1}	5.0×10^{-2i}	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	3.4×10^{-4}	High
South of Division Street	Moderate	1.2×10^{-1}	1.7×10^{-1}	5.0×10^{-2} [i]	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	1.4×10^{-4}	High

Notes:

a) See Appendix F
b) From Table 9.5
c) The probability of a dwelling being located below the escarpment is based on the ratio of the escarpment length and the cumulative width of existing dwellings.
d) It is assumed that the reserve land located immediately north of the SH2 bypass will not be developed into residential properties based on the known debris flow hazard in this area.
e) It is assumed that any landslide within the high hazard zone will be able to reach a dwelling also located there
f) Person most at risk is assumed to be present 75% of the time.
g) Based on experience at Ōhope where considerable protection is offered by the dwelling itself. It is assumed that only 25% of the time will a a person be impacted directly by landslide debris or a collapsing structure.
h) Assumed that if a person is directly impacted, the probability of a fatality is 75%.
i) Based on observations of landslides in 2005 and 2010-2011, it is assumed that only 5% of landslides could travel into the moderate hazard zone

11.3 Assessment of the Debris Flow Risk for Matatā

The objective of the assessment presented here is to determine the broad-scale risks associated with debris flows occurring within the streams emerging from the Matatā Escarpment. The objective has not been, and the available data does not support, assessments of individual properties, buildings or persons. The destructive nature of debris flows means that the shielding effect described above for landslides may not be as relevant for these larger events.

11.3.1 Qualitative Risk

Section 10.3 described how magnitude (i.e. volume) is an important parameter when it comes to determining debris flow hazard. The same is true also for risk. This is because the area potentially affected by a debris flow can vary much more significantly with magnitude than is the case for landslides. Those properties located close to a debris flow source will potentially be affected by all debris flows regardless of their magnitude, whereas more distal properties will potentially only be affected by larger and more infrequent events.

Currently there is only one data point on the Matatā debris flow frequency-magnitude curve – the 18 May 2005 event. One method of acquiring an overview of the risks that debris flows present in the absence of more data is a qualitative assessment using the general risk matrix (Table 11.1) and the results of existing numerical debris flow modelling (T&T, 2009a).

Three different magnitude debris flow events are available for analysis for both the Awatarariki and Waitepuru Streams:

- A moderate sized flow equivalent to half the volume of the 2005 event;
- A large debris flow modelled directly on the 2005 event; and
- A very large debris flow that is twice the volume of the 2005 event.

The terms moderate, large and very large have been adopted on the basis that the 18 May 2005 debris flows were large, even on a world scale. A debris flow even half the volume of the 2005 event would be considered an unusually large flow in many areas affected by debris flows.

The distribution of the potentially damaging debris from these three events are shown on the debris flow hazard maps Figures F1 to F3 (Appendix F) as low, moderate and high respectively. Note that in each case, silt-laden debris flood flows can be expected to extend further than the debris indicated on Figures F1 to F3.

It has been estimated that the return period of the 2005 event was in the order of a few centuries, rather than decades or millennia. The return period range of 200 to 500 years adopted by T&T for earlier analyses (T&T, 2009a) has been retained for this qualitative assessment. It is entirely speculative as to the volume and frequency of smaller debris flows in the Awatarariki and Waitepuru Streams might be. They certainly have occurred before but they are not regular occurrences. Limited evidence suggests that small events may occur every 50 to 100 years.

Table 11.7: Property Loss Risk – Landslides

Escarpment Location	Landslide Hazard Zone[a]	Annual Probability of Impact[b]	AGS (2007) Risk		
			Qualitative Likelihood in 50 years	Inferred Consequence	Risk Class
West of Awatarariki Stream	High	N/A[c]	-	-	-
	Moderate	N/A[c]	-	-	-
Awatarariki Stream to Division Street	High	1.4×10^{-2}	Likely	Major	Very High
	Moderate	2.4×10^{-3}	Possible	Medium	Medium
South of Division Street	Moderate	1.0×10^{-3}	Possible	Medium	Medium

Notes:

a) See Appendix E. Areas of Low Hazard are assumed to have a Low Property Loss Risk.
b) Product of landslide occurrence, probability of dwelling being present and landslide travel distance. Same values as were used in the $R_{(LOL)}$ calculations.
c) No residential buildings are present.

Likewise, the return period of very large debris flows is unknown, and neither is the potential maximum size of flows that could be generated in the catchments behind Matatā. We do know however, that based on the distribution of an inferred debris field that extends beyond the depositional extent of the 2005 event that larger debris flows may have occurred, although development of the debris field can also be attributed to normal alluvial processes that are far less dramatic in their consequences that debris flows.

In keeping with the qualitative nature of this assessment, specific return periods have not been selected for the different debris flow magnitudes but the Table 11.4 terminology has been used. On this basis, it has been possible to define the occurrence of moderate, large and very large debris flows as likely, possible and unlikely respectively for a 50 year design period

From the qualitative debris flow risk matrix presented as Table 11.8, and an assumption that impact by a debris flow has a medium to catastrophic level of consequence depending upon individual circumstances, it is possible to conclude that:

- Properties located within high debris flow hazard zones (see Figures F1 to F3) are subject to a high to very high debris flow risk;
- Properties located within moderate hazard zones have a moderate to very high risk; and
- Properties located in low hazard zones have a low to high risk.

The wide range of risk assessed for the low hazard zone reflects the broad physical expanse of this hazard zone as well as the limited degree of certainty as to the frequency of the debris flow events that could potentially affect those areas. In reality the risk can be considered to grade from the higher classification to the lower classification as a function of distance from the source of debris flows.

11.3.2   Loss of Life Risk

As the 18 May 2005 event demonstrated, the potential for major or catastrophic damage to occur as a result of a debris flow is significant. This level of impact can result in deaths and injuries. It is possible that many deaths could result from a single large debris flow event, although todate, nothing like this has occurred in New Zealand. The actual extent of impact will depend of the nature of the debris flow i.e. its volume, velocity, depth and size of entrained boulders, trees and other debris. Those properties located within the boulder field were essentially destroyed, whereas those located beyond it tended to suffer flood-like damage. The distribution of the boulders was not uniform but reflected the primary flow paths of that particular event. It should be expected that the pattern of damage and property loss from an equivalent event would be somewhat different, particularly towards the periphery of the flows. The distribution of the larger debris is more likely to correspond to those areas where deaths may be expected to occur.

Loss of life risk is difficult to estimate for debris flows because of the considerable uncertainty around return periods of events of different magnitude. Given the destructive nature of debris flows, it is the value selected for the annual probability of an event occurring that is the primary determinant of risk. This is because most of the spatial, spatial-temporal and vulnerability probabilities tend towards 1.0. On this basis, the loss of life risk for properties within the area affected by the 18 May 2005 event has been calculated for the assumed range of return periods. The results, presented in Table 11.9, indicate that the area affected significantly by the 18 May 2005 debris flow events had an annual loss of life risk of between 5.0×10^{-4} (0.05%) to 1.0×10^{-3} (0.1%), depending upon the return period adopted. This classifies as a high to very high loss of life risk according to AGS (2007; see Table 11.2). Note that this is the minimum risk, as larger, but less frequent debris flows will also cross this area during their travel to more distal areas, thereby adding to the annual risk value.

Table 11.8:   Qualitative Risk Matrix for Debris Flows

Representative Debris Flow Event	Approximate Volume (m³) Awatarariki Waitepuru	Relative Likelihood in 50 years	Approximate Return Period (years)	Hazard Zone (Appendix F)	Consequences				
					Catastrophic	Major	Medium	Minor	Insignificant
Half 2005	150,000 50,000	Likely	<200 <100?	High	VH	VH	H	M	L
2005	300,000 100,000	Possible	200 - 500	Moderate	VH	H	M	M	VL
Twice 2005	600,000 200,000	Unlikely	>500 >2000?	Low	H	M	L	L	VL

Notes: The design return period of the 2005 event has been estimated as being somewhere in the order of 200 to 500 years. For the purposes of this assessment, it has been assumed that an event that has half the volume of the 2005 event would have a return period less than this (say less than 200 years) but no value has be assumed. IT has been assumed that given the very large size of the 2005 event, a future event that is twice this size would be a very rare event, if indeed it is even possible. The return period is unspecified but is assumed to be much greater than 500 years. It has been assumed that large debris flows are more difficult to generate within the smaller Waitepuru catchment and therefore have a longer, but known return period than the Awatarariki Stream.

Table 11.9: Annual Loss of Life Risk for the 18 May 2005 Debris Flows and Over-size Events

Assumed Event Return Period (years)	Event Description	Factors						$R_{(LOL)}$[g]	AGS (2007)[h] Classification
		$P_{(H)}$[a]	$P_{(S:H-1)}$[b]	$P_{(S:H-2)}$[c]	$P_{(T:S-1)}$[d]	$P_{(T:S-2)}$[e]	$V_{(D:T)}$		
200 years	Possible lower range for the18 May 2005 event	5.0×10^{-3}	1.0	1.0	1.0	2.5×10^{-1}	7.5×10^{-1}	1.0×10^{-3}	High to Very High
500 years	Possible upper range for the 18 May 2005 event	2.0×10^{-3}	1.0	1.0	1.0	2.5×10^{-1}	7.5×10^{-1}	5.0×10^{-4}	High
1,850 years[i]	Event much larger than the 18 May 2005 event	5.4×10^{-4}	1.0	1.0	1.0	2.5×10^{-1}	7.5×10^{-1}	1.0×10^{-4}	Moderate to High
18,500 years[j]	Rare event	5.4×10^{-5}	1.0	1.0	1.0	2.5×10^{-1}	7.5×10^{-1}	1.0×10^{-5}	Low to Moderate

Notes:

a) Annual probability of a debris flow occurring based on the assumed return period

b) It is assumed that the probability of a dwelling located within the inundation zone being impacted is 100%

c) The probability that debris will reach the inundation zone is 100%

d) It is assumed that the "person most at risk" is home 100% of the time. A higher value has been adopted compared to the 75% adopted for individual landslides as debris flows have the potential to impact multiple properties and it is near certain that at least one impacted property will be occupied at the time of the event. This assumes that no warning had been issued by authorities.

e) Based on the 18 May 2005 event, it is assumed that there is a 25% probability of debris physically impacting the occupant of a home.

f) A vulnerability (probability of death if struck by debris) of 75% has been assumed. This is in line with international practice.

g) Rounded to nearest half magnitude.

h) See Table 11.2.

i) The return period corresponding to an estimated loss of life risk of 10^{-4}

j) The return period corresponding to an estimated loss of life risk of 10^{-5}

The loss of life risk from these very large debris flows is difficult to determine as there is no meaningful way that a return period can be reliably predicted. It is possible to calculate what return period corresponds to the major AGS (2007) risk classes. By adopting the same probabilities for the spatial, temporal-spatial and vulnerability parameters as the 2005 event analysis, it has been possible to identify return periods of 1,850 years and 18,500 years as corresponding to the upper boundaries of the moderate and low risk classes respectively (Table 11.9). It is clear that a significant loss of life risk is associated with both the moderate and high debris flow hazard areas (Figures F1 to F3). It is not possible to provide a meaningful loss of life risk estimate for the low hazard area other than to say that a risk exists and that it would reduce significantly with distance from the higher hazard areas.

