REPORT

Whakatane District Council

Supplementary Risk Assessment
Debris Flow Hazard
Matata, Bay of Plenty

Report prepared for:

Whakatane District Council

Report prepared by:

Tonkin & Taylor Ltd

Distribution:

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

July 2015

T&T Ref: 29115.2000

Table of contents

List of Figures

List of Tables

Executive summary

On 18 May 2005, the township of Matatā was impacted by large debris flows generated by intense rainfall within adjacent hill country. The largest and most destructive of these debris flows originated within the catchment of the Awatarariki Stream. In July 2013, Whakatane District Council (WDC) commissioned Tonkin & Taylor (T&T) to undertake a detailed risk assessment capable of identifying the magnitude of risk for individual properties, as well as the overall societal risk from debris flows originating within the Awatarariki Stream.

The assessment has been made primarily on the basis of detailed numerical modelling calibrated to the 2005 event. The results of the modelling has been used to prepare a series of maps that estimate the distribution of the debris flow intensity zones within the vicinity of the Awatarariki Stream for a range of events of different magnitude. The debris flow intensity estimates have in turn been used to estimate individual loss of life, societal loss of life and property loss risk values, both for the current property density and a possible future higher density scenario.

The results of the analyses are as follows:

- The area affected by the 18 May 2005 event is considered to be a high hazard zone;
- The individual loss of life risk for the Awatarariki fanhead west of the stream is typically 10^{-4} or greater except, for the few most distant properties;
- The individual loss of life risk east of the stream is significantly lower than the west, although some properties have risks of 10^{-4} or greater;
- Societal risks for much of the fanhead are significant, with cumulate risk being in excess of 10^{-3}.
- The risk estimates exceed those values commonly adopted as defining what an acceptable risk is. However, that being said, New Zealand currently does not have any established criteria for determining whether a particular risk is acceptable, tolerable or unacceptable.

This report supplements the broader scale risk assessment presented in T&T (2013b). This earlier report should be referred to for additional background information. A draft of this report was issued in November 2013 for public comment. Responses to the issues raised in the public consultation process are noted where relevant.

Definitions

Alluvium
A general name given to materials transported and deposited by streams and rivers.

Alluvial Fan
A fan or cone-shaped deposit of sediment built up by streams. Typically located at the point where a stream changes from a confined to unconfined condition.

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

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

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

Colluvium
A general term applied to any loose and heterogeneous mass of soil and rock fragments deposited by downslope creep and periodic movement by sheetwash etc. May occur as a layer parallel to the slope surface or a fan or cone at the base of slopes.

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 Fan
A fan or cone-shaped deposit of sediment built up by debris flows.

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.

Fanhead
The upslope higher-energy portion of an alluvial or debris fan where the coarsest material is deposited.

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 also 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 Detection and Ranging is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

Likelihood
Same as probability.

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

Person most at risk
The theoretical person who has the largest occupancy of a site

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

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

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

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

Quantitative
A type of information based in quantities.

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

Return Period
An estimate of the average time between occurrences of an event. It 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.

Runout
The furthest distance that landslide debris travels down-slope beyond its source. Particularly refers to the lateral distance that debris travels beyond the base of the slope on which the landslide occurred.

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.

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

On 18 May 2005, the township of Matatā was impacted by large debris flows generated by intense rainfall within adjacent hill country. The largest and most destructive of these debris flows originated within the catchment of the Awatarariki Stream. Following an extended period of options assessment, Whakatane District Council (WDC) decided in late 2012 not to proceed with an engineered solution to reduce the risk posed to occupants of the Awatarariki Stream fanhead from future debris flows. Other planning-based approaches are now being investigated.

In March 2013, WDC commissioned Tonkin & Taylor Ltd (T&T) to undertake a Quantitative Landslide Risk Assessment (QLRA) of the Matatā Escarpment. The purpose of the assessment, which was undertaken along the general lines of the QLRA previously undertaken for the Whakatāne and Ōhope Escarpments, was primarily to map the intensity and extent of the landslide and debris flow hazard within the vicinity of Matatā.

The study provided a broad assessment of the individual loss of life risks for potentially affected areas based primarily on observations made of the 2005 debris flow event, supported by the modelling principles and methodologies used for the Whakatāne and Ōhope escarpment project. The available information was not adequate to assess the risk to individual properties.

Following a review of the outcomes of the event-based assessment, and as a consequence of recognising that debris flow hazards have features distinct from those associated with more typical landslides, WDC determined that a supplementary assessment of the debris flow risk to property owners on the fanhead was merited. WDC subsequently commissioned T&T to undertake a detailed risk assessment capable of identifying the magnitude of risk for individual properties, as well as presenting for the first time, an assessment of overall societal risk. The supplementary risk assessment was prepared because of the complex nature and widespread impact of the debris flow hazard, and because individual owners were unlikely to have the capacity or capability to prepare such an assessment.

This report presents the results of the detailed risk-based assessment. It has been based largely on a series of detailed computer models developed through correlations with the 2005 debris flow event. This supplementary report presents only that information directly relevant to the completion of the detailed risk assessments. It is intended that the results presented here will be read in conjunction with T&T (2013b), which presents extensive background information which are not repeated here.

A draft of this report was issued in November 2013 for public comment. Responses to the issues raised in the public consultation process are noted where relevant.

2 Purpose and Scope of work

The purpose of the detailed quantitative debris flow risk assessment is to characterise the magnitude of loss of life risk across that area of Matatā that could potentially be affected by future debris flows emerging onto the fanhead of the Awatarariki Stream. The study does not consider debris flows originating in other streams exiting the Matatā Escarpment.

The scope of work defined by WDC in their briefing document to T&T was to provide a detailed and site-specific quantitative landslide (debris Flow) risk assessment report of the Awatarariki Stream fanhead at Matatā. The report reflects the variable levels of loss of life risk for individual properties on the Awatarariki fanhead as well as a brief commentary on the scale of property loss risk.

This study covers all areas of Matatā potentially affected by future debris flows generated within the catchment of the Awatarariki Stream (Figure 1, Appendix A) as determined by the modelling. As such, the entire township was included in the study, although the analyses identified those areas effectively outside of the Awatarariki debris flow hazard area.

A post 2005 debris flow event aerial photograph showing the property boundaries and major features of the fanhead as referred to in this report is presented as Figure 2.

3 Methodology

3.1 General

The broad-scale debris flow hazard and risk assessment presented in T&T (2013b) was based primarily on the observed and inferred effects of the 18 May 2005 debris flow event. Judgements were made as to what effects both larger and smaller future debris flows would have on the Awatarariki fanhead.

In order to develop a detailed understanding of potential impacts of future debris flows, it is necessary to assess in detail, a number of separate and interrelated factors, such as debris flow travel paths, flow thickness, flow velocity, boulder travel distance, impact forces etc. for a range of potential event magnitudes and recurrence intervals.

In order to do this, detailed numerical modelling of the fanhead was undertaken using the debris flow module of the software program RAMMS. This software was previously used by T&T to undertake analysis of the formerly proposed Awatarariki debris detention barrier (T&T, 2009b).

3.2 Debris Flow Modelling

3.2.1 Software

RAMMS (Rapid Mass Movement) is a “2D” numerical debris flow simulation program developed by the Swiss Federal institute for Forest, Snow and Landscape Research (WSL) and the Institute for Snow and Avalanche Research (SLF). RAMMS models the movement of debris flows over a 3D digital terrain, yielding runout distance, flow heights, flow velocities and impact pressure.

Information about RAMMS can be obtained from http://ramms.slf.ch/ramms/

The modelling is able to reflect the post-2005 changes in terrain on the fanhead as well as the effects of embankments etc.

3.2.2 Event initiation

Previous modelling undertaken by T&T (2009a) for the Awatarariki debris detention structure was used a beta version of RAMMS provided by WSL. One of the limitations of RAMMS at that time was that one or more landslides defined by GIS shape files needed to be initiated within the hills of the stream catchment in order to generate a debris flow of a particular volume. It was not possible to model a single debris flow event with multiple surges, nor to define specific flow characteristics (such as velocity or height) at any particular observation point.

The debris flow module used in the RAMMS modelling reported here allows the use of a hydrograph which defines the discharge (m^3/s) and duration (s) of the flow at a point along the flow path. Because of the significant influence that the former rail bridge appears to have had on the outcomes of the 18 May 2005 debris flow event, the back analysis was undertaken with the hydrograph position set immediately upstream of the bridge. All subsequent forward (i.e. predictive) analyses retained this same hydrograph position for the purpose of consistency.

The back analysis of the 18 May 2005 event and the forward analysis of a 300,000m^3 event were both undertaken using a 2 surge hydrograph based on the flow characteristics described in Section 4. This hydrograph is reproduced in Figure 3. This hydrograph was scaled to provide both smaller and larger volume events with broadly similar characteristics.

3.2.3 Event magnitude

Four debris flow events have been modelled: 50,000m^3, 150,000m^3, 300,000m^3 and 450,000m^3. The 300,000m^3 model is considered to be approximately the same magnitude as the 18 May 2005 event. These values represent the volume of the flows active within the Awatarariki Stream channel rather than the post-event deposits which tend to be somewhat smaller in volume.

3.2.4 Return period

The return period (or recurrence interval) of large debris flows of the type that impacted Matatā in 2005 are difficult to estimate. Based on previous assessments presented in T&T (2009a) and T&T (2009b), it is assumed that the 2005 event (i.e. also the 300,000m^3 forward analysis) had a return period of several hundred years. Given the range of possible return periods for the 2005 event, two values have been adopted as a means of assessing the sensitivity of the results to this parameter. These values are 200 years and 500 years respectively. Proportional ranges are also provided for smaller and larger magnitude design events. These values are presented in Table 3.1.

3.2.5 Flow parameters

Flow parameters were selected on the basis of the 2009 debris detention structure modelling (T&T, 2009a) as well as extensive additional back analyses undertaken for this study. The flow RAMMS flow parameters adopted for the Awatarariki Stream fanhead are as follows:

Flow density (ρ):	1700 kg/m3
Coulomb-type friction (μ):	0.02
Viscous-turbulent friction (Xi):	1500 m/s^2
Earth pressure coefficient (λ):	1.75

3.2.6 Modelling outputs

RAMMS models debris flows in a step-wise manner equivalent to the passage of time. Outputs include flow depth and flow velocity, either instantaneously or as maximum values. An example of the output is presented as Figure 4.

Because RAMMS models debris flows a single phase fluid, there is no distinction between the boulders which rapidly drop out of the thinning flow and the finer-grained component that is capable of travelling a considerably greater distance. It is critical however to be able to estimate those areas of the fanhead that may be impacted by the large boulders carried by the debris flow, as these are most likely to be associated with property damage and the potential for fatalities.

The potential for a debris flow to carry (or deposit) its boulder component is a function of both flow depth, flow velocity and density. The deeper and faster a debris flow travels, the greater is its capacity to carry large boulders. One means of representing the ability to transport boulders is the Debris Flow Intensity Index (I_{DF}) or Momentum Flux, which is defined as:

$$(I_{DF}) = dv^2$$

Where: d is flow depth and v is flow velocity. It can be seen from the form of the equation that the Intensity Index is related to kinetic energy and momentum.

It was possible by extracting depth and velocity data from RAMMS into a spreadsheet, to calculate I_{DF}. Importing the results into mapping software allowed the distribution of I_{DF} across the fanhead area. The mapping of I_{DF} across the fanhead for debris flows of different magnitudes provided a means of defining debris flow hazard zones. This is discussed further in Section 5.

3.3 The assessment of risk

3.3.1 Definition of risk

Risk is the product of hazard and consequence. It can be defined in terms of either risk to people or risk to property. When considering risk to people, there is often a distinction drawn between the risk to an individual (i.e. loss of life risk) and the risk to groups of people (i.e. societal risk). Definitions of these types of risk to people are as follows:

> *Loss of life risk is the frequency at which an individual may be expected to sustain a given level of harm from the occurrence of a specified hazard. It is usually reported as an annual probability for the "person most at risk" e.g. the person most at risk has a 1 in 10,000 chance (10^{-4}) per annum of being killed by the hazard;*
>
> *Societal risk expresses the relationship between the frequency of an event and the number of people suffering from a specific level of harm in a given population. It is usually reported as a set of related probabilities e.g. the annual probability that the hazard will result in 1 or more fatalities is 1 in 10,000 (10^{-4}), 10 or more fatalities is 1 in 100,000 (10^{-5}) and 100 or more fatalities is 1 in a million (10^{-6}).*

The risk to property (property loss risk) is also considered in some cases. This is usually reported either as a proportion of the structure (damage ratio e.g. 60%), relative level of damage or as a dollar value.

3.3.2 Individual Loss of Life Risk

Loss of life risk for a residential community from a debris flow hazard can be represented in the following form:

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

Where:

$R_{(LOL)}$	annual loss of life risk
$P_{(H)}$	annual probability of a debris flow occurring
$P_{(S:H)}$	probability of the debris flow impacting a particular location (i.e. spatial probability)
$P_{(T:S)}$	probability that someone is present at the impacted property (temporal spatial probability)
$V_{(D:T)}$	vulnerability of the individual to impact i.e. the probability of a fatality occurring given that an impact has occurred and a person is present

3.3.3 Societal risk

As described above, societal risk is a means of relating the likelihood of an event with the expected number of fatalities resulting from it. Societal risk is most commonly used where a large number of casualties could result from a single event e.g. dam burst.

The simplest method of estimating societal risk is to multiply the annual loss of life risk for an individual by the number of people expected to be present. This is commonly referred to as the Expected Value.

A more common way of representing societal risk is to calculate the number of deaths that can be expected for a range of events with different return periods or recurrence intervals. By cumulatively adding these risks from the largest to the smallest event, a Frequency – Number (F-N) relationship can be developed. By plotting the results of the calculations on established F-N charts, an assessment can be made as to whether the societal risk is acceptable, tolerable or unacceptable.

3.3.4 Property Loss Risk

Property loss can be expressed in a number of different ways. For the purpose of this report, it is expressed in a qualitative way as defined in Table 3.2.

Table 3.1: Assumed event magnitudes and return periods

Event No.	Magnitude	Return Period (years)
1	50,000m^3	50 - 100
2	150,000m^3	100 - 250
3	300,000m^3	200 - 500
4	450,000m^3	500 - 1000

Table 3.2: 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

4 A Review of Previous Debris Flow Events at Matatā

4.1 18 May 2005 Event

The 18 May 2005 event is moderately well documented, having being witnessed by a number of residents as well as being inspected by geologists and engineers from T&T and GNS Science[1] in the immediate aftermath of the disaster. A valuable record of observations was compiled by Dr the Hon Ian Shearer via a series of interviews conducted with residents who witnessed the event as it unfolded. Relevant extracts from Shearer (2005a) are presented in Appendix B.

Photographs of the aftermath of the 18 May 2005 event are presented in Appendix C to support the descriptions of the effects of the debris flows described within this report.

Based on aerial photograph interpretation, a debris distribution map has been prepared (Figure 5). From a consideration of the available information (provided in detail in previous T&T and GNS reports), we have assumed the following with respect to the 18 May 2005 event:

- The debris flow occurred in two main surges;
- The nature of the flow surges and the direction of travel of the debris was significantly affected by the blocking of the rail bridge by timber debris and by the presence of obstacles in the stream;
- The debris flows deposited some 250,000m^3 of debris on the fanhead with additional material lost to both the lagoon and ocean. A flow volume of 300,000m^3 has been assumed for the purposes of back analysis of the fanhead area;
- The rainfall that initiated the debris flows had a return period of between 200 to 500 years; and
- Flows across the upper fanhead reached depths in excess of 3m. Flows thinned rapidly as the debris moved away from the rail bridge.

A number of submissions from residents were received as a result of the draft version of this report being issued in November 2013. These reflected personal opinions on the extent of debris flow impact on a particular property during the 2005 event. These tended to be contradictory and of a small-enough scale that modifications the assessment were not justified.

4.2 Pre-2005 Events

Geomorphological evidence points to alluvial flood and debris flow events having formed the Awatararariki fanhead over the past several thousand years. Details supporting this, such as the presence of large boulders within the township as well as out at sea, have been presented in earlier T&T and GNS reports.

Shearer (2005b) undertook a review of historic flood events in and around Matatā. He lists 28 floods that have occurred in the eastern Bay of Plenty in the last 137 years, some of which are known to have affected Matatā. One event in 1869 destroyed a flour mill on what is presumed to be on the fan of Awatararariki Stream. It is thought that floods in 1906, 1939 and possibly 1950, may also have been associated with debris flows.

Mapping undertaken by both GNS and T&T indicates that low-angle alluvial/debris fans extend well out from the base of the Matatā Escarpment and beyond the area affected by the 18 May

[1] Then the Institute of Geological and Nuclear Sciences Limited

2005 event. The evidence for the presence of this material is subtle and may be related to lower-hazard alluvial processes rather than major debris flow events. Nevertheless, the presence of these deposits, together with other evidence, may suggest that debris flows larger than the 2005 event may have occurred in the distant past.

