REPORT

Whakatane District Council

Quantitative Landslide Risk Assessment
Whakatane and Ohope Escarpments

Volume 1 of 2

Report prepared for:

Whakatane District Council

Report prepared by:

Tonkin & Taylor Ltd

Distribution:

Whakatane District Council	**3 copies**
Tonkin & Taylor Ltd (FILE)	**1 copy**

June 2013

T&T Ref: 28273.rev3 (issued)

Table of contents

Volume 1

Definitions **xii**

1 Introduction 1

2 Scope of Work 2

2.1 Purpose 2
2.2 Study Area 2
2.3 Tasks 2
2.4 Limitations on Scope and Outcomes 2

3 The Landslide Risk Management Process 4

3.1 Terminology 4
3.2 General Risk Management Framework 4
3.3 Landslide Risk Management Framework 5

4 Previous Work 9

5 Setting 10

5.1 Whakatane Escarpment 10
5.2 Ohope Escarpment 10
5.3 Topography and DEM 10

6 Geology 13

6.1 General 13
6.2 Published and Unpublished Research 13
6.3 Greywacke Basement 13
6.4 Ohope Beds 15
6.5 Younger Volcanic Ash 18
6.6 Project-Specific Geological Maps 18
6.7 Ohope Escarpment Bench 18
6.8 Hydrogeology 18
6.8.1 Whakatane Escarpment 18
6.8.2 Ohope Escarpment 18
6.9 Active Faulting and Seismicity 21

7 Landslide Formation 25

7.1 Instability Types 25
7.2 Landslide triggers 25
7.3 Landslide Run-Out Distances 25

8 Landsliding on the Whakatane Escarpment 28

8.1 Historic Instability 28
8.2 Recent Instability 28
8.3 Instability Types and Locations 32
8.3.1 Type W1: Shallow Landslides within Upper Ohope Beds 32
8.3.2 Type W2: Structurally Controlled Landslides within Greywacke 32
8.3.3 Type W3: Small-Scale Rock falls from Greywacke Bluffs 32

9 Landsliding on the Ohope Escarpment 35

9.1 Historic Instability 35
9.2 Recent Instability 37
9.3 Instability Types and Locations 37
9.3.1 Type O1: Shallow Landslides within Talus Slope 37
9.3.2 Type O2: Rock Falls from Sub-Vertical Sandstones Faces 37

9.3.3 Type O3: Shallow Talus Landslides from Intermediate Benches 42
9.3.4 Type O4: Shallow Landslide of Primarily Soil and Vegetation from Steep Rock Faces 42
9.3.5 Types O5 and O6: Landslides within Upper Ohope Beds and Younger Pumice Ash 42
9.4 Steep Slope Weathering and the Landslide Cycle 45
10 Landslide Inventory 47
11 Assessment of Landslide Trigger Mechanisms 48
11.1 Rainfall 48
11.2 Earthquakes 52
12 Landslide Susceptibility 54
12.1 General 54
12.2 Susceptibility Classification 54
12.3 Controls on Landslide Initiation 54
12.3.1 Geological Control 54
12.3.2 Topographic Control 54
12.3.3 Normalised Difference 56
12.4 Landslide Susceptibility Zoning 58
12.4.1 Landslide Initiation 58
12.4.2 Landslide Inundation 58
12.4.3 Results 60
13 Landslide Hazard 62
13.1 Definition 62
13.2 Landslide Frequency 62
13.3 Landslide Hazard Zones 62
13.4 Results 63
14 Landslide Risk 66
14.1 Loss of Life Risk 66
14.1.1 Loss of Life Risk Criteria 66
14.1.2 Quantitative Loss of Life Risk Estimation 67
14.1.3 Results of Risk Estimation 67
14.2 Property Loss Risk 72
15 Comparison to Other Risks 77
16 Landslide Risk Management 78
16.1 Hazard Avoidance 78
16.1.1 Land Use Zoning 78
16.1.2 Building Set-Back Distances 78
16.2 Hazard Elimination 78
16.3 Hazard Reduction 79
16.3.1 Stormwater and Groundwater Control 79
16.3.2 Vegetation Control 80
16.4 Risk Reduction 80
16.4.1 Debris Barriers 80
16.4.2 Monitoring 81
16.4.3 Warnings 81
16.5 Owner Self-Help Options 88
17 Review of Landslide Hazard Management Objectives, Policies and Rules 89
17.1 Purpose and Methodology 89
17.2 New Zealand Approaches to Landslide Management 89
17.2.1 GNS Science Planning Guidelines 89

17.2.2 Review of Selected New Zealand District Plans 91
17.2.3 Whakatane District Plan – Landslide Hazard Review 91
17.2.4 Summary 100
17.3 Approach of Selected Australian Councils 100
17.3.1 Introduction 100
17.3.2 Pittwater Council, NSW 100
17.3.3 Manly Council (NSW) 105
17.4 Discussion 106
17.5 Conclusions and Suggestions 108
18 Discussion and Conclusions 109
19 References 111
20 Applicability 113

Volume 2

Appendix A: A3 Figures

Appendix B: Location and Elevation – Whakatane

Appendix C: Location and Elevation – Ohope

Appendix D: Geology – Whakatane

Appendix E: Geology – Ohope

Appendix F: Landslide Inventory – Whakatane

Appendix G: Landslide Inventory – Ohope

Appendix H: Geology and Landslide Inventory – Whakatane

Appendix I: Geology and Landslide Inventory – Ohope

Appendix J: Slope Class – Whakatane

Appendix K: Slope Class – Ohope

Appendix L: Landslide Initiation Susceptibility – Whakatane

Appendix M: Landslide Initiation Susceptibility – Ohope

Appendix N: Landslide Susceptibility – Whakatane

Appendix O: Landslide Susceptibility – Ohope

Appendix P: Landslide Hazard – Whakatane

Appendix Q: Landslide Hazard – Ohope

List of Tables

Table 3.1: Definitions of Terms

Table 3.2: Equivalent Terms for Risk

Table 6.1: Data for Seismic Sources near Whakatane

Table 6.2: Modified Mercalli Intensity Scale

Table 11.1: Daily Rainfall Associated with Known Landslides

Table 12.1: Landslide Susceptibility Descriptors

Table 12.2: Slope Classes

Table 12.3: Normalised Difference, Whakatane Escarpment

Table 12.4: Normalised Difference, Ohope Escarpment

Table 12.5 Susceptibility to Landslide Initiation

Table 12.6: Landslide Debris Travel Distance

Table 12.7: Basis for Mapping Inundation Susceptibility

Table 13.1: Definition of Small Landslide Hazard

Table 13.2: Average Landslide Frequency Based on Inventory

Table 13.3: Landslide Initiation Hazard

Table 13.4: Landslide Inundation Hazard

Table 13.5: Basis for Mapping Inundation Hazard

Table 14.1: Descriptors for Loss of Life Risk Criteria

Table 14.2: Example of Loss of Life Risk Calculation

Table 14.3: Long-Term Loss of Life Risk for Escarpment and Talus Slope

Table 14.4: Property Loss Risk Matrix (AGS, 2007)

Table 14.5: Risk to Property - Qualitative Measures of Likelihood

Table 14.6: Risk to Property - Qualitative Measures of Consequence to Property

Table 14.7: Approximate Property Loss Risk

Table 15.1 Examples of Early Warning Systems for Landslides

Table 15.2 Event Warning Systems for Landslides

Table 17.1: Assessment of Tools to Manage Landslide Risk Within District Plans

Table 17.2: Comparison of Objectives and Policies

Table 17.3: Qualitative Measures of Likelihood of Instability Occurring

List of Figures

Figure 2.1 Location plan indicating the extent of the QLRA study

Figure 3.1 Landslide Risk Management Framework from AGS (2007)

Figure 3.2 Project Landslide Risk Analysis Framework

Figure 5.1 View of the Whakatane Escarpment

Figure 5.2 3D topographic model of the Whakatane Escarpment

Figure 5.3 View of Ohope Beach and the Ohope Escarpment

Figure 5.4 3D LiDAR model of the Ohope Escarpment above West End Rd

Figure 6.1 Geology of the Whakatane and Ohope areas

Figure 6.2 Whakatane Mélange exposed at the Whakatane Head

Figure 6.3 View of the western end of Ohope Beach

Figure 6.4 Cutting on Ohope Road

Figure 6.5 Gravel bed within the Upper Ohope Beds

Figure 6.6 Upper Ohope beds overlying a highly disturbed greywacke (mélange)

Figure 6.7 View of the Ohope Escarpment from the Otarawairere Bay track

Figure 6.8 LiDAR model of the Ohope Escarpment

Figure 6.9 LiDAR model of West End Road

Figure 6.10 West End catchments and flow paths

Figure 6.11 LiDAR model of the Ohope Escarpment in the vicinity of Pohutukawa Ave

Figure 6.12 Geological structure of the eastern Bay of Plenty

Figure 6.13 Faults from GNS Active Fault Database

Figure 7.1 Major landslide types

Figure 7.2 Landslide debris deposited between No 22 and 23 West End Road

Figure 7.3 View of highly fluidised debris

Figure 8.1 View of the Wepiha St/Harvey St area in c1900-1910

Figure 8.2 Google Earth oblique view of the Wepiha St/Harvey St area

Figure 8.3 View of the Wepiha/Harvey Street area in 1964

Figure 8.4 3D DEM of the Muriwai Terrace area

Figure 8.5 Photo from 1964 showing the greywacke escarpment behind Commerce St

Figure 8.6 View of the northern end of the Whakatane Escarpment

Figure 8.7 Landslide (A) and debris chute (B) behind No. 7 Muriwai Drive

Figure 8.8 Large structurally-controlled landslide behind No. 33 Muriwai Drive

Figure 8.9 Minor rock falls within highly jointed greywacke, Whakatane Heads

Figure 9.1 Presence of three significant landslides on the Ohope escarpment in 1949

Figure 9.2	West End Road, Ohope, 1955
Figure 9.3	West End Road, Ohope, 1951
Figure 9.4	Large landslide that occurred above below No. 14 Cliff Road in July 2004
Figure 9.5	General location of landslides on Ohope Escarpment, 2004 and 2011-2012
Figure 9.6	Landslide within the talus slope behind West End Road
Figure 9.7	Sandstone boulder and smaller rock debris on talus slope
Figure 9.8	Recent rock fall debris from sub-vertical sandstone exposure
Figure 9.9	Rock fall at the rear of a property on Pohutukawa Ave, Ohope
Figure 9.10	View of scar from the fatal July 2011 landslide at 55 West End Road
Figure 9.11	Contact between Upper Ohope Sandstone and Lower Ohope Sandstone
Figure 9.12	Shallow failure of the very thin soil and vegetation cover from a steep face
Figure 9.13	View of the top of the Ohope Escarpment adjacent to Ohope Road
Figure 9.14	Cycle of vegetation establishment, growth and landslide on the escarpment
Figure 11.1	Mean Daily Rainfall Data for Ohope, 1978 to 2013
Figure 11.2	Annual Rainfall statistics for Ohope
Figure 14.1	Debris travel distance expressed as an H/L ratio
Figure 15.1	Comparison of Individual Fatality Risk for Different Hazards in New Zealand
Figure 16.1	Earth bund constructed behind 71/71a West End Road
Figure 16.2	Line of steel posts providing protection across a potential landslide path
Figure 16.3	Informal line of iron posts on West End Road
Figure 16.4	Example of flexible ring-net barrier
Figure 17.1	Example of a planning map showing natural hazards at property level
Figure 17.2	Geotechnical Risk Management Plan, Pittwater NSW. Pittwater Council
Figure 17.3	“Landslips Potential Hazards Plan” from Manly DCP

Executive summary

Historic and recent evidence indicates that the steep escarpment slopes that form the backdrop to Whakatane and Ohope have been, and will continue to be, susceptible to landslide events. These landslides represent a significant risk to both people and property.

Following a number of significant landslides between 2004 and 2011, the Whakatane District Council (WDC) commissioned Tonkin & Taylor Ltd (T&T) to undertake a Quantitative Landslide Risk Assessment study to assess the level of risk posed by future landslides from the escarpments. The methodology published by the Australian Geomechanics Society (AGS, 2007) has generally been adopted by this study.

The study includes a consideration of potential options for managing landslide hazards and reducing the risk they represent to lower levels, as well as a review of the current WDC policies relating to landslide hazard management.

WDC defined the study areas as follows:

Whakatane Escarpment:	*The northern and western faces from Mokorua Gorge Road in the south, through to 1C Muriwai Drive in the north.*
Ohope Escarpment:	*The northern face from 254 Pohutukawa Avenue in the east through to 71 West End Road in the west.*

The geology of the study areas consists of greywacke basement rock overlain by a series of much younger marine, terrestrial and volcanic deposits. Steep terrain and the very weak nature of the geology makes both escarpments susceptible to landslides.

A landslide inventory has been developed for the escarpments based primarily on T&T's record of landslide investigations for the Earthquake Commission, but also from historical photographic records and field mapping. The period covered by the inventory is approximately 50 years in the case of the Whakatane Escarpment and 70 years for the Ohope Escarpment. The inventory indicates that the study area can be divided into four hazard sectors based on the frequency of recorded landslides and assessed susceptibility:

- Whakatane Escarpment north of the Wairere Stream;
- Whakatane Escarpment south of the Wairere Stream;
- Ohope Escarpment behind West End Road; and
- Ohope Escarpment behind Pohutukawa Avenue.

All of the landslides in the inventory were triggered by rainfall. An assessment of past rainfall and escarpment landslide records indicates that landslides occur both as a result of individual high intensity rain storms, and during unusually wet years. The available data indicates that significant rainfall-induced landslides occur when the daily rainfall exceeds the typical monthly average, a situation which is likely to occur approximately once every 10 years.

Seismic events can also trigger landslides. Rupture along the Whakatane Fault is the most likely source of seismic landsliding on the Whakatane and Ohope escarpments. Although dozens of landslides could potentially be triggered by a major rupture of the Whakatane Fault, the long return period of a major seismic event (1,000 to 2,300 years) means that the annualised risks associated with seismic-induced landslides are one or two orders of magnitude less (between 10 and 100 times less likely) than those associated with rainfall.

The overall landslide susceptibility, hazard and loss of life risk classifications of the study area sectors are as follows. Note that 'susceptibility' is a measure of the likelihood of an event happening in a particular area; 'hazard' includes an analysis of the estimated frequency of that event; and 'risk' is a measure of both the likelihood of the event and the consequences it would have for people exposed to it i.e. the expected loss.

Sector	Susceptibility	Hazard	Loss of Life Risk
Whakatane – N[th] of Wairere Stream	High	High	Very High
Whakatane – S[th] of Wairere Stream	Moderate	Moderate	Very High
Ohope – West End Road	High	High	Very High
Ohope – Pohutukawa Avenue	High	Moderate	Very High

Although all four sectors fall within the loss of life risk range that AGS (2007) classifies as very high, there is an order of magnitude difference in the annual loss of life risk between the highest risk and lowest risk sectors. In the context of AGS (2007) a very high risk is where one or more deaths can be expected within a 1,000 year period. A high loss of life risk is one where a single death can be expected to occur in a time period of between 1,000 and 10,000 years. It is highly likely that a lay person's concept of what constitutes a high or very high risk is very different to this.

It should be noted that this study provides an estimate of the level of landslide risk present on the two escarpments, however it does not draws conclusions as to whether they are acceptable or unacceptable for specific properties. These issues lie outside the scope of a general study such as this.

Options for reducing the occurrence of landslides on the Whakatane and Ohope escarpments are very limited, due to both the scale of the escarpments and the unpredictable and cyclic nature of the landslides. Realistically, landslide management should therefore focus on reducing (avoiding or mitigating) the risk to both people and property (i.e. reducing the consequences should a landslide occur). Methods of reducing landslide risk include controls on new development and building, warning systems, the construction of landslide debris barriers and, in extreme situations, the abandonment of very high risk sites.

Home owners can adopt a number of strategies to reduce the risk profile applying to their properties. These include:

- Monitoring the vegetation on the slopes behind their property, with a particular focus on the stability or health of large trees;
- Looking for slabs of rock that may have partially come away from a rock face and have the potential to fall;
- Where space allows, undertaking minor earthworks at the rear of properties to direct surface water and mud slurry flows away from dwellings; and
- Installing debris catch structures, such as those described in Section 11.3, behind their properties.

After reviewing the operative Whakatane District Plan, we consider that the WDC has stronger provisions relating to landslide hazards than many other Councils facing similar issues.

This report presents recommendations relating to:

- The use of the hazard maps showing those areas where landslides are most likely to occur;
- A high level assessment of the risks posed by the landslide hazard;
- A review of the Council's objectives and policies in the District Plan;
- Landowner education; and
- Monitoring recommendations for landslide hazards.

Definitions

Acceptable risk
A risk for 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. End is 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 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 the rupture of a fault line. 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 warm period.

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 and undesirable consequence.

Landslide susceptibility
The qualitative or quantitative assessment of an areas 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 analyzing 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.

Mélange
A rock mass that has been brecciated and heavily disturbed by tectonic processes

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 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 and evaluation.

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 goes beyond that of an individual.

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

Tectonic
The processes and forces within the earth that shape the structure of the crust. Relates to the tectonic crustal plates, faulting, mountain building and continental drift

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 a particular 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

Between May 2010 and June 2011, a series of high rainfall weather events passed over the eastern Bay of Plenty, triggering numerous landslides within the escarpment slopes that form the backdrop to both Whakatane and Ohope Beach. The latter was the most severely affected area, with some 22 houses being directly impacted by landslide debris. These landslides resulted in a severe injury in 2010 and a fatality in 2011. The Whakatane Escarpment was affected to a much lesser extent, although five residential dwellings were damaged by debris and Muriwai Drive was closed to traffic on several occasions.

While there has been a long history of slope instability on the two escarpments, the intensity of landsliding during 2010 and 2011 appears to be greater than that experienced in preceding decades. This is particularly the case for the Ohope Escarpment, where extensive landsliding and three landslide-related fatalities have occurred since the 1950s.

Whakatane District Council (WDC) has commissioned Tonkin & Taylor Ltd (T&T) to undertake a Quantitative Landslide Risk Assessment (QLRA) as a means of assessing the level of risk posed by future landsliding on the Whakatane and Ohope escarpments. The study includes a consideration of potential management and mitigation options.

The risk aspects of this study are limited to those associated with landsliding only. Risks associated with other natural hazards such as tsunami or flooding do not form part of the scope of this report.

This report is presented in two volumes: Volume 1 contains the report text and embedded figures. Volume 2 contains Appendices A to Q in A3 format.

This project has been reliant upon landslide data collected by T&T for the Earthquake Commission (EQC). The Commission's assistance is gratefully acknowledged.

Since the draft report was issued, peer review comments have been received from GNS Science. This final report includes revisions reflecting the issues raised during the peer review process.

2 Scope of Work

2.1 Purpose

The purpose of this QLRA was outlined in the brief issued by WDC on 4 August 2011:

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

2.2 Study Area

WDC defined the study area as follows:

- *Whakatane Escarpment:* *The northern and western faces from Mokorua Gorge Road in the south, through to 1C Muriwai Drive in the north.*
- *Ohope Escarpment:* *The northern face from 254 Pohutukawa Avenue in the east through to 71 West End Road to the west.*

The extent of the study area is shown in Figure 2.1.

2.3 Tasks

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

- Data compilation and review;
- Base map preparation;
- Landslide inventory development;
- Field validation of data;
- Landslide mechanisms and control;
- Landslide susceptibility assessment;
- Landslide hazard assessment;
- Landslide risk assessment
- Review of landslide management policy; and
- Review of landslide hazard mitigation and control measures

Each of these tasks is addressed within this report.

2.4 Limitations on Scope and Outcomes

The scope of the QLRA is limited to the identification and characterisation of the broad level of landslide hazard and risk over the Whakatane and Ohope escarpments. It was not the intent of this study to provide hazard or risk assessments for individual properties. The outcomes presented here are limited to that general scale considered in the District Plan.

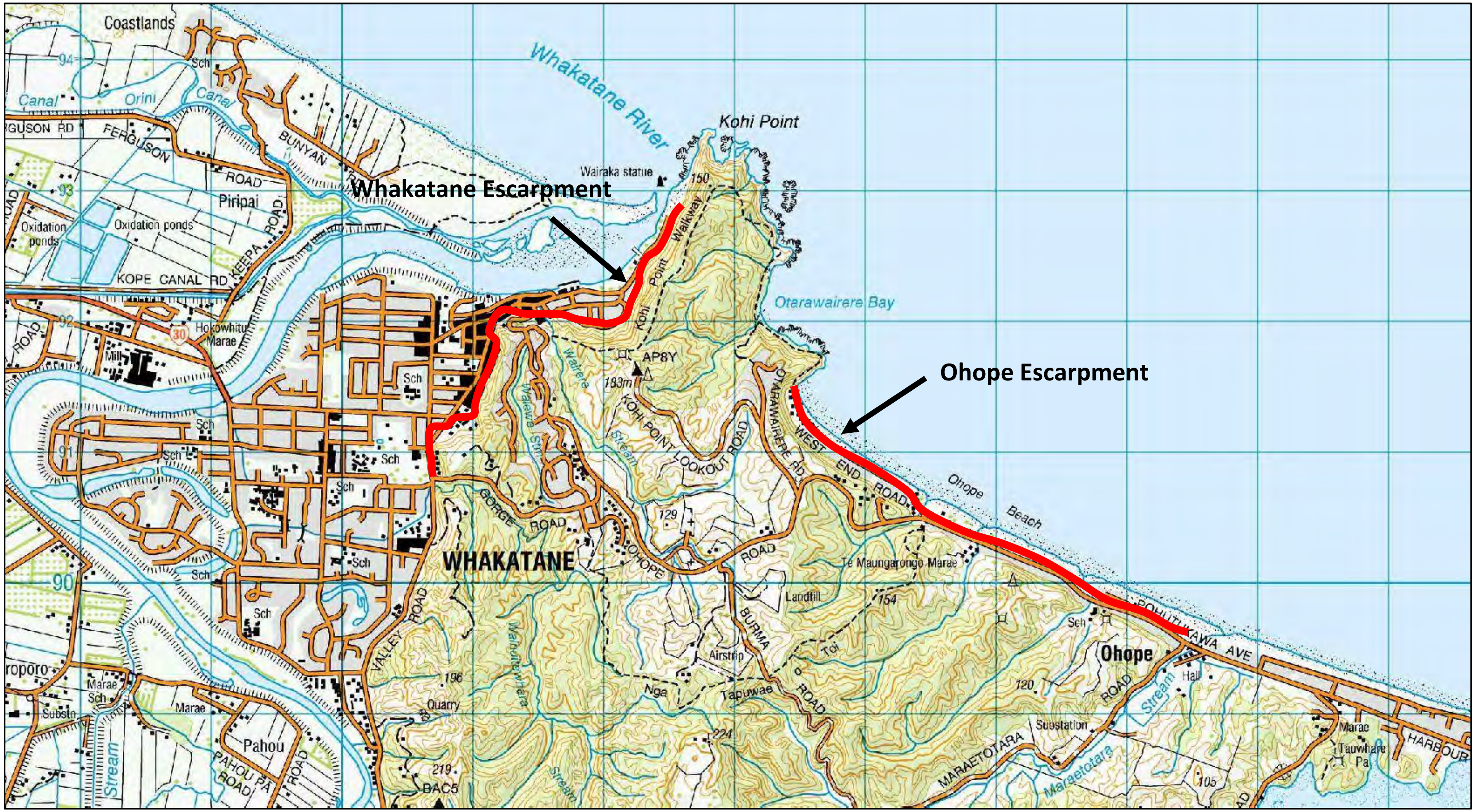

Figure 2.1: Location plan indicating the extent of the QLRA study.

3 The Landslide Risk Management Process

3.1 Terminology

Risk assessments can take numerous forms depending upon the nature of the hazard and the aims of the assessment. Landslide analyses have historically been more qualitative than quantitative in nature, although QLRA are increasingly being used to inform policy decisions.

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 AGS (2007) and are presented in Table 3.1. The primary distinction that needs to be made 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. expected annual loss.

Table 3.1: Definitions of Terms

Term	Definition in Landslide Risk Management
Susceptibility	The relative potential for a landslide event to occur *e.g. this area has a high susceptibility to landsliding because of the soft geology and steep terrain .*
Hazard	Probability or likelihood of a landslide occurring *e.g. this area typically experiences 5 landslides/km^2/annum, therefore warranting a high landslide hazard rating.*
Risk	Hazard x consequence *e.g. the annual loss of life risk for the person most at risk in this area is 1x10^{-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 provided by AS/NZS 31000:2009 *Risk management – Principals and Guidelines*. This Standard provides the following principals for effective risk management:

a) Creates and protects value;
b) Is an integral part of all organisational processes;
c) Is part of decision making;
d) Explicitly addresses uncertainty;
e) Is systematic, structured and timely;
f) Is based on the best available information;
g) Is tailored;
h) Takes human and cultural factors into account;
i) Transparent and inclusive;
j) Dynamic, iterative and responsive to change;
k) 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

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 been adopted for geotechnical risk assessments in New Zealand, it is the methodology published by the Australian Geomechanics Society (AGS, 2007) 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 appropriate.

The landslide risk management framework presented in AGS (2007) is reproduced in Figure 3.1. This breaks 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 AGS (2007) framework. The analytical methods undertaken in the execution of this QLRA are identified in the project specific framework presented as Figure 3.2. The metric of risk used in this study is annual individual fatality risk or Loss of Life Risk (R_{LOL}). This is consistent with both AGS (2007) and other organisations such as the British Health and Safety Executive (HSE).

Sometimes the risk to numerous people from a single rare event (i.e. societal risk) is adopted as a measure of risk e.g. when considering the failure of large dams. Given the limited size and potential impact of landslides occurring on the two escarpments, annual individual loss of life risk is considered a more appropriate measure for this study.

Risk is reported here in terms of scientific notation. Table 3.2 provides translations between this notation and others common numeric forms.

Table 3.2: Equivalent Terms for Risk

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%

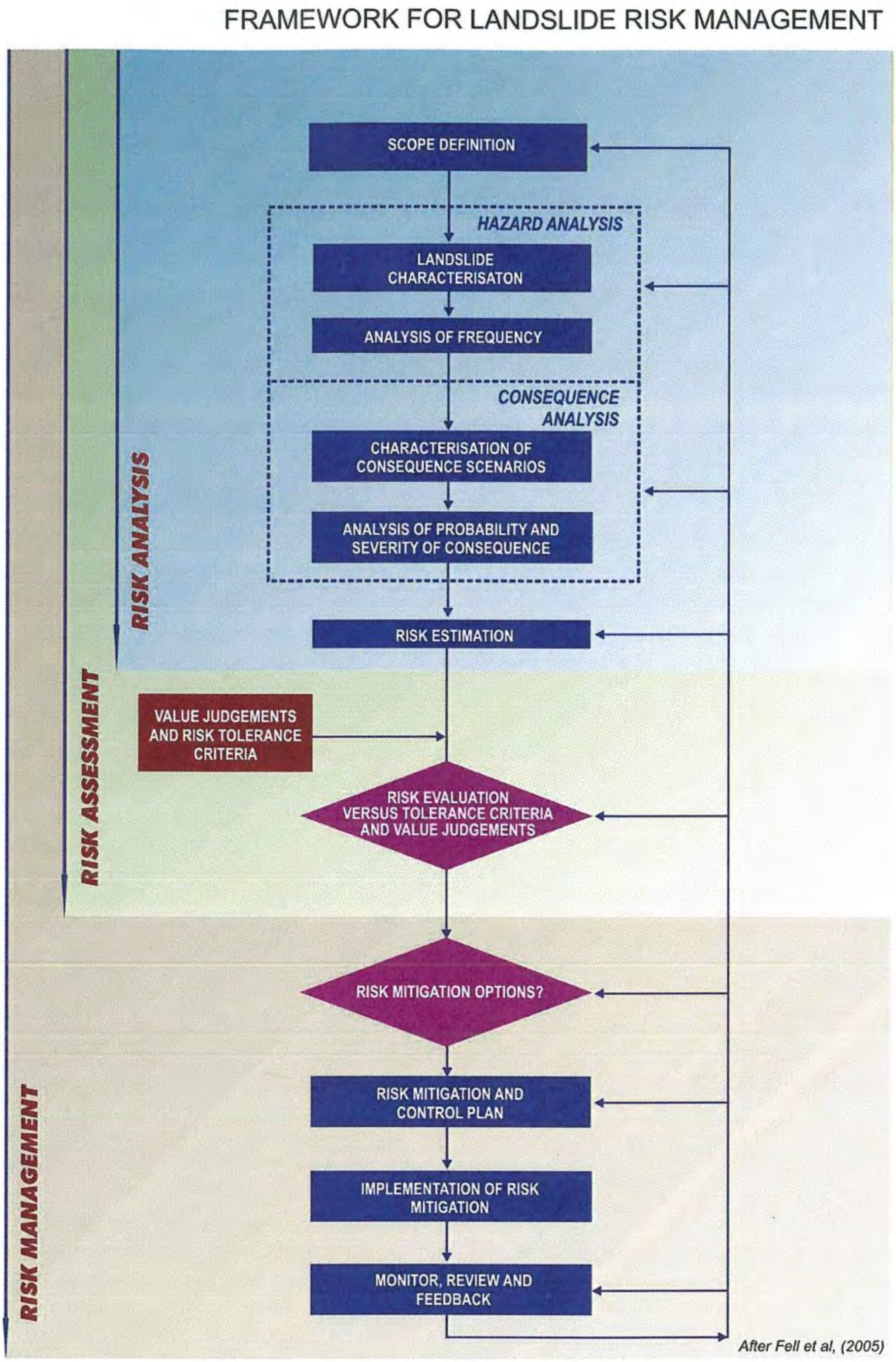

Figure 2: Abbreviated flowchart for Landslide Risk Management.
Ref: AGS (2007a, 2007c)

Figure 3.1: Landslide Risk Management Framework from AGS (2007).

