Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Life-safety risk from rockfalls (boulder rolls) in the Port Hills

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BIBLIOGRAPHIC REFERENCE

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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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EXECUTIVE SUMMARY

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 and much property damage from rockfalls and cliff collapse in the earthquakes of 22nd February 2011. This report is one of a series of reports which assess the risk to life faced by an individual living below rocky bluffs in the Port Hills where life safety is threatened by the hazard of falling debris. This report covers those areas where the life-safety hazard is from isolated boulders rolling and bouncing downslope and which were not assessed in Massey et al. (2012a) (GNS Science Report CR2011/311: Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Pilot study for assessing life-safety risk from rockfalls (boulder rolls)). The risk to life is expressed as the annual individual fatality risk.

The annual individual fatality risk in this report is the probability (likelihood) that a particular person will be killed by rockfall 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 Geotechnical Society framework for landslide risk management (AGS, 2007). It provides risk estimates suitable for use under AS/NZS ISO31000: 2009.

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

1) presents a regional-scale analysis of rockfall risk for the Port Hills residential areas; and
2) estimates the annual individual fatality risk, i.e. the risk of death of an individual, in these areas from rockfall.

The residential areas not assessed in the pilot study rockfall report (Massey et al., 2012a) are Hillsborough, Richmond Hill Road, McCormacks Bay, Mt Cavendish, Taylors Mistake, Moncks Bay, Cass Bay, Governors Bay, and some areas in Lyttelton (east and west), Bowenvale, Sumner (Wakefield St, and Heberden Ave), Vernon Terrace, and Avoca Valley. These areas are assessed in this report and hereafter are referred to as "non-pilot study areas". Some dwellings within these areas are also affected by cliff collapse 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 report presents the annual individual fatality risks from rockfalls in those areas of the Port Hills that were topographically surveyed using airborne Light Detecting and Ranging (LiDAR) surveys in 2011. This report does not analyse rockfalls from source areas that are: 1) not rock (e.g., loess); 2) typically less than 2 m in height; and 3) plan area typically less than 50 m^2. These slopes are below the scale of this suburb-scale assessment. The risks associated with these slopes are assumed by GNS Science to be significantly less than those slopes analysed in this report.

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 rockfall is considerably higher than it was before September 2010. The annual individual fatality risk from earthquake-induced rockfall is expected to decrease as the seismic hazard decreases.
2. This report covers areas of the Port Hills where few rockfalls were generated by the 2010/11 Canterbury earthquakes but where there was an identifiable rockfall hazard. Information on earthquake-induced rockfalls from the well characterised pilot study suburbs were able to be extrapolated to these non-pilot study Port Hills suburbs which may be affected in future earthquakes.
3. The extrapolation increased the uncertainty in the risk analysis, through uncertainties in the identification of potential rockfall sources and through the assumption that these sources potentially can produce numbers of boulders that travel distances down slope when shaken by amounts that are all similar to those determined in the pilot study.
4. In the non-pilot study areas there are a total of 518 dwellings (including those classified as "buildings of unknown use") located in the assessed annual individual fatality risk zones. Of these, about 60 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 235 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 154 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 69 expose people to risks less than 10^{-5}/year.
5. In the total Port Hills area (pilot study and non-pilot study areas), there are a total of 1,072 dwellings (including those classified as "buildings of unknown use") located in the assessed annual individual fatality risk zones. Of these, about 252 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 458 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 259 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 103 expose people to risks less than 10^{-5}/year.

ES.3 Recommended Christchurch City Council actions

It is recommended that:

1) Council accepts the information regarding annual individual fatality risk from rolling boulders presented in this report;
2) Council uses the information in reaching decisions about future risk management for rockfall-affected dwellings in the Port Hills;
3) Council monitors performance of the fatality risk model by continuing to monitor the state of the catchments (where the rockfalls originate) above dwellings, in particular identifying any new rockfalls indicating the instability of the source areas; and

4) Council re-evaluates the fatality risks after a period of 10 years, to incorporate a seismic hazard model appropriate to the knowledge of that time, and incorporating knowledge about the post-2011 performance of rockfall sources in the Port Hills.

ES.4 Method used

The methods adopted in this report are based on the Australian Geomechanics Society (AGS) 2007 landslide risk management framework. The risk-assessment method is 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 Rockfall-source identification

Rockfall sources in the pilot study areas were classified as to the extent of exposed steep rocky surface and numbers of boulders generated per unit area. This was to allow the estimated annual boulder yields from specific source types to be applied to non-pilot study areas of the Port Hills where the source types were similar.

The stages of the risk analysis comprised:

1. Identification of potential rockfall sources;
2. Identification of the areas below these potential sources likely to be at risk from rolling boulders;
3. Comparison of the heights and extents of the potential rockfall sources with known sources from the pilot study; and
4. Selection of a distribution of risk below a known source from the pilot study that best fitted the nature of the potential source and the shape of the slope below it.

ES.4.2 Distribution of risk below potential sources

For those Port Hills areas not in the pilot study, a distribution of risk that best suited a given source area class was adopted using the following procedure:

1. Where the area was immediately adjacent to a pilot study area, the distribution of risk values within the pilot study area was used regardless of the potential-source classification;
2. Where the area was not adjacent to a pilot study area then the risk profile from the pilot study area with a similar class of source was adopted, based on a classification of the source types; and
3. The shapes of the slopes below the source areas in the pilot study areas from where the preferred risk profiles were chosen were checked for similarity with those slopes in the new areas. Two dimensional numerical modelling was used to verify the likely limits of rockfall runout.

ES.5 Uncertainties

The major uncertainties in the model inputs are discussed 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 that will travel given distances downslope; and 3) the assumption that on a given hillside the number of falling rocks, and thus the risk of being hit by one, is uniform along the slope. It is likely that the frequency of rockfalls 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 suburban 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 two-dimensional rockfall-runout modelling and 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 rockfall hazard management.

ES.6 Acknowledgments

This report was prepared by GNS Science, assisted by the Port Hills Geotechnical Group of Consultants comprising URS, OPUS, Aurecon and GHD. The assistance provided by the University of Canterbury staff and students is also acknowledged. Data collection and analysis was funded in part by the New Zealand Natural Hazards Platform.

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 and much property damage from rockfalls and cliff collapse in the earthquakes of 22nd February 2011. This report is one of the series of reports on areas where rockfall 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 report. It presents an assessment of the risk to life faced by an individual living below rocky bluffs where life safety is threatened by the hazard of falling debris in the form of isolated boulders rolling and bouncing down slope. It provides a suburb-scale (overview) assessment of the average annual fatality risk to individuals from rockfalls. 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 suburban areas not previously assessed in Massey et al. (2012a) were Hillsborough, Richmond Hill Road, McCormacks Bay, Mt Cavendish, Taylors Mistake, Moncks Bay, Cass Bay, Governors Bay, and extensions to the areas in Lyttelton (east and west), Bowenvale, Sumner (Wakefield St, and Heberden Ave), Vernon Terrace, and Avoca Valley. These areas are assessed in this report and hereafter are referred to as “non-pilot study areas”. Some dwellings within these areas are also affected by other earthquake-triggered landslides; these landslides are not believed to pose an immediate fatality risk, but their movement has made some dwellings uninhabitable.

1.1 Aims and objectives

The objectives of this work are to:

1) Present a suburb-scale rockfall life-safety risk assessment for those Port Hills areas not included in the pilot study report (Massey et al., 2012a); and
2) Estimate the annual fatality risk to an individual on a residential property in the Port Hills from rockfalls triggered by earthquakes and compare these to risks from rockfalls 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 rockfalls triggered by the 22nd February 2011 earthquakes in the pilot study (Massey et al., 2012a).

This report presents the annual individual fatality risks from rockfalls in those areas of the Port Hills that were topographically surveyed using airborne Light Detecting and Ranging (LiDAR) surveys in 2011. This report does not analyse rockfalls from source areas that are: 1) not rock (e.g., loess); 2) typically less than 2 m in height; and 3) plan area typically less than 50 m^2. These slopes are below the scale of this suburb scale assessment. The risks associated with these slopes are assumed by GNS Science to be significantly less than those slopes analysed in this report.

2.0 DATA

The data used to develop the risk model are listed in Table 1.

Table 1 Summary of datasets used in the rockfall-risk analyses

Data	Description	Source	Date	Where used in the analysis
Massey et al. (2012a)	Contains the results from the rockfall risk assessment carried out in the pilot study areas.	GNS Science	March 2012	Provides the methodology and risk data 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 rockfall source areas, rockfall end points, and travel paths for those rockfalls triggered by 22nd February 2011 earthquakes.
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 rockfall source areas and development of the shadow angles.
Christchurch building footprints	Footprints are derived from aerial photographs. The data originate from 2006 but have been updated in the rockfall zones 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 rockfall zones and to proportion the population (from the 2006 census data).
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 source areas 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 source areas used for modelling and the risk maps.

3.0 METHODOLOGY

The methods for quantitative risk-estimation used for this work generally follow the Australian Geomechanics Society framework for landslide risk management (AGS, 2007) where this is possible and appropriate.

Using Australian Geomechanics Society (2007) (and the accompanying practice notes), for loss of life, the risk of loss-of-life to an individual is 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 rockfall;
- $P_{(H)}$ is the annual probability of a rockfall-initiating event;
- $P_{(S:H)}$ is the probability of a building or person, if present, being in the path of one or more boulders at a given location;
- $P_{(T:S)}$ 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 (or receiving injuries which prove fatal in the near aftermath of the event) by a rockfall.

The key steps in the rockfall risk analysis include:

1) Risk analysis carried out as per the Australian Geomechanics Society (2007) method;
2) Two-dimensional numerical rockfall modelling using the Rocscience® Rocfall™ programme. This was carried out to determine the likely distances travelled by rockfalls (runout) down a slope and was used to define the probable maximum limits of rockfall runout;
3) Field verification (ground truthing) of the analysis by the Port Hills Geotechnical Group; and
4) Updating of the assessed risk to include the results from the field verification and two-dimensional rockfall modelling.

3.1 Risk analysis

The pilot study (Massey et al., 2012a) covered the residential areas most affected by the 2010/2011 Canterbury Earthquakes (Appendix A). Other parts of the Port Hills and Banks Peninsula were also affected, but were either less populated or were beyond the main zone of aftershock activity in the 2010/2011 Canterbury Earthquakes, e.g. towards the west of the Port Hills (Figure 1). These areas lacked sufficient rockfall data to allow use of exactly the same method of assessment as was used in the pilot study. The method was modified to allow use of the information on rockfalls from the pilot study.

In these other (non-pilot study) areas, rockfalls from the 2010/2011 Canterbury Earthquakes have not been mapped, or did not occur because the ground accelerations there were not high enough to generate rockfalls. It was therefore not possible to assess risk using rockfall data from these areas. The locations of the areas covered in this report, along with those covered in the pilot study (Massey et al., 2012a), are shown in Appendix A.

The downslope profiles of risk used in this report have been taken from Massey et al. (2012a) based on the following assumptions:

A. 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 pers. com.).

B. The numbers of boulders generated from a rockfall source is dependent on the nature of the source area, e.g. areal extent, height, slope angle, amount of loose debris, and material type.

C. Sources that are similar in appearance are likely to behave in similar ways during similar earthquakes or other events such as storms.

D. Slopes of a similar material and profile (below source areas) are likely to have similar rockfall runout characteristics (i.e., the proportions of boulders that pass a given shadow angle). Two broad slope-profile classes are recognised in the Port Hills, planar stepped and concave; these are discussed in Massey et al. (2012a).

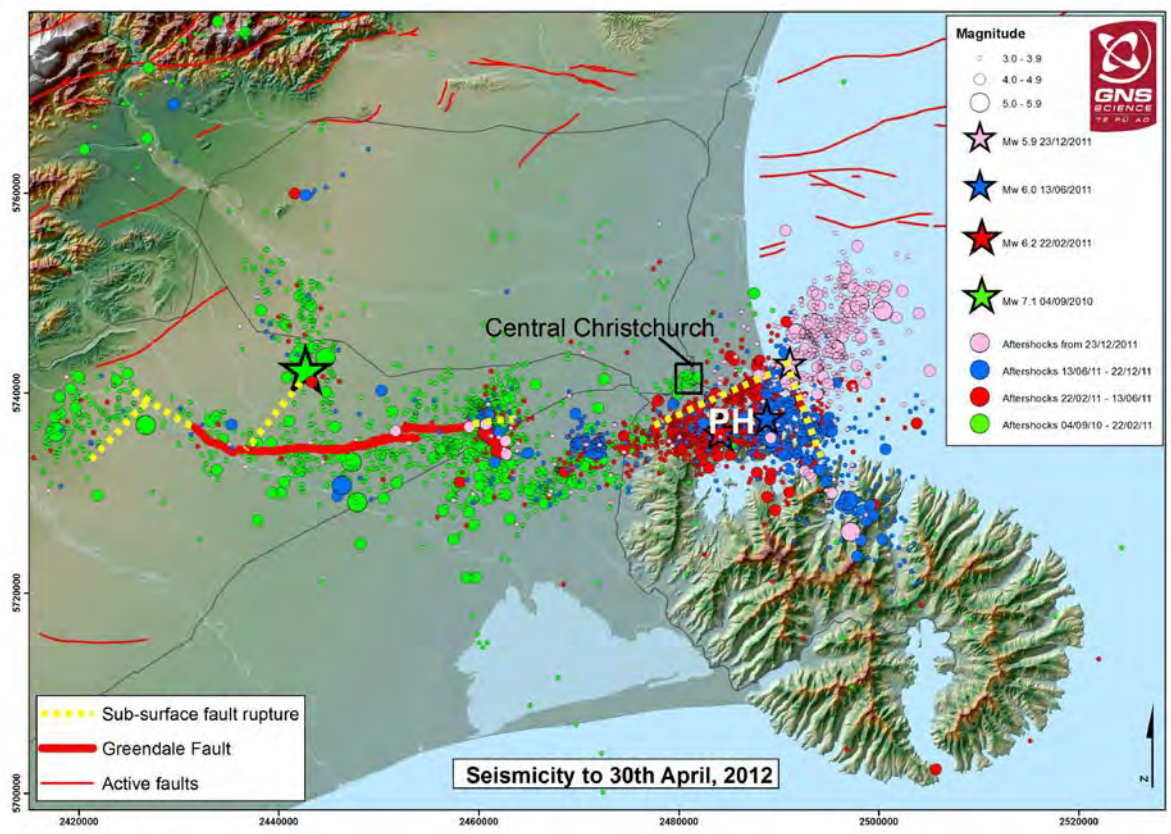


Figure 1 Sequence of aftershocks from the Darfield Earthquake on 4th September 2010 up to 30th April 2012. PH is the Port Hills.