It is also likely that these larger events be assessed in terms of Societal Risk rather than individual loss of life risk. However in order to do this a debris flow-specific F-N[6] curve would need to be developed. When assessing the risks posed to people on a debris fan, consideration should be given to the potential for multiple fatalities from a single event. For example, a location may have a landslide loss of life risk of say 5×10^{-3}, whereas another location has the same loss of life risk for debris flows. Even though the risk of the person most at risk is the same, there is a greater probability that a larger number of people will lose their lives in the debris flow event. The risk to an individual is the same in both cases however the consequences to the community could be quite different.

11.3.3   Property Loss Risk

As the 18 May 2005 event demonstrated, the potential for major or catastrophic damage to occur as a result of a debris flow is significant. The actual extent of damage will depend of the nature of the debris flow i.e. its volume, velocity, depth and size of entrained boulders, trees and other debris. The 18 May 2005 event illustrated that the extent of property damage depended upon the travel distance of the larger boulders entrained by the flow. Those properties located within the boulder field were essentially destroyed, whereas those located beyond it tended to suffer flood-like damage. The distribution of the boulders was not uniform but reflected the primary flow paths of that particular event. It should be expected that the pattern of damage and property loss from an equivalent event would be somewhat different, particularly towards the periphery of the flows.

Table 11.10 presents an assessment of property loss risk for the different debris flow hazard zones based on a qualitative assessment of the likelihood of an event taking place and the expected damage outcome. A range of consequences have been assumed as damage will vary significantly within nearby areas.

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[6] Frequency (F) of N or more fatalities per year vs. Number (N) of fatalities.

Table 11.10:   Property Loss Risk – Debris Flows

Location	Debris Flow Hazard Zone[a]	AGS (2007) Risk		
		Qualitative Likelihood in 50 years	Inferred Consequence	Risk Class
Vicinity of the Awatarariki Stream	High	Likely	Medium to Catastrophic	High to Very High
	Moderate	Possible	Minor to Major	Medium to High
	Low	Unlikely	Minor to Major	Low to Medium
Vicinity of the Waitepuru Stream	High	Likely	Medium to Catastrophic	High to Very High
	Moderate	Possible	Minor to Major	Medium to High
	Low	Unlikely	Minor to Major	Low to Medium
Vicinity of the Waimea Stream	Low	Possible	Minor to Major	Medium to High
General flatlands area	Low	Unlikely	Minor to Major	Low to Medium

Notes:

a)   See Appendix F.

11.4   Acceptability of Risk

Risk assessments typically define risks, particularly loss of life risk as being either acceptable, tolerable or unacceptable (or intolerable). What makes a risk acceptable or otherwise is a vexed question, as different individuals, groups, communities and societies view these issues differently. The discussion below provides some background on the assessment of risk levels, however it is not the intent nor purpose of this study to determine what is, or is not, an acceptable risk. This is for others to decide.

New Zealand does not have established criteria for determining these risk levels. A number of overseas government and non-government organisations have published what they consider to be reasonable interpretations of these limits:

- AGS (2007) suggests 10^{-5}/annum be adopted as the limit for acceptable risk and 10^{-4} /annum for tolerable risk for the Person Most at Risk for existing slopes (excluding those with existing landslides);
- The Government of Hong Kong has adopted a tolerable limit of 10^{-4}/annum for existing slopes (AGS, 2007); and
- The British HSE suggests an upper limit of tolerability of 10^{-4} for the public and 10^{-3} for workers (Taig, 2012).

When it comes to assessing the risks associated with natural hazards, it is usually the tolerable-unacceptable boundary that is important. This reflects the abundance of natural hazards, as well as the limited ability for communities to mitigate the associated risks in a significant way. This is particularly relevant to New Zealand where natural hazards are both plentiful and frequent.

The analyses reported above indicate that loss of life risks associated with the landslide and debris flow hazards at Matatā are greater than the 10^{-4}/annum level often adopted by others as the tolerable-unacceptable boundary. The 10^{-4}/annum value is approximately equal to the risk of death in a road accident in New Zealand. This study is not making a recommendation as to whether risks greater than 10^{-4}/annum should be considered unacceptable or not. It is suggested however that what is considered appropriate in other jurisdictions may not be appropriate for New Zealand. It is noted that Christchurch City Council have adopted these levels of acceptable and unacceptable risk for the Port Hills zoning assessment. It is useful to compare the estimated risks with those associated with other activities (Figure 11.1).

The loss of life risk levels calculated for those areas in moderate to high hazard zones are classified as moderate to very high according to AGS (2007). AGS (2007) implies that where the risk level is moderate or above, measures must be undertaken to reduce the risk to low (Table 11.11). The practicality of such risk reduction in the New Zealand environment is however quite limited.

It is also noted that AGS (2007) distinguishes existing slopes and development from new ones and existing landslides, yet assigns them the same "acceptable" risk limits. This is in contrast to their assessment of life risk in which the suggested tolerable limit for existing conditions is an order of magnitude greater than that for new slopes, new development or existing landslides. AGS (2007) also states that "tolerable" property risk can be considered to be one risk category higher than the suggested Acceptable level (Table 11.12). It is likely that certifying authorities may consider these risks too high.

The AGS (2007) suggested levels of acceptability for property damage are presented in Tables 11.11 and 11.12.

Table 11.11: **Definition of Risk Level for Property Damage (modified from AGS, 2007)**

Risk Level	Example Implications
Very High Risk (VH)	Unacceptable without treatment Work likely to cost more than half the value of the property - may be too expensive and not practical to undertake
High Risk (H)	Unacceptable without treatment Work would cost a substantial sum in relation to the value of the property
Moderate Risk (M)	May be tolerated in certain circumstances but requires implementation of treatment options to reduce the risk to Low
Low Risk (L)	Usually acceptable Where treatment has been undertaken to reduce the risk to this level, ongoing maintenance is required
Very Low Risk (VL)	Acceptable Manage by normal slope maintenance procedures

Notes:

1: The terms "unacceptable, acceptable and tolerable" are not defined for landslides in New Zealand. The adoption of such terms should be used with caution.

Table 11.12: **AGS suggested "Acceptable" risk to property criteria (modified from AGS, 2007)**

Importance Level of Structure[1]		Suggested Upper Limit of Risk to Property[a]	
		Acceptable	Tolerable[b]
1	Generally low risk to life or property e.g. farm buildings, minor temporary facilities	Moderate	High
2	e.g. low-rise residential buildings	Low	Moderate
3	Buildings that may contain crowds or contents of high value e.g. school buildings, heath care facilities, water treatment plants etc	Low	Moderate
4	Buildings that are essential to post-disaster recovery or contain hazardous material	Very Low	Low

Notes:

a) The original table in AGS (2007) divided this into separate columns for existing and new slopes/development but allocated the same acceptable risk level to both

b) Tolerable risk levels are not presented in AGS (2007) Table C10 but are defined in the accompanying text as "one class higher" than Acceptable Risk.
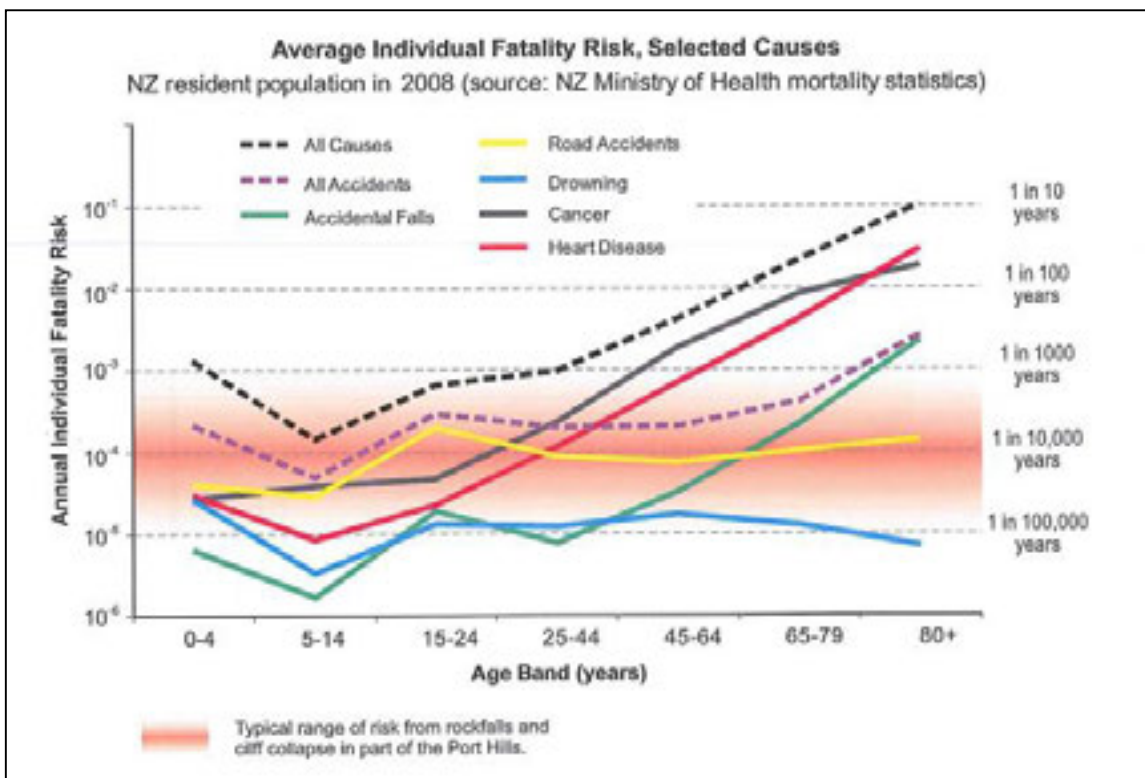
Figure 11.1: Comparison of Individual Fatality Risk for Different Hazards in New Zealand (Source: GNS, 2012)

12 Landslide Risk Management

Strategies to manage landslide risk fit broadly into the following types: avoidance, elimination and reduction. There is also the option of doing nothing, although there are obligations with respected to the Resource Management Act 1991 and the Building Act 2004. These obligations are to avoid natural hazards unless they can be either mitigated or remedied. The approach adopted typically depends upon the nature and severity of the landslide hazard, the possible consequences of occurrence (i.e. risk), property ownership, legislative responsibility and available funds. Complete mitigation of all but the smallest landslide hazards is rarely feasible.