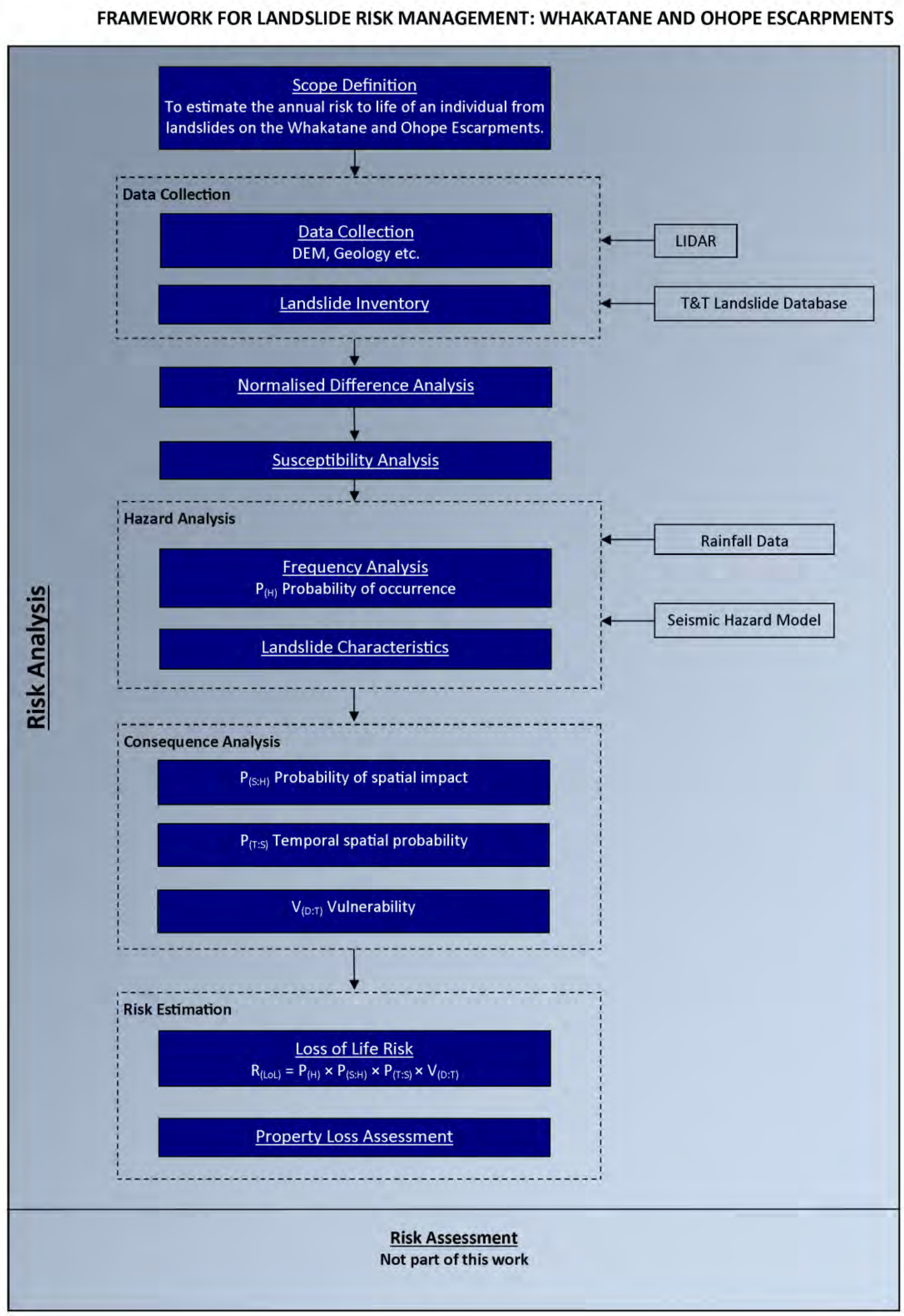

Figure 3.2: Project Landslide Risk Analysis Framework.

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 intolderable/unacceptable. There are currently no formal definitions of these risk levels applied in New Zealand. As a consequence, this study specifically excludes any judgement as to whether the landslide risks are acceptable or not. This is for others to decide. A discussion on the risks associated with a range of activities is however presented in Section 15.

4 Previous Work

The only significant landslide study to have previously been undertaken in the study area was an assessment of the landslides that affected the Ohope Escarpment in July 2004 (T&T, 2005). Although T&T (2005) assessed the nature of the landslides and presented possible options for landslide prevention and mitigation, it did not contain a risk assessment, in either a qualitative or quantitative form.

A number of other geotechnical assessments have been undertaken by T&T for the WDC since completion of the 2004 - 2005 Ohope Escarpment study. These assessments were as follows:

Tonkin & Taylor, 2007. West End Beach Cliff Assessment. Letter report prepared for Whakatane District Council.

Tonkin & Taylor, 2007. Ohope West End Escarpment: Geotechnical Assessment of Ngati Awa Farm Block for Future Development. Letter report prepared for Whakatane District Council.

Tonkin & Taylor, 2010. Geotechnical Advice for Whakatane District Council – Whakatane Escarpment. Letter report to Whakatane District Council.

Tonkin & Taylor, 2011. Ohope Escarpment Condition Survey, No. 63 to 71 West End Road. Report prepared for Whakatane District Council.

Tonkin & Taylor, 2011. Geotechnical Inspection of Landslips, Muriwai Drive and Muriwai Terrace, Whakatane. Report prepared for Whakatane District Council.

Tonkin & Taylor, 2011. Review of proposed slope remediation, Ohope Road. Report prepared for Whakatane District Council.

The vast majority of data used to develop the QLRA landslide inventory were contained within dozens of geotechnical inspection reports prepared by T&T for the Earthquake Commission (EQC) between 2004 and 2011.

Fully quantitative risk assessments for landslides or related phenomena are relatively rare in New Zealand. The most detailed assessments of this kind completed recently are a series of quantitative rock fall and cliff collapse risk assessments undertaken by GNS Science for the Port Hills area of Christchurch in response to the earthquakes of 2010 and 2011. Although both this and the Port Hills project are QLRA, they differ in a number of ways. These differences reflect to some extent the nature of the local slope instability and their triggers, but most importantly, it reflects the scope, purpose and intent of each project, especially the required outcomes and deliverables.

5 Setting

The Whakatane and Ohope escarpments are located either side of a prominent upland area that separates the town of Whakatane from the small settlement of Ohope (Figure 2.1). Both escarpments are former coastal cliffs that have been stranded by a late Quaternary progradation of the coastline. Reclamation along the true right hand bank of the Whakatane River has also contributed to the current separation of the Whakatane Escarpment from the river.

5.1 Whakatane Escarpment

The Whakatane Escarpment (Figure 5.1) represents the eastern limit of the Whakatane Graben, a regional-scale down-thrown tectonic block that has been partially infilled with a range of volcanic and marine sediments to form the Rangitikei Plains. The Whakatane Escarpment can be divided into two discrete parts. The northern section runs approximately parallel to the Whakatane River and Muriwai Drive. Here it is a steep linear feature rising from sea level to a single knife-edge ridge striking NNE-SSW (Figure 5.2). The ridge has an elevation of approximately RL160m.

The southern section of the escarpment backs onto the Whakatane CBD. It is noticeably more dissected and has an elevation only half that of the northern section. The southern section also has two distinct orientations, one W-E and the other NNW-SSE.

5.2 Ohope Escarpment

The Ohope Escarpment is a steep vegetated line of cliffs and steep slopes located between Ohope Beach and an upper dissected plateau (Figure 5.3). A discontinuous bench is apparent at an elevation of approximately RL70m (Figure 5.4). This bench is the location of the Cliff Road residential settlement and the Ngati Awa farm block.

5.3 Topography and DEM

A digital elevation model (DEM) has been developed for both escarpments using aerial LiDAR (Light Detection and Ranging) data supplied by Environment Bay of Plenty (EBoP). Elevation contour maps of the Whakatane and Ohope Escarpments are presented in Appendices B and C respectively (Volume 2).

Figure 5.1: View of the Whakatane Escarpment from the junction of Muriwai Drive and the Strand, Whakatane.

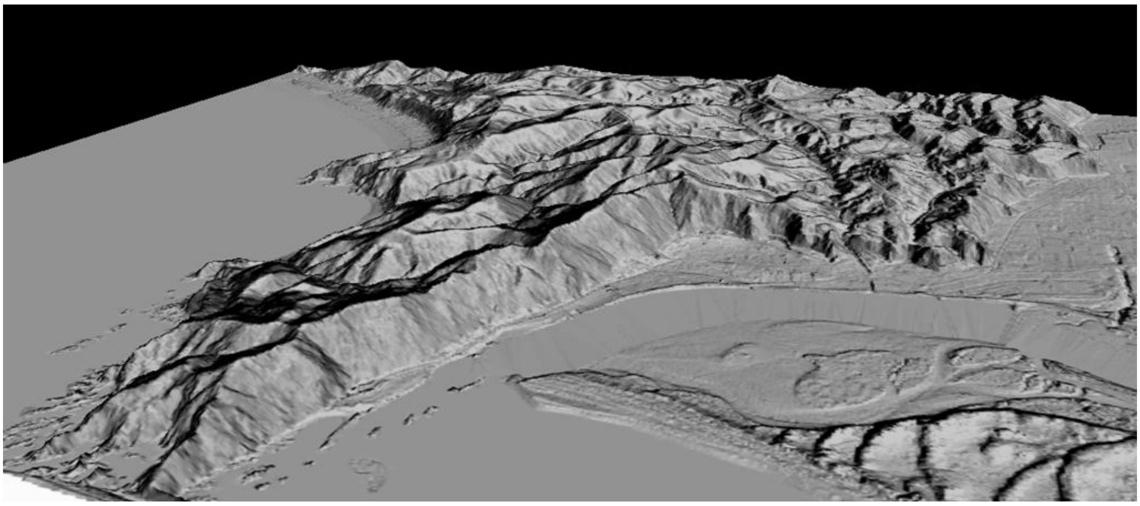

Figure 5.2: 3D topographic model of the Whakatane Escarpment generated from LiDAR data, viewed from the north-west.

Figure 5.3: View of Ohope Beach and the Ohope Escarpment from the Otarawairere Bay track.

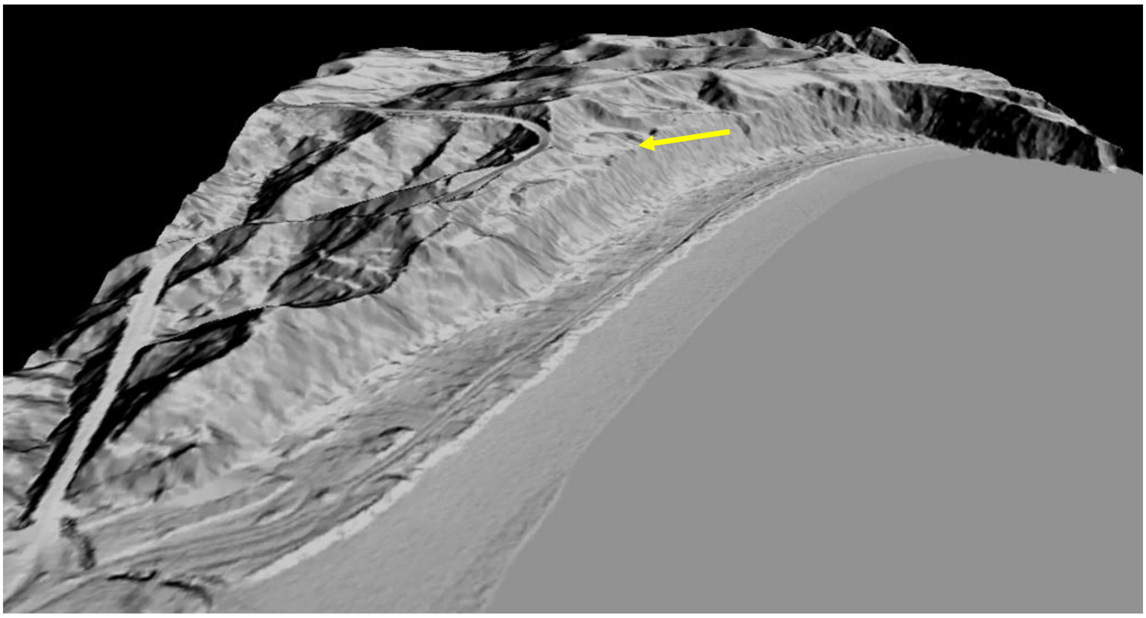

Figure 5.4: 3D LiDAR model of the Ohope Escarpment above West End Rd, view looking west. The bench present at approximately RL70m is indicated by an arrow.

6 Geology

6.1 General

The geology of the study area can be characterised as a narrow NNE-SSW striking ridge of greywacke basement rock overlain by a series of much younger marine, terrestrial and pyroclastic deposits. The Whakatane Escarpment represents the western edge of the greywacke ridge, whereas the Ohope Escarpment has formed from the erosion of primarily marine deposits that were deposited against the eastern side of the greywacke.

A schematic stratigraphy of the two escarpments is presented in Figure A1 (Appendix A, Volume 2).

6.2 Published and Unpublished Research

The most recent published geological information for the study area is the 1:250,000 Rotorua “Qmap” (Leonard *et al*, 2010). This provides an assessment of the greywacke basement exposed on both the Whakatane and Ohope escarpments, however little information is provided on the Pleistocene Tauranga Group deposits that overly the greywacke. Like its predecessor (Healy *et al*, 1964), the stratigraphic details on the Qmap are insufficient for incorporation into this study.

The first detailed study of the Ohope Pleistocene geology was that of Fleming (1955) who reported on the stratigraphy and palaeontology of a landslide scar at 35 West End Road, Ohope. This same location was used by Paltridge (1958) and Edbrooke (1977) to develop stratigraphic profiles behind West End Road. The general geology of Whakatane and Ohope was presented by Dr David Kear in several self-published documents (Kear, 1997; 2003a; 2006).

Each of these authors has used different nomenclature to describe the Castlecliffian and post-Castlecliffian deposits that overlie the greywacke. The stratigraphic nomenclature adopted for this study is presented in Figure A2, together with those of earlier studies for comparison.

6.3 Greywacke Basement

The most prominent geological feature of the study area is the large greywacke ridge that forms the Whakatane Heads (Figure 6.1). Described as the Whakatane Greywacke by Paltridge (1958) and the Whakatane Mélange[1] by Leonard *et al* (2010), the greywacke basement consists predominantly of strongly bedded alternating sandstone (greywacke) and mudstone (argillite) beds of Jurassic age (Kear, 1997). Leonard *et al* (2010) describe the presence of a range of other rock types within the greywacke mass, including diamictite, chert, basalt, limestone and marble.

A characteristic of the Whakatane Mélange is the presence of largely intact blocks of rock enclosed within a highly disturbed matrix (Figure 6.2). Large coherent blocks can be seen forming the more prominent rock outcrops and overhangs along the base of the escarpment. The Whakatane Mélange forms the bulk of the Whakatane Escarpment, although it is exposed only at the extreme western end of the Ohope Escarpment.

[1] A mélange is a rock mass that has been brecciated and heavily disturbed by tectonic processes.

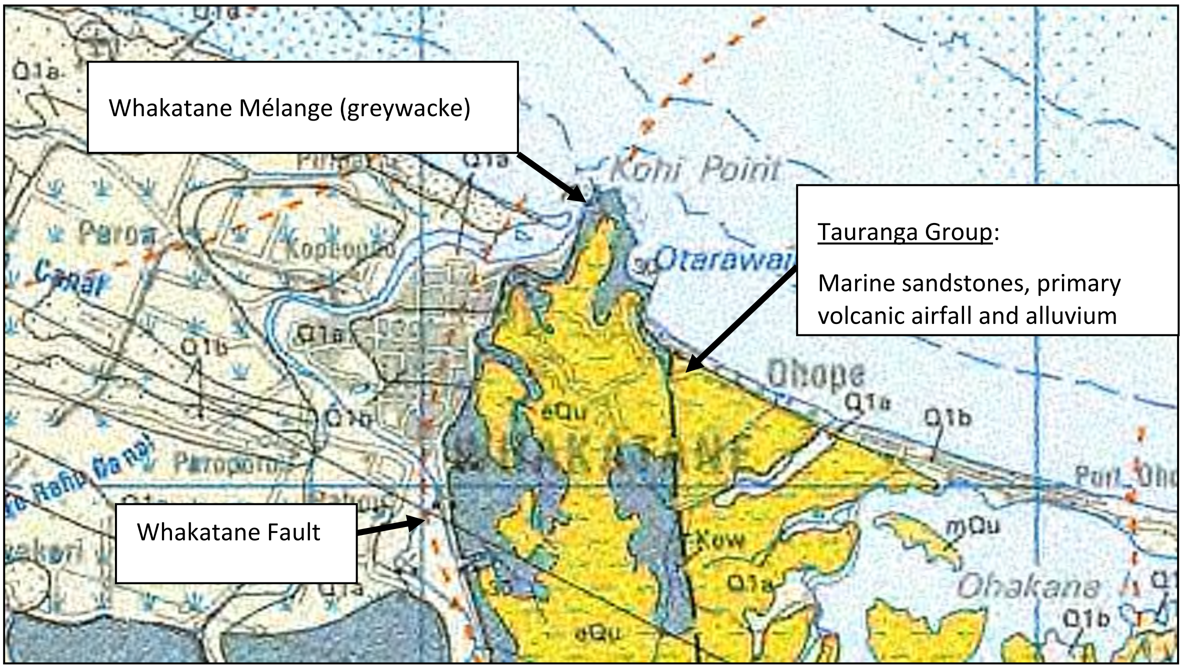

Figure 6.1: Part of Leonard et al (2010) showing the geology of the Whakatane and Ohope areas.

Figure 6.2: Whakatane Mélange exposed at the Whakatane Heads. Displaced but coherent blocks of steeply dipping (A) and flat dipping (B) bedded greywacke and argillite can be seen enclosed within an intensely deformed and sheared matrix (C).

Figure 6.3: View of the western end of Ohope Beach showing Lower Ohope Beds unconformably overlying basement greywacke. The contact is indicated.

6.4 Ohope Beds

The greywacke basement is unconformably overlain by a much younger Quaternary sequence of shallow marine sediments, volcanic airfall deposits and alluvium, known locally as the Ohope Beds. The oldest of these sediments are the Castlecliffian marine sandstones described in detail by Fleming (1955) and Edbrooke (1977). For the purposes of this study, these beds are defined as the Lower Ohope Beds. Only at the extreme west of Ohope Beach can the greywacke be seen unconformably underlying the Lower Ohope Beds (Figure 6.3). The Lower Ohope Beds have been divided into the Upper Ohope Sandstone and Lower Ohope Sandstone units (Figures A2, A3 and A4). These correspond approximately to the Upper Westend [sic] and Lower Westend Sandstone units of Edbrooke (1977).

The predominantly marine Lower Ohope Beds are overlain by terrestrial-dominated deposits that are defined for the purposes of this study as the Upper Ohope Beds. These are dominated by brown fine sands, pumiceous sands and gravel beds. The uncemented sands and gravels have been associated with significant occurrences of instability within cut slopes along the Ohope – Whakatane Road (Figure 6.4). A widespread yet discontinuous gravel layer is thought to mark the contact between the Upper and Lower Ohope Beds (Figure 6.5) and is associated with the presence of the bench on which Cliff Road residential area has been developed (Figures 5.4 and A1).

The higher elevation of the greywacke to the west means that only the Upper Ohope Beds overlie the greywacke on the Whakatane Escarpment (Figures 6.6 and A1). Stratigraphic profiles along the Ohope Escarpment are presented in Figure A5. Figure 6.7 is a photograph of the Ohope Escarpment showing the major geo-topographic features.

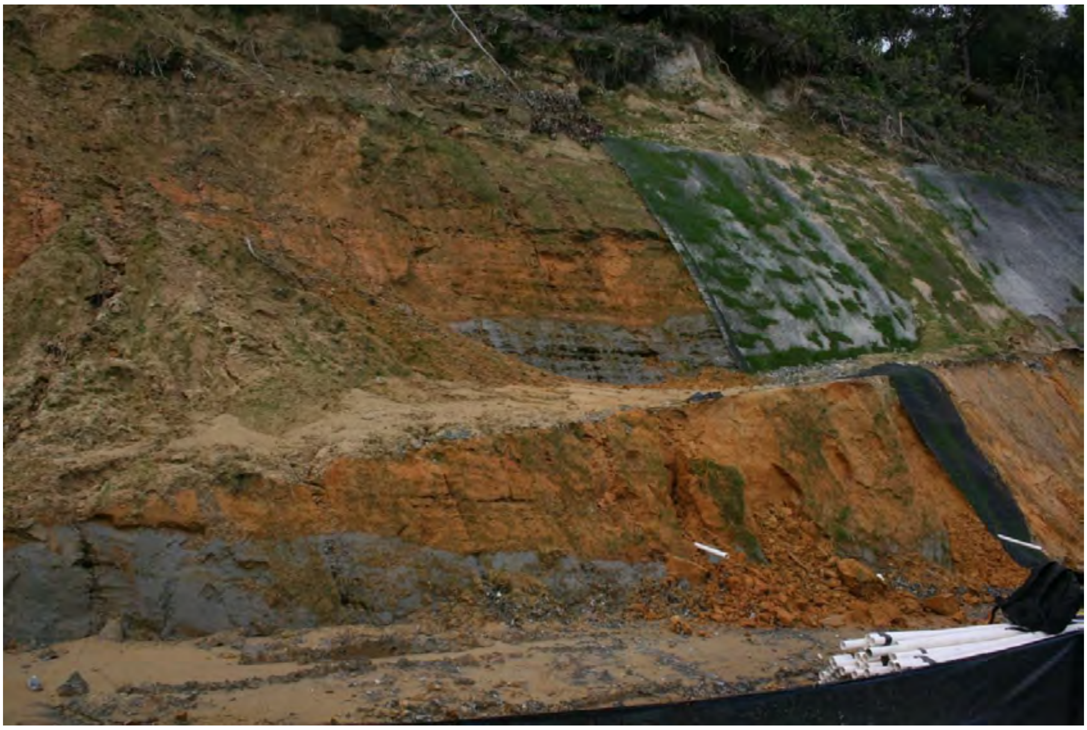

Figure 6.4: Cutting on Ohope Road showing the dipping contact between the grey muddy marine sediments of the Lower Ohope Beds and the overlying orange-brown sands of the Upper Ohope Beds. Light-coloured young pyroclastic airfall deposits of the Young Pumice Ash can be seen at the top of the exposure.

Figure 6.5: Gravel bed within the Upper Ohope Beds which generally marks the level of the intermediate bench.

Figure 6.6: Light-coloured Upper Ohope beds overlying a highly disturbed greywacke rock mass (mélange), seen in the large Muriwai Drive landslide.

Figure 6.7: View of the Ohope Escarpment from the Otarawairere Bay track. The main elements of the escarpment can be seen: Lower Ohope Sandstone (A); Upper Ohope Sandstone (B); Upper Ohope Beds (with landslide debris) (C); Young Pumice Ash exposed in a landslide headscarp (D).

6.5 Younger Volcanic Ash

The uppermost geological unit present within the study area is a series of bedded tephras and pumice breccias. These represent primary and remobilised pyroclastic deposits from the Okataina and Taupo Volcanic centres that drape the underlying topography. These deposits were collectively termed the Younger Volcanic Ash in T&T (2005) and T&T (2007). This nomenclature has been retained for this study.

6.6 Project-Specific Geological Maps

The approximate distributions of the different geological units defined in Figure A2 are presented as a series of geological maps in Appendices D (Whakatane) and E (Ohope).

6.7 Ohope Escarpment Bench

The presence of a discontinuous bench on the Ohope Escarpment at approximately RL70m was introduced in Section 5. T&T (2005) interpreted this "intermediate bench" as corresponding to the elevation of the "slipping sandstone" of Fleming (1955) and that its presence corresponded to the contact between the Upper and Lower Ohope Beds (Figure A3). Landform features suggest that the bench has developed, and continues to develop, by the preferential instability and erosion of the Upper Ohope Beds (Figures 6.8 and 6.9).

6.8 Hydrogeology

Groundwater and surface water are both important controls on landslide occurrence and form. Rainfall has been the clear trigger for the spate of landslides recorded across the study area in 2004 and 2010-2011. This is discussed in detail in Section 11.

6.8.1 Whakatane Escarpment

North of the Wairere Stream, the Whakatane escarpment consists of a steep near-linear rock face rising from river level to a narrow ridge at approximately RL160m. The only surface water that passes over this part of the escarpment is that which falls directly on it. The southern part of the escarpment is backed by a sizeable catchment, whose topography directs surface water flows into the Wairere and Waiewe Streams.

Observations made of the large landslide at No. 33 Muriwai Drive have indicated that significant groundwater flows occur within the broken rock mass of the Whakatane Mélange.

6.8.2 Ohope Escarpment

The hydrology of the Ohope Escarpment can be divided into two distinct areas: West End Road and Pohutukawa Ave. The steep escarpment behind West End Road is backed by an undulating plateau surface which collects rainfall and directs it over the escarpment as numerous small flows of limited longevity. Groundwater emerges at a number of locations and elevations on the escarpment as springs. These springs were used as a source of water prior to the establishment of a municipal supply.

The Bay of Plenty Regional Council (BoPRC) undertook a stormwater catchment delineation and analysis exercise for the West End Road area in 2011. This work identified a total of 28 catchments that discharge to the foot of the escarpment (Figure 6.10). Despite the volume of water that flows over the escarpment in this area, there are no established streams. The catchments at the eastern end of the escarpment were extensively modified in 2007 by a scheme to collect and reticulation stormwater in the Cliff Road area.

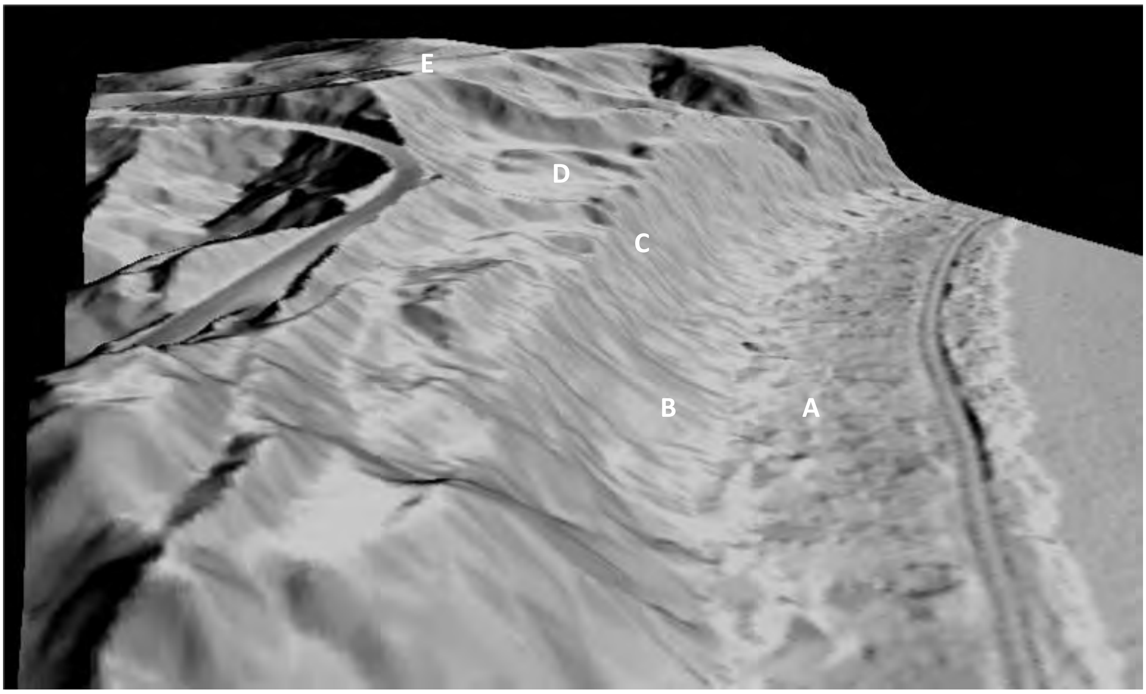

Figure 6.8: 3D LiDAR model of the Ohope Escarpment looking west across the Cliff Rd area. Coastal strip (A); talus slope (B); Ohope Escarpment (C); Escarpment bench (D) and a dissected plateau surface(E).