Based on the information available we conclude that:

- Large potentially destructive debris flows have previously occurred on the fanhead of the Awatarariki Stream, as well as other locations around Matatā;
- The 2005 debris flow event is expected to be classed as rare, with a return period of several hundred to a few thousand years rather than decades or many thousands of years;
- There is geomorphologic evidence of debris flows potentially much larger than the 18 May 2005 event having occurred previously; and
- There is some evidence for smaller debris flows and/or floods having affected the fanhead in approximately 50 year intervals.

5 Hazard Assessment

A necessary first step in the calculation of risk is the establishment of the underlying hazard. With respect to Matatā, this involves characterising the frequency, physical extent and intensity of past and future debris flows. This section presents the basis on which debris flow hazard zones were defined for the Awatarariki Stream fanhead.

5.1 General

The hazard associated with debris flows emerging from the catchment of the Awatarariki Stream is ultimately a function of distance from the point where debris flows emerge onto the fanhead from the narrow escarpment gulch located immediately upstream from the East Coast Main Trunk Railway bridge. There are two main reasons for this:

- The velocity and thickness of the debris reduces with distance as the flows spread out across the unconfined fanhead. This also directly reduces the ability of the debris flows to transport larger boulders and trees;
- The greater the distance a location is from the source of a debris flow, the larger and therefore less frequent any impacting event will be.

Modelling using RAMMS has shown that as debris flow volume increases, both the distance and area covered by the debris increases, but at an ever decreasing rate. An increase in event volume appears to result in a somewhat larger spatial extent accompanied by an increase in flow and deposit thickness.

5.2 Definition of hazard zones

In reviewing the effects of the 2005 event, it has been possible to identify a number of areas where the debris flows had relatively distinct impacts (Figure 5):

- Essentially complete destruction of property occurred within the inner zone of significant boulder and timber accumulation;
- Significant property damage occurred in the intermediate zone of abundant boulders and trees within a sand, silt and gravel matrix. Depending upon individual circumstances, some of the dwellings located within this area were able to be repaired whereas others required demolition and replacement;
- Repairable damage occurred within the outer zone dominated by the deposition of sand, silt and gravel.

As described in Section 3.2.6, a Debris Flow Intensity parameter (I_{DF}) has been adopted as an appropriate metric to map the reduction in the debris flow hazard across the fanhead as the flows thinned, slowed and deposited their coarser and most destructive components (Figure 6).

By comparing the I_{DF} contours from the RAMMS back analysis (Figure 7) with the depositional patterns observed from the 18 May 2005 event (Figure 5) it has been possible to match I_{DF} to the depositional patterns observed. Four intensity zones have been defined. These are described in Table 5.1 together with photographs of examples from 2005.

The results of the RAMMS modelling and back analysis has been used to prepare a series of maps that estimate the distribution of the debris flow intensity zones within the vicinity of the Awatarariki Stream. These modelling scenarios cover 50,000m^3 (Figure 8), 150,000m^3 (Figure 9), 300,000m^3 (Figure 10) and 450,000m^3 (Figure 11).

Table 5.1: Definition of Intensity Index (I_{DF}) zones

Intensity Zone	Intensity Index (I_{DF})	Debris Description	Description of Effects
1 Red	>15	Mass boulder passage and deposition. Abundant boulders of several metres in diameter with large trees. Deposits several metres thick, boulders commonly being clast supported (boulder to boulder contact)	Complete destruction of surface infrastructure and dwellings. Total loss of dwellings can be expected Impact force from 1m diameter boulder: 15 – 60 kN Impact pressure from flow: 20 – 200 kPa
2 Orange	15 - 5	Abundant boulders and trees within a matrix of sand silt and gravel. Boulders to several metres in diameter but typically less than 1m. Boulders are matrix supported	Severe to moderate effects depending on nature of structure and individual circumstances with respect to boulder impact. Total loss of some dwellings, significant to damage to others Impact force from 1m diameter boulder: 10 – 15 kN Impact pressure from flow: 5 – 20 kPa
3 Yellow	5 – 0.5	Predominantly sand, silt and gravel with occasional boulder, typically less than 0.5m in diameter, although occasional boulders up to 2m in diameter may enter this zone	Generally minor structural damage to dwellings but significant damage to furnishings etc from water and sediment inundation of lower storey. Some significant localised damage may result from isolated boulder impact Impact force from 1m diameter boulder: <10 kN Impact pressure from flow: <5 kPa
4 Blue	<0.5	Predominantly silt and sand-laden water (debris flood) with minor coarse material. No or rare boulders present	Generally insignificant structural damage but flood damage to lower storey Impact force from 1m diameter boulder: Not applicable Impact pressure from flow: <5 kPa

Examples of qualitative risk zone debris type and structural damage

			
Intensity Index Zone: 1 (Red) I_{DF} : > 15	Intensity Index Zone: 2 (Orange) I_{DF} : 5 - 15	Intensity Index Zone: 3 (Yellow) I_{DF} : 0.5 – 5.0	Intensity Index Zone: 4 (Blue) I_{DF} : 0.0 – 0.5

Each of the debris flow intensity zones can be used as a metric for the debris flow hazard, although the hazard effectively changes depending upon the magnitude of the event being considered. For the purposes of representing the overall debris flow hazard within the vicinity of the Awatarariki Stream fanhead, a single debris flow hazard map (Figure 12) has been developed based on the distribution of debris from the following events;

- High Hazard Zone: area impacted by a debris flow with half the volume of the 2005 event (i.e. 150,000m^3) or larger;
- Medium Hazard Zone: area impacted by a debris flow with the same volume as the 2005 event (i.e. 300,000m^3) or larger;
- Low Hazard Zone: area impacted by a very large (i.e. 450,000m^3)[2] but rare debris flow event.

This confirms the more general distribution of hazard zones presented in T&T (2013b).

[2] T&T (2013b) based the low hazard zone on an area affected by a debris flow twice the size of the 2005 event i.e. 600,000m^3. In this report the over-size event has been assumed to be 450,000m^3 as currently it is speculative to assume that the Awatarariki Stream catchment has the capability to generate a debris flow that is twice the volume of that seen in 2005.

6 Risk assessment

The concept of risk was introduced in Section 3.3. This section presents qualitative assessments of loss of life and property loss risk for those properties potentially at risk of being impacted by debris flows originating within the Awatarariki Stream.

6.1 Quantitative Loss of Life Risk

The quantitative loss of life risk i.e. the annual probability of the person most at risk being killed by a debris flow has been calculated for all areas across the Awatarariki Stream fanhead and beyond using the equation presented in Section 3.32. The calculations are presented in Table 6.1.

The process of the risk calculation is as follows:

- The same four debris flow event magnitudes used in the RAMMS modelling have been adopted for the loss of life risk calculations: 50,000m^3, 150,000m^3, 300,000m^3 and 450,000m^3;
- A shorter and longer return period was adopted for each event magnitude. This allowed the sensitivity of the results to the uncertainty around the return period of the debris flows to be assessed. The risk calculations have been undertaken for Case 1 where shorter return periods are assumed for the suite of design magnitude events and Case 2 where longer return periods are assumed for each debris flow magnitude;
- The fanhead is divided into six risk zones based upon the potential physical effects of debris flow impact. These risk zones are the same as the Intensity Index zones shown on Figures 8 to 11, although Zones 3 and 4 are both divided into sub-zones which represent areas inside and outside the main boulder field respectively. Each zone and subzone are identified on Table 6.1 with a unique cell colour;
- The probability of boulder impact ($P_{(S:H)}$) and the vulnerability of occupants of dwellings to such an impact ($V_{(D:T)}$) have been estimated based on observations made in 2005 as well as a consideration of the velocity and thickness of flows predicted by RAMMS. The values assigned to each risk zone are defined in Table 6.1 and their distribution across the fanhead are shown on Figure 13;

A common factor associated with each risk zone is an occupancy rate of 75% for the "person most at risk". This is consistent with the other risk assessments undertaken for the Whakatāne and Ōhope (T&T, 2013a) and Matatā escarpments (T&T, 2009b). An assumed occupancy greater than 75% would result in a corresponding increase in the calculated loss of life risk.

The loss of life risk at any particular location depends upon whether it can be impacted significantly by one or more of the events of different magnitude. The risks for each are cumulative. This is illustrated on Figure 14 where three hypothetical dwellings are shown at increasing distances from the apex of the fanhead. A dwelling located a significant distance from the apex will only be impacted significantly from larger volume – longer return period (low frequency) events, whereas a dwelling located near the apex of the fanhead can be affected not only by the large events but also from intermediate and low volume - short return period (higher frequency) events. The risk at any particular location is therefore a product of the complex interrelationship between location, event return period and debris travel distance.

Table 6.1: Design Loss of Life Risk Factors

Flow Intensity Zone	Boulder Impact Zone	Probability of structural impact $P_{(S:H)}$	Vulnerability ($V_{(D:T)}$)	Comments
1	Inside main boulder field	1.00 (100%)	0.75 (75%)	Certain to be impacted by mass boulders
2	Inside main boulder field	1.00 (100%)	0.20 (20%)	Certain to be impacted by mass boulders
3	Inside main boulder field	0.20 (20%)	0.05 (5%)	Risks associated with single boulders
3	Outside main boulder field	0.05 (5%)	0.05 (5%)	Risks associated with rare boulders
4	Inside main boulder field	0.10 (10%)	0.05 (5%)	Risks associated with rare single boulders
4	Outside main boulder field	0.01 (1%)	0.01 (1%)	Risks associated with very rare boulders

The loss of life risk calculated for each risk zone in Table 6.2 correspond to the equivalent spatial areas shown on Figures 8 to 11. The cumulative effect of having overlapping risks was assessed by overlapping each of the risk zones graphically to identify 22 zones with a unique combination of risk. These areas, together with the individual risk components that contribute to them, are presented in Table 6.1 as zone combinations A to J.

By summing the risk contributed by each magnitude event, contours of loss of life risk were able to be developed for both the shorter return period and longer return period event scenarios. The resulting loss of life risk contours for shorter and longer return periods are presented in Figures 15 and 16 respectively. As would be expected, the annual loss of life risk is somewhat higher for the shorter return period (i.e. more frequent) events than the longer return period (i.e. less frequent) events. The similarity in the two sets of results indicate however that the cumulative loss of life risk is not sensitive to the range of return periods assumed.

It is important to note that although the potential impacts of future debris flows can readily be estimated for the upper and central parts of the fanhead, such estimates become increasingly less reliable towards the boundaries of the potentially impacted areas.

Caution must be used when interpreting the level of risk for those properties located east of the Awatarariki Stream.

6.2 Quantitative Societal Risk

The level of societal risk depends upon the assumed population of the impacted area. For the case of Matatā, two scenarios have been modelled:

- A low density model in which the number of dwellings in the vicinity of the Awatarariki Stream does not increase above its current status;
- A higher density model in which dwellings are assumed to be present on those properties in the Clem Elliot Drive area that are currently undeveloped. The distribution of dwellings assumed in the calculations is shown on Figure 17. Based on discussions held at the time of the debris detention structure project it has been assumed that the majority of properties south of Clem Elliot Drive will not be developed.
- An occupancy of between 2 and 3 people per dwelling has been assumed (i.e. average of 2.5 persons per dwelling)

6.2.1 Expected Value

By overlying the individual loss of life risk contours shown on Figures 15 and 16 with the current and assumed residential density shown on Figure 17 and assuming an average dwelling occupancy of 2.5, the number of people potentially exposed to a certain level of individual loss of life risk can be estimated. The results for time periods of 50 and 100 years are presented in Table 6.3.

Table 6.2: Loss of Life Risk Calculation Matrix

Loss of Life Risk Calculations for Awatarariki Stream Fanhead

Definitions

$P_{(H)}$	Annual probability of debris flow event
$P_{(S:H)}$	Probability that the debris flow will impact the house
$P_{(T:S)}$	Probability that someone will be home
$V_{(D:T)}$	Probability that a fatality will result from a direct impact of the house or property

Legend

- Risk Zone 1 (Debris Flow Intensity Index >15)
- Risk Zone 2 (Debris Flow Intensity Index 5 -15)
- Risk Zone 3 (Debris Flow Intensity Index 0.5 -5) within boulder field
- Risk Zone 3 (Debris Flow Intensity Index 0.5 -5) beyond boulder field
- Risk Zone 4 (Debris Flow Intensity Index <0.5) within boulder field
- Risk Zone 4 (Debris Flow Intensity Index <0.5) beyond boulder field

Case 1: Shorter return period events assumed

Event Volume	Return Period (yrs)	Common Risk Factors		Risk Zone 1			Risk Zone 2			Risk Zone 3			Risk Zone 3			Risk Zone 4			Risk Zone 4		
		$P_{(H)}$	$P_{(T:S)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$
				$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$	
50,000m3	50	2.00E-02	7.50E-01	1.00E+00	7.50E-01	1.13E-02	1.00E+00	2.00E-01	3.00E-03	2.00E-01	5.00E-02	1.50E-04	5.00E-02	5.00E-02	2.11E-05	1.00E-01	5.00E-02	3.00E-06	1.00E-02	5.00E-02	3.75E-09
150,000m3	100	1.00E-02	7.50E-01	1.00E+00	7.50E-01	5.63E-03	1.00E+00	2.00E-01	1.50E-03	2.00E-01	5.00E-02	7.50E-05	5.00E-02	5.00E-02	1.05E-05	1.00E-01	5.00E-02	1.50E-06	1.00E-02	5.00E-02	1.88E-09
300,000m3	200	5.00E-03	7.50E-01	1.00E+00	7.50E-01	2.81E-03	1.00E+00	2.00E-01	7.50E-04	2.00E-01	5.00E-02	3.75E-05	5.00E-02	5.00E-02	9.38E-06	1.00E-01	5.00E-02	1.88E-05	1.00E-02	5.00E-02	1.25E-08
450,000m3	500	2.00E-03	7.50E-01	1.00E+00	7.50E-01	1.13E-03	1.00E+00	2.00E-01	3.00E-04	2.00E-01	5.00E-02	1.50E-05	5.00E-02	5.00E-02	2.11E-06	1.00E-01	5.00E-02	3.00E-07	1.00E-02	5.00E-02	3.75E-10

Case 2: Longer return period events assummed

Location	Return Period (yrs)	Common Risk Factors		Risk Zone 1			Risk Zone 2			Risk Zone 3			Risk Zone 3			Risk Zone 4			Risk Zone 4		
		$P_{(H)}$	$P_{(T:S)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$	Variable Risk Factors		$R_{(LoL)}$
				$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$		$P_{(S:H)}$	$V_{(D:T)}$	
50,000m3	100	1.00E-02	7.50E-01	1.00E+00	7.50E-01	5.63E-03	1.00E+00	2.00E-01	1.50E-03	2.00E-01	5.00E-02	7.50E-05	5.00E-02	5.00E-02	1.05E-05	1.00E-01	5.00E-02	1.50E-06	1.00E-02	5.00E-02	1.88E-09
150,000m3	250	4.00E-03	7.50E-01	1.00E+00	7.50E-01	2.25E-03	1.00E+00	2.00E-01	6.00E-04	2.00E-01	5.00E-02	3.00E-05	5.00E-02	5.00E-02	4.22E-06	1.00E-01	5.00E-02	6.00E-07	1.00E-02	5.00E-02	7.50E-10
300,000m3	500	2.00E-03	7.50E-01	1.00E+00	7.50E-01	1.13E-03	1.00E+00	2.00E-01	3.00E-04	2.00E-01	5.00E-02	1.50E-05	5.00E-02	5.00E-02	2.11E-06	1.00E-01	5.00E-02	7.50E-06	1.00E-02	5.00E-02	2.00E-09
450,000m3	1000	1.00E-03	7.50E-01	1.00E+00	7.50E-01	5.63E-04	1.00E+00	2.00E-01	1.50E-04	2.00E-01	5.00E-02	7.50E-06	5.00E-02	5.00E-02	1.05E-06	1.00E-01	5.00E-02	1.50E-07	1.00E-02	5.00E-02	1.88E-10

Distribution of Loss of Life Risk for shorter return period events

Zone Combination	450,000	300,000	150,000	50,000	Sum
A1	3.75E-10	1.25E-08	1.88E-09	3.75E-09	1.85E-08
A2	1.00E-07	1.88E-05	1.88E-09	3.75E-09	1.91E-05
B1	2.11E-06	9.38E-06	1.05E-05	3.75E-09	2.20E-05
B2	2.11E-06	9.38E-06	1.05E-05	2.11E-05	4.31E-05
C1	1.50E-05	9.38E-06	1.05E-05	3.75E-09	3.49E-05
C2	1.50E-05	9.38E-06	1.05E-05	2.11E-05	5.60E-05
D1	1.50E-05	3.75E-05	1.05E-05	3.75E-09	6.31E-05
D2	1.50E-05	3.75E-05	1.05E-05	2.11E-05	8.41E-05
D3	1.50E-05	3.75E-05	1.88E-09	3.75E-09	5.25E-05
D4	1.50E-05	3.75E-05	7.50E-05	2.11E-05	1.49E-04
D5	1.50E-05	3.75E-05	7.50E-05	1.50E-04	2.78E-04
E1	3.00E-04	3.75E-05	1.05E-05	3.75E-09	3.48E-04
E2	3.00E-04	3.75E-05	1.05E-05	2.11E-05	3.69E-04
F1	3.00E-04	7.50E-04	1.05E-05	2.11E-05	1.08E-03
F2	3.00E-04	7.50E-04	1.05E-05	2.11E-05	1.08E-03
F3	3.00E-04	7.50E-04	7.50E-05	2.11E-05	1.15E-03
G1	3.00E-04	7.50E-04	7.50E-05	3.75E-09	1.13E-03
G2	3.00E-04	7.50E-04	7.50E-05	1.50E-04	1.28E-03
H1	1.13E-03	1.13E-03	1.50E-03	1.50E-04	3.90E-03
H2	1.13E-03	7.50E-04	1.50E-03	1.50E-04	3.53E-03
I1	1.13E-03	1.13E-03	5.63E-03	3.00E-03	1.09E-02
J	1.13E-03	1.13E-03	5.63E-03	1.13E-02	1.91E-02

