Canterbury earthquakes 2010/11 Port Hills Slope Stability: Life-safety risk from cliff collapse in the Port Hills

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BIBLIOGRAPHIC REFERENCE

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This report in draft form was independently reviewed by T. Taig, TTAC Limited and F.J. Baynes of Baynes Geologic Pty. Ltd. Internal GNS Science review of drafts were provided by N. Litchfield.

The Geographical Information System data used in the risk modelling was independently checked by I. Jones and T. Caspari of Aurecon Ltd.

This report was completed May 2012 with corrections of minor typographical errors September 2012.

Maps in appendices A and B were updated in July 2013 to take into account new information relating to some of the areas covered by this report.

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ES.1 Scope and purpose

GNS Science has been commissioned by Christchurch City Council to assess and report on slope-instability risk in the Port Hills following the deaths of five people (two from rockfalls and three from cliff collapse) in the earthquakes of 22nd February 2011. This report is one of the series of reports on areas where much damage occurred. It specifically uses the methodology presented in Massey et al. (2012a) (GNS Science Report CR2012-57: Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Pilot study for assessing life-safety risk from cliff collapse). This report covers those areas of the Port Hills that were not included in that pilot study report and in which the cliffs meet certain criteria. It presents an assessment of the risk to life faced by an individual living above or below cliffs. This risk is expressed as the annual individual fatality risk. The report does not assess the risk of damage to critical infrastructure, nor does it assess the particular risks to particular people at particular places such as roads and right-of-ways.

The report considers cliff collapse, a type of landslide involving many boulders, triggered by earthquakes (taking into account expected changes in seismic activity in the Port Hills region over time) and by other non-seismic triggering events such as rainfall and spontaneous collapse.

This report uses the terms: "cliff-top recession" to describe the result of landslides from the top and face of cliffs, and "debris avalanche" to describe the landslide process that inundates land at the cliff foot (referred to as "toe") with countless boulders. The two are collectively referred to as cliff collapse.

Debris avalanche refers to a type of landslide comprising many boulders falling simultaneously from a slope. The avalanching mass starts by sliding, toppling or falling before descending the slope rapidly (> 5 m/sec) (following Cruden and Varnes, 1996) by any combination of falling, bouncing and rolling.

Some dwellings within these areas are also affected by rockfall (boulder roll) hazards, which are dealt with in Massey et al. (2012b). Landslide types other than rockfalls and cliff collapse also occurred in the 2010/2011 Canterbury earthquakes. Movement of these landslides have made some dwellings uninhabitable, but these landslides pose no immediate fatality risk and are not discussed in this report.

The annual individual fatality risk in this report is the probability (likelihood) that a particular person will be killed by cliff collapse in any year at their place of residence. For most localities, this probability is an imprecisely determined, very small number, for which the report uses the scientific number format, expressing risk in terms of powers of ten. For example, the fraction 1/10,000, and the decimal number 0.0001 expressed in the scientific number format is 10^{-4} ("10 to the power of minus 4"). The units of risk are probability per unit of time and the units of annual individual fatality risk are probability of death per year.

The reported fatality risks are obtained through a quantitative risk estimation method that follows appropriate parts of the Australian Geomechanics Society framework for landslide risk management (AGS, 2007). It provides risk estimates suitable for use under AS/NZS ISO31000: 2009.

The report considers both cliff collapses triggered by earthquakes (taking into account expected changes in seismic activity in the Port Hills region over time), and by other cliff collapse-triggering events such as rainfall and spontaneous collapse. The report:

1) presents an analysis of the cliff collapse hazard in those Port Hills residential areas above and below steep cliffs not included in the pilot study report; and
2) estimates the annual individual fatality risk, i.e. the risk of death of an individual, from cliff collapse in these areas.

Analysis of risk in the areas covered by this report is based largely on data collected from cliff collapses triggered by the 22nd February 2011 earthquakes. The work presented herein is based on smaller cliffs (typically less than 40 m in height) than those discussed by Massey et al. (2012a). Cliffs in this report comprise coastal cliffs that are either still being eroded by the sea, or those cliffs now abandoned by the sea, some of which have been quarried. All of these cliffs have relatively flat slopes beyond their bases.

ES.2 Conclusions

1) Following the 4th September 2010 Darfield Earthquake the levels of seismic activity in the Christchurch region have been considerably higher than the long-term average, and are likely to remain higher for several decades. The long-term seismicity is also recognised to be higher than it was understood to be before 4th September 2010. As a result the previously unknown annual individual fatality risk from cliff collapse is considerably higher than it was before September 2010. The fatality risk from earthquake-induced cliff collapse is expected to decrease as the seismic hazard decreases.
2) For the small (typically less than 40 m in height) cliffs in the non-pilot study areas, debris avalanches were relatively rare, and falls of individual boulders were the dominant recorded landslide type. As a result, the risk assessment methodology in this report differs from that carried out for the pilot study areas (contained in Massey et al., 2012a).
3) The annual individual fatality risks from debris avalanches in the pilot study areas are typically an order of magnitude greater than those risks estimated for the same Fahrboeschung zones relating to the non-pilot study area, smaller, cliffs. This is because in the pilot study areas many thousands of cubic metres of debris, and therefore many thousands of boulders, fell from the cliffs.
4) The cliffs in the pilot study areas are steeper, and much greater in height, with relatively flat areas at their crests, when compared to the smaller and more rounded cliffs in the non-pilot study areas.
5) In those areas not included in the pilot study areas, but included in this report, there are a total of 87 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones relating to debris avalanches. Of these, about 37 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 16 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 22 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 12 expose people to risks less than 10^{-5}/year.

6) In the Port Hills total areas, including both the pilot study areas and those areas analysed in this report, there are a total of 131 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones relating to debris avalanches. Of these, about 73 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 19 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 23 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 16 expose people to risks less than 10^{-5}/year.

7) Within the analysed cliff-top recession areas, annual individual fatality risks are greater than 10^{-4}/year.

8) Cliff-top recession mainly occurs during earthquakes, as witnessed during the 2010/2011 Canterbury earthquakes. It is likely that in the next decade further recession of the cliff edge will also occur during earthquakes. Each time the cliff top moves so too will the risk zones by an equal amount.

9) To take account of cliff-top recession and to make the risk assessment robust to further large earthquakes, “earthquake event” lines have been included on the maps. These lines represent the likely maximum loss of the cliff edge in future earthquakes with associated peak ground accelerations of about twice the gravitational acceleration (2 g), which is similar to those in the 22nd February and 13th June 2011 earthquakes.

10) These earthquake event lines do not mean that the entire cliff between that line and the cliff edge will recede in a single event; they mean that any given part of the cliff in this area could recede back to this line in another event of this magnitude. The distance between each earthquake event line is set equal to the width of the maximum cliff-top recession measured at each cliff after the 2010/11 Canterbury earthquakes.

11) There are 50 dwellings (including those classified as “unknown”) located in the cliff recession annual individual fatality risk zones, where the risks are estimated to be greater than 10^{-4}/year.

ES.3 Recommended Christchurch City Council actions

It is recommended that:

1) Council accepts the information regarding annual individual fatality risk from cliff collapses presented in this report;

2) Council uses the information in reaching decisions about future risk management for cliff collapse-affected dwellings in the Port Hills;

3) Given the time-varying nature of the seismic hazard, the assessed individual fatality risks should be re-evaluated after a period of about 10 years to incorporate a seismic hazard model appropriate to the knowledge of that time. This would also allow data collected on the stability of the now seismically-disturbed cliffs of the Port Hills to be considered in the risk;

4) Cliffs less than 50 m^2 in plan area were not included in this analysis as they are too small for this suburb-scale analysis. It is recommended that these cliffs, where identified, are inspected in the field on a site-by-site basis by members of the Port Hills Geotechnical Group;

5) Cliffs modified by cutting were not included unless they were abandoned coastal cliffs that were subsequently quarried or modified for housing. Where identified, these should be inspected in the field on a site-by-site basis by members of the Port Hills Geotechnical Group; and

6) Cliffs formed predominantly of loess or other non-rock materials have not been included in this analysis. These should be analysed at a later date.

ES.4 Methods used

The methods adopted in this report are based on the Australian Geomechanics Society (AGS) 2007 landslide risk management framework. The risk-assessment method has been presented in detail in Massey et al. (2012a).

The key steps which differed from that in Massey et al. (2012a) are summarised below:

ES.4.1 Cliff collapse source identification

This analysis only includes current and former coastal cliffs, some of which have been quarried, and which have buildings located above or below them.

Generally the height, slope angle and shape of the cliffs appear to have been the controlling factors on the susceptibility of the cliffs to failure and on the nature of the failure (whether it comprises the fall of an individual boulder or debris avalanches). It appears that cliff shape, geometry and geology may have influenced the severity of the ground shaking experienced near the cliff. These observations are summarised in Figure ES.1.

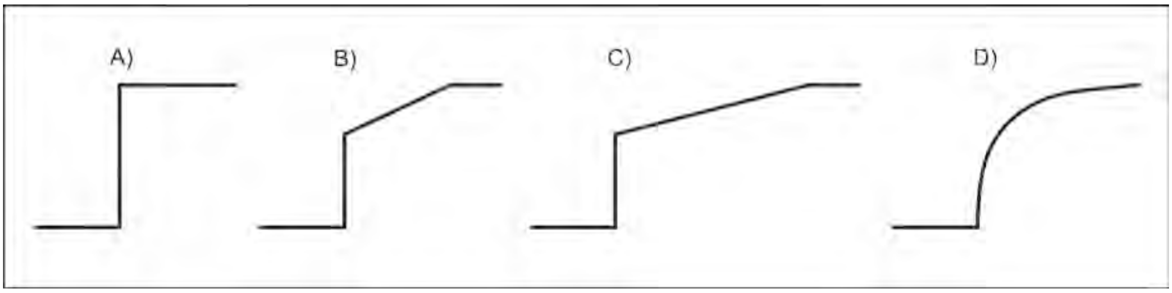


Figure ES.1 Schematic diagram showing cliff morphology in the Port Hills. A) and B) represent the majority of cliff shapes in the pilot study areas, where most of the 2010/11 Canterbury earthquake-triggered cliff collapse occurred. C) and D) represent the majority of cliff shapes in the non-pilot study areas.

Based on the geometrical relationships of cliffs in the Port Hills outside the pilot study areas, this risk analysis only includes cliffs that are: 1) coastal or relict coastal cliffs; 2) formed in rock; 3) greater than 10 m in vertical height (referring to the rock slope portion of the cliff); 4) steeper than 45° (referring to the rock slope portion of the cliff); and 5) greater than 50 m^2 in plan area.

Cliffs less than 10 m in height and/or at slope angles of less than 45° did not tend to fail during the 2010/11 Canterbury earthquakes. Areas above and below these types of slope are therefore assessed as being at lower levels of risk, and have not been included in the risk analysis presented in this report. Cliffs less than 50 m^2 in plan area were not included as they are too small for this suburb-scale analysis.

Cliffs modified by man-made cutting were not included unless they were originally abandoned coastal cliffs and satisfied the above five criteria.

ES.4.2 Risk analysis

The annual individual fatality risk from debris avalanches or individual boulders is dependent upon the volume of material falling from the cliffs for a given event. The volumes of material falling from cliffs in the pilot study areas involved several tens of thousands of cubic metres of debris, whilst the volumes of debris falling from cliffs in the non-pilot study areas were significantly smaller, comprising mainly the fall of individual boulders and occasional debris avalanches of a few 100 cubic metres.

For many of these slopes the numbers of boulders that have fallen from them during the 2010/11 Canterbury earthquakes have been mapped by consultants of the Port Hills Geotechnical Group. The volumes of fallen boulders, rather than volumes of debris, have been used to develop the risk analysis for debris avalanches from these slopes.

For debris avalanches and cliff-top recession the risk analysis comprises the same steps as those used in the pilot study analysis, except that the volumes of rock, or in this case the numbers of boulders produced in each event, were estimated differently. These steps are:

1. Consider the full possible range of triggering events (e.g., earthquakes, rain) in terms of a set of earthquake triggers and a set of non-seismic triggers.
2. Choose a small set of representative events for each type of trigger spanning the range of severity of events from the smallest to the largest.
3. For each representative event, estimate:

For debris avalanches:

a) the frequency of the event and the volume of material produced.
b) the number of boulders reaching/passing a given Fahrboeschung angle (distance) down the slope and the probability of one of *N* boulders hitting a person at that location on the slope.
c) the probability that a person is present on the slope as the boulder moves through it.
d) the probability that a person will be killed if present and hit by one or more boulders.

4. Combine 3(a) – (d) for debris avalanche to estimate the annual individual fatality risk for individuals at different locations below the cliff or at the cliff edge contributed by each representative event.
5. Sum the risks from all events to estimate the overall risk.
6. Enter the risk values at each Fahrboeschung zone into a Geographical Information System programme and interpolate between the risks estimated for each zone to produce contours of equal risk on a map.

For cliff-top recession:

7. No systematic mapping of the cliff tops outside the pilot study areas has been carried out since the 22nd February 2011 earthquakes. Field inspections of some of the cliffs made by GNS Science and members of the Port Hills Geotechnical Group identified a few locations where about 1 to 2 m of the cliff edge had recessed. To take the lack of data into account, a conservative approach has been adopted where the annual individual fatality risk for cliff-top recession, estimated for Nayland Street in the pilot study area, have been used. Nayland Street data has been adopted as it represents the upper bound height of those cliffs included in this assessment and it is geometrically

similar (in angle and shape), to these cliffs. These assumptions were subsequently verified in the field by the Port Hills Geotechnical Group.

ES.4.3 Field verification

The results from the suburb-scale analysis have been verified in the field to the extent possible by appropriately qualified members of the Port Hills Geotechnical Group of consultants. Each property within the areas covered by this risk assessment has been visited and the risk maps accompanying this report take account of these results.

No additional obvious signs of cracking behind the cliff edges were identified during the field verification. It was confirmed that in a few locations about 1 – 2 m of the cliff edge had recessed. Adopting the Nayland Street annual individual fatality risk cliff top recession zone for the non-pilot study cliffs was therefore considered appropriate.

ES.5 Uncertainties

The risk-model sensitivities and uncertainties have been discussed in detail in section 7.2 in Massey et al. (2012a). The most important uncertainties are: 1) the expected frequency of a given earthquake ground acceleration; 2) the proportion of boulders (seismic triggers) or volume of debris (non-seismic triggers) that will travel given distances downslope; and 3) the assumption that all cliffs potentially can produce similar numbers of boulders when shaken by similar amounts. It is likely that the frequency of cliff collapses triggered by events other than earthquakes, such as long-duration or high intensity rainstorms, has been increased because the shaking has made the rockfall source areas more unstable. Such an increase will only become apparent through continued monitoring of rockfalls as they occur.

Although the uncertainties in the annual individual fatality risks estimated for the non-pilot study areas in this report are marginally higher than those for the pilot study areas, the major uncertainties affect all areas equally. The uncertainties have been reduced by field verification, but it is not possible to quantify what this reduction has been.

The expected confidence limits on the assessed risk levels are estimated to be marginally higher than an order of magnitude (higher or lower), in terms of the absolute risk levels presented in this report. That is, an assessed risk of 10^{-4} per year could reasonably range from 10^{-3} per year to 10^{-5} per year. Despite these uncertainties, GNS Science considers the annual individual fatality risks presented in this report are robust and Christchurch City Council should have confidence using these values for cliff collapse hazard management.

ES.6 Acknowledgments

This work for Christchurch City Council was carried out by GNS Science, assisted by the Port Hills Geotechnical Group of Consultants comprising URS, OPUS, Aurecon and GHD. The technical advice provided by L. Richards is also acknowledged. Data collection and analysis was funded in part by the New Zealand Natural Hazards Platform. This report was reviewed by Nicola Litchfield, GNS Science, and Tony Taig, Tony Taig Consulting Ltd. Eileen McSaveney, GNS Science, provided an editorial review.

1.0 INTRODUCTION

GNS Science has been commissioned by Christchurch City Council to assess and report on slope-instability risk in the Port Hills following the deaths of five people (two from rockfalls and three from cliff collapse) in the earthquakes of 22nd February 2011. This report is one of the series of reports on areas where much damage occurred; it specifically uses the methodology presented in Massey et al. (2012a), and covers those areas of the Port Hills that were not included in that pilot study report (Appendix A). It presents an assessment of the risk to life faced by an individual living above or below cliffs. This risk is expressed as the annual individual fatality risk. Fatality risk includes the risk of life-threatening injury. The report does not assess the risk of damage to critical infrastructure, nor does it assess the particular risks to particular people at particular places such as roads and right-of-ways.

The report considers cliff collapses, a type of landslide involving many boulders, triggered by earthquakes (taking into account expected changes in seismic activity in the Port Hills region over time) and by other non-seismic triggering events such as rainfall and spontaneous collapse. The report:

1) presents an analysis of the cliff collapse hazard in those Port Hills residential areas above and below steep cliffs; and

2) estimates the annual individual fatality risk (the risk of death) from cliff collapse in these areas.

1.1 Aims and objectives

The objectives of this work are to:

1) Present a suburb-scale cliff collapse life-safety risk assessment for those Port Hills areas not included in the pilot study report (Massey et al., 2012a) (Appendix A); and
2) Estimate the annual fatality risk to an individual on a residential property (dwelling) in these areas from cliff collapses triggered by earthquakes and compare these to risks from cliff collapses occurring in other events (such as storms), using the methodology contained in Massey et al. (2012a).

This work has been undertaken in conjunction with field verifications by the Port Hills Geotechnical Group. The Port Hills Geotechnical Group is a consortium of geotechnical engineers contracted to Christchurch City Council to assess slope instability in the Port Hills.

Analysis of risk in the areas covered by this report is based largely on data collected about cliff collapses triggered by the 22nd February 2011 earthquakes. This work is based on smaller cliffs (smaller than those discussed in Massey et al., 2012a), which comprise coastal cliffs that are either still being eroded by the sea, or those cliffs now abandoned by the sea, some of which have been quarried. All of these cliffs have relatively flat slopes beyond their bases.

1.2 Cliff collapse

In this report and the pilot study report (Massey et al., 2012a) GNS Science uses the terms: “cliff-top recession” to describe the result of landslides from the top and face of cliffs, and "debris avalanche" to describe the landslide process that inundates land at the cliff foot (referred to as "toe") with countless boulders. Collectively the two are referred to as cliff collapse.

Debris avalanche refers to a type of landslide comprising many boulders falling simultaneously from a slope. The rocks start by sliding, toppling or falling before descending the slope rapidly (>5 m/sec) (following Cruden and Varnes, 1996) by any combination of falling, bouncing and rolling.

For those cliffs included in the pilot study (Massey et al., 2012a) the main observed landslide type comprised debris avalanches. For those cliffs outside the pilot study areas the main observed landslide types comprised both debris avalanches and falls of individual boulders, referred to as "boulder rolls" (addressed by Massey et al., 2012b). Debris avalanches and boulder rolls both are classified as rockfalls (Cruden and Varnes, 1996).

For the smaller (typically between 10 and 40 m in height) cliffs discussed in this report, debris avalanches were relatively rare, and falls of individual boulders were the dominant recorded landslide type. As a result the risk-assessment methodology in this report differs from that carried out for the pilot study areas (contained in Massey et al., 2012a).

1.3 Limitations

Cliffs less than 10 m in height and/or at slope angles of less than 45° have not been included in this analysis. These cliffs only shed a few isolated boulders during the 2010/11 Canterbury earthquakes and therefore areas above and below these types of slope are assessed as being at lower levels of risk than those estimated in this report.

Cliffs less than 50 m^2 in plan area were not included in this analysis as they are too small for this suburb-scale analysis. It is recommended that these cliffs, where identified, are inspected in the field on a site-by-site basis by members of the Port Hills Geotechnical Group.

Cliffs modified by man-made cutting were not included unless they were originally abandoned coastal cliffs. Where identified, these should be inspected in the field on a site-by-site basis by members of the Port Hills Geotechnical Group.

Cliff formed predominantly of loess or other non-rock materials have not been included in this analysis. These should also be analysed at a later date.

Cliffs that are formed of rock, but are not costal or relict costal cliffs, are potential rockfall source areas. Some dwellings within the cliff collapse annual individual fatality risk zones may therefore also be affected by rockfall (boulder roll) hazards. The annual individual fatality risks from rockfall are estimated in Massey et al. (2012b).

Landslide types other than rockfalls and cliff collapse also occurred in the 2010/2011 Canterbury earthquakes. Movement of these landslides have made some dwellings uninhabitable, but these landslides pose no immediate fatality risk and are not discussed in this report.

2.0 DATA

The data used to develop the risk models in the Port Hills are listed in Table 1.

Table 1 Summary of datasets used in the cliff collapse risk analyses

Data	Description	Source	Date	Where used in the analysis
Massey et al. (2012a)	Contains the results from the cliff collapse risk assessment carried out in the pilot study areas.	GNS Science	March 2012	Provides data used in this report.
Massey et al. (2012b)	Contains the results from the rockfall (boulder roll) risk assessment carried out in the pilot study areas.	GNS Science	March 2012	Provides the methodology and used in this report.
Post 22nd February 2011 earthquake digital aerial photographs	Aerial photographs were taken on 24/02/2011 by New Zealand Aerial Mapping and were orthorectified by GNS Science (10 cm ground resolution).	New Zealand Aerial Mapping	Last updated 24/02/2011	Used to identify cliffs.
Light Detecting And Ranging (LiDAR) digital elevation model (DEM)	Digital elevation model derived from post 13th June 2011 earthquake LiDAR survey re-sampled to 3 m ground resolution.	New Zealand Aerial Mapping	18th July to 26th August 2011	Used as the base topography model, including identifying cliffs and development of the Fahrboeschung angles.
Christchurch building footprints	Footprints are derived from aerial photographs. The data originate from 2006 but have been updated in some areas by Christchurch City Council staff using the post-earthquake aerial photographs.	Christchurch City Council	Snapshot of the database taken 20/02/2012	Used to identify the locations of residential buildings in the cliff collapse zones.
Christchurch City Council rockfall database	The location, date and size of fallen rocks mapped in the field which were triggered by the 2010/11 Canterbury earthquakes, including rocks sourcing from the cliffs included in this report.	Engineering consultants working for Christchurch City Council. Data compiled by Christchurch City Council staff	Last updated April 2012	Used to estimate the numbers of rockfalls produced from the cliffs mainly by the 22nd February 2011 earthquakes, and the likelihood of a boulder striking a person at a particular location.

Data	Description	Source	Date	Where used in the analysis
Composite seismic hazard model for the Canterbury region	The increased level of seismicity in the Canterbury region since 4th September 2010 has been quantified using a modified form of the national seismic hazard model.	GNS Science	Updated 1st January 2012	Used to estimate the frequency of occurrence of a given peak ground acceleration.
Field work	Field mapping of the cliffs and field verification of the risk analyses.	GNS Science and the Port Hills Geotechnical Group	April and May 2012	Results from field verifications used to update the cliffs used for modelling and the risk maps.

3.0 METHODOLOGY

Using the Australian Geomechanics Society guidelines for landslide risk management (Australian Geomechanics Society, 2007), the risk of loss of life to an individual was calculated from:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad [1]$$

where:

- $R_{(LoL)}$ is the risk (annual probability of loss of life (death) of a person) from debris avalanches or cliff-top recession;
- $P_{(H)}$ is the annual probability of an initiating event;
- $P_{(S:H)}$ is the probability of a person, if present, being in the path of avalanching debris at a given location, or the probability of a person at a given location falling over the edge of the cliff as the cliff recedes;
- $P_{(T:S)}$ is the probability that a person is present at that location; and
- $V_{(D:T)}$ is the vulnerability, or probability of a person being killed if present and hit by debris or from falling over the edge of the cliff top as it recedes.

The key steps in the cliff collapse risk analysis include:

1) Risk analysis carried out as per the Australian Geomechanics Society (2007) method;

2) Field verification of the initial analysis by the Port Hills Geotechnical Group; and

3) Updating of the initial assessed risk with the results from the field verification.

3.1 Risk analysis

The pilot study areas of (Massey et al., 2012a) (Appendix A) cover the areas of residential housing most affected by cliff collapses triggered by the 2010/11 Canterbury earthquakes (Figure 1). Other areas in the Port Hills were also affected, but were either less populated or were beyond the main zone of aftershock activity in the 2010/11 Canterbury Earthquake sequence, e.g., towards the west of the Port Hills (Figure 1). In some areas of the Port Hills cliffs did not collapse because the ground accelerations there were not high enough to cause them to collapse.

The cliffs discussed in this report also differ in geometry (slope height and angle) from those of the pilot study areas, and as a result they behaved differently during the 2010/11 Canterbury earthquakes. Therefore it is inappropriate to apply the annual individual fatality risks from the cliffs in the pilot study areas to these smaller cliffs.

The risk analysis presented in this report assumes that it is possible for a large earthquake (>M_W 6) to occur anywhere beneath the Port Hills. Peak ground acceleration hazard curves for all locations in the Port Hills show very little geographical difference in the seismic hazard (G. McVerry personal communication, 2012).

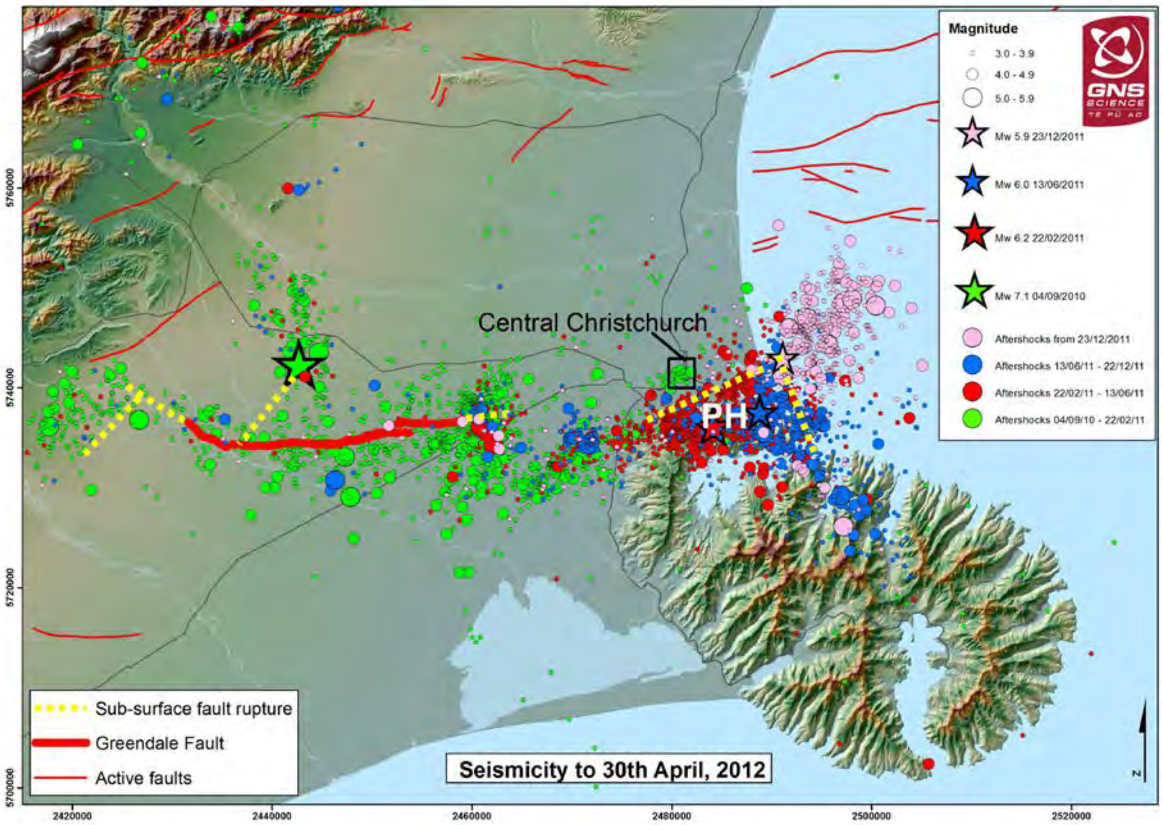


Figure 1 Sequence of aftershocks from the 4th September 2010 Darfield Earthquake to 30th April 2012. PH is the Port Hills.

The different stages of the risk analysis were:

1. Identification of cliffs outside the pilot study areas that could be susceptible to collapse;
2. Estimation of the annual individual fatality risk from debris avalanches falling from these cliffs; and
3. Estimation of the annual individual fatality risk from recession of the top of these cliffs.

3.1.1 Identifying cliffs with potential to collapse

This analysis only includes coastal cliffs that have buildings located above or below them and are either still being eroded by the sea, or are now abandoned by the sea. Some of these cliffs have also been quarried. All of these cliffs have relatively flat slopes beyond their bases.

Material falling from the cliffs during the 2010/11 Canterbury earthquakes landslides typically comprised debris avalanches and individual rockfalls. It should also be noted that many cliffs only shed a few isolated boulders and some did not shed anything. In the Port Hills, the susceptibility of a cliff to failure, and the nature of the failures (whether they predominantly comprise debris avalanches or falls of individual boulders) appears to be governed by slope geometry, mainly the height, slope angle and geology of the rock face (Figure 2), and the magnitude of the earthquake-induced peak ground accelerations they experience.

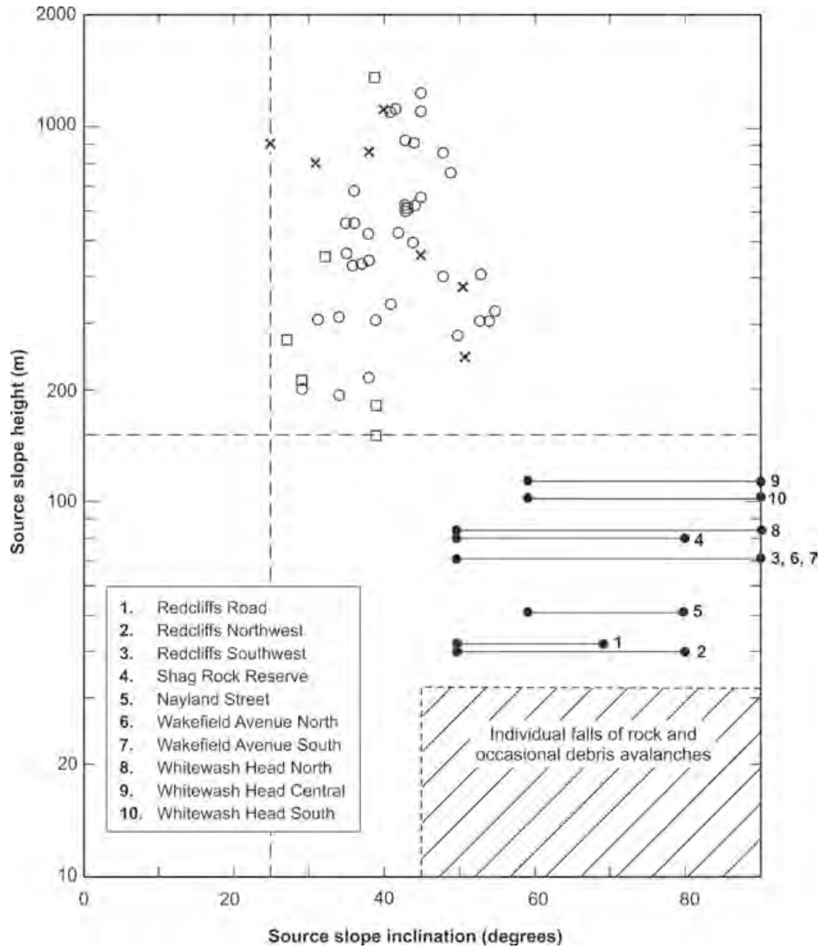


Figure 2 Relationship between source slope inclination and the slope height (note the logarithmic scale) for coastal cliffs in the Port Hills (modified from Keefer, 1984). The data from Keefer (1984) is shown as hollow circles, squares and crosses. The data from the pilot study areas (Massey et al., 2102a) are the numbered solid circles. The hatched box represents those coastal cliffs in the non-pilot study areas.

Numerous cliffs in the Port Hills, including those in the pilot study areas, were measured for height and slope along representative section lines using a digital elevation model derived from Light Detection And Ranging (LiDAR) survey carried out between 18th July to 26th August 2011 (Figure 3). These data show that:

- Cliffs that had few or no rockfalls had a mean slope height of about 13 m (±7 m at one standard deviation) and a mean slope angle of 59 (±9° at one standard deviation). Where rockfalls occurred, they were typically isolated individual blocks that were kinematically controlled;
- Cliffs primarily susceptible to the fall of individual blocks and occasional debris avalanches that were typically kinematically controlled, had a mean slope height of about 20 (±9°) inclined at a mean angle of 62° (±9°); and
- Cliffs that were most susceptible to debris avalanches, involving large portions of the cliff face, had a mean slope height of about 44 m (±25 m) and were inclined at a mean angle of 69° (±7°).

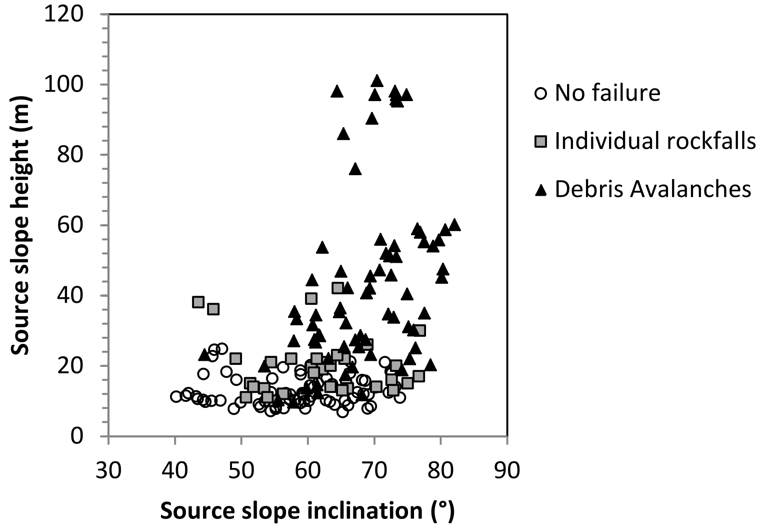


Figure 3 Relationship between source slope inclination and slope height for coastal cliffs in the Port Hills, including those in the pilot study areas (n = 180).

The geological material forming the cliffs is another important factor in the susceptibility of cliffs to failure, and their mechanism of failure. Data from the cliffs in the pilot study areas suggest that each cliff behaved differently during the earthquakes, with their behaviour being a function of slope geometry (Figure 4) and geology (Massey et al., 2012a).

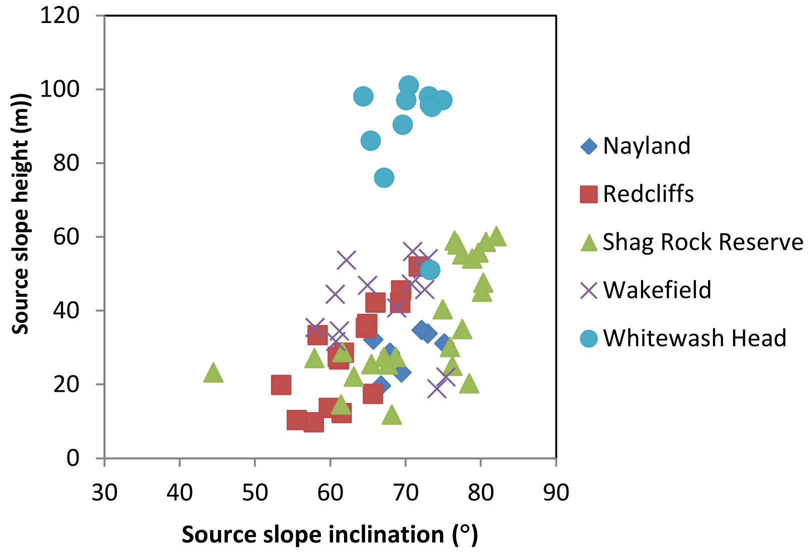


Figure 4 Relationship between source slope inclination and slope height for coastal cliffs in the pilot study areas.

The geometrical and geological material control is particularly apparent for the cliff tops. For those cliffs in the pilot study areas the magnitude of cliff-top recession in response to the 2010/11 Canterbury earthquakes ranges from 4 m at Nayland Street to 17 m at Whitewash Head, and the width of the zone of cracking (from cliff edge to limit of main cracks at the cliff top) ranged from 5 m to almost 80 m (Figures 5 and 6).

Field observations of some of the non-pilot study area cliffs indicate that, where identified, cliff-top recession has been in the order of a few metres. No systematic mapping of cracks at the cliff tops outside the pilot study areas has been carried out.

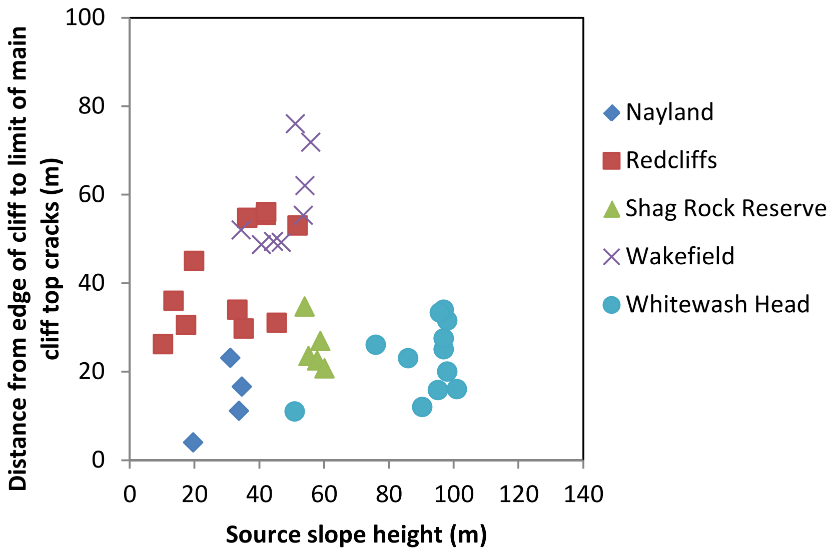


Figure 5 Relationship between source slope height and the distance from the cliff edge to the limit of the main cliff top cracks for coastal cliffs in the pilot study areas.

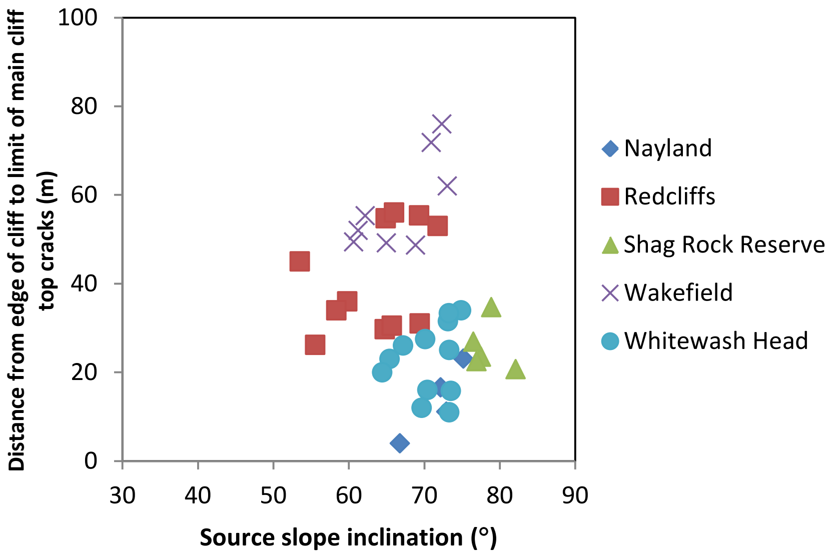


Figure 6 Relationship between source slope inclination and the distance from the cliff edge to the limit of the main cliff top cracks for coastal cliffs in the pilot study areas.