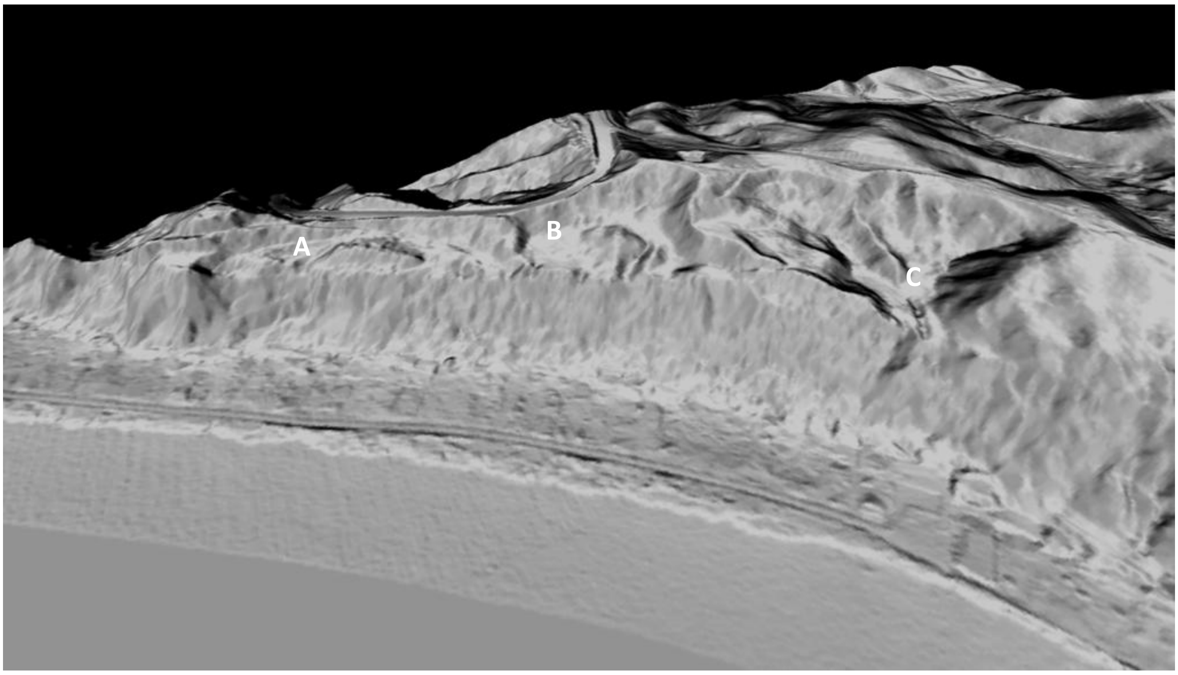

Figure 6.9: 3D LiDAR model of West End Road showing stages in the progressive development of the escarpment bench: Cliff Road (A), large slips at Ohope Road (B) and deeply incised erosion down to bench level below Otarawairere Road (C).

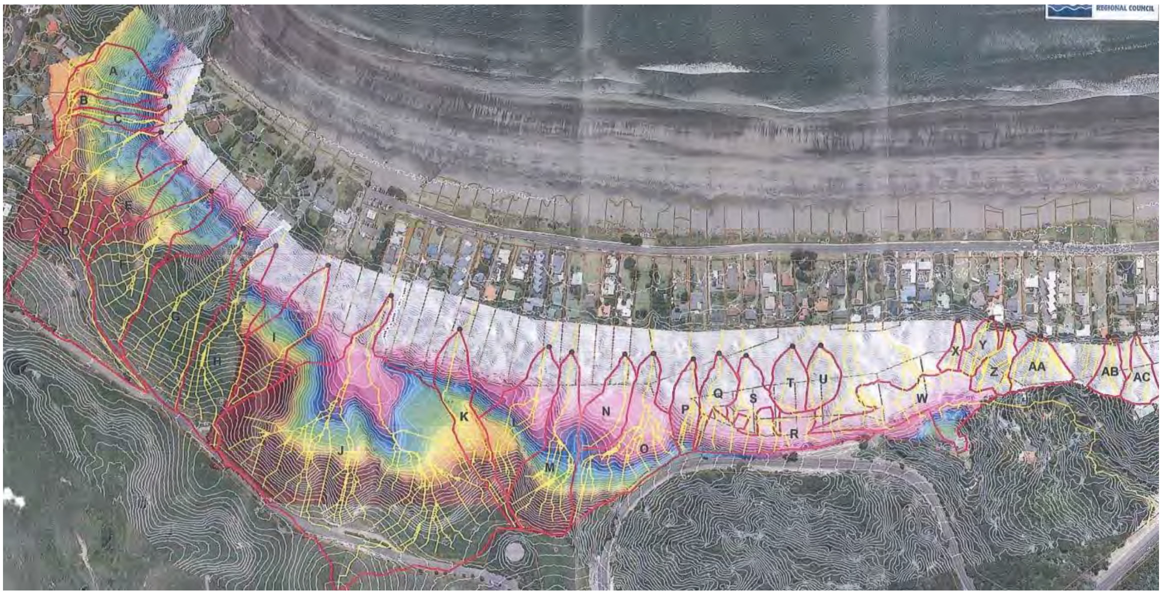

Figure 6.10: *West End catchments and flow paths (Bay of Plenty Regional Council, supplied by WDC).*

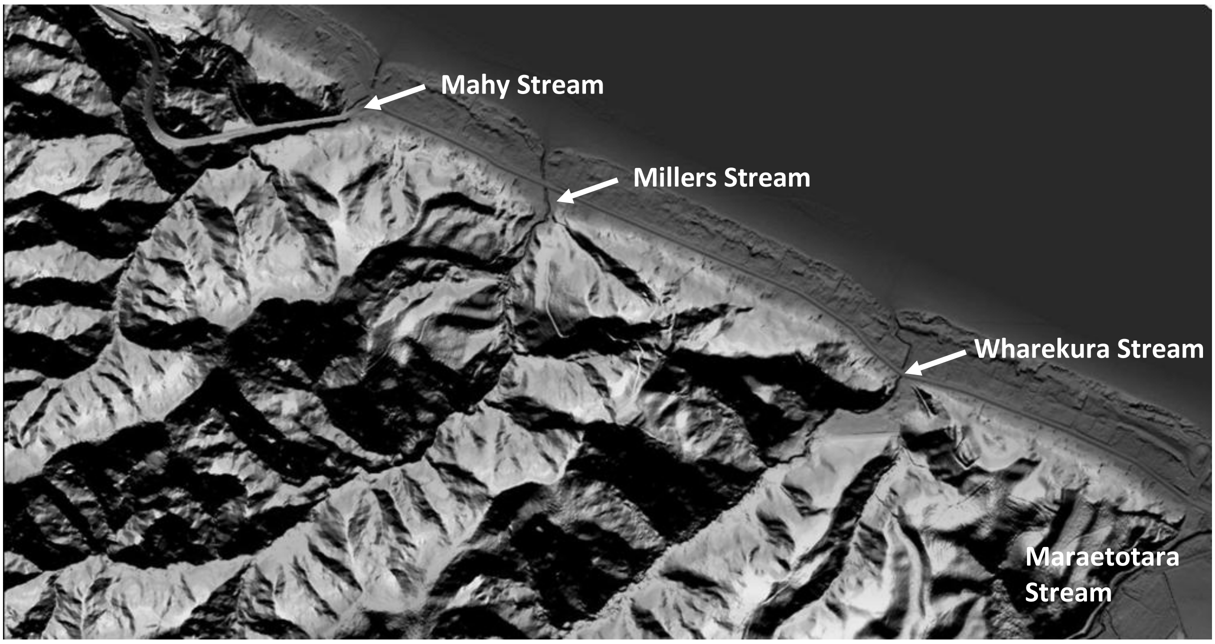

Figure 6.11: *3D LiDAR model of the Ohope Escarpment within the vicinity of Pohutukawa Ave. The four named streams that cross the escarpment are indicated.*

That section of the Ohope escarpment located behind Pohutukawa Ave is crossed by four named streams (Figure 6.11). Mahy Stream separates West End Road from Pohutukawa Ave. Maraetotara Stream exits to Ohope Beach at Maraetotara Road, and defines the southern limit of this QLRA study. The Miller and Wharekura streams are located approximately equidistant between the Mahy and Maraetotara streams. The topography of this area is such that, unlike West End Road, surface water flows laterally towards the streams rather than over the front of the escarpment.

6.9 Active Faulting and Seismicity

Whakatane is located within a seismically active area, being located immediately to the east of the Taupo Volcanic Zone (TVZ) and at the northern termination of the North Island Shear Belt (NISB)(Figure 6.12). The Whakatane Fault is the only known active fault in immediate proximity to the study area (Figure 6.13), although several other active faults occur to the west (TVZ) and east (NISB). The Whakatane Fault is located within the central Whakatane urban area to the west of the Whakatane Escarpment, although it's exact location is unknown. An approximate location of the Whakatane Fault is shown on Figures 6.1 and 6.13.

The most frequently active faults are those located within the TVZ e.g. the Edgecumbe Fault. The faults in the broader Whakatane area are capable of generating earthquakes of maximum magnitude of between Mw6.5 and M_w 7.4. The Whakatane Fault is thought to have a recurrence interval of between 1,000 and 2,300 years (Beetham *et al*, 2004) and has the potential to generate the largest earthquakes of any fault in the eastern Bay of Plenty.

The potential for an earthquake to generate landslides is ultimately on the intensity of the ground shaking at the location of interest rather than the magnitude of the earthquake at the site of rupture, although this does dictate the maximum shaking intensity. The relative intensity of seismic shaking is described by the Modified Mercalli Earthquake Intensity Scale (MM), a summary of which is presented in Table 6.2.

Beetham *et al* (2004) identified two basic classes of seismic events that could potentially affect the Whakatane Escarpment[2]:

- A rupture of the Whakatane Fault generating MM9 to MM10 shaking intensity. Such an event would have a return period of approximately 1600 years (range 1000 to 2300 years); and
- Rupture of other near-by active faults generating MM7 to MM8 intensity shaking. Such events would occur approximately every 30 to 200 years.

Beetham *et al* (2004) presented the following assessment of earthquake-triggered landslides in Whakatane:

> *"The earthquake triggered landslide hazard in Whakatane is considered to be generally moderate along the old, steep sea cliffs behind the town and at their toe which is in the landslide run-out zone, is low in the hill suburbs and non-existent on the plains (see Figure 4.5). However, the landslide hazard increases along the old cliffs and on the hills during the much less frequent Whakatane Fault earthquake caused by fault rupture through the town. This earthquake would cause significant, damaging landslides during its strong, MM9 to 10 intensity shaking. By contrast for the other more frequent earthquakes that may cause MM7 to MM8 intensity shaking in Whakatane, the landside damage is likely to be minor."*

[2] It is assumed here that the effects on the Ohope Escarpment will be similar.

Figure 6.12: Geological structure of the eastern Bay of Plenty. Whakatane and Ohope lie at the junction of the Taupo Volcanic Zone and the North Island Shear Belt[3] (Source: Beetham et al (2000))

[3] *Note that the fault annotated as the Waikaremoana Fault is called the Waiotahi Fault on the GNS Active Faults database.*

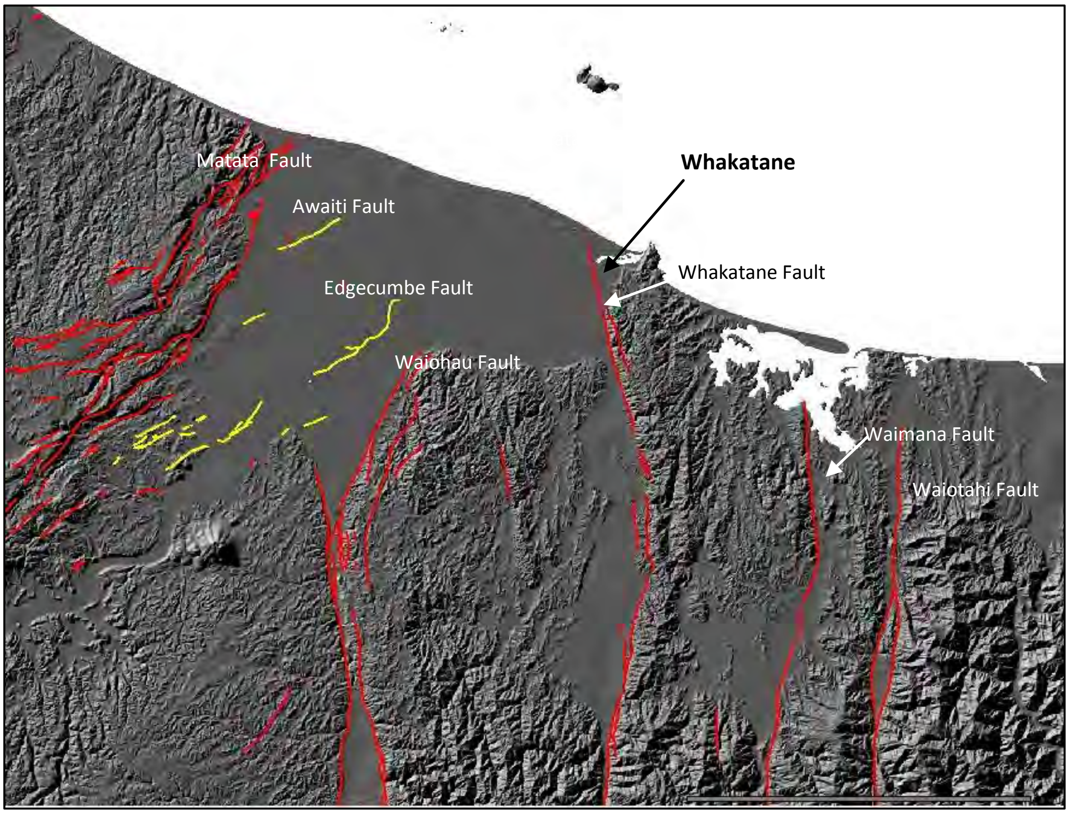

Figure 6.13: Faults from GNS Active Fault Database. Those with historically active faults shown in yellow (source: http://maps.gns.cri.nz/website/af/viewer.htm).

Table 6.1: Data for Seismic Sources near Whakatane & Ohope

Fault	Slip Rate (mm/year)	Estimated Maximum Earthquake (M_{max})	Average Recurrence (years)
Whakatane	1.0	7.4[1]	1,000 - 2,000
Edgecumbe	2.5	6.5	500 - 1,500
Waimana	0.7	7.4	2,000 – 3,500
Waiotahi/Waikaremoana	0.5	7.0	2,000 – 3,500
Waiohau	1.4	7.1	2,000 – 3,500
Matata	2.0	6.5	370 - 1,000
Awaiti	-	-	2,000 – 3,500

Notes:

Sources: Perrin, 1999, Beetham *et al* (2004), Stirling *et al* (2000) and GNS Active Faults Database

Table 6.2: Modified Mercalli Intensity Scale

Intensity Level		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.

Source: info.geonet.org.nz

7 Landslide Formation

7.1 Instability Types

Landslides occur in many different forms depending upon, amongst other things, geology, topography and triggering mechanism. The major types of landslide are presented in Figure 7.1. The main movement types observed within the Whakatane and Ohope escarpments are:

- Rotational (to semi-rotational) landslides: these occur within thick engineering soils located at or behind the crest of the escarpments. Many of the landslides in the Cliff Road area of Ohope in 2004 were of this type;
- Rock fall: most of the rock material lost from the greywacke outcrops on the Whakatane Escarpments are of this type. Rock falls also originate from bands of stronger sandstone within the Lower Ohope Sandstone on the Ohope Escarpment.
- Debris avalanche: this represents the most common form of landsliding in the study area and is prevalent within the Ohope beds exposed on both of the escarpments.

The different forms of instability on the Whakatane and Ohope escarpments are described further in Section 8 and 9 respectively.

7.2 Landslide triggers

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.

Experience from both Whakatane and Ohope, as well as other locations such as the Matata Escarpment, clearly demonstrate the close association between high rainfall events and the occurrence of landslides. The few known exceptions to this is a single seismically-induced landslide in Otarawairere Bay resulting from the 1987 Edgecumbe earthquake and small rock falls that may have occurred at various times with no apparent direct trigger.

The subject of triggering mechanisms and their assessed impact on risk is addressed in detail in Section 11.

7.3 Landslide Run-Out Distances

A landslide originating on either of the escarpments will, in most cases, be expected to generate debris that extends some distance beyond the foot of the steep face to form a debris fan or talus slope. The distance that this debris travels (i.e. run-out or travel distance) will have a significant effect on the risk to people and property located along the bottom of the escarpments.

The extent of the talus slopes present at the base of both escarpments provide direct evidence for the run-out distance of debris from previous failures, as do the mapped extent of landslides recorded in numerous EQC reports. T&T (2005) noted that debris generated during the 2004 landslide event typically remained on the talus slope, although occasionally debris extended up to 5m from the seaward edge of the talus slope, and in one case, twice this distance. Highly fluidised mud associated with the landslides was able to reach West End Road.

Observations made of the 2010 and 2011 landslides confirmed these characteristics (Figure 7.2). In a relatively limited number of cases however, highly fluidised debris and entrained vegetation may extend well beyond the recognised edge of the talus slope, as was the case with the 2010 landslide at No. 67 and 68 West End Road (Figure 7.3).

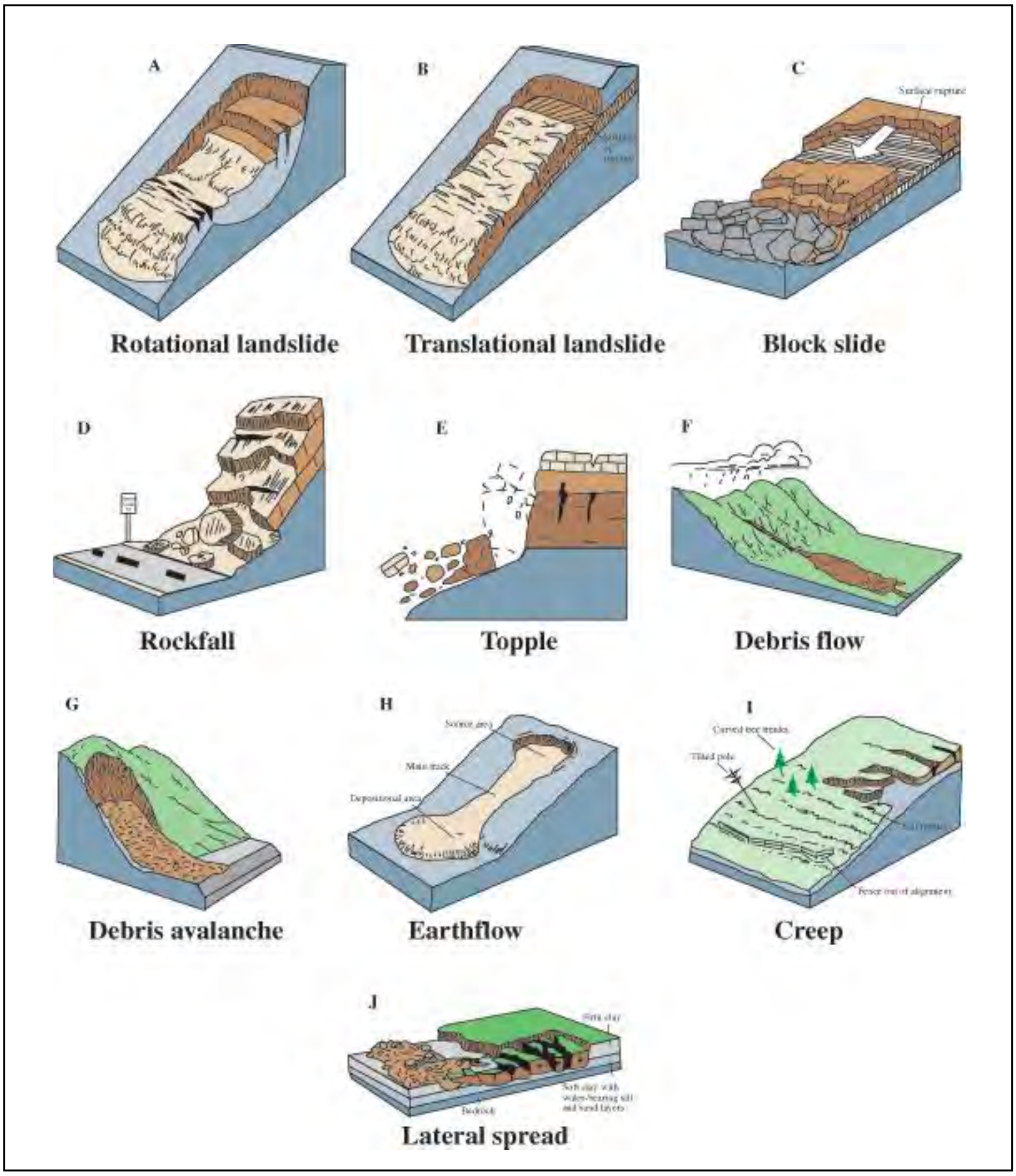

Figure 7.1: Major landslide types (US Geological Survey Fact Sheet 2004-3072, July 2004).

Figure 7.2: Landslide debris deposited between No 22 and 23 West End Road in June 2010. This is an example of landslide debris extending to the edge or a little beyond the recognisable edge of the talus slope. This is also an example of a landslide occurring entirely within the talus slope rather than the steep escarpment.

Figure 7.3: View of highly fluidised debris which travelled significantly beyond the recognised extent of the talus slope at 67 West End Road in 2010.

8 Landsliding on the Whakatane Escarpment

8.1 Historic Instability

There are few records available to indicate that landsliding has occurred on the Whakatane Escarpment in the past with any significant frequency or intensity. Indeed T&T have no EQC landslide records for the Whakatane Escarpment prior to 2004. Nevertheless, the spate of landslides above Muriwai Drive in 2010 and 2011 clearly indicates that the Whakatane Escarpment is susceptible to landsliding during periods of high rainfall. It is primarily the frequency of such landsliding events that is not well known.

A photograph of the Wepiha St/Harvey St area taken at the turn of the 20th Century (Figure 8.1) shows not only a significantly less extensive vegetation cover on the Whakatane escarpment than is currently the case (Figure 8.2) but that there is a substantial talus slope present along the base of the escarpment. This talus slope has developed by the accumulation of rock and soil debris that has fallen down the escarpment. Exposures of light coloured Ohope Beds within non-vegetated scars (Figure 8.1) indicate the occurrence of small shallow landslides immediately above the greywacke rock face.

Aerial photographs indicate that by the early to mid 1960's (Figure 8.3) a significantly more extensive vegetation cover had developed on the escarpment. The presence of relatively small landslides within the Ohope Beds is a clearly visible, although not common, feature of the escarpment at this time. The landslides seen in Figure 8.3 appear to be of the same type as those which occurred high above Muriwai Drive in 2010-2011.

LiDAR data indicates an extensive area of gently sloping yet hummocky terrain on which Muriwai Terrace has been developed (Figure 8.4). This is potentially the debris from a large historic landslide(s) in the adjacent escarpment, possibly similar in nature to the large landslide that has occurred recently on Muriwai Drive (see Section 8.3.2).

Between Wairere Street and Gorge Road, the escarpment is considerably lower in elevation than it is behind Muriwai Drive. The southern section is formed almost entirely from greywacke (Figure 8.5). This area appears to have developed a significantly smaller talus slope, presumably as a result of a lower input of Ohope Bed debris. With the talus slope in this area being formed predominantly from greywacke rock fragments, much of the talus in this area may have been exploited as a ready source of aggregate or fill and has subsequently be largely removed in places.

8.2 Recent Instability

The only significant instability to have occurred on the Whakatane Escarpment in recent years are the landslides that occurred at the northern end of Muriwai Drive in 2010 and 2011 (Figure 8.6). These landslides were all shallow, of relatively small volume and initiated within the Upper Ohope Beds. In some cases the debris from these landslides dispersed amongst the lower bush-clad slopes of the escarpment, whereas others reached the toe of the slope via narrow debris chutes. A single very large structurally controlled landslide has occurred at No. 29 to 33 Muriwai Drive within the greywacke mélange (Figure 8.6).

Small landslides reported within the undulating terrain behind the escarpment are not considered relevant to this study.

Figure 8.1: View of the Wepiha St/Harvey St area c1900-1910 showing the presence of shallow landslides within the Ohope Beds. A talus slope has developed below the denuded greywacke rock face (Reproduced with permission of Alexander Turnbull Library).

Figure 8.2: Google Earth oblique view of the Wepiha St/Harvey St area showing a near complete vegetation cover (aerial photo dated February 2011).

Figure 8.3: View of the Wepiha/Harvey Street area in 1964. Two apparently recent landslides within the Ohope Beds can be seen on the right (Reproduced with permission of Alexander Turnbull Library).

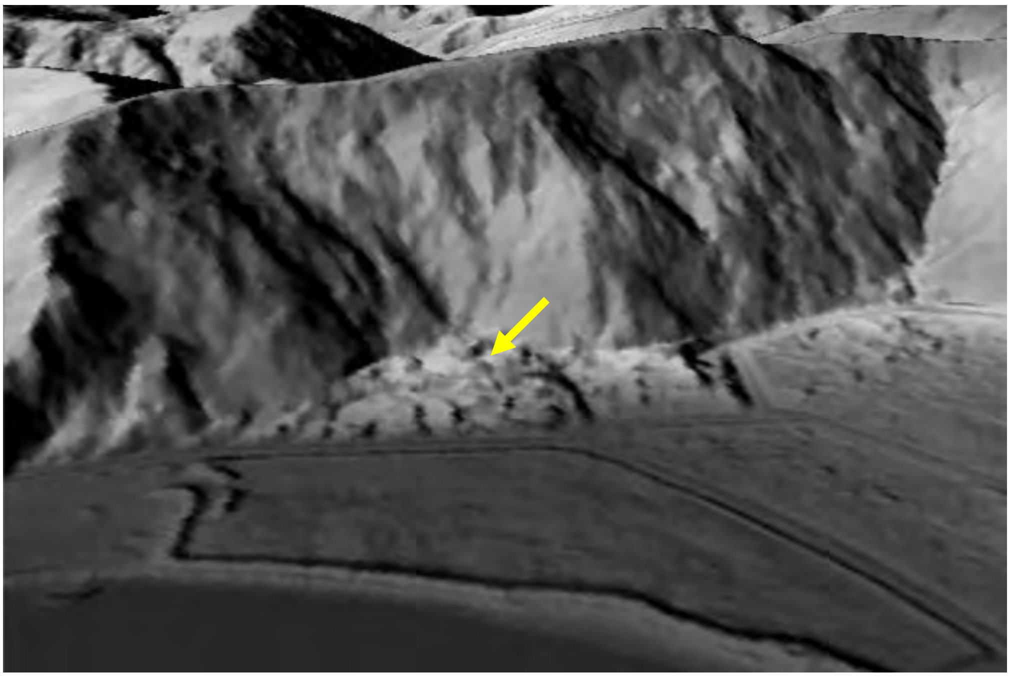

Figure 8.4: 3D DEM of the Muriwai Terrace area indicating a possible large-scale landslide debris deposit (arrow).

Figure 8.5: Photo from 1964 showing the greywacke escarpment behind Commerce Street. Note the lack of vegetation on a significant proportion of the greywacke and the presence of a relatively small talus fan. (Reproduced with permission of Alexander Turnbull Library).

Figure 8.6: View of the northern end of the Whakatane Escarpment from the Coastlands area. Scars from numerous small landslides within the Upper Ohope Beds can be seen (circled). The large landslide that can be seen on the right is located behind No. 33 Muriwai Drive.