Rockfall source areas from the pilot study were classified by their areal extent of rock outcrop and number of boulders generated per unit area. This allowed the estimated annual boulder yield from a specific source types to be applied to non-pilot study areas of the Port Hills with similar source types. The stages of the risk analysis were:

1. Identification of potential rockfall sources;
2. Identification of the areas below these potential sources likely to be at risk from rolling boulders;
3. Comparison of the heights and extents of the potential rockfall sources with known sources from the pilot study;
4. Selection of a distribution of risk below a known source from the pilot study that best fitted the nature of the potential source and the shape of the slope below it; and
5. Incorporation of the risk values at each shadow angle into a Geographic Information System and interpolation between shadow angles to provide contours of equal risk on a map.

3.1.1 Identifying potential rockfall source areas

Potential rockfall-source areas were identified as slopes >35° in a digital elevation model derived from Light Detection and Ranging (LiDAR) surveys. These sources were then verified against visible rock outcrops on the post-22nd February 2011 earthquake ortho-rectified aerial photographs. The toes (bases) of the lowest source areas were then digitised.

3.1.2 Modelling rockfall hazard areas

Areas with an identified rockfall hazard below potential sources were determined using the ArcGIS® "visibility" tool. The rockfall runout zone was assumed to be the section of slope under a straight line, projected at an angle of 21° from the toe of the lowest (in elevation) rock slope (or apex of the talus) to where it intersected the ground surface. This angle is termed a shadow angle.

The ArcGIS visibility tool works by assessing which areas should be visible from a particular location. For this study it was used to assess what areas of slope were visible from the toes of the rockfall source areas (toes of the rock slopes), using the minimum rockfall shadow angle. Whether or not an area of slope was visible (and was therefore within the minimum shadow angle) was determined using an elevation grid of 3-m resolution, derived from the post-22nd February 2011 earthquake LiDAR. The visibility of each grid cell (from a source area) was determined by comparing the altitude and angle of the grid cell with the altitude and angle of the local horizon. The local horizon was computed by considering the intervening terrain between the point of observation (each node on the line defining the toe of the rockfall source area) and the current grid cell. If the point lay above the local horizon, it was considered to be visible. The process was repeated for shadow angles of 21°, 22°, 23°, 24°, 25°, 27°, 29° and 31°. One-degree shadow angle increments were used in the distal runout zones as these were the more populated areas where greater resolution of risk zones was desirable, whilst two-degree increments were used in the upper, typically non-residential, zones.

Once generated, the toe of each 21° visibility grid was digitised, and this formed the assumed limit of the rockfall runout zone, and the limit of predicted rockfall fatality risk. In some cases, the toe of the visibility grid extended beyond drainage lines and up adjacent slopes, or across ridgelines. In such cases, the grids were limited to the drainage or ridge lines, as it was considered unlikely that a rockfall would cross these. The edges of each runout zone were determined by projecting a line perpendicular to the end point of the line delineating the lowest (in elevation) rock-slope toe. An angle of 30° was added to the azimuth to take into account that rockfall trails may deviate up to 30° from the line of greatest slope.

In areas of complex topography, the potential rockfall trails from three-dimensional rockfall modelling (Avery, 2012) were used to assist in delineating boundaries to the shadow-angle zones.

3.1.3 Geomorphology of the rockfall source areas

The rockfall sources in the pilot study areas were quantified with their areal extent (surface area and not plan area) and height (Appendix B). It was assumed that the larger the source, the more boulders it could produce. Data on source surface area versus number of fallen boulders reported in Massey et al. (2012a) were further subdivided into local catchments. Other catchments in the Port Hills were also included where sufficient data on fallen boulders had been collected (Figure 2).

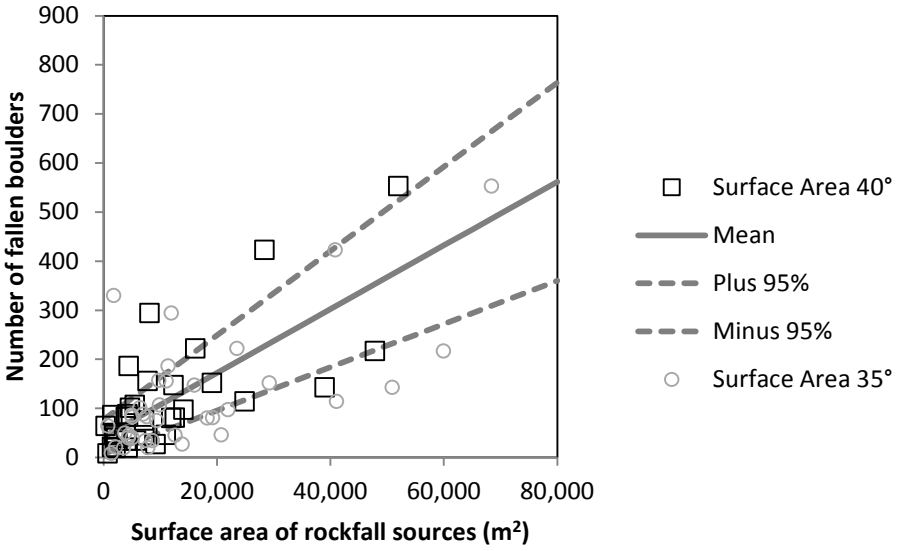


Figure 2 Relationship between source surface area and the number of fallen boulders (in all earthquakes) per measured catchment in the Port Hills. The surface areas of slopes above 35° and above 40° have been calculated. The mean and 95th percentiles are based on the above 40° slopes.

The source area types in the pilot study are listed in Table 2 and described and illustrated in Appendix B. The correlation between surface area and number of fallen boulders is shown in Figure 3. Heathcote Valley (classified as a continuous major source), Castle Rock and Rapaki Bay (both classified as isolated major sources) provided the most boulders per unit surface area, and Vernon Terrace (classified as a discontinuous minor source) provided the fewest. However, the number of boulders produced in a given area is also a function of the peak ground accelerations experienced.

Table 2 Pilot study source area classification

Pilot study area	Source classification
Lyttelton	Continuous major
Heathcote Valley	Continuous major
Avoca Valley	Continuous minor
Horotane Valley	Continuous minor
Sumner (Heberden Avenue)	Continuous minor
Sumner (Wakefield Avenue)	Continuous minor
Hillsborough (Vernon Terrace)	Discontinuous minor
Bowenvale	Discontinuous major
Rapaki Bay	Isolated major
Castle Rock	Isolated major

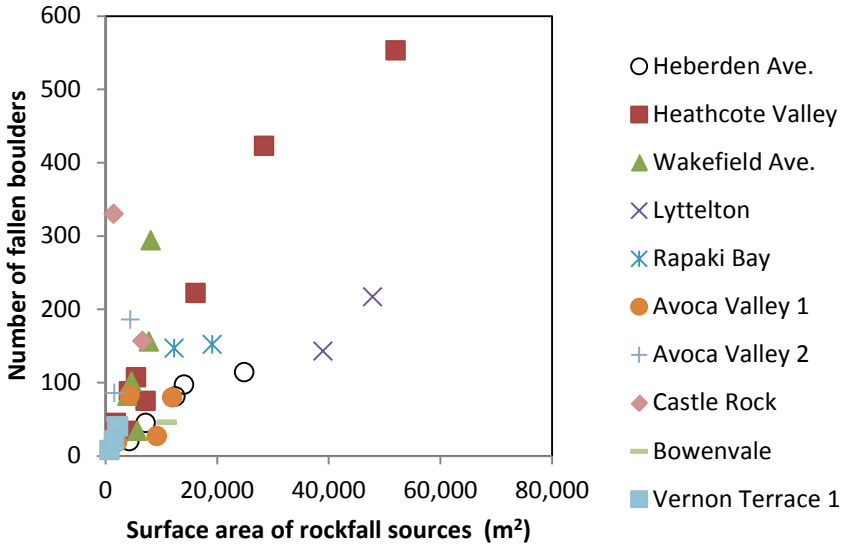


Figure 3 Relationship between source surface area and the number of fallen boulders (in all earthquakes) for measured catchments in the Port Hills. The calculated surface areas are for slopes above 40°.

3.1.4 Risk profiles

The pilot rockfall risk assessments (Massey et al., 2012a) show downslope risk profiles that vary from site to site, primarily as a function of the numbers of boulders that the source areas in a given location produced (Figure 4). Those areas with higher annual individual fatality risks are associated with source areas classified as “continuous major”, “isolated major” or “continuous minor”.

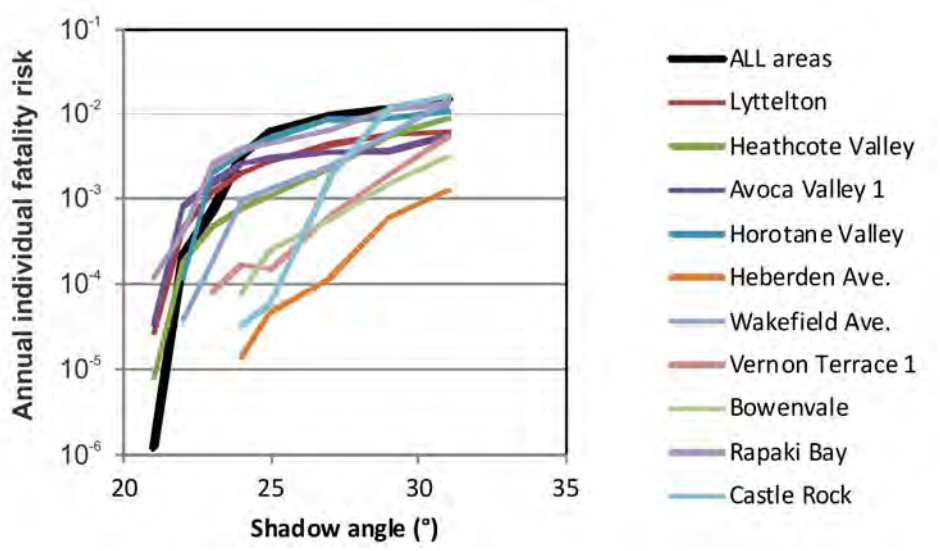


Figure 4 Annual individual fatality risk at a given shadow angle for the main areas within the pilot study. The thick black line represents the risk across all areas, calculated using the total numbers of boulders (all pilot study areas) generated per earthquake and non-earthquake band (Massey et al., 2012a).

For those areas of the Port Hills outside the pilot study, a risk profile that best suited a given source-area class was adopted using the following procedure:

1. Where the area was immediately adjacent to one of the pilot study areas, then the risk values from that area were used.

2. Where the area was not adjacent to a pilot study area, then the risk profile from a pilot study area with a similar class of source was adopted, based on the classification of the source types.

The risk profiles used are shown in Table 3.

Table 3 Source area classification and pilot study risk profiles adopted

Area	Source classification	Pilot study risk profile adopted[1]
Sector 9 West	Discontinuous major	Bowenvale
Bowenvale Extension	Discontinuous major	Bowenvale
Wakefield Avenue Extension	Continuous minor	Wakefield Avenue
Richmond Hill Road	Discontinuous minor	Vernon Terrace 1
Heberden Avenue Extension	Continuous minor	Heberden Avenue
McCormacks Bay	Discontinuous minor	Vernon Terrace 1
Vernon Terrace Extension	Discontinuous minor	Vernon Terrace 1
Mt Cavendish	Continuous major	Heathcote Valley
Avoca Valley 1 Extension	Continuous minor	Avoca Valley 1
Avoca Valley 3 Extension	Discontinuous major	Avoca Valley 3
Taylors Mistake	Discontinuous minor	Vernon Terrace 1
Moncks Bay East	Discontinuous minor	Vernon Terrace 1
Moncks Bay West	Discontinuous major	Heberden Avenue
Inner crater	Continuous major	Lyttelton
Lyttelton East Extension	Discontinuous minor	Vernon Terrace 1
Lyttelton West Extension	Continuous major	Lyttelton

3.1.5. Rockfall runout characteristics

Valley-side profiles in the Port Hills and therefore the profiles of rockfall trails, can be classified into two broad types: 1) planar stepped; and 2) curved (concave and merging asymptotically onto a flat valley floor) (Massey et al., 2012a).

Planar slopes and trails tend to be shorter, with smaller elevation difference between top and bottom than for the curved slopes and trails. The planar slopes comprise intermittent areas of rock outcrops (lava flows), and tend to end abruptly at sharp breaks in slope, which mark

[1]The risk profiles adopted use the parameters for risk Scenario C as described by Massey et al. (2012a).

the boundary with flat basin/marine deposits. The curved slopes tend to be longer, with the steep bluffs (rockfall sources) in the upper parts. The shape of the slope below the rockfall source areas is a major factor controlling rockfall runout (Massey et al., 2012a), with the rockfalls on curved slopes tending to travel further than those on planar slopes.

The slopes below sources were examined to ensure that the risk profile adopted from a pilot study area was appropriate for the slope.

3.1.6 Rockfall risk modelling

The annual individual fatality risks from the appropriate pilot study areas were applied to the non-pilot study areas. This was done by taking the risk at a given shadow angle from the best suited pilot study area and applying it to the corresponding shadow angle in the non-pilot study area.

These values were then modelled using ArcGIS® to generate modelled fatality-risk zones. ArcGIS is used to interpolate between the risks calculated at given shadow angles, so as to produce contours of equal risk within each fatality-risk zone. Contours were developed for logarithmic classes, e.g., $10^{-2} – 10^{-3}$, $10^{-3} – 10^{-4}$, of individual risk values.

3.2 Field verification of ground conditions in the rockfall-risk model

Members of the Port Hills Geotechnical Group, in collaboration with GNS Science, undertook field verification of the modelled fatality-risk zones to either:

1) confirm for each dwelling that fatality risk was correctly defined in relation to the local rockfall source areas and local topography; or

2) recommend changes to the local risk-zone boundaries on the basis of site-specific ground conditions that were not able to be considered in the broader-scale assessments.