Cliff shape also appears to have been a controlling factor on the susceptibility of a cliff to failure and to the nature of the failure. This cliff shape control occurs whether it comprises the fall of an individual boulder or debris avalanches. It is thought that cliff shape, geometry and geology may have influenced the severity of the ground shaking experienced in particular settings. These observations are summarised in Figure 7.

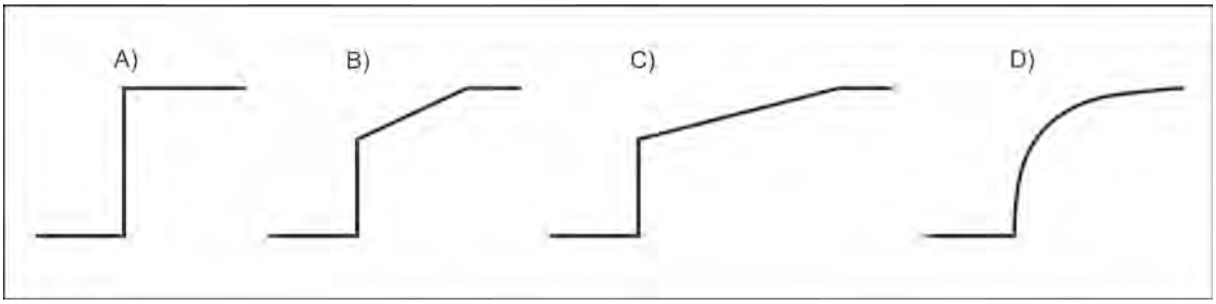


Figure 7 Schematic diagram showing cliff morphology in the Port Hills. A) and B) represent the majority of cliff shapes in the pilot study areas, where most of the 2010/11 Canterbury earthquake-triggered cliff collapse occurred. C) and D) represent the majority of cliff shapes in the non-pilot study areas.

As each of the cliffs tops analysed in the pilot study areas behaved differently during the 2010/11 Canterbury earthquakes, it is unrealistic to transfer the annual individual fatality risks from cliff-top recession estimated for these cliffs to cliffs in the non-pilot study areas.

The annual individual fatality risk from debris avalanches or individual boulders is dependent upon the volume of material falling from the cliffs for a given event. The volumes of material falling from cliffs in the pilot study areas involved several tens of thousands of cubic metres of debris, whilst the volumes of debris falling from cliffs in the non-pilot study areas were significantly smaller, and comprised mainly individual boulders and occasional debris avalanches of a few 100 cubic metres.

Based on the geometry of cliffs in the both the pilot and non-pilot study areas, the risk analysis presented in this report only includes cliffs that are:

1) coastal or relict coastal cliffs;
2) formed in rock;
3) greater than 10 m in vertical height (referring to the rock slope portion of the cliff);
4) steeper than 45° (referring to the rock slope portion of the cliff); and
5) greater than 50 m^2 in plan area.

Cliffs less than 10 m in height and/or at slope angles of less than 45° did not tend to fail during the 2010/11 Canterbury earthquakes. Areas above and below these types of slope are therefore considered to be at lower levels of risk, and have not been included.

A Geographical Information System programme (ArcGIS®) was used to apply criteria 2 to 4 to a digital elevation model derived from Light Detection And Ranging (LiDAR) surveys. The identified cliffs were then checked using the post-22nd February 2011 earthquake ortho-rectified aerial photographs and verified in the field. The crests of the validated cliffs were then digitised (their locations are shown in Appendix A).

3.1.2 Risk analysis steps

The analyses includes the assessment of the risk to an individual from: 1) debris avalanches (derived from the cliffs); and 2) cliff-top recession.

The risk is expressed as the annual individual fatality risk, which is the probability (likelihood) that a particular individual will be killed by a cliff collapse in any year. For most localities this probability is an imprecisely determined, very small number, and the report makes extensive use of the scientific number format of expressing risk in terms of powers of ten. For example the number 10^{-4} ("10 to the power of minus 4") is the fraction 1/10,000, and the decimal number 0.0001; it may also be expressed as 0.01%. The units of risk are probability per unit of time and the units of annual individual fatality risk are probability of death per year. In this study, the annual individual fatality risk is estimated only for residential properties.

For debris avalanches and cliff-top recession the risk analysis comprises the following steps:

1. Consider the full possible range of triggering events (e.g., earthquakes, rain) in terms of a set of earthquake triggers and a set of non-seismic triggers.
2. Choose a small set of representative events for each type of trigger spanning the range of severity of events from the smallest to the largest.
3. For each representative event, estimate:

For debris avalanches:

a) the frequency of the event and the number of boulders produced (seismic triggers) or volume of material (non-seismic triggers) ($P_{(H)}$).

b) the number of boulders reaching/passing a given Fahrboeschung angle (distance) down the slope and the probability of one of *N* boulders hitting a person at that location on the slope ($P_{(S:H)}$).

c) the probability that a person is present on the slope as the boulder moves through it ($P_{(T:S)}$).

d) the probability that a person will be killed if present and hit by one or more boulders ($V_{(D:T)}$).

4. Combine 3(a) – (d) for debris avalanche to estimate the annual individual fatality risk for individuals at different locations below the cliff or at the cliff edge contributed by each representative event.
5. Sum the risks from all events to estimate the overall risk.
6. Enter the risk values at each Fahrboeschung zone into a Geographical Information System programme and interpolate between the risks estimated for each zone to produce contours of equal risk on a map.

For cliff-top recession:

7. No systematic mapping of the cliff tops outside the pilot study areas has been carried out since the 22nd February 2011 earthquakes. Field inspections of some of the cliffs made by GNS Science and members of the Port Hills Geotechnical Group identified a few locations where about 1 to 2 m of the cliff edge had recessed. To take the lack of data into account, a conservative approach has been adopted, in which the annual individual fatality risk for cliff-top recession, estimated for Nayland Street in the pilot study area, has been used. Nayland Street data has been adopted, as it represents the upper bound height of those cliffs included in this assessment and it is geometrically similar (in angle and shape), to these cliffs.

3.1.2.1 Event magnitude and frequency

For many of these slopes in the Sumner to Heathcote areas, the numbers of boulders that have fallen from them during the 2010/11 Canterbury earthquakes have been mapped by consultants of the Port Hills Geotechnical Group. These fallen boulders have been used to develop the risk analysis for debris avalanches from these slopes (Table 2).

Table 2 Numbers of boulders falling from the cliffs in the Port Hills during the 2010/11 Canterbury earthquakes (non-pilot study areas).

Earthquake date	Peak ground acceleration (g)	GeoNet Station	Number of fallen boulders
3/09/2010	0.4	Lyttelton Port Company (LPCC)	1
22/02/2011	1.3	Lyttelton Port Company (LPCC)	924
16/04/2011	0.8	Panorama Road (PARS)	24
	0.4	Godley Head (GODS)	
13/06/2011	1.0	Panorama Road (PARS)	548
	2.2	Godley Head (GODS)	
23/12/2011	0.3	Panorama Road (PARS)	5
	0.2	Godley Head (GODS)	

There is not enough data to establish the magnitude (numbers of boulders) and frequency (annual frequency of occurrence) for all of the representative events taking into account seismic and non-seismic triggers (referred to as “bands” in Massey et al., 2012a) for these specific cliffs.

For seismic triggers (bands) the numbers of boulders triggered by the 22nd February 2011 earthquakes have been used as the representative event in the 1.0 to 2.0 g peak ground acceleration band. The numbers of boulders triggered by the 16th April 2011 earthquake have been used as the representative event the 0.4 to 1.0 g peak ground acceleration band. For the 2.0 to 5.0 g peak ground acceleration band a scale factor has been used to multiply the numbers of boulders generated in the 1.0 to 2.0 g band. This scale factor is based on the mean increase in the volumes of material falling from the cliffs in the pilot study areas, from the 1.0 to 2.0 g to the 2.0 to 5.0 g band, a scale factor of 17 (i.e., the volume falling from the pilot study area cliffs in the 2.0 to 5.0 g band is on average 17 times larger than the volume in the 1.0 to 2.0 g band). The numbers of boulders triggered by the 23rd December 2011 earthquake have been used as the representative event in the 0.1 to 0.4 g peak ground acceleration band (Table 3).

The annual frequency of the representative event per band occurring are taken from the composite seismic hazard model using the next 1-year median results, which is the same model used in the pilot study report (Massey et al., 2012a).

Table 3 Relationship between the volume falling from the cliff and the area of cliff top lost for seismic triggers, adopting the next 1-year seismic hazard model median values.

	Seismic events (per peak ground acceleration band (g))[1]			
	0.1 – 0.4	0.4 – 1.0	1.0 – 2.0	2.0 – 5.0
Numbers of boulders falling from ALL cliffs per event	5	24	924	15,708
Annual Frequency of event	0.60	0.168	0.0164	0.00076

[1]Note only the first non-zero digit of the number is significant

No data was available at the time of writing to assess the magnitude and frequency of debris avalanches and rockfalls triggered by non-seismic, mainly storm, events. To incorporate non-seismic events into the risk analysis, the magnitude frequency information relating to the Nayland Street cliff in the pilot study has been used. These data were used because Nayland Street is at the upper bound height of those cliffs in the non-pilot study area and the one that is most geometrically similar to these. The volumes of debris falling from the Nayland Street cliff for each representative event per time-period band were converted to numbers of boulders by assuming each cubic metre of debris comprises two boulders (refer to Massey et al., 2012a for details). These data are summarised in Table 4.

Table 4 Relationship between the volume falling from the cliff and the area of cliff top lost for non-seismic triggers.

	Non-seismic events (per time-period band (years))[1]			
	1 – 15	15 – 100	100 – 1,000	>1,000
Volume of debris falling from the Nayland Street cliff (in pilot area) (m^3)	5	170	1,500	10,000
Numbers of boulders falling from ALL cliffs per event, assuming each 1 m^3 of debris is formed of two boulders (based on estimated volumes from Nayland Street)	10	340	3,000	20,000
Annual Frequency of event	0.12	0.0044	0.0002	0.00001

[1]Note only the first non-zero digit of the number is significant

3.1.2.2 Impact from debris avalanche

$P_{F(S:H)}$ is the probability of a boulder hitting a portion of slope as it travels downhill from a source. The probability of one boulder hitting an object when passing through a particular portion of the slope, perpendicular to the boulder path, is expressed as:

$$P_{F1(S:H)} = \frac{(2D+d)}{L} \quad [1]$$

where *D* is the diameter of the design boulder (assumed to be 1.0 m) that travels along a path either side of *d,* within which the boulder cannot miss, *d* is the diameter of an object such as a person or width of a building, and *L* is the unit length of slope perpendicular to the runout path.

The probability of hitting the same portion of slope increases with each successive boulder travelling down the slope. The probability of one boulder of the total number *N* boulders hitting an object when passing through that same portion of slope is then given, if all *N* of the boulders are randomly distributed across the slope, by:

$$P_{N(S:H)} = 1 - (1 - P_{1(S:H)})^{N} \quad [2]$$

For the purposes of risk estimation, it is necessary to have a quantitative measure of the size of a person. In this report, a "person" is assumed to be a cylinder of 1 m diameter and unspecified height (no specification of height was required in the model).

The numbers of boulders reaching or passing a given distance on a slope within a runout zone was estimated for all non-pilot study cliffs using the numbers of boulders that fell from them during the recent earthquakes (Table 2). Fahrboeschung angles were used to provide a consistent measure of map distance out from the cliff edges, while talking into account the height of the cliff as a runout-controlling factor. The numbers and proportion of boulders passing a given Fahrboeschung angle were then calculated using the fallen boulder data, and the length of each Fahrboeschung-angle line, perpendicular to the cliff, was calculated (Table 5 and Figure 8 respectively).

Table 5 Non-pilot study cliffs – The numbers of boulders passing a given Fahrboeschung angle that were triggered by the recent Canterbury earthquake sequence.

Fahrboeschung angle (°)	N boulders passing	Length of Fahrboeschung-angle line
Cliff crest	1,502	6,043
60	1,077	6,166
50	612	6,116
40	29	6,355
36	9	6,311
33	6	6,527
31	3 (stopped within 1 - 2 m either side of Fahrboeschung angle)	6,519

The numbers of boulders generated by the representative event in each seismic and non-seismic band, and passing a given Fahrboeschung angle were then estimated using the relative proportions of boulders estimated from Table 5. No boulders travelled past the 31° Fahrboeschung angle and three boulders (0.2% of all boulders) landed within 1 to 2 m either side of it.

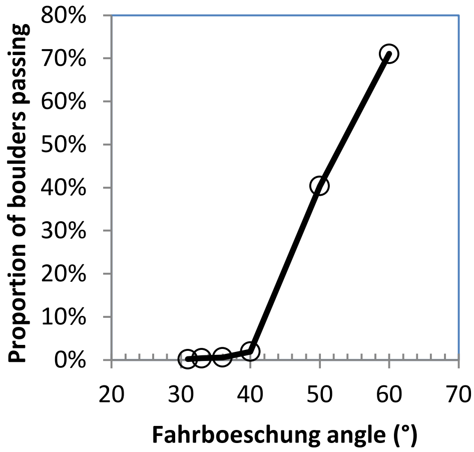


Figure 8 Proportion of boulders passing a given Fahrboeschung angle for cliffs in the non-pilot study areas. Calculated as the proportion of the total number of boulders passing each Fahrboeschung angle.

3.1.2.3 Falling due to cliff-top recession

$P_{R(S:H)}$ is the probability of loss of a particular location at the cliff top and a person falling should they be present. The probability of a person or object falling is dependent upon the total area of cliff edge lost during a given event, and how close the person or object is to the cliff edge, as the proportion of cliff top that is lost in any event decreases away from the cliff edge.

There are no data for the cliffs outside the pilot study areas, although field inspections of some of the cliffs made by GNS Science and members of the Port Hills Geotechnical Group identified a few locations where about 1 – 2 m of the cliff edge had failed. To take the lack of data into account, a conservative approach was adopted and the annual individual fatality risk model from cliff-top recession calculated for Nayland Street (in the pilot study areas) was used. At Nayland Street the width of the annual individual fatality risk zone is about 4 m. The risk within this zone is estimated to be greater than 10^{-4}.

Cliff-top recession is likely to occur during discrete events. Therefore, if a portion of the cliff top collapses in a future event (e.g., an earthquake) then the annual individual fatality risk zones will accordingly migrate parallel with the new cliff top edge.

To take these issues into account and to make the risk assessment robust to future cliff-top recession, “earthquake event” lines have been shown on the maps. These lines represent the possible maximum recession position of the cliff edge given future earthquakes with associated peak ground accelerations in the 2.0 g range, similar to the 22nd February and 13th June 2011 earthquakes. These lines do not mean that the entire cliff in front of them, and extending to the cliff edge, is likely to recess, but that any given part of the cliff in this area could recess back to this line given a future event of this magnitude.

Thus each line can be considered a worse-case-scenario in an individual earthquake. The width of each earthquake event zone is equal to the width of the maximum cliff-top recession. For Nayland Street this width is about 4 m.

3.1.2.4 Probability of a person being present

$P_{(T:S)}$ is the probability that an individual being present on the portion of the slope when either the boulder moves through it or when it falls away, and is a function of the proportion of time spent by a person at a particular location each day.

For a person standing at the cliff bottom the probability $P_{(T:S)}$ of being present in a portion of slope when the boulder moves through it is assumed to be 1.0 and the person cannot get out of the way. This is consistent with the value used in Massey et al. (2012a), and takes into account that in places the boulders leaving the non-pilot study area cliffs comprised clusters of many boulders.

For a person standing at the cliff top the probability $P_{(T:S)}$ of being present on an area of ground as it falls is assumed to be 0.9 to allow for the possibility of escape. This is consistent with the value used for the cliffs in the pilot study areas.

3.1.2.5 Probability of the person being killed if hit or falling

$V_{(D:T)}$ is the probability of a person being killed (or receiving injuries which may prove fatal in the near aftermath of the event) if present on the slope and either in the path of debris, or falling from the cliff top.

For this study, $V_{(D:T)}$, the probability of being killed or receiving fatal injuries for a person impacted by a boulder is assumed to be 0.5, and the probability of being killed or receiving fatal injuries for a person falling from a cliff, is assumed to be 1.0. These values are consistent with those used in the pilot study reports (Massey et al., 2012a,b).

3.1.3 Field verification of risk results

Consultants of the Port Hills Geotechnical Group, in collaboration with GNS Science, carried out field verification of the risk zones, to either:

1) Ensure all cliffs matching the five assessment criteria in section 3.1.1 were included in the analysis;
2) Confirm that the hazard zones (Fahrboeschung angles) were correctly defined in relation to the known source-slope areas; or
3) Recommend changes to the risk-zone boundaries on the basis of site-specific ground conditions that were not detectable in the ArcGIS analysis.

The field verification methodology and pro forma are contained in Appendix E of Massey et al. (2012a). The risk maps have been updated with the results from the field verification.

4.0 RESULTS

The results from the risk analysis are summarised in Tables 6 and 7 and the risk maps are shown in Appendix B. The values of risk are the annual individual fatality risk of an individual located in either the debris avalanche (Fahrboeschung) zones used in the analyses, adopting the next 1-year (median) composite seismic hazard model results, or the cliff-top recession zones.

Table 6 Contribution to annual individual fatality risk from debris avalanches across each earthquake peak ground acceleration band, using the median 1-year composite seismic hazard model results, and $P_{(T:S)}$ = 1.0 and $V_{(D:T)}$ = 0.5.

Fahrboeschung angle (º)	Earthquake peak ground acceleration band				Total earthquake annual individual fatality risk
	0.1 – 0.4 g	0.4 – 1 g	1 – 2 g	2 – 5 g	
60	7.8×10^{-4}	5.5×10^{-3}	8.2×10^{-3}	3.8×10^{-4}	1.5×10^{-2}
50	4.5×10^{-4}	1.8×10^{-3}	8.2×10^{-3}	3.8×10^{-4}	1.1×10^{-2}
40	2.1×10^{-5}	4.0×10^{-6}	1.0×10^{-5}	1.7×10^{-4}	2.0×10^{-4}
36	6.4×10^{-6}	3.9×10^{-7}	3.1×10^{-7}	2.1×10^{-6}	9.2×10^{-6}
33	4.1×10^{-6}	1.7×10^{-7}	9.0×10^{-8}	3.9×10^{-7}	4.8×10^{-6}
31	2.1×10^{-6}	4.2×10^{-8}	1.1×10^{-8}	2.5×10^{-8}	2.1×10^{-6}

Table 7 Contribution to annual individual fatality risk from debris avalanches across each non-seismic event band, adopting $P_{(T:S)}$ = 1.0 and $V_{(D:T)}$ = 0.5.

Fahrboeschung angle (º)	Non-seismic band				Total non-seismic annual individual fatality risk
	1 – 15 years	15 – 100 years	100 – 1,000 years	> 1,000 years	
60	4.2×10^{-4}	4.6×10^{-4}	8.8×10^{-5}	5.0×10^{-6}	9.7×10^{-4}
50	2.4×10^{-4}	2.8×10^{-4}	7.0×10^{-5}	5.0×10^{-6}	5.9×10^{-4}
40	1.1×10^{-5}	1.4×10^{-5}	5.3×10^{-6}	1.5×10^{-6}	3.1×10^{-5}
36	3.4×10^{-6}	4.3×10^{-6}	1.7×10^{-6}	5.4×10^{-7}	9.9×10^{-6}
33	2.2×10^{-6}	2.7×10^{-6}	1.1×10^{-6}	3.5×10^{-7}	6.4×10^{-6}
31	1.1×10^{-6}	1.4×10^{-6}	5.5×10^{-7}	1.8×10^{-7}	3.2×10^{-6}

The above results show that:

1. Earthquakes contribute more to the overall risk than non-seismic triggering events;
2. Frequently occurring non-seismic events contribute more risk than do frequently occurring earthquakes; but
3. Earthquakes dominate the risk for rare events that occur every few hundred years.

The risk estimated for these cliffs are compared to those risks estimated for cliffs in the pilot study areas (Figure 9). The annual individual fatality risks from debris avalanches in the pilot study areas are typically an order of magnitude greater than those risks estimated for the same Fahrboeschung zones from the non-pilot study area cliffs. This is because in the pilot study areas many thousands of cubic metres of debris, and therefore many thousands of boulders, fell from them, whilst only a few boulders along with the occasional few hundred cubic metres of debris fell from these non-pilot study area cliffs.

The greater number of cliff collapses in the pilot study areas is because the cliffs there are steeper, and much greater in height, with relatively flat areas at their crests, when compared to the smaller and more rounded cliffs in the non-pilot study areas (Figure .

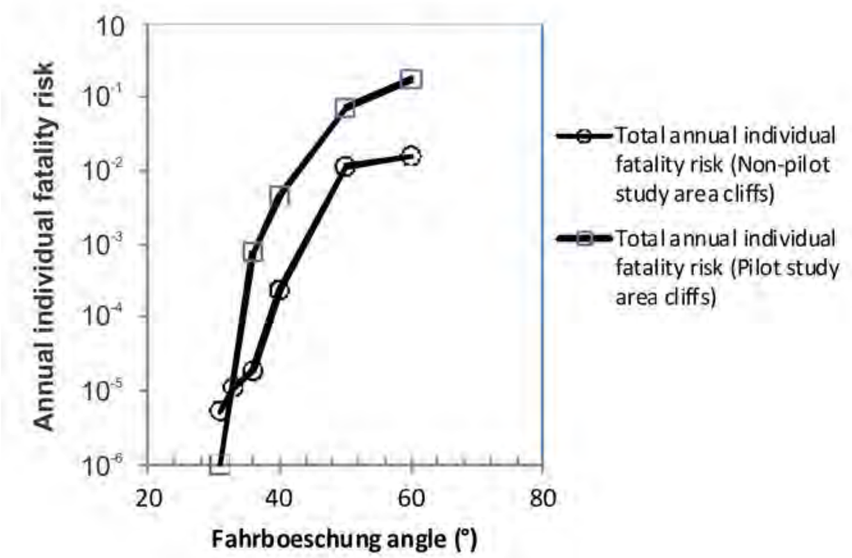


Figure 9 Annual individual fatality risk estimated for the pilot study area cliffs and the non-pilot study area cliffs. Risk is for both seismic and non-seismic events.

4.1 Numbers of residential homes in each risk category

The annual individual fatality risks at each Fahrboeschung angle were modelled using the ArcGIS programme to produce the risk contour maps, and the numbers of homes falling into different risk bands were derived from these maps (Tables 8 and 9).

Table 8 Buildings within assessed Port Hills risk zones below cliffs and subject to the hazard of debris avalanche (note: does not include buildings exposed to the hazard of boulder rolls).

Building type	**Annual individual fatality risk category**				
	$10^{-1} – 10^{-2}$	**$10^{-2} – 10^{-3}$**	**$10^{-3} – 10^{-4}$**	**$10^{-4} – 10^{-5}$**	**Below 10^{-5}**
Buildings below cliffs in the non-pilot study areas					
Dwellings	11	15	14	22	10
Building-type unknown	9	2	2	0	2
Total	20	17	16	22	12
Buildings below cliffs in the pilot study areas					
Dwellings	16	11	3	1	4
Building-type unknown	6	3	0	0	0
Total	22	14	3	1	4
All buildings below cliffs in the pilot and non-pilot study areas					
Dwellings	27	26	17	23	14
Building-type unknown	15	5	2	0	2
Total	42	31	19	23	16

No additional obvious signs of cracking behind the cliff edges were identified during the field verification. It was confirmed that in a few locations about 1 – 2 m of the cliff edge had recessed. Adopting the Nayland Street annual individual fatality risk cliff top recession zone for the non-pilot study cliffs was therefore considered appropriate.

Within the analysed cliff-top recession areas, annual individual fatality risks are greater than 10^{-4}/year. The numbers of homes falling into the annual individual life risk cliff top recession zones and within the earthquake event lines are given in Table 9.

Table 9 Buildings within assessed Port Hills risk zones subject to the hazard of cliff-top recession (note: does not include buildings exposed to the hazard of boulder rolls).

Building type	Earthquake event lines		
	Annual individual fatality risk zone >10^{-4}	**2nd**	**3rd**
Buildings below cliffs in the non-pilot study areas			
Dwellings	16	18	15
Building type unknown	1	2	2
Total no. of buildings	17	20	17
Dwellings within the pilot study areas			
Total no. of dwellings	33	15	25
Total dwellings in the pilot and non-pilot study areas			
Total no. of dwellings	50	35	42

4.2 Model sensitivities and uncertainties

The risk-model sensitivities and uncertainties have been discussed in detail in section 7.2 of Massey et al. (2012a). The most important uncertainties are: 1) the expected frequency of a given earthquake ground acceleration; 2) the proportion of boulders (seismic triggers) or volume of debris (non-seismic triggers) that will travel given distances downslope; and 3) the assumption that all cliffs potentially can produce similar numbers of boulders when shaken by similar amounts. It is likely that the frequency of cliff collapses triggered by events other than earthquakes, such as long duration or high intensity rainstorms, has been increased because the shaking has made the rockfall source areas more unstable. Such an increase will only become apparent through continued monitoring of rockfalls as they occur.

Additional risk uncertainty has been introduced into the risk analysis in this report through uncertainties in the identification of the cliffs and their geometry, and through the assumption that all cliffs can potentially produce similar numbers of boulders (volumes of debris) that travel similar distance down slope when shaken by similar amounts.

Although the uncertainties in the annual individual fatality risks estimated for the non-pilot study areas in this report are marginally higher than those for the pilot study areas, the major uncertainties affect all areas equally. The uncertainties have been reduced by field verification, but it is not possible to quantify what this reduction has been.

The expected confidence limits on the assessed risk levels are estimated to be marginally higher than an order of magnitude (higher or lower), in terms of the absolute risk levels presented in this report. That is, an assessed risk of 10^{-4} per year could reasonably range from 10^{-3} per year to 10^{-5} per year. Despite these uncertainties, GNS Science considers the annual individual fatality risks presented in this report are robust and Christchurch City Council should have confidence using these values for cliff collapse hazard management.

5.0 CONCLUSIONS

1) Following the 4th September 2010 Darfield Earthquake the levels of seismic activity in the Christchurch region have been considerably higher than the long-term average, and are likely to remain higher for several decades. The long-term seismicity is also recognised to be higher than it was understood to be before 4th September 2010. As a result the previously unknown annual individual fatality risk from cliff collapse is considerably higher than it was before September 2010. The fatality risk from earthquake-induced cliff collapse is expected to decrease as the seismic hazard decreases.

2) For the small (typically less than 40 m in height) cliffs in the non-pilot study areas, debris avalanches were relatively rare, and falls of individual boulders were the dominant recorded landslide type. As a result the risk assessment methodology in this report differs from that carried out for the pilot study areas (contained in Massey et al., 2012a).

3) The annual individual fatality risks from debris avalanches in the pilot study areas are typically an order of magnitude greater than those risks estimated for the same Fahrboeschung zones relating to the non-pilot study area, smaller, cliffs. This is because in the pilot study areas many thousands of cubic metres of debris, and therefore many thousands of boulders fell from the cliffs.

4) The cliffs in the pilot study areas are steeper, and much greater in height, with relatively flat areas at their crests, when compared to the smaller and more rounded cliffs in the non-pilot study areas.

5) In those areas not included in the pilot study areas, but included in this report, there are a total of 87 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones relating to debris avalanches. Of these, about 37 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 16 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 22 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 12 expose people to risks less than 10^{-5}/year.

6) In the Port Hills total areas, including both the pilot study areas and those areas analysed in this report, there are a total of 131 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones relating to debris avalanches. Of these, about 73 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 19 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 23 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 16 expose people to risks less than 10^{-5}/year.

7) Within the analysed cliff-top recession areas, annual individual fatality risks are greater than 10^{-4}/year.

8) Cliff-top recession mainly occurs during earthquakes, as witnessed during the 2010/2011 Canterbury earthquakes. It is likely that in the next decade further recession of the cliff edge will also occur during earthquakes. Each time the cliff top moves so too will the risk zones by an equal amount.

9) To take account of cliff-top recession and to make the risk assessment robust to further large earthquakes, “earthquake event” lines have been included on the maps. These lines represent the likely maximum loss of the cliff edge in future earthquakes with associated peak ground accelerations of about twice the gravitational acceleration (2 g), which is similar to those in the 22nd February and 13th June 2011 earthquakes.

10) These earthquake event lines do not mean that the entire cliff between that line and the cliff edge will recede in a single event; they mean that any given part of the cliff in this area could recede back to this line in another event of this magnitude. The distance between each earthquake event line is set equal to the width of the maximum cliff-top

recession measured at each cliff after the 2010/11 Canterbury earthquakes.

11) There are 50 dwellings (including those classified as “unknown”) located in the cliff recession annual individual fatality risk zones, where the risks are estimated to be greater than 10^{-4}/year.

6.0 RECOMMENDED CHRISTCHURCH CITY COUNCIL ACTIONS

It is recommended that:

1) Council accepts the information regarding annual individual fatality risk from cliff collapses presented in this report;
2) Council uses the information in reaching decisions about future risk management for cliff collapse-affected dwellings in the Port Hills;
3) Given the time-varying nature of the seismic hazard, the assessed individual fatality risks should be re-evaluated after a period of about 10 years to incorporate a seismic hazard model appropriate to the knowledge of that time. This also would allow data collected on the stability of the now seismically disturbed cliffs of the Port Hills to be considered in the risk;
4) Cliffs less than 50 m^2 in plan area were not included in this analysis as they are too small for this suburb-scale analysis. It is recommended that these cliffs, where identified, are inspected in the field on a site to site basis by members of the Port Hills Geotechnical Group;
5) Cliffs modified by cutting were not included unless they were abandoned coastal cliffs that were once quarried or modified for housing. Where identified, these should be inspected in the field on a site to site basis by members of the Port Hills Geotechnical Group; and
6) Cliff formed predominantly of loess or other non-rock materials have not been included in this analysis. These should be analysed at a later date.

7.0 REFERENCES

Australian Geomechanics Society (AGS) 2007. Practice Note Guidelines for Landslide Risk Management. Journal and News of the Australian Geomechanics Society 42(1): 63–114.

Cruden, D.M.; Varnes, D.J. 1996. Landslide types and processes. Landslide: investigation and mitigation. Turner, K.A.; Schuster, R.L. (eds.). Special report, Transportation Research Board, National Research Council, 247. Chapter 3, 36–75.

Gerstenberger, M.C.; McVerry, G.; Rhoades, D.A.; Stirling, M.W.; Berryman, K.; Webb, T. 2011. Update of the Z-factor for Christchurch considering earthquake clustering following the Darfield earthquake. GNS Science Consultancy Report 2011/29.

Keefer, D.K. 1984. Landslides caused by earthquakes. Geological Society of America Bulletin 95(4): 406–421.

Massey, C.I.; McSaveney, M.J.; Yetton, M.D.; Heron, D.; Lukovic, B.; Bruce, Z.R.V. 2012a. Canterbury Earthquakes 1020/11 Port Hills Slope Stability: Pilot study for assessing life-safety risk from cliff collapse. GNS Science Consultancy Report 2012/57.

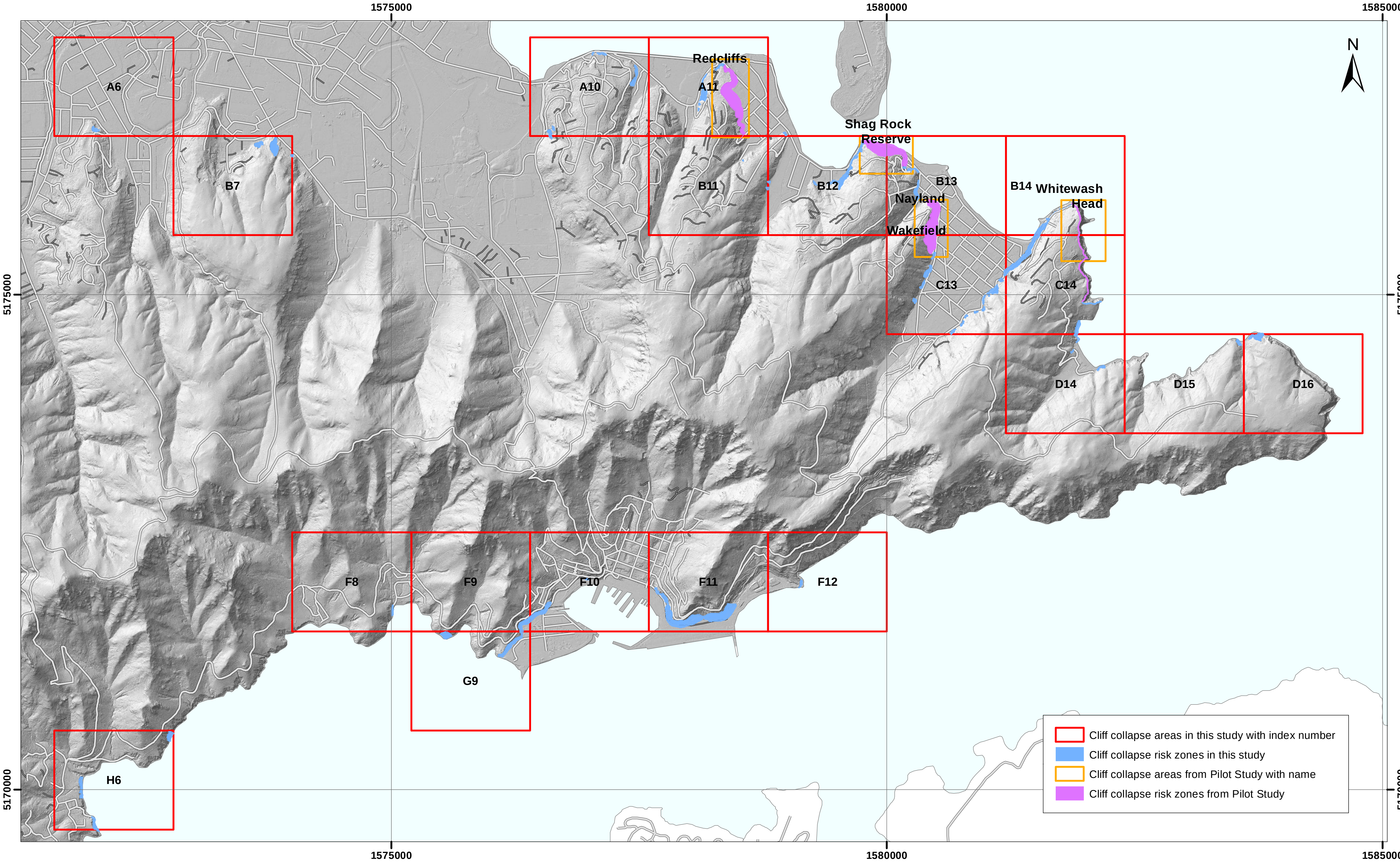
Massey, C.I.; McSaveney, M.J.; Heron, D.; Lukovic, B. 2012b. Canterbury Earthquakes 2010/11 Port-Hills Slope Stability: Pilot study for assessing life-safety risk from rockfalls (boulder rolls). GNS Science Consultancy Report 2011/311.

8.0 ACKNOWLEDGEMENTS

This work for Christchurch City Council was carried out by GNS Science, assisted by the Port Hills Geotechnical Group of Consultants comprising URS, OPUS, Aurecon and GHD. The technical advice from L. Richards is also greatly acknowledged. Data collection and analysis was funded in part by the New Zealand Natural Hazards Platform. This report was reviewed by Nicola Litchfield, GNS Science, and Tony Taig, Tony Taig Consulting Ltd. Eileen McSaveney, GNS Science, provided an editorial review.

APPENDICES

APPENDIX A LOCATION PLAN



SCALE BAR: 0 0.5 1 1.5 2 2.5 km

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution.

Roads provided by Christchurch City Council.

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

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LOCATION PLAN

Port Hills Christchurch

APPENDIX A

FINAL ISSUE 2

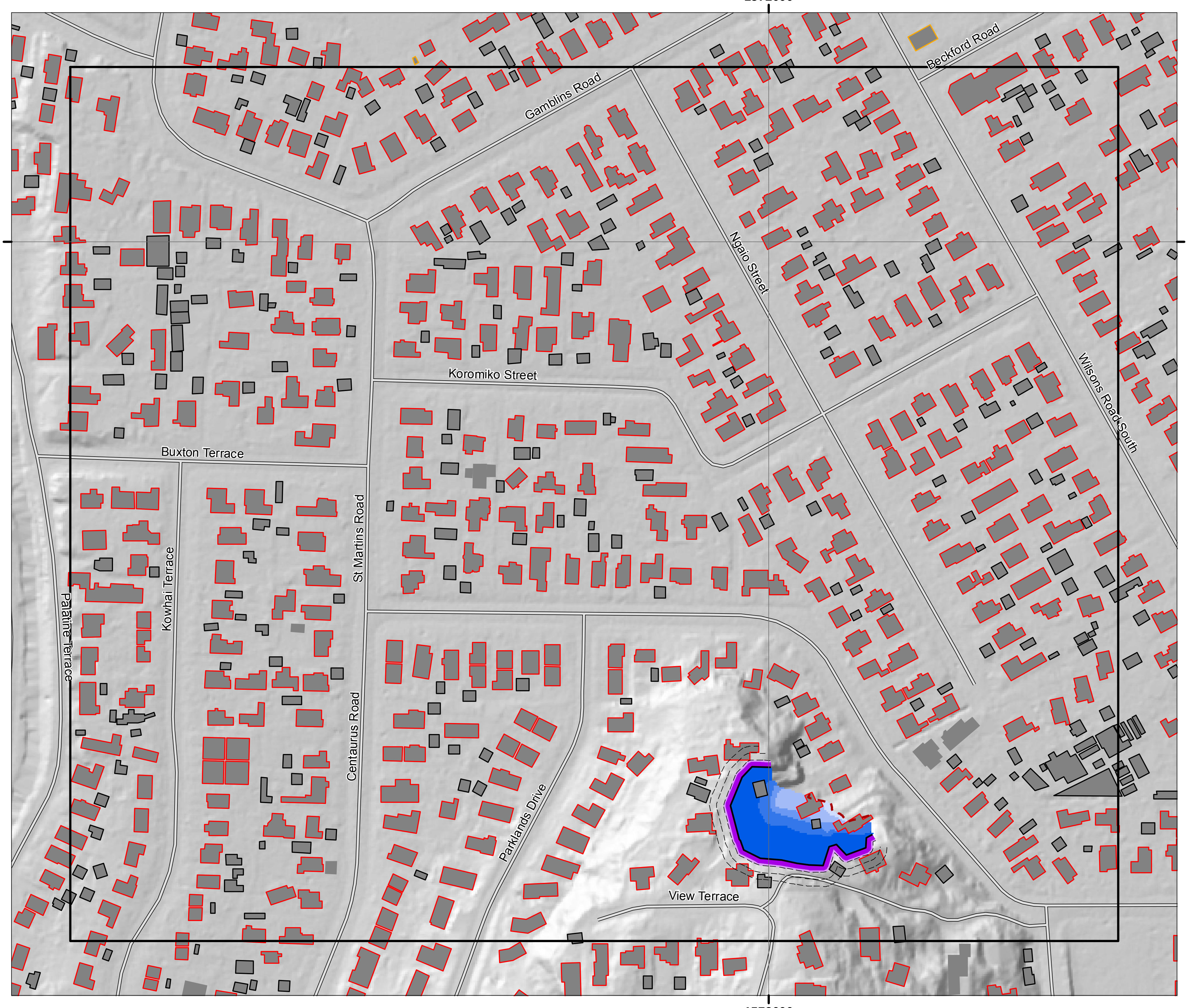
REPORT: CR2012/124

DATE: July 2013

APPENDIX B ANNUAL INDIVIDUAL FATALITY RISK FROM CLIFF COLLAPSE MAPS

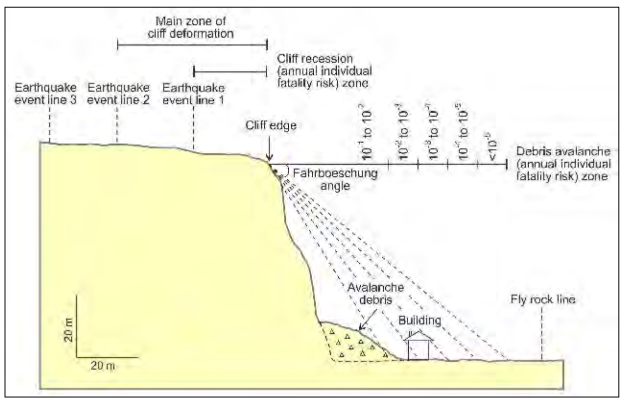
1572000

5177000



5177000

1572000



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

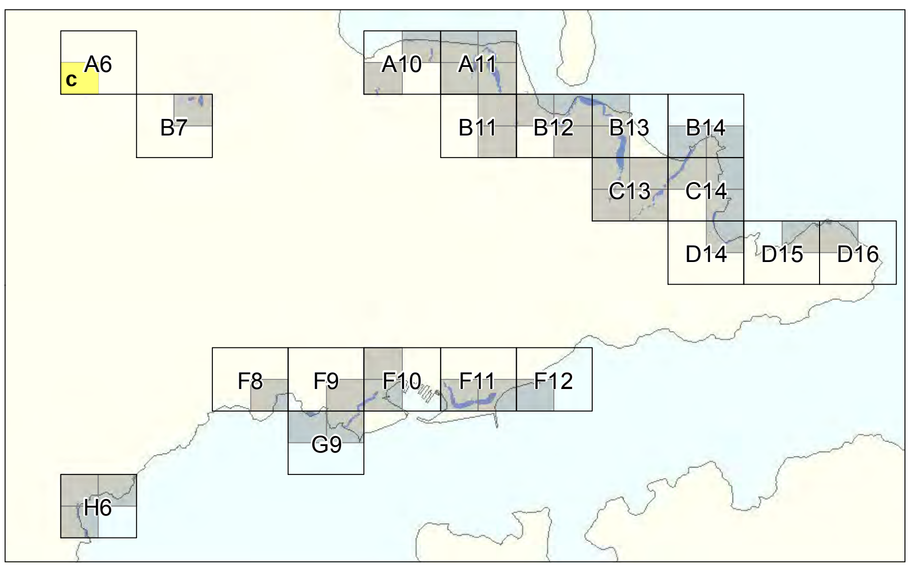
Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

Debris avalanche - A type of landslide comprising many boulders falling simultaneously from a slope. The rocks start by sliding, toppling or falling before descending the slope rapidly (greater than 5 metres per second) by any combination of falling, bouncing and rolling.