T&T has no record of landslides occurring on the Whakatane Escarpment as a result of either the 2004 storm that severely impacted the Ohope Escarpment or the 2005 storm event that generated the destructive debris flows in Matata and numerous landslides around Tauranga. We do expect that small landslides were generated during these events, however they appear not have been significant enough, or located in those areas that would have initiated EQC geotechnical assessments.

8.3 Instability Types and Locations

Three types of instability have been identified as occurring on the Whakatane escarpment:

- Type W1: shallow landslides within the Upper Ohope Beds;
- Type W2: structurally controlled rock slides within greywacke; and
- Type W3: small-scale rock falls from steep rock faces in jointed greywacke.

These are illustrated in Figure A6 (Volume 2).

No landslides are known to have originated within the talus slopes.

8.3.1 Type W1: Shallow Landslides within Upper Ohope Beds

Shallow landslides of relatively limited volume (10-20m^3) initiating in the upper parts of the escarpment are the most common form of landslide occurring on the Whakatane Escarpment (Figure 8.6). The landslides occur almost universally at a position immediately above the contact between the Upper Ohope Beds and the underlying but more steeply inclined greywacke.

The pumiceous landslide debris tends to liquefy upon mobilisation, meaning that the debris typically descends the escarpment in the form of a slurry that contains a significant proportion of vegetative matter. Debris from initial landslides tend dissipate and terminate on the vegetated greywacke slopes. Debris from subsequent expansion of the initial landslide or from adjacent areas may utilise a clear path or debris chute from such an earlier landslide to more readily reach the base of the escarpment (Figure 8.7).

8.3.2 Type W2: Structurally Controlled Landslides within Greywacke

Structurally controlled landslides are those in which the discontinuities (joints, bedding planes, shears etc) within a rock mass allow blocks of rock to detach, typically in the form of planar, wedge or toppling failures. Only one landslide of this type is present within the inventory, and that is the very large landslide at No. 33 Muriwai Drive (Figure 8.8). This landslide is very complex and has resulted from a particular set of conditions present at this one location, although as mentioned earlier, a large landslide of this type may have occurred historically in the Muriwai Terrace area.

8.3.3 Type W3: Small-Scale Rock falls from Greywacke Bluffs

Rock falls are recognisable in a number of areas around Whakatane. Figure 8.9 presents two examples from the Whakatane Heads car park. These are small in size and localised in nature, although repeated historic rock falls of this type have contributed to a noticeable talus slope accumulating near the intersection of Canning Place and Commerce Street.

Figure 8.7: *Landslide (A) and debris chute (B) behind No. 7 Muriwai Drive.*

Figure 8.8: *Large structurally-controlled landslide behind No. 33 Muriwai Drive. The complexly deformed greywacke of the Whakatane Mélange is overlain by the light coloured Upper Ohope Beds.*

Figure 8.9: Minor rock falls within highly jointed greywacke (circled), Whakatane Heads.

9 Landsliding on the Ohope Escarpment

9.1 Historic Instability

Records of instability at Ohope extent back to 1946, when the occurrence of a large landslide behind No. 35 West End Road was recorded by Mr J. Healy of the New Zealand Geological Survey (Fleming, 1955). A photograph presented in Fleming (1955)[4], which is reproduced here as Figure 9.1, indicates the presence of not one, but three significant landslide scars. These same landslide scars are visible in an aerial photograph taken in 1955 (Figure 9.2). The lack of vegetation regrowth on the slips by 1949 suggests that if landslides (B) and (C) did not occur at the same time as the one reported by Fleming (1955), they are likely to have also occurred sometime in the early 1940's.

A history of landsliding at Ohope was developed by T&T (2005) as part of an earlier geotechnical assessment. It was reported that a long-term resident of West End Road, who was then aged about 85, remembered only one landslide incident comparable to the large slip that occurred below Cliff Road in 2004, and that was the 1946 event reported in Fleming (1955). This may further indicate that the other landslides present within Figure 9.1 occurred concurrently with the one reported by Fleming (1955).

In addition to landslides, a number of rock falls are known to have occurred along the Ohope Escarpment. Evidence of rock fall is common, with sandstone boulders commonly being found amongst the trees growing on the talus slope at the rear of many properties. Two fatalities have been attributed to rock fall, although whether they were actually rock fall or debris associated with landslides is unknown. A four year old girl is reported to have been killed in 1959 by a boulder that hit the tent in which she was sleeping (Beetham, 2012). This fatality occurred at 54 West End Road, the neighbouring property to one where the 2011 fatality occurred. A second fatality is reported to have occurred on West End Road in the 1960's. Neither the location nor date are of this second incident is known, although the victim was reportedly in the rear of his property rather than in the dwelling.

In a more general sense, the presence of a talus slope extending 20 to 30m up the side of the Ohope Escarpment is proof in itself that a significant quantity of debris has periodically fallen from the upper escarpment and been deposited at its toe (Figure 9.3). This talus slope has developed only within the last 5,000 years or so with the mid to late Holocene northward migration of the beach. The extensive talus slopes at Ohope have therefore developed over a relatively short geological period. The thickness and volume of the talus slopes are large compared to the thickness and volume of the debris typically deposited by the many landslides mapped between 2004 and 2012 (<2m), indicating that a significant number of landslides have occurred within each section of escarpment. The cyclic nature of landsliding on the Ohope Escarpment is discussed further in Section 9.4.

[4] It is assumed that the photograph presented in Fleming (1955) was taken in 1949 during a reported site visit by the author.

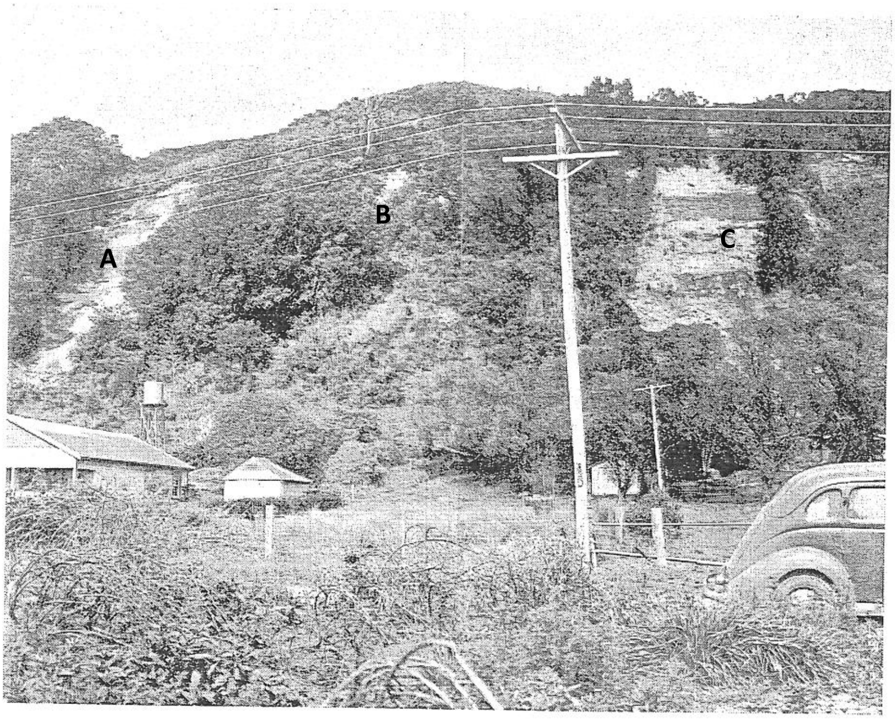

Figure 9.1: Photograph reproduced from Fleming (1955) indicating the presence of three significant landslides on the Ohope escarpment in 1949. Landslide (A) was the subject of Fleming's research. The central landslide (B) is largely obscured by vegetation from this view.

Figure 9.2: West End Road, Ohope, 1955. Slips identified in the text are indicated. "X" indicates the estimated location of where Figure 9.1 was taken. A large pohutukawa effectively blocks much of the Fleming (1955) slide ("A") from view (Reproduced with permission of Alexander Turnbull Library).

9.2 Recent Instability

Two major episodes of landsliding have occurred on the Ohope Escarpment in recent years. An intense rainstorm between 17th and 18th July 2004 generated a number of landslides, the most significant being located at the top of the escarpment in the vicinity of No. 14 Cliff Road (Figure 9.4), although landslides occurred at a number of other localities. It is understood that some slope instability occurred along 12 – 14 Cliff Road in 2001 and 2003, although T&T have no records of EQC claims for this period.

The 18 month period between May 2010 and October 2011 saw a significant escalation in the frequency and number of landslides on the Ohope Escarpment compared to previous years. The majority of these landslides occurred between June 2010 and July 2011. These occurred not only on the steep face of the escarpment (as was the case in 2004) but also within the talus slope.

The approximate locations of the 2004 and 2010-2011 landslides are indicated on Figure 9.5. The 2004 landslides were concentrated within the vicinity of Cliff Road, whereas the 2010-2011 landslides were distributed approximately evenly along the entire escarpment behind West End Road. Minor landsliding also occurred behind Pohutukawa Ave, Ohope.

9.3 Instability Types and Locations

Six forms of landsliding are recognised for the Ohope Escarpment. These are:

- Type O1: Shallow landslides within the talus slope;
- Type O2: Rock falls from sub-vertical sandstones faces;
- Type O3: Shallow talus landslides from intermediate slope benches;
- Type O4: Shallow landslide of primarily soil and vegetation from steep rock faces;
- Type O5: Shallow landslide within Upper Ohope Beds or at the top of the escarpment;
- Type O6: Deep landslides within the Upper Ohope Beds.

9.3.1 Type O1: Shallow Landslides within Talus Slope

With a slope angle typically around 25° to 35°, the talus slope is significantly flatter than the main escarpment. Nevertheless, some landslides have occurred entirely within the talus materials (Figure 9.6). Although debris from these landslides is likely to move at lower velocities than those that originate higher on the escarpment, their large mass and tendency to transport vegetative material (including large pohutukawa trees) has resulted in significant damage to some dwellings. The impact from one such landslide in 2011 was sufficient to require complete demolition of the impacted two storey house.

9.3.2 Type O2: Rock Falls from Sub-Vertical Sandstones Faces

The very weak to weak nature of the Ohope Beds means that other than isolated sandstone units, the Ohope Escarpment is not generally able to generate significant quantities of rock fall material. The talus slope is nevertheless populated with rock debris (Figure 9.7). Rock falls have occurred in recent time behind both West End Road (Figure 9.8) and Pohutukawa Avenue (Figure 9.9). Although small in volume, rock falls have relatively high velocities and are potentially destructive and pose a risk to life.

Figure 9.3: West End Road, Ohope, 1951. Even at this relatively early stage in Ohope's development, houses tended to be located at the rear of the properties. Reproduced with permission of Alexander Turnbull Library.

Figure 9.4: View of the large landslide that occurred above below No. 14 Cliff Road in July 2004. The affected properties at the base of the slope are No. 34 and 35 West End Road. Immediately to the right of the landslide scar is the location of the large landslide recorded in Fleming (1955). This section of slope was fully vegetated by 2004.

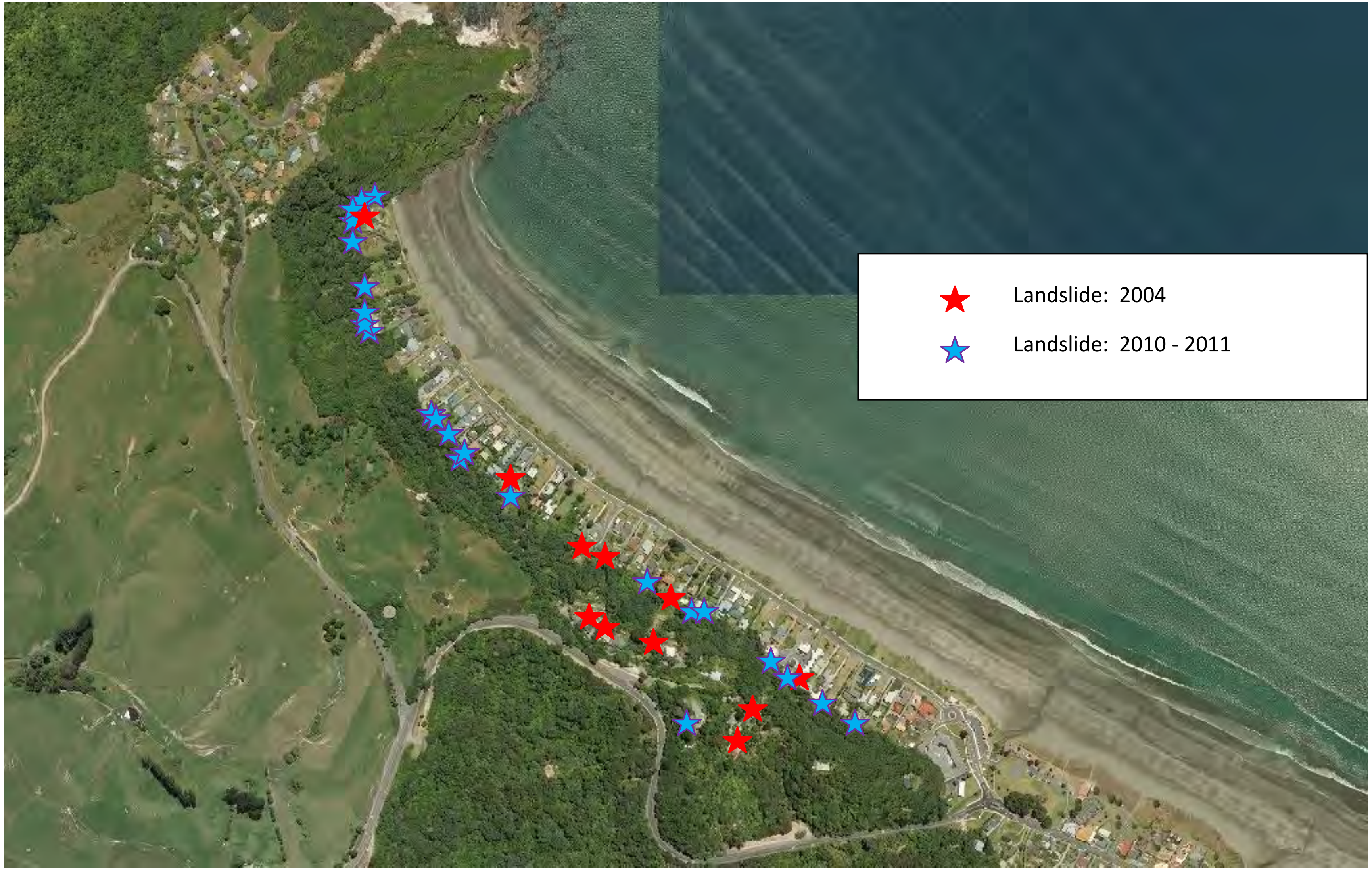

Figure 9.5: *General location of landslides on Ohope Escarpment for the periods 2004 and 2011-2012.*

Figure 9.6: Landslide within the talus slope behind West End Road. A large pohutukawa tree mobilised by the landslide caused sufficient damage to the adjacent dwelling.

Figure 9.7: Sandstone boulder and smaller rock debris on the talus slope behind the West End property where a rockfall fatality is reported to have occurred in 1959.

Figure 9.8: Recent rock fall debris from sub-vertical sandstone exposure. The rockfall was associated with the failure of a large pohutukawa tree.

Figure 9.9: Rock fall at the rear of a property on Pohutukawa Ave, Ohope.

9.3.3 Type O3: Shallow Talus Landslides from Intermediate Slope Benches

A discontinuous inclined bench is commonly present mid-slope along the Ohope Escarpment at the contact between the Upper and Lower Ohope Sandstones[5]. The bench is clearly seen in the landslide scar behind No. 55 West End Road (Figures 9.10 and 9.11). The inclined bench appears to have formed as a result of higher rate of cliff retreat for the weaker, more closely bedded upper sandstones. The soil and vegetative matter that accumulates on the bench periodically slides off. It was just such a failure that initiated the fatal July 2011 landslide.

9.3.4 Type O4: Shallow Landslide of Primarily Soil and Vegetation from Steep Rock Faces

The steep cliff faces of the western Ohope Escarpment have a minimal cover of soil held together by the root systems of trees and bushes which manage to cling to the surface of the rack face. A significant proportion of the western headland between Ohope Beach and Otarawairere Bay has been subject to this form of failure between 2010 and 2011 (Figure 9.12). Tabular slabs of rock also fall from these steep faces as a result of stress release.

9.3.5 Types O5 and O6: Landslides within Upper Ohope Beds and Younger Pumice Ash

Unconsolidated pumiceous sandy to gravelly deposits of the Upper Ohope Beds and the overlying Younger Pumice Ash, form the undulating terrain behind the steep escarpment (Figure 9.13). The presence of both large headscarps and hummocky ground are clear indicators of extensive historic instability in this area. This landsliding and the associated erosion of the mobilised material have resulted in the formation of discontinuous bench at the top of the steep escarpment. Two forms of landsliding are recognised:

- Smaller scale instability associated with the edge of the steep escarpment (Type 5); and
- Larger scale instability associated with the formation of the broad bench (Type 6).

Movement of displaced materials over the escarpment, either directly as landslide debris or indirectly through erosion and remobilisation, has probably contributed significantly to the formation of the talus slope.

Although the landform of the upper slopes clearly indicates the presence of landslides, no significant landslides are known to have occurred in this area in recent years, other than the small slips that are common on rural land.

The large historic slides present within the Upper Ohope Beds and Younger Pumice Ash have not been included in the landslide inventory, however their presence is reflected in the landslide susceptibility and hazard maps.

[5] This bench is distinct from the bench developed at the top of the escarpment which defines the approximate contact between the Upper and Lower Ohope Beds.

Figure 9.10: View of scar from the fatal July 2011 landslide at 55 West End Road. The sloping bench or contact between the pale Lower Ohope Sandstone and the orange-brown upper Ohope Sandstone was the source of the debris that initiated the landslide.

Figure 9.11: Inclined bench marking the contact (arrow) between the Upper Ohope Sandstone and the Lower Ohope Sandstone. The fatal landslide of July 2011 originated at this location.

Figure 9.12: Shallow failure of the very thin soil and vegetation cover from a steep face formed from the Lower Ohope Beds. The debris also removed the vegetation cover of the underlying greywacke.

Figure 9.13: View of the top of the Ohope Escarpment adjacent to Ohope Road. Deep seated instability is indicated by large headscarps (left) and hummocky debris field (centre).

9.4 Steep Slope Weathering and the Landslide Cycle

There is strong historic and field evidence to suggest that the recent spate of landslides on the Ohope Escarpment is part of a natural and cyclical process. The landslide cycle was described by T&T (2005) and is illustrated in Figure 9.14.

The four-step cycle is as follows:

- Step A: a landslide generates a fresh rock face on the escarpment whilst depositing additional debris on the talus slope;
- Step B: with time, the landslide scar become colonised by small plants, whilst small trees become established on the talus slope;
- Step C: as the vegetation becomes established, soil begins to accumulate on the scar and trees become established on both the escarpment and the talus slope; and
- Step D: The mature slope is characterised by a relatively thick soil mantle and large trees on both the escarpment and the talus slope. The escarpment is susceptible to a further cycle of landsliding.

It is immediately after the occurrence of a landslide that the hazard at that particular location is probably at its lowest, unless partially mobilised debris remains on the slope. T&T (2005) considered that the landslide cycle was in the order of 200 years, based on the estimated age of large pohutukawa tress uprooted by the 2004 landslides. Observations of the landslide scars dating from 1946 and as recently as 2004, show that there is a rapid recolonisation of landslide scars by vegetation, suggesting that the landslide cycle could potentially be as short at 50 to 70 years in some cases.

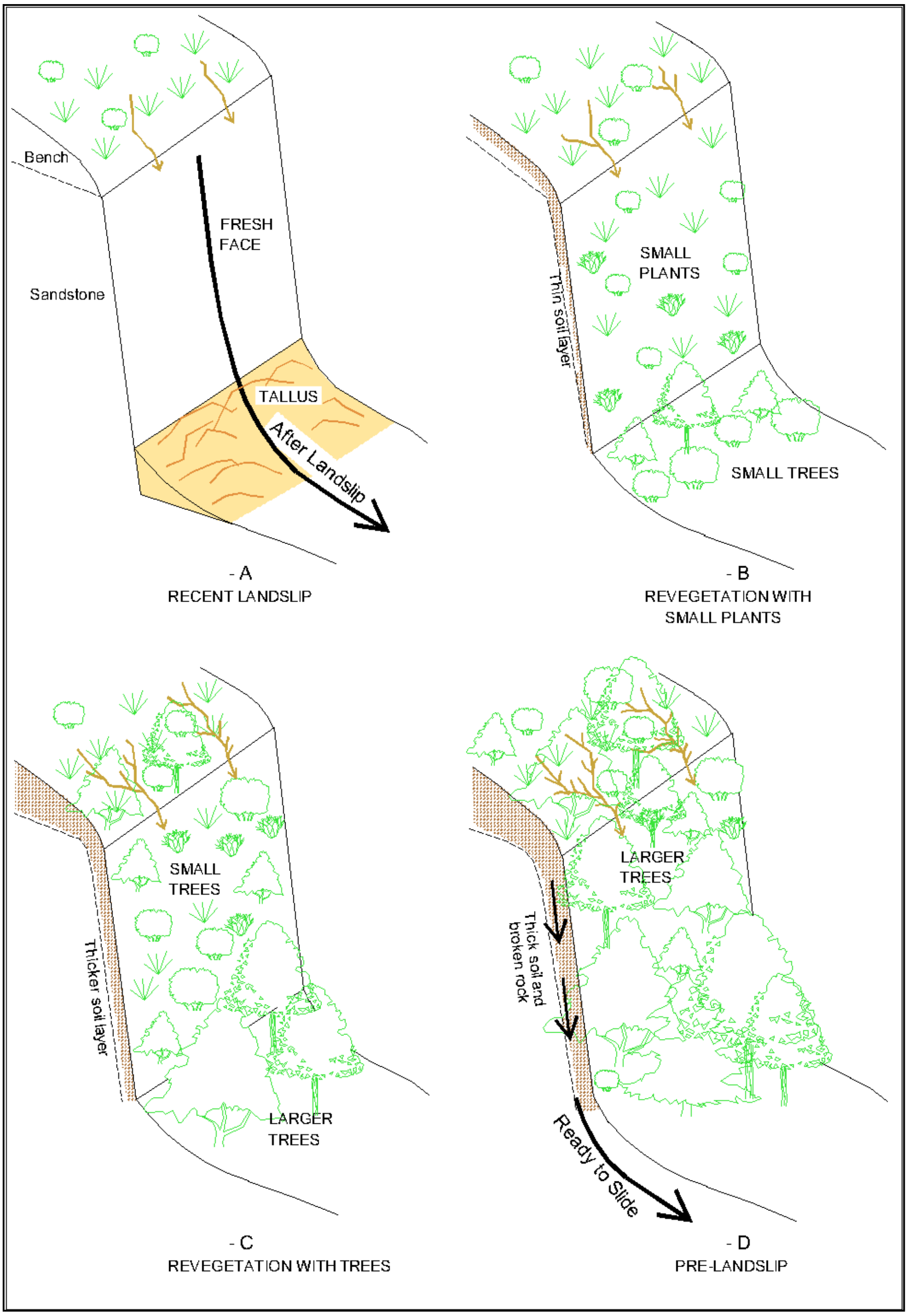

Figure 9.14: Illustration from T&T (2005) showing the natural cycle of vegetation establishment, growth and landslide on steep sections of the escarpment.

10 Landslide Inventory

A landslide inventory has been developed for both the Whakatane and Ohope escarpments. This has been based primarily on T&T's record of landslide investigations, but it also includes information sourced from historical photographic records and field mapping. The time period covered by the inventory is approximately 50 years for the Whakatane Escarpment and 70 years for the Ohope Escarpment.

Landslide inventory maps for the Whakatane and Ohope escarpments are presented in Appendices F and G respectively.

The inventory indicates that the study area can be divided into four sectors based on the relative abundance of recorded landslides:

- Whakatane Escarpment north of the Wairere Stream
- Whakatane Escarpment south of the Wairere Stream
- Ohope Escarpment behind West End Road
- Ohope Escarpment behind Pohutukawa Ave

11 Assessment of Landslide Trigger Mechanisms

All of the landslides investigated by T&T between 2004 and 2012 were the result of intense rainfall events. Although the 1987 Edgecumbe earthquake resulted in the collapse of a steep section of cliff at the northern end of Whakatane Heads (Otarawairere Bay), no other landslides are known to have occurred within the study area (T&T, 2005). The available evidence therefore indicates that rainfall has historically been the primary trigger of landslides on both of the escarpments. This does not however rule out the possibility of seismic-induced landslides in the future, although these will occur on a significantly less frequent basis. The relative importance of rainfall and seismic triggers is discussed below.

11.1 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 threshold or trigger point for landslides, it is clear that the greater the quantity and intensity of rainfall, the greater the probability of landslides occurring. It is considered essential for a significant rainfall event to have occurred in order for landslides to form on either escarpment. Possible exceptions to this might be minor rock fall in steep greywacke outcrops, which could conceivably occur at anytime.

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.The BoPRC collects rainfall data from a range of locations in the Whakatane and Ohope area. T&T acquired daily rainfall data for the following locations within the study area:

- 21B West End Road, Ohope (1998 to 2011);
- Pohutukawa Ave, Ohope, BoPRC Ref: 779005 (1978 to 2007);
- Harbour Road, Ohope, BoPRC Ref: 779102 (1997 to 2013);
- Ohakana Island, BoPRC Ref: 779004 (1983 to 2013).

Some variation between each of these recording stations is evident for single rain events. For the purpose of analysing the relationship between rainfall and landslides, a single rainfall record was developed using the mean of the three Ohope locations. This has provided a daily rainfall record comprising nearly 13,000 data points between 1978 and 2013. By matching the rainfall record with the inventory of known landslides, it has been possible to:

- Plot the daily rainfall record for the past 35 year, with the rainfall associated with landslide occurrence indicated (Figure 11.1);
- List the landslide-inducing rainfall events with respect to the total rainfall record (Table 11.1); and
- Identify those years with higher than normal rainfall and landslide activity (Figure 11.2).

Figure 11.1: Mean Daily Rainfall Data for Ohope, 1978 to 2013. Known landslide events are indicated in red.

Table 11.1: Daily Rainfall Associated with Known Landslides

Ranking of daily rainfall (1978 – 2013)	Rainfall (mm)	Date	No. of Recorded Landslides	
			Whakatane Escarpment	Ohope Escarpment
1	159.6	18/07/2004	3	5[a]
2	131.0	2/06/2010	-	7
3	128.6	25/05/2010	-	4
6	117.3	17/07/2004	-	5[a]
10	114.0	29/01/2011	3	5
12	107.0	25/04/2011	2	-
34	75.0	10/05/2008	-	1
35	74.0	12/10/2011	-	1
36	73.8	26/04/2011	-	1
58	65.8	18/06/2011	-	2
63	63.8	25/04/2011	-	4
81	58.0	15/08/2010	1	
114	51.0	27/05/2011	-	4
139	47.8	11/06/2011	-	1
140	40.2	4/08/2010	-	1

Notes

a) A total of 10 landslides are recorded for the storm event of 17-18 July 2004. The number that occurred on each day is unclear. For the purposes of this table they have been distributed evenly between the dates

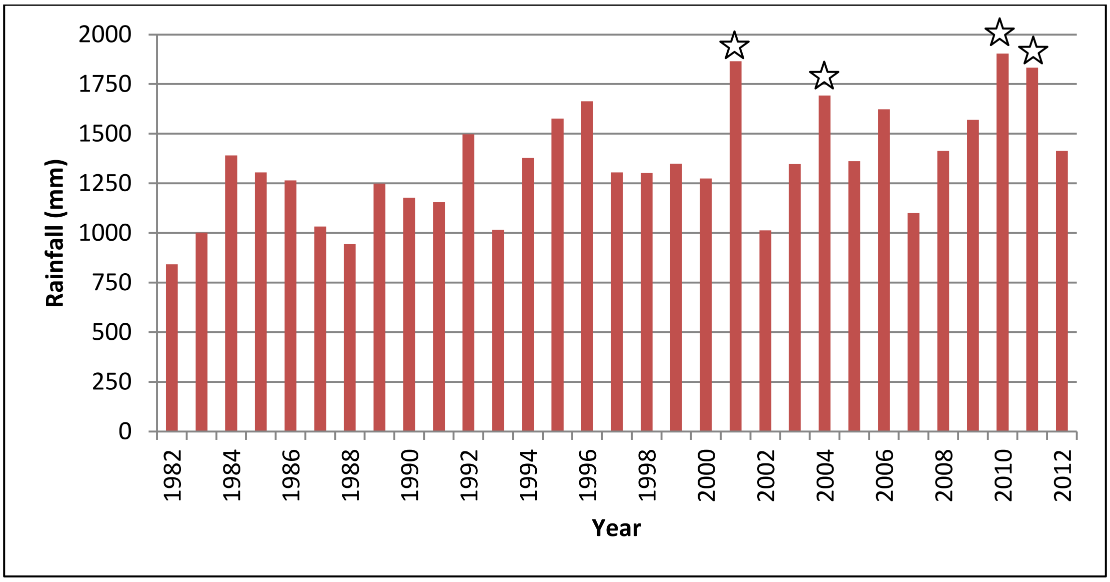

Figure 11.2: Annual Rainfall statistics for Ohope. The years in which landslides are known to have occurred are indicated by a star.