Field verification was confined to those areas with existing dwellings.

3.2.1 Assessment method

The verification method is detailed in Massey et al. (2012a) and is summarised below:

1) initial office (desk-top) assessment, including:
   a. generating base maps for field use
   b. identifying all properties (and dwellings) within the risk zones defined by this project
   c. reviewing all available relevant information (such as aerial photographs and any other field-mapped geotechnical data carried out as part of the Port Hills slope stability assessments);
2) identification of dwellings/areas that appeared to be anomalous (for example where risk zones had been modelled but no boulders had fallen);
3) two-dimensional rockfall modelling (using the RocScience program RocFall®) to check potential runout distances at specific locations to help refine the furthest limit of detectable fatality risk (i.e. the rockfall limit line) before commencing field verification; and
4) field inspection of all dwellings within the risk zones defined by this project to determine whether the risk at each was consistent with, less than, or greater than the risk assessed through the risk model. Field checking used a standard *pro forma* (a copy is included in

Appendix F of Massey et al., 2012a) to ensure consistency between the areas and to document how particular decisions were reached. One *pro forma* was completed for each residential property, including those properties without dwellings. These data are held by Christchurch City Council.

The seismic hazard is a major factor in the fatality-risk assessment but it is not amenable to field verification because it is not able to be seen in the field. The seismic hazard was applied uniformly across all of the assessed rockfall areas. It was derived specifically for the Port Hills from the statistical composite national seismic hazard model (Gerstenberger et al., 2011), as detailed in Massey et al. (2012a).

3.2.2 Revising the modelled risk assessments

The annual individual fatality risk of 10^{-6} is about the average risk that New Zealanders are exposed to from landslide hazards (Taig et al., 2012). Rockfall annual individual fatality risks below this level of risk have not been shown on the maps.

A risk contour line was drawn showing where the estimated annual individual fatality risk was 10^{-6} per year. The position of this contour was largely determined from the assessed limit of rockfall-runout and was developed using the following information:

- Two-dimensional rockfall modelling which took account of local slope angle and shape;
- Geomorphological evidence of historical (post 1840 AD) and pre-historic rockfalls, derived from geomorphological mapping of the Port Hills (Townsend and Rosser, 2012); and
- Shadow angles and mapped 2010–2012 rockfall boulder distributions.

The position of the 10^{-6} per year fatality risk contour was then verified against the extent of mapped historical and pre-historical boulders, the recently mapped fallen boulders, and the location of the 21° shadow angle line. The position of the risk contour indicating annual individual fatality risk of 10^{-6} per year was adjusted to incorporate these features. The mapped position of the 10^{-6} per year contour included a +10 m buffer to allow for probabilistic model uncertainty.

Local variations from the suburb-average risk were taken into account by showing on the maps those areas where:

- The risk was field verified as being greater than the suburb-level assessment at the particular dwelling, e.g., where the property was within a depression that directed boulders onto it, or where the source area (where the boulders originate) was larger or more fractured than the suburb average; or
- The risk was field verified as less than the suburb-level assessment at the particular dwelling, e.g., the property was sheltered by a local permanent topographic feature or where boulder runout was stopped by, for example, extensive natural or man-made flat ground (such as roads, tennis courts and large swimming pools). Features such as buildings, fences, rockfall protection structures, and trees were not classed as permanent features that would limit the runout of boulders.

The field-verified risk maps are presented in Appendix C.

4.0 RESULTS

4.1 Numbers of residential homes in each risk category

The annual individual fatality risks at each shadow angle were modelled using ArcGIS to produce the risk contour maps, and the numbers of dwellings in different risk bands were derived from these maps (Figure 5 and Table 4).

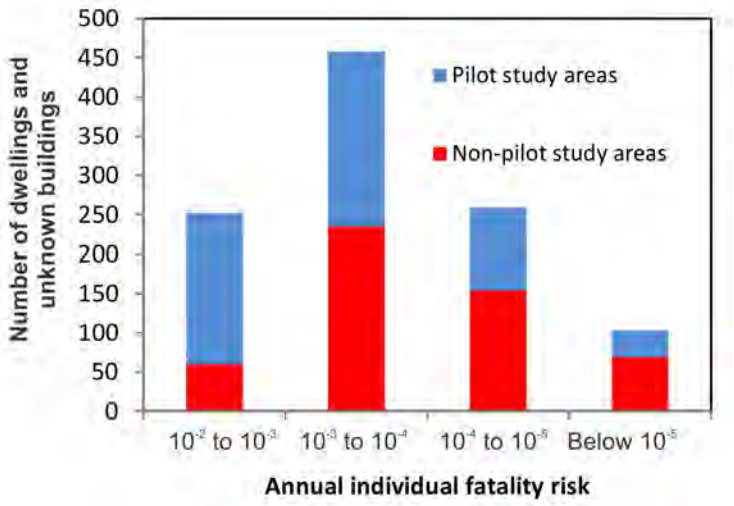


Figure 5 Numbers of dwellings and unknown buildings within each annual individual fatality risk band within: 1) the pilot study areas; and 2) the non-pilot study areas.

Table 4 Buildings within assessed Port Hills risk zones subject to the hazard of boulder roll.

Building type	Annual individual fatality risk category			
	$10^{-2} – 10^{-3}$	$10^{-3} – 10^{-4}$	$10^{-4} – 10^{-5}$	Below 10^{-5}
Dwellings on the Port Hills in the non-pilot study areas				
Dwellings	42	186	127	54
Building type unknown	18	49	27	15
Total no. of dwellings + buildings, type unknown	60	235	154	69
Dwellings within the pilot study areas				
Dwellings	118	159	78	29
Building type unknown	74	64	27	5
Total no. of dwellings + buildings, type unknown	192	223	105	34
Total dwellings within the pilot and non-pilot study areas				
Dwellings	160	345	205	83
Building type unknown	92	113	54	20
Total no. of dwellings + buildings, type unknown	252	458	259	103

4.2 Model sensitivities and uncertainties

The major uncertainties in the model inputs are discussed 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 that will travel given distances downslope; and 3) the assumption that on a given hillside the number of falling rocks, and thus the risk of being hit by one, is uniform along the slope. It is likely that the frequency of rockfalls 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 assessment in this report through uncertainties in the identification of rockfall sources and assessment of their types, and through the assumption that adjacent sources potentially can produce similar numbers of boulders that travel similar distance down slope when shaken by similar amounts.

Although the uncertainties in the annual individual fatality risks estimated for the suburban 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 two-dimensional rockfall-runout modelling and 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 rockfall 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 rockfall is considerably higher than it was before September 2010. The fatality risk from earthquake-induced rockfall is expected to decrease as the seismic hazard decreases.
2. This report covers areas of the Port Hills where few rockfalls were generated by the 2010/11 Canterbury earthquakes but where there was an identifiable rockfall hazard. Information on earthquake-induced rockfalls from the well characterised pilot study suburbs were able to be extrapolated to these non-pilot study Port Hills suburbs which may be affected in future earthquakes.
3. The extrapolation increased the uncertainty in the risk analysis through uncertainties in the identification of potential rockfall sources and through the assumption that these sources potentially can produce numbers of boulders that travel distances down slope when shaken by amounts that are all similar to those determined in the pilot study.
4. In the non-pilot study areas there are a total of 518 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones. Of these, about 60 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 235 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 154 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 69 expose people to risks less than 10^{-5}/year.
5. In the total Port Hills area (pilot study and non-pilot study areas), there are a total of 1,072 dwellings (including those classified as “buildings of unknown use”) located in the assessed annual individual fatality risk zones. Of these, about 252 dwellings expose people to annual individual fatality risks estimated to be greater than 10^{-3}/year; 458 dwellings expose people to risks between 10^{-3} and 10^{-4}/year; 259 dwellings expose people to risks between 10^{-4} and 10^{-5}/year; and 103 expose people to risks less than 10^{-5}/year.

6.0 RECOMMENDED CHRISTCHURCH CITY COUNCIL ACTIONS

It is recommended that:

1) Council accepts the information regarding annual individual fatality risk from rolling boulders presented in this report;
2) Council uses the information in reaching decisions about future risk management for rockfall-affected dwellings in the Port Hills;
3) Council monitors performance of the fatality risk model by continuing to monitor the state of the catchments (where the rockfalls originate) above dwellings, in particular identifying any new rockfalls indicating the instability of the source areas; and
4) Council re-evaluates the fatality risks after a period of 10 years, to incorporate a seismic hazard model appropriate to the knowledge of that time, and incorporating knowledge about the post-2011 performance of rockfall sources in the Port Hills.

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.

Avery, M. 2012. Port Hills 3D Rockfall Modelling Sector 6 – Lyttelton Preliminary Modelling Results. 14th March 2012.

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.

Massey, C.I.; McSaveney, M.J.; Heron, D.; Lukovic, B. 2012a. 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.

Massey, C.I.; McSaveney, M.J.; Heron, D. 2012b. Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Life-safety risk from cliff collapse in the Port Hills, GNS Science Consultancy Report 2012/124.

Taig, T.; Massey, C.; Webb, T. 2012. Canterbury Earthquakes Port Hills Slope Stability: Principles and Criteria for the Assessment of Risk from Slope Instability in the Port Hills, Christchurch, GNS Science Consultancy Report 2011/319.

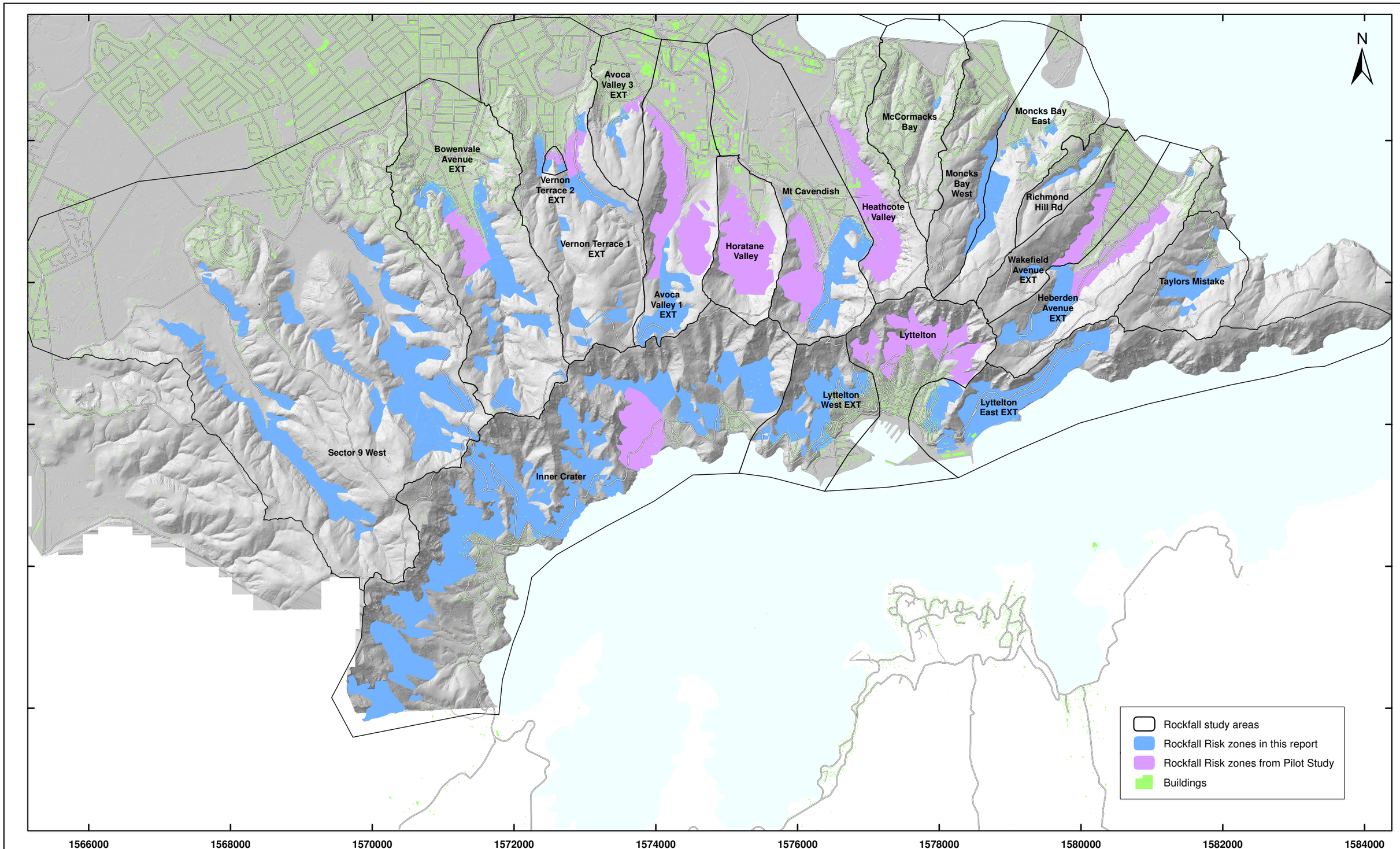
Townsend, D.B.; Rosser, B. 2012. Canterbury Earthquakes 2010/2011 Port Hills slope stability: Geomorphology mapping for rockfall risk assessment, GNS Science Consultancy Report 2012/15.

8.0 ACKNOWLEDGEMENTS

This report was prepared by GNS Science, assisted by the Port Hills Geotechnical Group of Consultants comprising URS, OPUS, Aurecon and GHD. The assistance provided by the University of Canterbury staff and students 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, Tony Taig, Tony Taig Consulting Ltd. and Fred Baynes, Baynes Geologic Ltd. Eileen McSaveney and Pilar Villamor, GNS Science, provided editorial reviews.