Distribution of Loss of Life Risk for longer return period events

Zone Combination	450,000	300,000	150,000	50,000	Sum
A1	1.88E-10	2.00E-09	7.50E-10	1.88E-09	4.81E-09
A2	1.50E-07	7.50E-06	7.50E-10	1.88E-09	7.65E-06
B1	1.05E-06	2.11E-06	4.22E-06	1.88E-09	7.38E-06
B2	1.05E-06	2.11E-06	4.22E-06	1.05E-05	1.79E-05
C1	7.50E-06	2.11E-06	4.22E-06	1.88E-09	1.38E-05
C2	7.50E-06	2.11E-06	4.22E-06	1.05E-05	2.44E-05
D1	7.50E-06	1.50E-05	4.22E-06	1.88E-09	2.67E-05
D2	7.50E-06	1.50E-05	4.22E-06	1.05E-05	3.73E-05
D3	7.50E-06	1.50E-05	7.50E-10	1.88E-09	2.25E-05
D4	7.50E-06	1.50E-05	3.00E-05	1.05E-05	6.30E-05
D5	7.50E-06	1.50E-05	3.00E-05	7.50E-05	1.28E-04
E1	1.50E-04	1.50E-05	4.22E-06	1.88E-09	1.69E-04
E2	1.50E-04	1.50E-05	4.22E-06	1.05E-05	1.80E-04
F1	1.50E-04	3.00E-04	4.22E-06	1.05E-05	4.65E-04
F2	1.50E-04	3.00E-04	4.22E-06	1.05E-05	4.65E-04
F3	1.50E-04	3.00E-04	3.00E-05	1.05E-05	4.91E-04
G1	1.50E-04	3.00E-04	3.00E-05	1.88E-09	4.80E-04
G2	1.50E-04	3.00E-04	3.00E-05	7.50E-05	5.55E-04
H1	5.63E-04	1.13E-03	6.00E-04	7.50E-05	2.36E-03
H2	5.63E-04	3.00E-04	6.00E-04	7.50E-05	1.54E-03
I1	5.63E-04	1.13E-03	2.25E-03	1.50E-03	5.44E-03
J	5.63E-04	1.13E-03	2.25E-03	5.63E-03	9.56E-03

Table 6.3: Societal Risk – Expected Value Analysis

Time Period (years)	Expected No. of Fatalities/Time Period	
	Current Population Density	Fully Developed Density
50	1	4
100	2	8

6.2.2 F-N Curve

The usual means of representing societal risk is through the development of a Frequency – Number (F-N) curve, which relates the number of expected fatalities with the return period of the relevant hazard. Societal risk calculations for the current and assumed increased residential density are presented in Tables 6.4 and 6.5 respectively.

The analyses were restricted to I_{DF} Zones 1 and 2 only as the potential for fatalities to occur are realistically restricted to these areas. An average 24 hour occupancy of 75% has been adopted. By calculating the fatalities per annum expected from each magnitude event in each zone, it is possible to develop a cumulative frequency of risk that is the basis of the F-N Curve presented as Figure 18.

6.3 Property Loss Risk

The distribution of the various debris types based on I_{DF} have been developed from modelling for the 50,000m^3, 150,000m^3, 300,000m^3 and 450,000m^3 design events. These are shown on Figures 8, 9, 10 and 11 respectively. Although similar to the hazard map, these assessments include an element of consequence in their evaluation, hence they represent a qualitative or semi-quantitative measure of risk.

The meaning of the I_{DF} zones in terms of their debris type and potential damage is defined in Table 5.1, together with photographs of equivalent effects from 18 May 2005.

In summary, the effects of future debris flows on standard dwellings are expected to be as follows:

- Zone 1: Complete destruction of property from passage of the main boulder front;
- Zone 2: Severe to moderate structural damage depending upon the number of strikes from individual boulders that extend beyond the main boulder front;
- Zone 3: Generally minor structural damage, with impacts from individual boulders possible. Most property damage is from silt and sand-laden water;
- Zone 4: Generally insignificant damage unless one of the relatively few boulders than makes it this far happens to impact the dwelling. The probability of such an impact is much greater inside the main boulder field. Most property damage is from silt and sand-laden water.

Note that these expected effects do not apply to any dwelling (or other structure) constructed specifically to resist the effects of debris flow impact.

An estimate of property loss risk has been made based on the debris flow intensity I_{DF} and the terminology used in Table 5.1. The property loss risk is presented in Figure 19.

Table 6.4: Societal risk calculations – current residential density

Event Magnitude	No. of Houses			Occupants			Vulnerability		No. Fatalities		Assumed average occupancy	Total No. Fatalities
	Risk Zone 1	Risk Zone 2	Total	Risk Zone 1	Risk Zone 2	Total	Risk Zone 1	Risk Zone 2	Risk Zone 1	Risk Zone 2		
50,000m^3	0	0	0	0	0	0	0.75	0.2	0.0	0	0.75	0.0
150,000m^3	0	4	4	0	10	10	0.75	0.2	0.0	0.8	0.75	0.6
300,000m^3	3	5	8	7.5	12.5	20	0.75	0.2	5.6	1	0.75	5.0
450,000m^3	3	8	11	7.5	20	27.5	0.75	0.2	5.6	1.6	0.75	5.4

Event Magnitude	Return Period (yrs)	$P_{(H)}$	No. of houses in Risk Zones 1 and 2	No. of people present	Estimated fatalities (N)	% of total residents killed	Fatalities per year
50,000m^3	100	1.00E-02	0	0.0	0.0	0.0	0.00E+00
150,000m^3	250	4.00E-03	4	10.0	0.6	2.2	2.40E-03
300,000m^3	500	2.00E-03	8	20.0	5.0	18.1	9.94E-03
450,000m^3	1000	1.00E-03	11	27.5	5.4	19.7	5.42E-03
		Total of suburb	11	27.5			

F-N Curve

Event Magnitude	Return Period (yrs)	$P_{(H)}$	Estimated fatalities (N)	Cumulative Frequency
450,000m^3	1000	1.00E-03	5.4	1.00E-03
300,000m^3	500	2.00E-03	5.0	3.00E-03
150,000m^3	250	4.00E-03	0.6	7.00E-03
50,000m^3	100	1.00E-02	0.0	1.70E-02

Note: Societal Risk Zones 1 and 2 are equivalent to the Debris Flow Intensity Zones 1 and 2 defined in Table 5.1. Zones 1 and 2 are represented by the pink and orange areas on Figure 17 respectively. It is assumed that fatalities do not occur within the lower I_{DF} zones 3 and 4.

Table 6.5: Societal risk calculations – increased residential density

Event Magnitude	No. of Houses			Occupants			Vulnerability		No. Fatalities		Assumed average occupancy	Total No. Fatalities
	Risk Zone 1	Risk Zone 2	Total	Risk Zone 1	Risk Zone 2	Total	Risk Zone 1	Risk Zone 2	Risk Zone 1	Risk Zone 2		
50,000m^3	1	2	3	2.5	5	7.5	0.75	0.2	1.9	0.4	0.75	1.7
150,000m^3	2	6	8	5	15	20	0.75	0.2	3.8	1.2	0.75	3.7
300,000m^3	4	15	19	10	37.5	47.5	0.75	0.2	7.5	3	0.75	7.9
450,000m^3	5	19	24	12.5	47.5	60	0.75	0.2	9.4	3.8	0.75	9.9

Event Magnitude	Return Period (yrs)	$P_{(H)}$	No. of houses in Risk Zones 1 and 2	No. of people present	Estimated fatalities (N)	% of total residents killed	Fatalities per year
50,000m^3	100	1.00E-02	3	7.5	1.7	2.5	1.71E-02
150,000m^3	250	4.00E-03	8	20.0	3.7	5.5	1.49E-02
300,000m^3	500	2.00E-03	19	47.5	7.9	11.7	1.58E-02
450,000m^3	1000	1.00E-03	24	60.0	9.9	14.6	9.88E-03
		Total of suburb	27	67.5			

F-N Curve

Event Magnitude	Return Period (yrs)	$P_{(H)}$	Estimated fatalities (N)	Cumulative Frequency
450,000m^3	1000	1.00E-03	9.9	1.00E-03
300,000m^3	500	2.00E-03	7.9	3.00E-03
150,000m^3	250	4.00E-03	3.7	7.00E-03
50,000m^3	100	1.00E-02	1.7	1.70E-02

Note: Societal Risk Zones 1 and 2 are equivalent to the Debris Flow Intensity Zones 1 and 2 defined in Table 5.1. Zones 1 and 2 are represented by the pink and orange areas on Figure 17 respectively. It is assumed that fatalities do not occur within the lower I_{DF} zones 3 and 4.

7 Discussion and Conclusions

A quantitative risk assessment of the debris flow hazard in the vicinity of the Awatarariki Stream has been undertaken, based mainly on detailed numerical modelling, calibrated to observations made of the 2005 debris flow event. The results of the analysis are:

- The area affected by the 18 May 2005 event is considered to be a high hazard zone;
- The individual loss of life risk for the Awatarariki fanhead west of the stream is typically 10^{-4} or greater except, for the few most distant properties;
- The individual loss of life risk east of the stream is significantly lower than the west, which is consistent with the distribution of damage observed in 2005. Nevertheless some properties have risks of 10^{-4} or greater, with a larger number being 10^{-5} or 10^{-6}. The steep gradient of these eastern risk contours requires extreme caution to be used when interpreting the risk of individual properties in this area;
- Societal risks are significant with cumulate risk being in excess of 10^{-3}.

Whether these levels of individual or societal risk are acceptable or not is a vexed question, as different individuals, groups, communities and societies view these issues differently. The discussion below provides some background on the assessment of risk levels, however it is not the intent nor purpose of this study to determine what is, or is not, an acceptable risk. This is for others to decide.

7.1 Individual Loss of Life Risk

New Zealand does not have established criteria for determining whether a particular annual loss of life risk is acceptable, tolerable or unacceptable. Some movement to defining or adopting such terminology has recently been made in Christchurch with respect to the boulder roll and cliff collapse risk associated with the recent earthquake events. Nevertheless, these are still not adopted as criteria elsewhere.

A number of overseas government and non-government organisations have published what they consider to be reasonable interpretations of these limits with 10^{-4} to 10^{-5}/annum typically be adopted as the limit for acceptable risk for the person most at risk.

If such commonly adopted criteria were also to be adopted at Matata, significant parts of the fanhead would be considered to have an unacceptable level of risk, especially the part west of the stream (Clem Elliot Drive area)

How this compares to other hazards in New Zealand can be gauged from Figure 20.

7.2 Societal Risk

Similarly with societal risk, a number of different agencies have defined acceptable, tolerable (if reduced as low as reasonably practicable) and unacceptable based on Frequency-Number charts. This report does not consider one to be better than the other. If however we plot our results on the F-N chart presented in the AGS (2007) we find that the societal risk for Debris Flow Intensity Zones 1 and 2 (which cover much of the fanhead – see Figure 17) lie in the unacceptable risk category for both the lower and higher residential density cases (Figure 18).

7.3 Property Loss Risk

The potential for future damage to property has been assessed based on calculated debris flow intensities. It is clear from both the numerical modelling and the observations made of the effects of the 2005 event, that significant property damage can be expected to occur for a range of debris flow event magnitudes. The most significant damage can be expected to occur west of the Awatarariki Stream, although, as was experience in 2005, some property loss can be expected to the east. The level of property loss can be expected to be very significant should the Clem Elliot Drive area be more developed than it currently is.

7.4 Further Assessments of Individual Properties

It is believed that RAMMS has provided a realistic means of evaluating the likely spatial extent of impact from future debris flows of varying magnitudes. Debris flows are however very complex in terms of their flow mechanisms and composition. Without some additional knowledge with respect to the volume and frequency of future debris flow events, we do not believe that additional numerical modelling would provide any additional information that could assist in the assessment of loss of life or property loss risk for individual properties within Matata.

RAMMS does offer the opportunity to model the effect of mitigation works such as deflection or detentions bunds (as was reported in T&T (2009)). However to be effect, such protection works will need to be suburb-wide, as our previous experience with the modelling of such structures has shown that property-specific defences are likely to be overwhelmed by the sheer volume of debris contained within debris flows of the type experienced in 2005. The construction of impact resistant structures may be a more productive avenue of design enquiry for individual properties.

8 References

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

Shearer, 2005a. *Matatā Recovery Project C – to collect information from Matatā residents describing their observations during the event*.

Shearer, 2005b. *Matatā Project D - to gather anecdotal and more formal historical records to identify and confirm previous significant flood events and land use practices in the catchments and confirm their effects on Matatā and the historical context of the recent event*.

Tonkin & Taylor 2009a. *Debris flow numerical modelling, Awatarariki Stream, Matatā*. Report to Whakatane District Council dated May 2009

Tonkin & Taylor, 2009b. *Debris Flow Control System, Awatarariki Stream, Matatā*. Report to Whakatane District Council dated June 2009.

Tonkin & Taylor, 2013b. *Quantitative Landslide Risk Assessment, Matatā Escarpment*. Report dated November 2013.

Tonkin & Taylor, 2013a. *Quantitative Landslide Risk Assessment, Whakatāne and Ōhope Escarpments*. Report dated November 2013

9 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

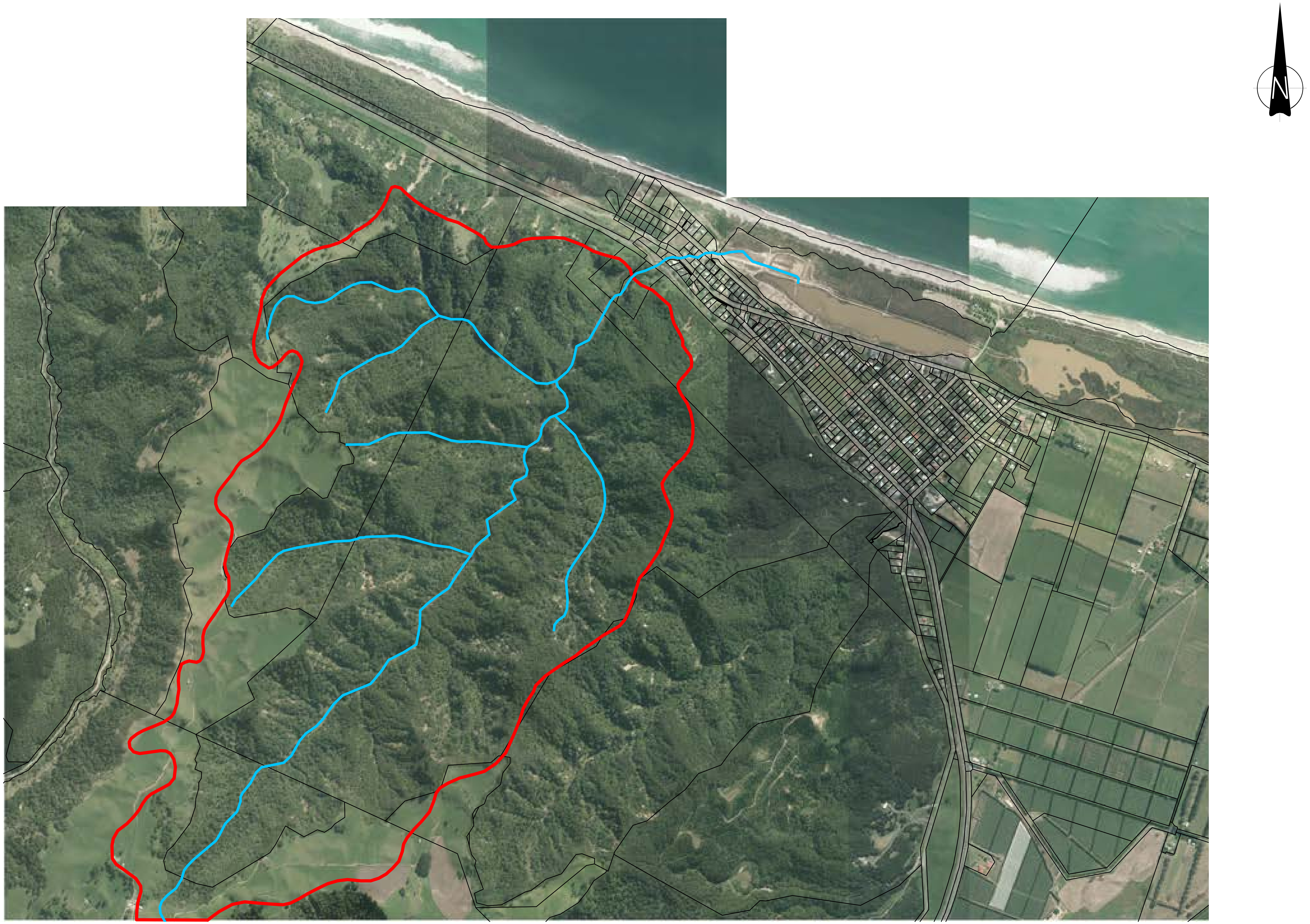
Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
	
....	....
Kevin J. Hind	Nick Rogers
Engineering Geologist	Project Director

kjh

p:\29115\29115.2000\workingmaterial\final report\kjh.supplimentary risk assessment for matata.final report july 2015.docx

Appendix A: Figures



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

A3 SCALE 1:15,000

0 160 320 480 640 800 (m)

Legend

Awatarariki Stream

Watershed Boundary

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15
ARCFILE	29115.1000-F1.mxd	
SCALE (AT A3 SIZE)	1:15,000	
PROJECT No.	29115.1000	

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Awatarariki Stream catchment and town of Matata

FIGURE No. Figure 1

Rev. 0

Path: L:\29115\29115.1000\Working Materials\GIS\MXD\201113\29115.1000-F1.mxd Date: 20/11/2013 Time: 8:13:54 a.m.