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Fly rock line – The fly rock line (brown dash) is the expected limit of fly rock. Fly rock is broken rock released as high-velocity projectiles created in impacts between rocks and other hard objects.

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

Port Hills
Christchurch

APPENDIX B
Map A6c

FINAL ISSUE 2

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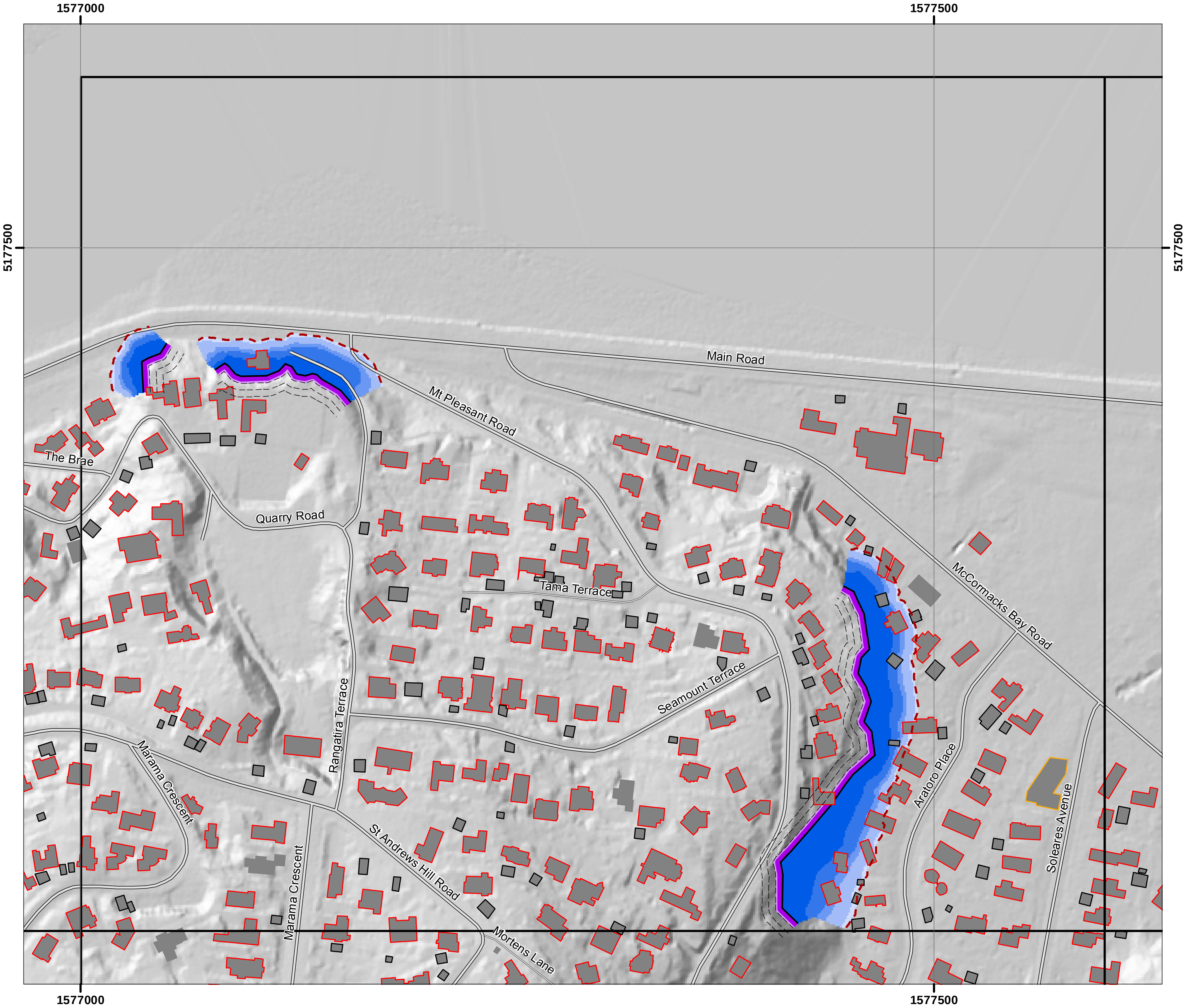
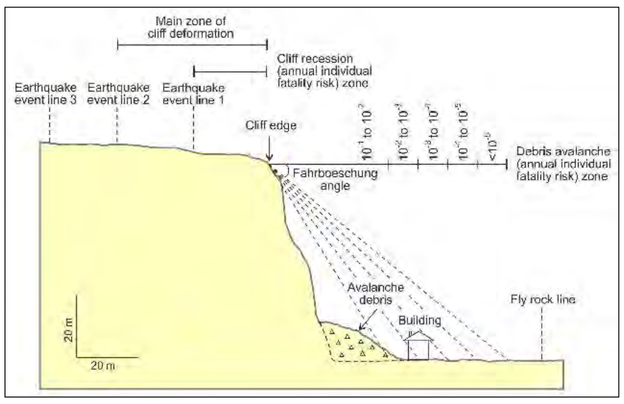
DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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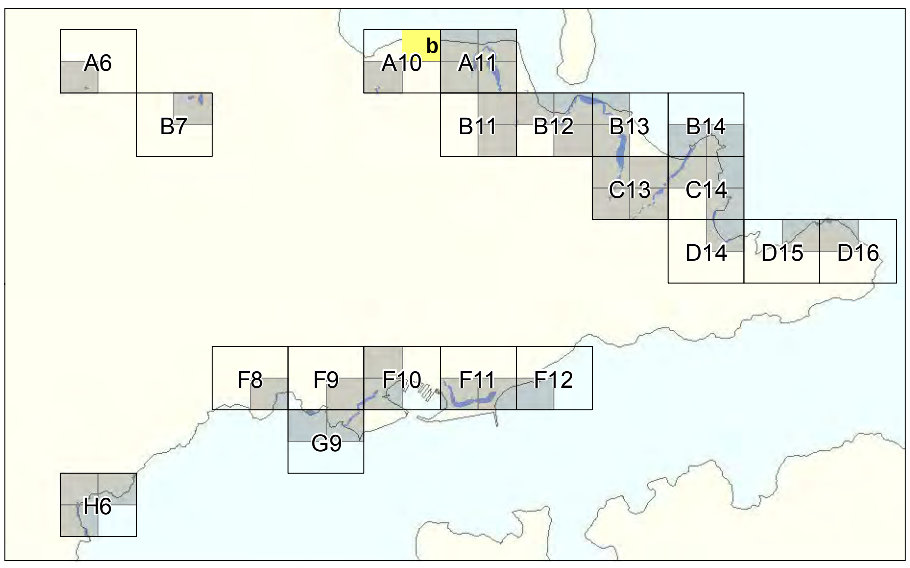

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

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CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

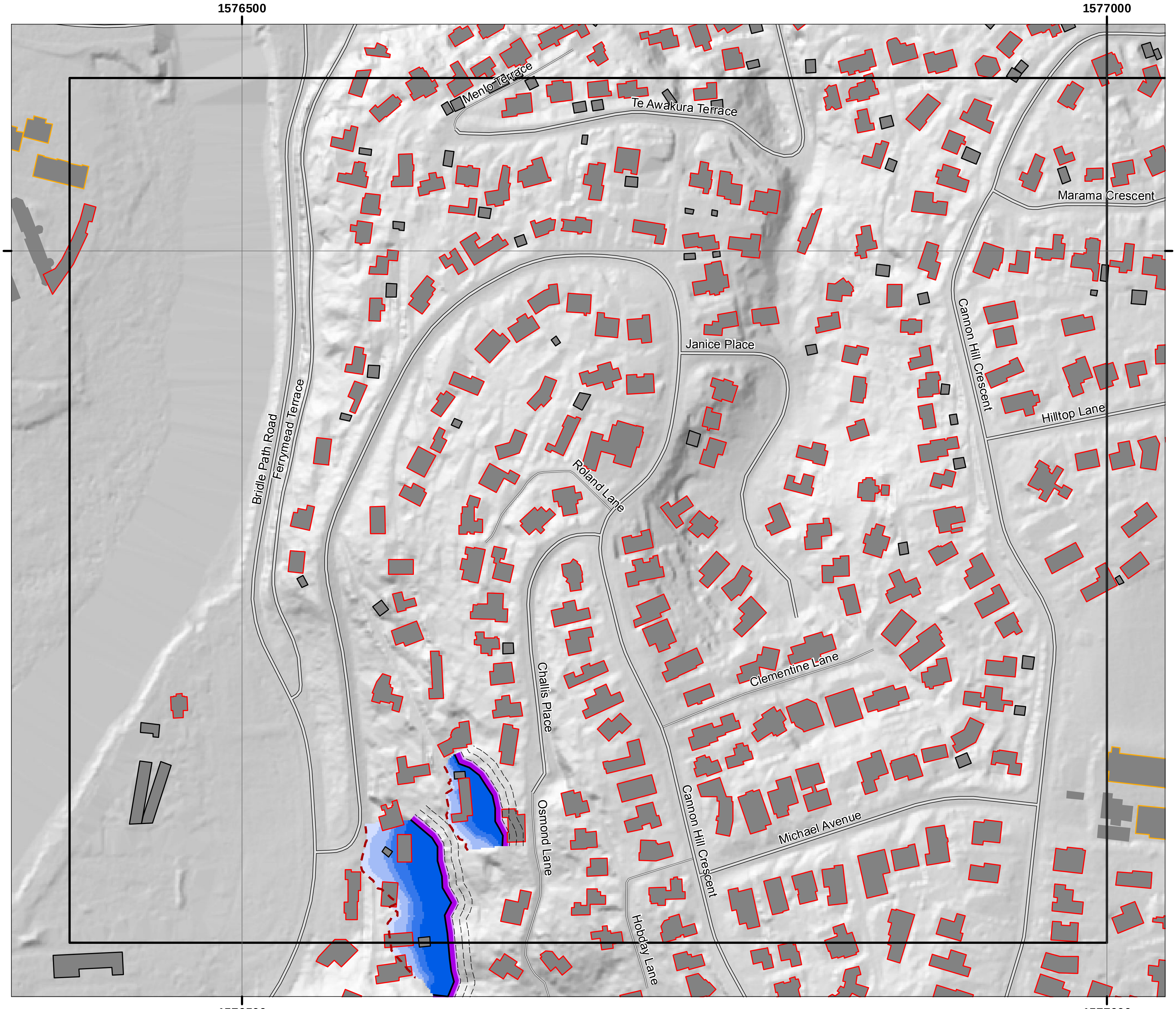
Port Hills Christchurch

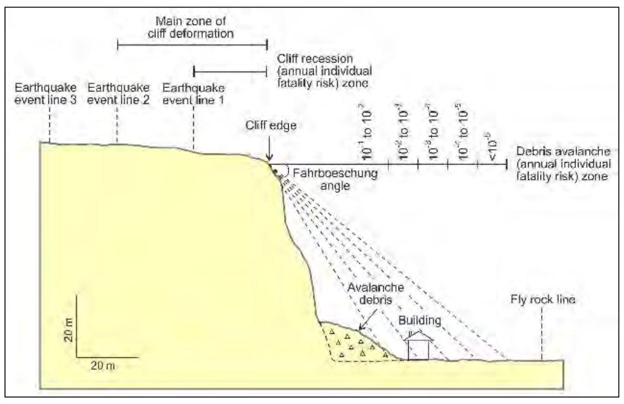
APPENDIX B Map A10b

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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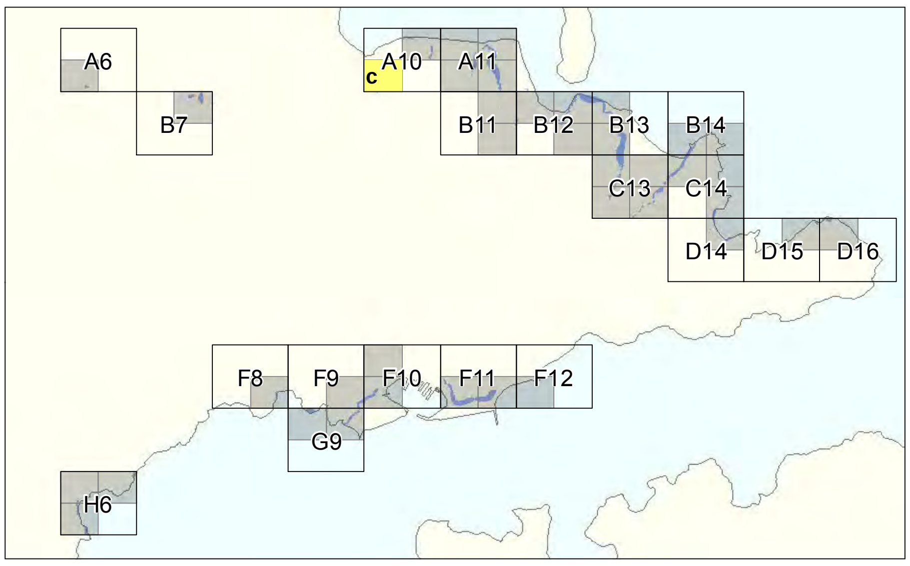

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

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CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

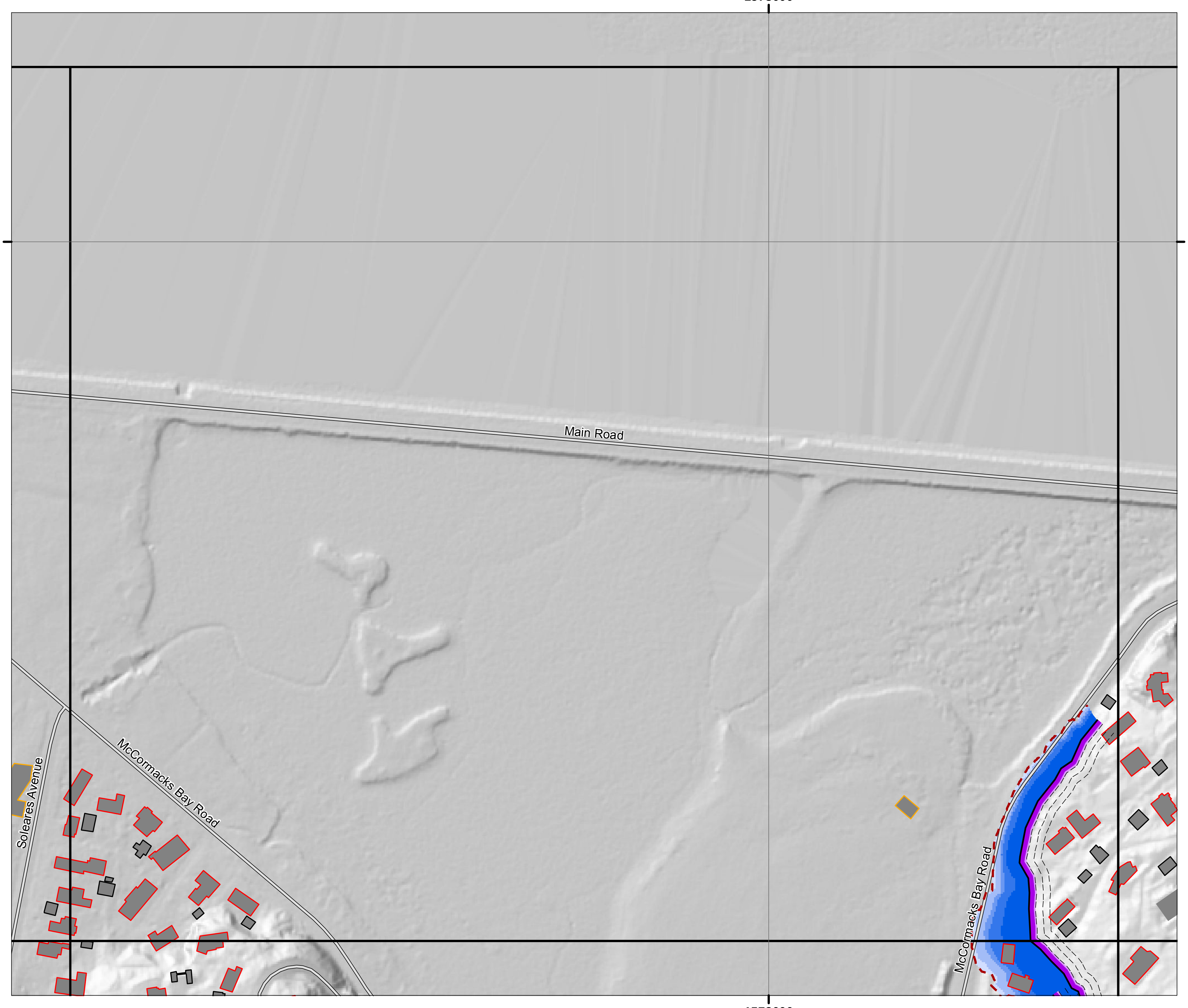
Port Hills Christchurch

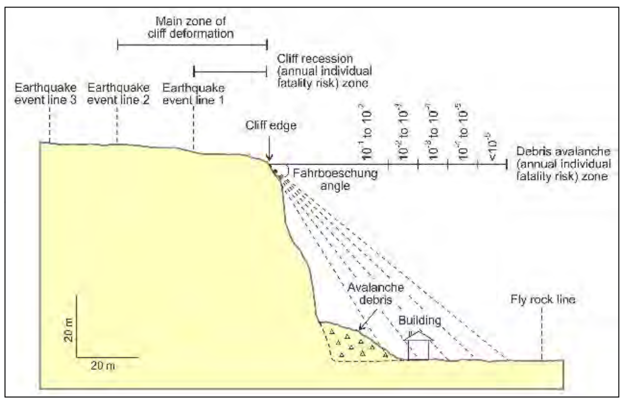
APPENDIX B Map A10c

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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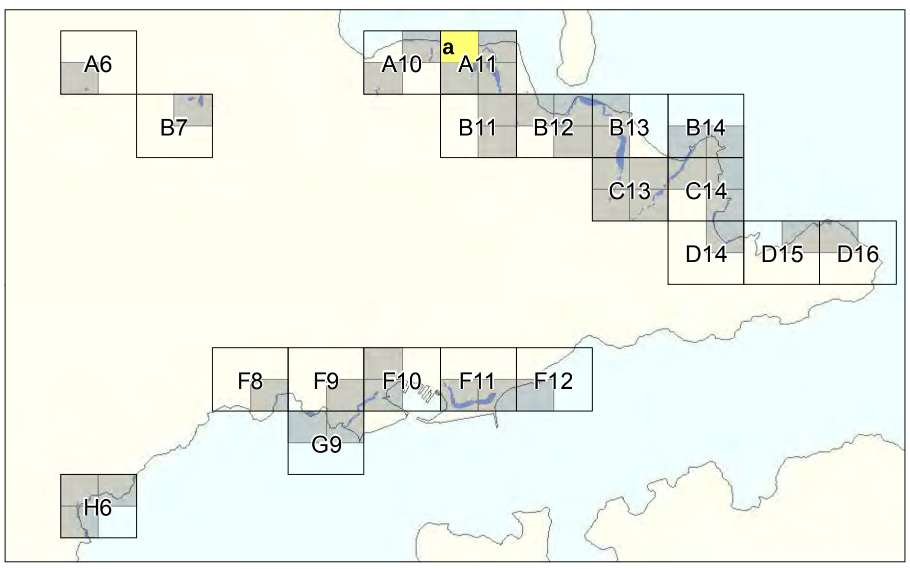

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EXPLANATION:
Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

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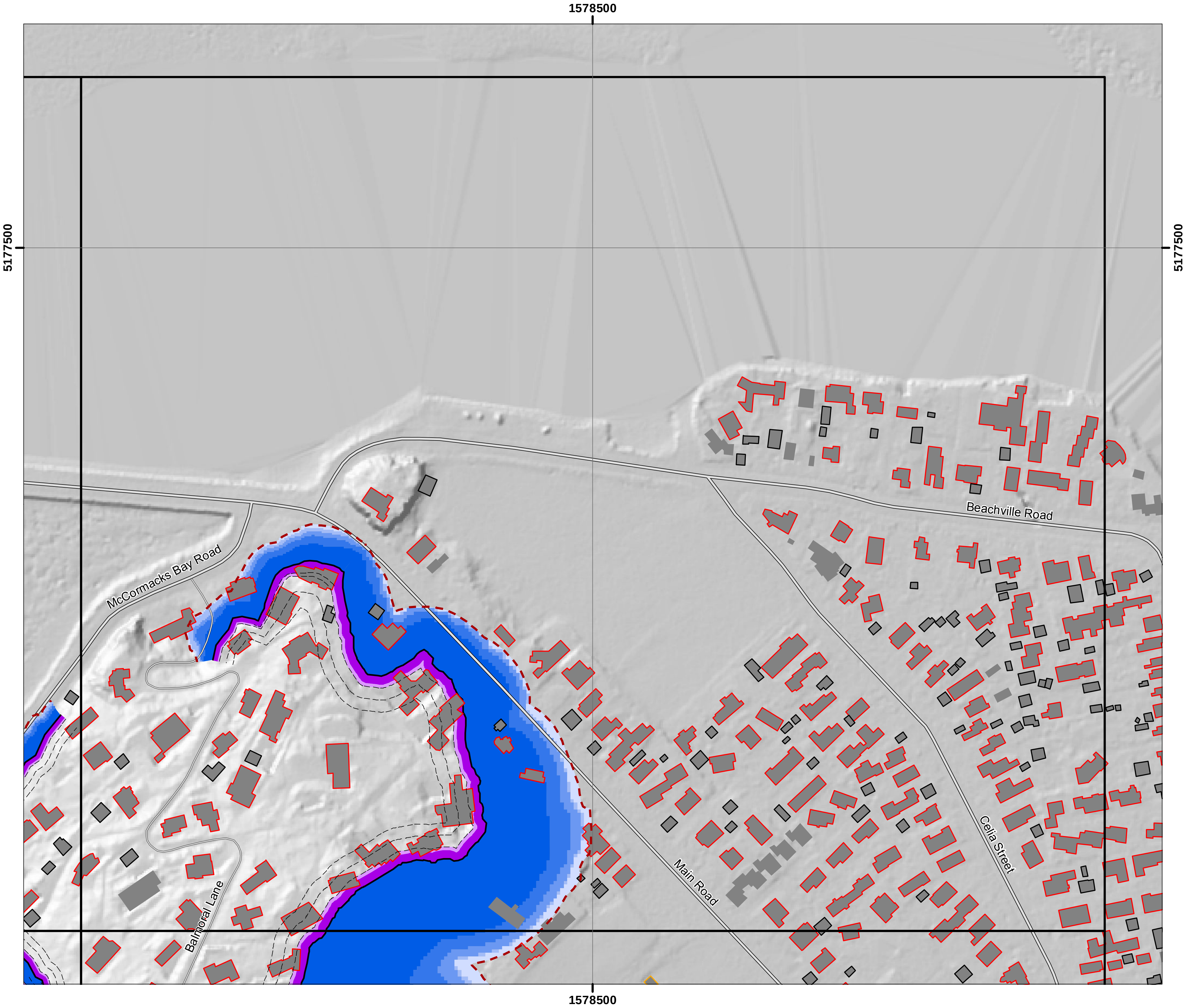
CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

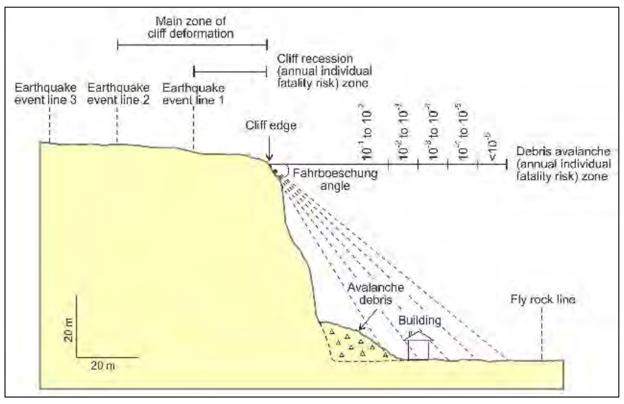
Port Hills Christchurch

APPENDIX B
Map A11a

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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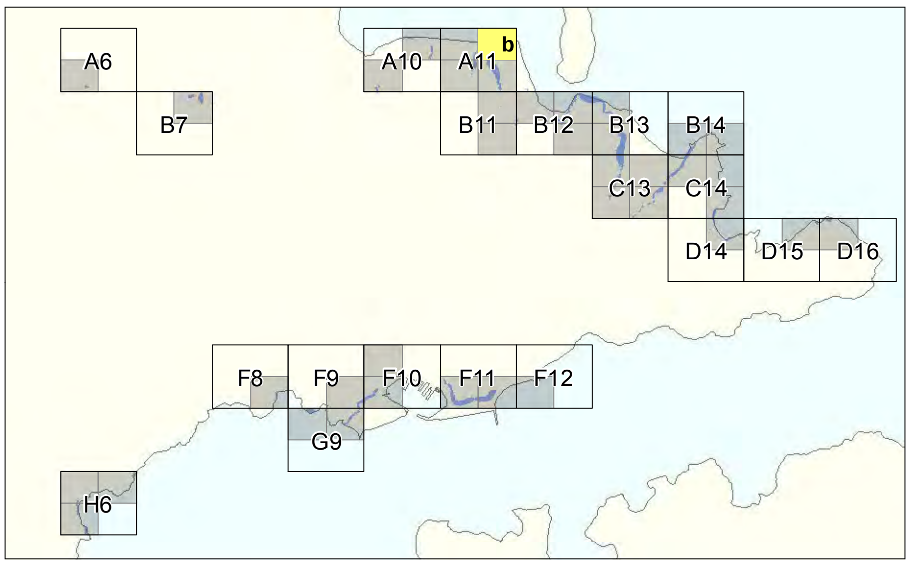

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EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

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CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

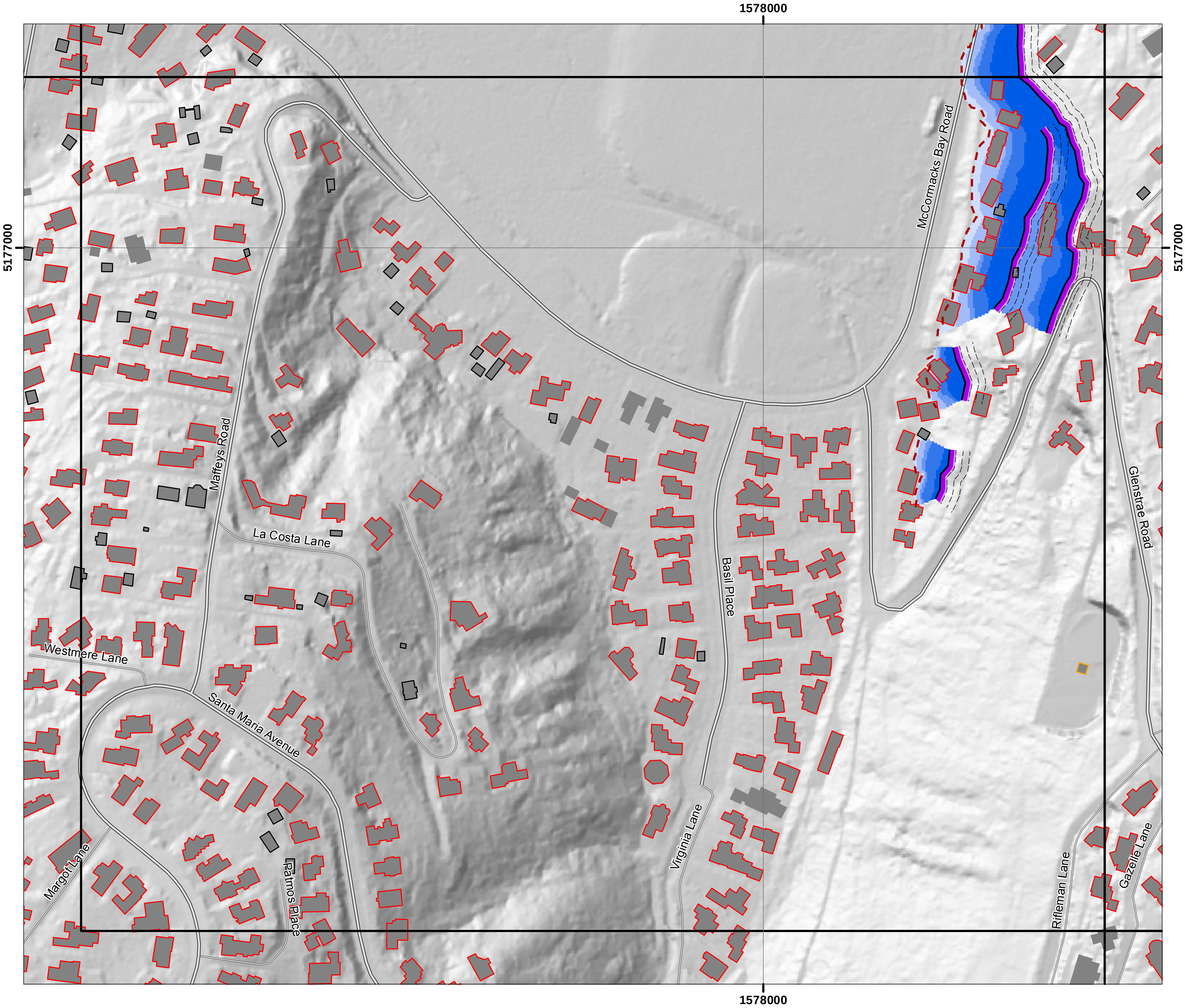
Port Hills Christchurch

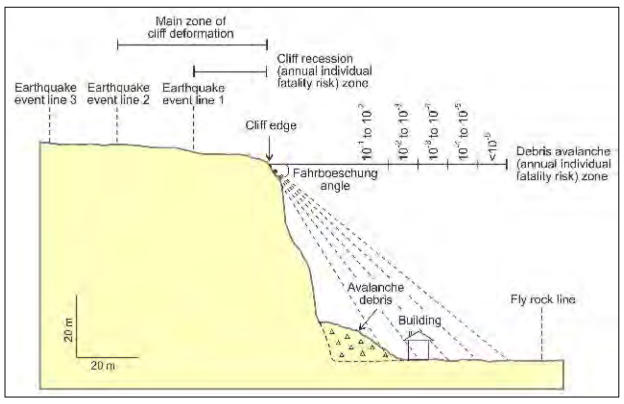
APPENDIX B Map A11b

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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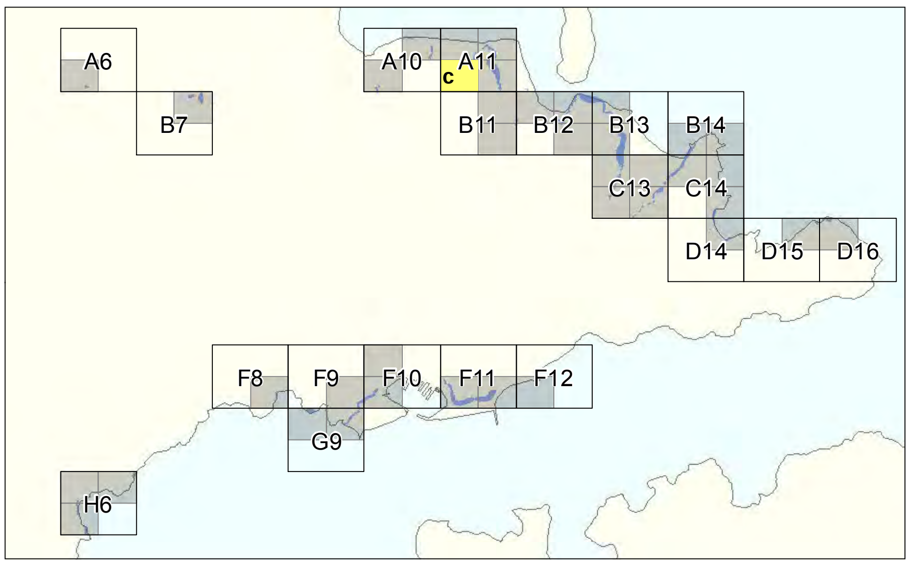

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

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CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

APPENDIX B Map A11c

Port Hills Christchurch

FINAL ISSUE 2

REPORT: CR2012/124

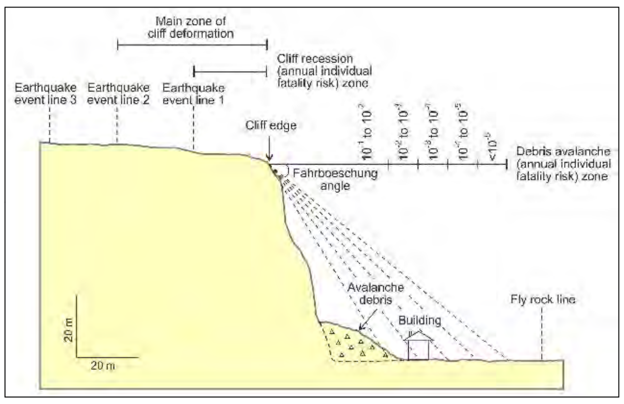
DATE: July 2013

1578500

5177000

1578500

5177000



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

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- Commercial-Industrial
- Accessory building
- Unknown

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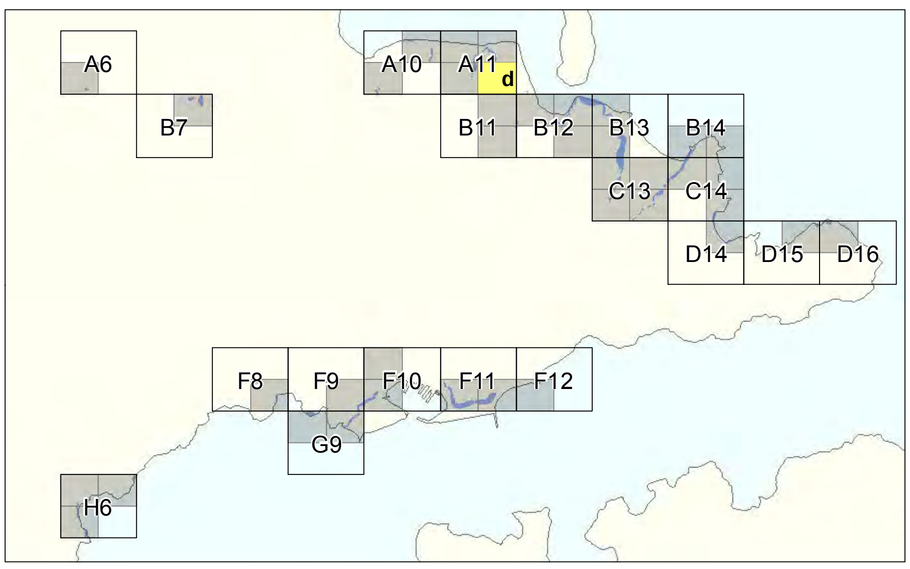