APPENDICES

APPENDIX A LOCATION PLAN



SCALE BAR: 0 1 2 Km

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: BL

CHK: CM

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ROCKFALL LOCATION MAP

Port Hills Christchurch

APPENDIX A

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APPENDIX B ROCKFALL SOURCE AREA DESCRIPTIONS

Rockfall source area descriptions - naming procedure

Primary descriptor	Secondary descriptor
Continuous	Major or minor
Discontinuous	Major or minor
Isolated	Major or minor
Intermittent*	

*Secondary descriptor does not apply

Description

Type (see photographs below)	Description	Approximate dimensions of outcrops
A) Continuous major	Outcrops are continuous over hundreds of metres, and comprise several or more lava flows, with each flow typically > 20 m in height.	Lateral extent = 100's of metres. Average height (combined layers) = greater than 40 m.
B) Continuous minor	Outcrops are continuous over hundreds of metres, but comprise mainly only one lava flow, about 15 - 25 m in height.	Lateral extent = 100's of metres. Average height = 15 - 25 m.
C) Discontinuous major	Outcrops are continuous over tens of metres but are separated by gaps of similar distance. Typically comprise multiple lava flows 5 - 20 m in height (per layer).	Lateral extent = 10's of metres. Average height (combined multi-layers) = about 20 m or greater.
D) Discontinuous minor	Many small outcrops, each about 5 - 10 m in height. Typically comprise only one lava flow.	Lateral extent = metres. Average height (including combined multi-layers) = between 5 and 20 m.
E) Isolated major	Single large outcrop – typically multi-layered flows up to 80 m in height.	Average height (combined multi-layers) = greater than 20 m, typically about 40 m or more.
F) Isolated minor	Single outcrop – typically single layered lava flow typically 5 - 15 m in height.	Average height = less than 20 m.
G) Intermittent	Many small outcrops less than 5 m in height separated by gaps of similar distance.	Lateral extent = metres. Average height = less than 5 m.

Type: A – Continuous major

Pilot study areas: Heathcote (Morgan's) Valley, Lyttelton.

Photograph: Heathcote Valley (Photo: D. Townsend, GNS Science).

Type: B – Continuous minor

Pilot study areas: Heberden Avenue, Wakefield, Avoca Valley.

Photograph: Heberden Avenue (Photo: D. Townsend, GNS Science).

Photograph: Above Wakefield Avenue (Photo: D. Townsend, GNS Science).

Photograph: Avoca Valley (above Avoca Valley Road) (Photo: D. Townsend, GNS Science).

Type: C – Discontinuous major

Pilot study areas: Bowenvale.

Photograph: Bowenvale (Photo: C. Massey, GNS Science).

Type: D – discontinuous minor

Pilot study areas: Vernon Terrace.

Photograph: Vernon Terrace (Photo: D. Townsend, GNS Science).

Photograph: Lyttelton West (Photo: D. Townsend, GNS Science).

Type: E – Isolated major

Pilot study areas: Castle Rock and Rapaki Bay.

Photograph: Castle Rock (Photo: G. Hancox, GNS Science).

Photograph: Rapaki (Tamatea) (Photo: G. Hancox, GNS Science).

Type: F – Isolated minor

Pilot study area: None.

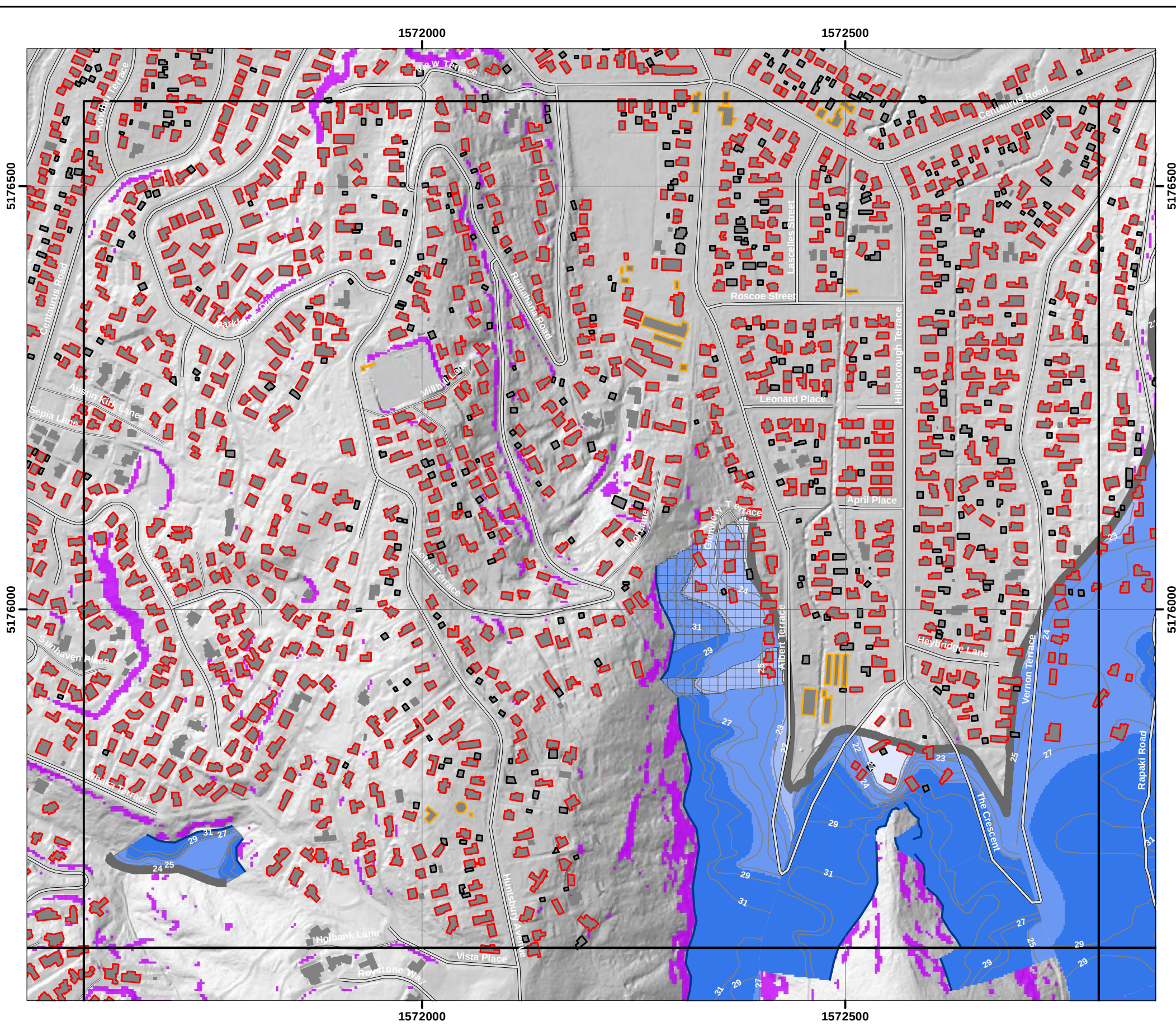
Photograph: Above Summit Road (foreground) (Photo: D. Townsend, GNS Science).

Type: G – Intermittent

Pilot study area: None.

Photograph: Ridge top near Avoca Valley (Photo: D. Townsend, GNS Science).

APPENDIX C ANNUAL INDIVIDUAL FATALITY RISK MAPS



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

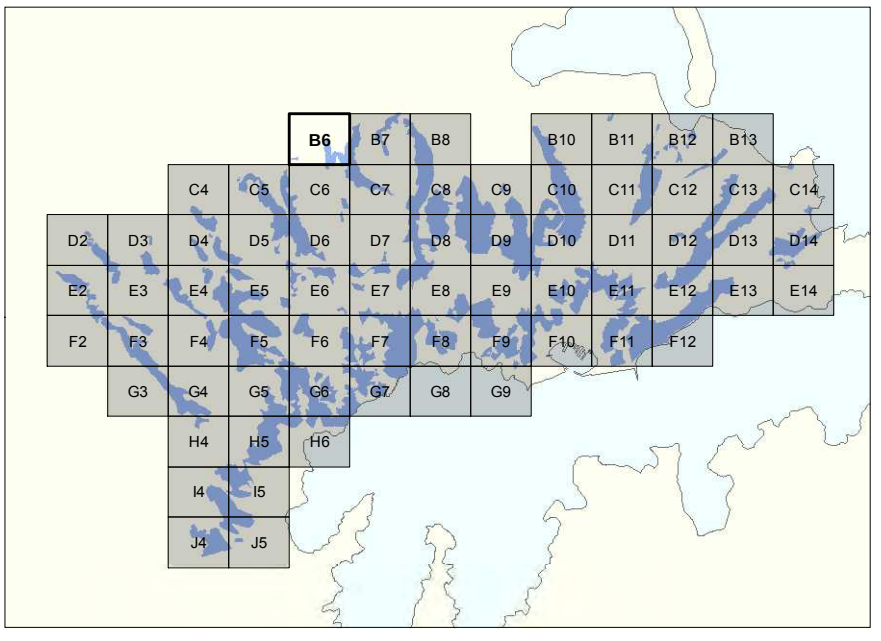
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map B6

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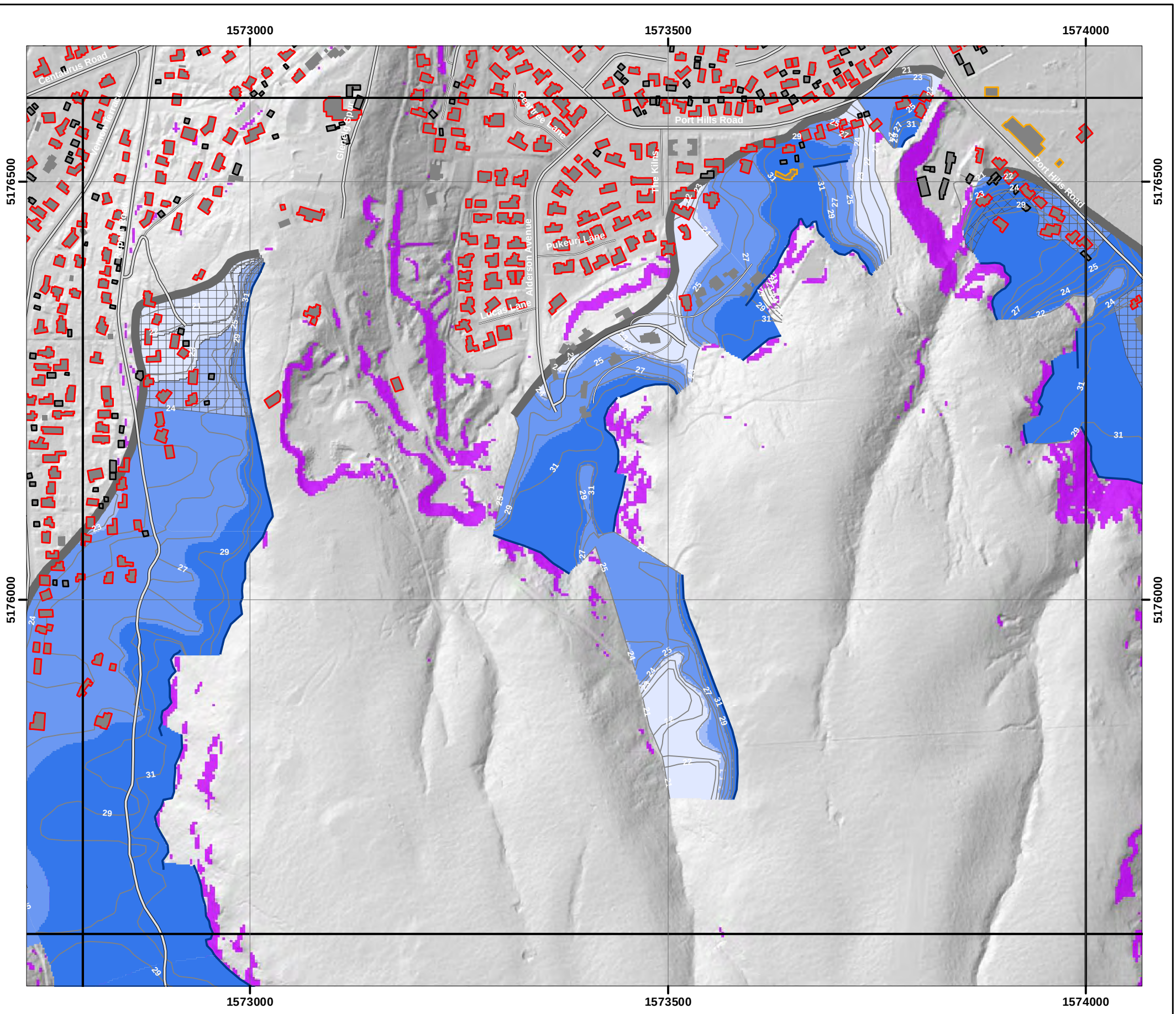


Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

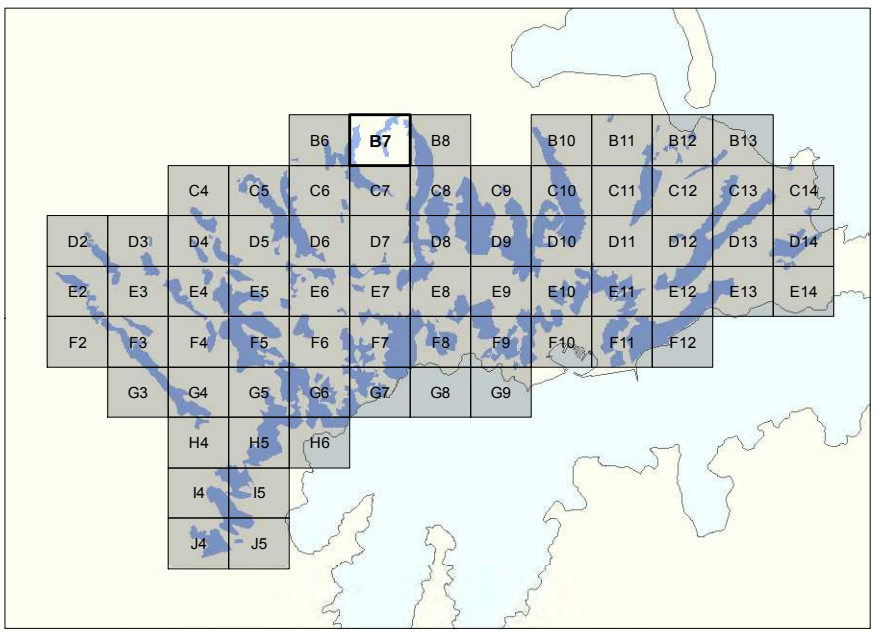
N

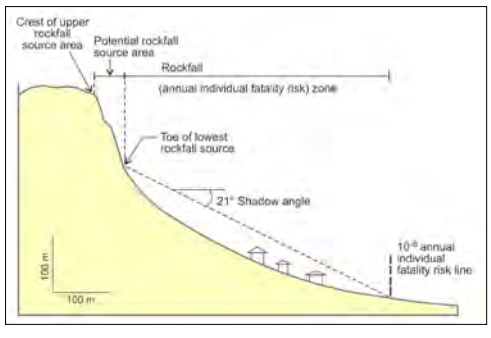
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map B7