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

A3 SCALE 1:2,500

0 30 60 90 120 (m)

Legend

Creek

Awatarariki Stream

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15
ARCFILE 29115.1000-F2.mxd		
SCALE (AT A3 SIZE) 1:2,500		
PROJECT No. 29115.1000		

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Awatarariki Stream fanhead

FIGURE No. Figure 2

Rev. 0

Path: L:\29115\29115.100\Working Material\GIS\MXD\20131120\29115.1000-F2.mxd Date: 20/11/2013 Time: 9:16:44 a.m.

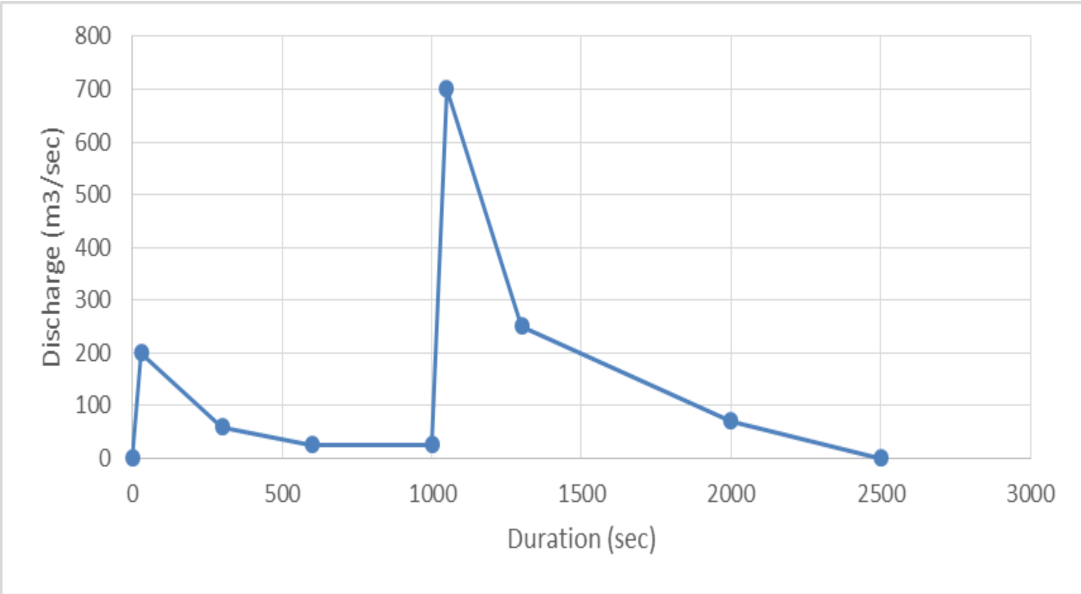


Figure 3: Debris flow hydrograph used to replicate the 2005 event (300,000m^3)

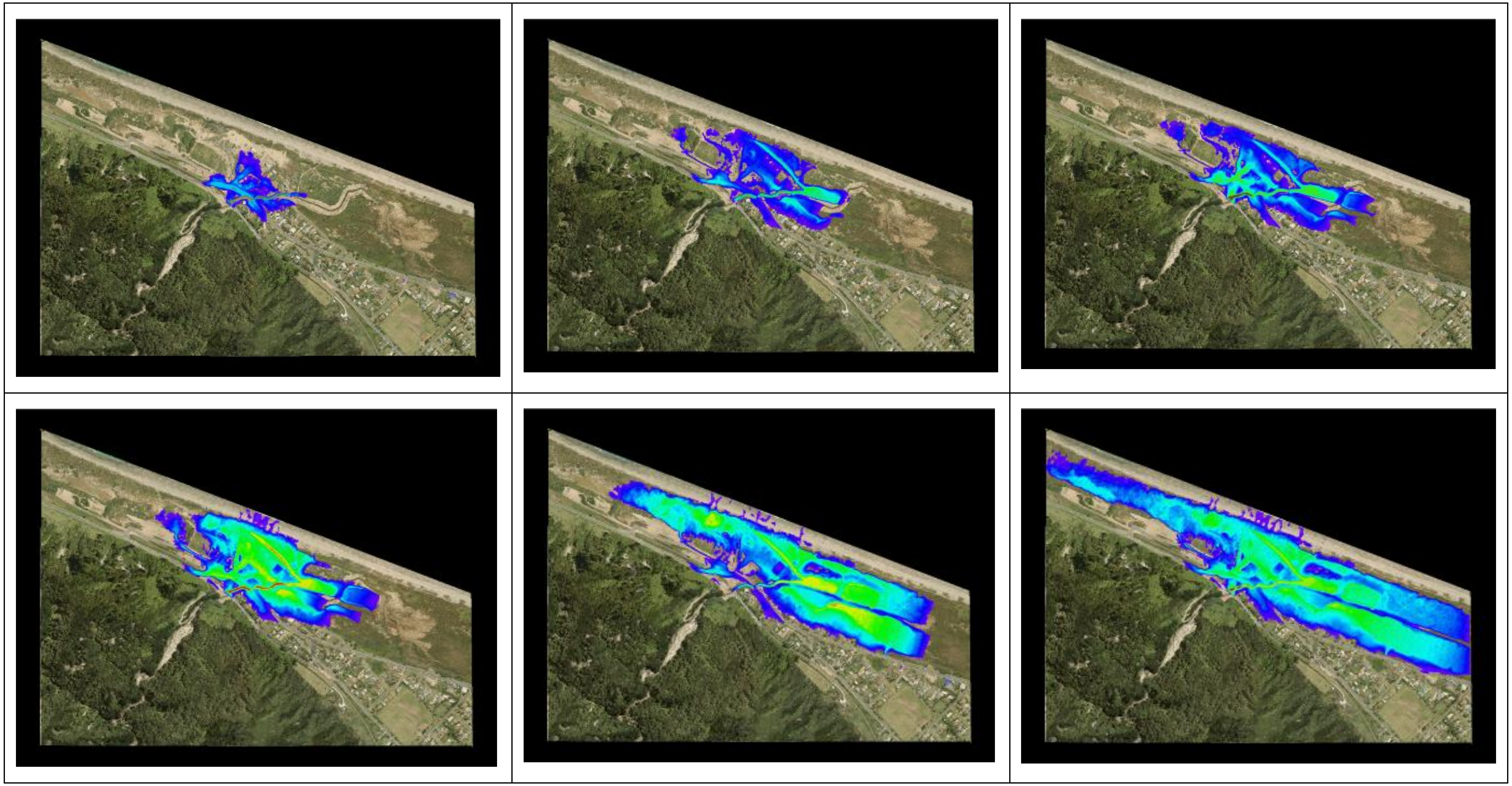
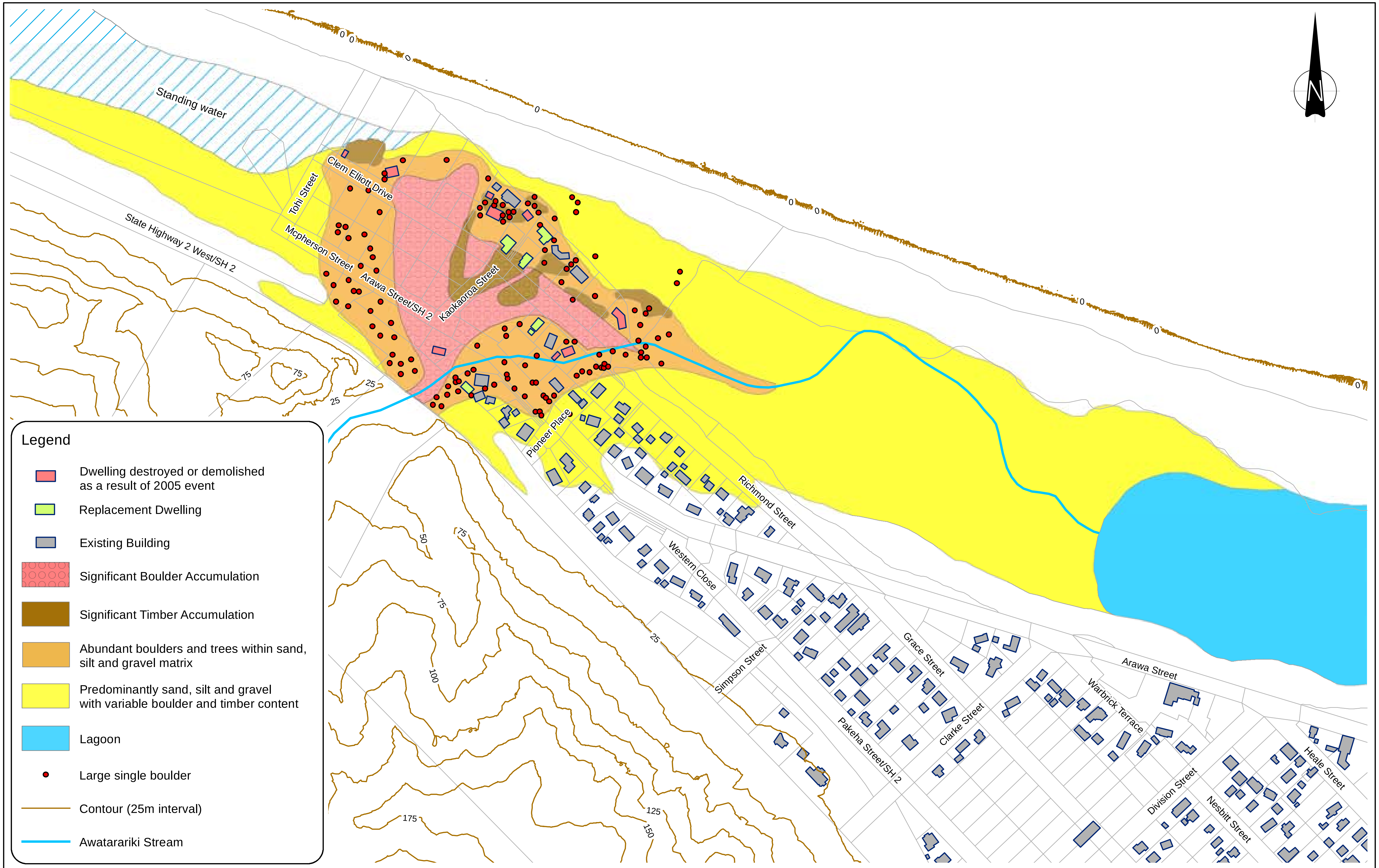


Figure 4: Example RAMMS outputs of a 300,00m^3, two-surge debris flow event



A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

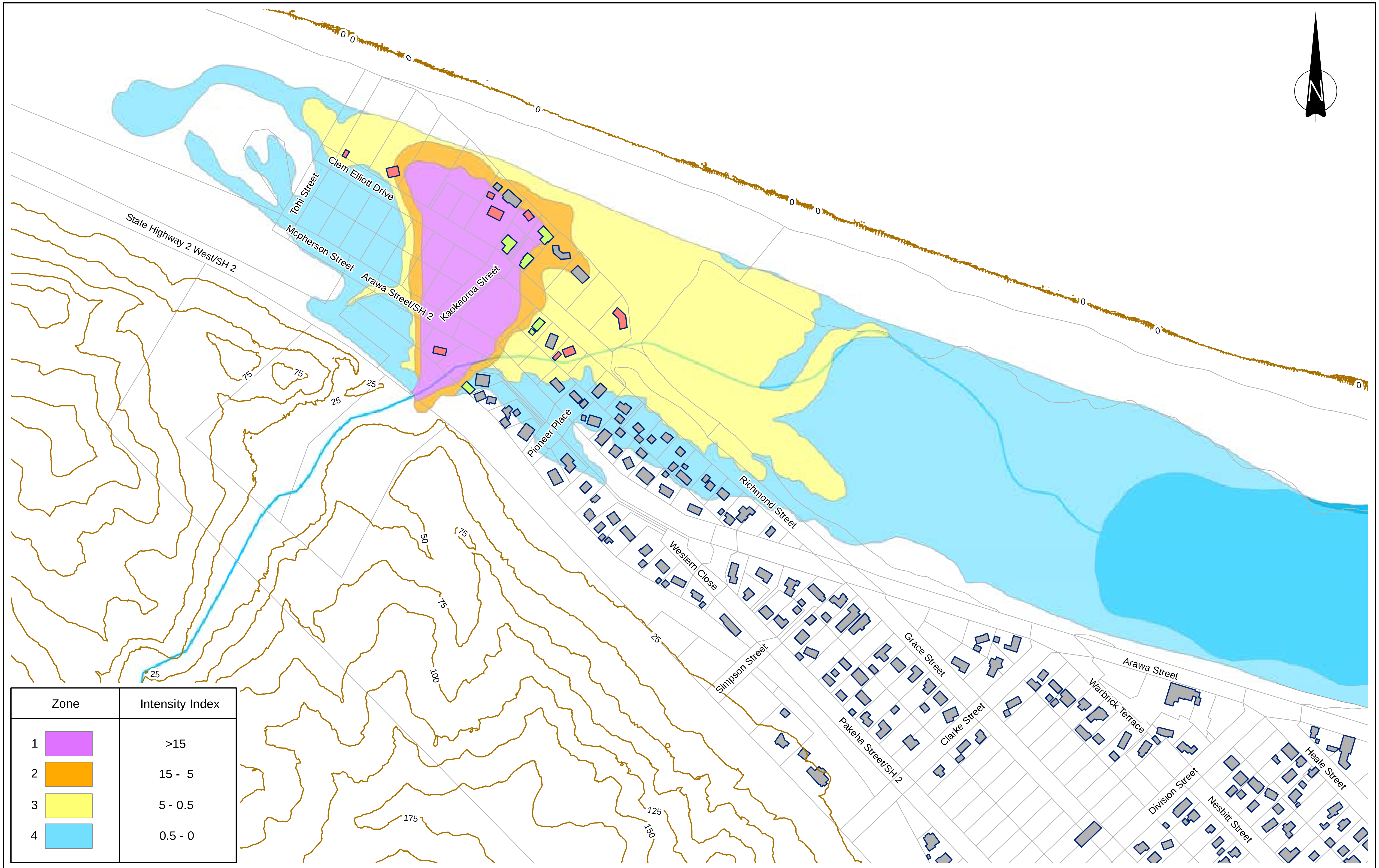
ARCFILE 29115.1000-F5.mxd
SCALE (AT A3 SIZE) 1:4,000
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris from 2005 event

FIGURE No. Figure 5
Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F5.mxd Date: 20/11/2013 Time: 8:20:19 a.m.