This section assesses a range of potential landslide risk management options. Some of the methods are concerned principally with landslide hazard (i.e. occurrence and frequency of landsliding) whereas others relate more to risk (i.e. managing the consequences of landslides).

12.1 Hazard Avoidance

12.1.1 Land Use Zoning

Avoidance is probably the most effective strategy for managing landslide hazards. It is particularly effective in reducing risks associated with debris flows as engineering mitigation options are limited. It is achieved primarily through the placement of restrictions on land use and future development. Planning controls are most effective when implemented prior to any significant development having taken place. Retrospective land use rezoning can have significant societal and financial implications.

In the case of the Matatā Escarpment, the reasonably mature nature of the settlement significantly constrains the WDC's ability to manage the hazard and risks in these areas through avoidance. Development restrictions would largely be limited to those properties that are not yet fully subdivided.

12.1.2 Building Set-Back Distances

Building set-back distances (i.e. the distance in front of an escarpment base) are an effective means of isolating elements at risk from impact. Unfortunately, many of those areas that potentially could be designated as no-development zones are typically already occupied. The primary exception to this is the coastal strip west of the Awatarariki Stream. The establishment of set-back distances would potentially require the abandonment of at least the talus zone beneath the escarpment. The lack of previous landslide impacts despite the obvious hazard, would however suggest that abandonment of these areas as an overly cautious approach and would have, as a bare minimum, significant financial implications for some residents as well as WDC. The debris flow hazard would however need to be considered separately.

The establishment of set-back distances for future developments would require site-specific geotechnical investigations to be undertaken. Setback distances are more appropriate for mitigating the risks associated with landslides on account of their relatively limited runout distances. Applying setback distances for all debris flow magnitudes would effectively sterilise large tracks of land for future development. Applying development limitations on those parts of the lowlands that could be affected by smaller but more frequent debris flow events is a possibility.

12.2   Hazard Elimination

The complete elimination of a landslide or debris flow hazard requires significant engineering works to prevent future events from occurring. There are many ways in which such an outcome can be achieved, although they can be classified as either reducing driving forces (i.e. those promoting the initiation of a landslide) or increasing resistance forces. The following are examples of commonly adopted methods:

- Reprofiling of slopes;
- Reducing the height of slopes and/or removing potential landslide material;
- Construction of earthwork buttresses to support the slope;
- Construction of retaining walls;
- Reinforcement of the slope by the installation of rock anchors etc; and
- Prevention of material falling from a slope through the placement of shotcrete, wire netting etc.

The typically shallow and random nature of landsliding on the Matatā Escarpment effectively excludes the use of landslide and debris flow elimination strategies.

12.3   Hazard Reduction

Landslide hazard reduction is typically much easier to achieve than complete elimination. Reductions may be achieved in the frequency of landsliding, the scale of landsliding or both. A range of hazard reduction methods are presented below.

12.3.1   Stormwater and Groundwater Control

The control of surface water and groundwater is the most widely used and generally the most effective slope stabilisation method (USGS, 2000). Although it can be highly effective, it is considered to be a means of reducing landslide hazard rather than eliminating it, as over-design storm events are always a possibility. Water control comprises two primary methods: diverting surface water flows away from landslide prone land and the lowering of groundwater levels though subsurface drains.

The shallow nature of the landsliding on the steep face of the escarpment precludes the use of subsurface drainage as a hazard reduction method. Such landsliding can be expected to occur to some extent as a direct result of heavy rainfall, regardless of any drainage measures adopted. The potential for adopting stormwater and/or groundwater controls is considered negligible.

12.3.2   Vegetation Control

The Matatā Escarpment has an extensive vegetative cover, except for cliff sections west of the Awatarariki Stream. Typically, the presence of vegetation on a slope has the effect of reducing landslide hazard by reinforcing the ground with their roots, reducing surface water flows and providing a protective cover. In general, the growth of vegetation on escarpments should be encouraged. This is particularly the case for the rugged terrain behind the escarpment face, as an extensive cover of vegetation will assist somewhat in the minimisation of debris avalanches and therefore the potential for debris flows to be generated. It is noted however that a near full cover of vegetation did not prevent the 18 May 2005 event from occurring.

Observations made between 2004 and 2011 identified vegetation to be a major, if not the major component of the destructive debris that reached residential areas in Ōhope as a consequence of landslides occurring higher in the escarpment. This has not been the case in Matatā, possibly because of the difference in vegetation.

12.4   Risk Reduction

A range of engineering options are available for landslide and debris flow risk reduction. The following section introduces some of the options available and provides examples used previously at Whakatāne and Ōhope. T&T has previously undertaken extensive evaluations of the engineering options available for the control of debris flows. However, WDC has previously concluded that debris flow control through engineering means is not a cost-effective option for Awatarariki Stream, although it is was seen as a viable option for the Waitepuru Stream, where mitigation works have been carried out.

12.4.1   Debris Barriers

Isolating residences at the base of an escarpment from debris impact through the use of physical barriers is an effective, albeit potentially expensive means of reducing landslide risk. These protective measures cannot be considered to eliminate risk entirely as there remains the potential for an over-design event.

A number of properties in Whakatāne and Ōhope have had debris barriers constructed at the base of their respective escarpments as a result of claims made to the EQC. The methods employed consist of earth bunds, steel posts, flexible ring-net barriers and impact walls.

The intent of earth bunds is to divert landslide debris and surface water/slurry flows away from dwellings towards open ground (Figure 12.1). The EQC has installed steel posts (lengths of railway track) upslope of a small number of properties at Ōhope as a means of reducing the imminent risk of further impacts of debris on adjacent dwellings (Figure 12.2). Although such open barriers are unable to prevent slurries of soil and small rocks from potentially reaching rear properties, they have proven to be highly effective in stopping the large trees and boulders that represent the most significant threat to residents and property located at the base of the Ōhope Escarpment (Figure 12.3). The slurry issue could potentially be addressed with the construction of relatively modest diversion bunds.

Figure 12.1:   Earth bund constructed behind 71/71a West End Road, Ōhope

Figure 12.2:   Line of steel posts providing protection across a potential landslide path, West End Road, Ōhope

Figure 12.3:   Informal line of iron posts which successfully prevented several large trees from impacting a rear dwelling on West End Road, Ōhope

Figure 12.4:   Example of flexible ring-net barrier

A flexible ring-net barrier has been constructed behind two properties on Muriwai Drive, Whakatāne to mitigate the risk of impact from debris associated with a large greywacke landslide. Such barriers have a proven track record in the containment of high velocity landslide debris, although they are one of the more expensive risk mitigation options and require on-going maintenance (Figure 12.4).

12.4.2   Monitoring

The application of landslide monitoring is limited to existing landslides that may reactivate or expand in the future. The essentially random nature of most landsliding on the Matatā Escarpment however effectively rules out monitoring as a means of landslide hazard or risk reduction.

12.4.3   Warnings

Public warning and notification systems are currently used for distant-sourced tsunami and flooding hazards. The WDC has in the past provided residents of the escarpment areas advance warning of expected high rainfall storm events. These warnings were part of a short term programme targeting those residents whose properties had recently been affected by landslides. No warnings are currently given. Whilst warnings allow concerned residents to temporarily leave their homes during large storms, most will not move, meaning the loss of life risk is effectively unaltered.

As discussed above, there is no absolute relationship between rainfall and landslide occurrence. With landslides occurring only one third of the time when daily rainfall reaches 100mm, it is likely that most storm warnings will not be accompanied by landslides. The risk of this is of course that heavy rain warnings will be increasingly ignored. If however a higher rainfall threshold is used to determine when warnings are given, there is the real risk that landslides may occur in absence of warning. The reality is that weather predictions are not accurate enough to predict the intensity or total amount of rainfall associated with a particular storm. Improved instrumentation and prediction systems may, in the future, make warnings a viable means of managing landslide risk.

For example, there was at least a days warning that exceptionally heavy rain was approaching Matatā before the 2005 debris flows occurred. This rainstorm left a swath of destruction as it passed down the coast from Tauranga, and automatic raingauges were recording heavy antecedent rainfall and an intense, slow-moving rainstorm. Tsunami warnings of minutes to hours and evacuation drills are now increasingly common in urban coastal areas of New Zealand, and could be used as a model for intense rainfall. As well, at-risk farms are commonly given flood alerts for stock (and people) evacuation.

The Property Loss Risk would however, remain unchanged.

12.4.3.1   Warning Systems for Landslides and Debris Flows

The development of a warning system for landslide and debris flow hazards can be clearly divided into two distinct types of system:

- Early warning systems that provide warning of the potential for a landslide event to take place. These warning systems relate to the landslide trigger event (e.g. high rainfall) rather than the landslide event itself; and
- Event warning systems which detect when a landslide is occurring or likely to occur.

Examples of warning and event warning systems are presented in Tables 15.1 and 15.2 respectively.

An early warning system could take many forms. A low-level system might include the following:

- Regular monitoring and assessment of risk areas by qualified staff; and
- Active monitoring of Metservice rainfall forecasts and radar during events to detect any potential issues

A high-level early warning system might include:

- Regular monitoring and assessment of risk areas by qualified staff;
- Forwarding of all severe weather warnings to residents in risk areas (email and text alert);
- Active monitoring of Metservice rainfall forecasts and radar during events to detect any potential issues;
- Deployment of mobile radar to monitor areas of concern during major events;
- Installation of wire sensors to measure land movement in all areas of high risk; and
- Rainfall sensors in all catchments.