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DATE: July 2013

1574000 1574500 1575000

5176500 5176000

Desi Place
Nuttall Drive
Kennaway Road
Dalziel Place
Brightlings Road
Caernarfon Place
Mary Muller Drive
Lock Crescent
Chapmans Road
Port Hills Road
Avoca Valley Road
Vega Place
Gilders Gr

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

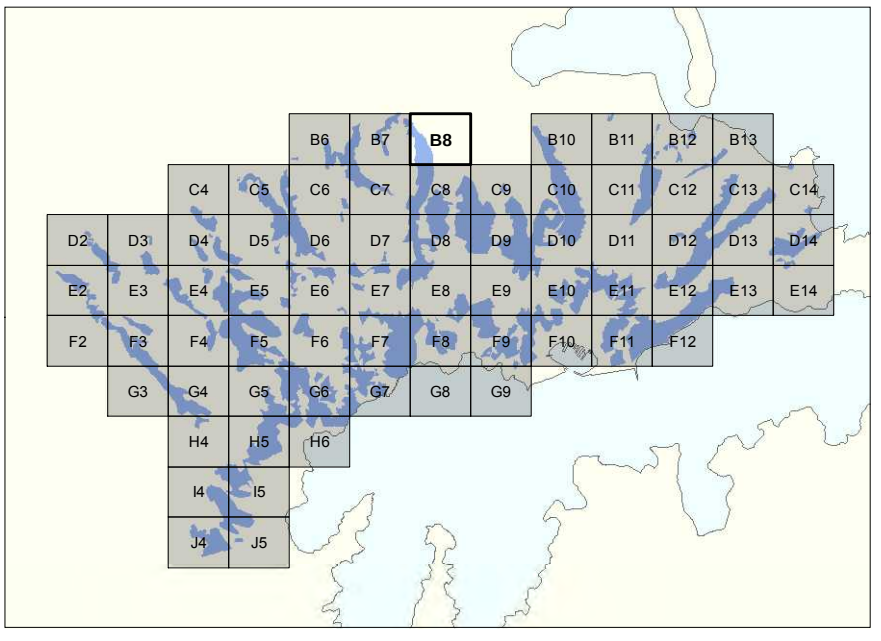
N

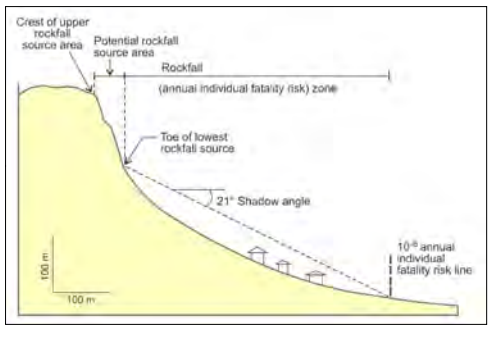
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

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SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map B8

FINAL ISSUE 2

REPORT: CR2012/123

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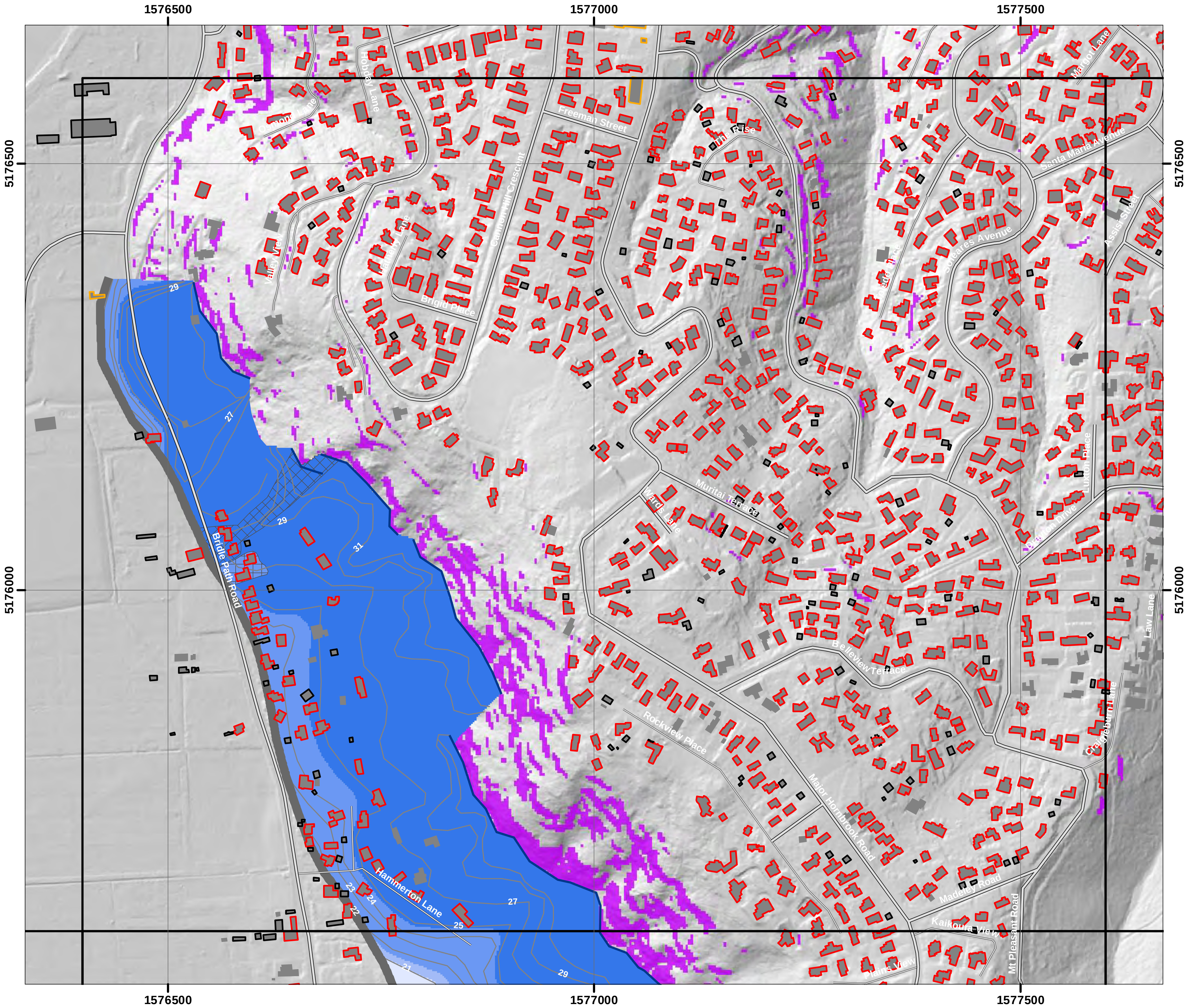


Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

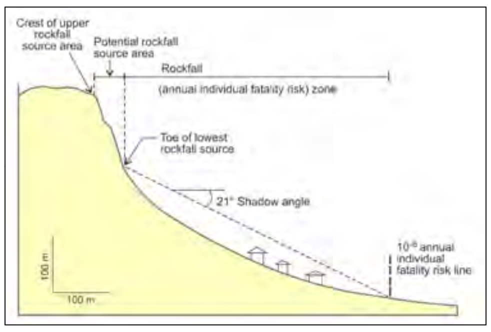
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

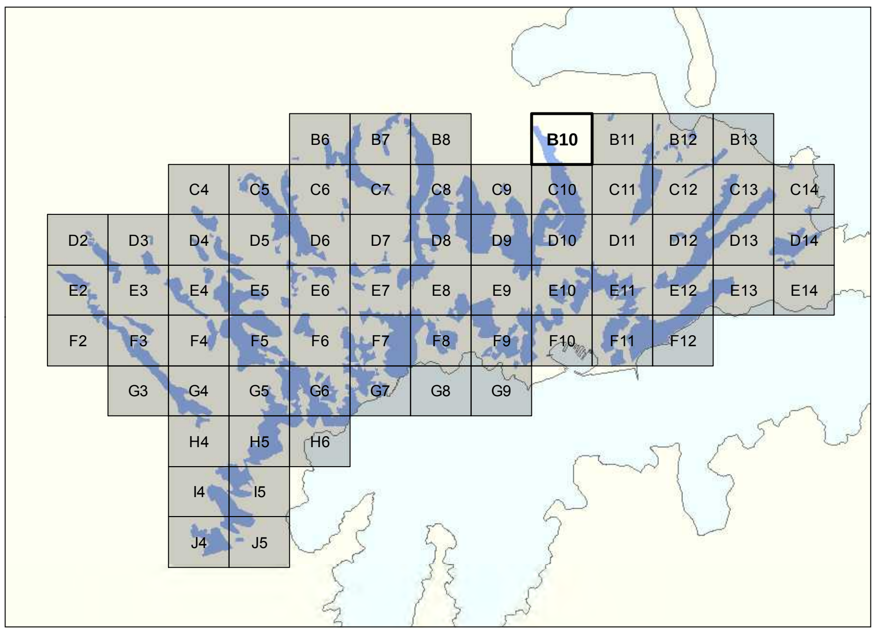
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 m		**ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK**	APPENDIX C Map B10
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: BL / CHK: CM	**Port Hills Christchurch**	**FINAL ISSUE 2** / REPORT: CR2012/123 / DATE: July 2013

1578000 1578500

5176500 5176500

5176000 5176000

1578000 1578500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

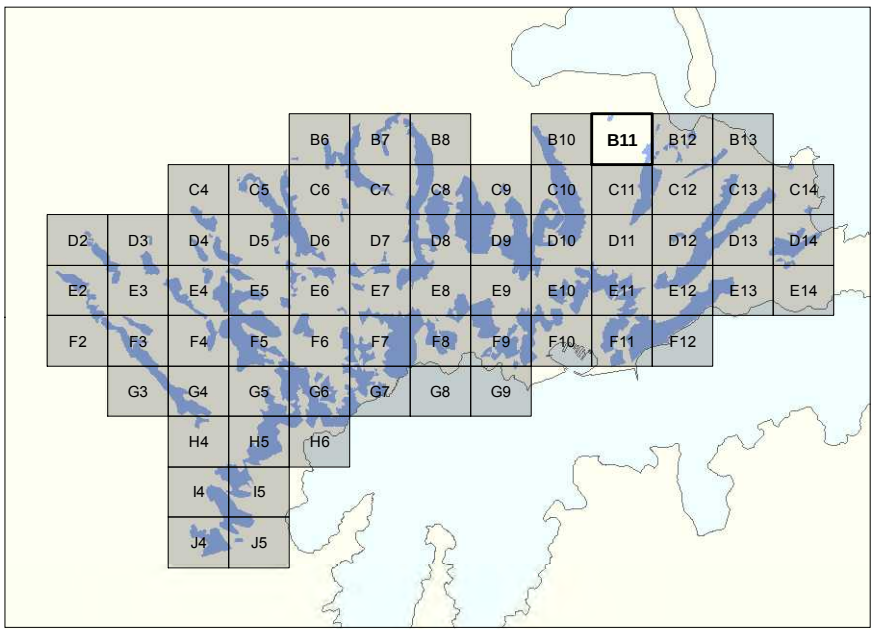
N

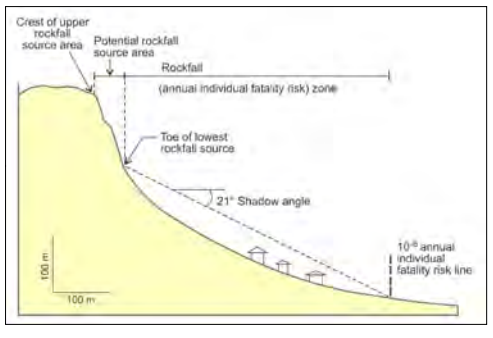
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