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX B Map A11d

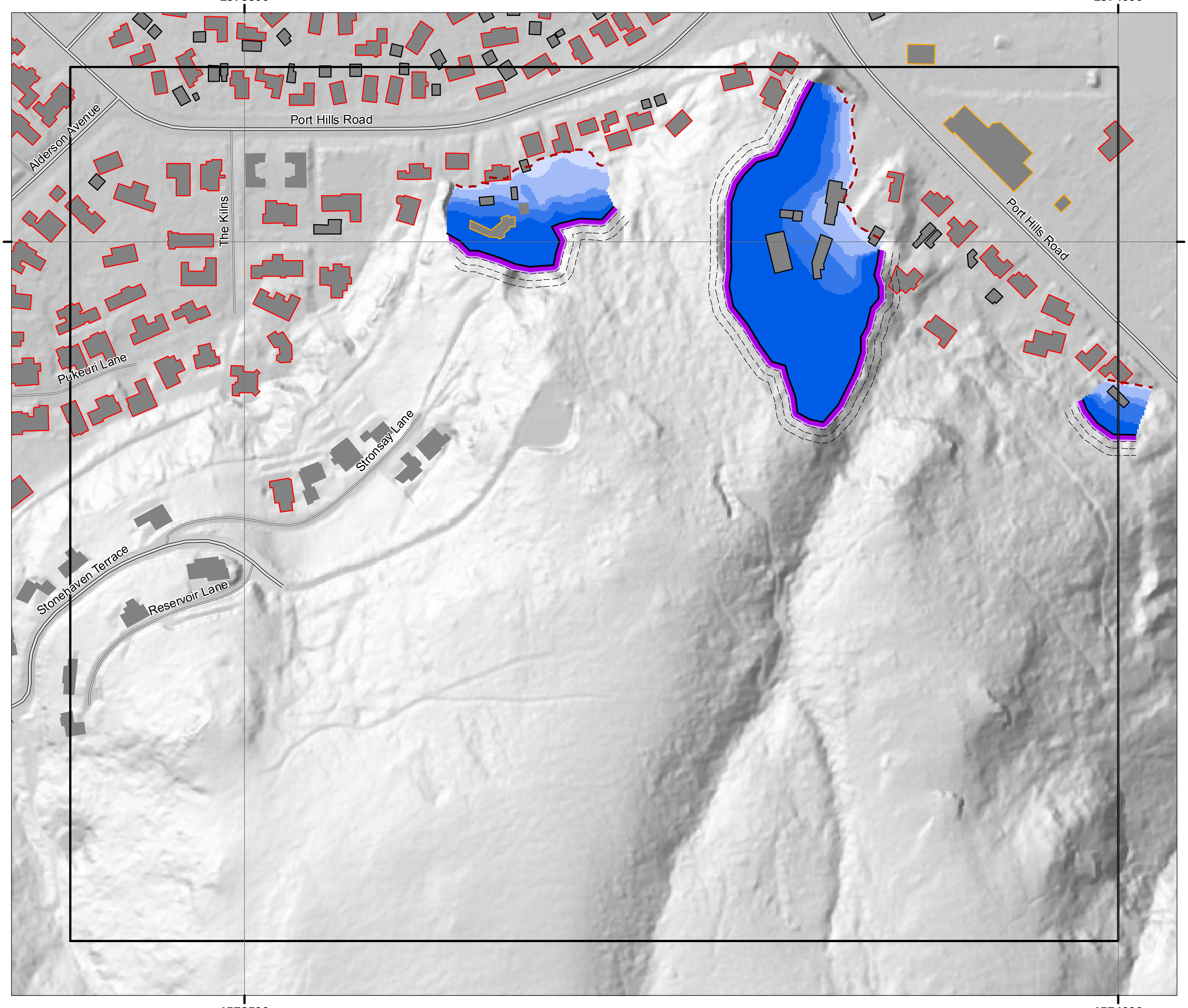
FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013

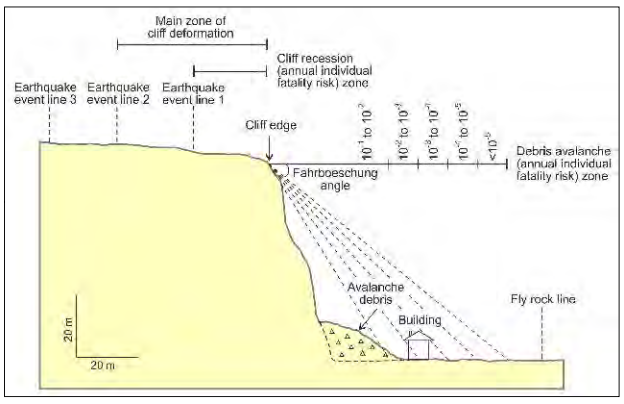
1573500 1574000

5176500



1573500 1574000

5176500



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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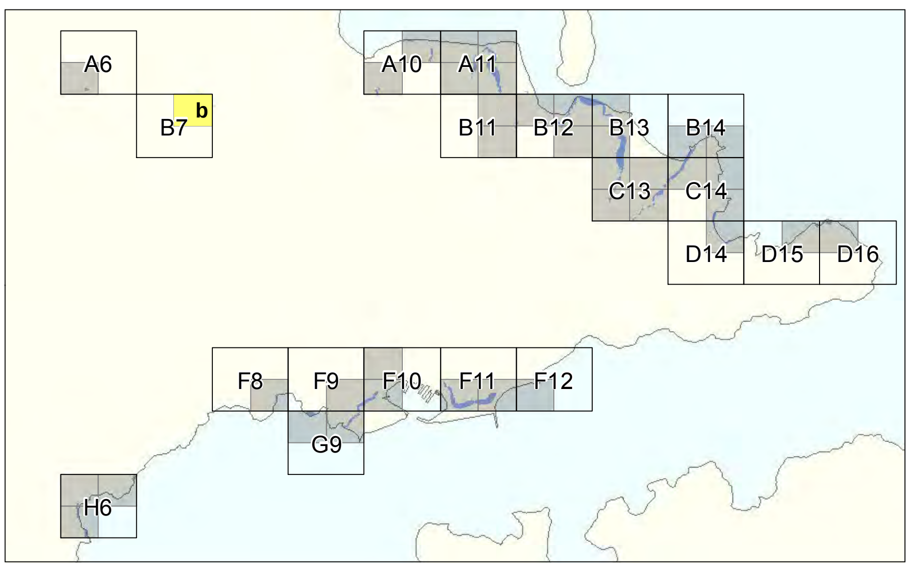


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:
Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

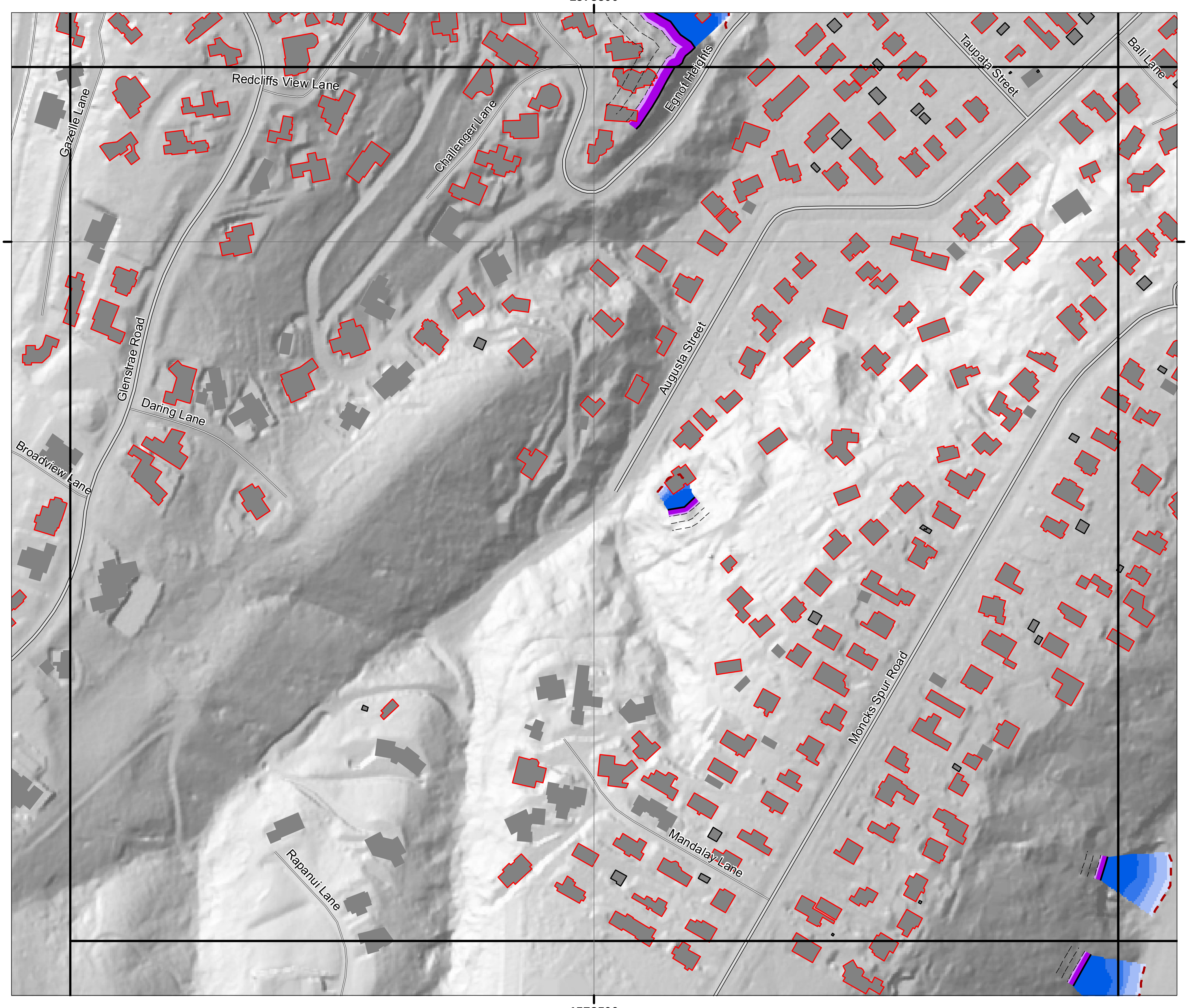
Port Hills Christchurch

APPENDIX B Map B7b

FINAL ISSUE 2

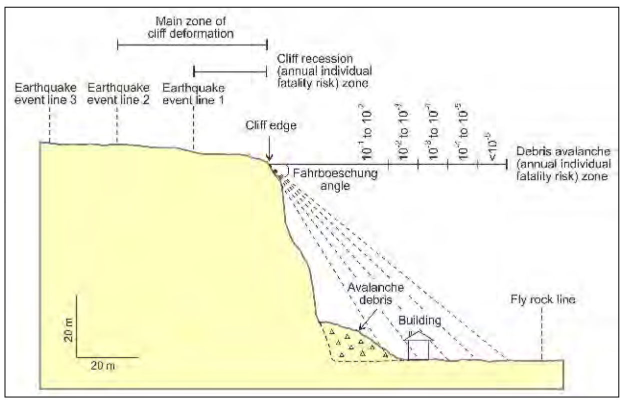
REPORT: CR2012/124
DATE: July 2013

1578500



5176500 5176500

1578500



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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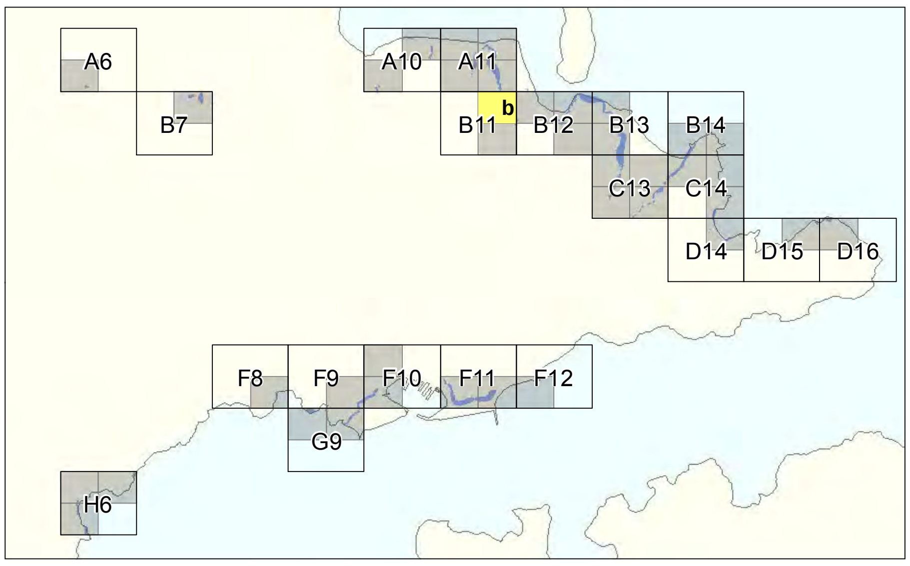
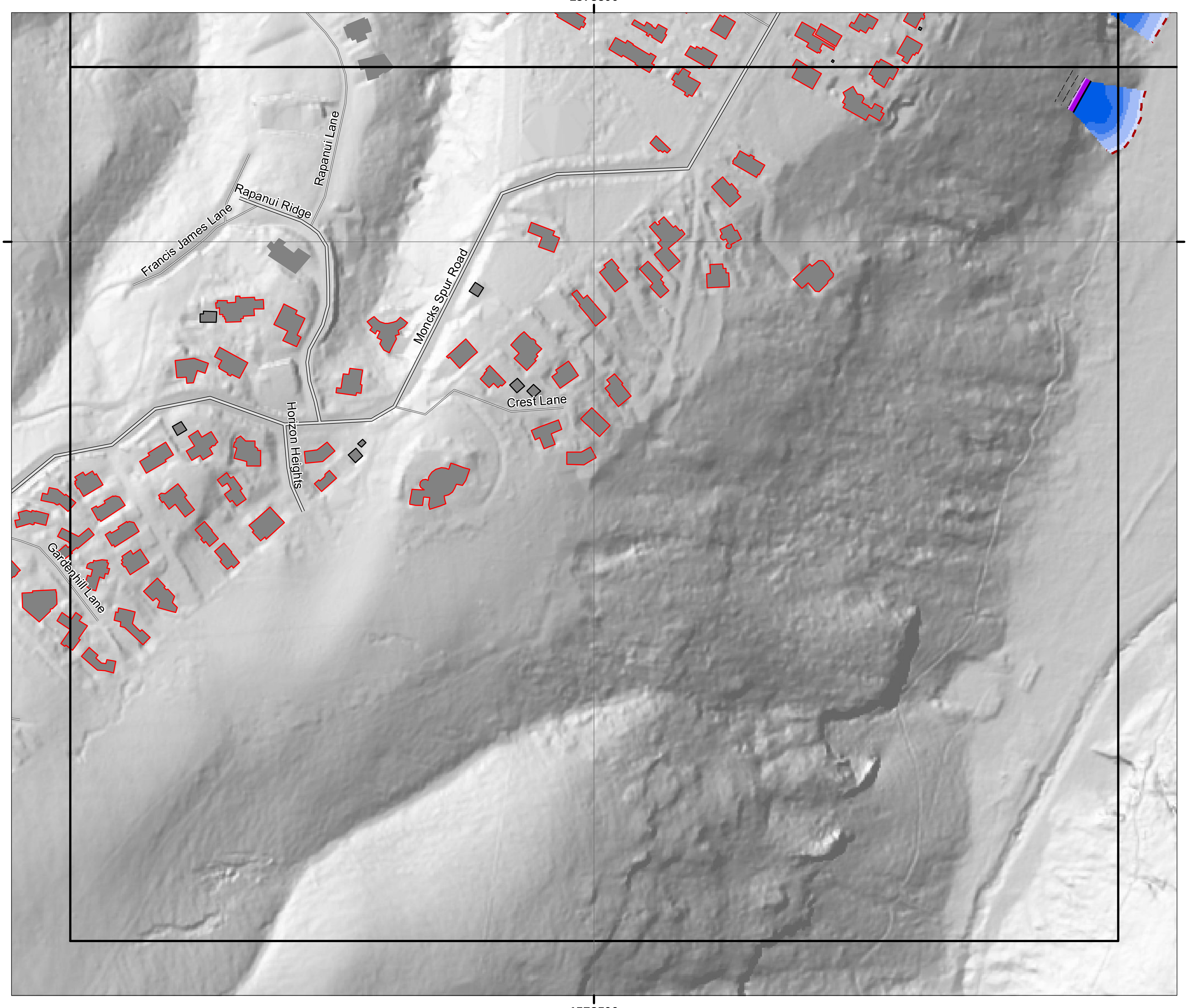
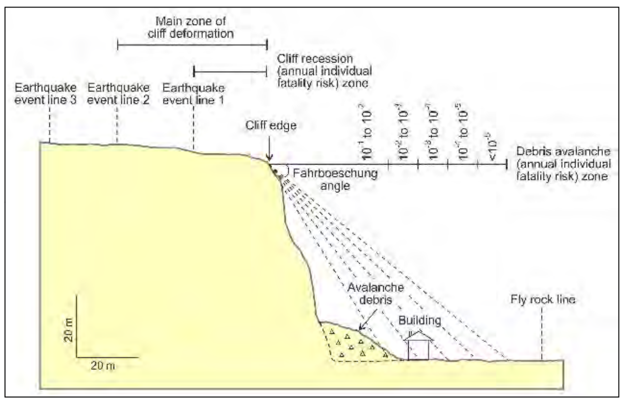


SCALE BAR: 0 20 40 60 80 100 m		GNS SCIENCE TE PŪ AO	CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map B11b
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM		Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

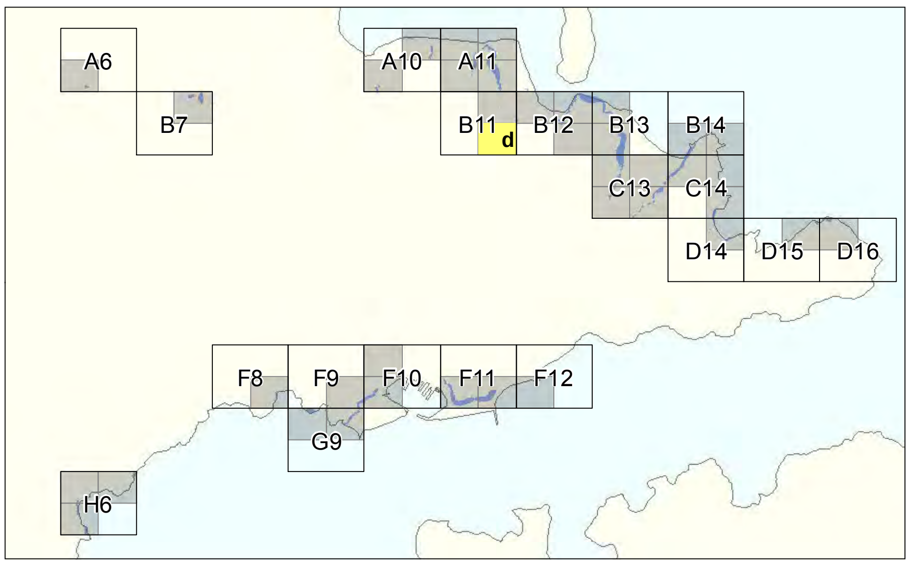
Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



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SCALE BAR: 0 20 40 60 80 100 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

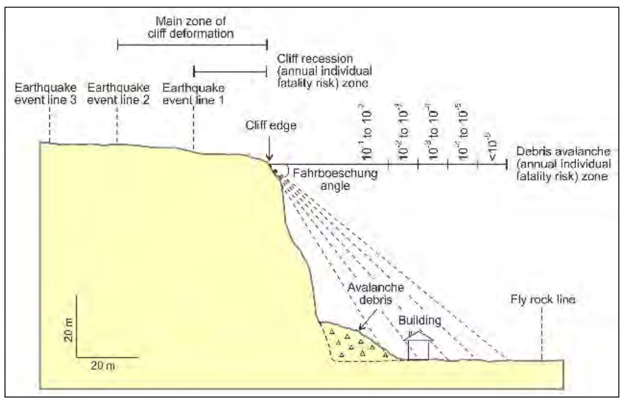
Port Hills Christchurch

APPENDIX B Map B11d

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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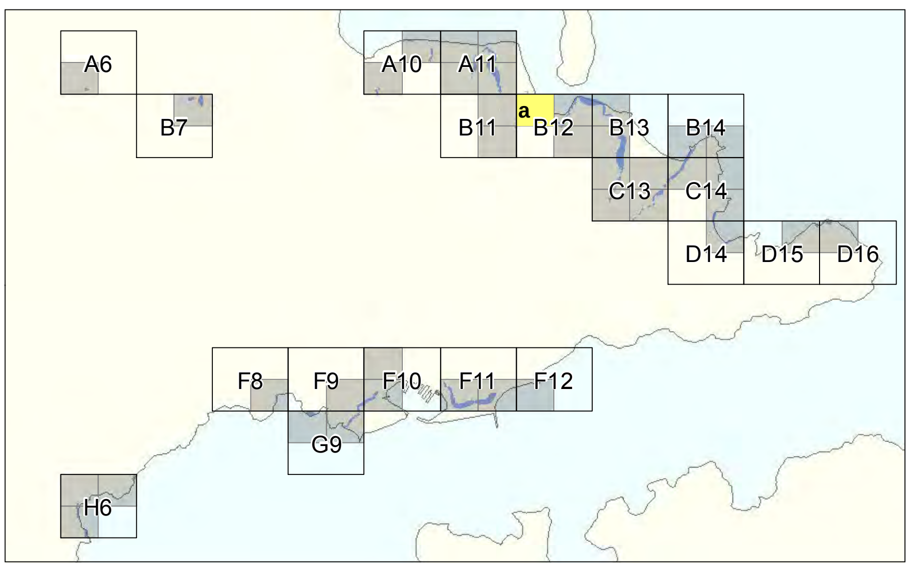
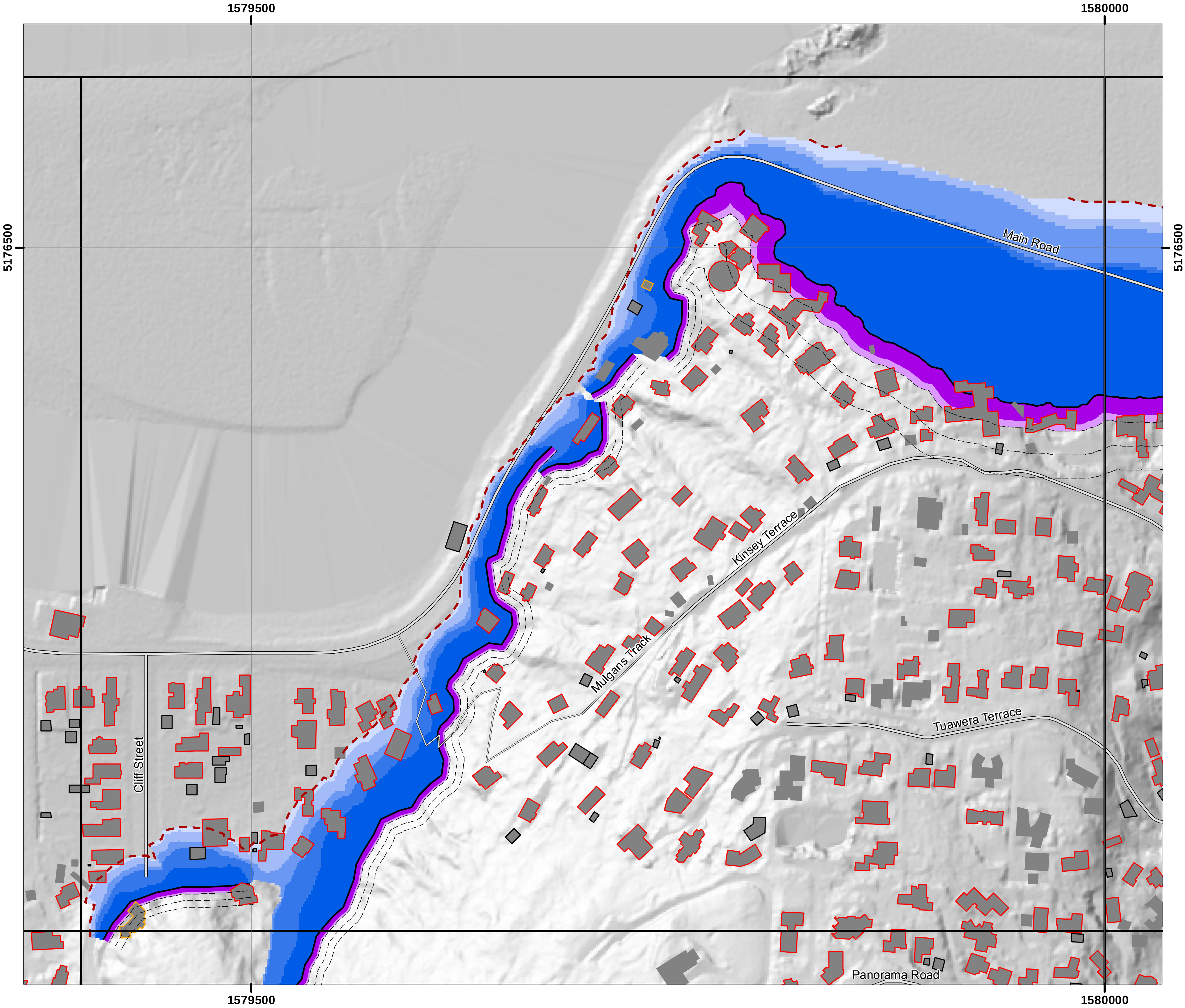
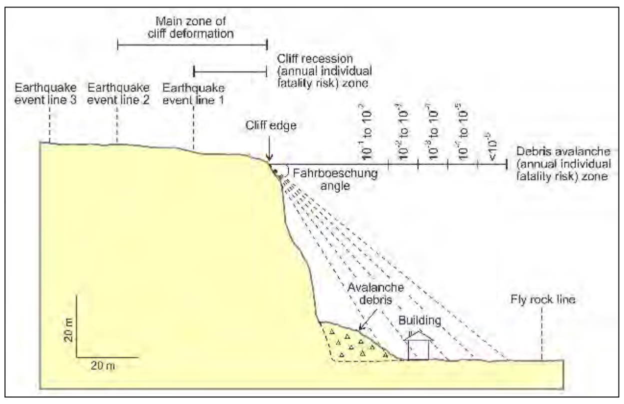


SCALE BAR: 0 20 40 60 80 100 m		CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map B12a
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013

GNS SCIENCE TE PŪ AO





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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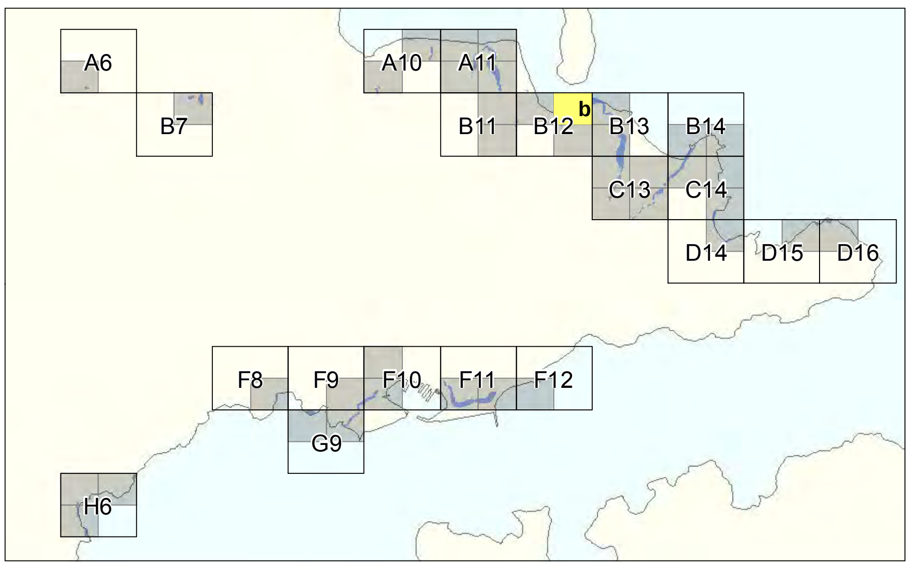
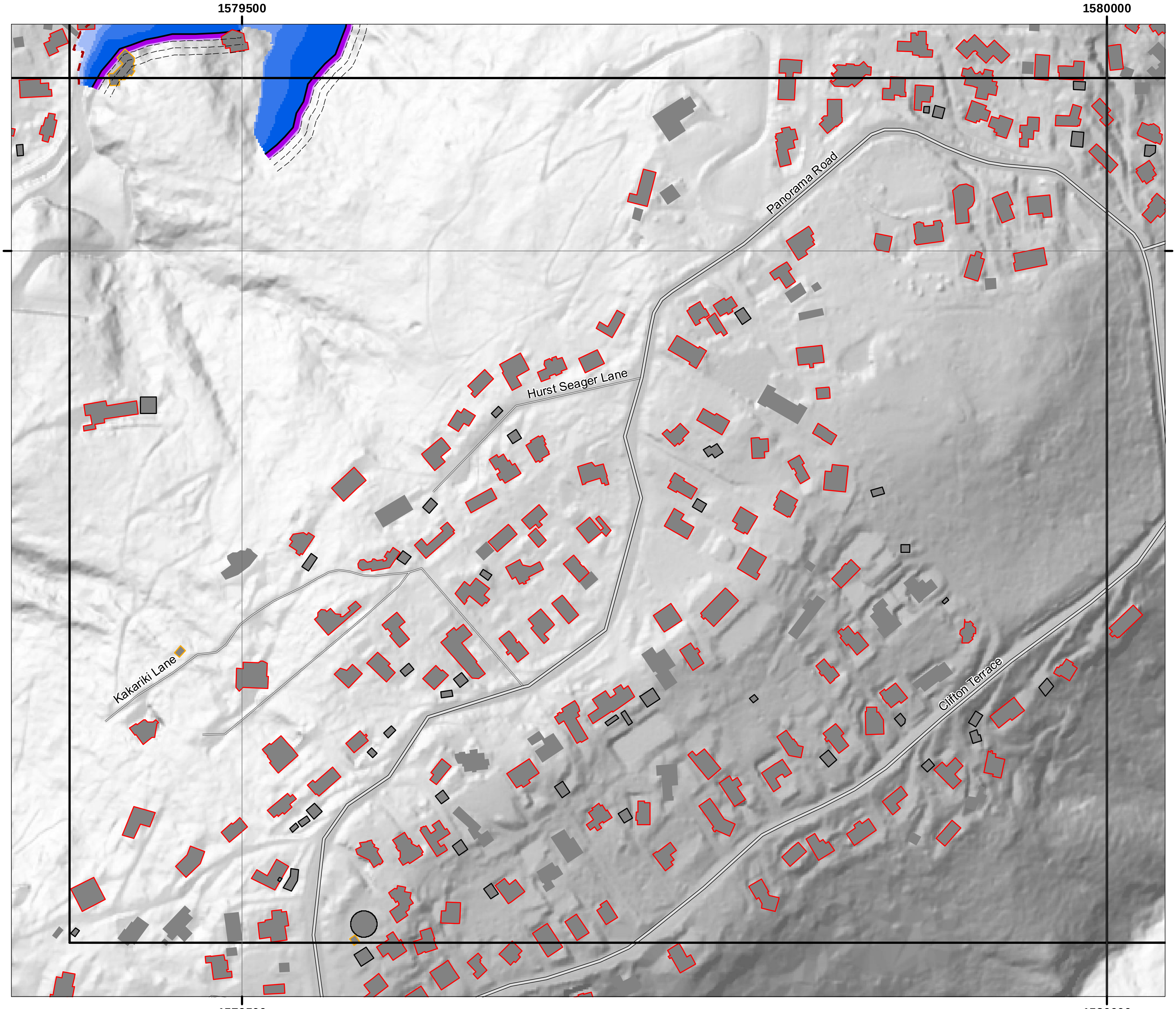
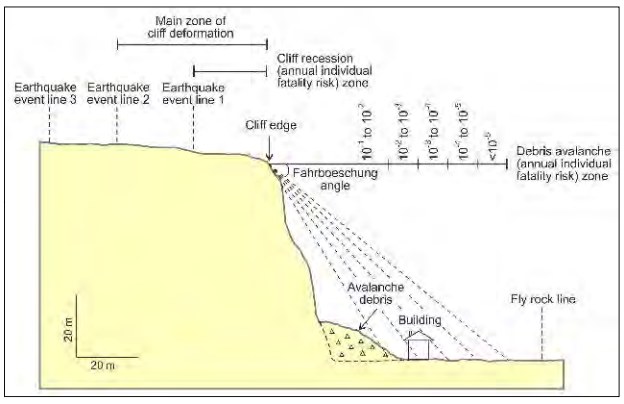


SCALE BAR: 0 20 40 60 80 100 m		GNS SCIENCE TE PŪ AO	CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map B12b
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM		Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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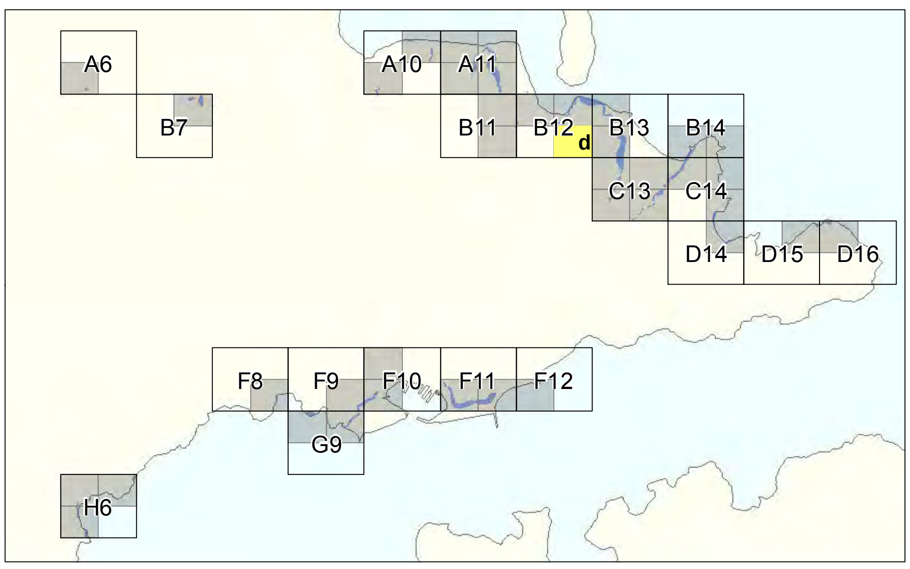

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

GNS SCIENCE TE PŪ AO

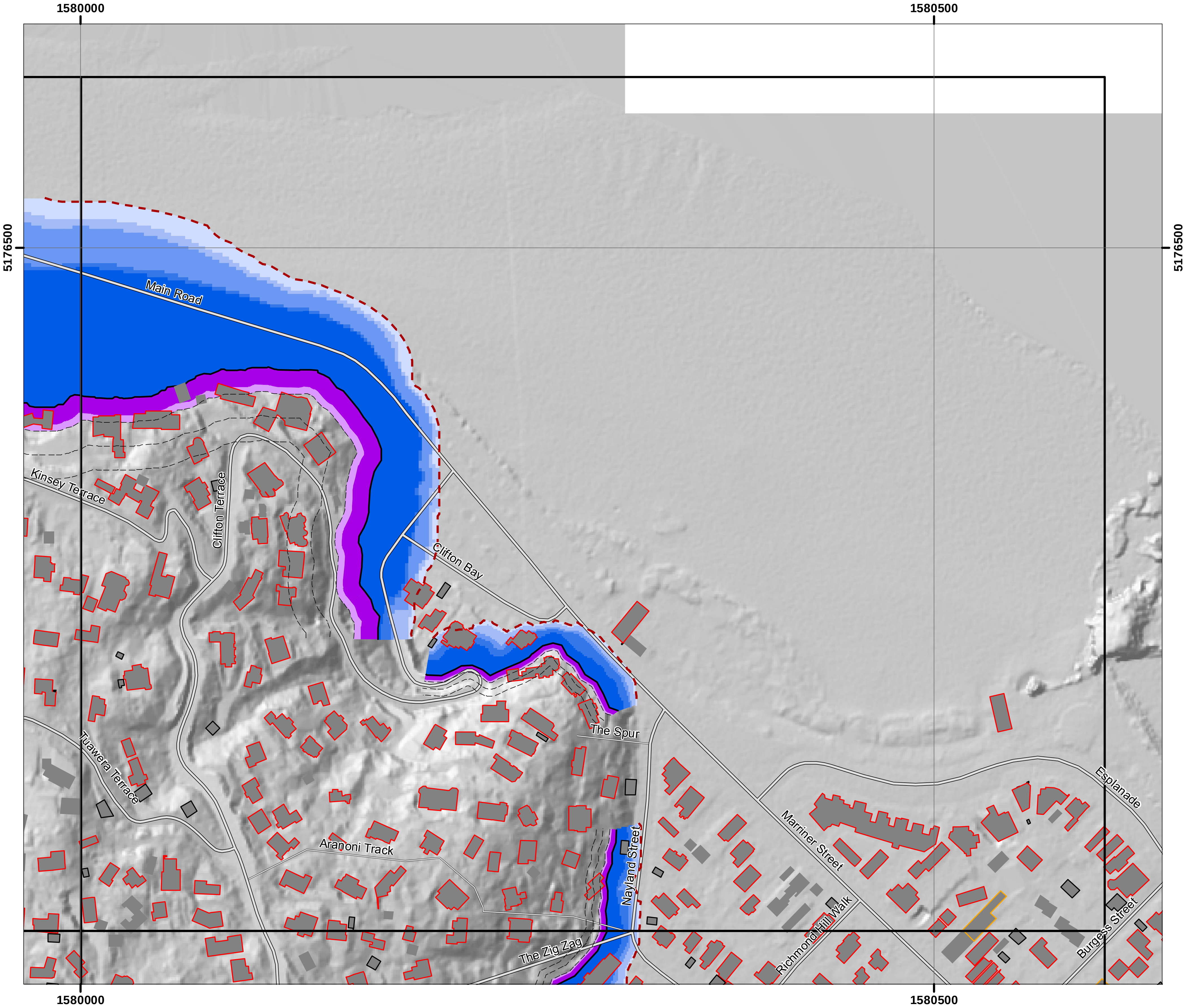
CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

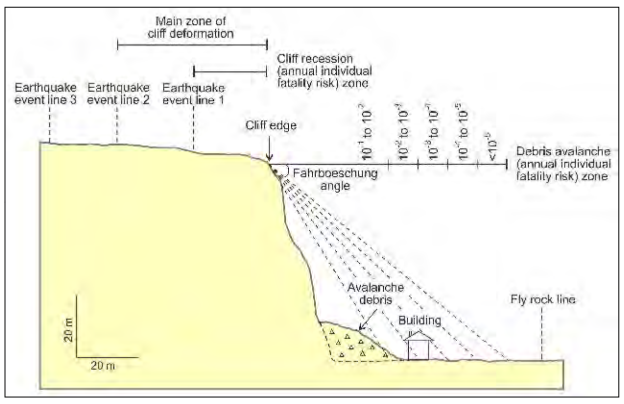
Port Hills Christchurch

APPENDIX B
Map B12d

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

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- Commercial-Industrial
- Accessory building
- Unknown

N

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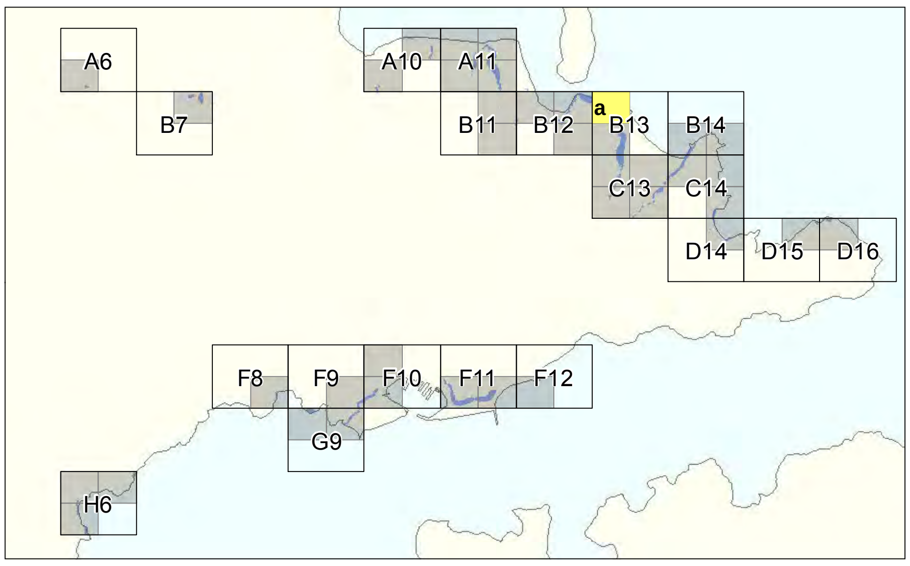