Although rainfall records cover the past 35 years, reliable data on landslides is only available from 2004, although we know slope instability had resulted in insurance claims for properties on 12-14 Cliff Road in 2001 and 2003. From the data presented in Figure 11.1, Figure 11.2 and Table 11.1, it is apparent that:

- Almost the entire inventory of known landslides occurred within the four wettest years between 1978 and 2013 (i.e. 2001, 2004, 2010 and 2011);
- The first onset of significant multiple landsliding events within recent times occurred as a result of the highest daily rainfall recorded in the past 35 years (160mm on 18th July 2004, preceded by 117mm on 17th July 2004);
- The significant multiple-landslide events of mid-2010 and early 2011 were associated with rainfall in excess of 120mm and 100mm respectively;
- Landslides occurred at increasingly lower daily rainfall totals as the wet conditions of 2010 persisted; and
- In general the number of landslides associated with each rainfall event decreases with total daily rainfall.

Table 11.1 shows that landsliding has occurred over wide range of daily rainfall totals (40.2 to 159.6mm). It is not possible to identify a single value of rainfall that can be considered to be a common trigger point or threshold, as the short term intensity of a storm event is known to be important. For example, the mean daily total of rainfall for the 18 June 2011 landslide event was 65.8mm[6], some 31mm of rain was recorded in a one hour period immediately prior to the landslide (Beetham, 2012). If the rainfall had occurred over a longer time frame (say 12 to 24 hours), it is doubtful whether this landslide would have occurred at all, as very few similar rainfall events have been associated with landslides in Ohope.

Nevertheless, the available data indicates that:

- Landsliding is always associated with rainfall in excess of 120mm per day;
- Landsliding becomes increasingly common once daily rainfall exceeds approximately 100mm. The number of landslides induced by such rainfall ranges from 5 to 7 on the Ohope Escarpment and 0 to 3 for the Whakatane Escarpment;
- Landslides can occur when daily rainfall is less than 100mm, although they are much more likely not to occur than occur and if they do, it is more likely that a single landslide will occur; and
- Antecedent rainfall and rainfall intensity are factors that can influence the occurrence of landslides in otherwise less extreme rainfall events.

The annual exceedance probability (AEP) for the 120mm rainfall event has been estimated from the project-specific rainfall database to be approximately 8%. The return period of the rainfall that appears to always trigger landsliding is therefore approximately 12 years. This is approximately equal to the normal monthly winter rainfall or 130% of the normal summer rainfall falling in a single day.

The AEP for 100mm or greater daily rainfall is approximately 40% i.e. such an event can be expected every 2.5 years. The project records show however that landslides occur only one third of the time this rainfall level is reached or exceeded. It is likely that rainfall intensity is an important element of determining whether landslides will or will not occur in such cases.

Rainfall-induced landslides can be expected to be more frequent during wet la Niña years and less frequent in dryer years, however, like many of the elements associated with the onset of landsliding, the relationship is not necessarily strong. For example, la Niña conditions were

[6] 88mm was recorded at 21B West End Road

present in both the 2010-2011 and 2011-2012 summers, but only the former was affected by landslides. Nevertheless, based on the data available, a landslide-inducing rainfall event can be expected to impact the Whakatane and Ohope escarpments approximately once a decade on average, with approximately 5 landslides being produced in Ohope and a lesser number in Whakatane.

11.2 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.

The level of seismic shaking that will trigger a landslide depends upon a number of factors, including geology, topography, groundwater conditions and the seismic sequence. 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°. Rock avalanches could be generated on high narrow slopes by earthquakes of M6.5 or greater.

The occurrence of seismic-induced landsliding on either of the escarpments depends not on the magnitude of the earthquake but upon the intensity of shaking felt at these locations. Attenuation of the seismic waves means that shaking intensity drops off significantly with distance from the point of rupture. The magnitude of the earthquake will however determine the maximum intensity of this shaking. The occurrence of seismically-triggered landsliding is therefore more closely related to MM than M_w.

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.

Hancox *et al* (1997) compiled data on landslides resulting from the Edgecumbe Earthquake of 1987. The earthquake generated many shallow landslides on the margins of the Rangitikei Plains, primarily on slopes steeper than approximately 40°, with the majority being cut slopes steeper than 50°. All landslides 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). The earthquake did not generate any landslides on either the Whakatane or Ohope escarpments, although a small section of cliff at Otarawairere Bay did collapse. Whakatane and Ohope were estimated to lie between the MM7 and MM8 isoseismals.

A microzoning study of Whakatane (Beetham *et al*, 2004) estimated peak ground accelerations (PGA) of approximately 0.3g and 0.5g for soft rock sites for the 475 and 2,500 year return period respectively on the Whakatane Fault. Research undertaken into the collapse of cliffs during the Canterbury earthquakes of 2010 – 2011 indicates that minimal slope instability occurs for PGA values less than 0.4g and that cliff collapse does not become widespread until PGA exceeds approximately 1.0g (Massey *et al*, 2012).

Obviously caution is required in comparing Whakatane and Christchurch because of the different geological settings. Nevertheless, information available at present (see Section 6.9) indicates that only rupture along the Whakatane Fault will generate sufficient ground shaking (>MM8) for significant landsliding to result and that the return period for such an event is approximately 1,000 to 2,300 years (Beetham *et al*, 2004).

In summary, an earthquake on the Whakatane Fault can be expected to produce widespread landsliding on the Whakatane Escarpment (and presumably also on the Ohope Escarpment) however at a return interval of approximately 1,600 years, such an event would be relatively rare. The number of landslides that would be generated by such a rupture is unknown, however it could conceivably be dozens. Rupture of other more distant faults will occur much more frequently, however their shaking intensity would be insufficient to generate anything other than minor landsliding at most.

12 Landslide Susceptibility

12.1 General

Landslide susceptibility is a measure of a particular area's propensity to either generate, or be affected (inundated) by landsliding. The assessment of susceptibility is based on the following two assumptions (AGS, 2007):

- That the past is a guide to the future i.e. areas that have experienced landsliding in the past are likely to experience landsliding in the future; and
- Areas with similar topography, geology and geomorphology as the areas that have experienced landsliding in the past are also likely to experience landsliding in the future.

By analysing the locations of existing landslides, it is possible to statistically identify those parameters most commonly associated with landsliding. This then allows predictions of future landslide susceptibility to be determined. The process undertaken in this study is described in the following section.

12.2 Susceptibility Classification

AGS (2007) provides both quantitative and relative (i.e. qualitative) criteria for the definition of landslide susceptibility (Table 12.1). A quantitative approach has been adopted for this study as this is a more powerful predictive tool when combined with an assessment of the factors controlling landslide initiation. Regardless of the method used, susceptibility assessments are necessarily subjective.

The assessment of rock fall has not been undertaken separate to that of the general landslide population as the inventory consists almost entirely of landslides. The additional level of susceptibility represented by rock fall will, in our opinion, be less than the uncertainty concerning the general landslide population.

12.3 Controls on Landslide Initiation

The susceptibility of an area to landsliding is (all regional-scale issues such as rainfall being equal) typically is a function of geology and topography (slope angle). It should be noted firstly that geology and slope angle are not independent variables, and secondly that the factors governing susceptibility are independent of trigger mechanisms, such as rainfall or seismic shaking.

12.3.1 Geological Control

The distribution of known and inferred landslides relative to the distribution of the different geological units for the Whakatane and Ohope escarpments presented in Appendices H and I, respectively.

12.3.2 Topographic Control

The landslide inventory maps (Appendices F and G) show the distribution of known and inferred landslides relative to topography. A slope gradient classification system has been defined for the purposes of GIS analysis (Table 12.2). Slope class maps for the Whakatane and Ohope escarpments are presented in Appendices J and K respectively.

Table 12.1: Landslide Susceptibility Descriptors (AGS, 2007)

Susceptibility Descriptor	Quantified Evaluation *The proportion of area in which landslides may occur*[1]	Relative Evaluation The proportion of the total landslide population in the study area[1]
High	>0.5	>0.5
Moderate	>0.25 to 0.5	>0.1 to 0.5
Low	>0.01 to 0.25	>0.01 to 0.1
Very Low	0 to 0.01	0 to 0.01

Notes

1: Refers to the source area of the landslide, not the total area affected by the landslide

Table 12.2: Slope Classes

Class	Slope Angle
I	0° to 10°
II	11° to 20°
III	21° to 30°
IV	31° to 40°
V	41° to 50°
VI	51° to 60°
VII	61°+

12.3.3 Normalised Difference

By overlaying the landslide inventory, geology and slope class maps using GIS software, it is possible to determine the proportion of the landslide population associated with different combinations of geology and slope class. By normalising this data relative to actual proportion of the study area occupied by each geology-slope class combination, those conditions most often associated with landsliding can be identified.

The process of deriving the Normalised Difference (ND) is as follows:

$$ND = (A_L - A_T)/A_T$$

Where:

A_L = Percentage of the landslide population associated with a given combination of geological unit and slope class

A_T = Percentage of the study area represented by the same combination of geological unit and slope class as A_L

A positive normalised difference value indicates that a particular combination of geology and slope class has a greater proportion of its area affected by landsliding than its relative abundance would suggest. The greater the normalised difference value, the greater the statistical association with landsliding. Likewise, negative normalised difference values indicate a reduced tendency for landslides to be associated with those particular conditions. The minimum value for normalised difference is -1.0. Theoretically there is no limit to positive values, although any value in excess of approximately 0.5 shows a strong association.

The normalised difference values calculated for the Whakatane and Ohope escarpments are presented in Tables 12.3 and 12.4 respectively. The highlighted positive values show that the occurrence of landsliding on the Whakatane Escarpment is most closely associated with steep slopes formed from Ohope Beds. The strong association between steep slopes in greywacke and instability reflects the occurrence of rock falls in steep greywacke outcrops south of the Wairere Stream. By comparison, landslides on the Ohope escarpment occur on a greater range of slope angles in a reflection of the greater variety of geological units.

Normalised difference provides a numerical basis for comparing those conditions most associated with landsliding. From this, those areas with the greater susceptibility to landsliding can be readily identified.

Table 12.3: Normalised Difference, Whakatane Escarpment

	Normalised Difference						
Geology	1	2	3	4	5	6	7
Alluvium	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Greywacke	-0.45	0.08	-0.41	-0.05	-0.09	**0.24**	**0.93**
Ohope Beds	-1.00	0.38[a]	-0.10	-0.06	-0.09	**0.29**	**0.36**
Talus	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-100

Notes:

a: This result is considered erroneous, as the large structural landslide on Muriwai Drive has undermined and incorporated a section of relatively flat-lying Ohope Beds into the landslide initiation zone.

Table 12.4: Normalised Difference, Ohope Escarpment

	Normalised Difference						
Geology	1	2	3	4	5	6	7
Greywacke	-0.73	0.09	-0.14	**0.44**	**0.36**	-0.10	-0.51
Upper Ohope Beds & Ash	-1.00	-0.80	**2.00**	**1.92**	**0.43**	-1.00	-1.00
Lower Ohope Beds	-0.96	-0.83	-0.58	0.08	**0.86**	**1.38**	**1.50**
Ohope Beds (General)	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Talus	-0.93	-0.27	**0.70**	**1.57**	**0.66**	-0.46	-1.00
Coastal-Sediments	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.00

12.4 Landslide Susceptibility Zoning

12.4.1 Landslide Initiation

Normalised difference provides a basis for comparing different locations in terms of their relative susceptibility to landsliding, however the numeric values cannot be directly applied to the AGS (2007) classification. Susceptibility mapping of the Whakatane and Ohope escarpments has instead been undertaken from a consideration of the following information:

- Geology and landslide inventory maps (Appendices H and I);
- Slope class maps (Appendices J and K); and
- Normalised differences (Tables 12.3 and 12.4)

The susceptibility of an area to landslide initiation is assessed according to the geological and topographic conditions existing at that site, as defined in Table 12.5. GIS software has been used to generate maps identifying the distribution of landslide initiation susceptibility along the Whakatane and Ohope Escarpments. These maps are presented in Appendices L and M respectively. The "pixelated" nature of the susceptibility maps directly reflect the slope classes generated from LiDAR (Appendices J and K).

The susceptibly maps support the findings of both the normalised difference calculations and field observations in identifying that:

- On the Whakatane Escarpment, the greatest susceptibility to landslide initiation (high to medium classification) is associated with the Ohope Beds located in the upper part of the escarpment north of the Wairere Stream. Susceptibility in other areas tends to be moderate to low, apart from relatively minor occurrences of Ohope Beds;
- On the Ohope Escarpment, almost the entire escarpment located behind West End Road is classified as being highly susceptible to landslide initiation. The escarpment behind Pohutukawa Ave is also typically classified as having a high susceptibility, although not nearly to the same uniformity as behind West End Road.

12.4.2 Landslide Inundation

In all cases (with the exception of the landslides that occurred in the Cliff Road area in 2004) the landslide hazard on both the Whakatane and Ohope escarpments is associated not with landslide initiation but inundation by debris originating from higher up the escarpment. Estimating the susceptibility of an area to inundation by landslide debris is more subjective than initiation alone, as it requires an assessment of future debris paths and travel distances. The landslide inventory, and particularly the landslide debris mapped by T&T between 2004 and 2012, has been used to estimate hazard class (Table 12.6).

Inundation hazard classifications were assigned on the basis of the following criteria:

- Each section of escarpment is given an inundation susceptibility rating equal to its initiation value;
- The talus slope is assigned the same inundation susceptibility rating as the adjacent escarpment;
- The coastal strips were given an inundation susceptibility rating based on the proportion of the mapped landslides that travel beyond the talus slopes (Table 12.7).

Table 12.5 Susceptibility to Landslide Initiation

Whakatane	Slope Class						
Geology	I	II	III	IV	V	VI	VII
Alluvium	VL	VL	L				
Talus	VL	VL	L	M	H		
Ohope Beds	VL	VL	L	M	H	H	H
Greywacke	VL	VL	VL	L	M	M	H
Ohope	**Slope Class**						
Geology	I	II	III	IV	V	VI	VII
Coastal-Sediments	VL	VL	VL				
Talus	VL	VL	L	M	H		
Ohope Beds (General)	VL	VL	L	M	H	H	H
Upper Ohope Beds & Ash	VL	VL	L	M	H	H	H
Lower Ohope Beds	VL	VL	L	M	H	H	H
Greywacke	VL	VL	VL	L	M	M	H

Table 12.6: Landslide Debris Travel Distance

Location	Landslides Reaching Downslope Areas No. of Landslides (% of Inventory)					
	Top of Talus Slope	Bottom of Talus Slope	10m beyond Talus Slope	20m beyond Talus Slope	35m beyond Talus Slope	>35m beyond Talus Slope
Whakatane North[a]	4 (21)[c]	2 (11)	2 (11)	0 (0)	0 (0)	0 (0)
Whakatane South[b]	1 (33)[d]	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Ohope West End	43 (95)[e]	12 (24)	5 (10)	1 (2)	1 (2)	0 (0)
Ohope Pohutukawa Ave	0 (0)[f]	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Notes:

a) North of Wairere Stream

b) South of Wairere Stream

c) Of a total landslide population of 19

d) Of a total landslide population of 5

e) Of a total landslide population of 49

f) Of a total landslide population of 3

Landslide initiation and inundation susceptibly maps for the Whakatane and Ohope escarpments are presented in Appendices N and O respectively. For the sake of simplicity, these maps are titled Landslide Susceptibility only. Note that the landslide statistics for Whakatane are insufficient to define separate low and very low suscetibility zones. For the purposes of mapping the landslide susceptibility at Whakatane, these two susceptibility classifications have been combined.

The susceptibility maps provide a broad-scale assessment independent of the potential shielding effects of dwellings or other structures. Determining the susceptibility of individual properties to landsliding would require the assessment of site-specific factors and therefore lies outside the scope of this study. It is expected that some individual properties have a different susceptibility class to that indicated by the broad-scale mapping.

12.4.3 Results

The following conclusions can be drawn from the landslide susceptibility assessment presented above:

- The Whakatane Escarpment north of the Wairere Stream has a high susceptibility to landsliding. This affects a number of properties located on Muriwai Drive, Muriwai Terrace and Wairaka Road;
- The Whakatane Escarpment south of the Wairere Stream is typically classified as being moderately susceptible to landsliding. This reflects the lower elevation of the escarpment in this area as well as a significantly reduced presence of Ohope Beds, which are the main source of landslides on the escarpment; and
- The entire Ohope Escarpment behind West End Road and Pohutukawa Ave has a high susceptibility to landsliding. This affects a large number of dwellings located towards the rear of the properties, particularly those located on the talus slope. Only those dwellings located within the immediate vicinity of West End Road are considered to have a low to very low susceptibility. It should be noted that although West End Road and Pohutukawa Ave have the same susceptibility classification, this does not imply either a similar hazard or similar risk classifications, as the frequency and magnitude of landsliding at West End Road is significantly greater than is the case for Pohutukawa Ave,

An extensive stormwater reticulation project was undertaken by WDC within the area of Cliff Road, Ohope following the widespread occurrence of landsliding from the top of the escarpment during the storm of July 2004. The storm saw a number of landslides fully evacuate down the front of the escarpment, whereas others only partially developed. Stormwater passing over the top of the escarpment from the cliff top residences was considered to have contributed to the extensive development of instability in this area.

The elevated risk of landslide impact for the properties both at the top and bottom of the escarpment as a result of the 2004 storm was mitigated by a combination of retaining walls and stormwater collection and reticulation. The reticulation system is considered to have mitigated the elevated landsliding risk brought about by the development of this area. It may have also reduced the susceptibility of the upper escarpment to landsliding to a level below what characterised the area pre-development, however the extent of this effect, if present, cannot be determined. In addition, the reticulation does not materially affect the susceptibility of the unmodified face of the escarpment from intense direct rainfall.

The susceptibility, hazard and risk assessments presented for the Ohope Escarpment therefore are not discounted to any extent to take into account of this stormwater reticulation.

Table 12.7: Basis for Mapping Inundation Susceptibility

Location	Escarpment Initiation Rating	Talus Rating	Coastal Strip Rating (Distance from talus lower edge)
Whakatane	High	High	0 – 10m: moderate 10m+: low to very low
	Moderate	Moderate	0 – 10m: moderate 10m+: low to very low
Ohope	High	High	0 -10m: moderate 10 - 35: low 35m+: very low

13 Landslide Hazard

13.1 Definition

Landslide hazard is similar in concept to susceptibility, except that the estimated frequency of landslide events is included in the analysis. For small landslides of the type that characterise the study area, the hazard is expressed as the number of landslides/ km^2/annum. The hazard descriptors recommended by AGS (2007) are presented in Table 13.1.

13.2 Landslide Frequency

The landslide inventory, together with the assessment of trigger events discussed in Section 11, forms the basis of frequency estimation. There is a tendency for landslide inventories to be biased towards more recent landsliding events, as older landslides typically become lost to the available historic record. The time period for the inventory is estimated to be 50 years for the Whakatane Escarpment (1961 to 2011) and 70 years for the Ohope Escarpment (1941 to 2011). These time frames reflect the effective photographic coverage and recorded landslide events available for the two escarpments.

In Section 11 it was estimated that rainfall events large enough to generate multiple landslides on the Ohope Escarpment occur approximately once every 10 years, whereas smaller storms with the intensity to generate a single landslide (or similar) occur approximately every 2 to 3 years. These are estimated long-term averages. The frequency of such events can vary widely over shorter timeframes. Based on this, it is estimated that some 50 to 60 landslides can be expected to occur on the Ohope Escarpment over a 70 year period (i.e. the time period of the landslide inventory). In fact the inventory contains 55 recognised landslides, 49 on West End Road and 6 on Pohutukawa Avenue (Table 13.2)

Although the escarpment behind West End Road has experienced the approximate number of landslides that the trigger frequency analysis indicates should have occurred, the remaining areas (Pohutukawa Ave area of Ohope and the entire Whakatane Escarpment) have experienced considerably fewer. This reflects the importance of local variations in geology and terrain on landslide formation over and above the influence of trigger events. Because of the uncertainty associated with rainfall return period and landslide generation for much of the study area, the average recurrence interval for rainfall-induced landslides has been estimated using the inventory of known landslides.

A further several dozen landslides could be generated on both escarpments in the event of a large rupture of the Whakatane Fault. However, as the return period of such an event is estimated to be somewhere between 1,000 and 2,300 years (see Section 6.9) the annual frequency of seismic induced landslides is at least one order of magnitude less than those resulting from rainfall. Given the uncertainties already associated with the return period of the more common rainfall-induced landslides, the landslide hazard and risk assessments described below do not include seismic-induced landslides as part of the landslide population. The hazard associated with rainfall and seismic events are nevertheless cumulative.

13.3 Landslide Hazard Zones

Landslide hazard zones have been developed for both the Whakatane and Ohope escarpments based on the AGS (2007) definition (Table 13.1). Hazards maps are presented in Appendices P and Q respectively. As was the case with the susceptibility mapping, the hazard of landslide initiation was firstly determined for the escarpment and talus slopes (Table 13.3). The landslide inundation hazard was estimated from the frequency of landslides in the inventory reaching certain distances from the base of the escarpments (Table 13.4). The combined initiation and inundation hazard was mapped as indicated in Table 13.5.

Note that the landslide statistics are insufficient to define separate low and very low hazard zones for either the Whakatane or Ohope escarpments. For the purposes of mapping the landslide hazard in these areas, these two susceptibility classifications have been combined.

13.4 Results

The following conclusions can be drawn from the landslide hazard assessment presented above:

- The Whakatane Escarpment north of the Wairere Stream has a high landslide initiation and inundation hazard. A number of properties located on Muriwai Drive, Muriwai Terrace and Wairaka Road are located within the high hazard zone;
- The Whakatane Escarpment south of the Wairere Stream is typically defined as having a moderate landslide hazard. This reflects the lower susceptibility of this area as well as few landslides within the inventory. A number of largely commercial buildings fall within this moderate hazard zone;
- The Ohope Escarpment behind West End Road has a high landslide hazard rating. A significant number of dwellings are located within this high hazard zone; and
- The Ohope Escarpment behind Pohutukawa Ave is defined as having a moderate landslide hazard. This largely reflects the limited number of landslides within the inventory for this area. A significant number of residential properties are located within this moderate hazard zone;

The landslide hazard maps illustrate how the highest hazard is present on the steep escarpments and talus slopes at their base. Hazard level reduces incrementally with distance from the escarpment in recognition of the travel distance of the landslide debris. This assessment <u>does not</u> take into account potential shielding effects of dwellings on individual properties.

Being limited to rainfall-induced landslides, the calculated risk values presented in Table 13.3 do not represent the maximum possible. However, as the inclusion of seismic-induced landslides could alter the result by no more than a decimal place, the rainfall-induced landsides alone represent the best means of representing the landslide hazard present on the two escarpments. Seismic landslides would likely be concentrated in those areas already identified as having a high landslide risk.

It should be noted that the values of landslide hazard are suitable for broad planning purposes but not for individual properties where local factors need to be taken into consideration.

Table 13.1: Definition of Small Landslide Hazard (AGS, 2007)

Hazard Descriptor	Landslides No. / km^2 /annum
Very High	>10
High	1 to 10
Moderate	0.1 to 1
Low	0.01 to 0.1
Very Low	<0.01

Table 13.2: Average Landslide Frequency Based on Inventory

	Landslide Inventory		Recurrence Interval, μ (years)
Location	No. (N)	Time Period, t (years)	
Whakatane – Nth of Wairere Stream	19	50	2.63
Whakatane – Sth of Wairere Stream	5	50	10.00
Ohope – West End Road	49	70	1.43
Ohope – Pohutukawa Ave	6	70	11.67

Table 13.3: Landslide Initiation Hazard

Location	No. of landslides in inventory	No./km^2/annum	Hazard Rating (AGS, 2007)
Whakatane - Nth of Wairere Stream	19	1.1	High
Whakatane – Sth of Wairere Stream	5	0.5	Moderate
Ohope - West End Road	49	5.0	High
Ohope - Pohutukawa Ave	6	0.5	Moderate

Table 13.4: Landslide Inundation Hazard

Location	No. of Landslides	Landslides Hazard (No./km2/Annum	AGS (2005) Rating
Whakatane - North of Wairere Stream			
On escarpment	19	1.1	High
On talus slope	4	1.1	High
0 – 20m beyond talus	2	0.9	Moderate
20m+ beyond talus	0	0.0	V. Low
Whakatane - South of Wairere Stream			
On escarpment	5	0.5	Moderate
0-20m beyond escarpment	2	0.9	Moderate
20m+ beyond talus	0	0.0	V. Low
Ohope - West End			
On escarpment	49	4.7	High
On Talus Slope	43	8.8	High
0 - 10m beyond Talus Slope	5	4.9	High
10 – 20m beyond Talus Slope	1	1.0	Moderate/High
0 – 20m beyond Talus Slope	5	2.4	High
20 – 35m beyond talus slope	1	0.7	Moderate
>35m beyond Talus Slope	0	0.0	Very Low
Ohope – Pohutukawa Ave			
On escarpment	6	0.6	Moderate
On talus slope	0	0.0	V. Low
0 - 10m beyond Talus Slope	0	0.0	V. Low

Table 13.5: Basis for Mapping Inundation Hazard

Location	Escarpment	Talus Slope	Distance beyond Talus Slope
Whakatane - North of Wairere Stream	High	High	0 – 20m: moderate 20m+: low to very low
Whakatane - South of Wairere Stream	High	High	0 – 20m: moderate 20m+: low to very low
	Moderate	Moderate	0m+: Low to very low
Ohope - West End Road	High	High	0 – 20m: high 20 – 35m: Moderate 35m+: low to very low
Ohope - Pohutukawa Av	Moderate	Moderate	0m+: Low to very low

Notes: Where a talus slope is absent due to development at the base of the Whakatane Escarpment, an equivalent estimated width is used.

14 Landslide Risk

Risk is often mistaken for the likelihood or probability that some adverse event may occur, when this is in fact the definition of hazard (see Section 3.1). Risk is the product of hazard (likelihood) and the consequence of occurrence. It can be assessed in terms of risk to people (loss of life risk) and risk to property (Property Loss Risk).

It is important to note that risk can vary significantly at times, even though the underlying hazard has not. For example, if no people or structures are present within an area of significant 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 is hazard.

14.1 Loss of Life Risk

Loss of life risk ($R_{(LOL)}$) can be calculated in a number of ways depending upon the purpose of the assessment. The objective of the assessment presented here is to determine the broad-scale risks present along both the Whakatane and Ohope escarpments. The objective has not been, and the available data does not support, assessments of individual properties, buildings or persons. This is particularly relevant to residents of dwellings effectively shielded from direct debris impact by the presence of an intervening structure. It is the risk to the occupiers of rear-most (unshielded) dwellings located on a talus slope that is specifically calculated here. Should a rear dwelling be removed, the risk to any other dwelling or its occupants now exposed to the debris path would correspondingly increase.

14.1.1 Loss of Life Risk Criteria

AGS (2007) provides risk zoning descriptors based on the annual probability of a fatality. These are reproduced in Table 14.1. The two escarpments have been divided into areas where a generally similar level of risk applies.

Table 14.1: Descriptors for Loss of Life Risk 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

14.1.2 Quantitative Loss of Life Risk Estimation

$R_{(LOL)}$ is defined by AGS(2007) as:

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

Where:

$R_{(LOL)}$ is the annual Loss of Life risk

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

$P_{(S:H)}$ is probability of spatial impact

$P_{(T:S)}$ is the temporal spatial probability

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

Definitions of these factors, as well as their components, are presented in Table 14.2. It is important to note that the annual probability of landslide occurrence has been limited to those landslides triggered by rainfall i.e. effectively all of the landslides in the project landslide inventory. Although a cliff collapse was observed at Otarawairere Bay during the 1987 Edgecumbe Earthquake, a separate assessment of seismically-induced landslides has not been undertaken, as any contribution they would make to the total risk profiles of either escarpment would be less than the uncertainty associated with the rain-fall induced landslides. Likewise, rockfalls have not been treated separately from landslides, but are included within the overall assessment based on the available inventory. This is considered justified based on the evidence that local rock falls do not have a greater run-out distance than the larger landslides.