GNS SCIENCE TE PŪ AO

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

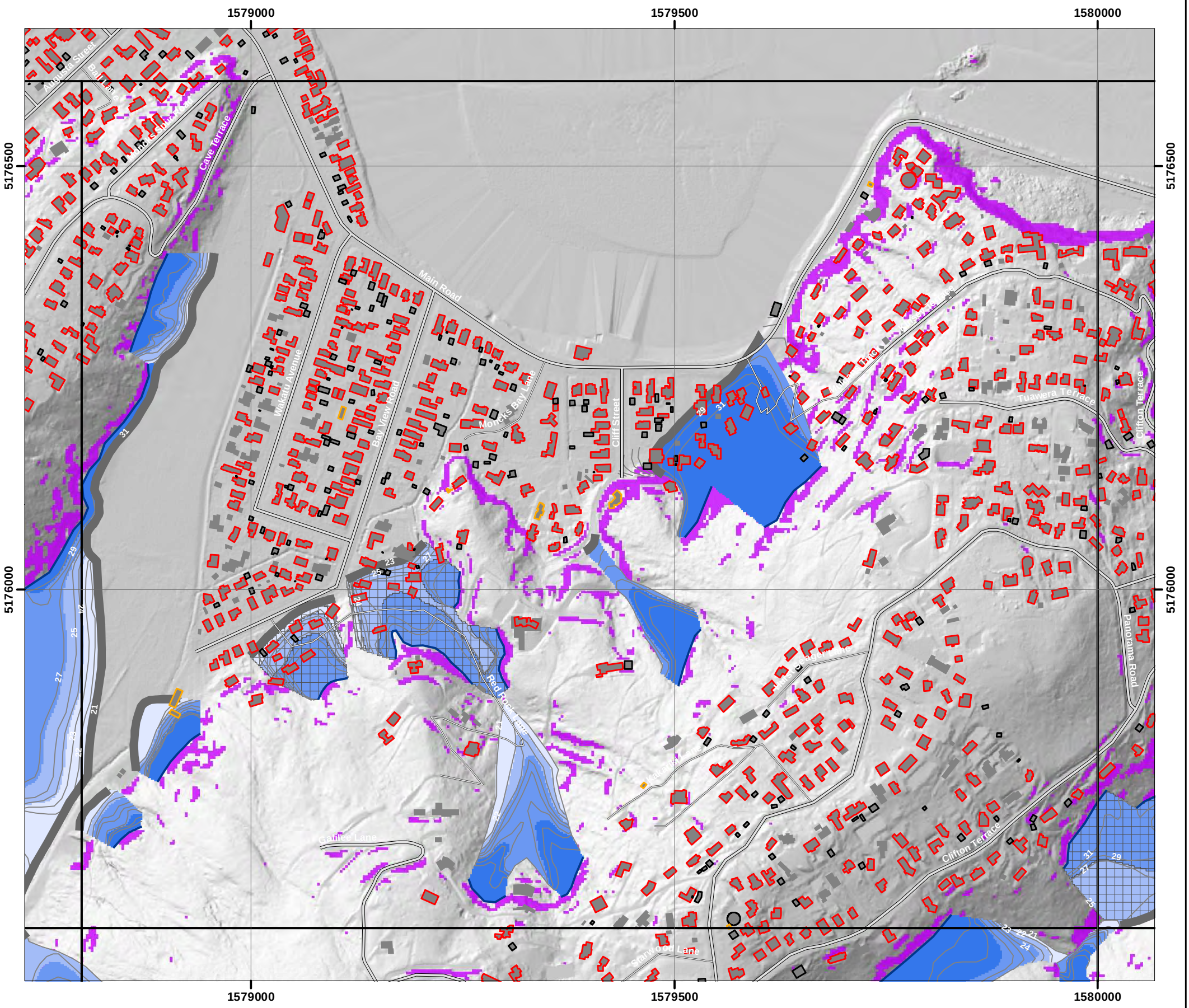
Port Hills Christchurch

APPENDIX C
Map B11

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

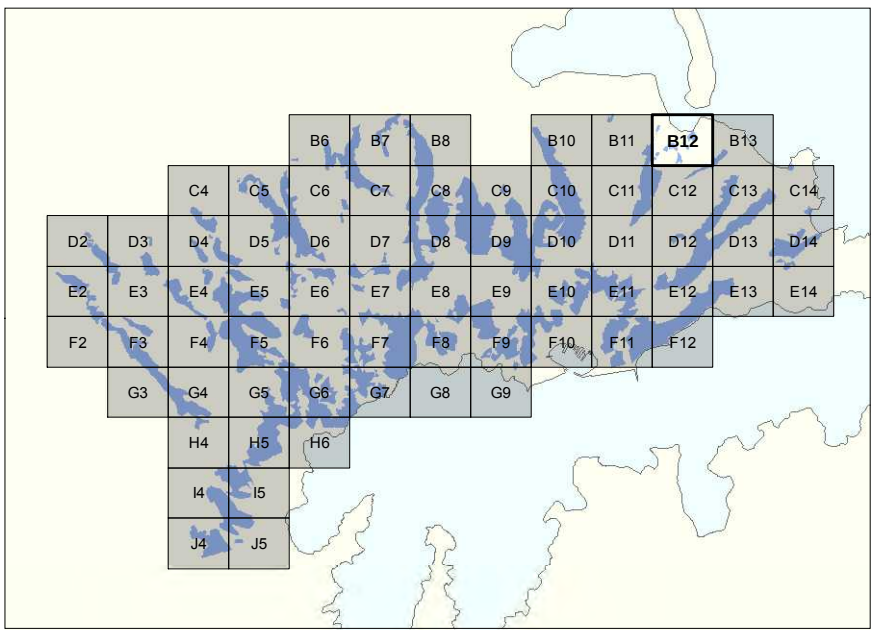
N

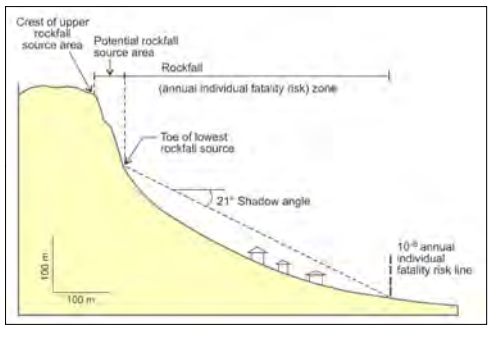
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map B12

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1580000 1580500 1581000

5176500 5176000

Main Road
Kinsey Terrace
Clifton Bay
The Spur
Truaveria Terrace
Clifton Terrace
Aranoni Track
Richmond Hill Road
Marine Street
Burgess Street
The Zig Zag
Panorama Road
Stoke Street
Wakefield Avenue
Wiggins Street
Wayland Street
Dryden Street
Hathaway Street
Menzies Street
Esplanade
De Thier Lane
21
25
29
31
32

1580000 1580500 1581000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

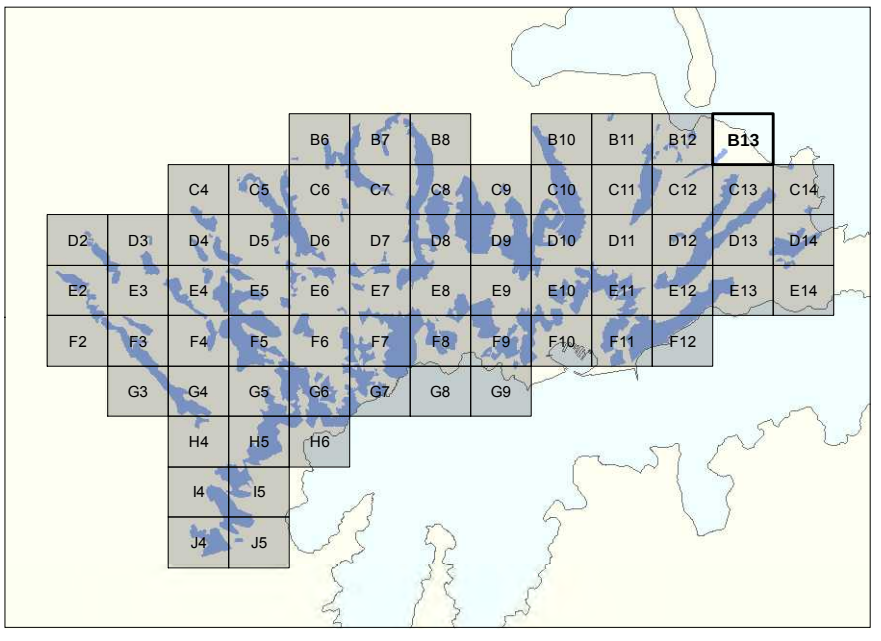
N

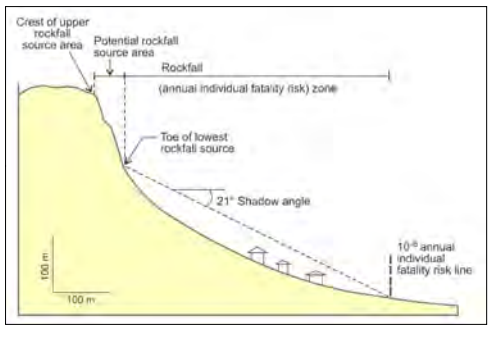
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

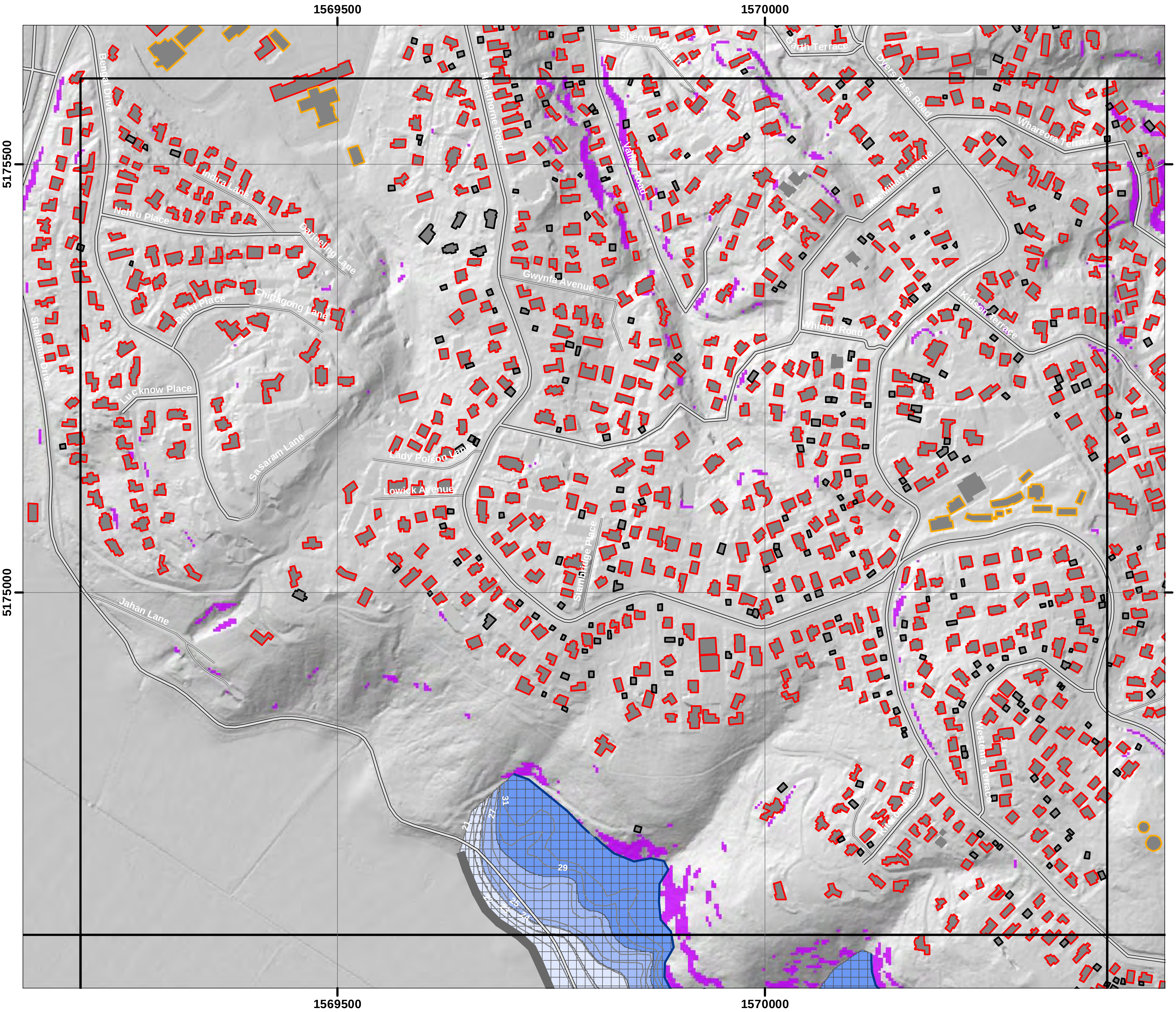
Port Hills Christchurch

APPENDIX C
Map B13

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

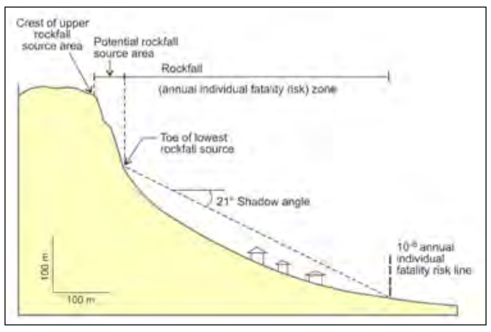
Only those areas with dwellings have been field verified and modified accordingly

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

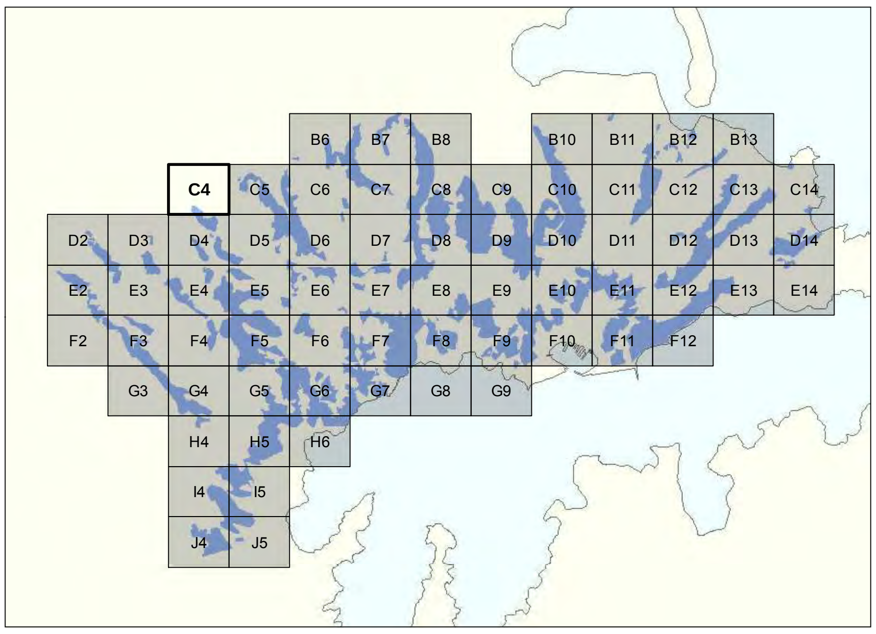
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL
CHK: CM