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

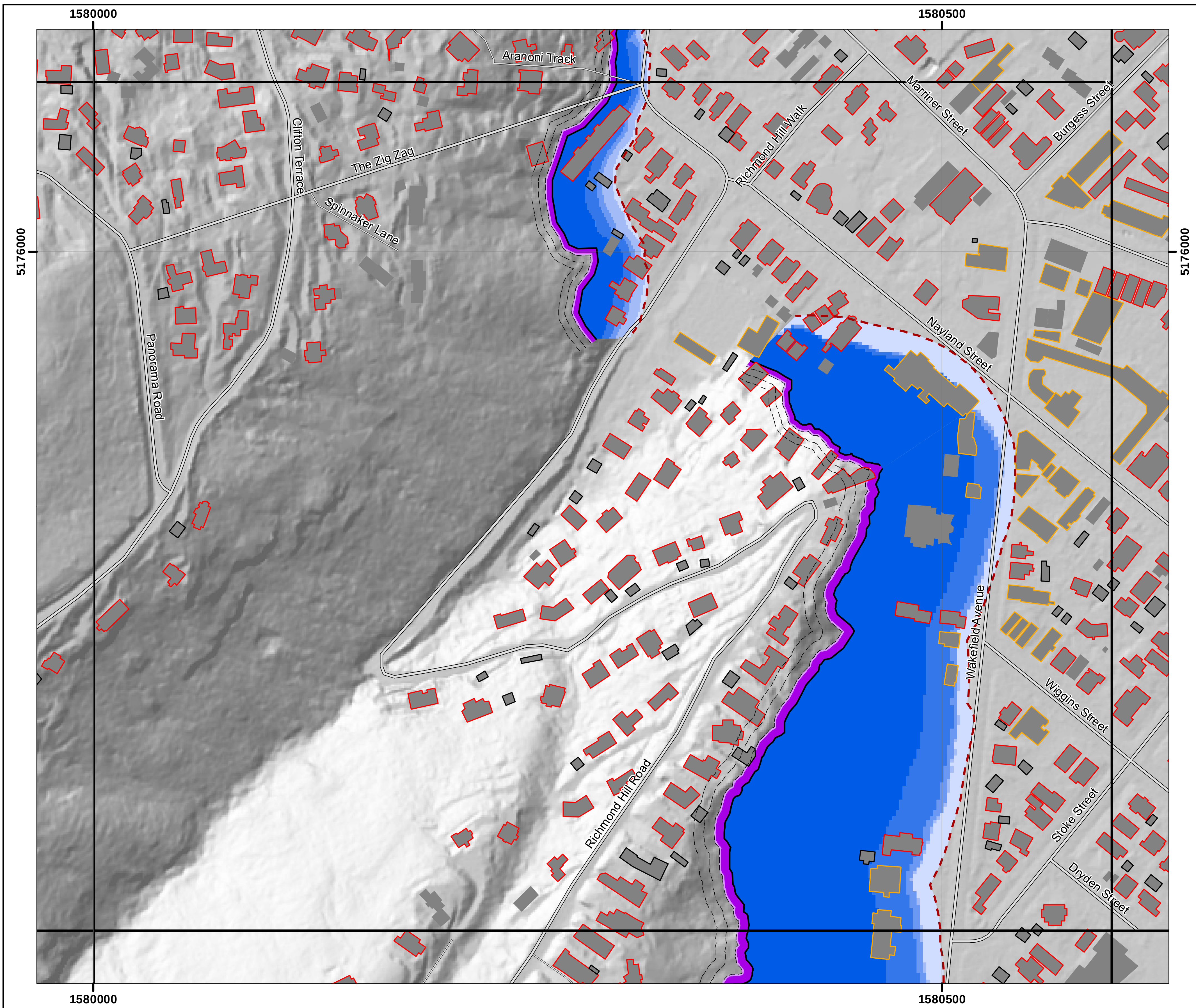
Port Hills Christchurch

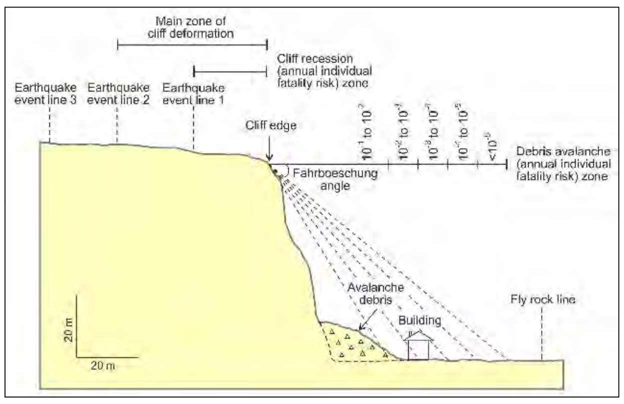
APPENDIX B Map B13a

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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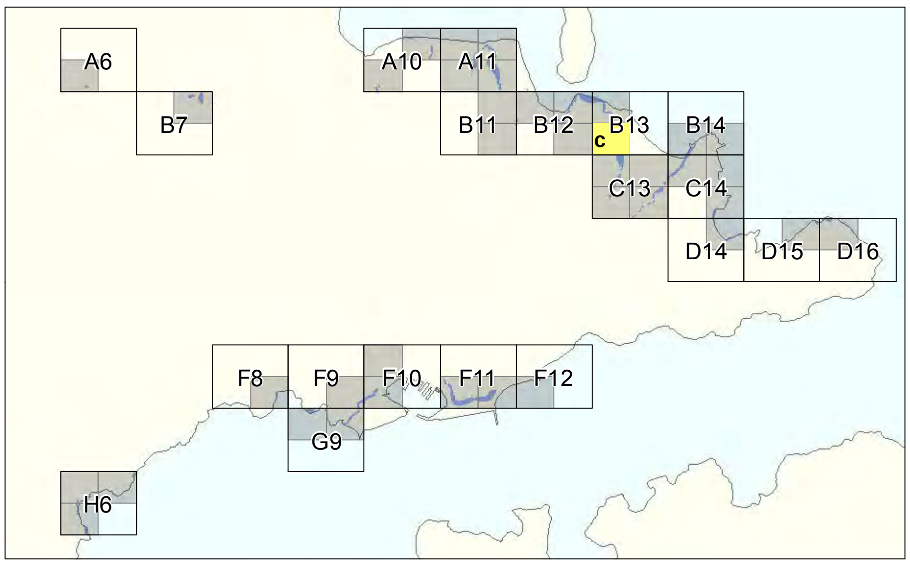

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

APPENDIX B Map B13c

Port Hills Christchurch

FINAL ISSUE 2

REPORT: CR2012/124

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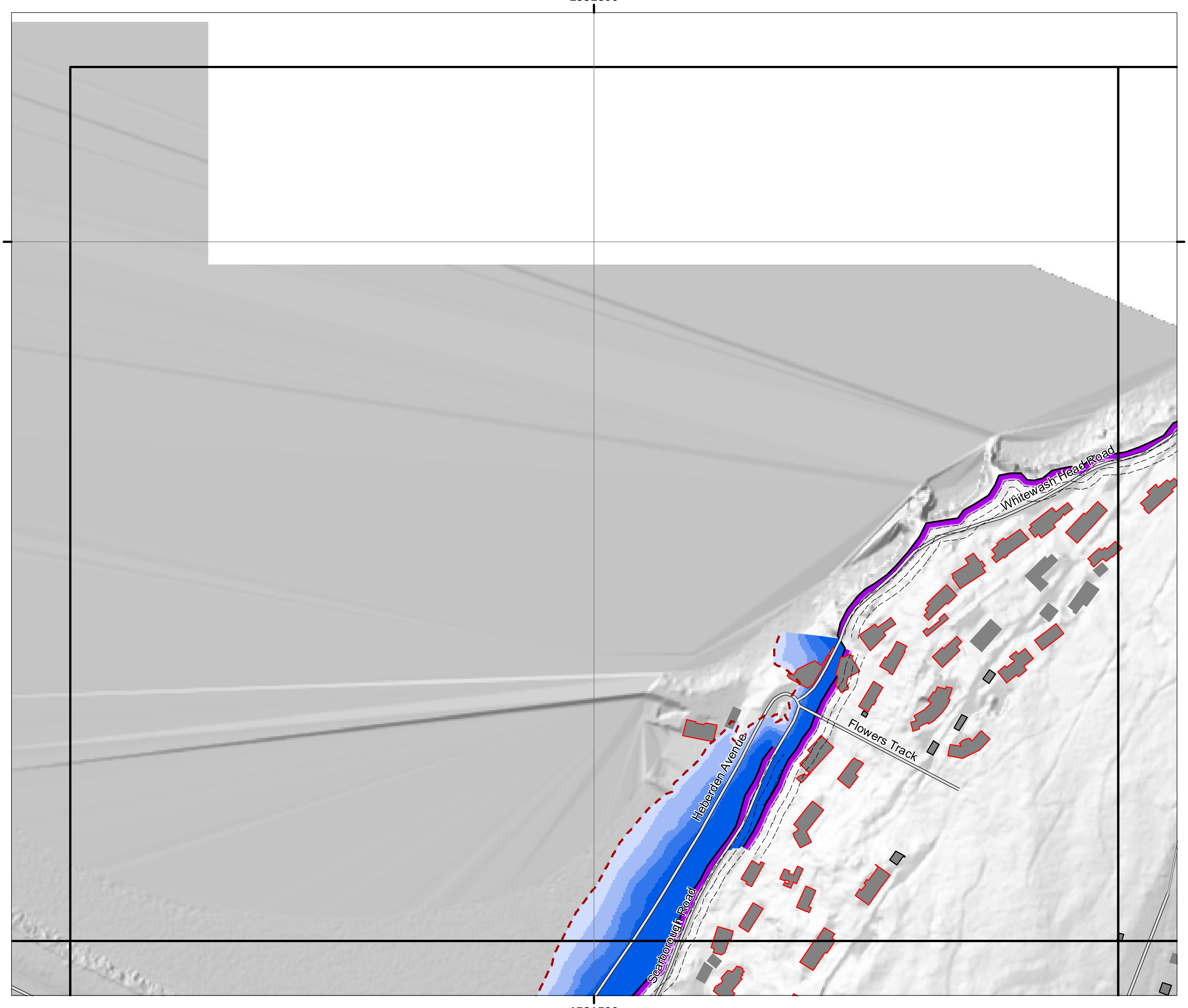
1581500

5176000



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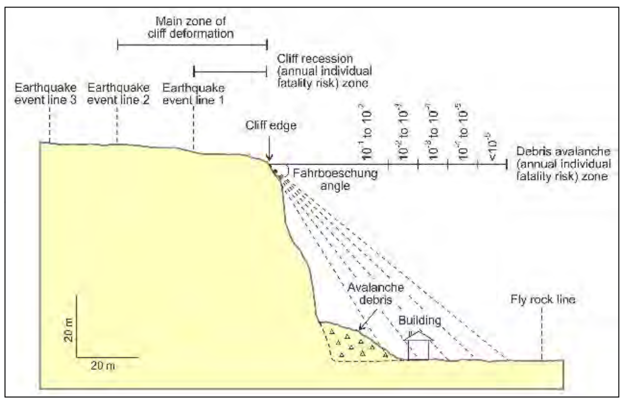

Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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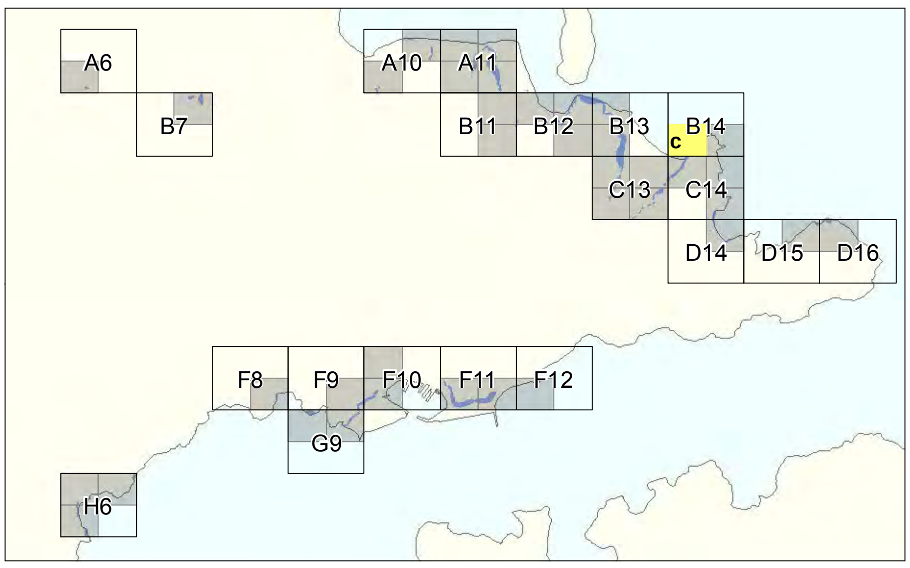


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

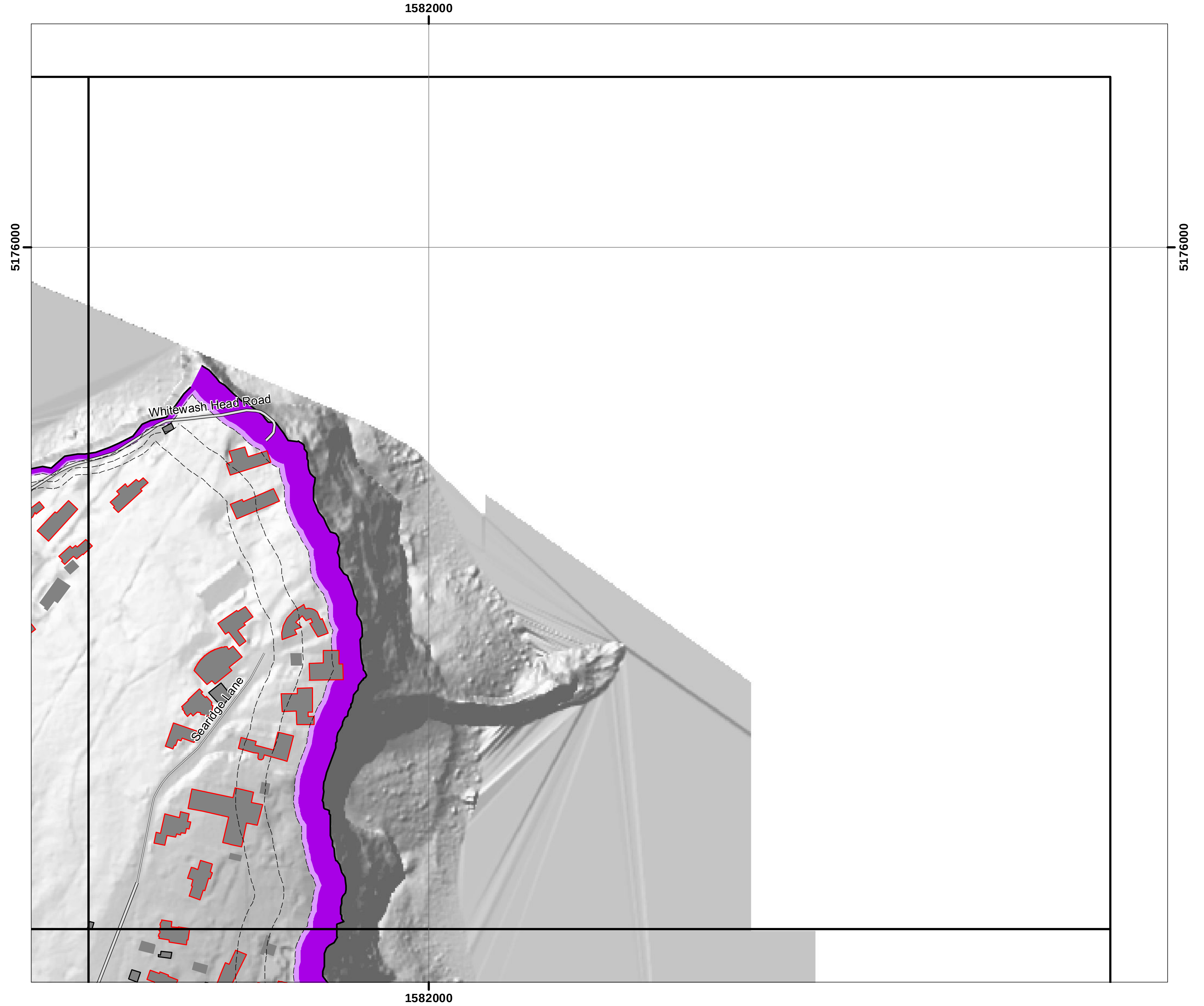
Port Hills Christchurch

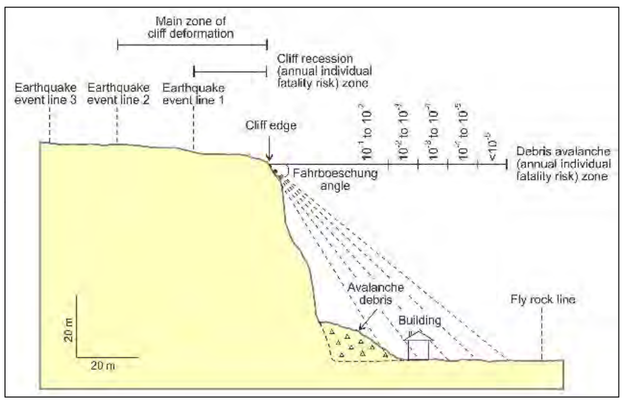
APPENDIX B Map B14c

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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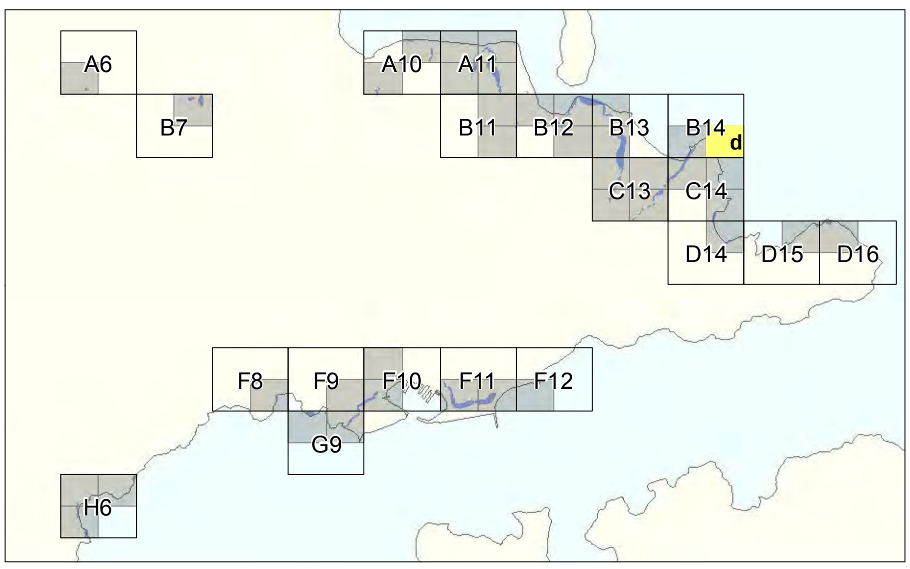
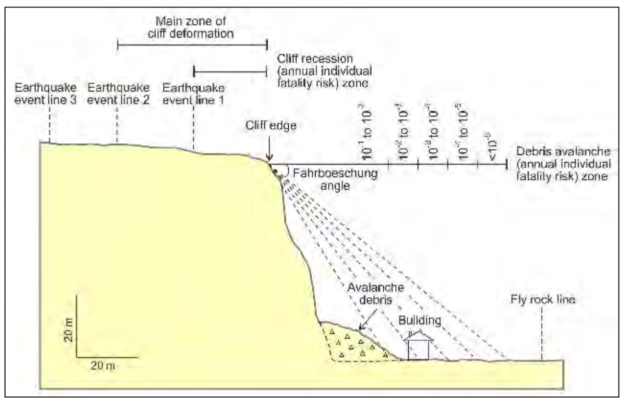


SCALE BAR: 0 20 40 60 80 100 m		GNS SCIENCE TE PŪ AO	CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map B14d
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM		Port Hills Christchurch	FINAL ISSUE 2
				REPORT: CR2012/124 DATE: July 2013



Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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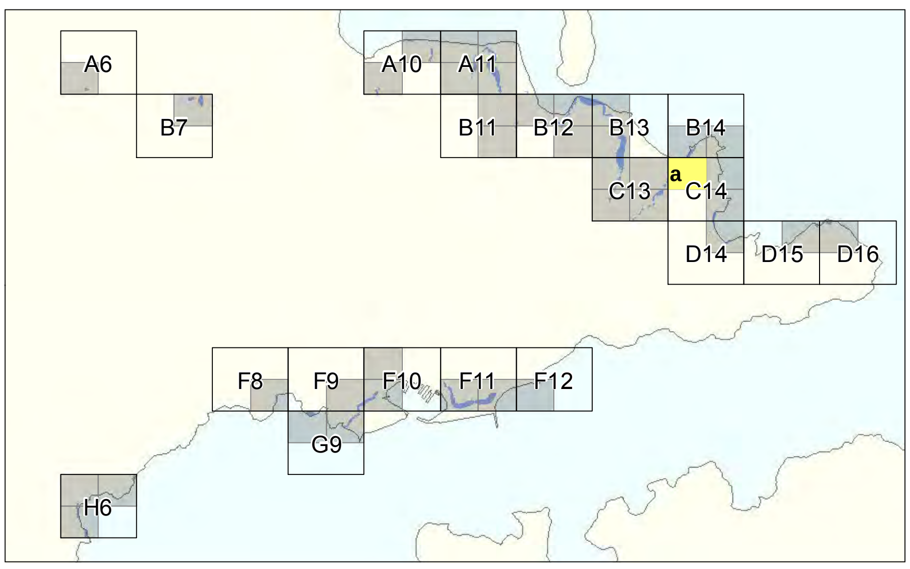


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:
Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

GNS SCIENCE TE PŪ AO

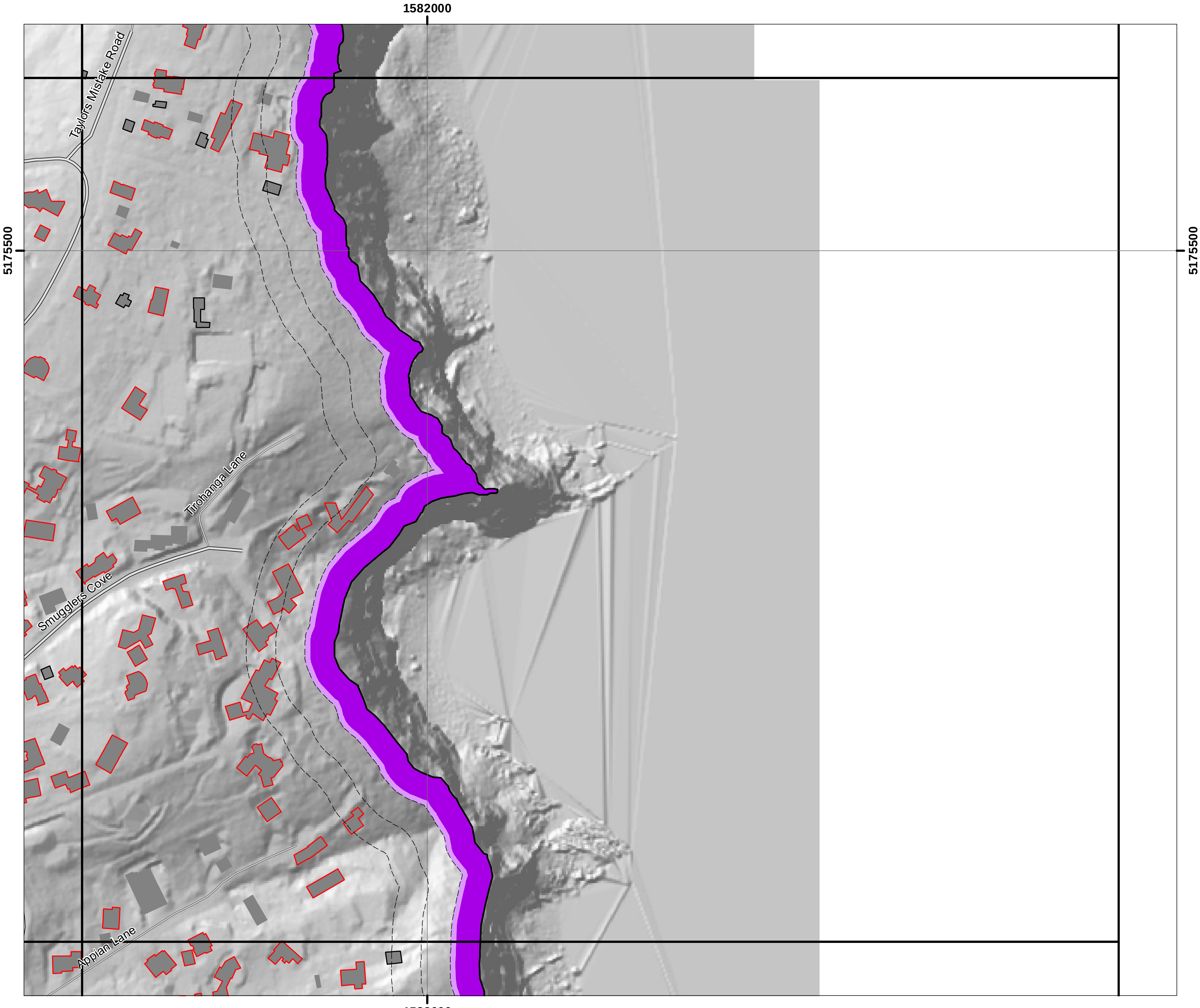
CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

Port Hills
Christchurch

APPENDIX B
Map C14a

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013



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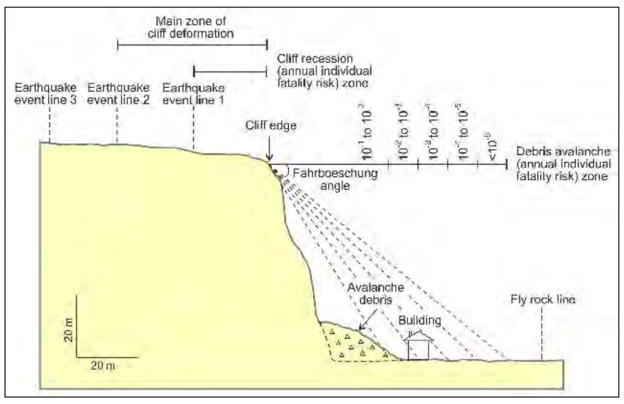

Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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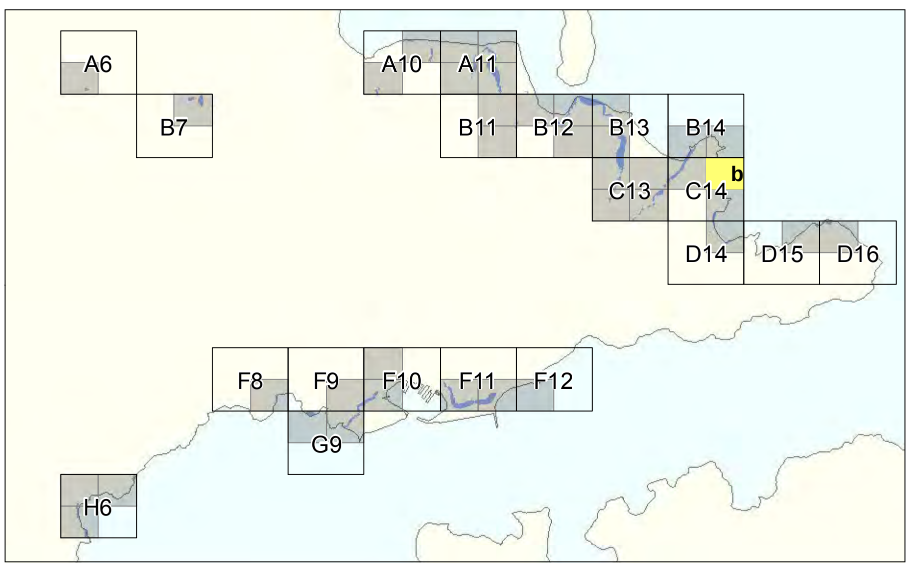
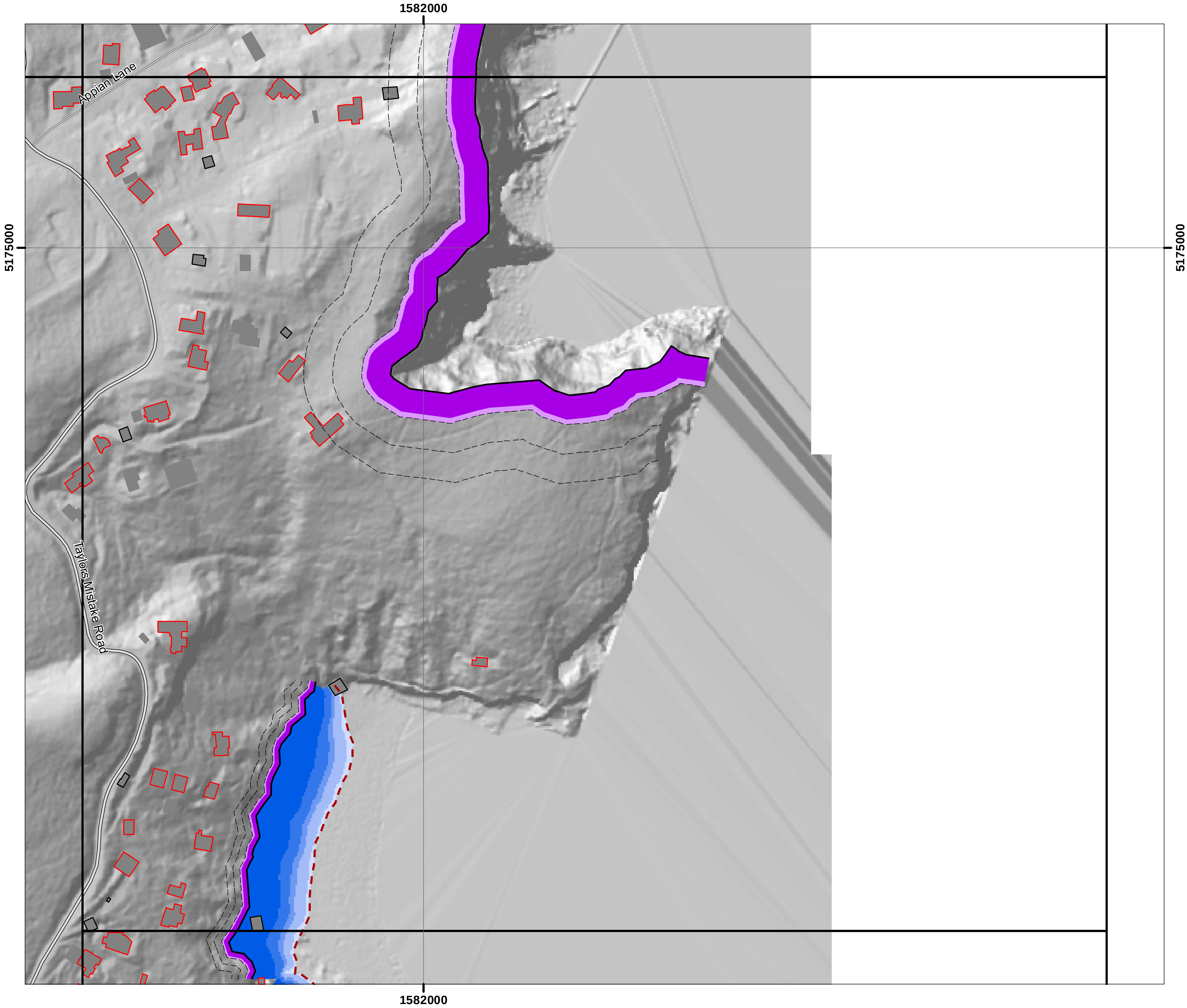
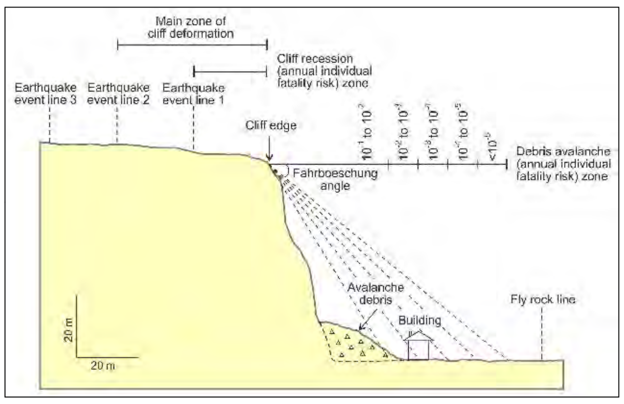


SCALE BAR: 0 20 40 60 80 100 m			CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map C14b
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	GNS SCIENCE TE PŪ AO	Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche

(annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession

(annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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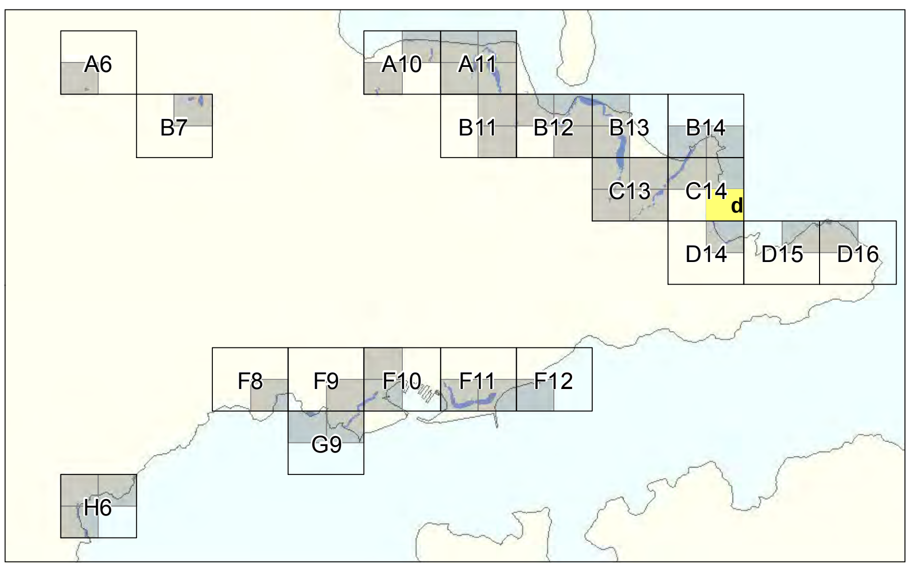