A low level event system would most likely entail only visual observation by residents in risk areas.

A high level system might include:

- Wire sensors connected to alarms placed in all areas with a high risk of potential landslide;
- Acoustic, remote sensing or physical triggering systems placed in the upper reaches of streams to indicate the passage of a debris flow;
- Staff deployed to monitor specific sites during heavy rainfall events and warn residents if movement in slope detected; and
- Regular escarpment condition surveys by geotechnical specialists

Table 15.1 Examples of Early Warning Systems for Landslides and Debris Flows

System Type	Capability	Advantages	Limitations
Rainfall forecast (Metservice)	The rainfall forecast is provided for 3 day periods (human and computer forecasting) in 3 hourly forecast periods	• No cost • Indication of rainfall amounts during each period well in advance of event	• Unable to get specific forecasts for individual catchments • Only provides likely amount over each 3 hour period. Does not provide indication of intensity of rainfall
Rain Radar (Metservice)	Bay of Plenty Rain radar provides images every 7 minutes through the Metservice website at 120km resolution. This can show areas of intense rain developing and provide some indication of likely intensities and track	• No cost – accessible through Metservice website • Provides some warning of intense rainfall	• Updates every 7 minutes, no real time tracking capability • Requires constant refreshing and observation • Rainfall intensity is shown only as light / moderate / heavy. No numerical values for likely rainfall intensities • Resolution does not allow tracking to a level of detail require for specific catchments
Rain Radar (Mobile Doppler)	Real time radar imagery for rainfall	• Mobile can be placed where highest quality imagery is required • High resolution imagery to detect and track intense areas of precipitation. Higher accuracy for rainfall intensities in specific catchments	• Cost – very expensive system • Needs to be deployed before an event and unlikely to provide a huge amount of extra warning time compared to the Metservice rain radar imagery
Raingauges	Collect rainfall data at specific site	• Accurate measurement of rainfall amounts and intensities at specific sites	• Only some raingauges are automatic

System Type	Capability	Advantages	Limitations
Severe Weather warnings (Metservice)	Issued when rainfall amounts are likely to exceed warning criteria (50mm in less than 6 hours)	• No cost, email subscription • Provided hours to days before an event develops • Provides indication of rainfall totals and likely intensities over a set period	• Sometimes very inaccurate – provided for large areas
Human observation	Regular visits to sites of concern to measure land movement, erosion etc	• Low cost	• Potential for human error

Table 15.2 Event Warning Systems for Landslides

System Type	Capability	Advantages	Limitations
Wire sensors	• Detect land movement from movement of wire reel or breakage of wire	• Simple system to install and use	• Limited to specific areas of unstable escarpments • Limited to known and existing landslides of a particular type e.g. rotational or translational landslides • Requires connection to monitors to provide alarm capability • Warning likely to activate too late for action to be taken
Visual observation	• Visual detection of cracks developing in slope, landslide occurring etc	• Low cost	• Capability based upon personnel available to carry out observations at specific sites • Limited ability to detect instability developing on the vegetation covered escarpments • Warning likely to activate too late for action to be taken

Table 15.3 Event Warning Systems for Debris Flows

System Type	Capability	Advantages	Limitations
Acoustic, radar, laser sensors	• Detect the passage of a debris flow past a monitoring point	• Easy to set thresholds for issuing of a warning Automatic and continuous monitoring • Could directly warn residents once a trigger level has been reach via SMS etc	• Potentially expensive to purchase, install and maintain • Sensors need to be hung across a channel, or positioned on banks • Susceptible to damage and vandalism • Potentially susceptible to false warnings, particularly as the system is bedding in • May give only a few minutes warning
Geophones and Seismometers	• Detect ground vibrations caused by movement of debris	• Sensors are easy to install and unlikely to be set off falsely due to being buried	• Difficult to set a warning threshold due to other influences that might cause vibration • High costs
Physical trigger	• Physical detection of the passage of a debris flow	• Simple and robust system	• Potentially expensive to purchase, install and maintain
CCD Camera	• Detect movement of debris in debris flow path	• Can be installed in safe area away from any potential flow path	• Potentially expensive to purchase, install and maintain
Visual observation	• Observations of debris dams in the streams that are originators of debris flows	• Low cost	• Capability based upon personnel available to carry out observations at specific sites • Warning likely to activate too late for action to be taken • Presence of dams may not actually result in a debris flow for many years • Difficult to define point when a warning should be given

12.5   Owner Self-Help Options

There may be little that existing building owners can do to reduce the landslide hazard affecting their properties to any meaningful degree. This is particularly the case with respect to debris flows. The best thing that residents could do is to be vigilant when unusually heavy rainfall is forecast. This may mean that those residents located close to points where drainage exits the escarpment (in particular the Awatarariki Stream) could self evacuate for a period of a few hours. Residents who have a property close to the base of the escarpment may want to leave the rear of the property and dwelling unoccupied for the duration of the storm event.

It is possible that landslide (including debris flows) risks to life and property could be mitigated amongst other ways, by the type of building design and construction used. For example, two storey houses with strong, impact resistant walls, fences and bunds, could be an effective mitigation option in some scenarios.

13   Conclusions

A quantitative landslide risk assessment has been undertaken for the escarpment and township of Matatā. The purpose of the study was to develop an understanding of the landslide and debris flow hazard within the vicinity of Matatā and the risks that future events of this type pose to residents and potential future developments. Through a process of developing a landslide inventory and mapping the extent of previous debris flows, a series of hazard maps have been developed that show the spatial distribution of landslide and debris flow hazards across the escarpment and flatlands of Matatā.

Estimates of loss of life risk and property loss risk have been assigned to the different hazard zones. The results indicate that the risks to some properties in Matatā are considered to be moderate to very high and therefore in excess of the level of risk commonly adopted as being tolerable. Despite the loss of life risk being considered high for some properties located near the base of the escarpment, a number of factors have contributed to a lack of previous landslide impacts. This distinguishes the Matatā Escarpment from the Whakatāne and Ōhope escarpments where many houses have been damaged or destroyed and lives have been lost. The greatest landslide-related risk to Matatā appears to be moderate to large debris flows. Mapping has shown that the Matatā area has been affected by an unknown number of debris flows other than the 18 May 2005 event. It is a certainty that the debris flows will occur in the future, most likely in the Awatarariki and Waitepuru Streams.

Options for mitigation of the risks associated with landsliding and debris flows are limited as the higher hazard zones are already occupied. Suitable planning restrictions, together with an early warning system of unusually heavy rain are probably the most suitable responses to the identified risks.

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15   Applicability

This report has been prepared for the benefit of Whakatāne District 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 without our prior review and agreement.

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Environmental and Engineering Consultants

Report prepared by: Authorised for Tonkin & Taylor Ltd by:

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Kevin J. Hind   Nick Rogers

Engineering Geologist   Project Director

kjh

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Appendix A: Location and Elevation Maps

Notes: Aerial Imagery 2007 sourced from Terralink International
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A3 SCALE 1:5,000

0   50   100   150   200   250   (m)
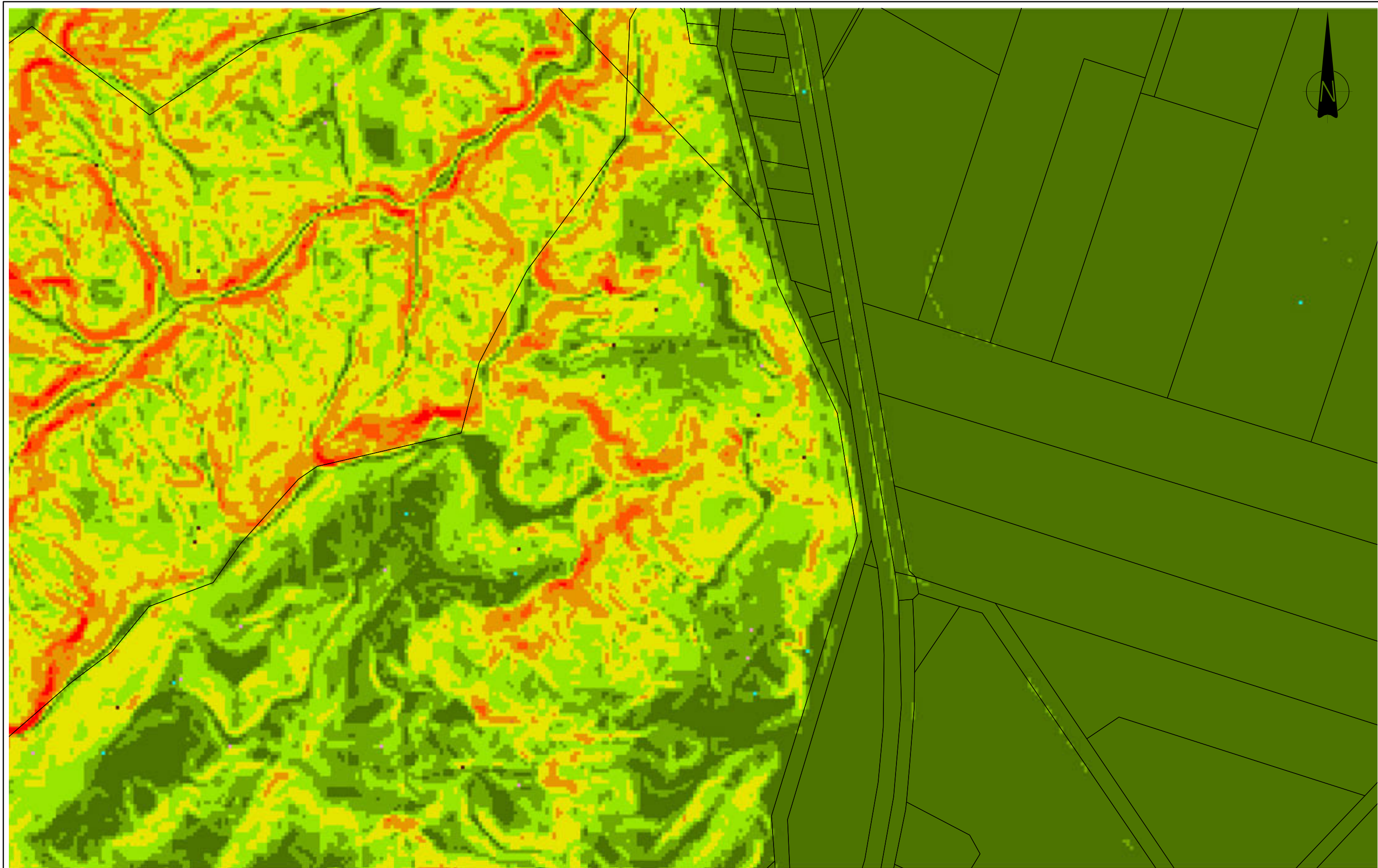
Location Plan