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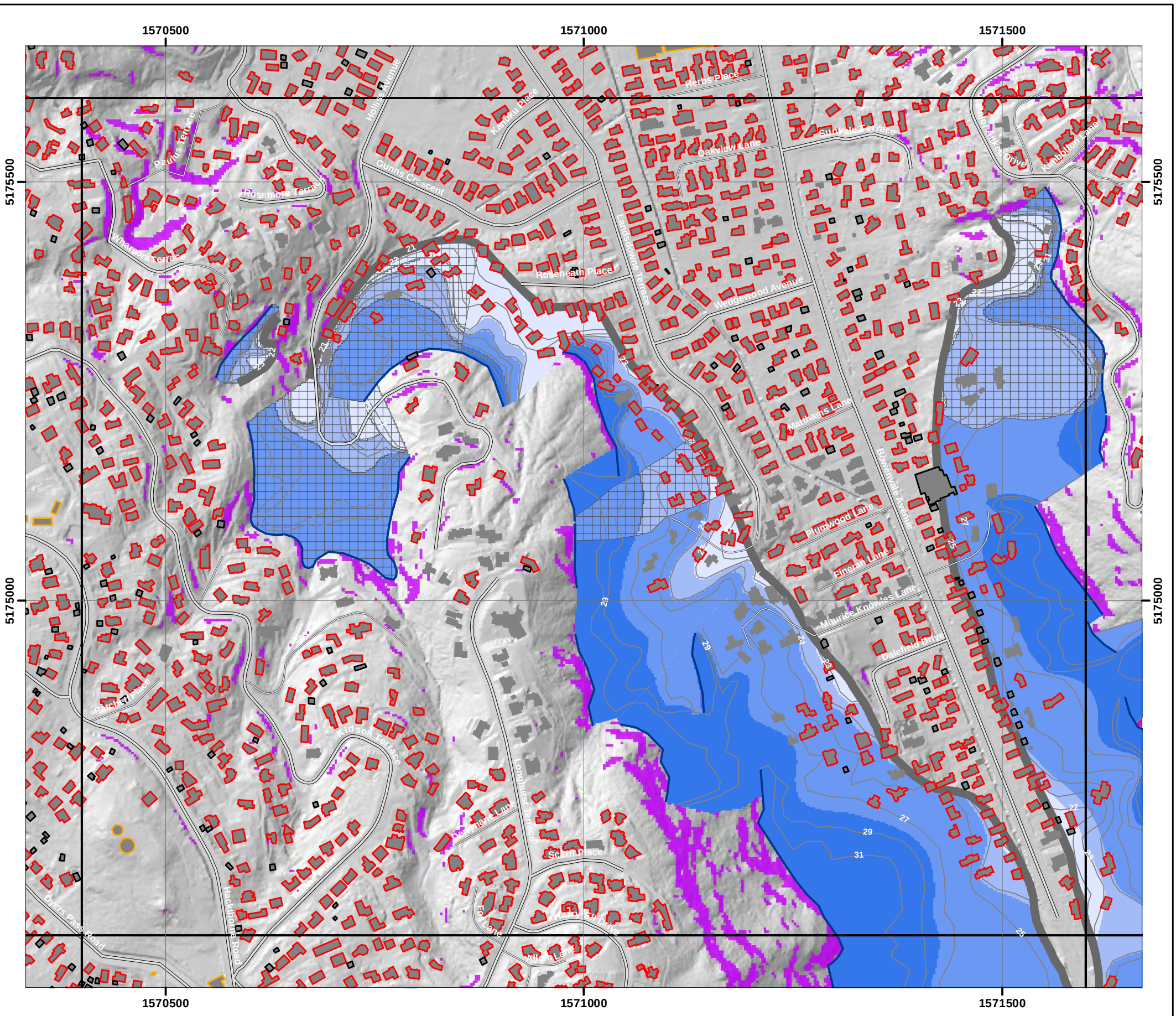
ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

APPENDIX C
Map C4

Port Hills Christchurch

FINAL ISSUE 2

REPORT: CR2012/123
DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

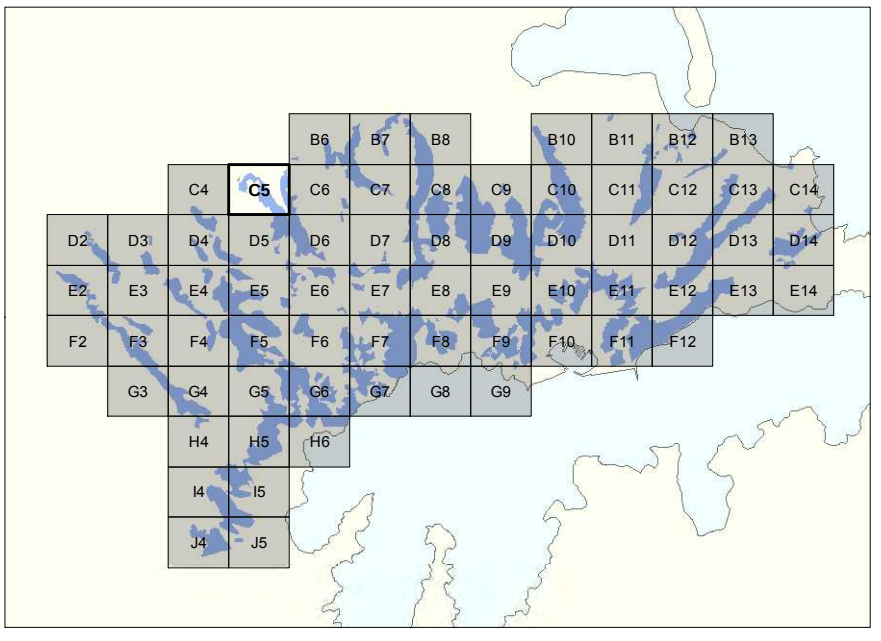
N

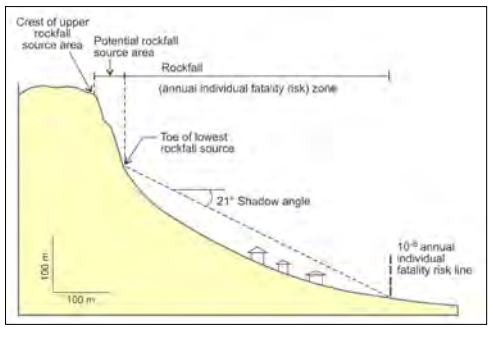
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

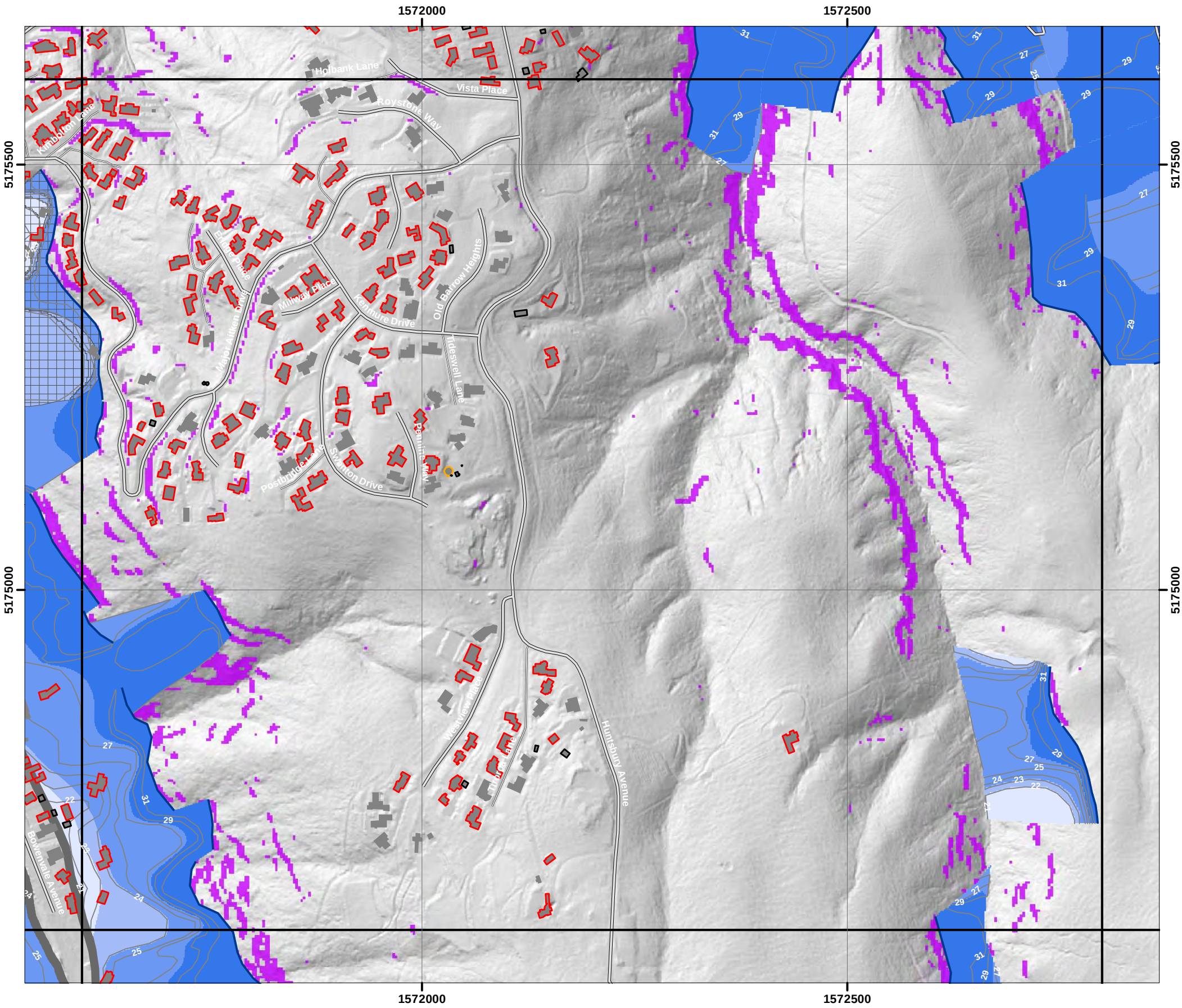
Port Hills Christchurch

APPENDIX C
Map C5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

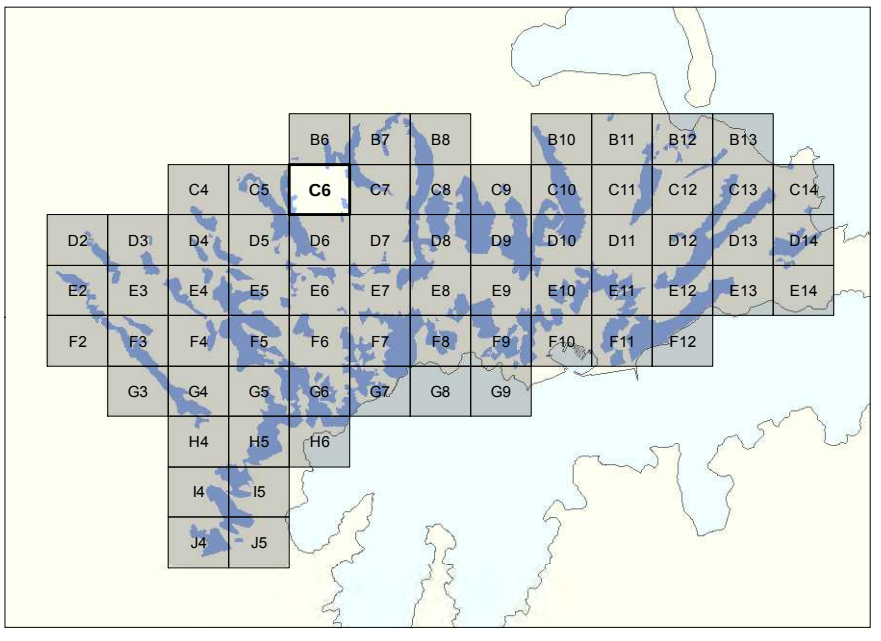
N

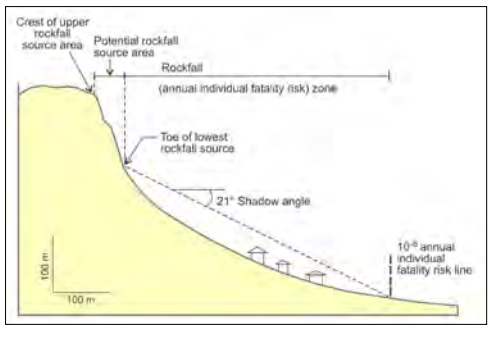
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1573000 1573500 1574000

5175500

5175000

Rapaki Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

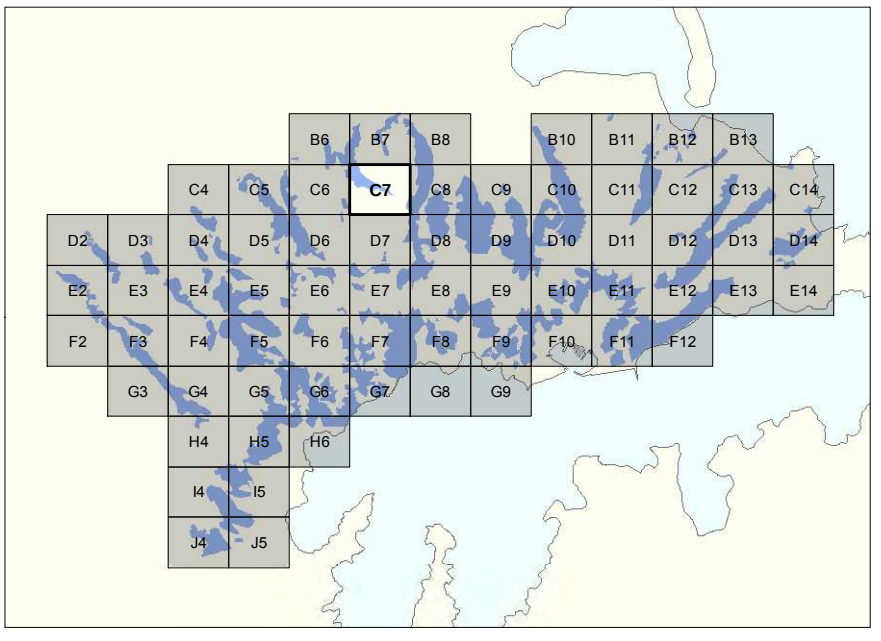
N

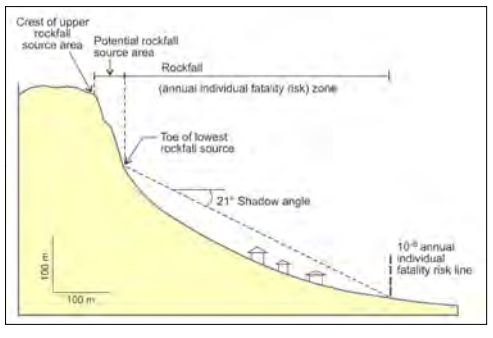
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