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

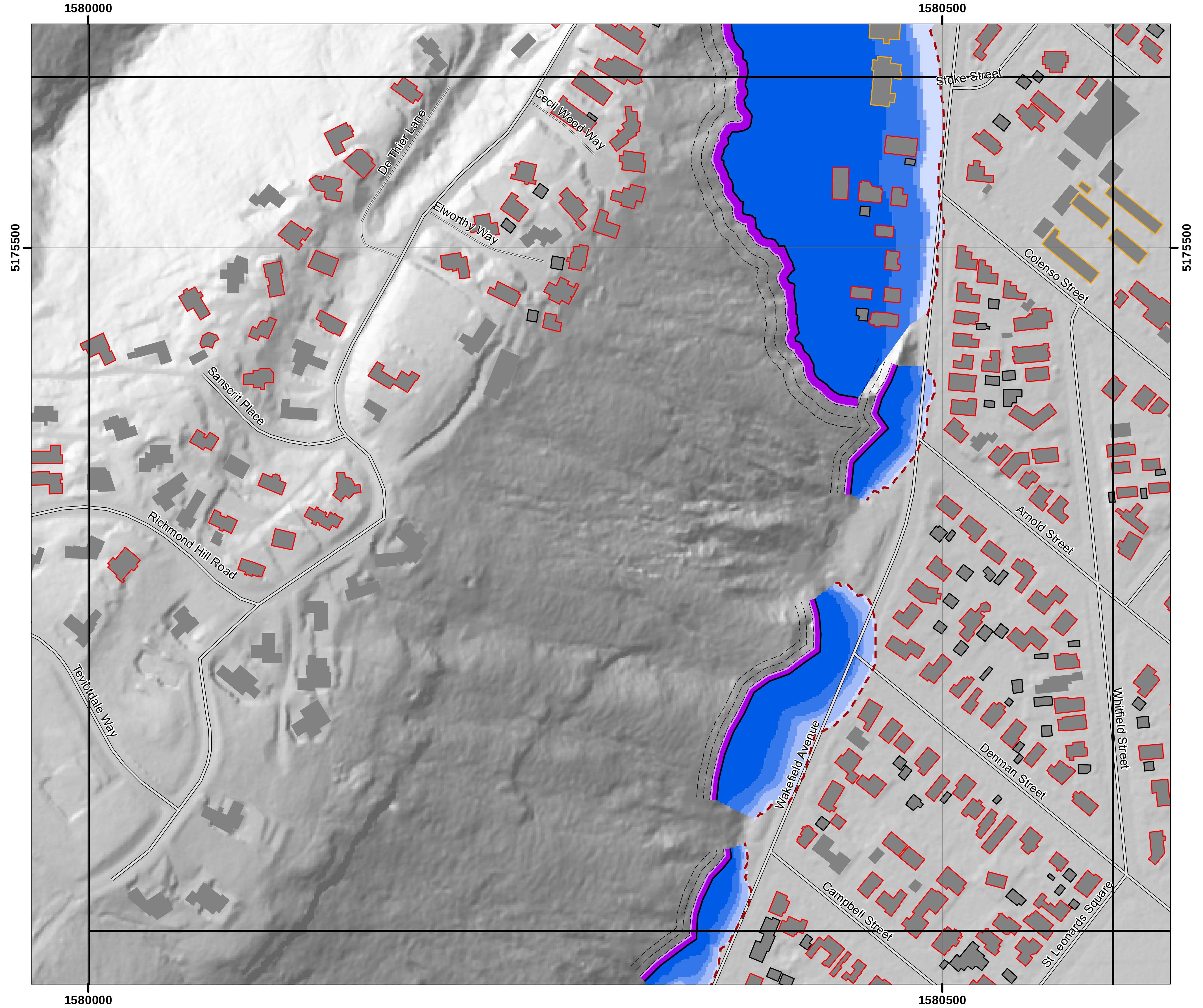
Port Hills Christchurch

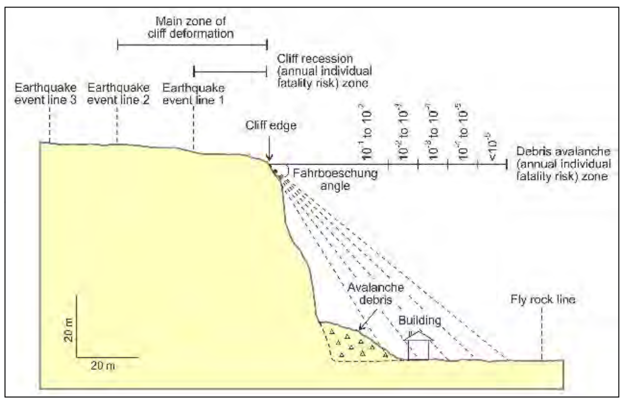
APPENDIX B Map C14d

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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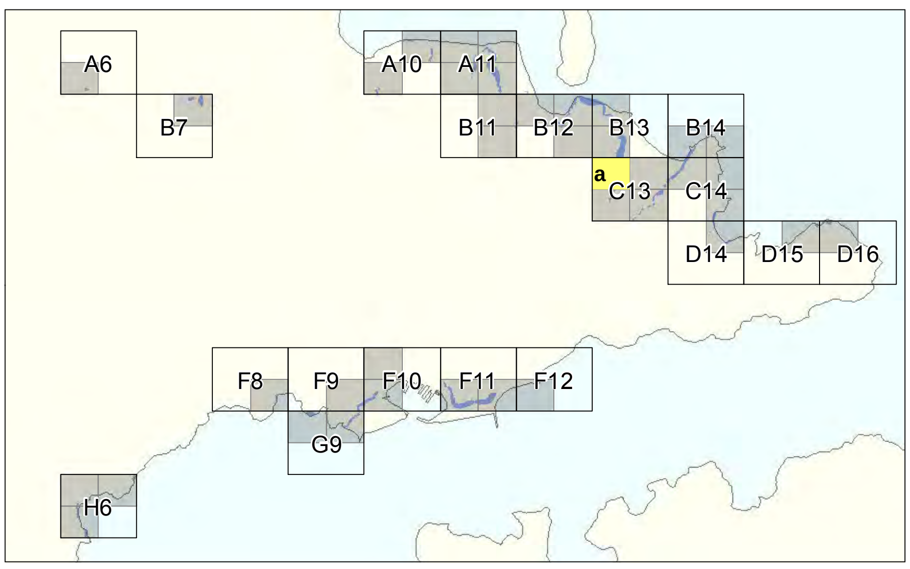
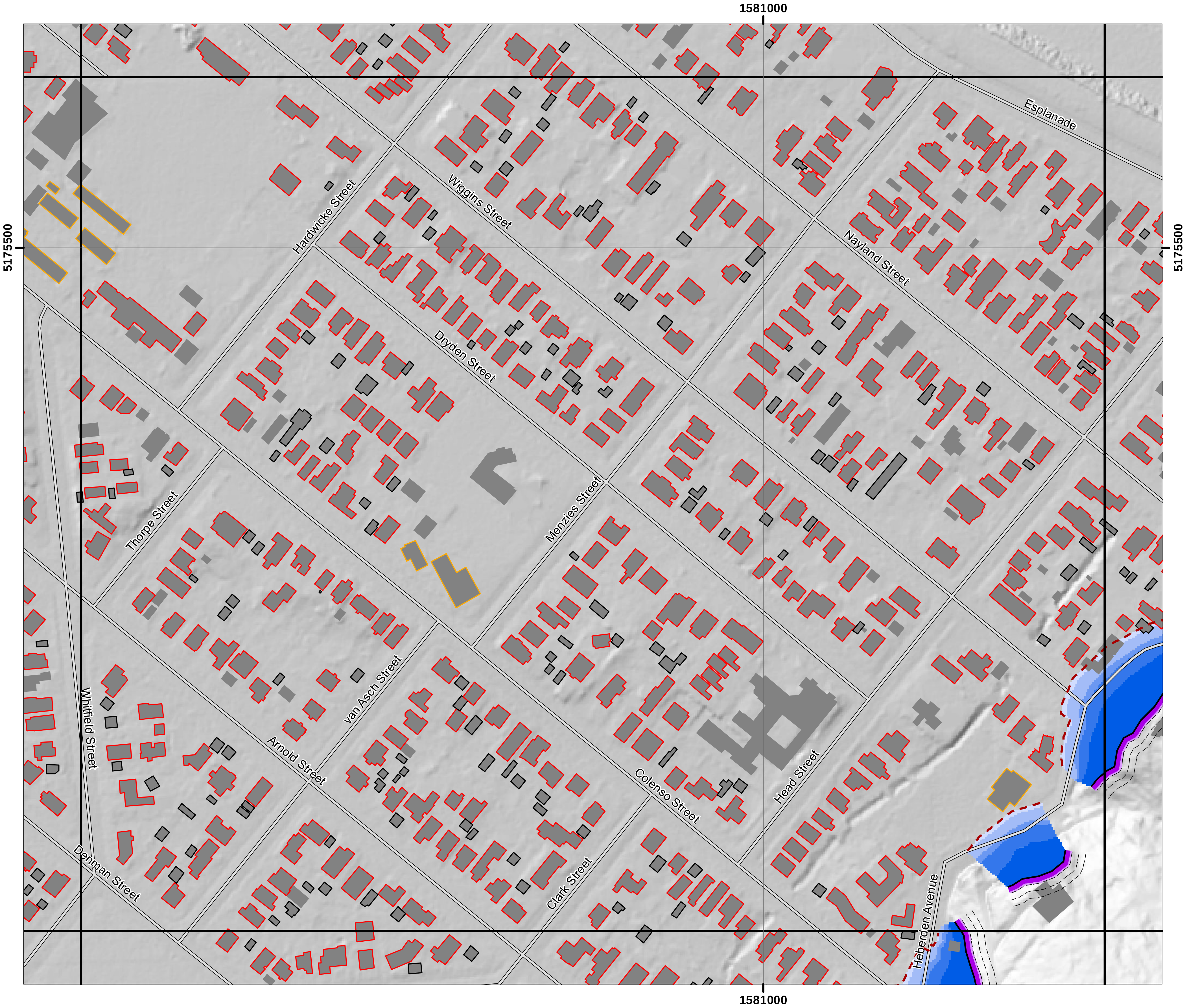
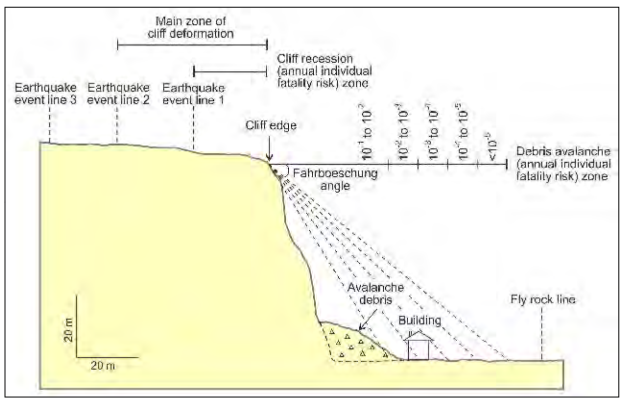


SCALE BAR: 0 20 40 60 80 100 m		CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map C13a
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

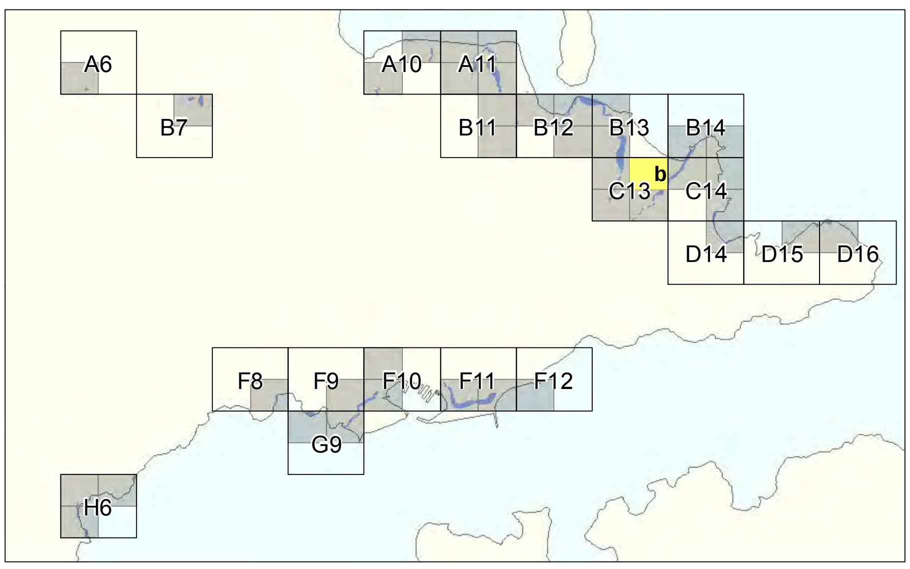
Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



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SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX B Map C13b

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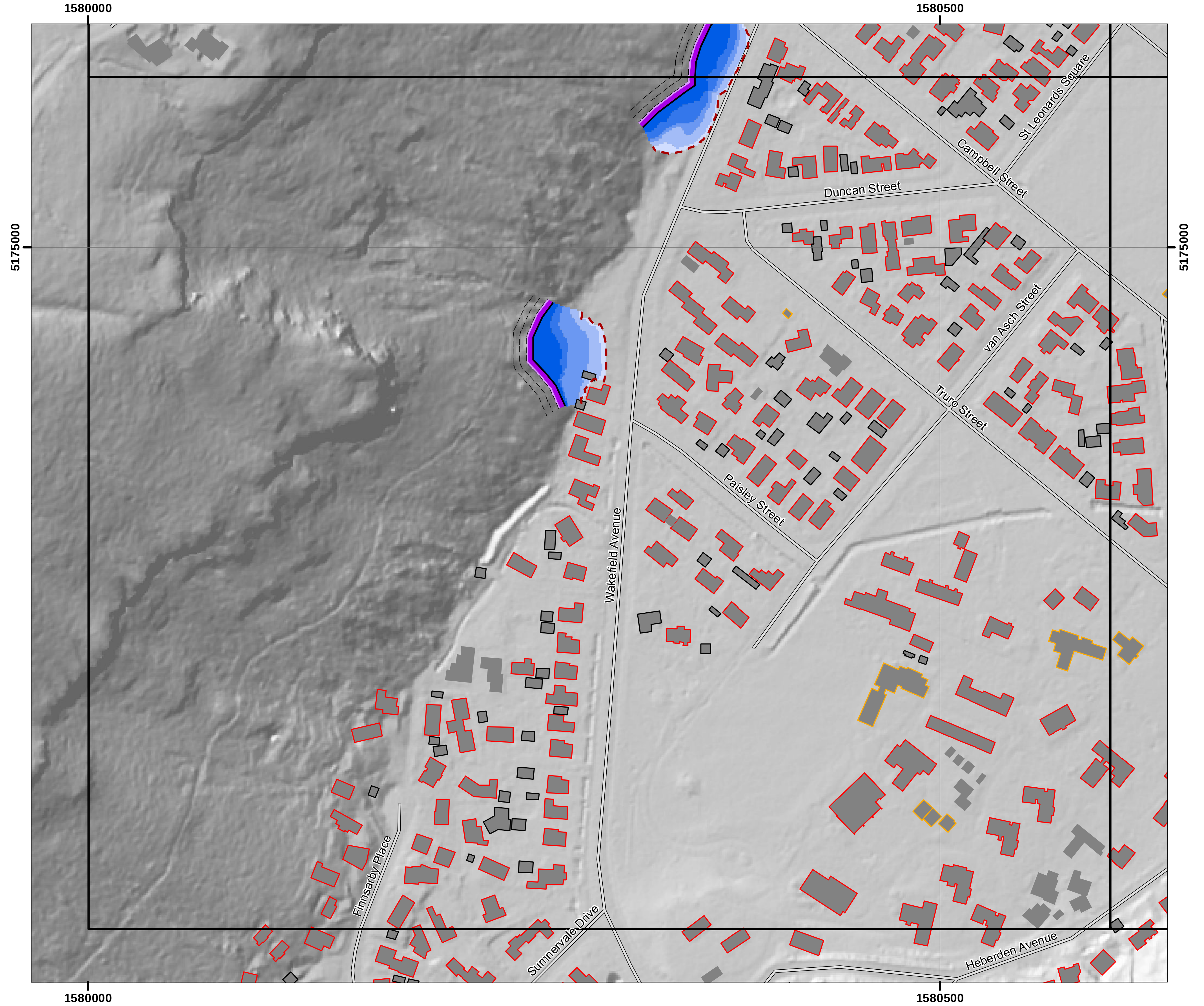
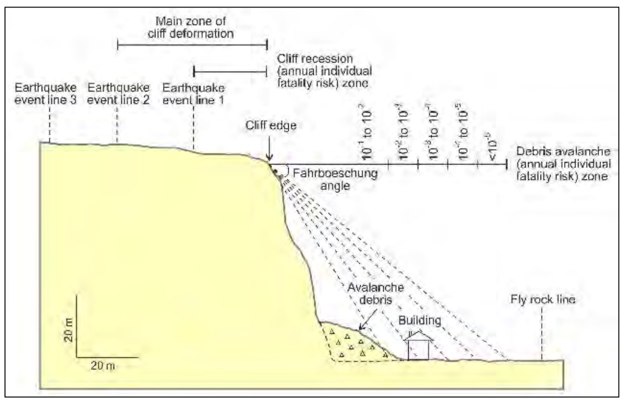
REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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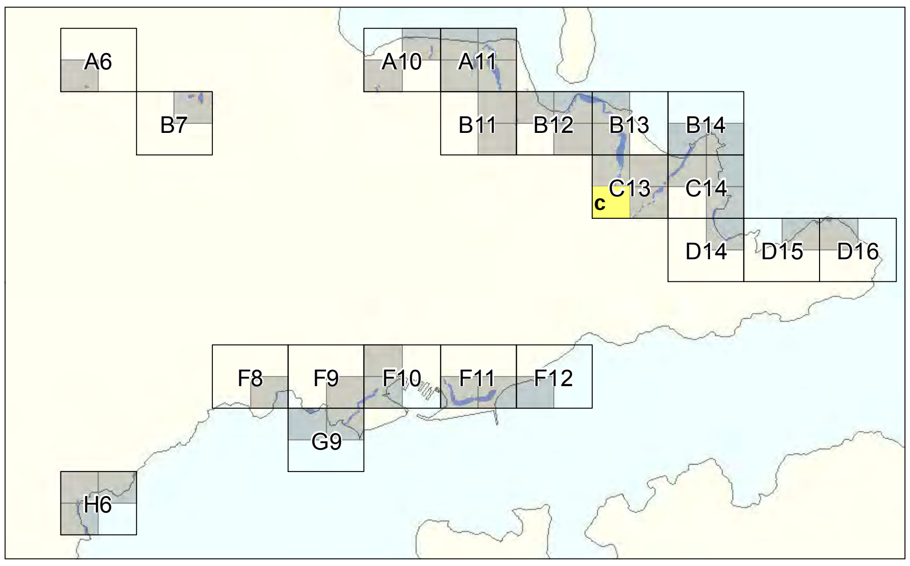


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

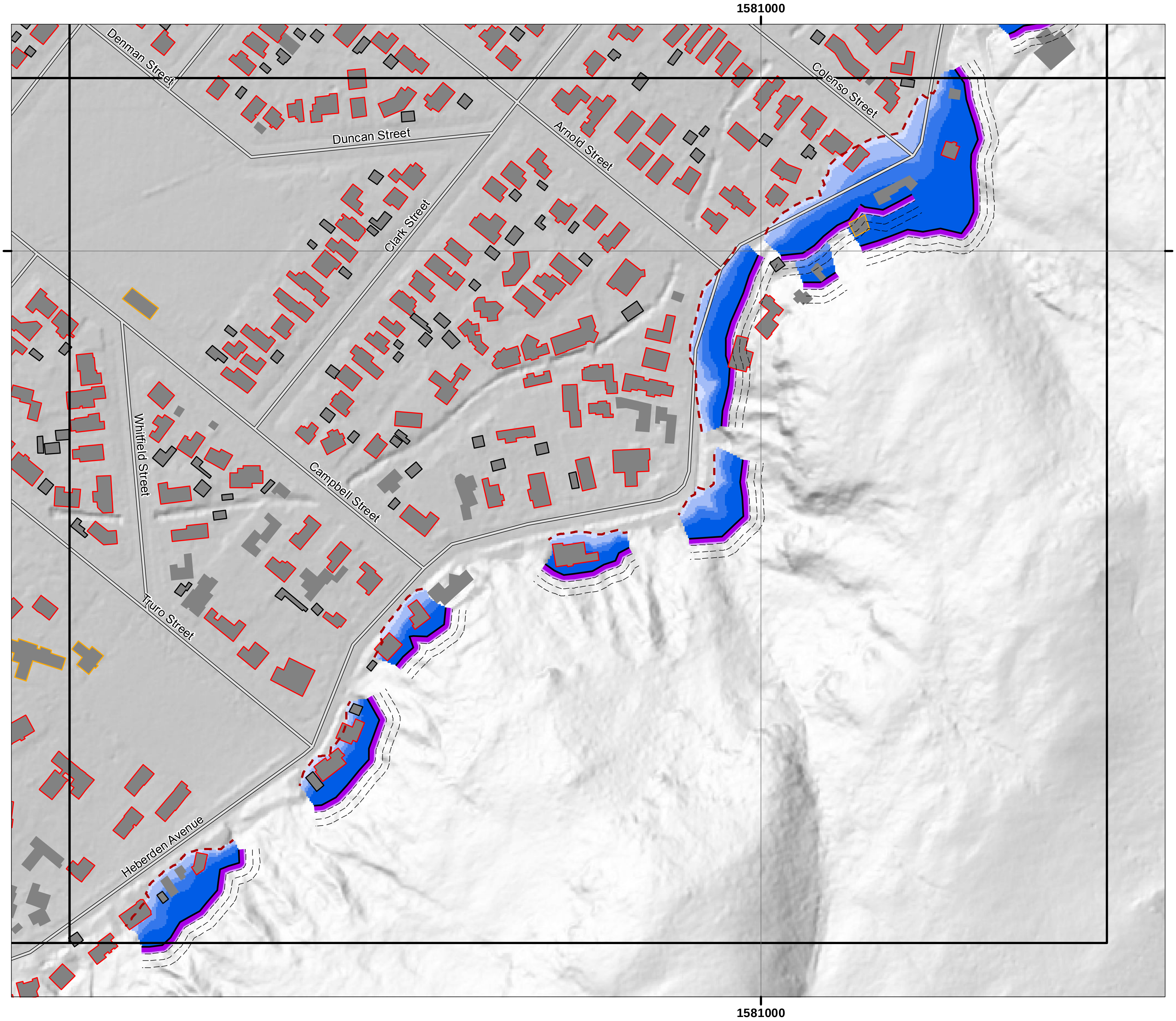
Port Hills Christchurch

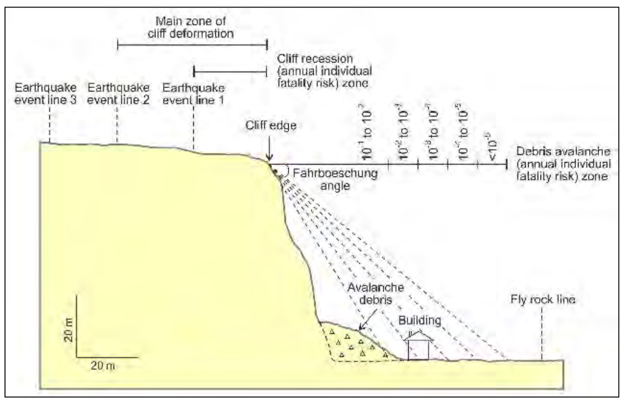
APPENDIX B Map C13c

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

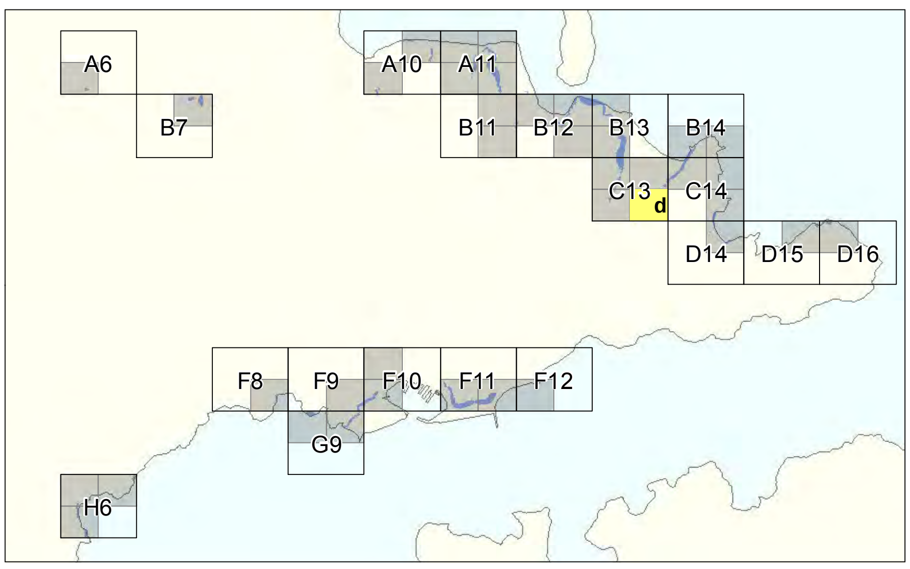
Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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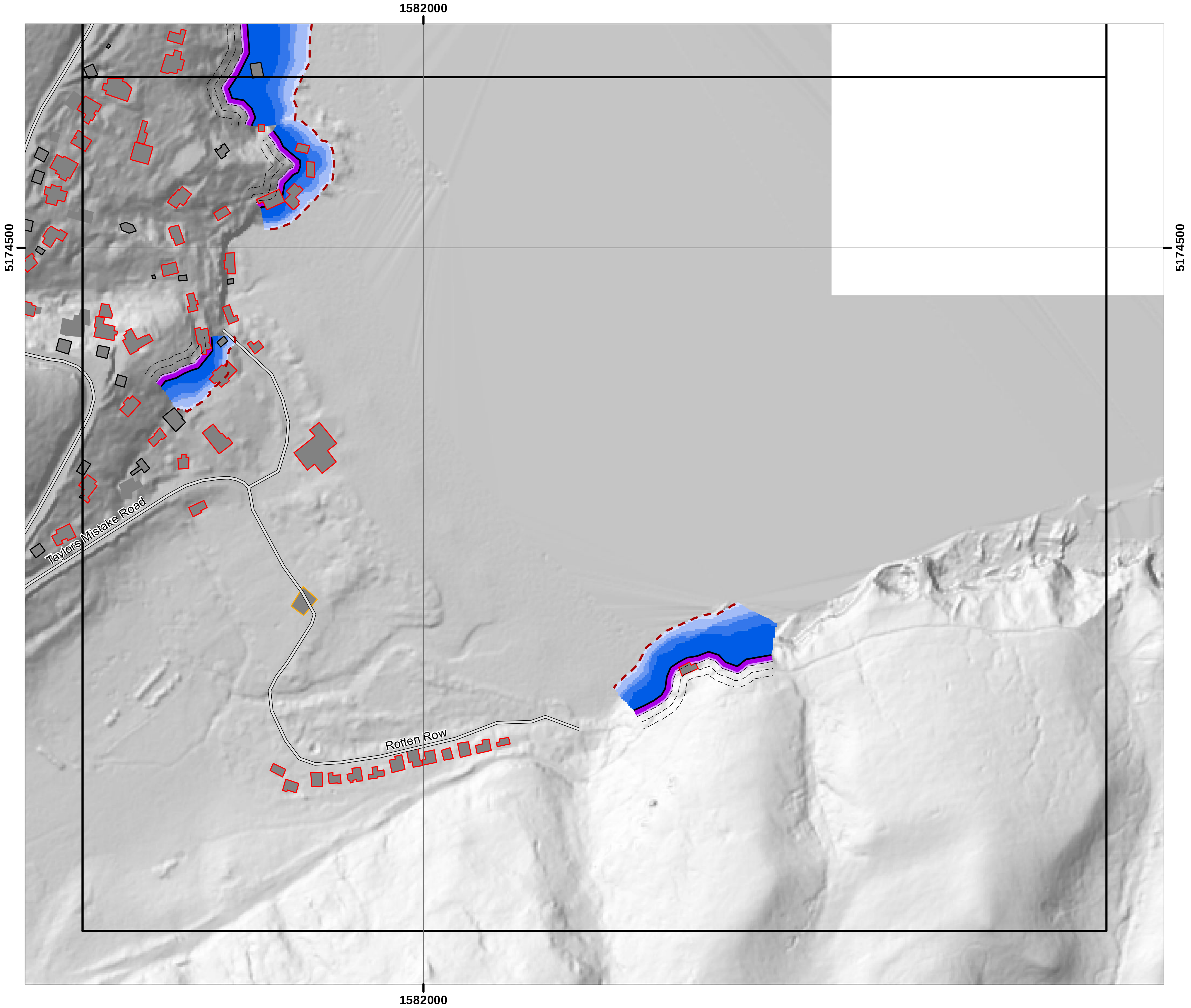
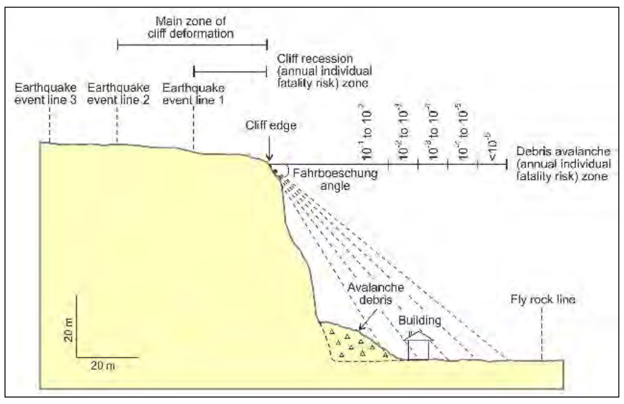
SCALE BAR: 0 20 40 60 80 100 m			CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map C13d
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	GNS SCIENCE TE PŪ AO	Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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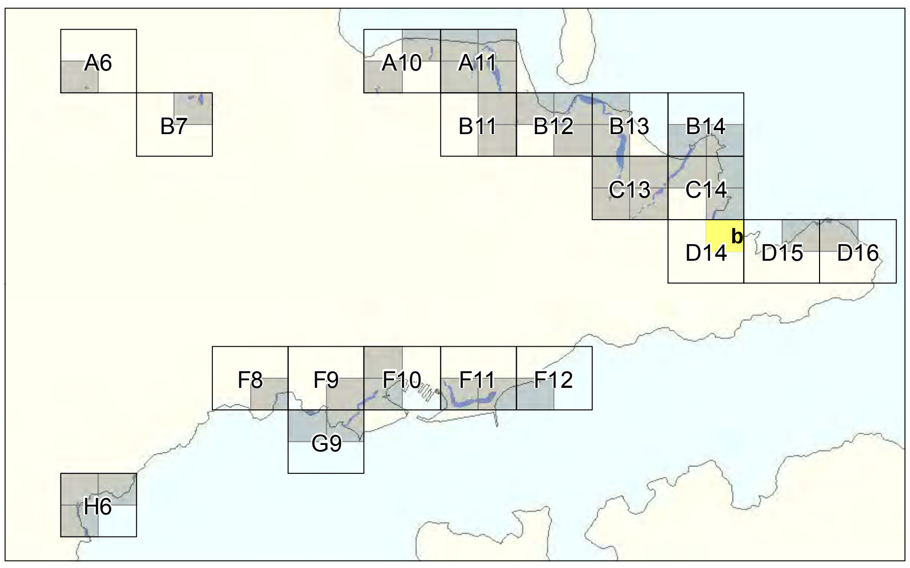
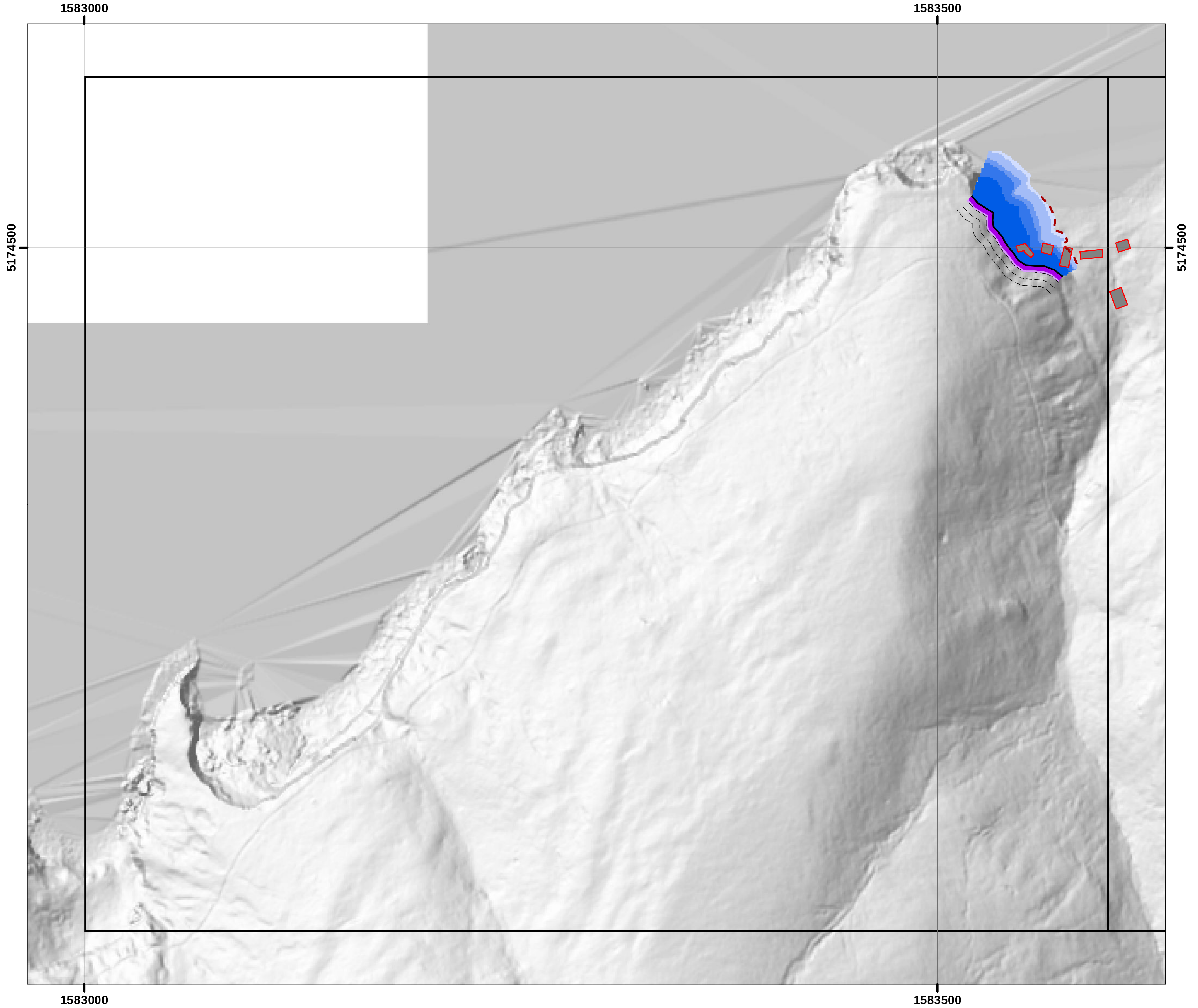
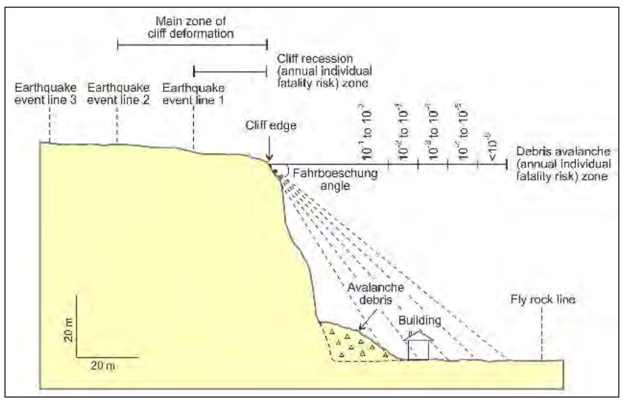


SCALE BAR: 0 20 40 60 80 100 m			CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map D14b
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	GNS SCIENCE TE PŪ AO	Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche

(annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession

(annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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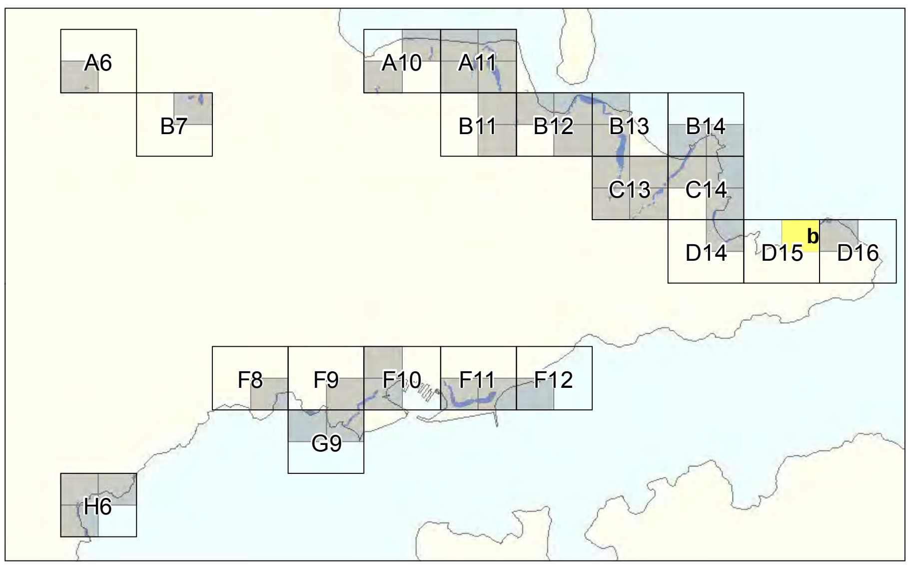


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

GNS SCIENCE TE PŪ AO

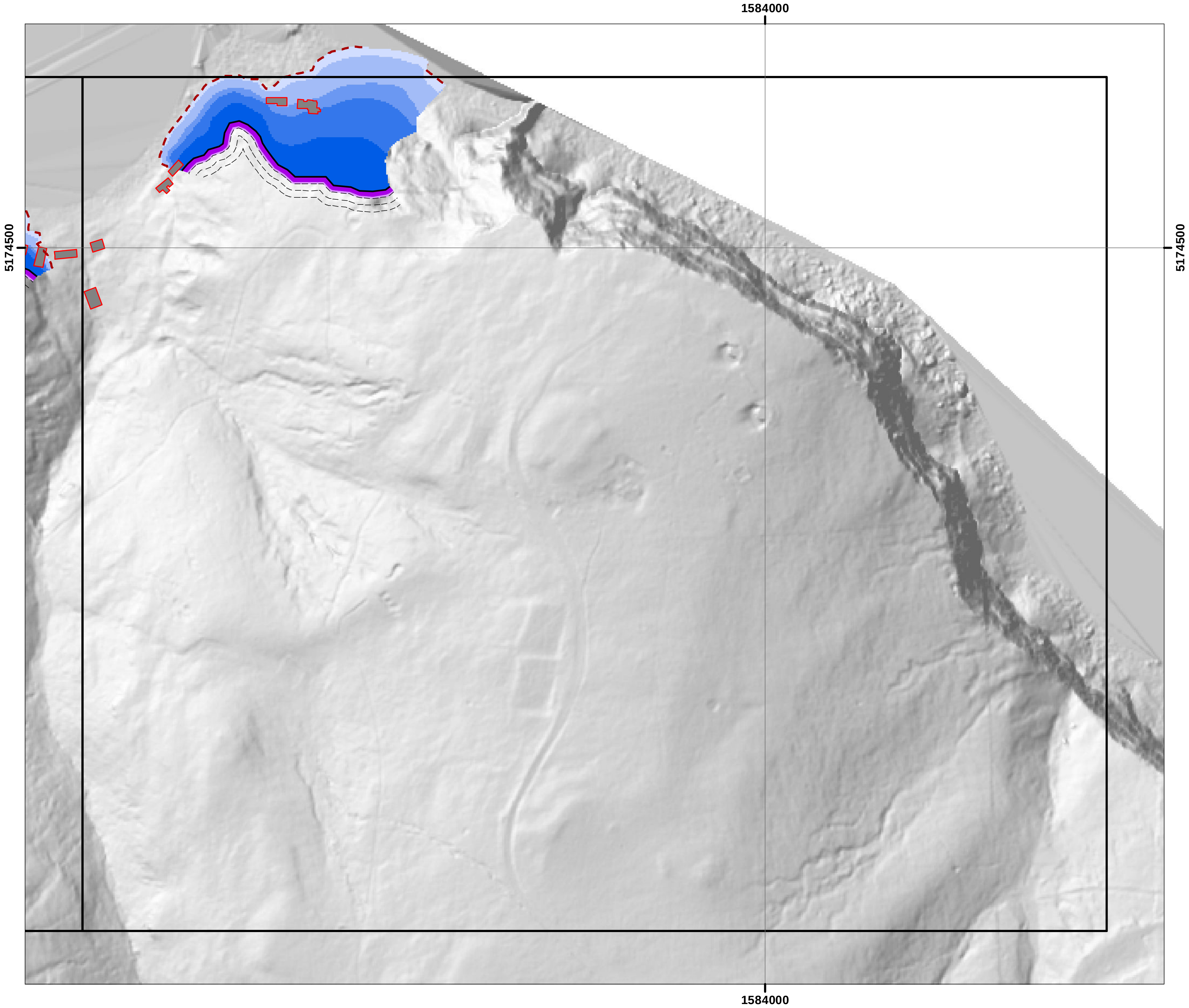
CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

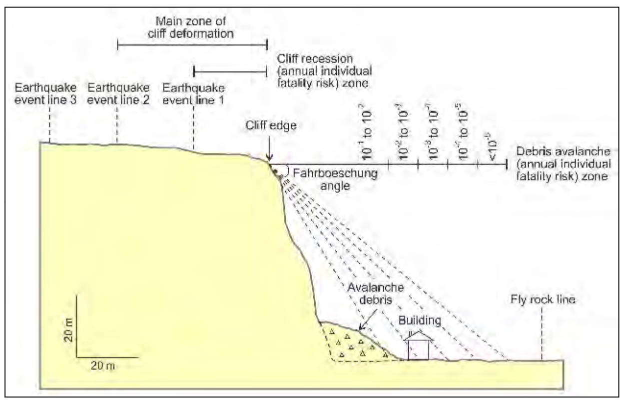
Port Hills
Christchurch

APPENDIX B
Map D15b

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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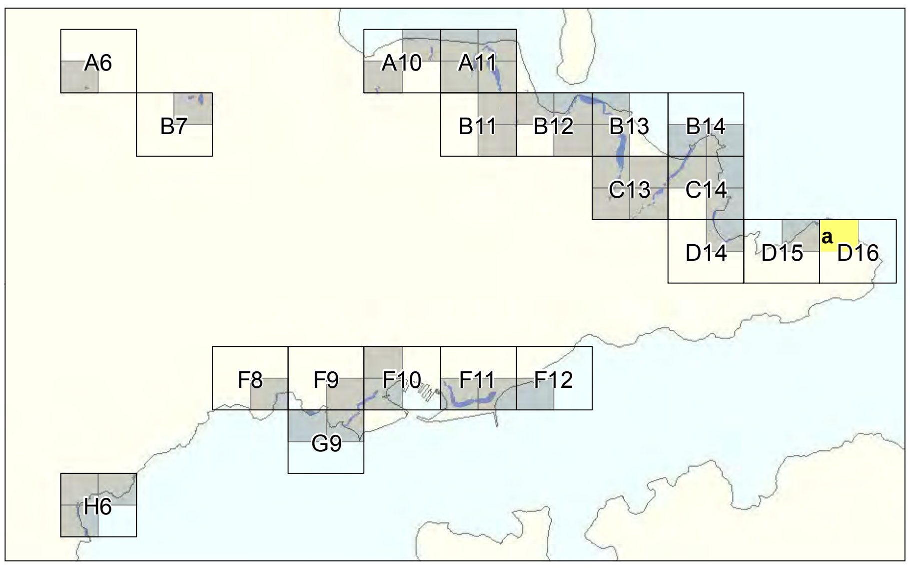