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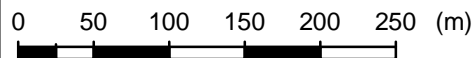
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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Location and Elevation
Sheet: 1

FIGURE No.   Figure A1

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A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

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Location Plan
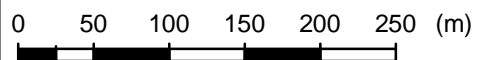
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MATATA QLRA
Location and Elevation
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FIGURE No.
Figure A2

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0

A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

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MATATA QLRA
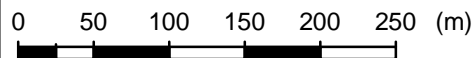Location and Elevation
Sheet: 3

FIGURE No.   Figure A3   Rev. 0

Appendix B: **Slope Class Maps**
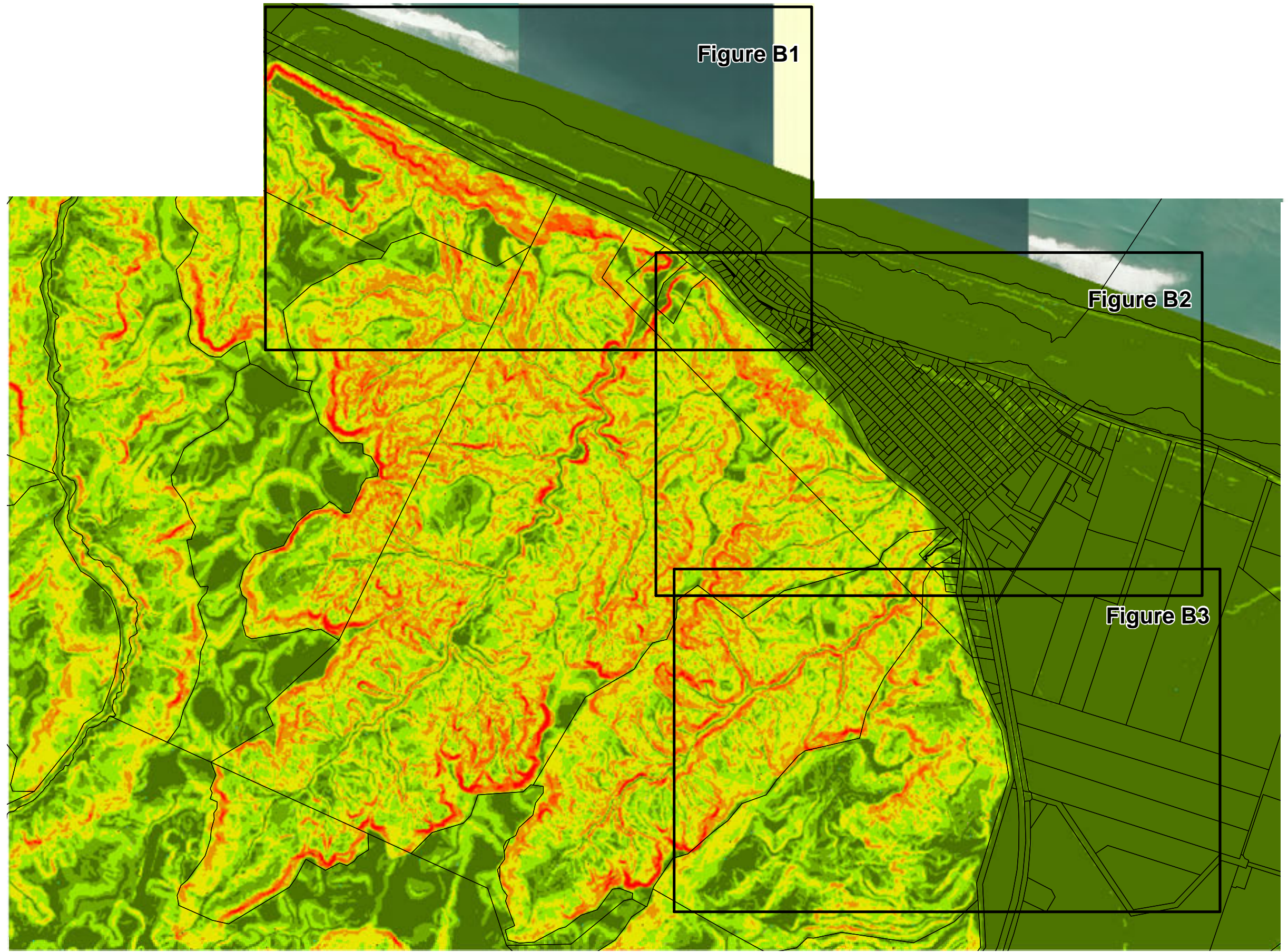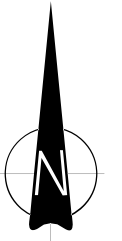
Figure B1

Figure B2

Figure B3

N

Notes: Aerial Imagery taken in 2011 and sourced from WDC.
25m Contours generated from LiDAR taken in 2011 and sourced from WDC.

A3 SCALE 1:15,000

0   200   400   600   800   (m)

LEGEND

⬛ 0 to 10	Slope (degrees)
⬛ 11 to 20	
⬛ 21 to 30	🟧 41 to 50
🟨 31 to 40	🟧 51 to 60
	🟥 >60

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SCALE (AT A3 SIZE) 1:15,000		
PROJECT No. 29115		

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MATATA QLRA
Slope Class
Sheet: 1

FIGURE No. Figure B	Rev. 0

Notes: Aerial Imagery taken in 2011 and sourced from WDC.
     25m Contours generated from LiDAR taken in 2011 and
     sourced from WDC.

     A3 SCALE 1:5,000

0   200   (m)

LEGEND	
■ 0 to 10 Slope (degrees)	
■ 11 to 20	■ 41 to 50
■ 21 to 30	■ 51 to 60
■ 31 to 40	■ >60

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MATATA QLRA
Slope Class
Sheet: 2

FIGURE No.
Figure B1

Rev.
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Notes: Aerial Imagery taken in 2011 and sourced from WDC.
25m Contours generated from LiDAR taken in 2011 and
sourced from WDC.

A3 SCALE 1:5,000

0   200 (m)

LEGEND

Slope (degrees)
- 0 to 10
- 11 to 20
- 21 to 30
- 31 to 40
- 41 to 50
- 51 to 60
- >60

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MATATA QLRA
Slope Class
Sheet: 3

FIGURE No.
Figure B2

Rev.
0

Notes: Aerial Imagery taken in 2011 and sourced from WDC.
  25m Contours generated from LiDAR taken in 2011 and
  sourced from WDC.

A3 SCALE 1:5,000

0   200 (m)

LEGEND

■ 0 to 10	Slope (degrees)
■ 11 to 20	■ 41 to 50
■ 21 to 30	■ 51 to 60
■ 31 to 40	■ >60

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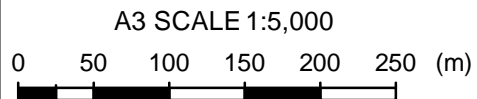**WHAKATANE DISTRICT COUNCIL**
MATATA QLRA
Slope Class
Sheet: 4

FIGURE No.
Figure B3

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Appendix C: **Landslide Inventory Maps**

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A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Legend
Deposit
Source
Travel
Historic Scarps

Location Plan

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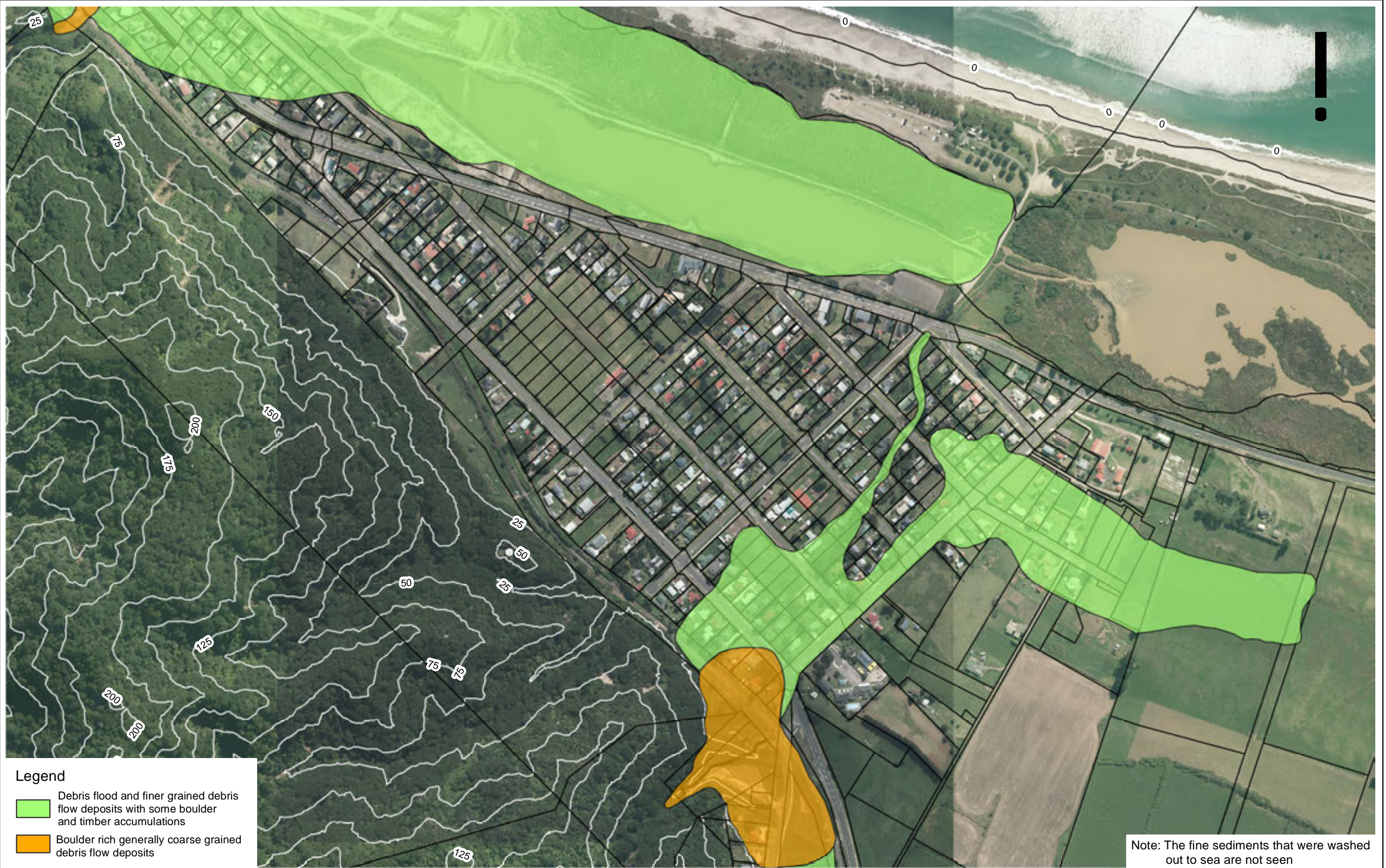105 Carlton Gore Road, Newmarket, Auckland
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MATATA QLRA
Landslide Inventory
Sheet: 1