Figure 6: Decay in Debris Flow Intensity Index across the fanhead



Zone	Intensity Index
1	>15
2	15 - 5
3	5 - 0.5
4	0.5 - 0

A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F7.mxd

SCALE (AT A3 SIZE) 1:4,000

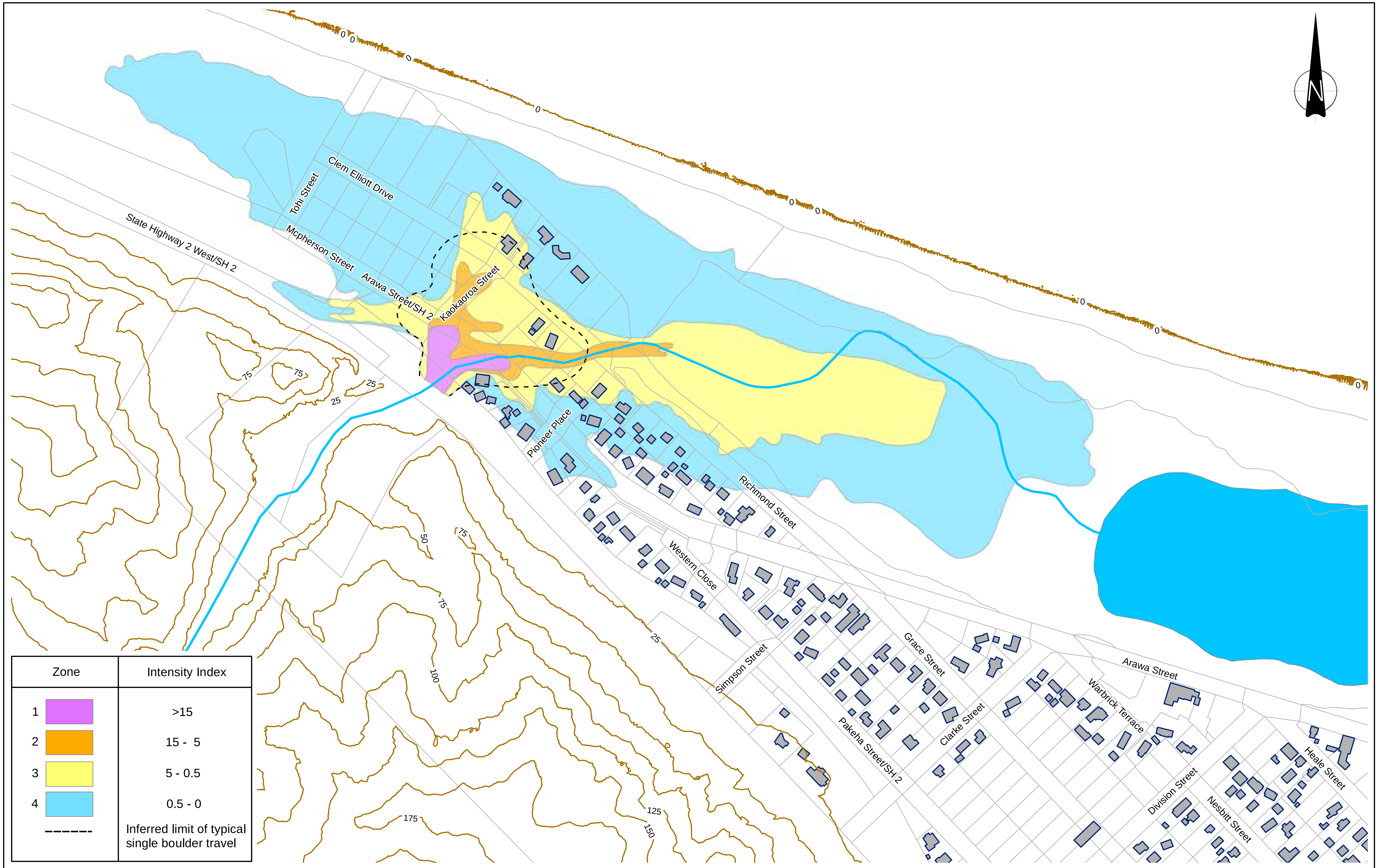
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Back analysis of 2005 event

FIGURE No. Figure 7

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F7.mxd Date: 27/11/2013 Time: 10:53:39 a.m.



Zone	Intensity Index
1	>15
2	15 - 5
3	5 - 0.5
4	0.5 - 0
------	Inferred limit of typical single boulder travel

A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

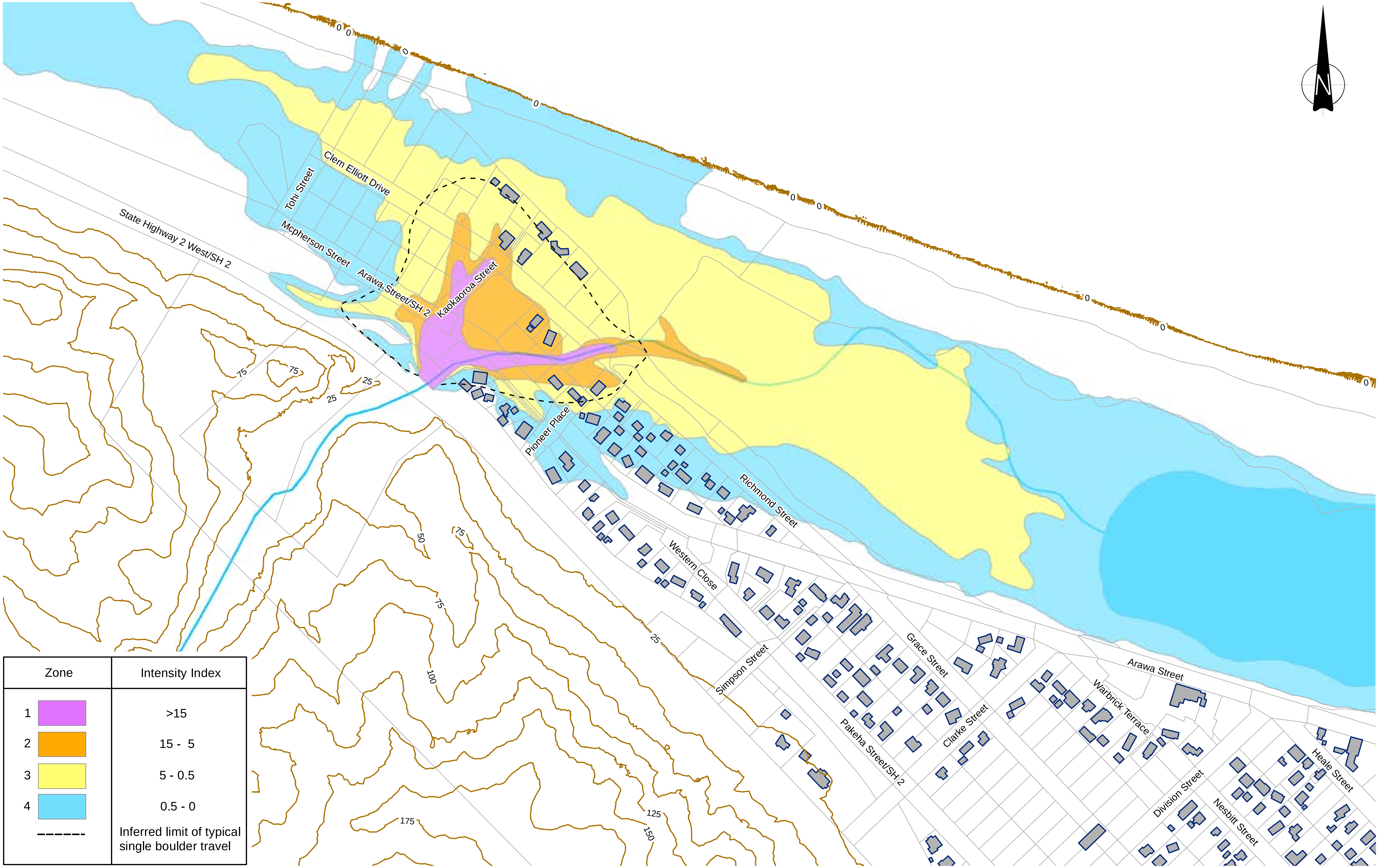
ARCFILE 29115.1000-F8.mxd
SCALE (AT A3 SIZE) 1:4,000
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris Flow intensity
50,000 m^3 Event

FIGURE No. Figure 8

Rev. 0

Path: L:\29115\29115.100\Working Material\GIS\MXD\20131120\29115.1000-F8.mxd Date: 27/11/2013 Time: 10:57:23 a.m.



A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F9.mxd

SCALE (AT A3 SIZE) 1:4,000

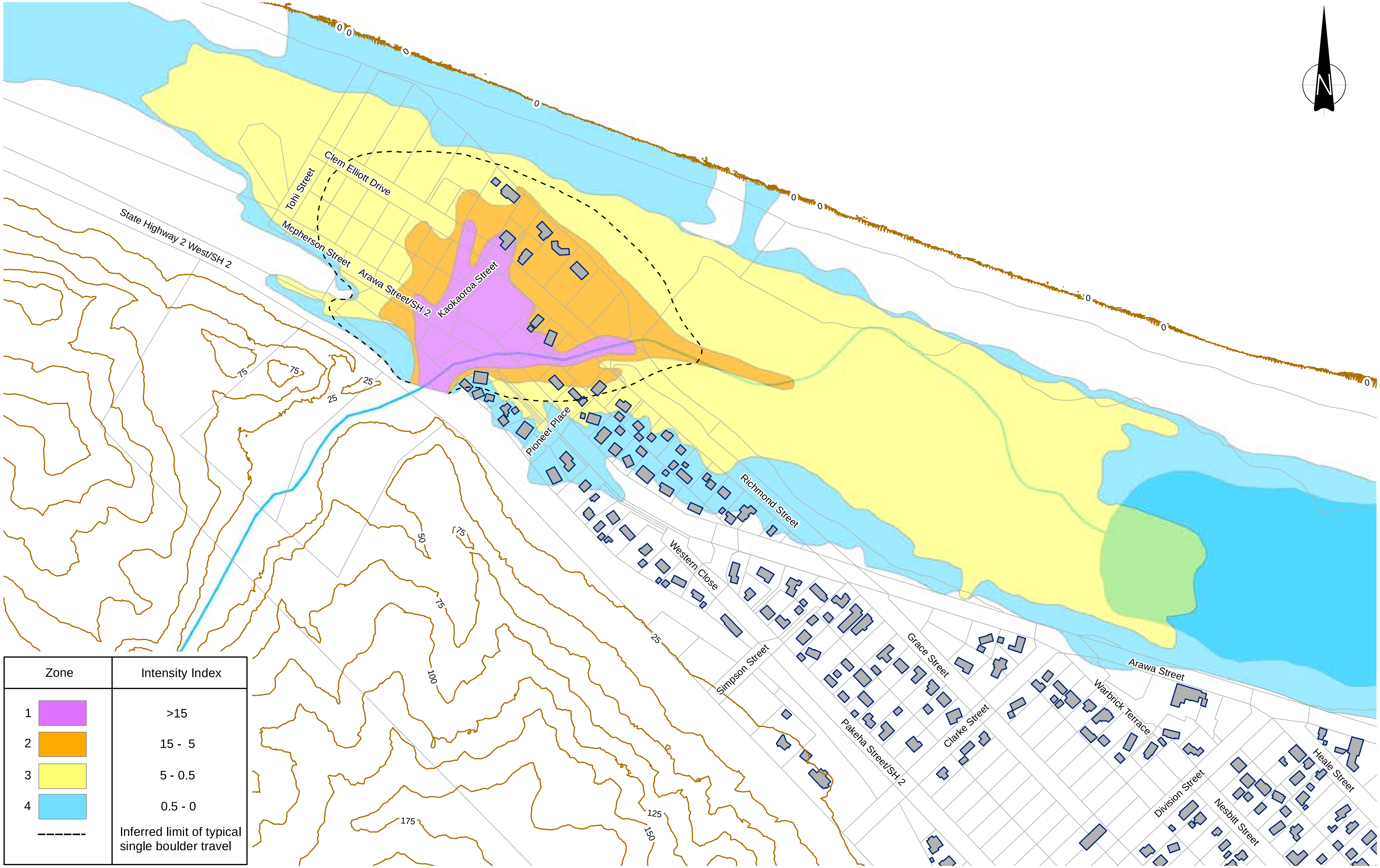
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris Flow intensity
150,000 m^3 Event

FIGURE No. Figure 9

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F9.mxd Date: 27/11/2013 Time: 10:59:35 a.m.



Zone	Intensity Index
1	>15
2	15 - 5
3	5 - 0.5
4	0.5 - 0
------	Inferred limit of typical single boulder travel

A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F10.mxd

SCALE (AT A3 SIZE) 1:4,000

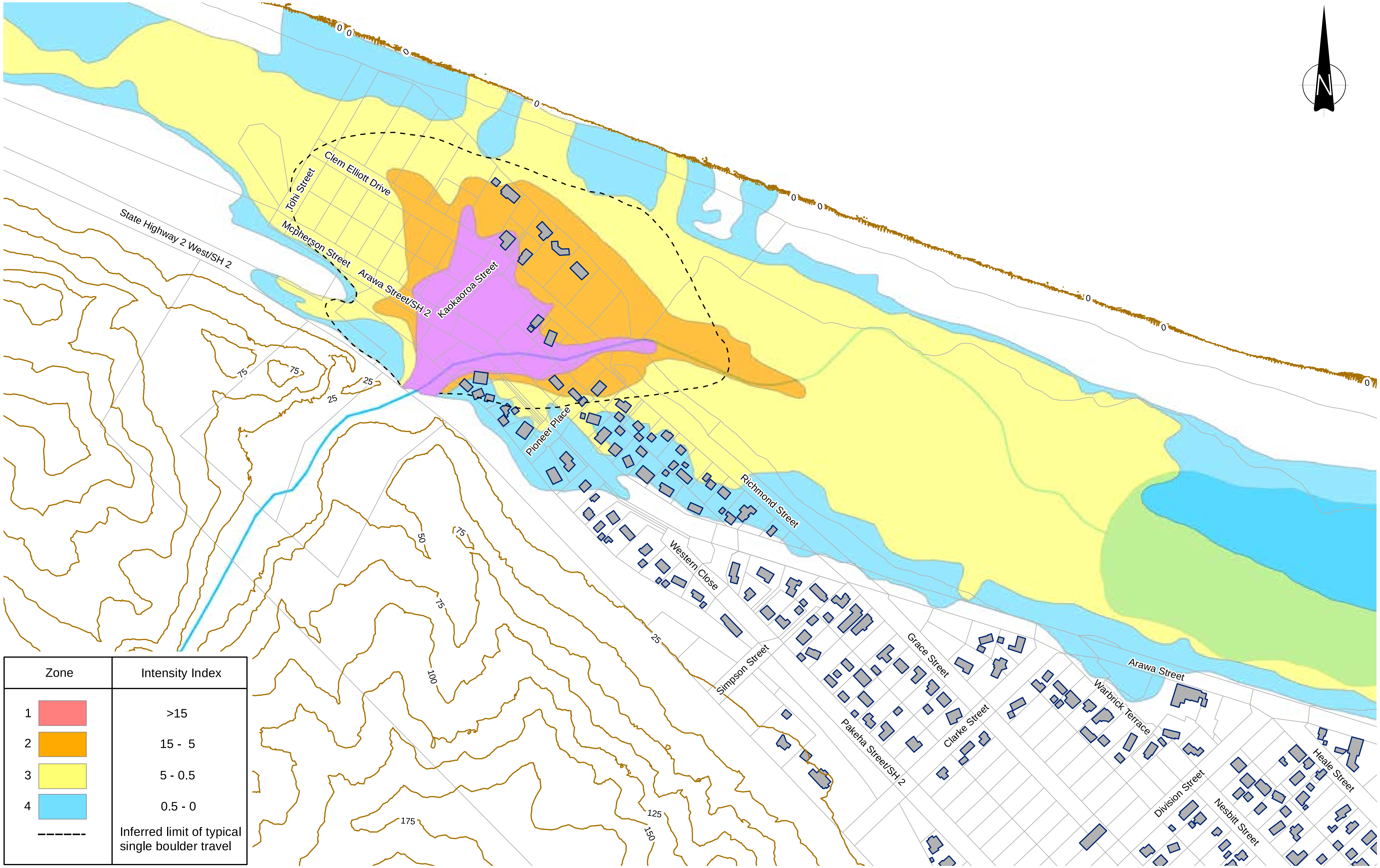
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris Flow intensity
300,000 m^3 Event

FIGURE No. Figure 10

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F10.mxd Date: 27/11/2013 Time: 11:01:29 a.m.