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

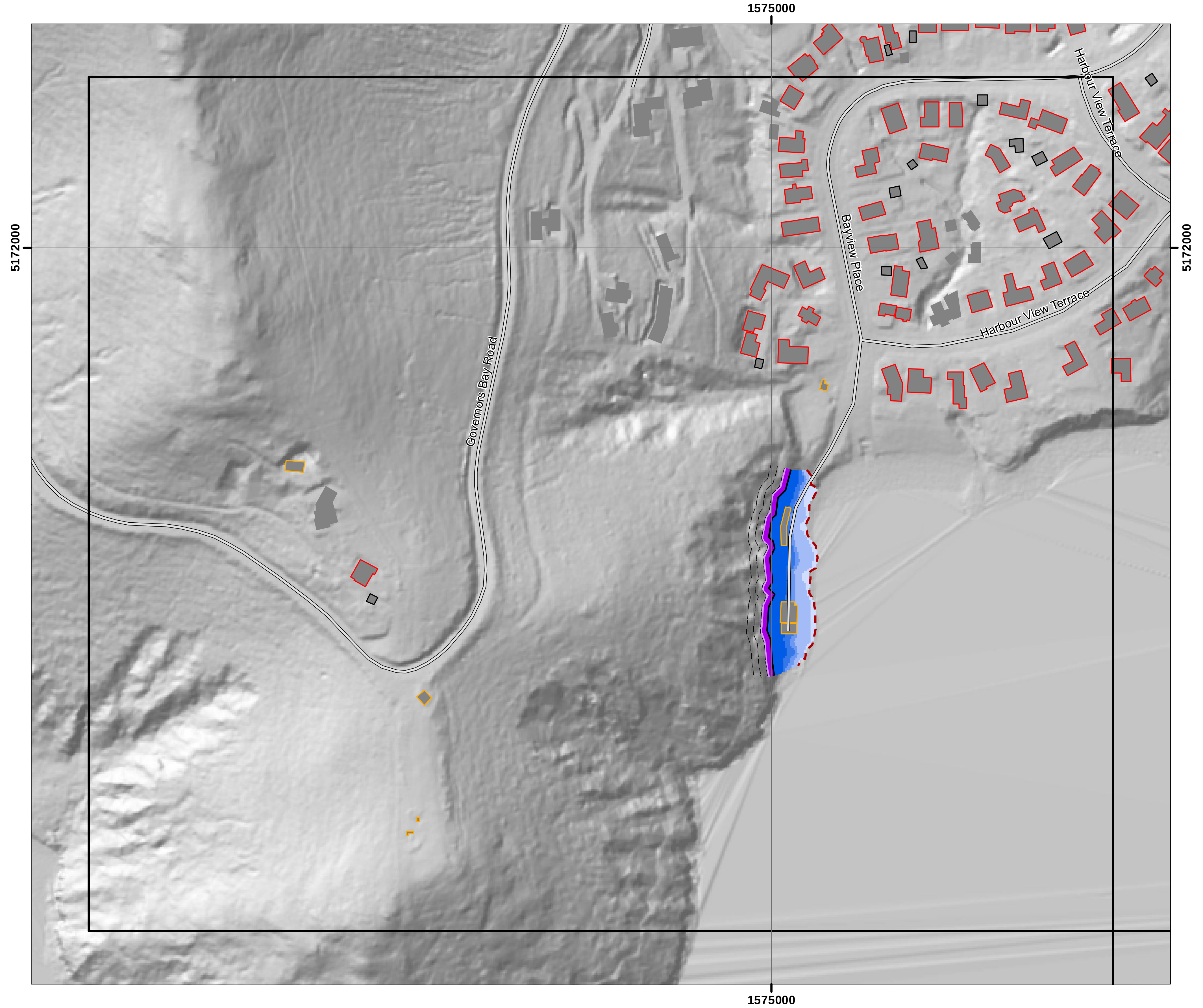
APPENDIX B
Map D16a

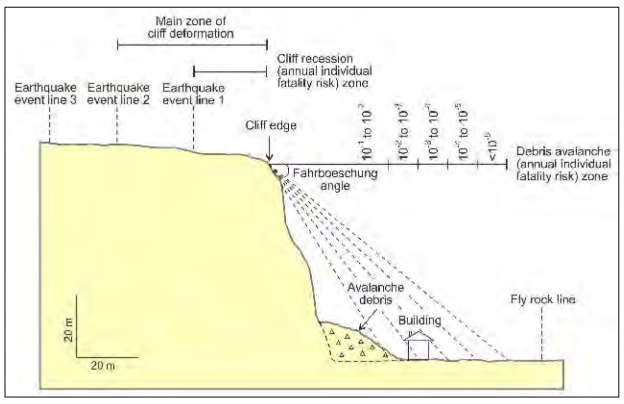
Port Hills Christchurch

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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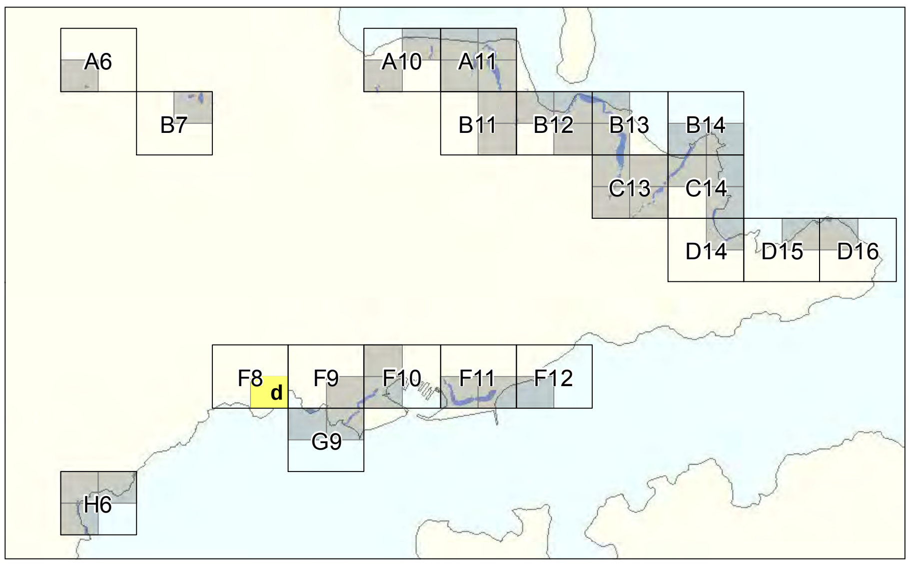

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

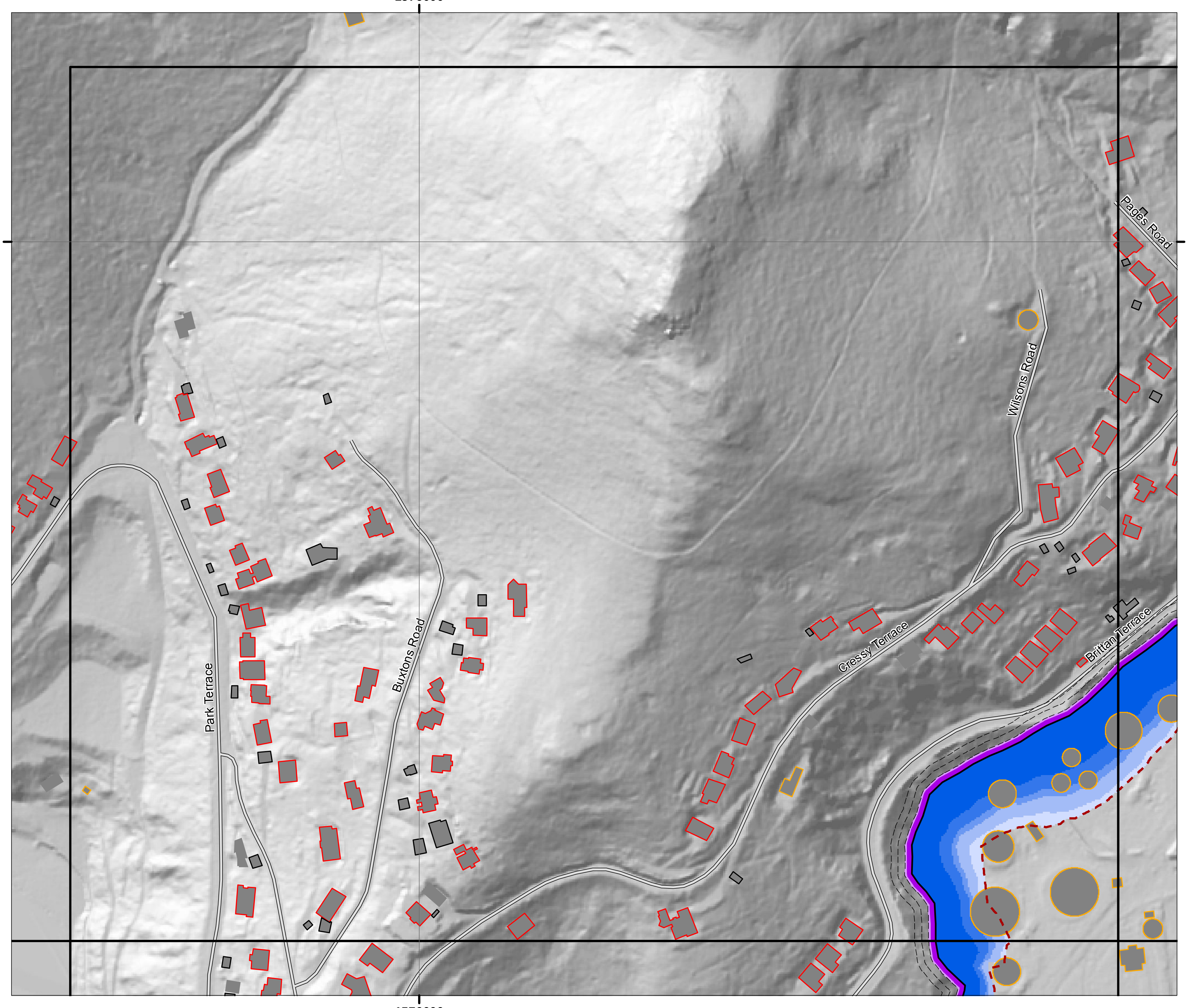
Port Hills
Christchurch

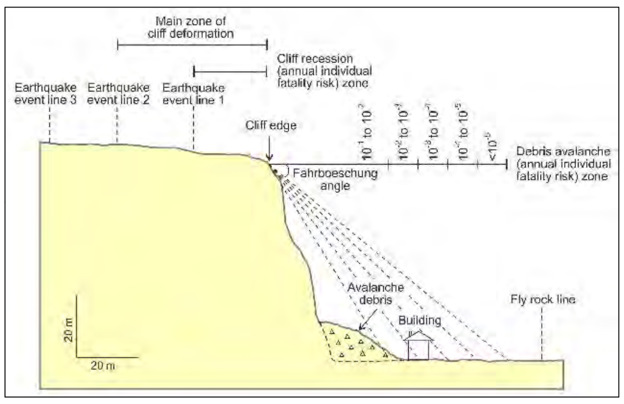
APPENDIX B
Map F8d

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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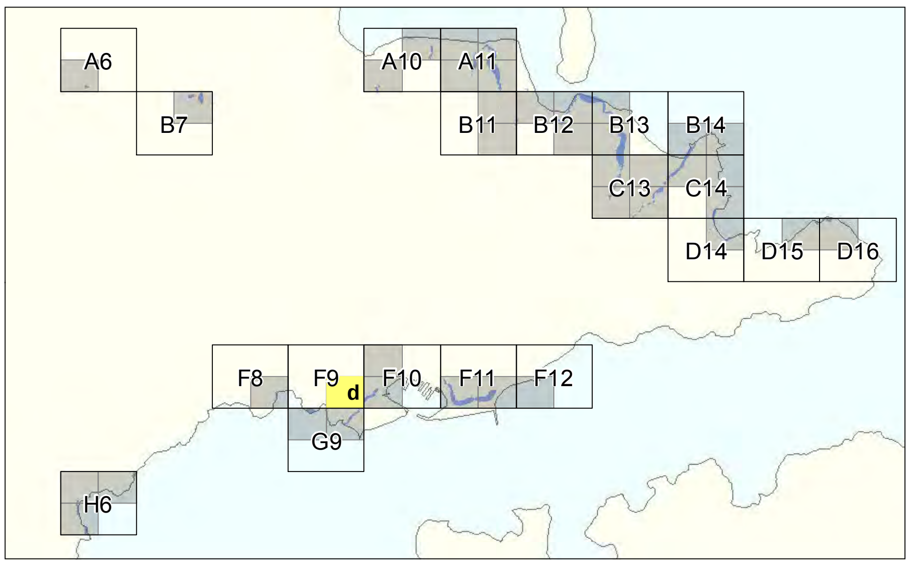

SCALE BAR: 0 20 40 60 80 100 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

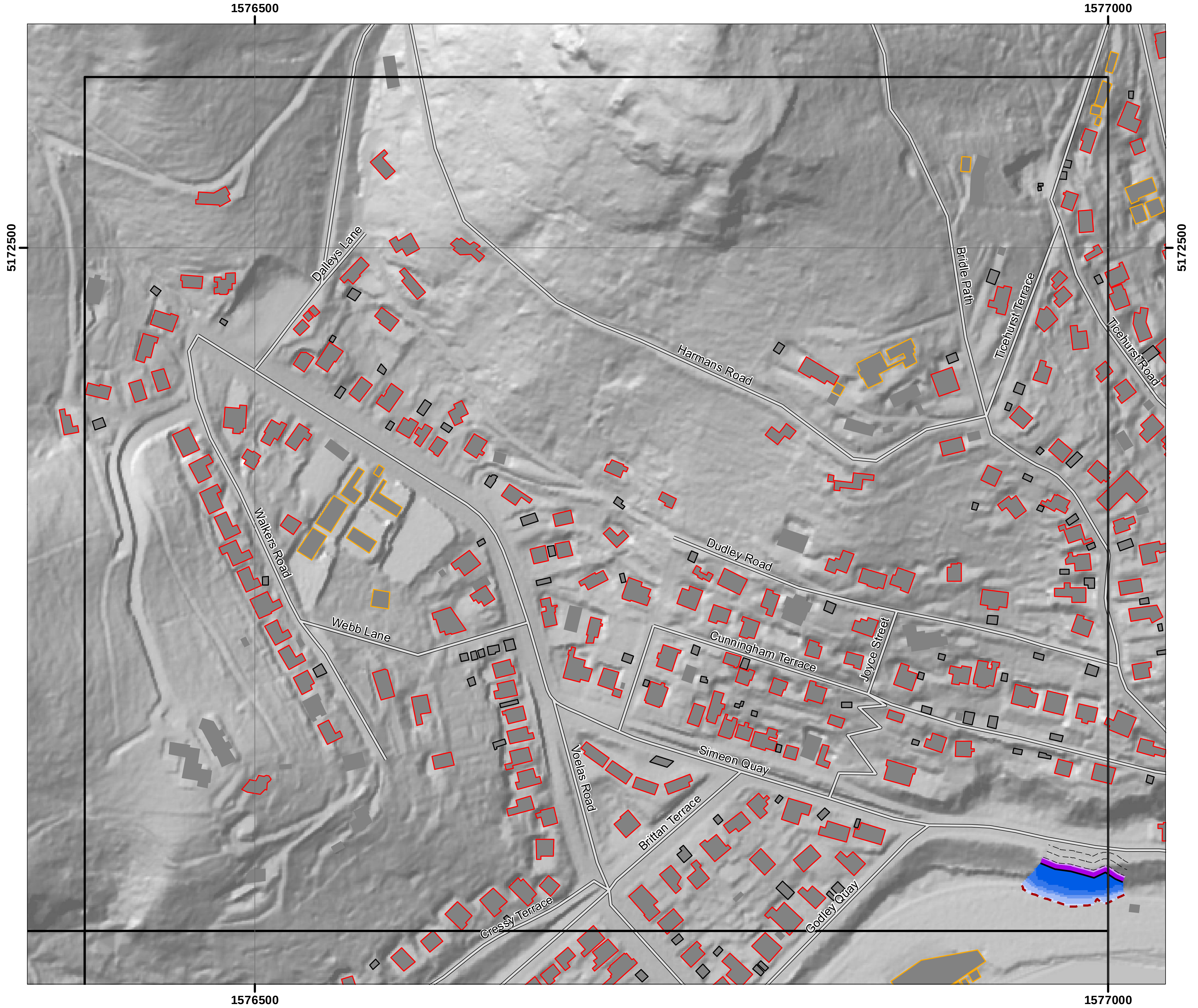
Port Hills Christchurch

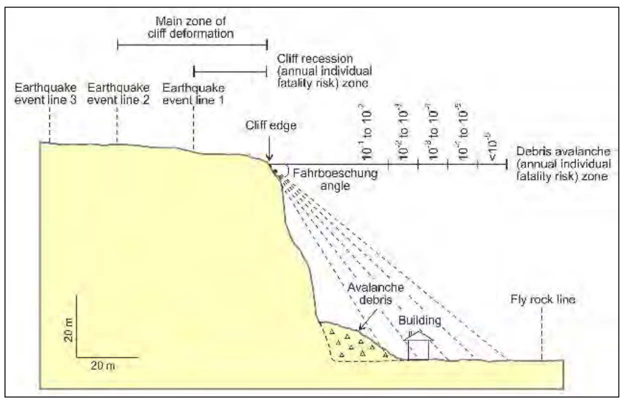
APPENDIX B
Map F9d

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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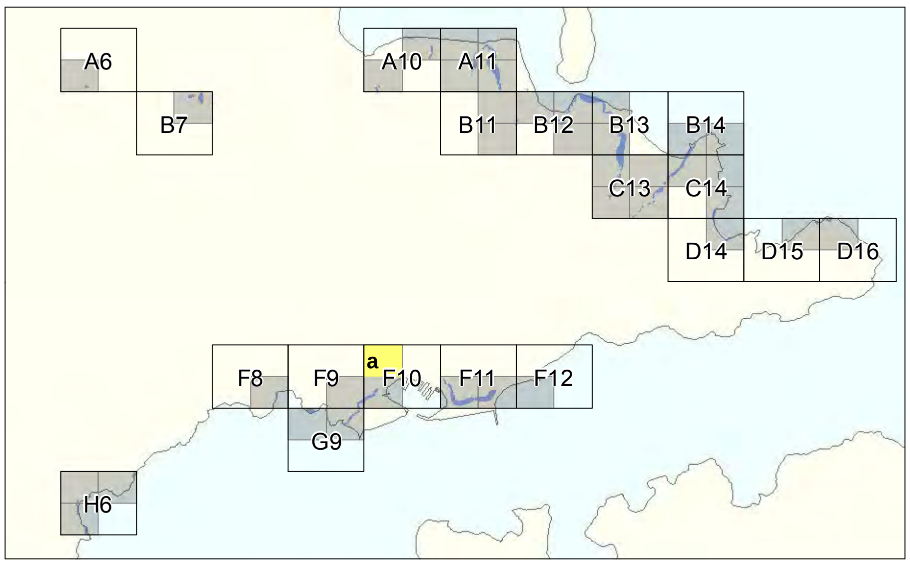

SCALE BAR: 0 20 40 60 80 100 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

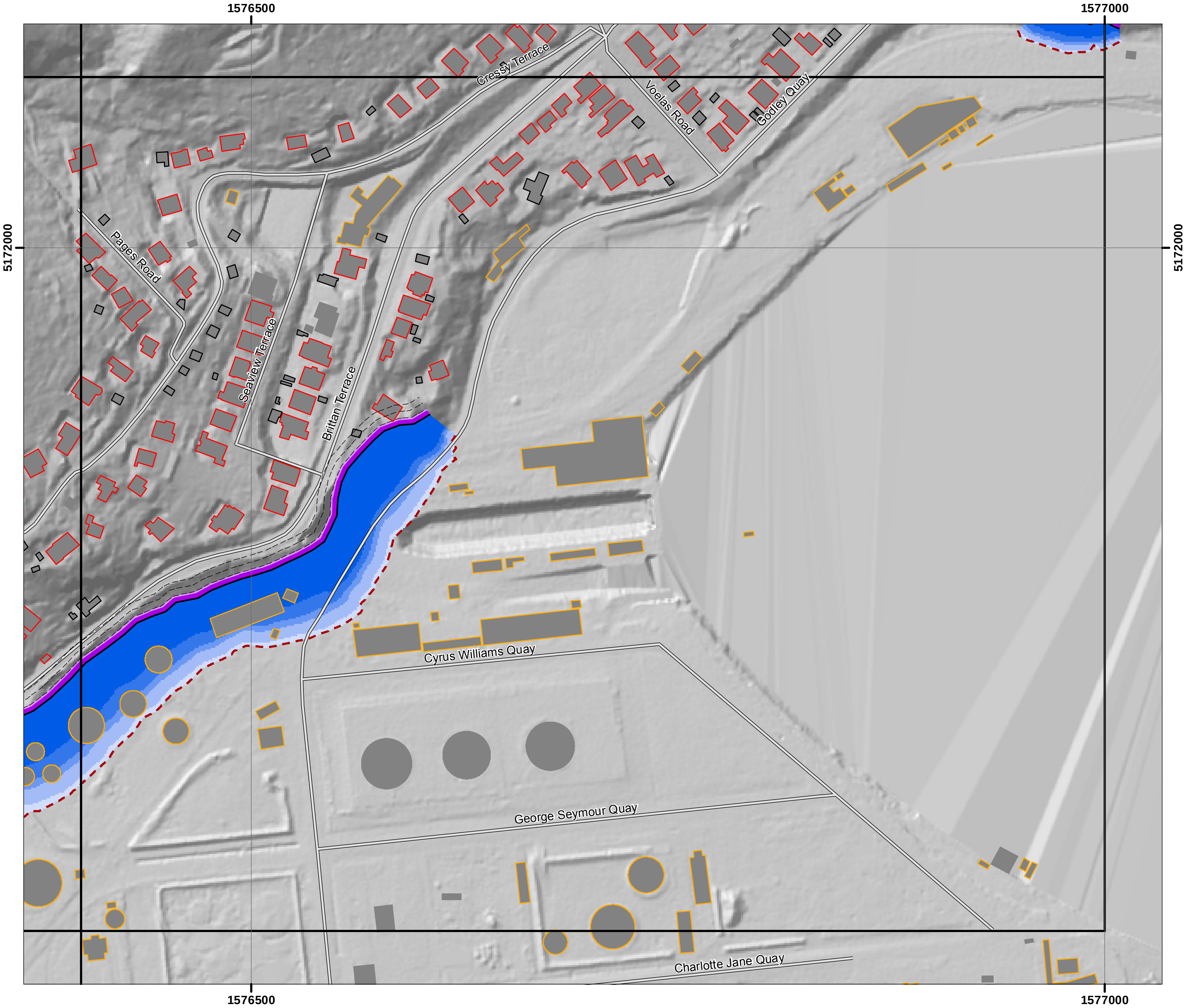
CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

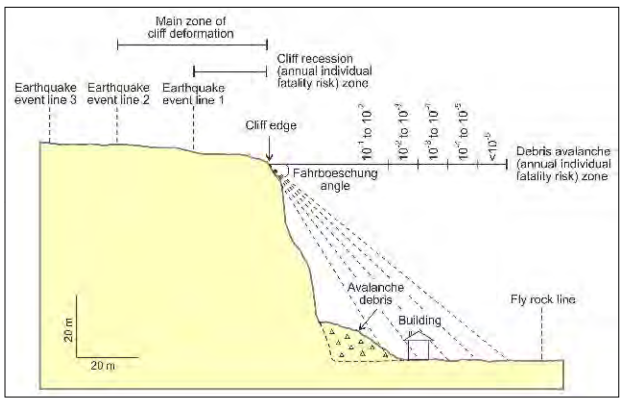
Port Hills
Christchurch

APPENDIX B
Map F10a

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013





Debris Avalanche
(annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession
(annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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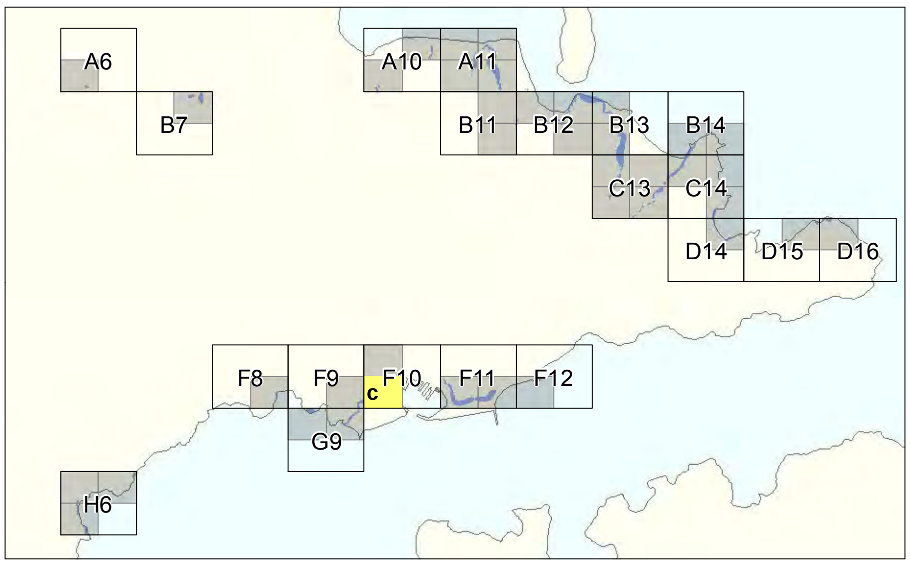


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

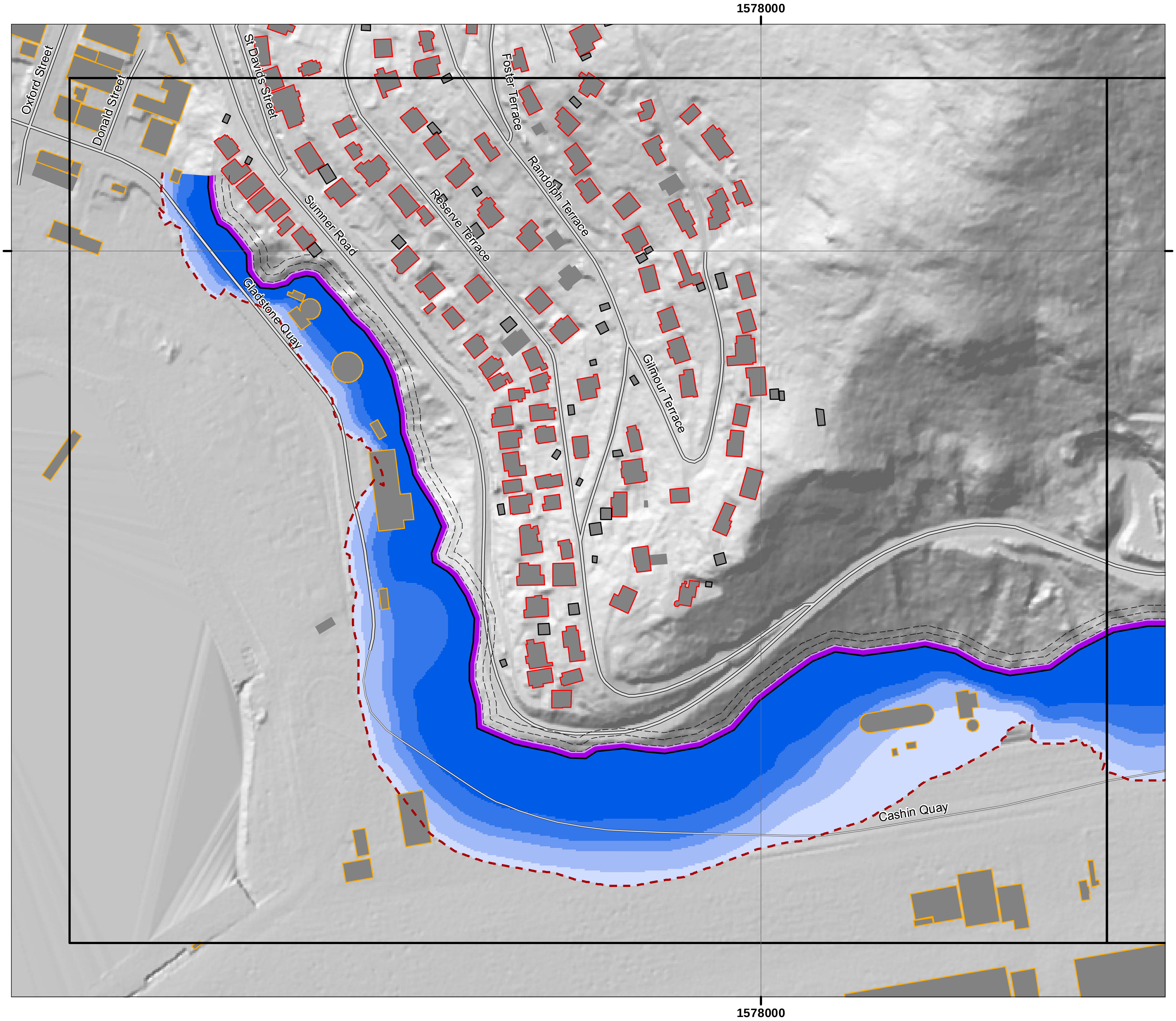
Port Hills
Christchurch

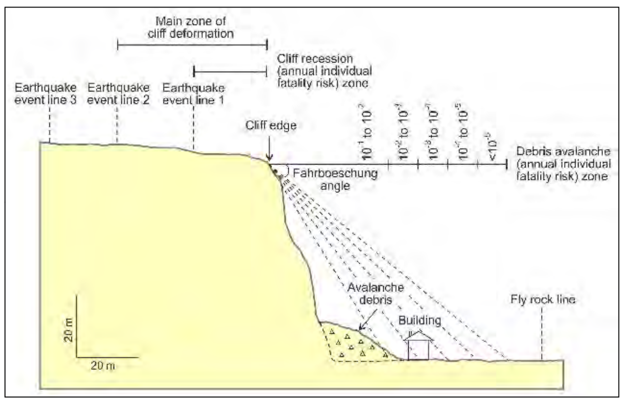
APPENDIX B
Map F10c

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

Annual individual fatality risk bands (e.g. 10^{-3} to 10^{-4}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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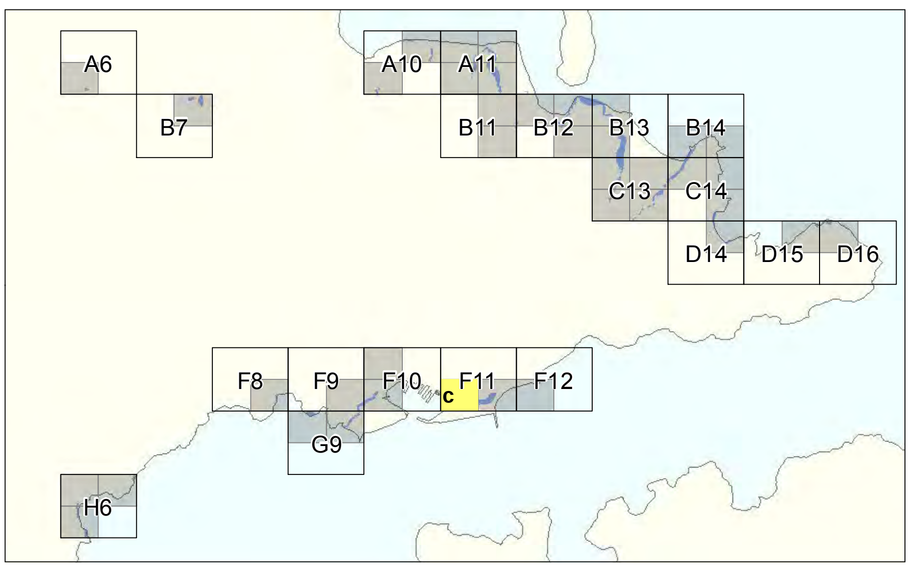
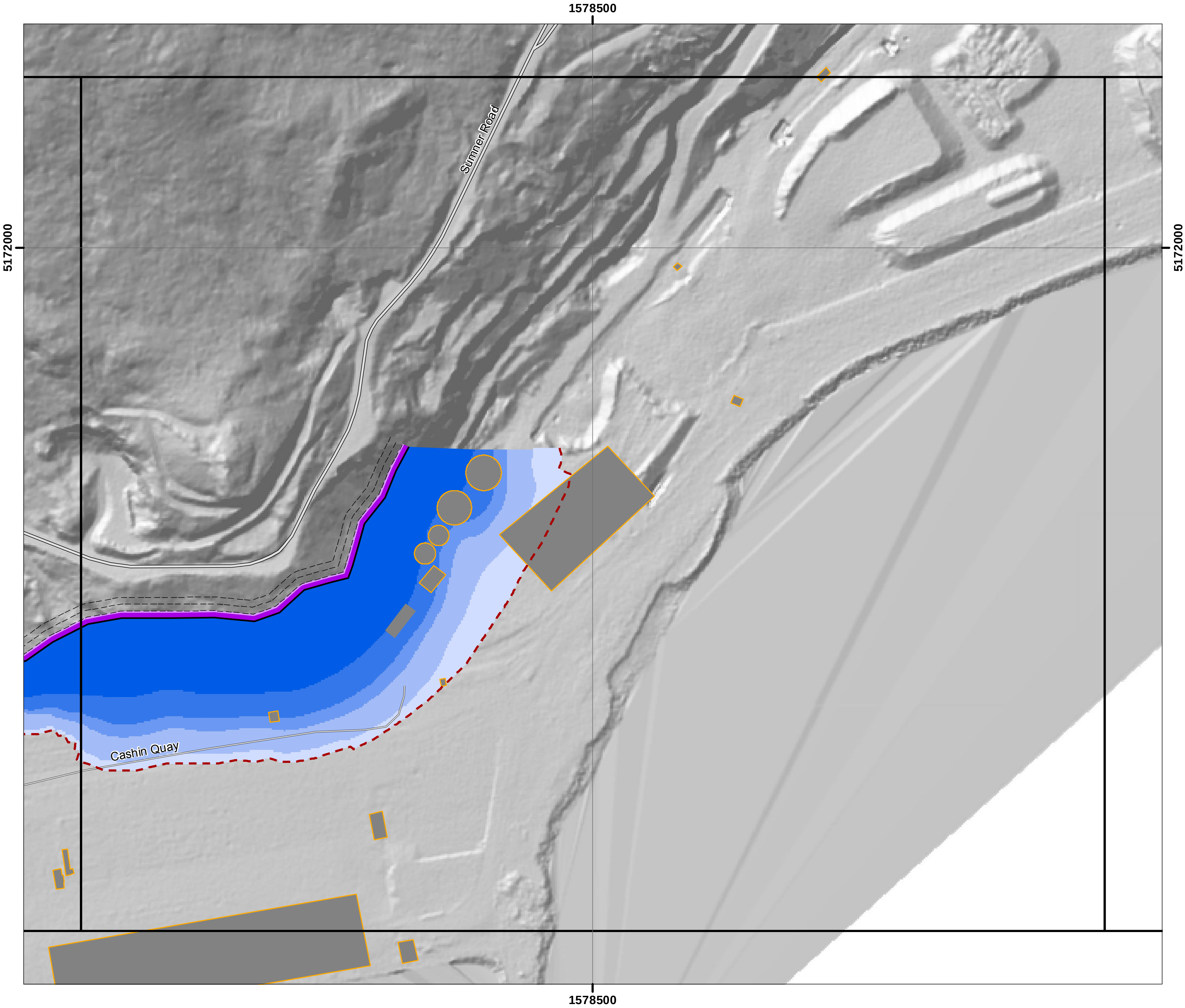
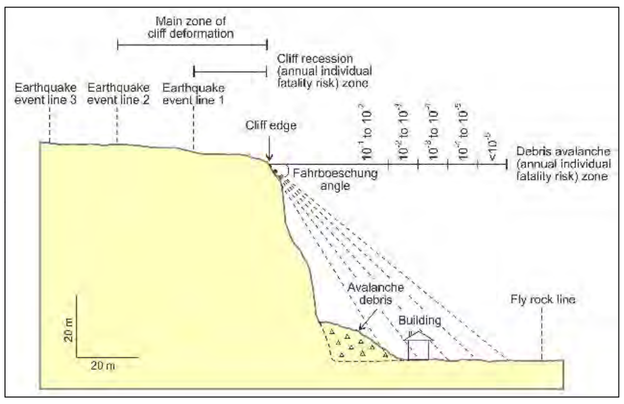


SCALE BAR: 0 20 40 60 80 100 m		GNS SCIENCE TE PŪ AO	CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map F11c
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM		Port Hills Christchurch	FINAL ISSUE 2 REPORT: CR2012/124 DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

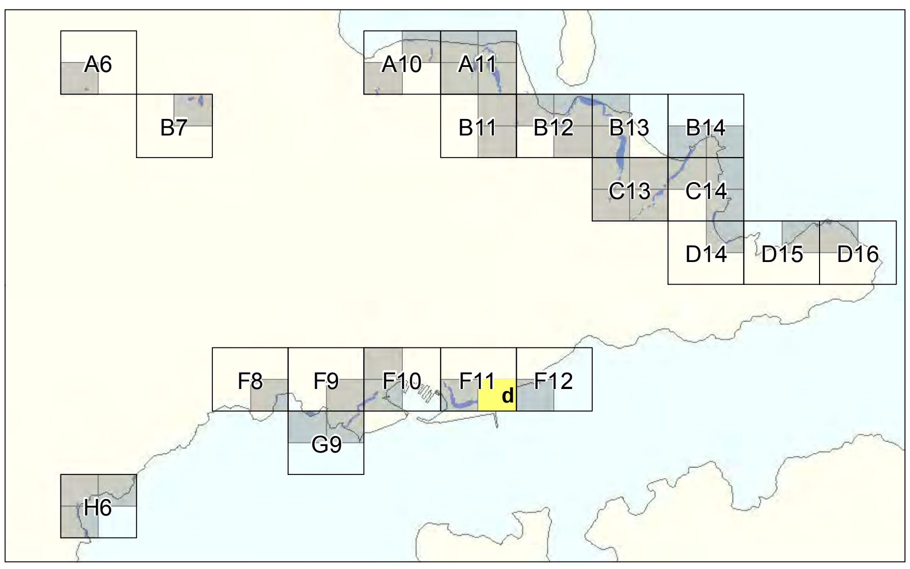
Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



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SCALE BAR: 0 20 40 60 80 100 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH
CHK: CM