FIGURE No.   Figure C1

Rev.
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A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Legend

⬚ Deposit

⬚ Source

☐ Travel

▽▽ Historic Scarps

Location Plan

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MATATA QLRA
Landslide Inventory
Sheet: 2

FIGURE No.
Figure C2

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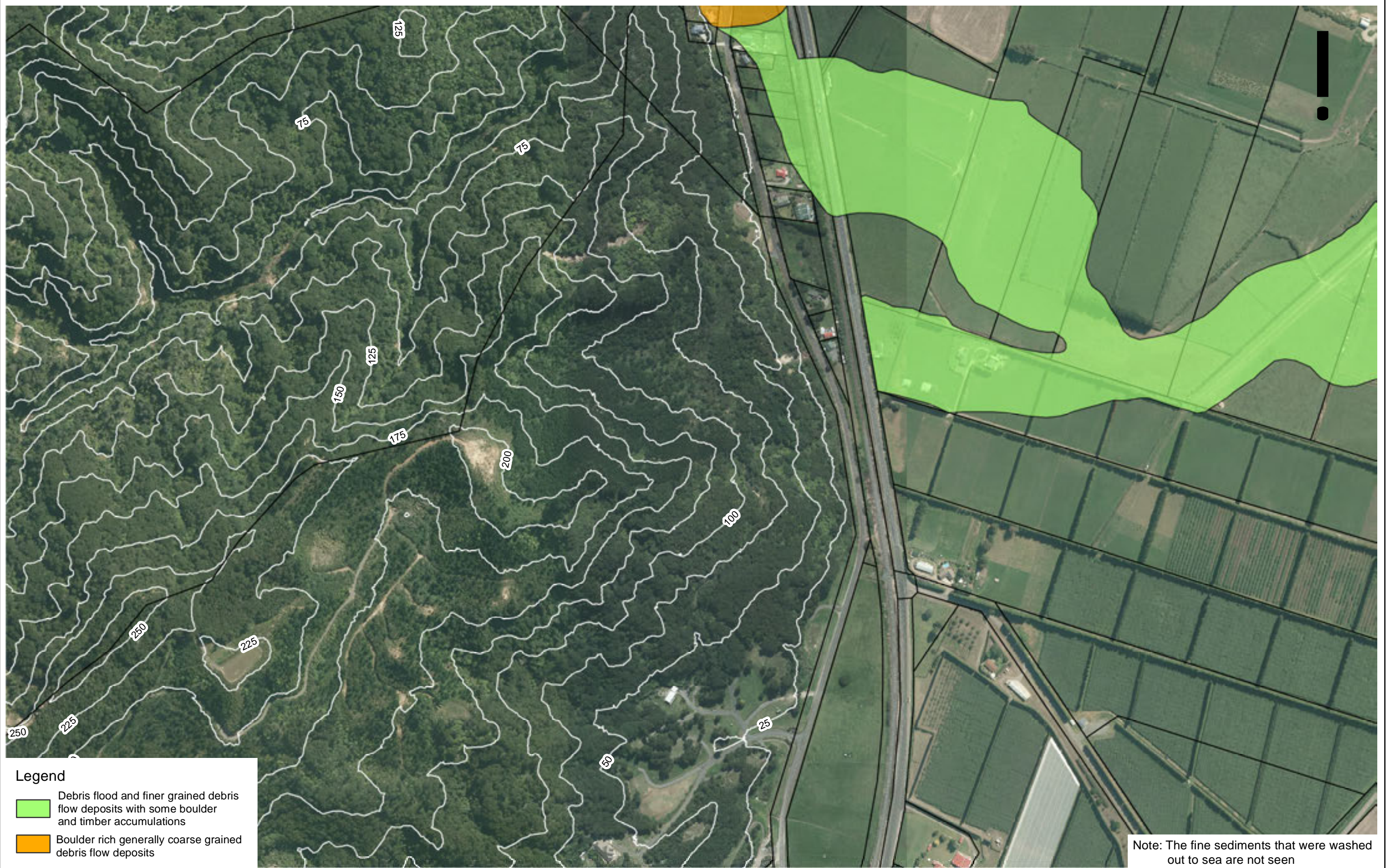licensors).

A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

Legend

⬡ Deposit

⬚ Source

▭ Travel

∇∇ Historic Scarps

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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Landslide Inventory
Sheet: 3

FIGURE No.
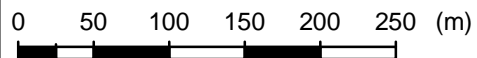Figure C3

Rev. 0

Appendix D: **2005 Debris Flow Maps**

Legend

🟩 Debris flood and finer grained debris flow deposits with some boulder and timber accumulations

🟧 Boulder rich generally coarse grained debris flow deposits

Note: The fine sediments that were washed out to sea are not seen

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A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

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MATATA QLRA
2005 Debris Flow
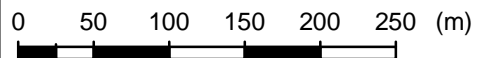Sheet: 1

FIGURE No.
Figure D1

Rev.
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Legend

Debris flood and finer grained debris flow deposits with some boulder and timber accumulations

Boulder rich generally coarse grained debris flow deposits

Note: The fine sediments that were washed out to sea are not seen

Notes: Aerial Imagery 2007 sourced from Terralink International (Copyright 2002-2005 Terralink International Limited and its licensors).

A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Location Plan

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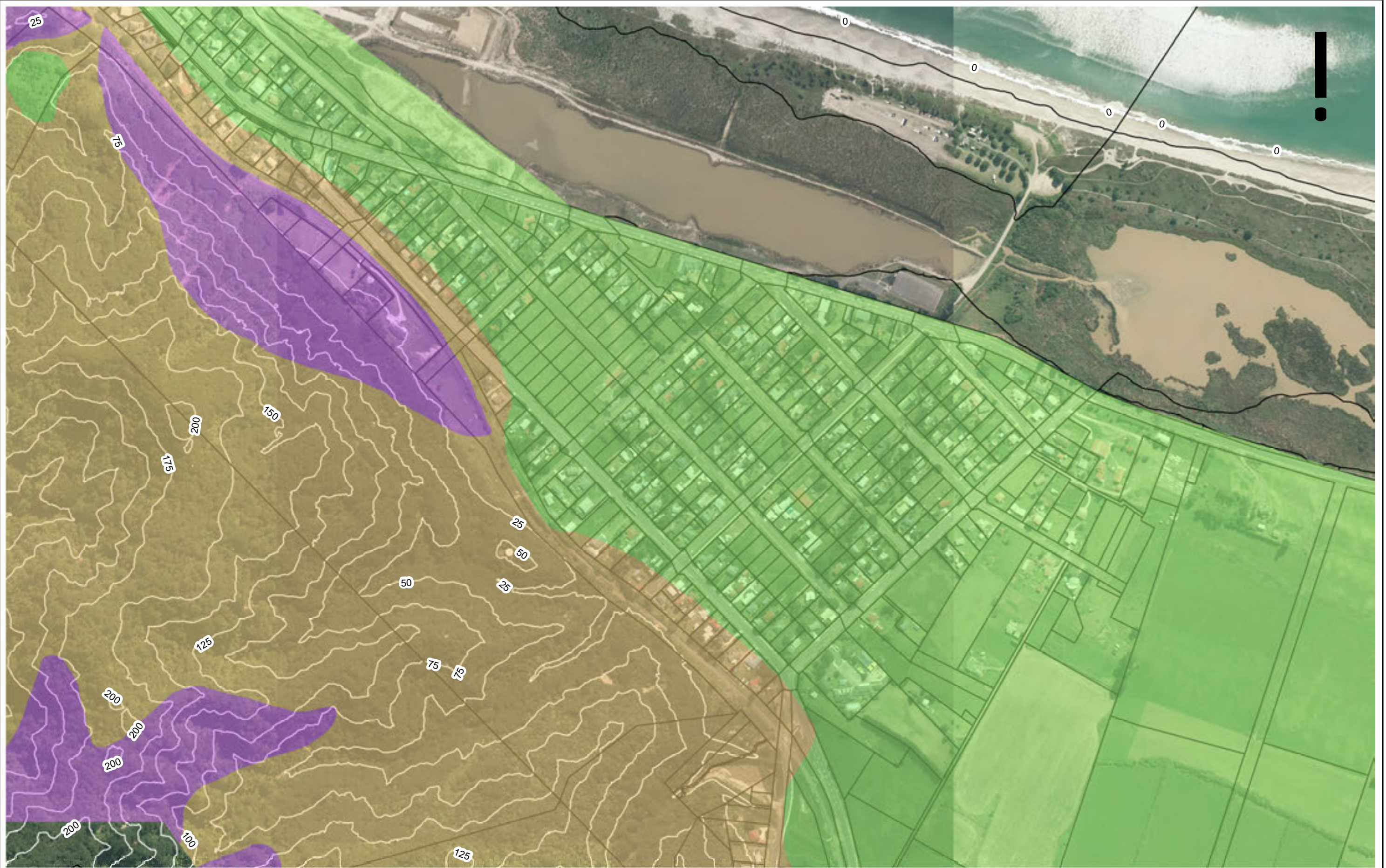105 Carlton Gore Road, Newmarket, Auckland
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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
2005 Debris Flow
Sheet: 2