14.1.3 Results of Risk Estimation

The annual loss of life risk has been determined for five escarpment sectors. These are the same sectors as those identified from the susceptibility and hazard, with the exception that the sector on the Whakatane Escarpment north of the Wairere Stream has been divided into Muriwai Drive/Muriwai Terrace and Wairaka Terrace. The reason for this further division is that the probability of a dwelling being struck by debris is typically greater along Muriwai Drive/Muriwai Terrace compared to Wairaka Road, where most of the dwellings are located at a greater distance from the escarpment.

The loss of life risk estimates presented in Table 14.3 are for the escarpments and adjacent talus slopes i.e. those areas with the greatest landslide hazard. These risk estimates therefore relate solely to those properties located at the base of the escarpments. Those properties located further away from the base of the escarpments have correspondingly lower loss of life risk.

The highest annual risk is 4.4×10^{-2}, estimated for the escarpment behind West End Road. The derivation of this estimate is illustrated in Table 14.2. Projected over the 70 year period of the Ohope Escarpment risk assessment (1941 to 2011), it would be expected that this level of risk would have resulted in three (3.1) deaths. In fact, three deaths and one near death injury are known to have occurred over this period. Two of the fatalities occurred several decades ago when the density of development along Ohope Beach was less that it currently is. The potential for dwellings and their occupants to be impacted by landslide debris has never been greater than it is now. We have not assumed an increase in the frequency of possible trigger events with time.

The level risk applicable to any particular property is dependent not only on distance but also the shielding effects of houses located closer to the escarpment on the same or adjacent properties. Given the highly variable nature of this shielding effect and the limited information available on annual probabilities of occurrence for landslides of different run-out distance, it is not considered appropriate to attempt to spatially map Loss of Life Risk, either in zones or contour values.

The outer limit of landslide travel or run-out distance can be evaluated on the basis of relationships between initiation height and travel distance. 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 14.1). 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 (<500m^3) with unconfined paths on steep slopes (such as at Whakatane and Ohope) 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

By interrogating the landslide inventory and topographic data for the large landslide inventory for Ohope, the typical travel distance ratio (H/L) where the landslide inundation become rare was found to be around 0.6. This is equivalent to a shadow angle of 30°, a typical value for such analyses. It was found that this correlated well with the mapped boundary between the moderate and low to very low hazard zones.

A common evaluative metric for loss of life risk is the 10^{-4} annual risk level. This probability, which is equivalent to 1 chance in 10,000 years has widely been adopted as representing the boundary between unacceptable and tolerable risk. Note that no New Zealand jurisdiction has applied numeric values to unacceptable, tolerable or acceptable risk levels. This is discussed further in Section 15.

Available data indicates that for West End Road at least, the 10^{-4} annual loss of life risk level is located in the vicinity of the boundary between the moderate and low to very low landslide hazard zones (Appendix Q). This is also approximately the position where landslide debris tends not to pass based on a 30° shadow angle. This assessment does not take into account the possible effects of shielding by buildings located closer to the escarpment.

The general location of the 10^{-4} annual loss of life risk level is indicated in Table 14.3. <u>It must be appreciated that this assessment is order of magnitude only and useful only for general planning purposes. The loss of life risk for individual properties needs to be undertaken as a separate exercise in which all of the site-specific variables are accounted for.</u>

Table 14.2: Example of Loss of Life Risk Calculation

Factor	Definition	Reference to this study	Notes	West End Road Example
Loss of Life Risk: $R_{(LOL)}$	Annual probability of loss of life of an individual	Calculated for the person considered most at risk (PMAR)	PMAR occupies a dwelling at the base of either escarpment and is typically present at home during the day	4.4×10^{-2} i.e. there is a 4.4% annual probability of a death resulting from a landslide
Probability of occurrence: $P_{(H)}$	Annual probability of a landslide occurring. This is the sum of all potential landslide types (landslide, earth flow, rockfall etc)	Design values are based on long-term recurrence intervals.	For the purposes of this study, the probability of landslide occurrence ($P_{(H)}$) is assumed to be $P\{N(t) \geq 1\}$, the annual probability that one or more landslides will occur. Only rainfall-induced landslides have been assessed.	5.0×10^{-1} i.e. there is a 50% probability that a landslide will occur somewhere on the escarpment behind West End Road in a 12 month period. In reality the return period of landsliding is greater than every two years but multiple landslides will tend to occur in a single event, giving a smaller average value.
Probability of Spatial Impact: $P_{(S:H)}$	Probability that, should a landslide occur, it is physically able to impact the reference property. This is made up of two components.	$P_{(S:H-1)}$ – the probability that a dwelling is located below a landslide, should it occur.	With the exception of several properties located on Cliff Road Ohope, $P_{(S:H)}$ is the probability that landslide debris will travel far enough to impact the dwelling located at the base of the escarpment. $P_{(S:H-1)}$ has been estimated from aerial photography.	9.0×10^{-1} i.e. should a landslide occur, there is a 90% probability that a dwelling or occupied property will be located below it.

Factor	Definition	Reference to this study	Notes	West End Road Example
Probability of Spatial Impact: $P_{(S:H)}$		$P_{(S:H-2)}$ – the probability that the landslide debris can travel far enough to impact a dwelling or rear property	$P_{(S:H-2)}$ has been estimated from the landslide inventory i.e. the travel distances of the landslides that occurred between 2004 and 2011.	$7.0x10^{-1}$ i.e. there is a 70% probability that landslide debris will reach a rear dwelling or occupied property, should it be located below the landslide
		$P_{(S:H)} = P_{(S:H-1)} \times P_{(S:H-2}$		$6.3x10^{-1}$ (63%)
Temporal spatial probability: $P_{(T:S)}$	The probability that, should a property or dwelling be impacted by debris from a landslide, the location of impact will be occupied by an individual This is made up of two components.	$P_{(T:S-1)}$ – the probability that somebody is home i.e. present somewhere on the property	The minimum conceivable value is 50%, given that few properties can be expected to be entirely unoccupied between say 6pm and 6am. The value of 75% has been adopted as applicable to the Person Most at Risk (PMAT), the basis for the AGS (2007) assessment; Note that some QLRA (e.g. Port Hills assume 100% occupancy, thereby calculating a higher $R_{(LoL)}$	$7.5x10^{-1}$ (75%)
		$P_{(T:S-2)}$ – the probability that person who is present is able to be impacted directly by landslide debris or collapsing building elements	It is assumed that in order to be impacted, the resident would need to be at the rear of the dwelling or in the back garden. It has been based largely from anecdotal evidence from the 2010 to 2011 landslides.	$2.5x10^{-1}$ (25%)
		$P_{(T:S)} = P_{(T:S-1)} \times P_{(T:S-2)}$		$1.9x10^{-1}$ (19%)

Factor	Definition	Reference to this study	Notes	West End Road Example
Vulnerability: $V_{(D:T)}$	The probability that, should physical impact occur, the individual is killed.	Assumed to be 75%	Vulnerability to landslide impacts are generally high for humans	$7.5x10^{-1}$ i.e. 75%.
$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$ $R_{(LOL)}$ = 50% x 63% x 19% x 75% = 4.4% (or 4.4×10^{-2})				

Table 14.3: Long-Term Loss of Life Risk for Escarpment and Talus Slope

Location	$P_{(H)}$	$P_{(S:H)}$	$P_{(T:S)}$	$V_{(D:T)}$	$R_{(LOL)}$	Descriptor	Very Approximate Location of 10^{-4} Level
Whakatane Escarpment							
Muriwai Drive/Terrace	3.2×10^{-1}	3.3×10^{-1}	$1.9x\ 10^{-1}$	$7.5x\ 10^{-1}$	1.5×10^{-2}	Very High	Approximately at Muriwai Drive or Muriwai Terrace
Wairaka Road	3.2×10^{-1}	1.8×10^{-1}	$1.9x\ 10^{-1}$	$7.5x\ 10^{-1}$	7.9×10^{-3}	Very High	Approximately 20m north of Wairaka Road
South of Wairere Stream	9.5×10^{-2}	3.5×10^{-1}	$1.5x\ 10^{-1}$	$7.5x\ 10^{-1}$	3.7×10^{-3}	Very High	Unknown. Cannot be determined from landslide data
Ohope Escarpment							
West End Road	5.0×10^{-1}	6.3×10^{-1}	$1.9x\ 10^{-1}$	$7.5x\ 10^{-1}$	4.4×10^{-2}	Very High	35m out from the edge of the talus slope. Approximates the moderate-low to very low hazard boundary.
Pohutukawa Ave	8.2×10^{-2}	7.0×10^{-1}	$1.9x\ 10^{-1}$	$7.5x\ 10^{-1}$	8.1×10^{-3}	Very High	The outer edge of the talus slope. Approximately 10m west of Pohutukawa Ave

14.2 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 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 14.4.

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 in terms of velocity and volume) needs to be assumed. Evaluation of the consequences also requires an understanding of the impacted structure, construction type, materials etc. The vulnerability of a structure to a landslide therefore is highly dependent on the characteristics of both the landslide and the building. The consequence of this is that property loss risk <u>cannot be defined spatially</u>. For example, two structures located adjacent to each other in the same landslide hazard zone can have quite different property loss risks on account of their different physical characteristics. This is in effect analogous to the different vulnerabilities that affect loss of life risk calculations.

Property loss risk has been estimated in broad terms only for each of the landslide hazard zones as a means of comparing one general area to another. The results are presented in Table 14.7. The risk ratings presented in Table 14.7 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.

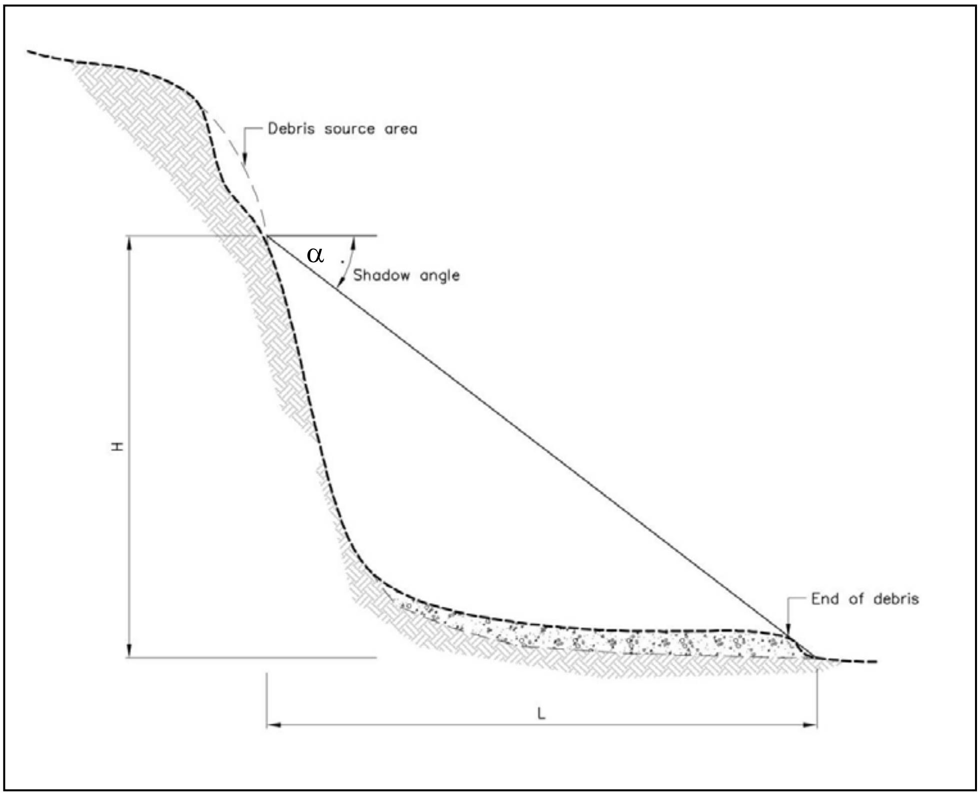

Figure 14.1: Debris travel distance expressed as an H/L ratio. The shadow angle is equivalent to the α angle of Hunter and Fell (2003)

Table 14.4: 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 14.5: 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} ($5x10^{-2}$ to $>1x10^{-1}$)	10 years (<20 yr)	The event *is expected* to occur	Almost certain	A
10^{-2} ($5x10^{-3}$ to $5x10^{-2}$)	100 years (20 – 200 yr)	The event *will probably* occur under adverse conditions	Likely	B
10^{-3} ($5x10^{-4}$ to $5x10^{-3}$)	1000 years (200 – 2,000 yr)	The event *could* occur under adverse conditions	Possible	C
10^{-4} ($5x10^{-5}$ to $5x10^{-4}$)	10,000 years (2,000 – 20,000 yr)	The event *might* occur under very adverse circumstances	Unlikely	D
10^{-5} ($5x10^{-6}$ to $5x10^{-5}$)	100,000 years (20,000 – 200,000 yr)	The event *is conceivable* but only under exceptional circumstance	Rare	E
10^{-6} ($<1x10^{-6}$ to $5x10^{-6}$)	1,000,000 years (>200,000 yr)	The event *is inconceivable* or fanciful	Barely credible	F

Table 14.6: 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%

Table 14.7: Approximate Property Loss Risk

Location	Landslide Hazard Zone	AGS (2007) Risk		
		Qualitative Likelihood in 50 years	Inferred Consequence	Risk Class
Whakatane Escarpment	High	Likely	Medium to Catastrophic	High to Very High
	Moderate	Possible to unlikely	Minor to Medium	Low to Medium
	Low to very low	Unlikely	Minor	Low
Ohope Escarpment	High	Likely	Medium to Catastrophic	High to Very High
	Moderate	Possible	Minor to Major	Medium to High
	Low to very low	Unlikely	Minor	Low

15 Comparison to Other Risks

With the loss of life risk calculated for the Whakatane and Ohope Escarpments, the next question is whether these values can be considered acceptable, tolerable or intolerable/unacceptable. Generally it is the boundary between tolerable and intolerable that is of importance when considering natural hazards. The acceptable risk level is typically an order of magnitude less than the tolerable level and is very difficult to achieve.

New Zealand does not have established criteria for determining these 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} 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} for existing slopes (AGS, 2007).
- The British HSE suggests an upper limit of tolerability of 10^{-4} for the public and 10^{-3} for workers (Taig, 2012).

The $R_{(LOL)}$ values estimated for the five escarpment sectors are one or two orders of magnitude greater than the 10^{-4} value generally adopted overseas as the tolerable limit for landslides. This is approximately equal to the risk of death in a road accident in New Zealand (Figure 15.1).

This study does not attempt to make value judgements with respect to the acceptability or otherwise of the estimated risks from landslides on the Whakatane and Ohope escarpments. Ultimately it is up to New Zealand's central, regional and local authorities to determine what level of risk is appropriate for inclusion in the risk assessment and risk management process.

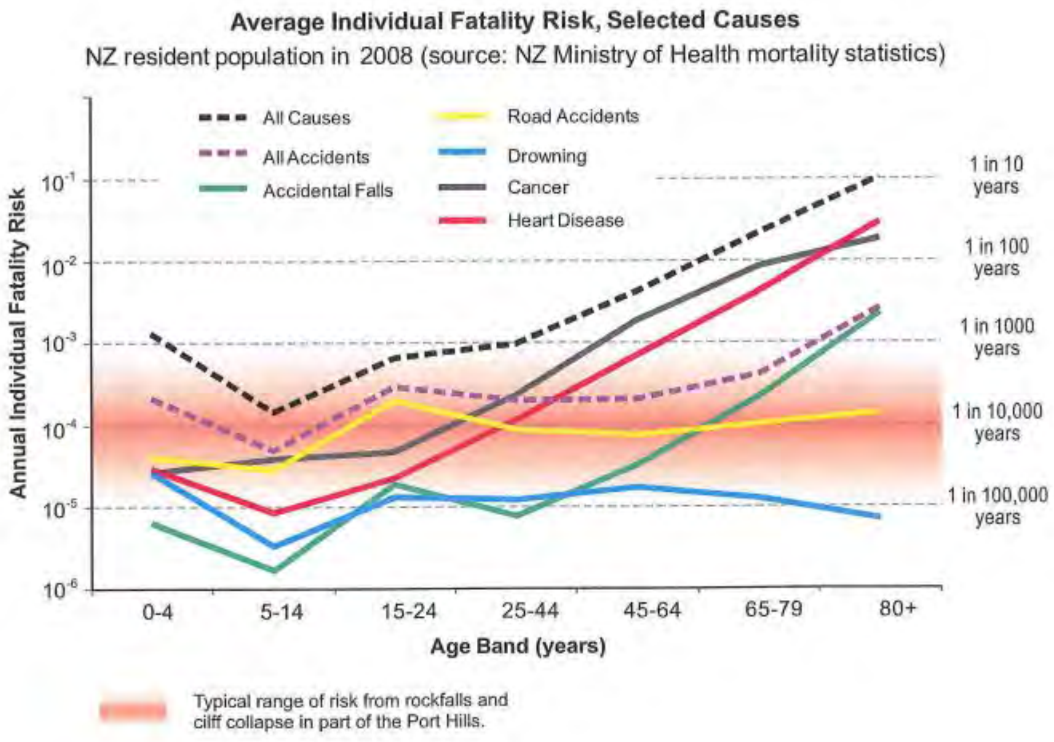

Figure 15.1: Comparison of Individual Fatality Risk for Different Hazards in New Zealand (Source: GNS, 2012)

16 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. 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 for the Whakatane and Ohope escarpments. 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).

16.1 Hazard Avoidance

16.1.1 Land Use Zoning

Avoidance is probably the most effective strategy for managing landslide hazards. It is achieved primarily through the placing 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 Whakatane and Ohope escarpments, the mature nature of both settlements significantly constrains the WDC's ability to manage the significant landslide hazard in these areas through avoidance. Development restrictions would largely be limited to those properties that are not yet fully subdivided or the Ngati Awa farm block. The latter is the only significant area of undeveloped land along either escarpment.

16.1.2 Building Set-Back Distances

Building set-back distances (either the distance back from an escarpment crest or in front of an escarpment base) are an effective means of isolating elements at risk from impact. Unfortunately, those areas that potentially could be designated as no-development zones are typically already occupied. The establishment of set-back distances would potentially require the abandonment of at least the talus zone beneath each escarpment and possibly an additional part of the coastal strip. A substantial number of properties would be affected. Such retrospective development controls would have, as a bare minimum, significant financial implications for some residents of Whakatane and Ohope as well as WDC.

The establishment of set-back distances for future developments would require site-specific geotechnical investigations to be undertaken. T&T (2005) recommended that universal set-back distances not be defined but that each development should be assessed independently. This opinion is supported by this study.

16.2 Hazard Elimination

The complete elimination of a landslide hazard requires engineering works to prevent future landslides 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 the landsliding on both the Whakatane and Ohope escarpments effectively excludes the use of landslide elimination strategies. The only potential exception to this is the construction of palisade retaining walls and stormwater reticulation to protect cliff top properties from crest regression. Remedial works of this type were undertaken along Cliff Road, Ohope following the 2004 landslide event.

16.3 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.

16.3.1 Stormwater and Groundwater Control

The relationship between high rainfall events and landsliding on both the Whakatane and Ohope escarpments was clearly established in 2004 and 2010-2011. 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.

16.3.1.1 Whakatane Escarpment

The potential for drainage control to be undertaken on the Whakatane Escarpment is negligible. The primary landslide hazard is associated with the Ohope Beds located in the upper part of the escarpment. These landslides are triggered by direct rainfall rather than water flowing over or into the escarpment from elsewhere.

16.3.1.2 Ohope Escarpment

The Ohope Escarpment offers greater opportunity for drainage control, although it is still constrained by the nature of the escarpment and the landsliding. A major source of surface water flowing over the Ohope Escarpment is the farmland that overlooks West End Road. The control of surface water flows in this area, and the delivery of captured water to the beach would likely reduce the occurrence of landslides on this part of the escarpment. The degree to which the landslide hazard could be reduced is not something that can be determined numerically. Suburban development of this farmland could provide an effective means of achieving stormwater control over an extensive section of the Ohope Escarpment behind West End Road provided that appropriate stormwater capture and removal systems are put in place.

The shallow nature of the landsliding on the steep face of both escarpments precludes the use of subsurface drainage as a hazard reduction method. Such landsliding can be expected to occur to some extent on both escarpments as a direct result of heavy rainfall, regardless of any drainage measures adopted.

Minor earthworks or landscaping on properties located at the base of the escarpments would go some way to reducing the potential damage that surface water or muddy slurries may have following a future landslide event.

Following the 2004 Ohope landslide event, a project was undertaken to capture the stormwater from the residences located at the top of the Ohope Escarpment and discharge it at the base was undertaken. Although none of the landslides that affected Cliff Road in 2004 were reactivated during 2010-2011, further landsliding nevertheless occurred on this section of escarpment. The most significant was a landslide in the talus slope below Cliff Road which resulted in the demolition of the dwelling at No. 33 West End Road. The reticulation is considered to have offset the negative impact that the discharge of stormwater from the development of Cliff Road had on slope stability, however it is unable to mitigate the hazard associated with landslides on the steep escarpment face triggered by direct rainfall.

16.3.2 Vegetation Control

Both the Whakatane and Ohope escarpments have an extensive vegetative cover. 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 the escarpments should be encouraged.

Observations made between 2004 and 2011 have however identified vegetation to be a major, if not *the* major component of the destructive debris that reached residential areas as a consequence of landslides occurring higher in the escarpment. It is evident that although the presence of vegetation generally reduces the incidence (or at least does not increase the incidence) of landsliding, when landsliding does occur, the vegetation readily becomes incorporated into the debris. The greatest damage to dwellings during the 2010-2011 landslides was observed to be the result of tree impacts. Pohutukawa trees are particularly vulnerable to being uprooted as a result of being hit by landslide debris from above.

As a means of reducing landslide hazard, shrubs and small trees should be encouraged to grow on the steep sections of the escarpments but that the number of large trees should be limited as eventually they can be expected to be incorporated into a landslide. Medium to large trees should be encouraged to grow on the talus slopes however, as they help bind the deep soil together as well as act as a physical barrier to landslide debris moving beyond the talus slope. Any large trees that appear to be unstable should however be trimmed or possibly removed entirely.

16.4 Risk Reduction

16.4.1 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. They can however reduce risks to desired levels.

A number of properties in Whakatane and Ohope 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 16.1). The EQC has installed steel posts (lengths of railway track) upslope of a small number of properties at Ohope as a means of reducing the imminent risk of further impacts of debris on adjacent dwellings (Figure 16.2). 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 Ohope Escarpment

(Figure 16.3). The slurry issue could potentially be addressed with the construction of relatively modest diversion bunds.

A flexible ring-net barrier has been constructed behind two properties on Muriwai Drive, Whakatane 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 some on-going maintenance (Figure 16.4). A large debris impact wall is to be constructed behind No. 33 Muriwai Drive. The intent of of this barrier is to provide protection form a combination or rock falls and high velocity debris flows. This structure is unlikely to have applicability beyond a particular set of circumstances that apply to the proposed location.

16.4.2 Monitoring

The application of landslide monitoring is limited to existing landslides that may reactivate or expand in the future. Such a monitoring programme was utilised for many months following initiation of the large landslide behind No. 27 to No. 33 Muriwai Drive in 2010. The essentially random nature of most landsliding on the Whakatane and Ohope escarpments however effectively rules out monitoring as a means of landslide hazard or risk reduction.

We consider that the primary area where monitoring could be of value is controlling the development of large trees on the escarpment. The monitoring of tree density, size and health would be beneficial to hazard management. In particular, large trees located on the steep part of the escarpments may require trimming to prevent them becoming too large and unstable. Also, any large tree that develops a significant lean or other signs of instability or ill health should be inspected and potentially removed.

16.4.3 Warnings

16.4.3.1 General

Public warning and notification systems are currently used for 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.

Figure 16.1: Earth bund constructed behind 71/71a West End Road

Figure 16.2: Line of steel posts providing protection across a potential landslide path

Figure 16.3: Informal line of iron posts which successfully prevented several large trees from impacting a rear dwelling on West End Road

Figure 16.4: Example of flexible ring-net barrier

16.4.3.2 Warning Systems for Landslides

The development of a warning system for landslide 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;
- 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

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
Wire sensors		• Can provide warning of minor land movement allowing measures to be taken to reduce risk	• Limited to known and existing landslides of a particular type e.g. rotational or translational landslides • Can prove more costly if connected to a monitor, rather than regular visual observations • Risk of false activation
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

16.5 Owner Self-Help Options

There is little that property owners can do to reduce the landslide hazard affecting their properties to any meaningful degree. They can however reduce the potential risk of injury or property damage by adopting the following:

- Monitor the state of the vegetation on the slopes behind their property, particularly the stability or health of large trees;
- Look for the presence of slabs of rock that may have partially come away from a rock face and has the potential to fall;
- If space allows, minor earthworks could be undertaken at the rear of properties to direct surface water and mud slurry flows away from dwellings
- Debris catch structures such as those described above could installed behind their property.

17 Review of Landslide Hazard Management Objectives, Policies and Rules

17.1 Purpose and Methodology

District Councils have obligations under the Resource Management Act 1991 (RMA) to address natural hazards such as landslides, as defined in section 31(b):

> *The control of any actual or potential effects of the use, development, or protection of land, including for the purpose of-*
>
> *(i) the avoidance or mitigation of natural hazards;.*

The purpose of this section of the report is to review the operative Whakatane District Plan with respect to the recommendations of the GNS Science policy guidelines and the landslide risk management methods adopted by other councils in New Zealand and Australia.

The following methodology was used to achieve the objectives of this review:

- Review of the New Zealand framework and approaches, including:
- Review the GNS Science guidelines for planning policy for landslide prone land to identify principles of landslide risk management and appropriate planning tools which can be utilised to minimise risk;
- Review and analyse the approach taken by five other territorial authorities in New Zealand which also manage landslide risk in their District Plans;
- Identify the strengths and weaknesses in each District Plan having regard to the GNS Science guidelines;
- Compare the GNS science guidelines and the strengths of other District Plans with the approach currently taken in the Whakatane District Plan;
- Identify areas of potential weakness in the Whakatane District Plan;
- Recommend land use planning and management strategies to assist Whakatane District Council (WDC) in reducing the landslide risk in the Whakatane District, using examples from other District Plans (NZ);
- Review the landslide risk management approach adopted by two Australian councils to identify any alternative methods that may be applicable to the Whakatane District Plan; and
- Summary of potential improvements to the Whakatane District Plan approach based on the New Zealand and Australian reviews.

17.2 New Zealand Approaches to Landslide Management

17.2.1 GNS Science Planning Guidelines

In 2007, GNS Science published a document entitled "*Guidelines for assessing planning policy and consent requirements for landslide prone land*" (Saunders and Glassey, 2007). The guidelines primarily aim is to assist planners in determining whether existing planning documents incorporate appropriate information on landslide and slope instability hazards. The GNS Science Guidelines provide examples of appropriate issues, objectives, policies, rules and assessment criteria, and is therefore a useful framework with which to critically assess the approach taken in District Plans throughout New Zealand.

17.2.1.1 Principles for Planning for Landslide Risk

The GNS Science guidelines are based on four overarching principles:

- *Gather accurate landslide hazard information*: Maps showing the location of landslide hazards must be developed at an appropriate scale for planning purposes;
- *Plan to avoid landslide hazards before development and subdivision*: Avoidance is the safest long-term solution for current and future landowners and the local authority. Engineered mitigation measures may be appropriate so that risk is reduced to an acceptable level;
- *Take a risk-based approach in areas already developed or subdivided*: In these areas there is an expectation that, for example, vacant sites can be built on. Appropriate land use planning is required to avoid or mitigate the increased risks from landslide hazards. The ideal approach is to avoid further development in high-risk landslide-prone areas, limit existing use rights to rebuild, and limit the use of buildings. The most realistic approach, however, is to accept the status quo whilst ensuring that any further development and use of buildings (building type) is consistent with the level of risk posed, and district plan maps clearly show landslide hazard zones.
- *Communicate risk of landslides in built-up areas*: Non-regulatory approaches, such as hazard education programmes and incentives to retire at-risk land, assist in ensuring landowners and building occupiers are aware of the probability of landslides. Hazard education initiatives must reflect the complex socio-economic nature of communities, therefore programmes need to target a range of at-risk groups, and may require a mix of approaches.