A3 SCALE 1:4,000

0 50 100 150 200 (m)

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE
29115.1000-F11.mxd

SCALE (AT A3 SIZE)
1:4,000

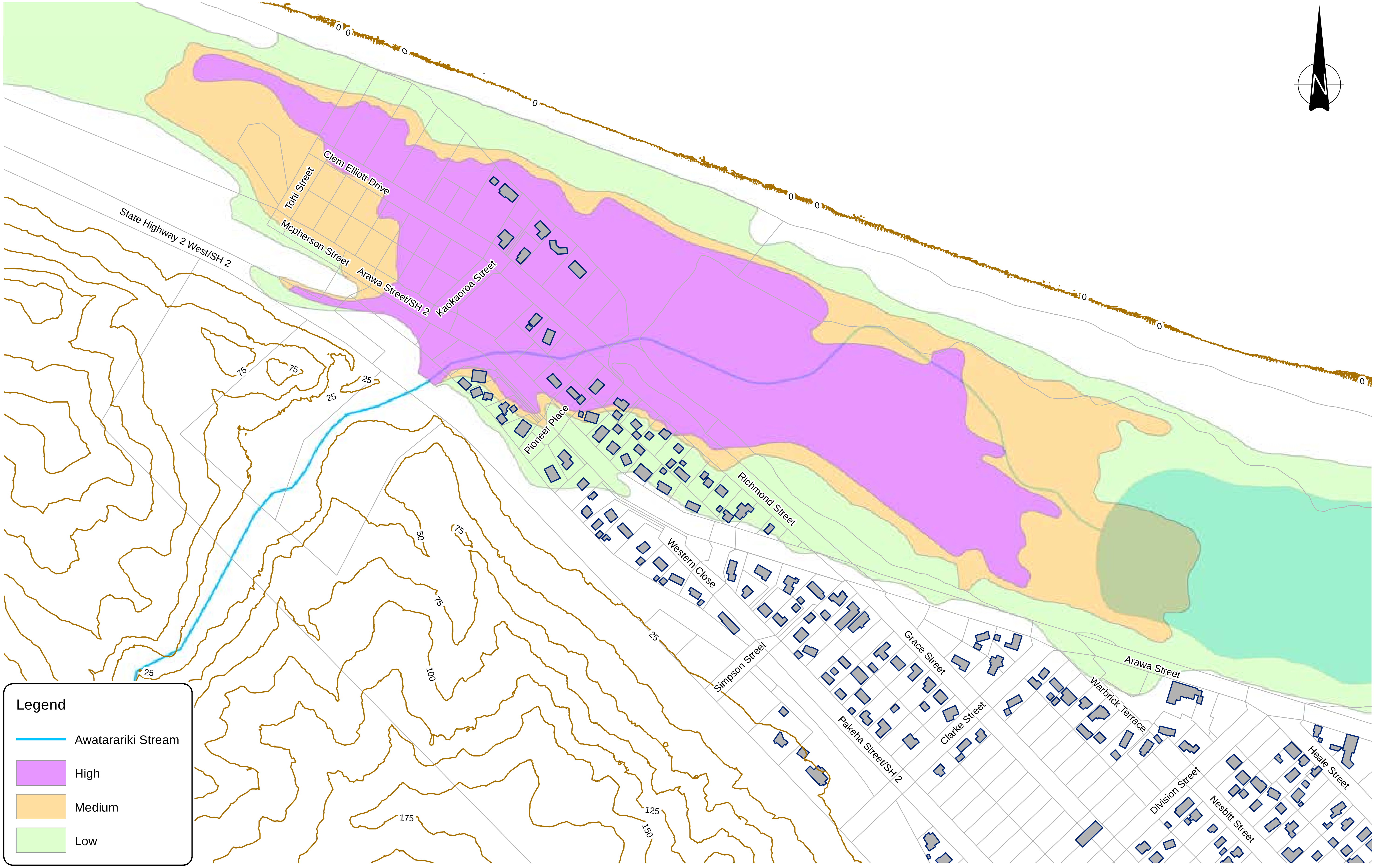
PROJECT No.
29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris Flow intensity
450,000 m^3 Event

FIGURE No. Figure 11

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F11.mxd Date: 27/11/2013 Time: 11:04:42 a.m.



A3 SCALE 1:4,000

0 50 100 150 200 (m)

Location Plan

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F12.mxd

SCALE (AT A3 SIZE) 1:4,000

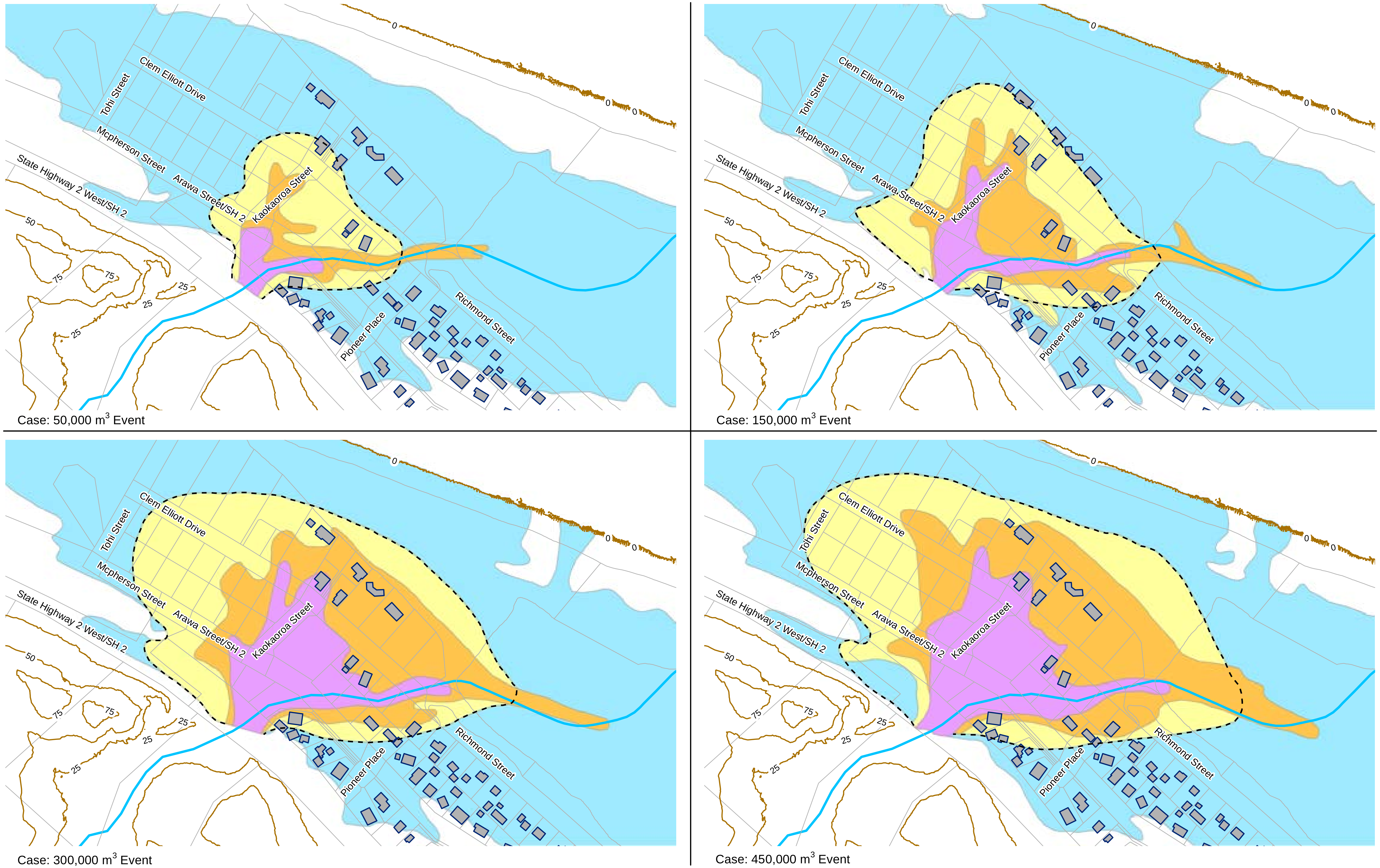
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris flow hazard classification

FIGURE No. Figure 12

Rev. 0

Path: L:\29115\29115.100\Working Material\GIS\MXD\20131120\29115.1000-F12.mxd Date: 27/11/2013 Time: 11:07:49 a.m.



A3 SCALE 1:4,000

0 50 100 150 200 (m)

Legend

	$P_{(S:H)}$	$V_{(D:T)}$
(magenta)	1.00	0.75
(orange)	1.00	0.20
(yellow)	0.20	0.05
(light blue)	0.05	<0.01

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

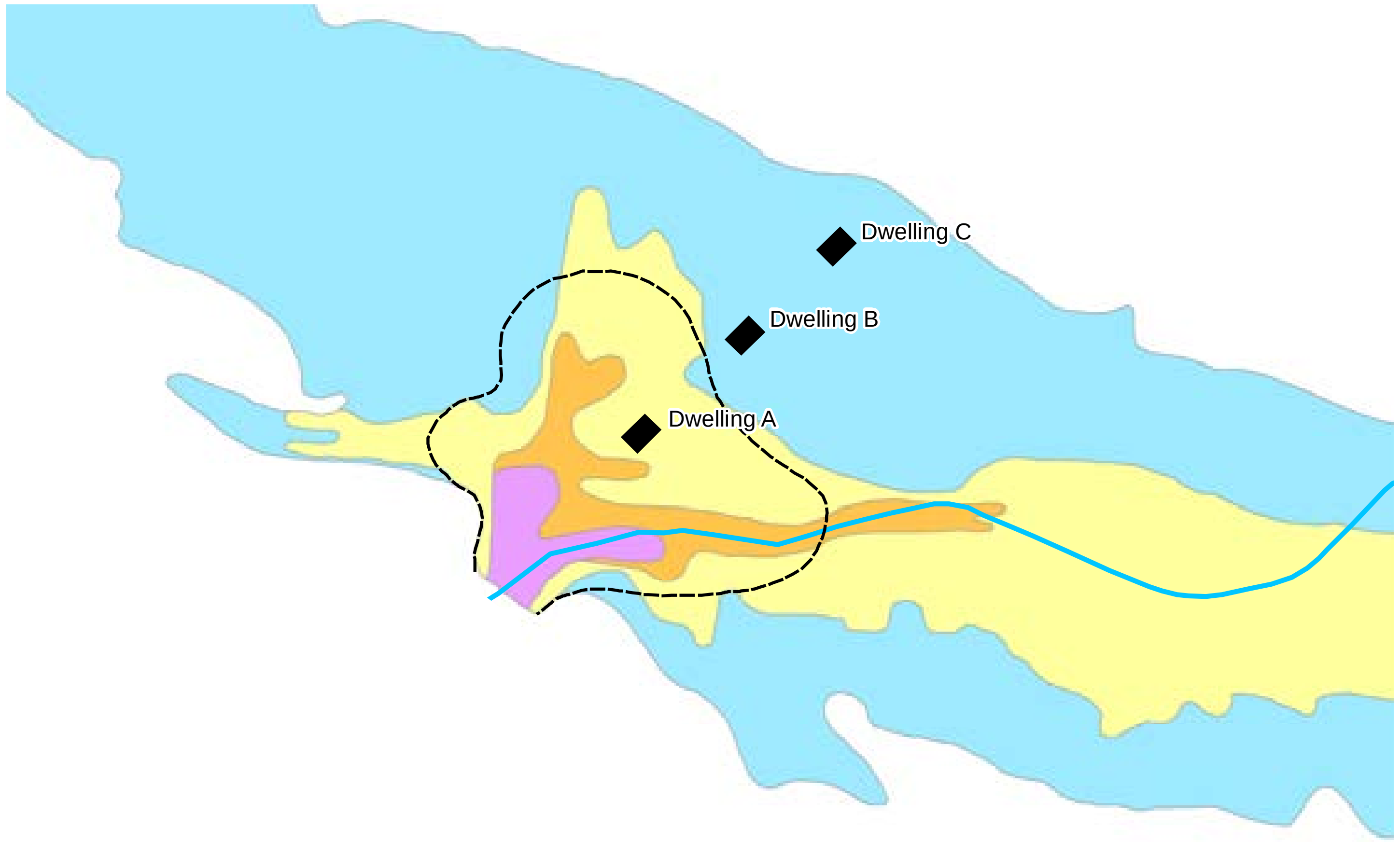
DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

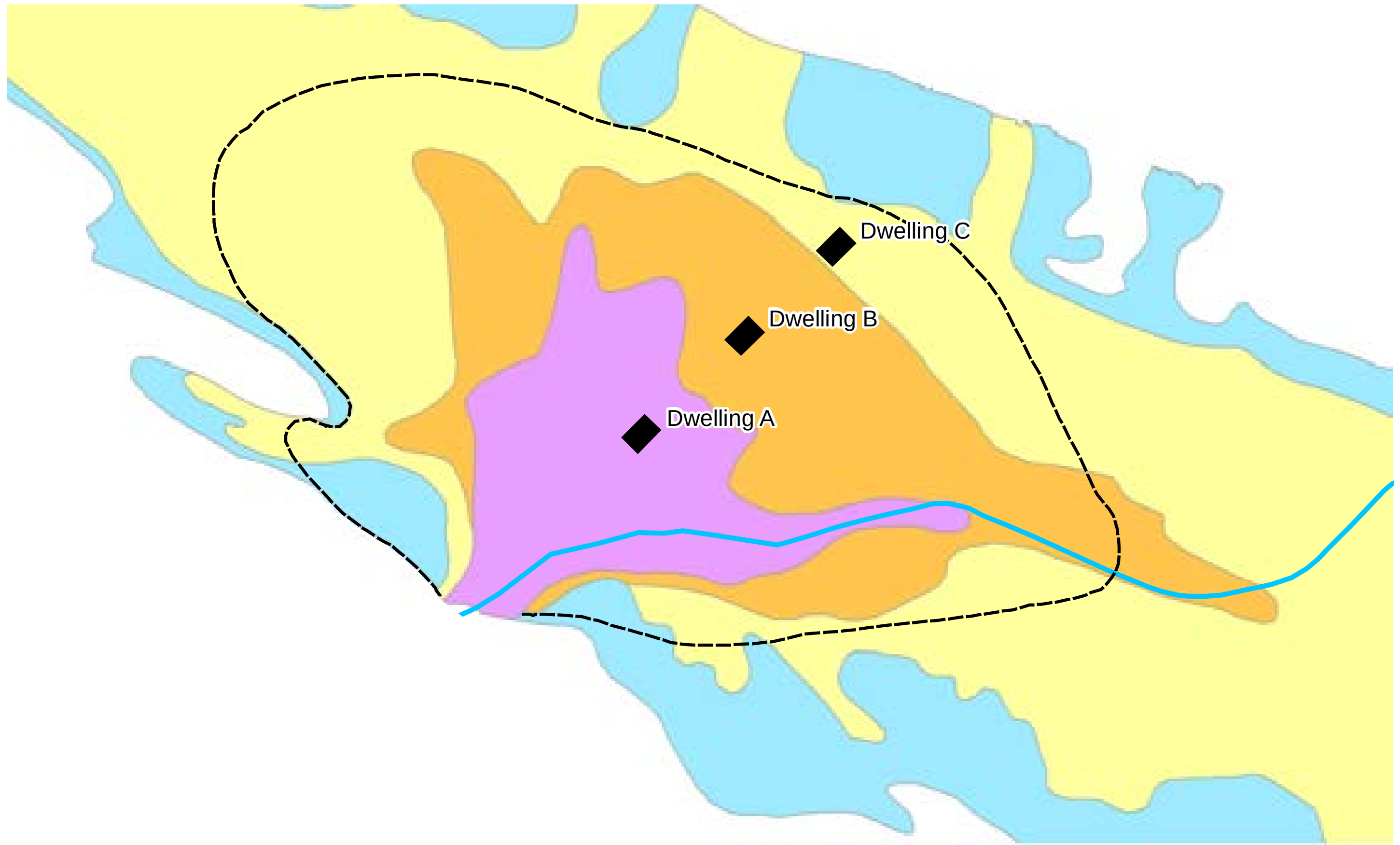
ARCFILE 29115.1000-F13.mxd
SCALE (AT A3 SIZE) 1:4,000
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Assumed vulnerability to fatal injury

FIGURE No. Figure 13

Rev. 0





Case1: Small Volume - Short Return Period Event

Hazard to example dwellings

Dwelling A: Debris flow intensity Zone 3 + single boulder impact zone
- Debris Type: predominantly sand, silt and gravel with occasional boulder extending to the limit indicated.
- Inferred structural damage: generally minor with some localized significant damage possible from isolated boulder impact.
- Inferred human vulnerability: moderate to low, fatality is possible but unlikely (5%).

Dwelling B: Debris flow intensity Zone 4
- Debris Type: predominantly silt and lader water.
- Inferred structural damage: generally insignificant but some flood damage possible to lower storey.
- Inferred human vulnerability: low, fatality is unlikely(<1%).

Dwelling C: Debris flow intensity Zone 4
- Debris Type: predominantly silt and lader water.
- Inferred structural damage: generally insignificant but some flood damage possible to lower storey.
- Inferred human vulnerability: low, fatality is unlikely(<1%).

Case1: High Volume - Long Return Period Event

Hazard to example dwellings

Dwelling A: Debris flow intensity Zone 1
- Debris Type: mass boulder and tree deposition.
- Inferred structural damage: complete destruction.
- Inferred human vulnerability: extreme, significantly possibility of fatality (75%).

Dwelling B: Debris flow intensity Zone 2
- Debris Type: abundant boulders and trees within a matrix of sand, silt and gravel.
- Inferred structural damage: severe to moderate damage, some houses knocked off their foundations.
- Inferred human vulnerability: moderate, fatality is a possibility (20%).

Dwelling C: Debris flow intensity Zone 3 + single boulder impact zone
- Debris Type: predominantly sand, silt and gravel with occasional boulder extending to the limit indicated.
- Inferred structural damage: generally minor with some localized significant damage possible from isolated boulder impact.
- Inferred human vulnerability: moderate to low, fatality is possible but unlikely (5%).