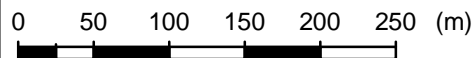FIGURE No.   Figure D2   Rev. 0

Legend

Debris flood and finer grained debris flow deposits with some boulder and timber accumulations

Boulder rich generally coarse grained debris flow deposits

Note: The fine sediments that were washed out to sea are not seen

A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Location Plan

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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
2005 Debris Flow
Sheet: 3

FIGURE No.   Figure D3   Rev. 0

Appendix E: **Landslide Hazard Maps**

Notes: Aerial Imagery 2007 sourced from Terralink International
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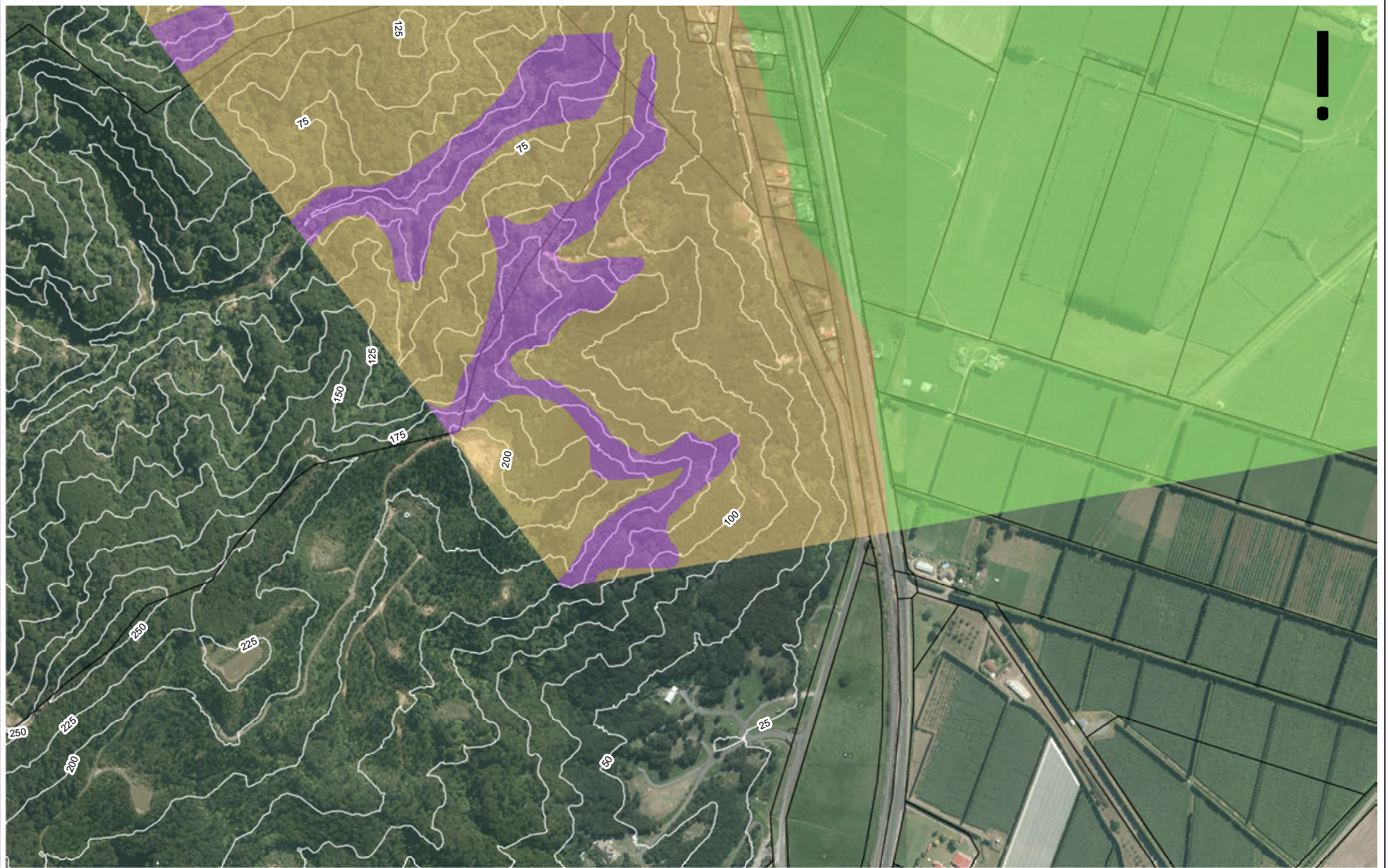licensors).

A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Legend

High

Moderate

Low to very low

Location Plan

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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Landslide Hazard
Sheet: 1

FIGURE No.   Figure E1

Rev. 0

Figure E2 — Matata QLRA Landslide Hazard, Sheet 2

Legend

High
Moderate
Low to very low

Location Plan

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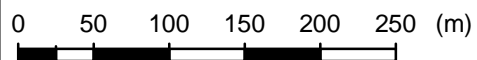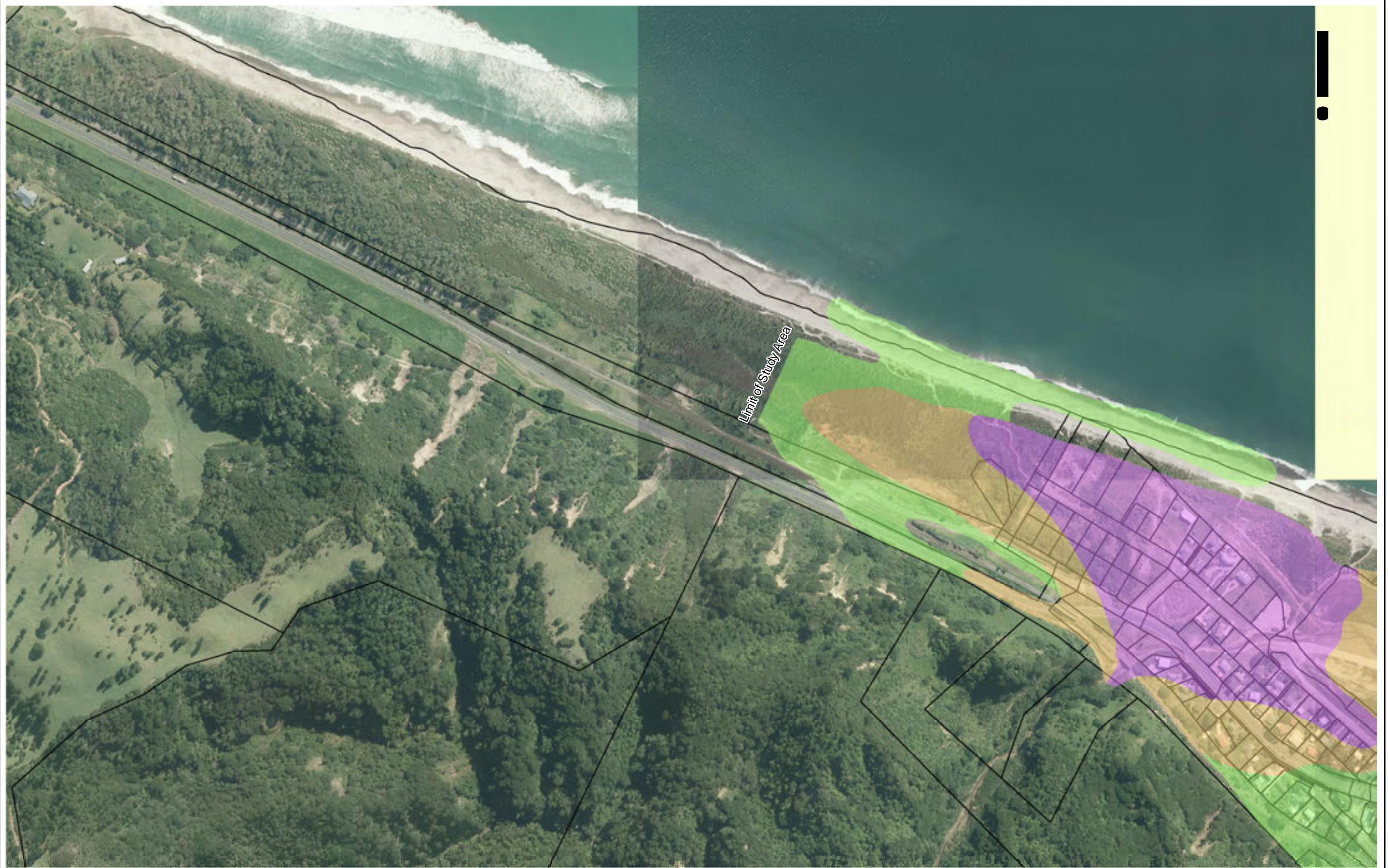www.tonkin.co.nz

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WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Landslide Hazard
Sheet: 2

FIGURE No.
Figure E2

Rev.
0

Legend

- High (purple)
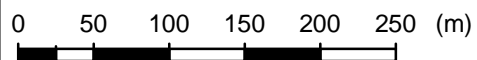- Moderate (tan/orange)
- Low to very low (green)

Location Plan

Notes: Aerial Imagery 2007 sourced from Terralink International
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A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

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WHAKATANE DISTRICT COUNCIL
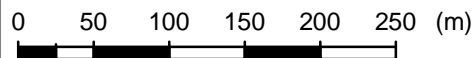MATATA QLRA
Landslide Hazard
Sheet: 3

FIGURE No.
Figure E3

Rev. 0

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Appendix F: **Debris Flow Hazard Maps**

Limit of Study Area

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A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

Legend

High

Moderate

Low

Location Plan

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MATATA QLRA
Debris Flow Hazard
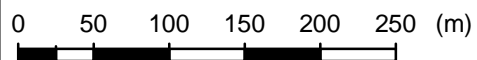Sheet: 1

FIGURE No.
Figure F1

Rev.
0

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A3 SCALE 1:5,000

0   50   100   150   200   250   (m)

Legend

High
Moderate
Low

Location Plan

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MATATA QLRA
Debris Flow Hazard
Sheet: 2

FIGURE No.   Figure F2   Rev. 0

Limit of Study Area

Notes: Aerial Imagery 2007 sourced from Terralink International (Copyright 2002-2005 Terralink International Limited and its licensors).