17.2.1.2 Summary of Recommended Planning Tools

Key approaches that the GNS Science Guidelines recommend may be utilised in District Plans to minimise landslide risk include the following:

- *Landslide hazard maps*: Planning maps to identify landslide risks having regard to the best technical information available, and displayed at a scale appropriate for land use planning (i.e. property boundaries shown, at a scale of around 1:10,000 depending on the size of sites);
- *Objectives and policies for development*: Contain objectives and policies that require avoidance of landslide risks in greenfields areas, and avoidance or mitigation of landslide risks in developed areas;
- *Rules for land use and subdivision*: Contain rules and activity status' for building and subdivision that are appropriate to the level of risk;
- *Earthworks, vegetation removal and services*: Contain objectives, policies and supporting rules controlling earthworks, vegetation removal, and location and design of services in areas subject to landslide risk;
- *Assessment criteria*: Provide appropriate assessment criteria and information requirements for resource consent applications to ensure landslide risk is adequately assessed and addressed through the resource consent process;
- *Non-regulatory methods*: Identify non-regulatory methods to be used in conjunction with the District Plan, including community education, incentives to retire risk-prone land, and preparation and implementation of a hazard management guidelines for planning staff to enhance decision making; and
- *Plan monitoring*: Have appropriate mechanisms to monitor the effectiveness of the District Plan in addressing landslide risk.

The above list forms the basis of the District Plan reviews presented below.

17.2.2 Review of Selected New Zealand District Plans

This section identifies the approaches taken in the District Plans of five New Zealand territorial authorities: Whangarei District Council, Tauranga City Council, Marlborough District Council[7], Christchurch City Council, and the Dunedin City Council. These Councils were selected based on their inclusion of methods to address landslide risk, and also from T&T's involvement and experience in these areas.

Each District Plan has been assessed having regard to the recommendations drawn from the GNS Science guidelines. These are summarised in Table 17.1. Key strengths and weaknesses of the approach taken in each District Plan are also presented.

All of the five District Plans reviewed had objectives and policies relating to avoiding and managing natural hazards (including landslides). Only the Marlborough Sounds Resource Management Plan clearly maps instability and contains rules relating to the mapped areas. Whangarei City Council has land instability information available on a publicly accessible GIS system, however this is not incorporated into the District Plan. In Dunedin, Christchurch and Tauranga, it is suggested in the plans that a lack of available technical information restricted the ability to include landslide planning maps and/or relevant rules and assessment criteria into the planning framework. Reliance is placed on a separate hazards register.

Objectives and policies regarding the avoidance of natural hazards and minimising land slippage risks are therefore generally not supported by rules controlling land use. Reliance is generally placed on subdivision and earthworks controls which trigger resource consent requirements, which then allow planners to assess the effects of the development on land slippage hazards against technical requirements and the established policy framework.

17.2.3 Whakatane District Plan – Landslide Hazard Review

This section provides an assessment of the Operative Whakatane District Plan provisions relating to managing landslide hazards. The assessment is based on, and draws from, the GNS Science guidelines. Comparisons and examples from the Whangarei, Tauranga, Marlborough Sounds, Christchurch, and Dunedin District Plans assessed in Table 17.1 are discussed where appropriate. The assessment concludes with suggestions of potential additions or alterations to the Whakatane District Plan that may strengthen the provisions relating to managing landslide hazards.

A draft proposed District Plan has been prepared by Whakatane District Council (dated 15 July 2011). The provisions relating to management of natural hazards, particularly with regards to the Whakatane and Ohope escarpments, are currently being reviewed. No further consideration has therefore been given to the draft District Plan in this section.

[7] Marlborough District Council has two Resource Management Plans within its district. This assessment is on the Marlborough Sounds Resource Management Plan.

Table 17.1: Assessment of Tools to Manage Landslide Hazard Within District Plans

Planning tool	Whangarei District Council	Tauranga City Council	Marlborough District Council	Christchurch City Council	Dunedin City Council
Operative Date	3 May 2007	5 August 2011	The Plan was made operative in parts on the 28 February 2003 and on 28 March 2003. The remainder is still at a proposed stage.	November 2005	Some parts of the Plan were made Operative in Part on 19 April 2004. The balance of the District Plan was made Operative as at 3 July 2006.
General	The Whangarei District Plan contains separate chapters for policies and rules. Chapter 19 provides the policy framework for Natural Hazards in the district. The approach to rules is generally permissive, with most activities allowed as a permitted activity in provided the relevant performance standards for the zone are met. Limits of discretion are provided where required, but there are no assessment criteria, with reliance being placed on the policy framework for assessing applications. Engineering standards are included as an Appendix to the District Plan and are used to assess subdivision proposals.	The Tauranga District Plan contains a specific chapter containing provisions for natural hazards (Chapter 6). It seeks to reduce the risk to life, property and the environment from the development of land known to be subject to instability.	This is a combined Plan containing the regional, regional coastal and district plans for the Marlborough Sounds area. Objectives and policies relating to Natural Hazards are contained in a separate chapter, whereas relevant rules are included in chapters relating to zones.	The Christchurch City Plan takes a performance standards based approach to managing activities. The City Plan is structured in three volumes. The first provides an introduction and an outline of the issues racing the region, the second includes objectives, policies, implementation and monitoring, and the third provides the rules and assessment criteria. Two series of planning maps are included, one which provides site zoning and the other provides further details on special interest sites, designations and hazardous areas.	The Dunedin District Plan contains a chapter focussing on hazards (Chapter 17). The District Plan acknowledges the Abbotsford slip in 1979 as being a key event that increased community awareness of potential land instability in the Green Island/Saddle hill area. The Otago Peninsula is also vulnerable to landslides and soil erosion.
Landslide hazard maps	No planning maps are provided in the District Plan which identify landslide hazards. Mapped hazards include flood susceptible areas, mining hazard areas, and coastal hazards. This may reflect the relative importance of landslides compared with other hazards in the district. However, information about instability areas is available on Council's online GIS system. This categorises the risk into high, medium and low instability.	The District Plan does not include a special hazard zone or mapping of land instability. The given reason for the lack of mapping is that the available information is not definitive enough to warrant the imposition of a special hazard zone. A natural hazard information base holds information assisting the assessment of site-specific instability issues.	A series of planning maps are provided which focus on mapping hazards in the district, including fault lines, flooding, and unstable land. These are provided at a range of scales, from 1:150,000 in rural areas to 1:10,000 in residential areas. This allows hazards to be identified at a site level.	Landslide hazards are not shown on the planning maps. The City Plan states that because the nature and extent of some natural hazards cannot readily be determined in advance, most are not identified in the Plan itself, but on a separate hazards register, and are assessed as matters to be taken into account on controlled activity subdivision application. The City Plan does show coastal and flooding hazards.	A hazard register is maintained, which includes areas of land instability. There are no general planning maps showing land instability risk areas. The structure plan for Grandvista Estate does include mapped hazard areas.
Objectives and policies for development	Chapter 19 focuses on avoiding adverse effects on people, property and the environment as much as practicable; maintain natural buffers; ensuring that development does not increase the risk from, or occurrence of natural hazard events; and ensuring that any mitigation measures do not cause adverse effects on the environment in themselves. Specific policies are provided for various hazards but not for landslides.	Chapter 6 contains specific objectives and policies relating to avoidance of landslide hazard; and requiring an assessment of effects on the environment to address the suitability of the site for development.	Separate objectives are included for avoiding the effects from natural hazards, and effects of activities on exacerbating natural hazard risk. Supporting policies provide an emphasis on avoiding effects where possible. Policies also include provision for protection works where the benefits outweigh the costs, emergency management, and consideration of local iwi values.	A key objective relates to avoiding or mitigating effects from natural hazards (Natural Environment 2.5). This is supported by policies controlling development in relation to the risk of natural hazards, avoiding increased risks of hazards, and mitigation works to be provided as supplementary to preventative measures. An objective relating to natural hazards and subdivision states that subdivision shall not be permitted to occur in localities where there are significant natural hazards, unless these can be adequately mitigated, and that any such mitigation measures not have significant adverse effects on the environment (Subdivision 10.1).	Chapter 17 contains objectives and policies related to landslide hazards. The policy framework is aimed at gathering and maintaining an information database on hazards; controlling building and vegetation removal in hazard areas; and controlling earthworks.
Rules for land	There are no rules that restrict building development within areas subject to landslide	There are no performance standards or rules relating to landslip hazards for land use	Relevant rules in each zone chapter require resource consent for any building (except for	Permitted activity standards for development in each zone do not include	There are no rules restricting building development on sites subject to landslide

Planning tool	Whangarei District Council	Tauranga City Council	Marlborough District Council	Christchurch City Council	Dunedin City Council
use	risk. Provided buildings meet the bulk and location controls, they are generally a permitted activity, meaning there is no opportunity for assessment of landslide risk through a resource consent process. We assume risk is addressed through the building consent process only. A natural hazard policy area does control earthworks and building development in areas subject to flooding, coastal hazards, or mining subsidence, but this has not been extended to landslide risk.	development.	from internal alterations to established buildings) in a mapped natural hazard overlay as a Discretionary Activity (e.g. Rule 30.1.7.1 and Rule 30.4 for the Sounds Residential zone).	consideration of landslide hazards (although fire and coastal hazards are addressed).	hazard in most zones. The Residential 6 zone contains areas subject to land instability. Low density rules restrict additional development in these zones. A structure plan has been prepared for Grandvista Estate which includes mapped hazard areas.
Rules for subdivision	All subdivision requires resource consent as a minimum as a Controlled activity. Matters of control for all subdivisions include the matters on which conditions can be imposed under Section 220 of the Resource Management Act 1991, which include protection against natural hazards. Engineering standards are also used for subdivision, which include a requirement for earthworks to safeguard people, property and the environment from the adverse effects of unstable land.	All subdivision requires resource consent as a minimum as a Controlled activity. Matters of control for all subdivisions include the matters on which conditions can be imposed under Section 220 of the Resource Management Act 1991, which include protection against natural hazards.	Subdivision is provided in most zones as a Controlled Activity, subject to performance standards. The performance standards do not include an exemption for sites with natural hazards. However, the land use requirements relating to buildings would apply. Assessment criteria include consideration of the effects on natural hazard risk.	Volume 3, Part 14, Rule 7 provides specific requirements for subdivision relating to natural hazards. Subdivision may be obtained as a controlled activity, however consideration is given to natural hazards.	Subdivisions require resource consent, with the lowest activity status being restricted discretionary. Matters of discretion include the consideration of hazards, including the effects of services, earthworks and vegetation removal on natural hazards.
Earthworks, vegetation removal and services	No regard is given in the rules or assessment criteria for the potential effects of these activities on landslide risk.	A specific policy addresses the potential for storm water discharges to affect land stability (Policy 6.1.2.3). Other stated methods include considering land stability when designing and locating Council services, and considering hazards as well as sedimentation when assessing earthworks and vegetation removal.	Policy 16.3.2.2 identifies the need to consider the effects of earthworks and vegetation clearance on the risk of occurrence, or potential to cause damage, from natural hazards. However this policy does not appear to be supported by any specific performance standards for earthworks or vegetation clearance. There are no requirements relating to landslide hazards that apply to utilities.	Specific requirements apply for earthworks within flood management and ponding areas, but not specifically with regard to landslide prone areas. A maximum slope for permitted earthworks of 15° applies in the Port Hills area (Volume 3, Part 9, Rule 5.5 Table 1). Over this slope, resource consent is required as a restricted discretionary activity. There are no rules or assessment criteria relating to natural hazards for vegetation removal or utility services.	Objectives and policies are provided in Chapter 17 regarding effects of earthworks and vegetation removal on site stability and slippage. Set back distances apply for permitted activity earthworks. There are no permitted activity conditions relating to natural hazards for utilities, however utilities requiring resource consent are subject to assessment criteria regarding health and safety and natural hazards.
Assessment criteria	The District Plan does not include assessment criteria.	Land use and subdivision consents are required to be accompanied by the location and area of any land that is, or may be subject to, land slippage; and a geotechnical assessment for any cut/fill earthworks and the suitability of the site for development, including any recommended mitigation works (Section 12.1 of the District Plan). There are no assessment criteria directly related to landslide hazards.	The only assessment criteria provided for buildings as a Discretionary Activity is to ensure the proposed works "do not increase any risk from natural hazards". Details on unstable areas are required to be shown on site plans where applicable (Rule 28.1.3(i)). All subdivision applications, and all land use applications in the Sounds Residential and Rural zones require assessment of land stability to accompany the application (Rule 28.1.12).	There are no assessment criteria relevant to landslide hazards for land use development. For subdivision, assessment criteria include consideration of any information held on the Council's hazards register, information provided by suitably qualified experts in relation to the subdivision, potential adverse effects on other land that may be caused by the subdivision or related development activities, and, in relation to erosion, falling debris or slippage, the need for ongoing conditions aimed at avoiding, remedying or mitigating future potential adverse effects, and any need for registration of consent notices on the allotment's certificate of title.	Should a building require resource consent (triggered by a rule not relating to landslide hazard), safety of occupants is listed as one criteria for assessment. Geotechnical reports are required to accompany resource consent applications where there is a slippage hazard.

Planning tool	Whangarei District Council	Tauranga City Council	Marlborough District Council	Christchurch City Council	Dunedin City Council
Non-regulatory methods	Chapter 19 identifies a range of non-regulatory methods including developing a natural hazard events' register, educate and inform landowners and residents about the hazards and the systems in place to monitor hazards, and maintaining hazard risk maps on Whangarei District Council's GIS system.	Identify those areas known or likely to be affected by landslides in a natural hazard information base, including relic slips and the 2:1 slope envelope line, and apply this information when considering subdivision or development of such land. No methods are prescribed around community education.	Listed non-regulatory methods for managing landslide hazards include promoting community understanding; maintaining protections works and structures; reassessing the natural hazard maps every 5 years; and maintaining emergency response procedures.	Non-regulatory methods provided for Objectives 2.5 include the maintenance and provision of information on the extent and location of hazards through Council's hazard register, education, and Council Work programmes.	Include Council works programmes to minimise the risk of natural hazards, formulating responses to natural hazards, and providing guidelines for earthworks activities.
Plan monitoring	Whangarei District Council has a Monitoring Strategy to measure progress against anticipated environmental outcomes identified in the District Plan. For natural hazards, the anticipated outcomes include natural hazard areas being identified on planning maps; subdivision, use and development avoided in natural hazard areas; adverse effects from natural hazards avoided or mitigated; and natural buffers relating to natural hazards being protected, maintained or enhanced.	Anticipated environmental results are stated as being the avoidance or minimisation of damage to property and the environment from land slippage, and minimal risk being posed to public safety or public infrastructure from land slippage. There is no stated means of monitoring the effectiveness of the plan provisions.	No details about plan monitoring are provided in the Plan.	Plan monitoring relating to natural hazards is included at the end of Volume 2, Section 2 (Natural environment). Field surveys and records of works undertaken by Christchurch City Council are intended to measure the change in number of hectares of land subject to erosion, and the change in the level of risk in specified areas due to property development choices and protection works.	There are no details of any District Plan monitoring to ensure the rules and methods are achieving the objectives.
Summary of approach	The Whangarei District Plan contains natural hazard mapping and policy framework; however these are not directed at landslide hazards and are not supported by rules and assessment criteria for land use activities. However, land instability is considered at the time of subdivision including through use of engineering standards. No consideration is given to the potential effects of earthworks, vegetation removal and services in exacerbating landslide risk. An online, publicly accessible GIS system provides categorised information on instability hazards to support decision making and community awareness of the risk.	The Tauranga District Plan is similar to Whangarei in that the mapping and implementation of rules controlling development in natural hazard areas is restricted to flooding and coastal hazards, and does not include landslide hazards. Reliance is placed on subdivision and earthworks standards to minimise risk of development on, and from, landslide hazards.	The Marlborough Sounds Resource Management Plan relies on Natural Hazard mapping on unstable land, requiring resource consent as a Discretionary Activity for any building development within the mapped hazard areas. The policy framework emphasises the avoidance of risk for new development. Permitted levels of earthworks and vegetation removal can be taken in unstable areas without resource consent.	The Christchurch City Plan does not map landslide hazards, nor does it require resource consents for building development in areas potentially subject to landslides. The City Plan relies on an up-to-date, separate hazards register which is applied at the subdivision stage. Earthworks are controlled within steep slopes in the Port Hills area.	The District Plan relies on a hazard register held by Dunedin City Council, rather than planning maps showing landslide hazards. The information on the hazard register is provided in Land Information Memoranda (LIMs). There are no rules which directly control land use development in landslide hazard areas, however if a resource consent is required for any other reason, landslide hazards are assessed through that process. Natural hazards are criteria for considering subdivision applications.

17.2.3.1 Landslide Hazard Maps

The GNS Science guidelines highlight the importance of having a good technical basis for managing landslide hazards. District Plan maps at an appropriate scale for making planning decisions are the best tool available to district councils. In addition to providing a basis for regulatory methods (i.e. rules and resource consent requirements), hazard maps also ensure that the hazard is communicated to the public, and that landowners and building occupiers are aware of the hazard.

Natural hazard zones and NHaz4 lines are shown on the District Plan maps. NHaz4 lines appear to relate directly to Rule 4.3.3 which controls development in the Whakatane and Ohope escarpments. However it is not clear from the objectives, policies and methods whether all landslide hazard areas are intended to be included in this mapping. As with the District Plans reviewed in this report, the Operative Whakatane District Plan does not include planning maps directly identifying landslide hazards, although coastal hazards are explicitly mapped. A natural hazard register is maintained to inform decision making.

Updating the planning maps to explicitly show landslide hazard areas at an appropriate scale, and including this as a stated method in Chapter 2.3 of the District Plan, would improve the communication of the risk and the management of the risk through District Plan rules. This is the approach used in the Marlborough Sounds Resource Management Plan (see Figure 17.1).

17.2.3.2 General Land Use Provisions

The Whakatane District Plan acknowledges that development pressure to subdivide and develop housing and businesses under the Whakatane and Ohope escarpment is continuing. Chapter 2.3 addresses natural hazards, including landslide risk. Objective NHaz1 is similar to key objectives in the District Plans reviewed in this report, as it relates to avoiding or mitigating the adverse effects of natural hazards on the life and wellbeing of people, and significant environmental values, through managing subdivision, use, development and protection of land. The objective does not include a priority of *avoiding* effects where practical, rather than mitigating effects. Examples from the plans reviewed in this report are presented in Table 17.2.

Objective NHaz1 is supported by Policy 7 which requires new structures to not have an adverse effect on the stability of the escarpment in Whakatane or Ohope. This provides more locally specific direction to implement the overall objective consistent with other District Plans throughout the country.

With regard to appropriate rules, the GNS Science guidelines suggest that if the landslide risk is low, the provisions contained in plans may be more permissive and make use of the permitted or controlled activity consent categories. If the risk is high, then provisions in plans may become more restrictive, with greater use made of discretionary and non-complying activity consent categories.

Figure 17.1: *Example of a planning map showing natural hazards at property level. Areas in red are subject to land instability (Source: Marlborough Sounds Resource Management Plan).*

Table 17.2: Comparison of Objectives and Policies

Plan	Objectives and policies
Whakatane District Plan	Objective NHaz 1: To manage the subdivision, use, and development and protection of land so as to avoid or mitigate the adverse effects of natural hazards on the life and wellbeing of people, and significant environmental values.
Whangarei District Plan	Objective 19.3.1: The adverse effects of natural hazards on people, property and the environment are avoided, as far as practicable, or otherwise remedied or mitigated
Tauranga District Plan	Policy 6.1.2.1: Subdivision, use and development should be avoided within areas of known or potential land instability where those activities or any subsequent use that is likely to be made of the land are likely to accelerate, worsen or cause damage to land (or in respect of the subsequent use of that land any other land or structure), structures or the environment through slippage or erosion.
Marlborough Sounds Resource Management Plan	Policy 16.3.1.1: Locate new works and structures to avoid their damage from the effects of natural hazards.

The Whakatane District Plan supports Objective NHaz1 and supporting policies through a rule controlling buildings, vegetation removal and earthworks within the Whakatane and Ohope escarpments as a discretionary activity. Rule 4.3.3 states:

"The following activities shall require resource consent as a discretionary activity within the area shown as NHaz4 on the planning maps, or alternatively, where NHaz4 is defined as a line on the planning maps, above or below the line to the point where the predominant slope is less than 35 degrees from horizontal:

a The placement, construction, alteration or addition of a building or accessory building (including swimming pools) for a residential, community or business activity;

b The removal of vegetation, provided that domestic gardening and the management of vegetation as provided below shall be a permitted activity;

- *Management of vegetation, for the purposes of this rule, means planned work undertaken in accordance with accepted arboricultural practices that will maintain the health of the vegetative cover on the escarpment and assist in stabilising the slope. Management may include:*
  - *Removal of weed species and animal and plant pests;*
  - *Replanting of vegetation;*
  - *Removal of dead or diseased vegetation where it is necessary to maintain the health of the vegetation or for public safety reasons;*
- *Trimming or pruning of vegetation that achieves the purpose of the rule as described above;*
- *Seed collection.*

c Earthworks, provided that this rule shall not apply to the disturbance of the ground for domestic gardening or for the establishment of a building platform after a building consent has been issued."

However, this rule applies only to development on the steepest slopes, above 35 degrees, and may not effectively address the risk of landslide hazard below this area, particularly areas that may be affected by debris flows or landslides within talus slopes.

Performance standards for permitted activities require buildings to be located so as to avoid falling debris hazard (Rule 4.1.1.2(c)), allowing all development in landslide hazard areas to be assessed through the resource consent process. Clear and easily accessible information on the location of falling debris hazards are required to ensure that this performance standard is enforceable.

17.2.3.3 General Subdivision Provisions

Subdivision of any land which contains an identified natural hazard area requires resource consent as a Discretionary Activity, as opposed to the general Controlled Activity status for sites without additional controls.

The assessment criteria of Rule 3.11.10 apply.

17.2.3.4 Earthworks, Vegetation Removal and Services

The District Plan recognises that earthworks and inappropriate planting on the Ohope and Whakatane escarpments have the potential to have an adverse affect on the stability of the slopes.

Policy 7 supporting Objective NHaz1 refers to the location, design and construction of storm water disposal systems to avoid having an adverse effect on the stability of the escarpment in Whakatane or Ohope. Policy 8 supporting Objective NHaz1 is to manage vegetation and earthworks on the escarpment in Whakatane or Ohope to assist in stabilising the slope. These policies are implemented through Rule 4.3.3.

Stormwater disposal systems are required to avoid accelerating the risk of landslides from the location of storm water outlets (Rule 4.1.15(b)). No other provisions for services relate to landslide hazards. Consideration of a similar performance standard and/or assessment criteria relating to other services including septic tanks, water mains and sewer lines may be appropriate.

17.2.3.5 Assessment Criteria and Information Requirements

Appropriate assessment criteria should be included in the District Plan to make it clear what factors will be considered when assessing resource consents for subdivision and land use. The GNS Science guidelines recommend that assessment criteria may include:

- Risk to life, property and the environment posed by a natural hazard;
- Likely frequency and size of landslide movement;
- Type, scale and distribution of any potential effects from the natural hazard;
- Degree to which the building, structural or design work to be undertaken can avoid or mitigate the effects of a landslide or slope instability; and
- Accuracy and reliability of any engineering and geotechnical information.

Section 3.11.10 of the Whakatane District Plan includes assessment criteria for Discretionary Activities relating to natural hazards. The criteria are prescriptive with regard to inundation, coastal hazards and high risk fire areas, but only provide general criteria in respect of landslide hazards. Additional criteria may enhance providing certainty to applicants about what needs to be addressed, and also may assist in the consistent processing of resource consent applications for sites subject to landslide hazards.

With regard to information requirements, the GNS Science guidelines recommend that an AEE should:

- Identify natural hazards (in this case, landslides);
- Provide a risk analysis;
- Consider alternatives;
- Show mitigation measures; and
- Determine residual risk with appropriate mitigation if required.

Section 3.4.2 of the District Plan states the information requirements for resource consent application. These include the requirement for a report from a certified geotechnical engineer in areas subject to falling debris. The geotechnical report is required to detail the effects of proposed building development on the stability of escarpments and the means of avoiding or mitigating potential adverse effects from slips or rockfalls, including, if necessary, alternative locations for buildings, and alternative building design features. This requirement is generally consistent with the GNS Science guidelines.

17.2.3.6 Non-Regulatory Methods

The District Plan does not currently identify any non-regulatory methods for addressing landslide hazards. Methods utilised in other districts, including those addressed in Section 3 of this report, may be considered in the District Plan review. These include the use of publicity material to enhance community understanding of hazards, the use of structure plans (e.g. Grandvista Estate, Dunedin) to provide more detailed information of landslide hazards in key growth areas, and considering land stability during planning, design and construction of Council services (e.g. Tauranga District Plan). Christchurch City has also communicated the landslide and falling debris hazard identified following the earthquakes. Information has been mapped and made accessible to the public.

The GNS Science guidelines also provide the following additional suggestions for consideration:

- Acquiring or purchasing at-risk land for passive recreational purposes;
- Exchanging at-risk land with land more suitable for the purpose;
- Allowing greater development rights on other land if at-risk land is retired or covenanted;
- Providing for at-risk land to form part of the reserves contribution as a condition of subdivision consent;
- Using financial incentives (for example, rates relief for at-risk land if it is not developed); and
- Promoting and helping fund the use of covenants (privately or through the QEII National Trust) for voluntary protection from development of open space on private land.

17.2.3.7 Plan Monitoring

The Whakatane District Plan includes more restrictive monitoring against the anticipated environmental outcomes than the District Plans reviewed in Section 17.2.2, including the requirement for an annual report on the type of development consents granted or refused in known hazard areas, and revising District Plan requirements if identified that the objectives are not being met.

The GNS Science guidelines suggest that outcomes can be measured by looking at:

- Number of buildings being built on or adjacent to landslide-prone land;
- Type of buildings being constructed and their intended use;
- Land subject to landslide activity being set aside/purchased; and
- The level of awareness of the community and their acceptance of risk-based plan provisions.

The existing District Plan monitoring requirements could be strengthened to include the above recommendations.

17.2.4 Summary

The Whakatane District Plan generally has stronger provisions relating to landslide hazards than the other District Plans reviewed which address similar issues. Rules require resource consents for mapped landslide hazard zones at the Whakatane and Ohope escarpments, and also for any site subject to falling debris hazard.

17.3 Approach of Selected Australian Councils

This section provides a discussion of the approaches taken by two Australian councils in response to national guidelines. The discussion identifies whether any alternative methods adopted in Australia can be applied in the New Zealand context.

17.3.1 Introduction

Guidelines, commentaries and practice notes for the management of landslide risk were published in 2007 by the Australian Geomechanics Society as a response to an earlier technical paper "*Landslide Risk Management Concepts and Guidelines*" (AGS, 2000).

A number of Australian councils have adopted AGS (2000) into their Development Control Plans (DCP), which are the Australian equivalent of District Plans in New Zealand. A significant driver for the adoption of these voluntary guidelines was a recommendation in the report of the Coroner's Inquiry into the 1997 Thredbo landslide that AGS (2000) be taken into account when assessing and planning urban communities in hillside environments. The Coroner's Inquiry report recommended that this would be achieved through directions in the Building Code of Australia and local codes dealing with planning, development and building approval procedures.

The Pittwater and Manly Councils are located within the greater Sydney area of New South Wales (NSW). Both Councils face issues regarding management of landslide risk, and have included management approaches based on AGS (2000) into their DCPs. The following sections provide a summary of the approaches to landslide risk management adopted by these two councils.

17.3.2 Pittwater Council, NSW

Pittwater Shire occupies the peninsula area of the Northern Beaches of Sydney. The occurrence of landslides and rock falls on the northern beach suburbs has been recognised since the 1970's when a number of homes were damaged or destroyed by landslides (MacGregor *et al*, 2007). The Pittwater Council administers the Pittwater Local Government Area (LGA).

Pittwater Council has adopted a Geotechnical Risk Management Policy for landslides based on the principles of AGS (2007). Landslide risk is controlled primarily through the requirement of geotechnical reports for any development located within defined and mapped hazard zones. These zones indicate the annual probability of a landslide event occurring. The GRMP states the absolute Loss of Life and Property Loss values to be adopted in geotechnical risk assessments. Technical studies have been undertaken to provide event frequency parameters to those applicants undertaking geotechnical risk assessments as part of a proposed development. Further information is provided in the following sections.

17.3.2.1 Development Control Plan - Pittwater 21 DCP

The Development Control Plan for Pittwater is known as Pittwater 21 DCP. It is a strategic document used to *"guide the sustainable management, development, and conservation of Pittwater"*. Section B3.1 relates specifically to the control of landslide hazard[8], requiring development to remove risk to an acceptable level, and to ensure the level of risk for any people, assets and infrastructure in the vicinity due to geotechnical hazards is not increased. The DCP refers to a Geotechnical Risk Management Policy (GRMP) prepared for the district.