A3 SCALE 1:4,000

0 50 100 150 200 (m)

Zone	Intensity Index
1	>15
2	15 - 5
3	5 - 0.5
4	0.5 - 0
-----	Boulder limit

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

DRAWN	JC	Dec.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15
ARCFILE	29115.1000-F14.mxd	
SCALE (AT A3 SIZE)	1:4,000	
PROJECT No.	29115.1000	

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Variation of hazard and risk with location and event magnitude

FIGURE No. Figure 14

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\2013\1120\29115.1000-F14.mxd Date: 2/12/2013 Time: 4:36:40 p.m.

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

A3 SCALE 1:4,000

0 50 100 150 200 (m)

Legend

1x10-4 Annual Loss of Life Risk

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

DRAWN	JC	Dec.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F15.mxd

SCALE (AT A3 SIZE) 1:4,000

PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Individual Loss of Life Risk
Shorter Return Periods Assumed

FIGURE No. Figure 15

Rev. 0

Path: L:\29115\29115.100\Working Materials\GIS\MXD\20131120\29115.1000-F15.mxd Date: 5/12/2013 Time: 8:05:32 a.m.

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

A3 SCALE 1:4,000

0 50 100 150 200 (m)

Legend

-·-1x10⁻⁴-·- Annual Loss of Life Risk

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

DRAWN	JC	Dec.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F16.mxd

SCALE (AT A3 SIZE) 1:4,000

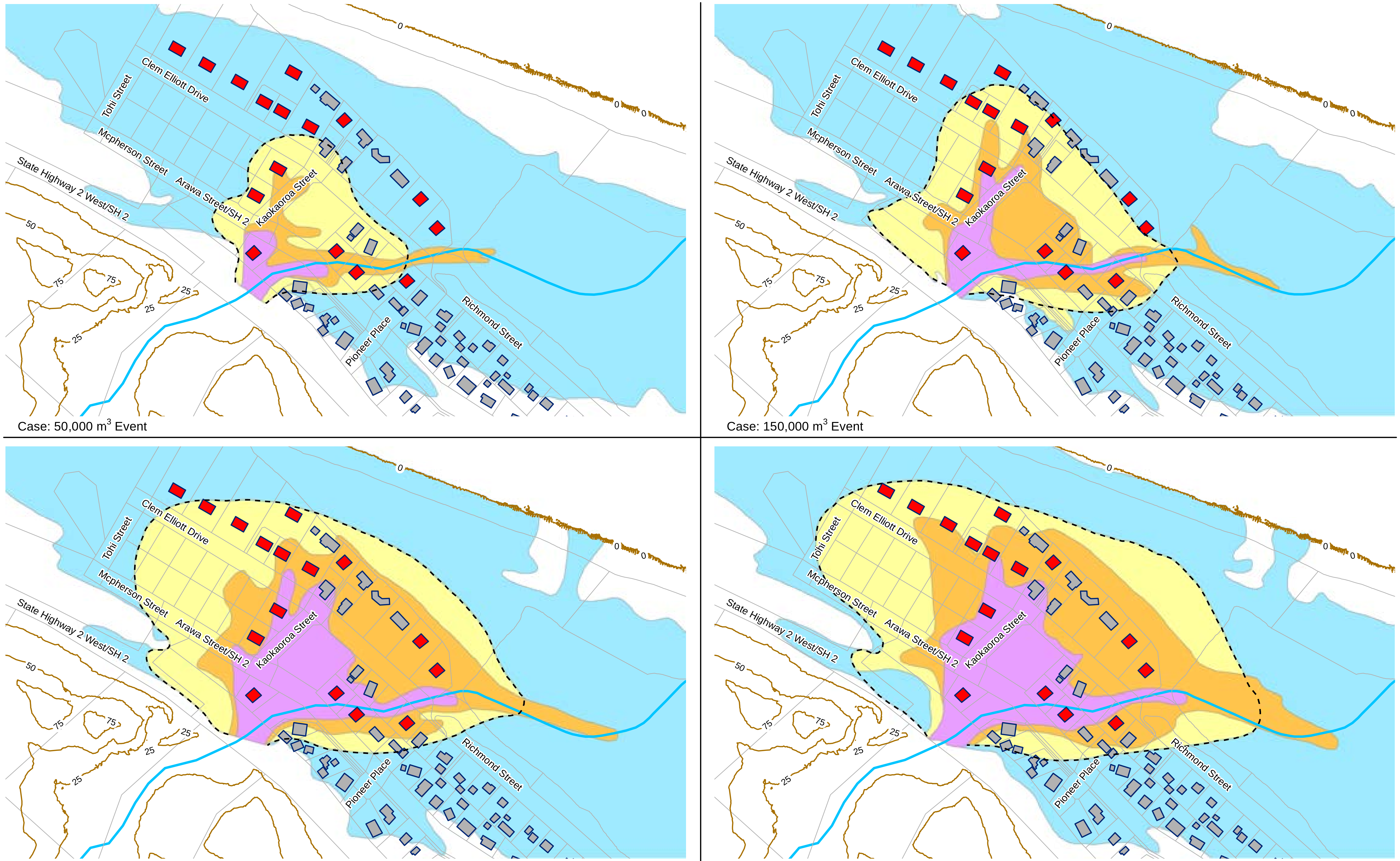
PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Individual Loss of Life Risk
Longer Return Periods Assumed

FIGURE No. Figure 16

Rev. 0

Path: L:\29115\29115.1000\Working Material\GIS\MXD\20131120\29115.1000-F16.mxd Date: 5/12/2013 Time: 8:07:49 a.m.



Case: 50,000 m^3 Event

Case: 150,000 m^3 Event

Case: 300,000 m^3 Event

Case: 450,000 m^3 Event

A3 SCALE 1:4,000

0 50 100 150 200 (m)

Legend

- Existing Structure
- Assume future structure
- Risk Zone 1
- Risk Zone 2

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15

ARCFILE 29115.1000-F17.mxd

SCALE (AT A3 SIZE) 1:4,000

PROJECT No. 29115.1000

WHAKATANE DISTRICT COUNCIL

MATATA QLRA

Assumed residential layout for societal risk

FIGURE No. Figure 17

Rev. 0

Path: L:\29115\29115.1000\Working Material\GIS\MXD\20131120\29115.1000-F17.mxd Date: 27/11/2013 Time: 11:29:20 a.m.

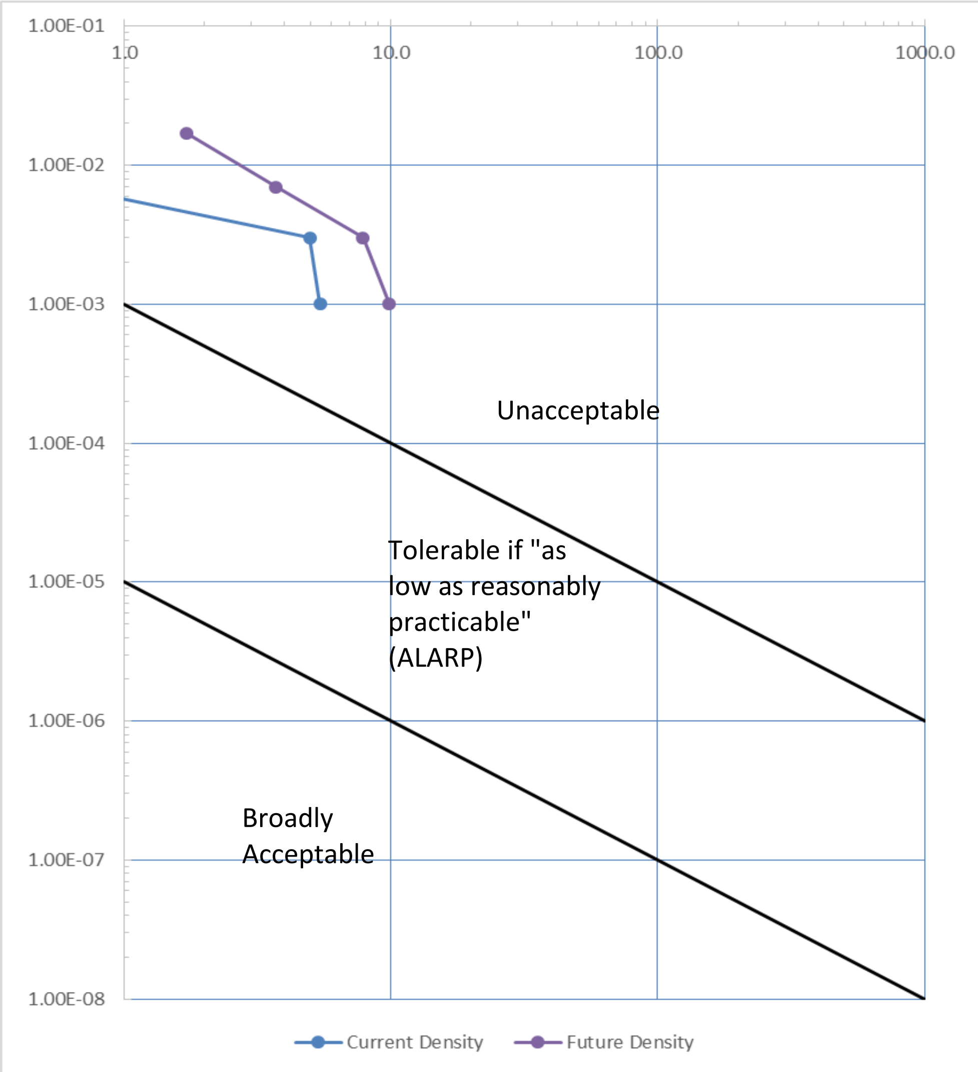
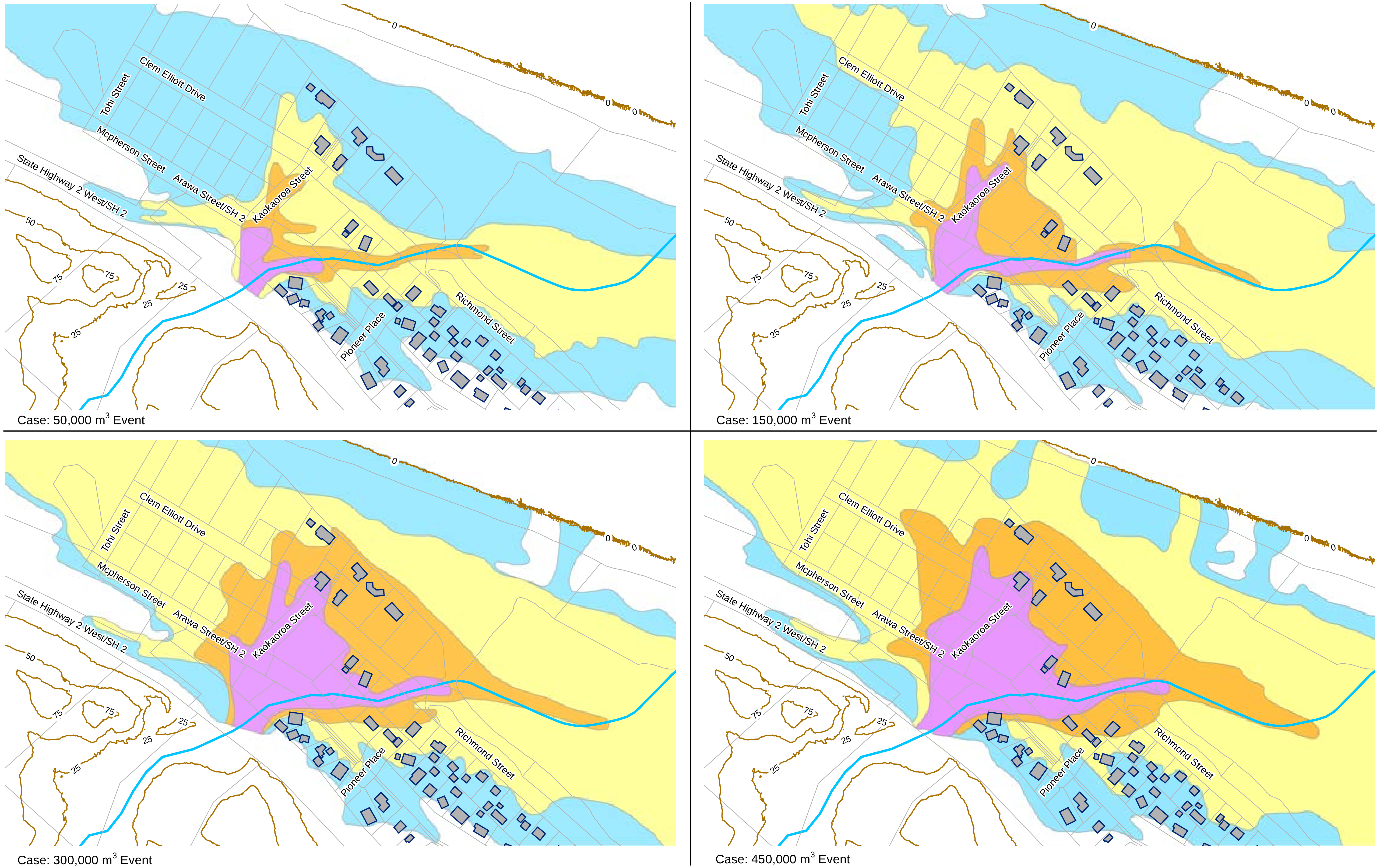


Figure 18: F-N Curve for Matatā. Commonly adopted acceptance criteria (AGS, 2007) are indicated.



Case: 50,000 m^3 Event

Case: 150,000 m^3 Event

Case: 300,000 m^3 Event

Case: 450,000 m^3 Event

A3 SCALE 1:4,000

0 50 100 150 200 (m)

Legend

- Catastrophic
- Major to medium
- Medium to minor
- Insignificant

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

DRAWN	JC	Nov.13
CHECKED	KJH	Jul.15
APPROVED	KJH	Jul.15
ARCFILE 29115.1000-F19.mxd		
SCALE (AT A3 SIZE) 1:4,000		
PROJECT No. 29115.1000		

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Assumed vulnerability of dwellings to damage

FIGURE No. Figure 19

Rev. 0

Path: L:\29115\29115.1000\Working Material\GIS\MXD\20131120\29115.1000-F19.mxd Date: 27/11/2013 Time: 11:23:35 a.m.

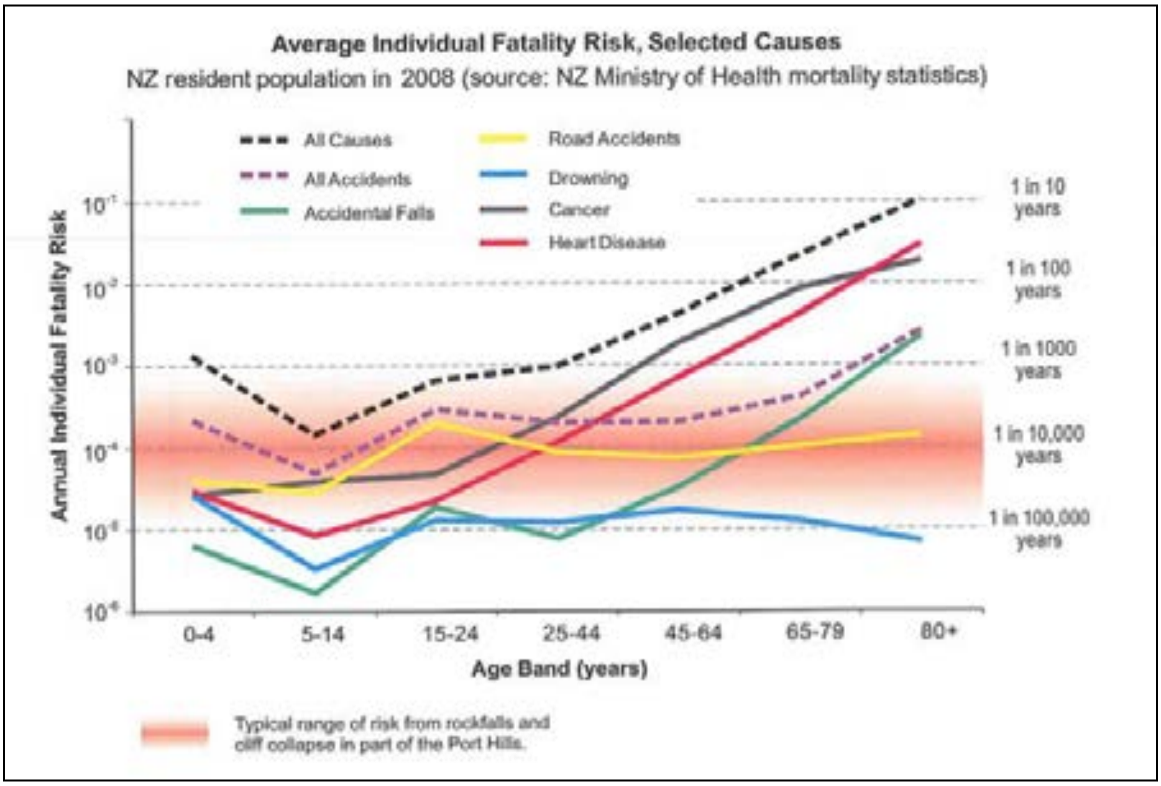


Figure 20: *Comparison of Individual Fatality Risk for Different Hazards in New Zealand (Source: GNS, 2012)*

Appendix B: Summary of some observations of the 18 May 2005 event (Shearer, 2005a)

Selected accounts by residents of the 18 May 2005 event (source: Shearer, 2005a)

Observer	Observation
David Potter	Very low flows in the Waitepuru stream at 1545 on Wednesday, but by 1645 it was in full flood. His father and his grandfather also experienced this phenomenon of flow stopping before the flood came and attributed it to earth dams forming in the stream gullies and eventually giving way. He saw a massive wave coming over the railway line at about 1700, about 3metres above the railway line.
Kay Fergusson	Noted the Awatarariki Stream very high at 0800 on Wednesday. Twenty minutes later water over the bridge and then went down again. Rain continued all day and she kept an eye on the stream but it did not appear to be coming up. Rain eased off at 1600. At 1630 she took the dog for a walk. Water in stream started to rise but no rain. The water rose 1m in 5-6 minutes. She saw a wall of water 1.5m to 2m feet high split two ways near the Reserve. She ended up waist deep in floodwaters. There were logs first then boulders.
Wayne Maloney	Water began to spill over onto his property shortly after 1710. The stream continued to move to the east across his property, probably due to the presence of a large Pohutukawa close to the original path of the stream that had by this time a tremendous amount of rubbish backed up against it. At the height of the flood the stream was flowing in waves, with the waves well above the banks of the stream. He was able to time the passage of several large objects flowing down the stream and maintains that they travelled approximately 100 metres in 3 seconds, as judged by the time they passed the house and the time they reached two large gum trees at the bottom of his driveway. He did not observe any reduction in stream flow prior to the flood. His estimate is that the water in the stream would be 30 feet (say 10 metres) deep and water on his front lawn was approximately 3 metres deep. Thirty to forty minutes after the flood, the stream was back to its usual trickle but in a different stream bed.
Neville Harris's	He was on his balcony when the stream came over the railway line and then demolished the railway bridge and much of the roadway. He confirms what others had suspected and that was that there were two waves of water, the first at about 1700 (but NH does not wear a wristlet watch) lasted about 20-30 minutes. Then the flow dropped off but after a few minutes, went up again. He has been up the stream since the flood and found the spot where there was a massive slip a couple of hundred feet high and the same wide. The two phases to the flood tells him there was another blockage further up the valley.