A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

Legend

High

Moderate

Low

Location Plan

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SCALE (AT A3 SIZE)
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MATATA QLRA
Debris Flow Hazard
Sheet: 3

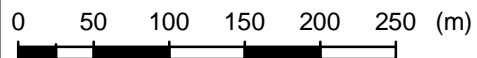| FIGURE No.		Rev.
Figure F3		0

Appendix G: **Combined Hazard Maps**

Limit of Study Area

L1

M1

H3

M3

M2

L1

H2

M3

H4

H5

M3

M2

L1

M1

H3

	Debris flow Hazard		
	Low	Moderate	High
Landslide Hazard High	H3	H2	H1
Moderate	M1	M3	H5
Low to Very Low	L1	M2	H4

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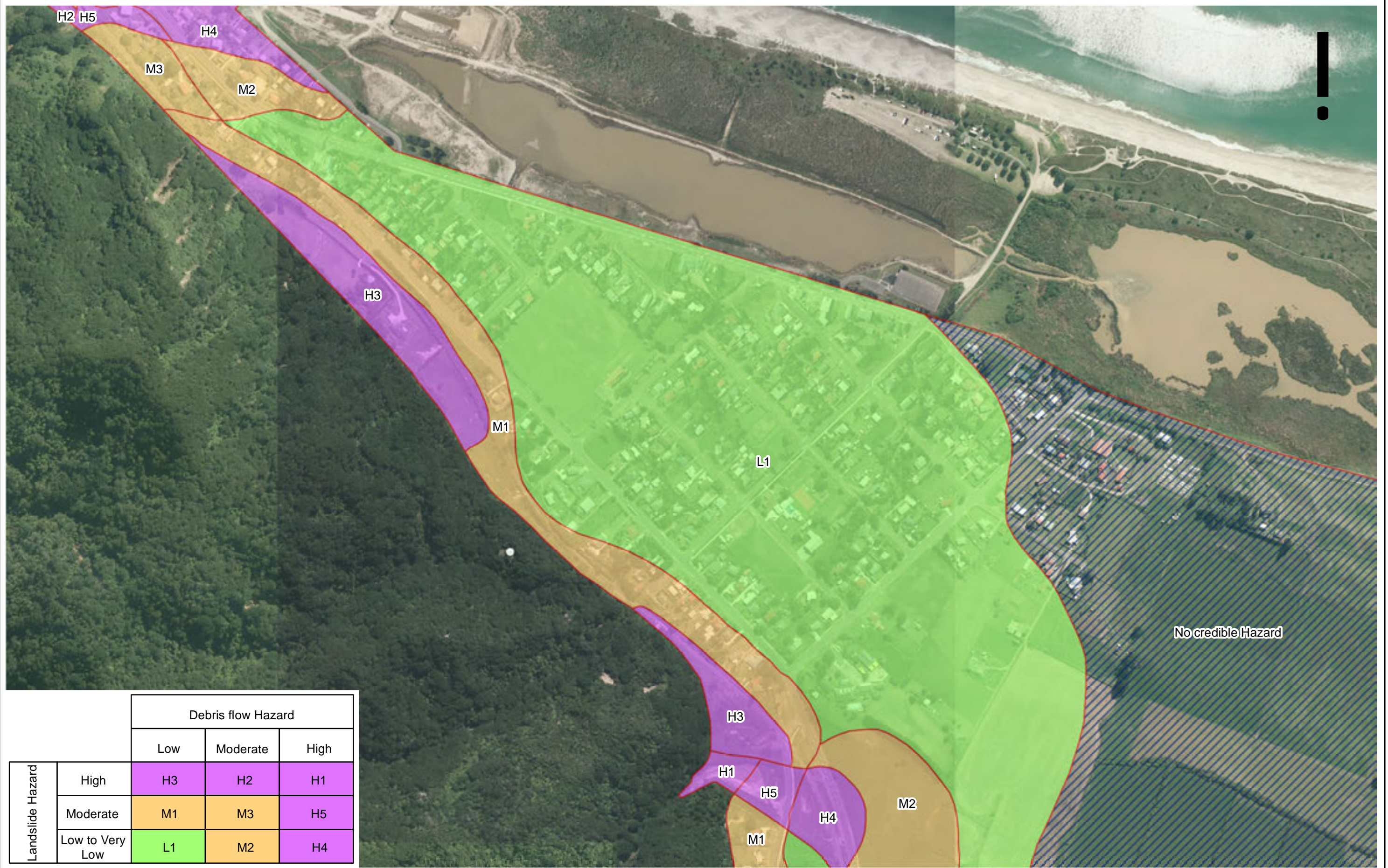   licensors).

A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

Location Plan

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1:5,000
PROJECT No.
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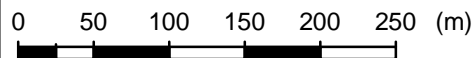MATATA QLRA
Combined Instability Hazard
Sheet: 1

FIGURE No.   Figure G1   Rev. 0

Combined Instability Hazard — Matata QLRA, Figure G2, Sheet 2

Landslide Hazard	Debris flow Hazard		
	Low	Moderate	High
High	H3	H2	H1
Moderate	M1	M3	H5
Low to Very Low	L1	M2	H4

No credible Hazard

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MATATA QLRA
Combined Instability Hazard
Sheet: 2

FIGURE No. Figure G2
Rev. 0

H4

M2

L1

M1

No credible Hazard

Limit of Study Area

	Debris flow Hazard		
	Low	Moderate	High
High	H3	H2	H1
Moderate	M1	M3	H5
Low to Very Low	L1	M2	H4

Landslide Hazard

Notes: Aerial Imagery 2007 sourced from Terralink International (Copyright 2002-2005 Terralink International Limited and its licensors).
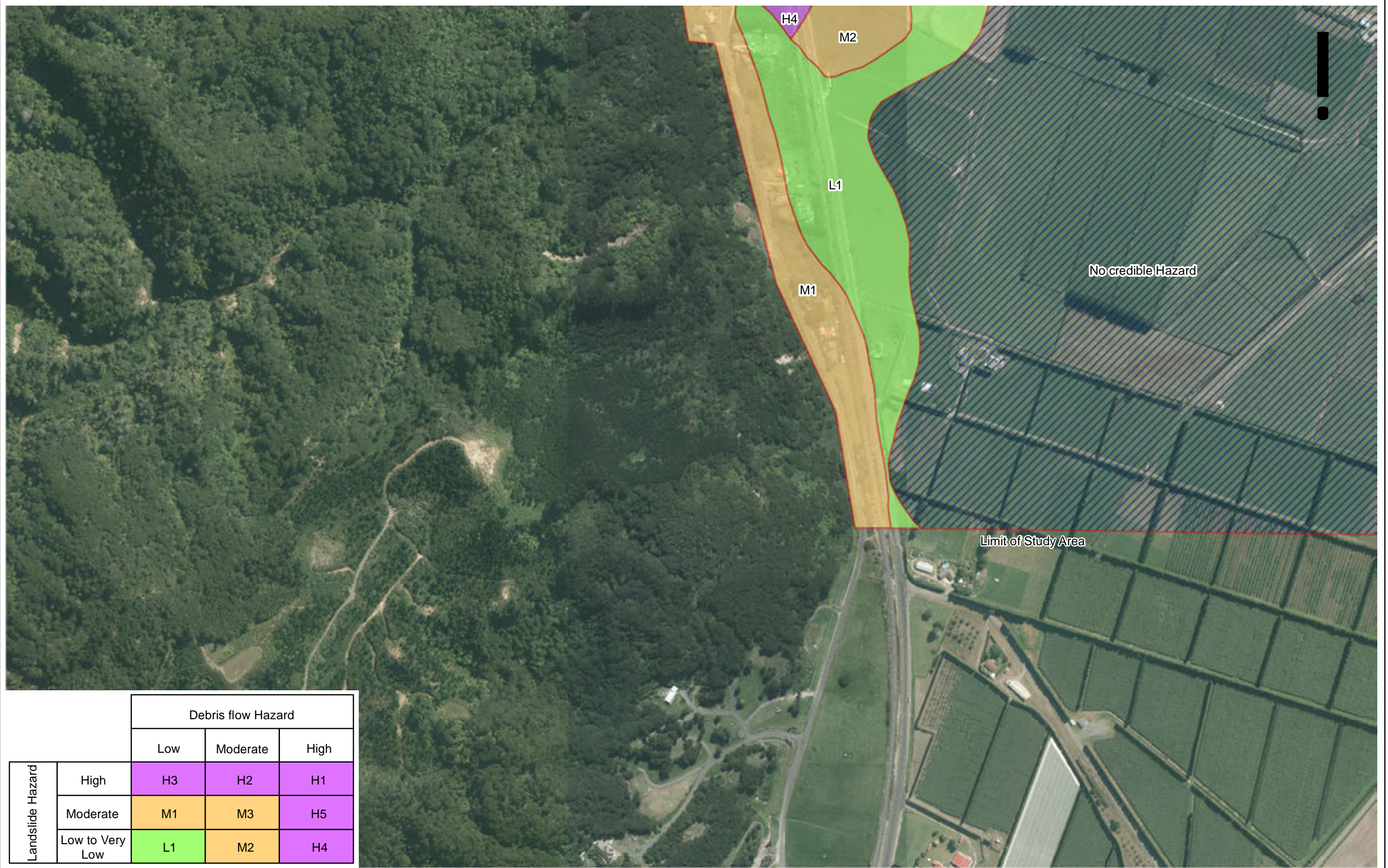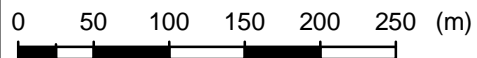
A3 SCALE 1:5,000

0 50 100 150 200 250 (m)

Location Plan

TᴛT
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
www.tonkin.co.nz

DRAWN	JC	Nov.13
CHECKED		
APPROVED		

ARCFILE
29115-FG1_G3.mxd
SCALE (AT A3 SIZE)
1:5,000
PROJECT No.
29115

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Combined Instability Hazard
Sheet: 3

FIGURE No.
Figure G3

Rev.
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