17.3.2.2 Geotechnical Risk Management Policy

The current Pittwater GRMP has been in operation since September 2009 and forms Appendix 5 of Pittwater 21 DCP. The GRMP is based around the AGS Landslide Risk Management Guidelines (AGS, 2007). The objective to the GRMP is to ensure development is undertaken in accordance with defined levels of acceptable risk for loss of property and loss of human life over a design project life (taken to be 100 years). This is achieved through mapping land as subject to geotechnical hazards, and requiring geotechnical reports submitted with development applications on these sites to address the risk in accordance with AGS 2007.

The land to which the GRMP and associated development controls are applied is identified on the Pittwater 21 DCP map reproduced below as Figure 17.2. This map identifies, but does not define, Landslide Hazard zones H1 and H2 as a property level. A total of some 10,000 properties are identified as being located within GRHZ H1 and H2 and, therefore, potentially affected by landslide risk.

Policies included within the GRMP which, therefore, apply to any development within the Landslide Hazard zones are similar to those adopted in the New Zealand context as discussed above. They include:

- Geotechnical and related structural matters to be adequately investigated and documented by applicants prior to planning or building consents being lodged;
- Should the activity only meet the acceptable risk criteria through implementation of geotechnical conditions, these should form part of the application;
- Ongoing requirements to maintain the integrity of the geotechnical solution as contained in consent are effectively carried out to the specified requirements for the life of the development;
- If the acceptable risk criteria cannot be met through geotechnical mitigation, then the development should not proceed.

The key difference between the Pittwater GRMP and the New Zealand examples reviewed is the inclusion of a statement of the Acceptable Risk, i.e. the absolute loss of life and property loss values to be adopted in geotechnical risk assessments. For example:

> *" the risk to life and the risk to property, both must be considered. The guidance for the establishment of acceptable risk criteria for this Policy has been based on the contents of AGS 2007 (c & d). Acceptable risk for Loss of Life for the person(s) most at risk, per annum is taken as having a probability of 10^{-6} per annum. Acceptable Risk for Loss of Property is taken as "Low", as defined by AGS 2007."*
>
> *"Risk Levels for both loss of life and property should be determined in accordance with the methodologies presented in AGS 2007(c). Risk of loss of life should be determined*

[8] Where "landslip" is used rather than "landslide", this is to reflect the terminology in the original document.

quantitatively. Risk of loss of property can be determined quantitatively or in accordance with the qualitative terminologies and matrices presented in AGS 2007(c)."

17.3.2.3 Hazard Maps

The geotechnical hazards have been zoned based on their assessed 'likelihood' of occurrence at each hazard location. The zoning is based on the qualitative parameters in Table 17.3. These are the same qualitative measures of likelihood defined by AGS 2007 for assessing risk to property. The hazard notations do not address either property risk (based on proportional damage to the property) or Loss of Life Risk which is based on the calculated annual probability of death of the person most at risk in the zone.

The map showing the land affected by the geotechnical hazard zones (Figure 17.2) does not distinguish between hazard classifications H1 and H2 and the colours assigned to these zones in the definition document (red and yellow respectively) are replaced by green, presumably so that the map does not appear to be alarmist. A search facility on the council website can be used to identify the relevant zoning for any given address.

Table 17.3: Qualitative Measures of Likelihood of Instability Occurring (Pittwater 21 DCP)

Level	Descriptor	Description	Indicative Annual Probability
A	Almost certain	The event is expected to occur over the design life	10^{-1}
B	Likely	The event will probably occur under adverse conditions over the design life	10^{-2}
C	Possible	The event could occur under adverse conditions over the design life	10^{-3}
D	Unlikely	The event might occur under adverse conditions over the design life	10^{-4}
E	Rare	The event is conceivable but only under exceptional circumstances over the design life	10^{-5}
F	Barely Credible	The event is almost fanciful over the design life	10^{-6}

Geotechnical Hazard Zones, H1, H2 and H3 have been defined as follows:

HAZARD ZONE 1 (H1)*: Area where the likelihood of instability is assessed to be Level A, B or C (possible to almost certain) on Table [10.2]*

HAZARD ZONE 2 (H2)*: Area where the likelihood of instability occurring is assessed to be Level D (unlikely) on Table [10.2]*

HAZARD ZONE 3 (H3)*: Area where the likelihood of instability occurring is assessed to be Level E (rare) on Table [10.2][9].*

[9] Presumably H3 includes Level F, barely credible.

The mapping of hazards is therefore based on a transparent methodology which provides information to the landowner.

17.3.2.4 Property notices

In addition to the use of controls in the DCP, the Pittwater Council has placed a notation on the Section 149 Planning Certificates applying to those properties mapped as being affected by geotechnical risk i.e. GRHZ H1 and H2. This notation reads:

> *"Geotechnical Risk (Landslide hazard):*
>
> *The Council has adopted by resolution, on 20 July 2009, a policy that has the effect of restricting development of the land (subject to satisfying policy requirements) because of the potential impact from geotechnical hazards. The policy is entitled "Geotechnical Risk Management Policy for Pittwater – 2009. A copy of the policy can be obtained from the Council".*

This notice requires provides an additional notice to landowners and property purchasers of the legal obligation for an assessment of the likelihood of landslides to be prepared for proposed developments within the zone.

17.3.2.5 Supporting Technical Information

An assessment of the landslide likelihood in the Pittwater LGA was undertaken by MacGregor *et al* (2007). One of the aims of this work was to determine the annual probability of sliding to be used in the geotechnical risk assessments required by the GRMP. The landslide study was based on the development of a landslide inventory. The Pittwater landslide inventory lists 193 landslide events between 1972 and 2004. Of the recorded landslides, 13% were rock falls from coastal cliffs however only 3% were considered to be natural slope failures. A full 84% of landslides in the Pittwater LGA inventory occurred in cuts and fills and can therefore be considered to a large extent, man-made. Of the landslides in the inventory, 80% were less then 4m in height.

The scale of landsliding within the Pittwater LGA therefore appears to be significantly smaller than that occurring on the Whakatane and Ohope escarpments.

17.3.2.6 Summary

Pittwater Council has adopted a Geotechnical Risk Management Policy for landslides based on the principles of AGS (2007). Landslide risk is controlled primarily through the requirement of geotechnical reports for any development located within defined and mapped hazard zones. These zones indicate the annual probability of a landslide event occurring. The GRMP states the absolute loss of life and property loss values to be adopted in geotechnical risk assessments. Technical studies have been undertaken to provide event frequency parameters to those applicants undertaking geotechnical risk assessments as part of a proposed development.

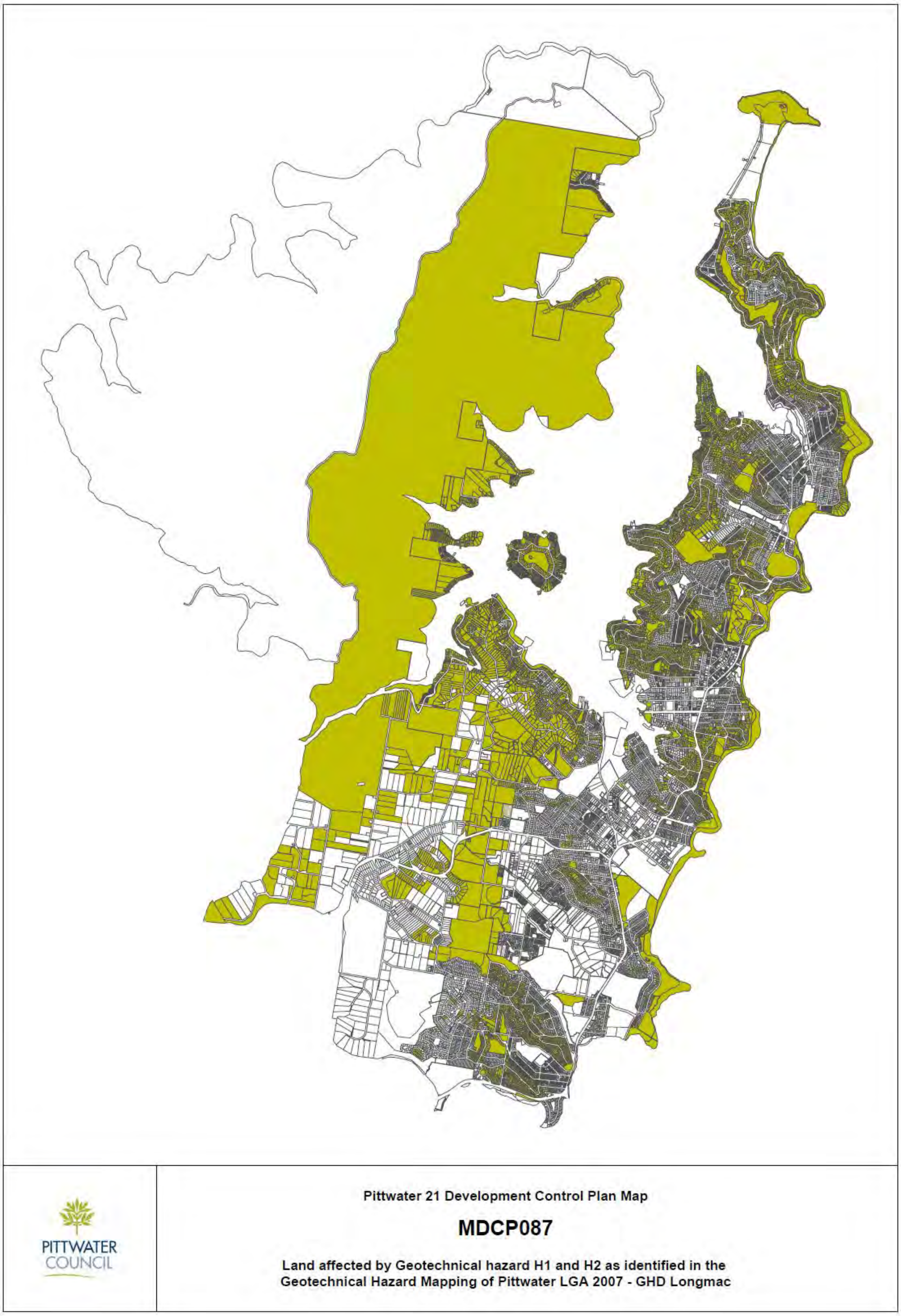

Figure 17.2: Geotechnical Risk Management Plan, Pittwater NSW. Pittwater Council

17.3.3 Manly Council (NSW)

17.3.3.1 Development Control Plan

Manly Council administers the Manly LGA located on the Northern Beaches of Sydney. Manly Council has a DCP specifically addressing Landslide and Subsidence. The DCP is designed to ensure that the Council and the Manly community are aware, and responds to all identified potential hazards as a result of landslide and subsidence. It is also intended to address the range of major risks to public safety, including risks to life, health, private and public property, the economy and the environment.

Issued in 2001 and updated in 2003, the Landslide and Subsidence DCP supplements the provisions of the Manly Local Environment Plan (1998). The document applies to all land in the Manly Council LGA, as indicated on a map reproduced below as Figure 17.3. The geotechnical zoning map was prepared by Coffey Geosciences Pty Ltd.

The aim of the DCP is to provide a framework for identification, assessment, treatment and monitoring of landslide and subsidence risk. It is also intended to guide the Council to properly assess any proposed Development Application.

The objectives of the DCP are to:

- *"to ensure that Council and the community is aware, and responds appropriately to all identified potential landslide & subsidence hazards;*
- *to provide a framework for identification, analysis, assessment, treatment and monitoring of landslip and subsidence risk;*
- *to outline the procedure to be followed when Council is considering applications for the development of land which may be subject to slope instability;*
- *to ensure that there is sufficient information to determine development applications for such land;*
- *to encourage development and construction which is compatible with the landslip hazard;*
- *to reduce the risk and costs of landslip and subsidence to existing areas;*
- *to inform the community of landslip hazards and amelioration techniques".*

These are generally consistent with the types of objectives encountered in the New Zealand district plans review earlier in this chapter.

17.3.3.2 Planning Map

The geotechnical zoning map identifies four Geotechnical Zones (A to D) that have been defined entirely on slope gradient:

Zone A: Ridge crests, major spur slopes and dissected plateau areas: slope angle <15°, Geotechnical assessment may be required

Zone B: Flanking slopes; 15° to 25°; Council assessment may be required

Zone C: Steeper slopes, generally near coastal or harbourside areas; >25°; Geotechnical assessment is required

Zone D: Beach foredune and alluvial flats; <5°; Should follow good engineering practice

It is notable that the only zoning presented in the DCP is based on slope angle. The Geotechnical Hazards plan is in fact a Susceptibility Zoning plan according to the definitions of AGS (2007). In contrast, Pittwater 21 DCP provides a true hazard map. The geotechnical “hazard” map is supplemented with tables containing:

- Potential geotechnical hazards and the typical consequences of failure are presented for each zone;
- Geotechnical implications on development and Council requirements;
- The requirements of a geotechnical assessment as well as Council requirements for applications.

17.3.3.3 Geotechnical Reports

Manly Council requires applicants to submit a geotechnical report for any land which has been identified as being at risk of landslide or subsidence. The geotechnical report is required to assess the risk of slope instability in accordance with AGS (2000). It is not clear whether the geotechnical report should follow AGS (2007) rather than AGS (2000), although it is assumed that it would. The geotechnical report is also required to nominate appropriate constraints to be placed upon development and recommendations for structural or civil engineers to provide appropriate design.

17.3.3.4 Summary

Manly has a specific DCP to address landslide and subsidence issues. The planning maps use gradient as a crude means to identify potential landslide and subsidence hazards. Reliance is placed on geotechnical reports to identify the level of risk and appropriate constraints. The Manly DCP provides little information or guidance on the levels of acceptable risk.

17.4 Discussion

Of the two Australian Councils evaluated, Pittwater Council had adopted the most rigorous approach to landslide risk management with the preparation of hazards maps and stated acceptable loss of life and property loss risk criteria in accordance with AGS (2007).

The approaches taken in the Australian examples are generally similar to those taken in the New Zealand district plans we reviewed. However, the inclusion of stated “Acceptable Risk Criteria” as policy in Pittwater was not encountered in the District Plans reviewed. This is most likely as acceptable levels of geotechnical risk are addressed through the Building Act 2004 rather than through the RMA. Discussion on more conservative levels of acceptable landslide risk in communities than provided for in the Building Act may be a relevant consideration for the Whakatane District Plan review. WDC may wish to consider including stated acceptable loss of life and property loss risk criteria as district plan policy for managing landslide risk. The benefits of this approach include ensuring consistency when assessing consent applications, providing certainty to applicants and geotechnical engineers over the level of risk that will be accepted through the resource consent process, education and public buy-in of the level of risk being accepted by the community.

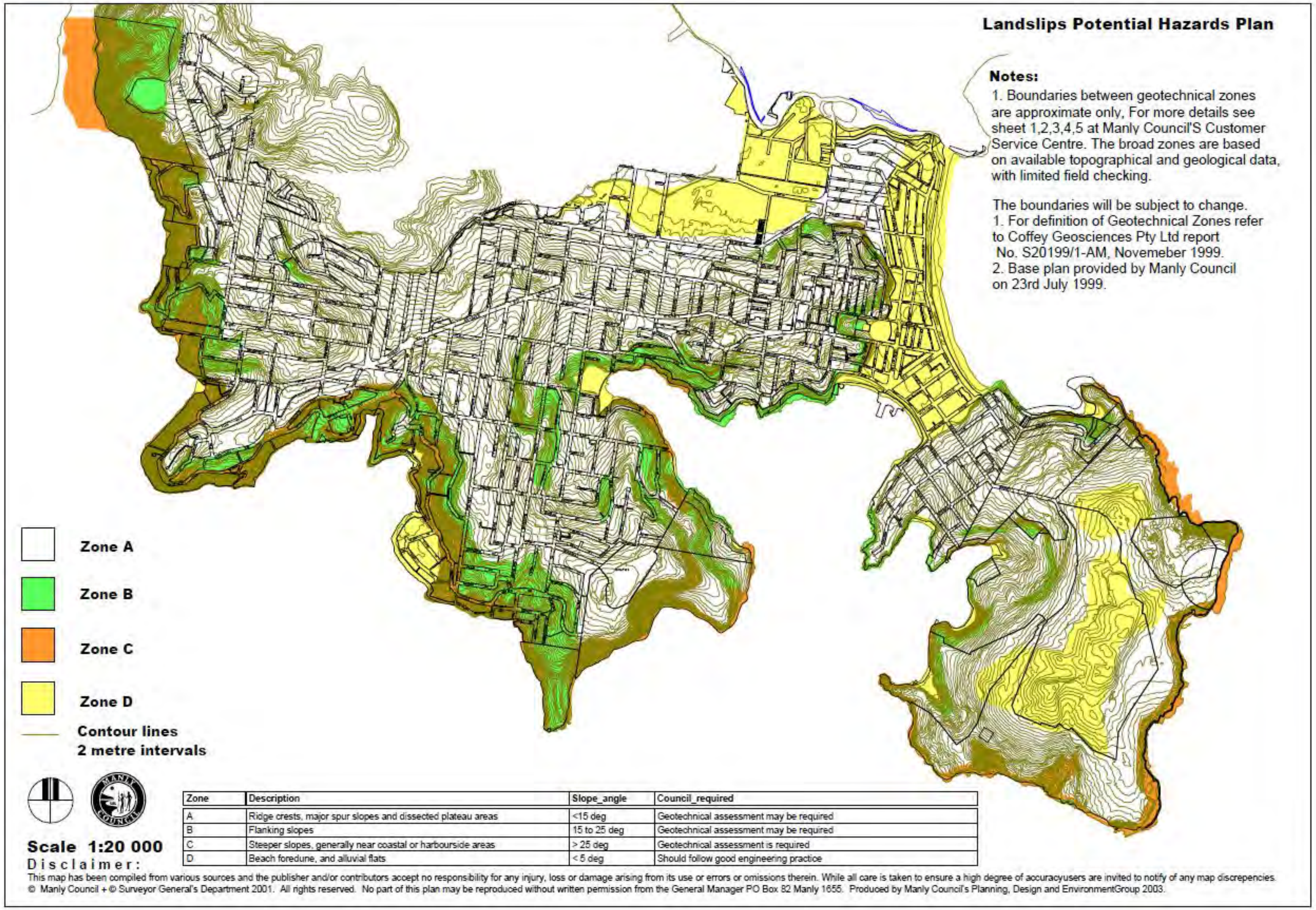

Figure 17.3: "Landslips Potential Hazards Plan" from Manly DCP for Landslip and Subsidence 2001, Manly Council

17.5 Conclusions and Suggestions

Based on the GNS Science guidelines, the strengths identified in the District Plans reviewed, and the review of two Australian examples, WDC may wish to consider the following recommendations as part of the WDP review:

- Enhance the existing planning maps to clearly show known information about landslide hazard areas. Consider categorising land with a landslide hazard from low to high. A publicly accessible GIS system may be appropriate, although we acknowledge that WDC has launched an online planning maps system for the draft District Plan (Section 4.2.1);
- Loss of life or property loss risk should not be mapped as the consequence of landsliding will be more site-specific than is the case for hazard. Risk calculations can be undertaken for individual properties or developments is required;
- Review the objectives and policies to ensure they are assisting the resource consent assessment process. Consider including a priority of avoiding effects on, and from, natural hazards where practical, before allowing for mitigation (Section 4.2.2);
- Permitted activity standards require assessment of the effects of, for example, falling debris flow on building sites, and the effects from storm-water discharges on landslide hazards. These provisions could be improved through greater use of mapping, requiring resource consents in for all works in areas of medium-high landslide risk rather than relying on compliance with permitted activity standards (Section 4.2.2 and Section 4.2.4);
- Consideration of a performance standard and/or assessment criteria relating to the effects from services including septic tanks, water mains and sewer lines on landslide hazards (Section 4.2.4);
- Consider additional, specific assessment criteria relating to landslide hazards (Section 4.2.5).
- Introduce appropriate non-regulatory methods, particularly with regard to education and informing resource users regarding known landslide and other natural hazard sites, and the systems in place to monitor these natural hazards (Section 4.2.6);
- Strengthen the District Plan monitoring requirements in relation to landslide hazards, and ensure internal funding is available to ensure monitoring is undertaken (Section 4.2.7); and
- Consider community discussion on the acceptable levels of landslide risk through the district plan review process, and include these as Acceptable Risk Criteria in district plan policy.

These are suggestions only and will require consideration as part of the Section 32 process when reviewing the District Plan.

18 Discussion and Conclusions

The steep escarpment slopes that form the backdrop to both Whakatane and Ohope have been subject to a number of significant landslide events between 2004 and 2011. There is strong evidence to indicate that both escarpments have been, and will continue to be, susceptible to significant future landsliding events.

In undertaking an assessment of landsliding on the Ohope Escarpment after the 2004 landslide event, T&T (2005) predicted that future landslides could damage or demolish houses located towards the base of the Ohope Escarpment and that there was a high risk of injury or death. This prediction has unfortunately proven accurate in light of the outcomes of the 2010-2011 landslides.

This quantitative landslide risk assessment has used both historic and recent data to develop a landslide inventory for the Whakatane and Ohope escarpments. It is apparent that the landslide hazard is both complex and widespread, although the reason for the landsliding is clear: steep slopes formed from very weak deposits that are highly susceptible to landslide generation during high intensity rainfall events. Numerous houses located at the base of the two escarpments are at risk of being impacted by voluminous and high velocity landslide debris. Dwellings located at the top of the escarpments are fewer in number, have a lower potential to be affected by landslide initiation and do not have the significant risk associated with inundation by high velocity debris.

The methodology published by AGS (2007) has been used to characterise the two escarpments is terms of landslide susceptibility, hazard and loss of life risk. The assessment has classified the majority of the two escarpments as having both high landslide susceptibility and hazard ratings. The estimated annual risk of death to residents or occupants of buildings located at the base of the escarpments is at least one order of magnitude greater than the value typically adopted by international authorities as being the tolerable level for natural landslides. There is currently no formal guidance from New Zealand authorities as to what level of risk can be considered acceptable, tolerable or intolerable/unacceptable.

Options for reducing the landslide hazard (i.e. the occurrence and frequency of landsliding) are limited. Engineered solutions are not realistic given the scale of the escarpments and the effectively random nature of the landslides. An increase in stormwater control on the Ohope Escarpment could provide a reduction in landslide frequency, however the combination of steep terrain and very weak geology present on the escarpments means that regardless of any drainage control measures implemented, landslides will nevertheless continue to periodically occur. It is unlikely that such measures could reduce landslide occurrence sufficiently for the risk to be reduced to a defined tolerable level. There is no identified opportunity to improve drainage on the Whakatane Escarpment.

Reducing the consequences of landsliding is likely to prove to be the most effective means of managing landslide risk on the two escarpments. This can be achieved by either the construction of engineered barriers at the base of the escarpments to catch debris or by ensuring that open ground is maintained at the base of each escarpment onto which landslide debris could deposit harmlessly. The former option will allow existing properties to remain but will potentially be expensive to implement. The latter will require numerous properties to be abandoned and clearly has high societal and financial implications. Land use restrictions could be placed on those properties that currently have sufficient open space to reduce impact risk to nominally tolerable levels.

The WDC will need to manage the identified landslide hazard and risk through provisions in the district plan. We consider the Whakatane District Plan to have stronger provisions relating to landslide hazards than most other New Zealand councils facing similar issues. No New Zealand Councils however have adopted a recognised method of managing landslides risk such as the AGS (2007) Landslide Risk Management Guidelines. Recommendations have been presented concerning the use of the hazard maps generated by this QLRA, a review the Councils objectives and policies, landowner education and District Plan monitoring requirements in relation to landslide hazards.

19 References

Australian Geomechanics Society. 2007. Landslide Risk Management. Australian Geomechanics, Vol. 42, No. 1 March 2007.

Australian National Committee on Large Dams. 2003. Guidelines on risk assessment.

Beetham, D. 2012. Ohope Beach landslide of June 2011. GNS Science Report 2011/46, 69p. Report dated March 2012.

Beetham, R.; Dellow, G.; Cousins, J.; Mouslopoulou, V.; Hoverd, J.; Gerstenberger, M.; Stephenson, B.; Davenport, P.; and Backer, P. 2004. Whakatane Microzoning Study. Institute of Geological and Nuclear Sciences Client Report 2004/18.

Edbrooke, S. W. 1977. The geology of the marine Castlecliffian strata in the Whakatane – Ohope Beach area, eastern Bay of Plenty. Unpublished M.Sc. thesis lodged in the University of Auckland library, Auckland.

Fleming, C. A. 1955. Castlecliffian fossils from Ohope Beach, Whakatane. New Zealand Journal of Science and Technology, B.36, pp 511-522.

GNS, 2012. Understanding life-safety risk concepts for rockfall and cliff collapse in the Port Hills. Summary Series 1/3.

Hancox, G.T.; Perrin, N. D. and Dellow, G. D. 1997. Earthquake-induced landsliding in New Zealand and implications for MM intensity and seismic hazard assessment. GNS Client Report 43601B, December 1997.

Healy, J.; Schofield, J. C. and Thompson, B. N. 1964. Sheet 5 Rotorua, Geological Map of New Zealand 1:250,000. DSIR, Wellington.

Hunter, G and Fell, R, 2003. Travel distance for “rapid” landslides in constructed and natural soil slopes. Can. Geotech. J. 40: 1123-1141.

Kear, D. 1997. Whakatane’s geological history. David Kear, Whakatane, New Zealand.

Kear, D. 2003a. Whakatane’s dynamic geology. David Kear, Whakatane, New Zealand.

Kear, D. 2006. Ohope – safe from the sea. David Kear, Whakatane, New Zealand.

Leonard, G. S.; Begg, J. G. and Wilson, C. J. N. 2010. Geology of the Rotorua area: scale 1:250,000 geological map 9. Lower Hutt: Institute of Geological & Nuclear Science Ltd. 99p + 1 folded map

MacGregor, P.; Walker, B.; Fell, R. and Leventhal, A. 2007. Assessment of landslide likelihood in the Pittwater Local Government Area. Australian Geomechanics Vol 42 No. 1. Pp183 – 196.

Massey, C. I.; McSaveney, M. J.; Yetton, M. D.; Heron, D.; Lukovic, B. and Bruce, Z.R.V. 2012. Canterbury earthquakes, 2010/11 Port Hills slope stability: pilot study for assessing life-safety risk from cliff collapse.

Paltridge, I. M. 1958. The Geology of the north-east part of Whakatane County. Unpublished M.Sc. thesis lodged in the University of Auckland Library, Auckland.

Perrin, N. D., 1999. Earthquake Hazards of the Bay of Plenty Region – Update to 1999. Institute of Geological and Nuclear Sciences Client Report 1999/116.

Riddolls & Grocott. 1999. Quantitative risk assessment methods for determining slope stability risk in the building industry. BRANZ Study Report No. 83.

Saunders, W. and Glassey, P. (Compilers). 2007. Guidelines for assessing planning, policy and consent requirements for landslide-prone land. GNS Science Miscellaneous Series 7.

Stirling, M, McVerry, G., Berryman, K., McGinty, P., Villamor, P., Van Dissen, R., Dowrick, D., Cousins, J. and Sutherland, R. 2000. Probabilistic seismic hazard assessment of New Zealand: New active fault data, seismicity data, attenuation relationships and methods. Geological and Nuclear Sciences Client Report 2000/3.

Taig, T. 2012. A risk framework for earthquake prone building policy. Report produced for the New Zealand Ministry of Business, Innovation and Employment.

Tonkin & Taylor. 2005. West End Escarpment geotechnical overview report. Report dated February 2005, prepared for Whakatane District Council.

Tonkin & Taylor. 2007. West End Beach cliff assessment. Letter report prepared for Whakatane District Council.

Tonkin & Taylor. 2007. Ohope West End Escarpment: geotechnical assessment of Ngati Awa farm block for future development. Letter report prepared for Whakatane District Council.

Tonkin & Taylor. 2010. Geotechnical advice for Whakatane District Council – Whakatane Escarpment. Letter report to Whakatane District Council dated 15 December 2010.

Tonkin & Taylor. 2011. Ohope Escarpment condition survey, No. 63 to 71 West End Road. Report prepared for Whakatane District Council.

Tonkin & Taylor. 2011. Geotechnical inspection of landslips, Muriwai Drive and Muriwai Terrace, Whakatane. Report prepared for Whakatane District Council.

Tonkin & Taylor. 2011. Review of proposed slope remediation, Ohope Road. Report prepared for Whakatane District Council dated August 2011.

United States Geological Survey, 2000. National landslide hazards mitigation strategy. Open File Report 00-450.

20 Applicability

This report has been prepared for the benefit of Whakatane 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.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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

DRAFT – NOT SIGNED

....	....
Kevin J. Hind	Nick Rogers
Engineering Geologist, Principal	Project Director

kjh

p:\28273\issueddocuments\rev2\whakatane & ohope qlra final draft_june_2013.docx