Appendix C: Photographs of the effects of the 18 May 2005 Event

Tonkin+Taylor

Job No: 29115.3000
2 October 2015

Whakatane District Council
14 Commerce Street
Whakatane 3120

Attention: Jeff Farrell

Dear Jeff

Awatarariki Debris Flow Peer Review Workshop

Further to the Awatarariki debris flow workshop held at Tonkin + Taylor's Auckland office on 17 September 2015, we are pleased to be able to provide the following information as requested.

Risk Overlay Map

Annualised Loss of Life Risk contours for shorter return period events (Figure 15 in T+T, 2015[1]) have been overlain on the debris distribution plan (Figure 4 in T+T, 2015). This is attached.

Note that areas of "significant timber accumulation" were expanded. The original Figure 4 essentially showed where large timber accumulations were located beyond the large debris field which consists of both boulders and timber. The reason for this minor edit was to better match the distribution see in aerial photographs.

Parameter Sensitivity

The annualised Loss of Life Risk contours presented in T+T (2015) were in the form of shorter return periods and longer return periods assigned to each event magnitude. These effectively bracket the range of Loss of Life Risk for the fanhead, with a "best estimate" of risk represented by some intermediate value. The other potential variables in the risk calculation were fixed on what were considered to be best estimates.

In order to determine the effect that choosing alternative input parameters could have on the outcome of the risk analyses, a Monte Carlo simulation was undertaken in which the shorter and longer return period risk calculation spreadsheets were replaced by a single spreadsheet in which the input parameters were chosen at random from distributions of potential values. A normal distribution was chosen in each case.

The mean and standard deviations of the distributions are presented in Table 1, together with the approximate minimum, mean and maximum values. A small number of lookup errors were found in the original spreadsheets affecting the distal low risk areas on the fringe of the debris flows. These errors, which have now been fixed, were 2 or more orders of magnitude less that the contribution to

[1] Tonkin + Taylor (2015). Supplementary Risk Assessment, Debris Flow Hazard, Matata, Bay of Plenty. Report prepared for Whakatane District Council dated July 2015.

Tonkin & Taylor Ltd | 105 Carlton Gore Rd, Newmarket, Auckland 1023, New Zealand
PO Box 5271, Wellesley St, Auckland 1141 P +64-9-355 6000 F +64-9-307 0265 E akl@tonkintaylor.co.nz

total risk from the high risk zones and therefore did not affect the distribution of the Loss of Life Risk contours.

The Monte Carlo simulation was run by generating input parameters and output for a single risk calculation. The outputs of this analysis was saved and the process repeated. A total of 100 analyses were undertaken.

The spreadsheet and the outputs can be seen on the spreadsheet attached to this letter.

Table 1: Distribution of Risk Input Parameters

Return Period (yrs)	Mean	Std Dev	Random Value	Min	Mean	Max
50,000m^3	75	10	77	45	75	105
150,000m^3	175	30	203	85	175	265
300,000m^3	350	60	280	170	350	530
450,000m^3	750	100	657	450	750	1050
	%	%	%	%	%	%
$P_{(T:S)}$	75	2	77	69	75	81
P(S:H) Zone 1	100			100	100	100
V(D:T) Zone 1	75	5	86	60	75	90
P(S:H) Zone 2	100			100	100	100
V(D:T) Zone 2	20	2	22.5	14	20	26
P(S:H) Zone 3	20	2	18.1	14	20	26
V(D:T) Zone 3	5	1	4.4	2	5	8
P(S:H) Zone 3	5	1	4.0	2	5	8
V(D:T) Zone 3	5	1	4.9	2	5	8
P(S:H) Zone 4	10	2	13.9	4	10	16
V(D:T) Zone 4	5	1	4.8	2	5	8
P(S:H) Zone 4	1	0.1	1.0	1	1	1
V(D:T) Zone 4	1	0.01	1.0	1	1	1

The results of the analyses are as expected, with the most common risk estimate essentially being the median or intermediate value between the risk values calculated for the shorter and longer return periods. This reflects the overriding importance of return period on the outcome of the result compared to other parameters such as vulnerability which have a much more restricted range of possible values.

To assess the effects that the Monte Carlo simulation may have had on the outcome of the risk analysis, the following assessment was made:

- The most seaward properties on the fanhead (No. 8 to 18 Clem Elliot Drive) all fall within the Risk Zone G1 based on where the properties are located within the debris field of each of the four different volume events;
- The calculated $R_{(LOL)}$ for area G1 is 1.13 x 10^{-3} and 4.8 x 10^{-4} for the shorter and longer return periods respectively. The 1 x 10^{-3} annualised $R_{(LOL)}$ contour passes through these properties for the shorter return periods. The properties lie between the 10^{-3} and 10^{-4} contours for the longer return period (approximately 3 x 10^{-3});

- The range of R(LOL) calculated for the G1 location using the Monte Carlo simulation was $5x10^{-4}$ to 1×10^{-3}, with a mean value of 7×10^{-4}. These closely match those risk values developed from the stand alone shorter and longer return periods.
- The range of risk values does not include a single value in the range of 10^{-5} i.e. regardless of the input values adopted, all properties within the Clem Elliot Drive area have a R(LOL) in excess of 10^{-4}. The 10^{-5} risk value does not lie on the histogram of results.

See attachments:

1) Figure 29115.3000-F1
2) Risk calcs rev4.xls

Yours sincerely

Kevin J. Hind
Project Director, PEngGeol

2-Oct-15
p:\29115\29115.3000\workingmaterial\kjh.debrisworkshop.02102015.docx

Peer Review: Awatarariki debris-flow-fan risk to life and retreat-zone extent

M.J. McSaveney, T.R.H. Davies

We have reviewed the annual individual fatality risk calculations and map produced by Tonkin & Taylor dated September 2015. These have acknowledged uncertainties caused by the paucity of event records and the consequent difficulty in assigning return periods to event magnitudes. Nevertheless, we accept that this work is based on the best available information and is sufficiently fit for purpose.

I. The attached accompanying map shows the minimum retreat zone we recommend. This is based on the Tonkin & Taylor map of the distribution of annual individual fatality risk on the fan as calculated based on the RAMMS modelling, and also on the distribution of boulders and large woody debris deposited by the 2005 event. The distribution of boulders and large woody debris is matched closely by the area delineated by the 10^{-5} annual individual fatality risk, so we recommend using the latter to delineate the minimum retreat area.

II. The fatality risk map uses information calculated through a sophisticated numerical model which, although one of the best available, necessarily incorporates a number of simplifying assumptions (for example, that the behaviour of a debris flow carrying boulders and trees can be represented by a single homogeneous fluid). These assumptions result in uncertainties that are difficult to quantify. For this reason, we do not rely on the model results alone in choosing the extent of the area to be retreated from, and place much significance on the boulder distribution that occurred in the 2005 event. The individual fatality risk used in Christchurch for earthquake rockfall hazard zoning was 10^{-4} per year, but there, the zones were based primarily on observed boulder distributions which introduced much lower modelling uncertainty than is available at Awatarariki, and on a more robustly determinable event occurrence frequency. We recommend a conservative approach here, which is to use the estimated 10^{-5} per year fatality risk (as indicated by the Tonkin & Taylor risk calculations) as the minimum extent of the area to be retreated from. This is not to imply that we recommend adopting a limit of 10^{-5} per year fatality risk, but is to be more certain of having included the 10^{-4} per year limit.

III. Although there were no fatalities in the 2005 event, the presence of boulders and trees deposited by that event was a widely recognised serious threat to life. The lack of fatalities in 2005 may simply have been the result of luck, and/or the time of day when the event occurred. It may also be that the return period of the 2005 event has been overestimated: in addition to the tendency for boulders and large woody debris to travel further on the Awatarariki fan than models predict, there may also be a tendency for debris flows to increase in volume in the upper catchment more than we expect. Either or both of these could result in overestimation of the 2005-event return period, with consequent underestimation of the overall fatality risk.

IV. We emphasise that the area outside this recommended minimum retreat zone is not free of risk to life from debris flows; a poorly quantified residual risk remains beyond the estimated 10^{-5} per year risk line. This residual fatality risk could be further reduced by extending the retreat zone, but this may be societally contentious.

V. The retreat zone will need on-going maintenance to ensure that changes within it over time due to further debris flows, other natural causes and alternative land uses do not further increase the risk to life on or near the fan. We note that the fan area includes infrastructure overseen by other authorities, and there is a clear need for all stakeholders to coordinate their activities on the fan with risks to others in mind.

VI. Within the recommended zone for retreat, there is no physical mitigation of the high fatality risk that would be faced by a permanent resident who might chose to remain under "existing use" provisions, and there remains a substantial fatality risk even for visitors to the area. To provide for self-management of the risk to people in the retreat zone, we recommend that Council consider the viability of providing a debris-flow warning system that can alert people to an imminent danger of a debris flow in Awatarariki Stream, and may allow them to seek shelter or evacuate if they are able to do this safely and quickly. A variety of warning systems are in use in similar situations overseas with varying degrees of success (e.g. Hong Kong, Taiwan, Japan). We note that road users and rail traffic also are vulnerable to future debris flows irrespective of other users of the land. While risks to road and rail users have not been calculated herein or by Tonkin & Taylor, we suggest that an early-warning system should also be capable of reducing the fatality risks to road users and rail traffic from a debris flow on the Awatarariki fan.

VII. Last, the Tonkin & Taylor risk analysis was made for the area under residential use, and in our opinion the high fatality risk to residents there from debris flows makes such residential use unsafe. Future alternative uses of the land, which will be largely council land, are for Council to decide, with due consideration of the existing unmitigated hazards and the risks that they pose to potential users.

…………………………………………………………………………M.J. McSaveney
Scientist Emeritus
GNS Science

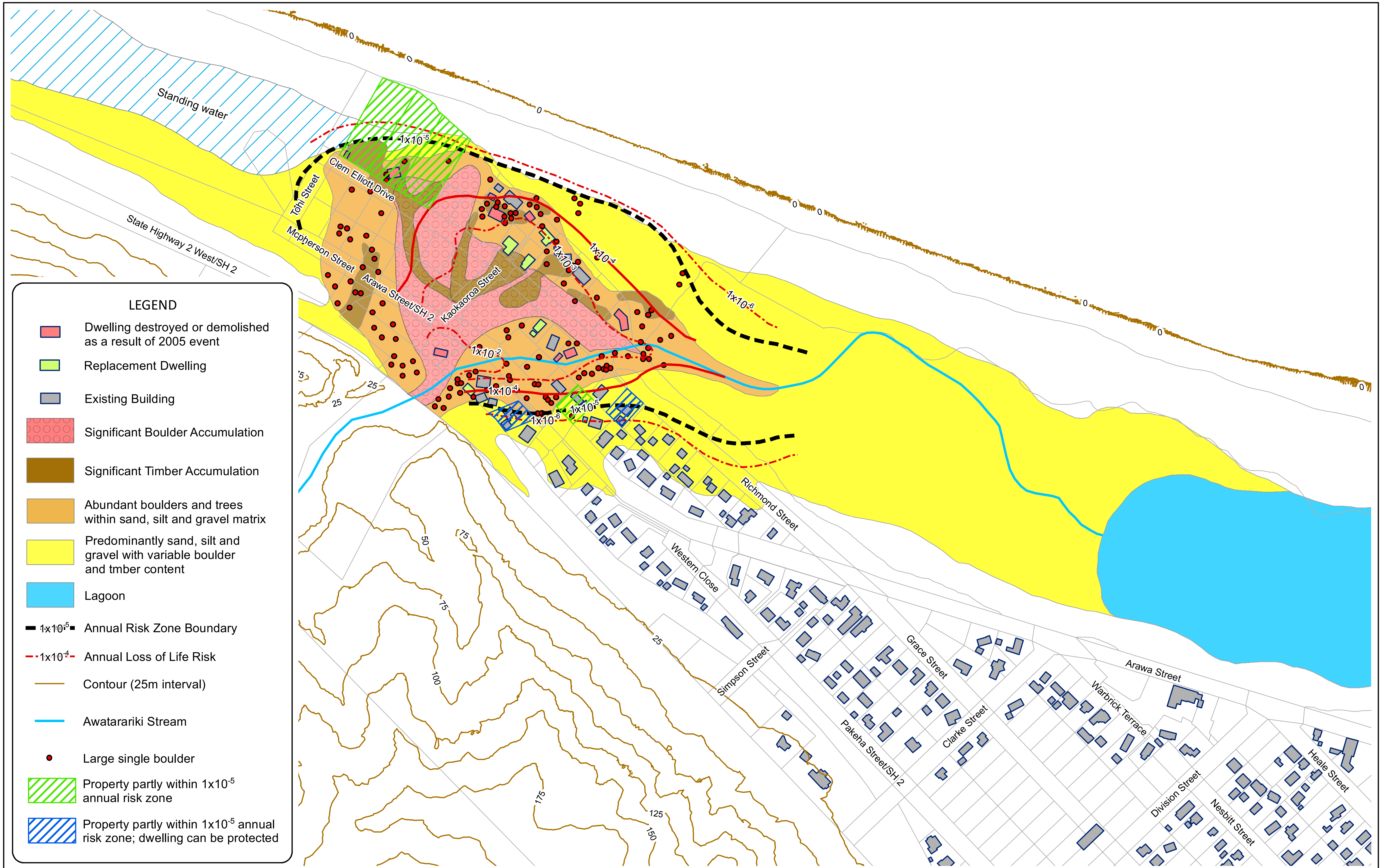
…………………………………………………………………………T.R.H. Davies
Professor
Department of Geological Sciences
University of Canterbury

17 November 2015

One attachment:

Awatarariki Fan risk distribution and suggested retreat zone boundary.

The outline of the recommended minimum retreat zone is marked by the heavy dashed line (**----**).



Path: L:\29115\29115.3000\WorkingMaterial\GIS\29115.3000-F1(10.2).mxd Date: 23/10/2015 Time: 10:10:14 a.m.

A3 SCALE 1:4,000

0 0.05 0.1 0.15 0.2 (km)

N

Location Plan

Tonkin+Taylor
105 Carlton Gore Road, Newmarket, Auckland
www.tonkintaylor.co.nz

DRAWN	JC	Oct.15
CHECKED		
APPROVED		
ARCFILE	29115.3000-F1(10.2).mxd	
SCALE (AT A3 SIZE)	1:4,000	
PROJECT No.	29115.3000	

WHAKATANE DISTRICT COUNCIL
MATATA QLRA
Debris distribution from 2005 event and predicted annual loss of life risk

FIGURE No. Figure 1.
Rev. 0