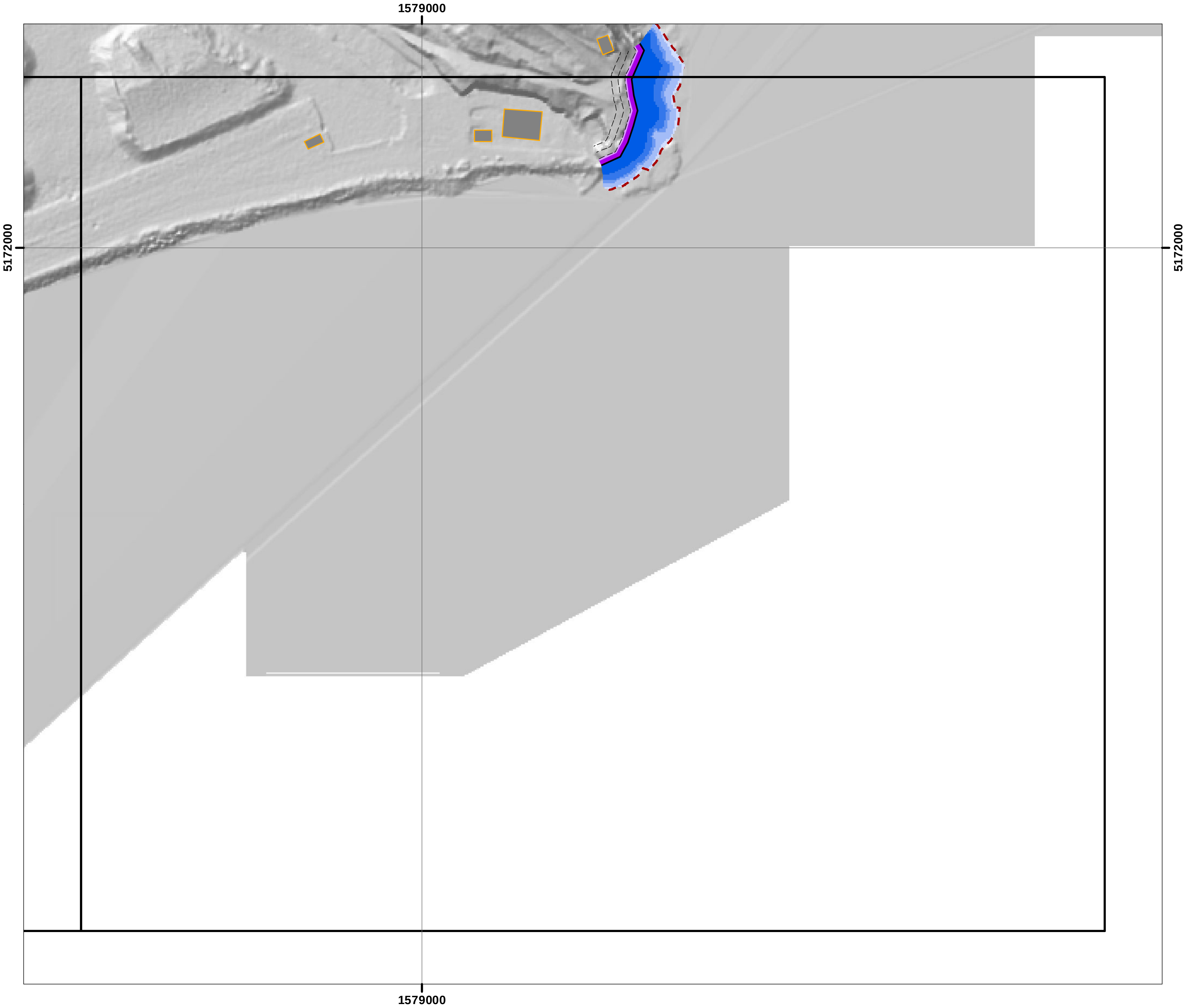
CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

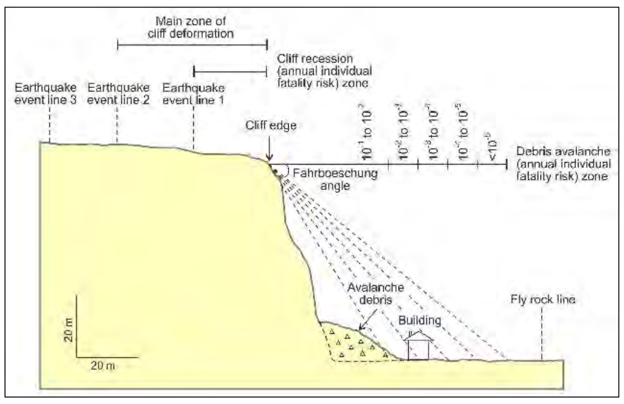
Port Hills Christchurch

APPENDIX B
Map F11d

FINAL ISSUE 2

REPORT: CR2012/124
DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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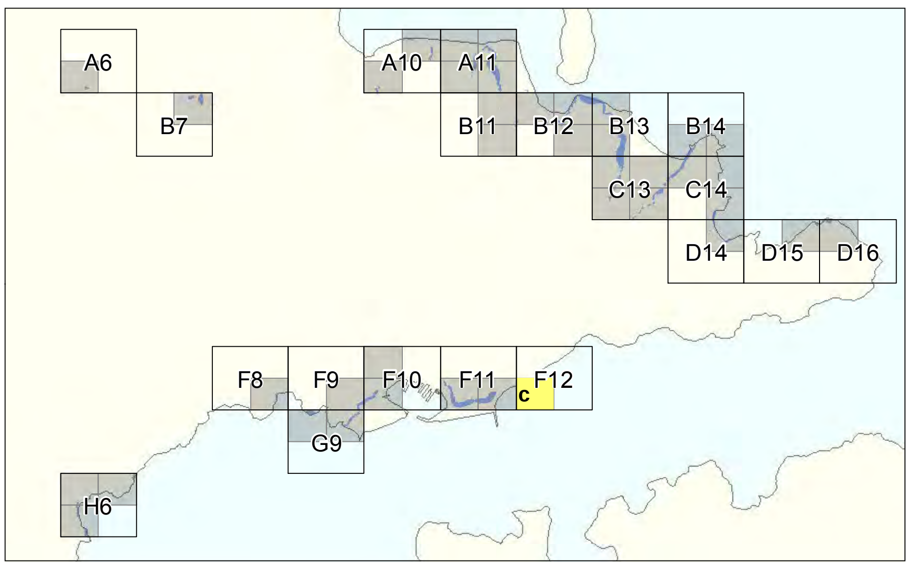


SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

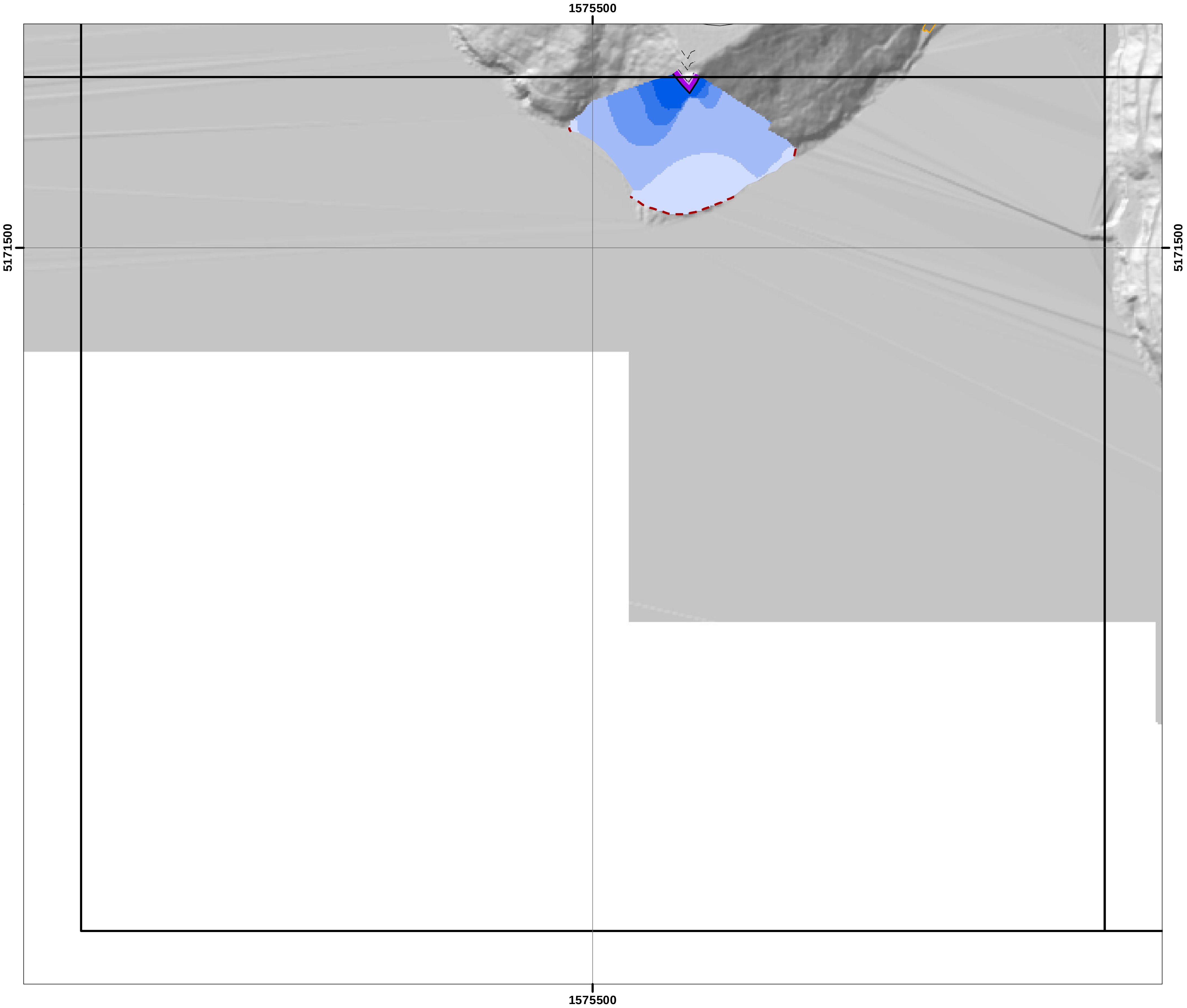
Port Hills Christchurch

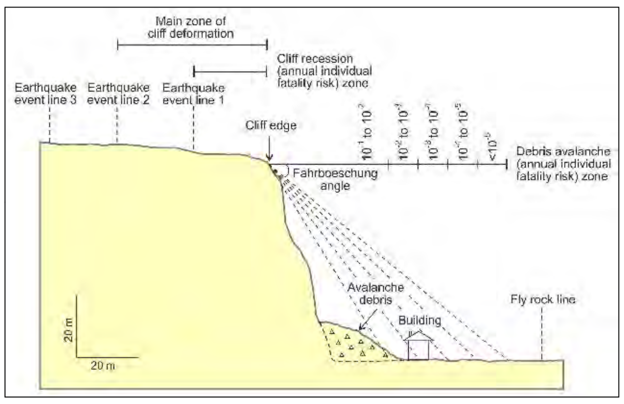
APPENDIX B Map F12c

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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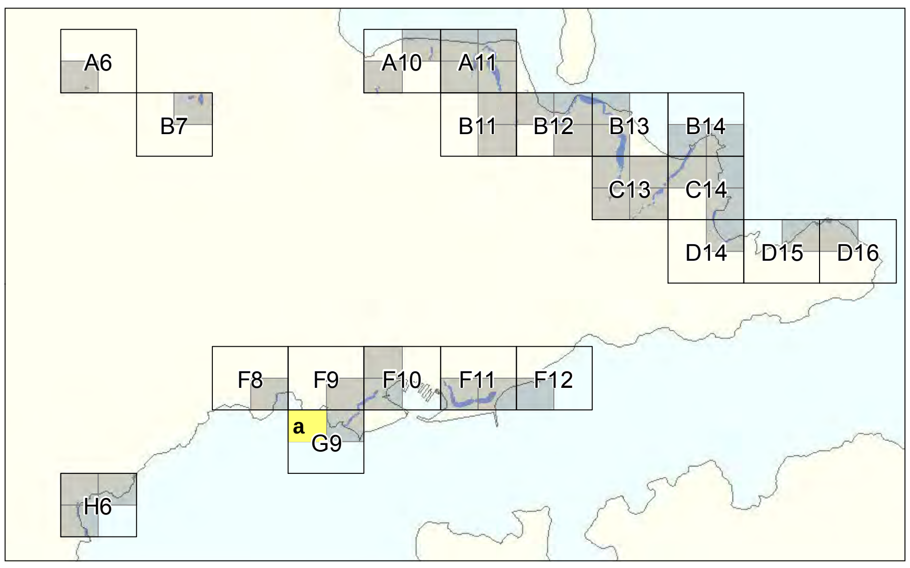
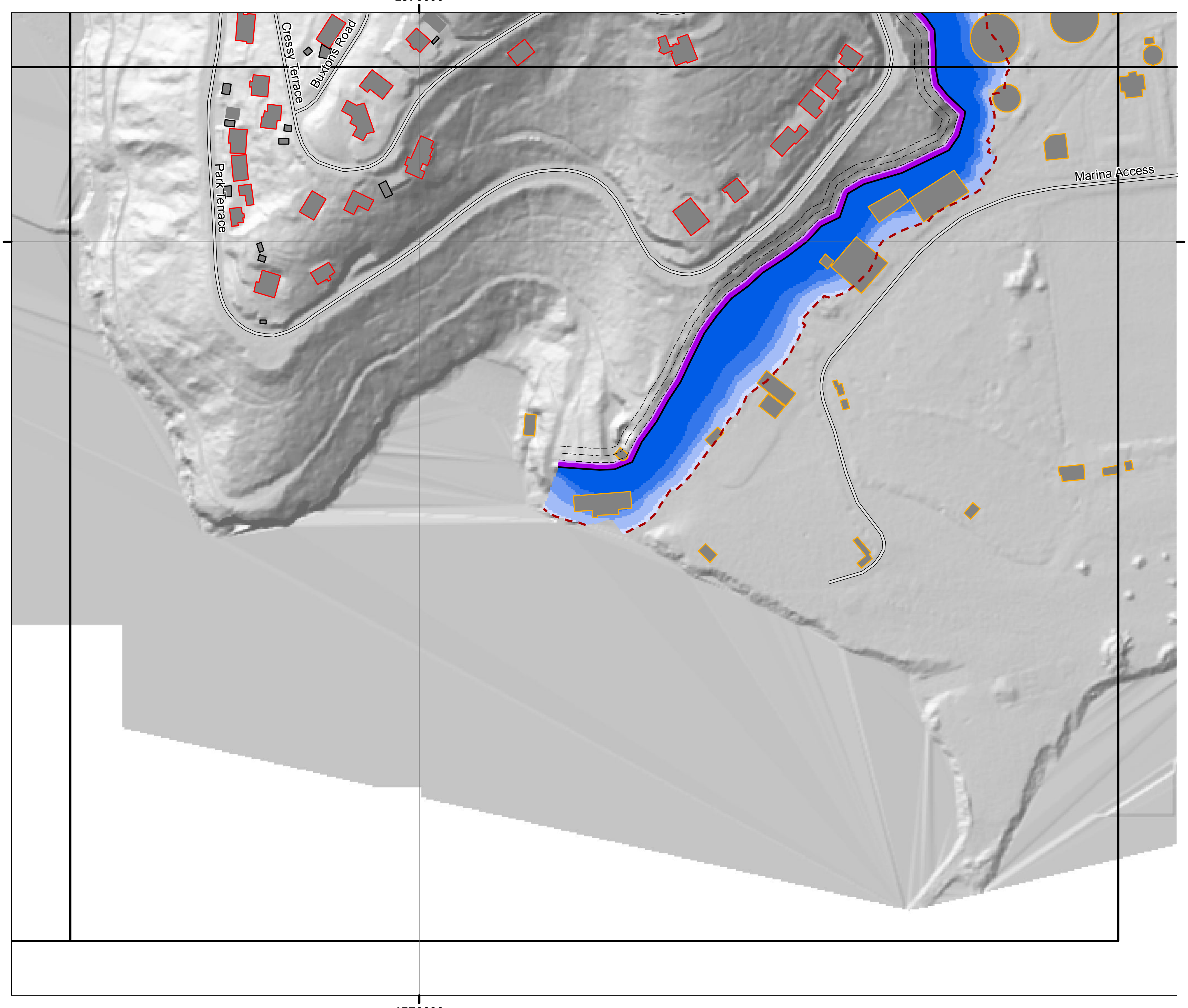


SCALE BAR: 0 20 40 60 80 100 m			**CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK**	APPENDIX B Map G9a
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	GNS SCIENCE TE PŪ AO	**Port Hills Christchurch**	**FINAL ISSUE 2** REPORT: CR2012/124 DATE: July 2013

1576000

5171500



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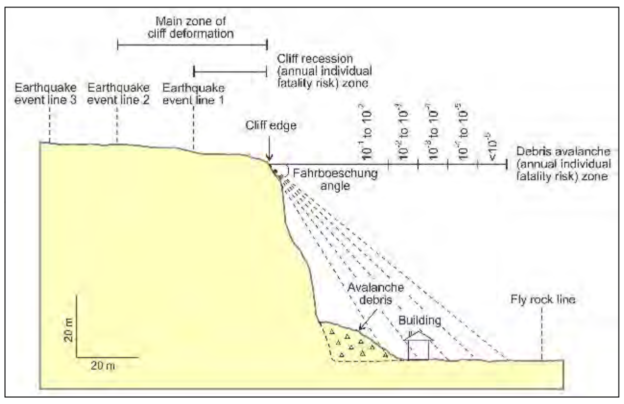

Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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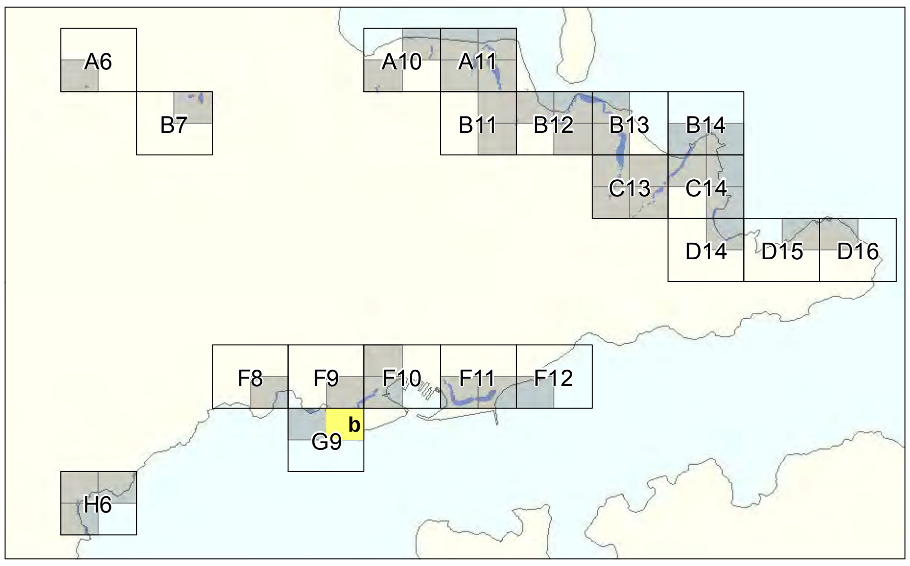

SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

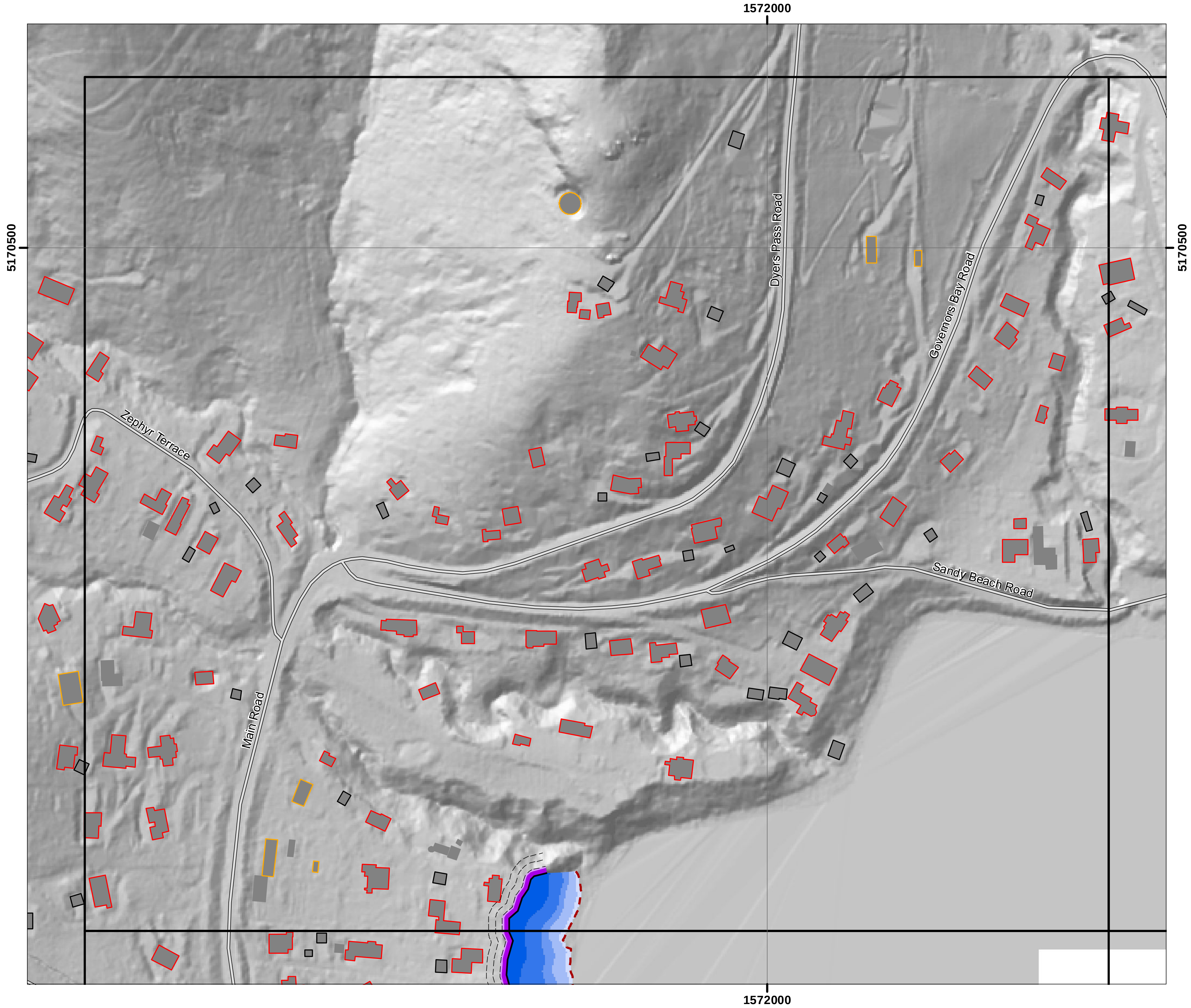
Port Hills Christchurch

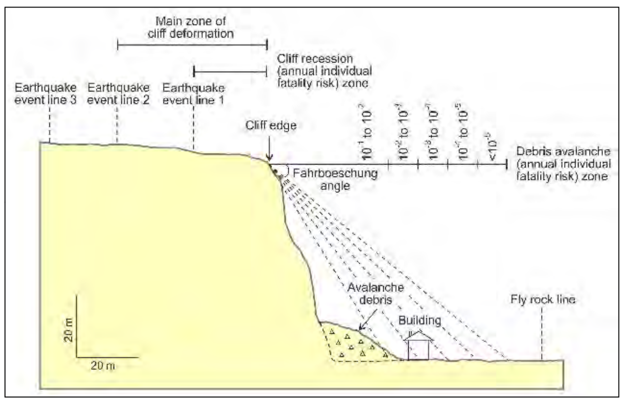
APPENDIX B Map G9b

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

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- Commercial-Industrial
- Accessory building
- Unknown

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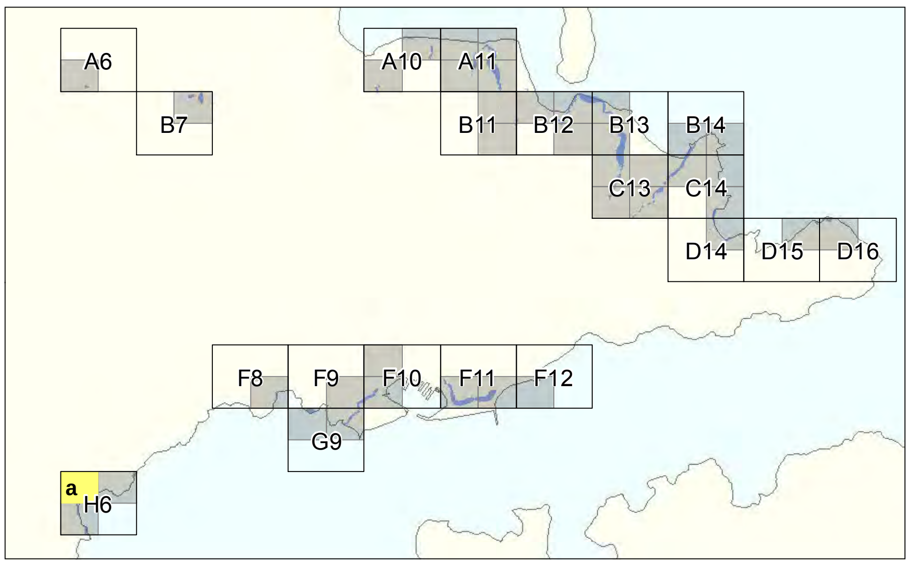

SCALE BAR: 0 20 40 60 80 100 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE
ANNUAL INDIVIDUAL FATALITY RISK

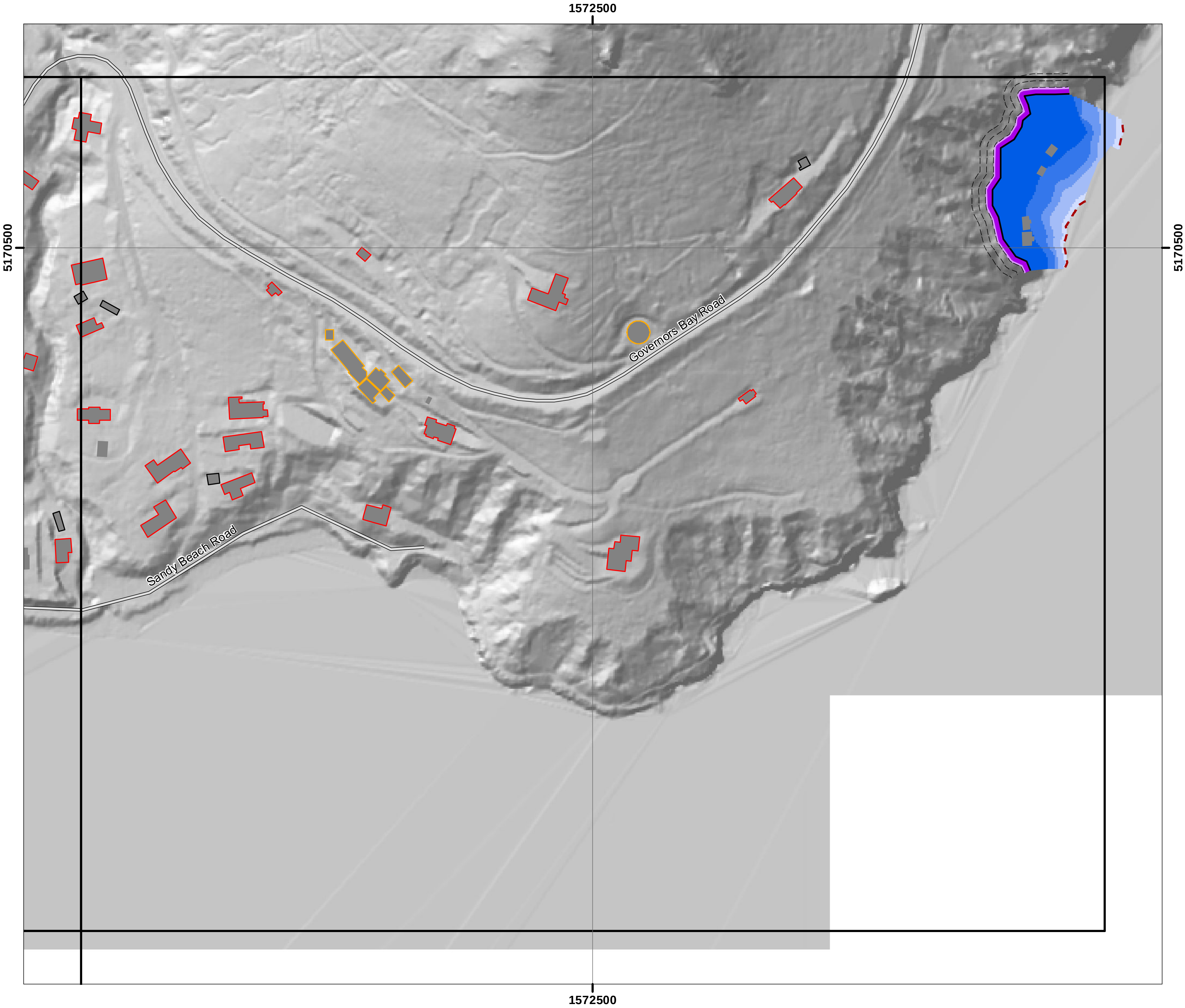
Port Hills Christchurch

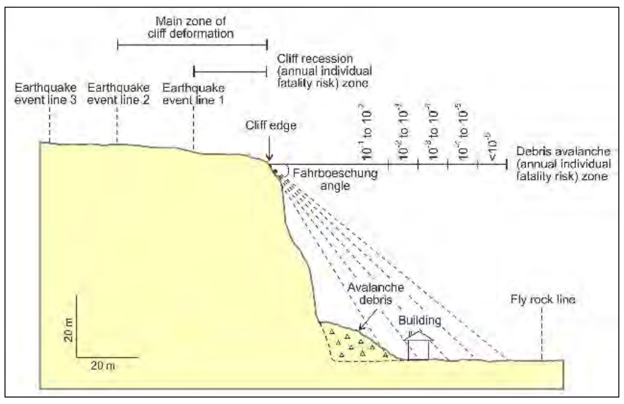
APPENDIX B
Map H6a

FINAL ISSUE 2

REPORT: CR2012/124

DATE: July 2013





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N

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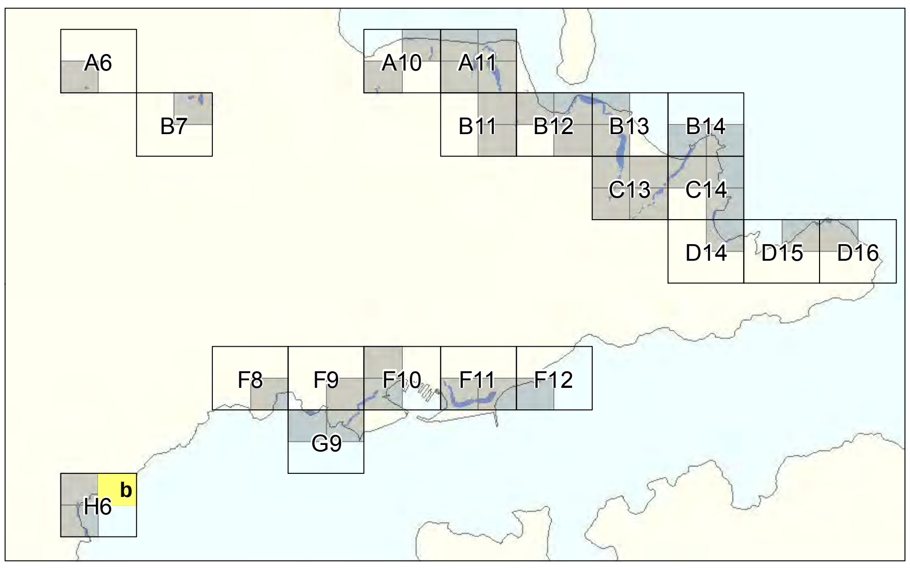
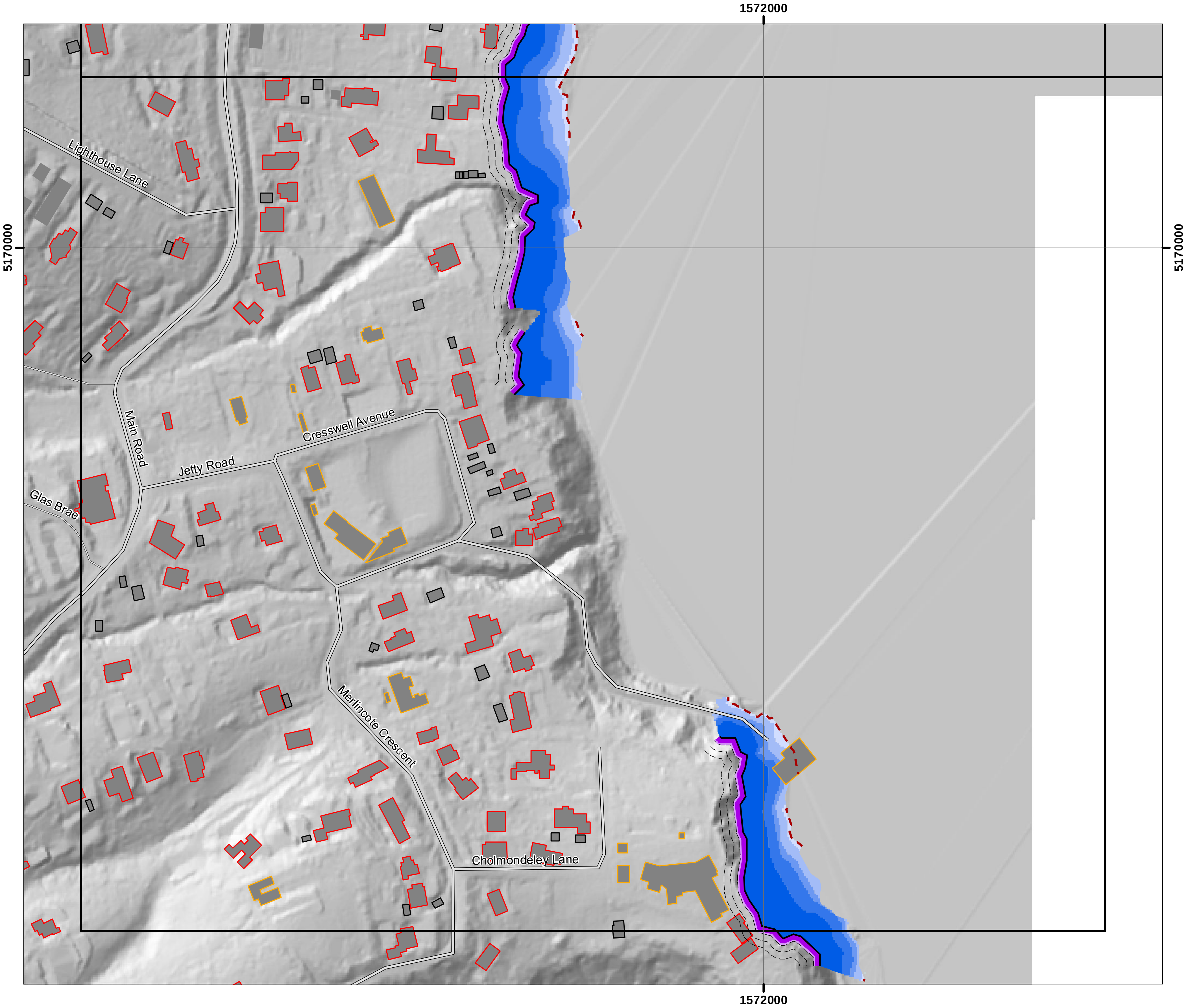
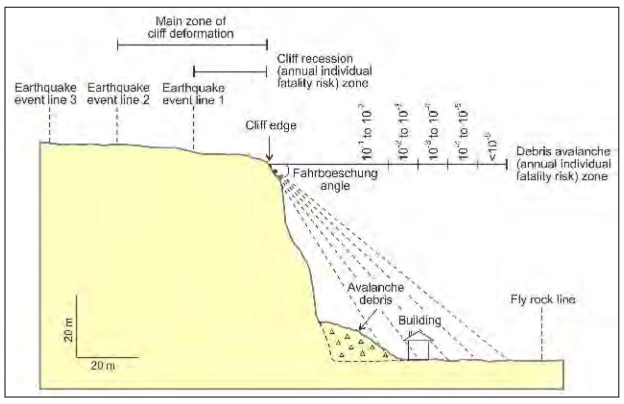


SCALE BAR: 0 20 40 60 80 100 m		**CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK**	APPENDIX B Map H6b
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM	**Port Hills Christchurch**	**FINAL ISSUE 2**
			REPORT: CR2012/124 DATE: July 2013

GNS SCIENCE TE PŪ AO





Debris Avalanche (annual individual fatality risk)

- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

Cliff Recession (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- Earthquake event line
- Cliff edge (2011c (July 2011) LiDAR survey)

Buildings (20/02/2012)

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- Commercial-Industrial
- Accessory building
- Unknown

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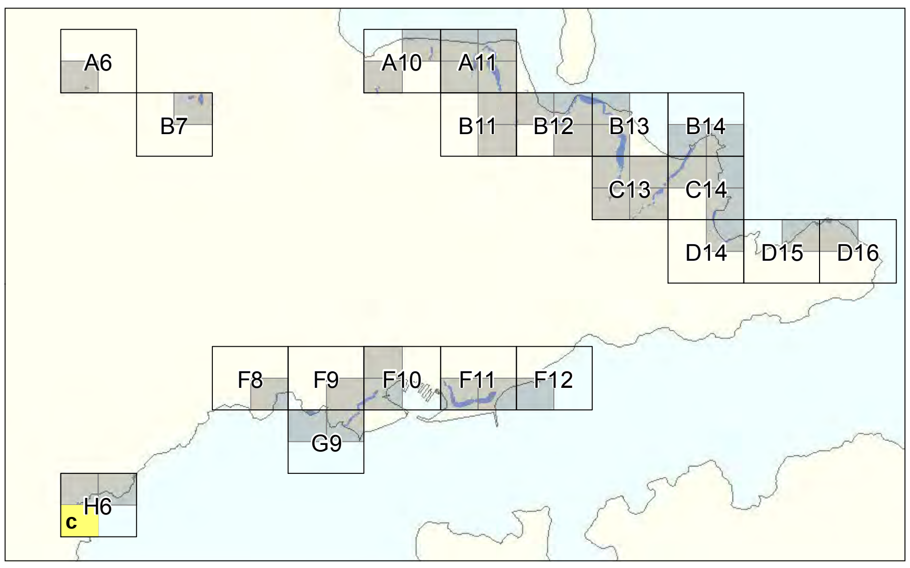
Cliff edge – The cliff edge (black solid line) was defined using the 2011c airborne LiDAR survey. The cliff edge is defined as the line of intersection between the steeper slope (greater than 45 degree slope), forming the cliff face and the shallower slope above the cliff face.

Cliff recession – Is the result of parts of the cliff top collapsing, causing the cliff edge to move back up the slope.

Earthquake event lines – The three earthquake event lines (black dash) represent the possible maximum recession position of the cliff edge given future earthquakes with associated peak ground accelerations in the 2.0 g range, similar to the 22 February 2011 and 13 June 2011 earthquakes. These lines do not mean that the cliff will fail along its entire length, but that any place along the cliff could fail back to this line given a future event of this magnitude.

Fly rock line – The fly rock line (brown dash) is the expected limit of fly rock. Fly rock is broken rock released as high-velocity projectiles created in impacts between rocks and other hard objects.



SCALE BAR: 0 20 40 60 80 100 m

EXPLANATION:

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20/02/2012).

PROJECTION: New Zealand Transverse Mercator 2000

DRW: DH

CHK: CM

GNS SCIENCE TE PŪ AO

CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX B Map H6c

FINAL ISSUE 2

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