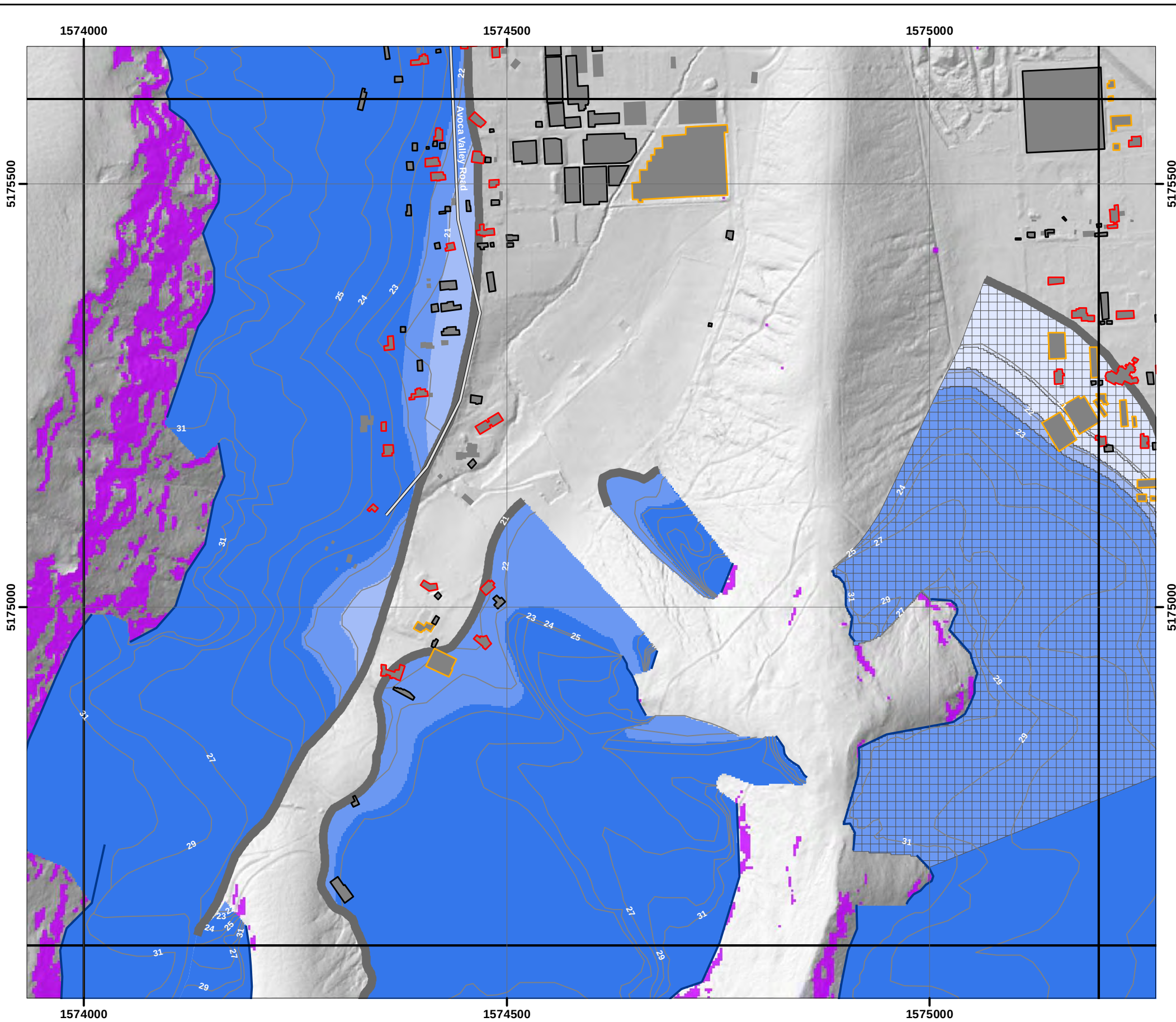
Port Hills Christchurch

APPENDIX C
Map C7

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

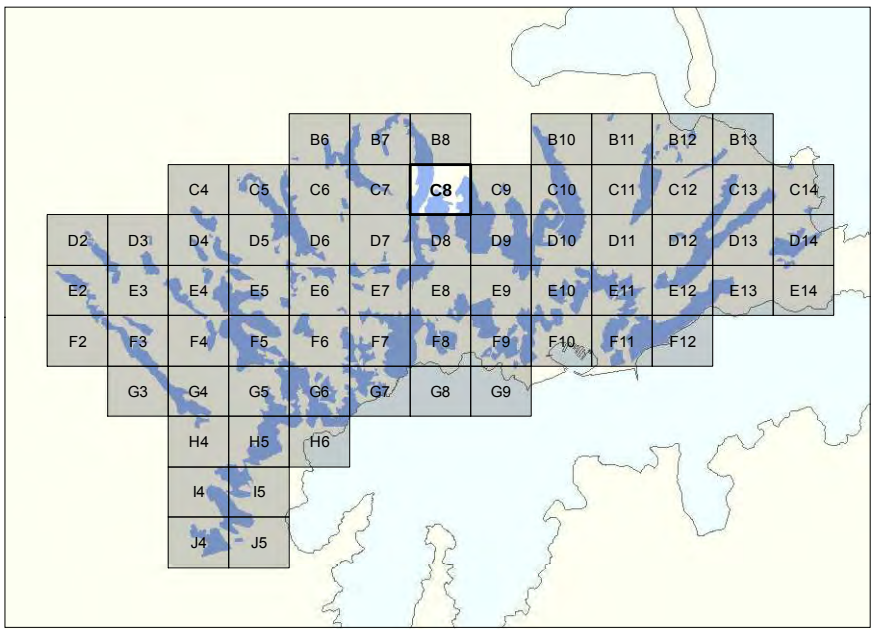
N

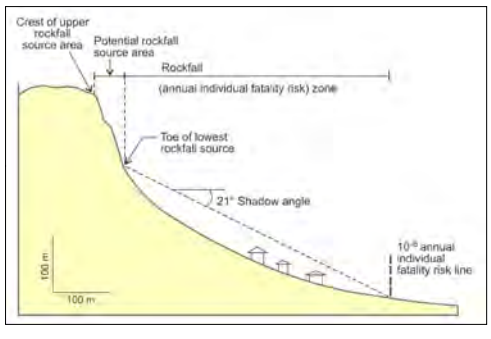
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C8

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

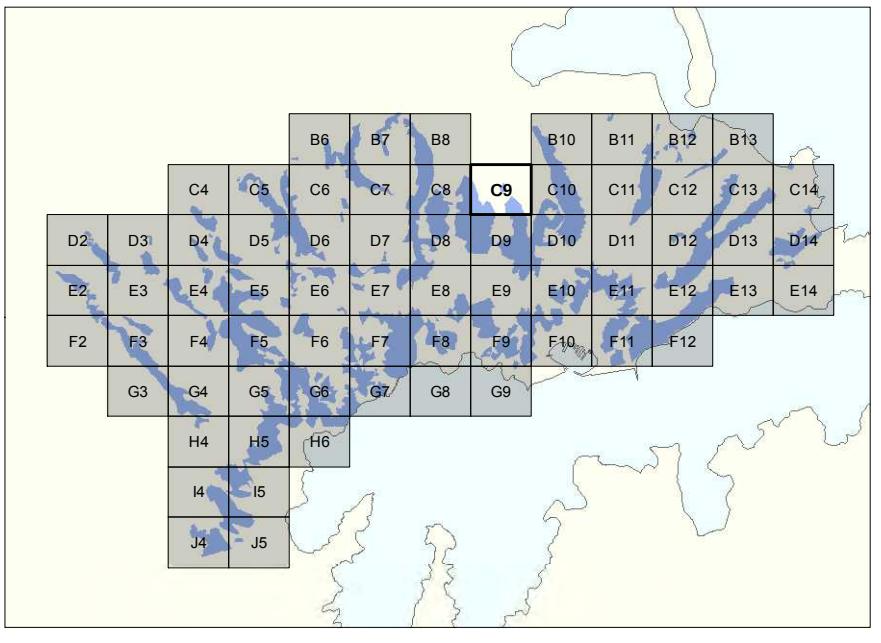
N

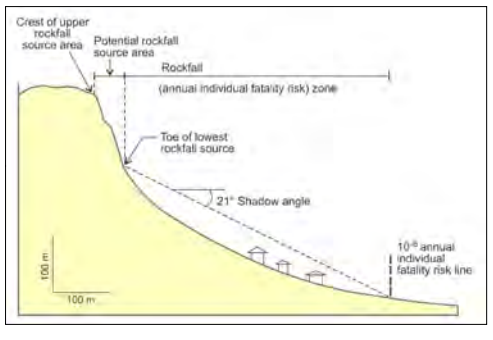
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C9

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1576500 1577000 1577500

5175500 5175000

Hammerton Lane
Madeley Road
Kaikoura Drive
Mt Pleasant Road
Mount Pleasant Road
The Terrace
Bridle Path Road
Cooks Lane
Martindales Road
Parkridge Place
Stonevirtue Close
Longshore Drive
Clearview Lane
Ridgeview Lane
Flavell Street
Marsden Street
Rollin Street
Sutton Road
Morgans Valley
Port Hills Road

27 29 24 24 31 29 25 22 21 23 27 24 25 27 29 31 29

1576500 1577000 1577500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

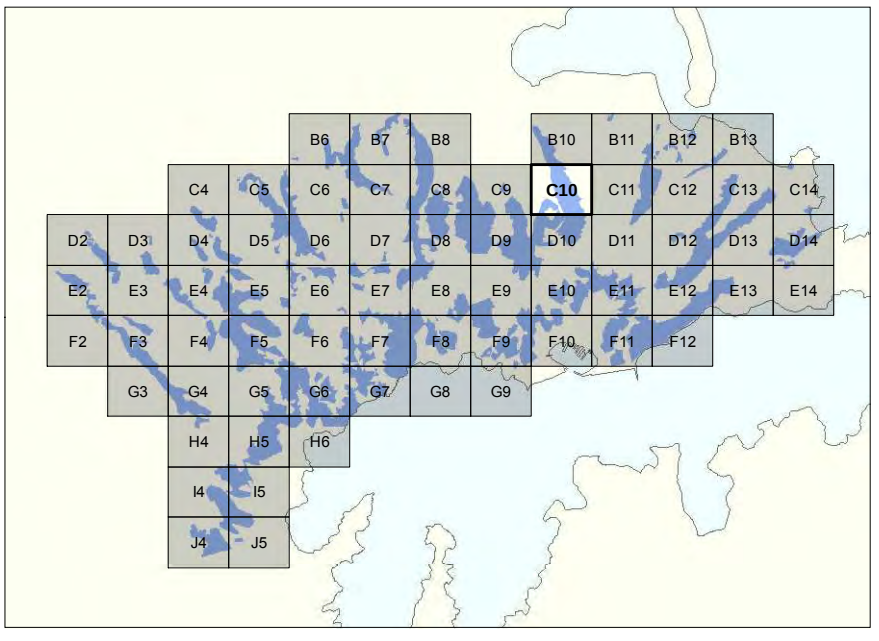
- Areas where the risk decreased
- Areas where the risk increased

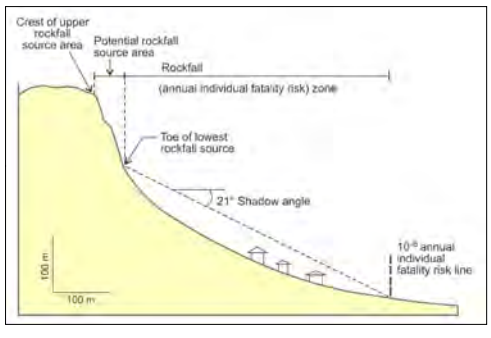
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C10

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1578000 1578500

5175500 5175500

5175000 5175000

1578000 1578500

Stoneyridge Close
Clearview Lane
Ridgeview Lane
Samarinore Close
Skinner Road
Upper Major Hornbrook Road
Mt Pleasant Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

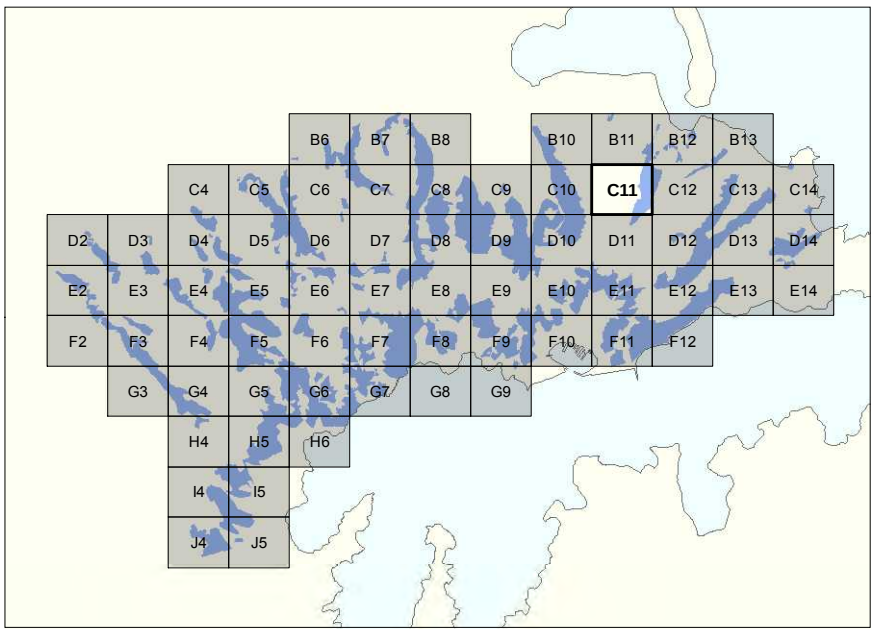
- Areas where the risk decreased
- Areas where the risk increased

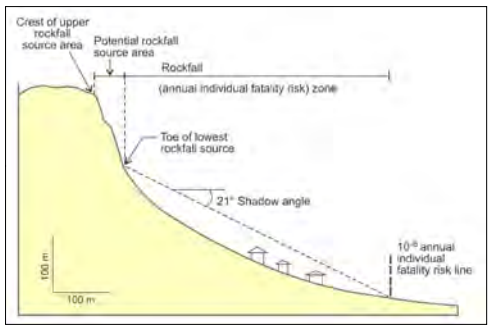
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

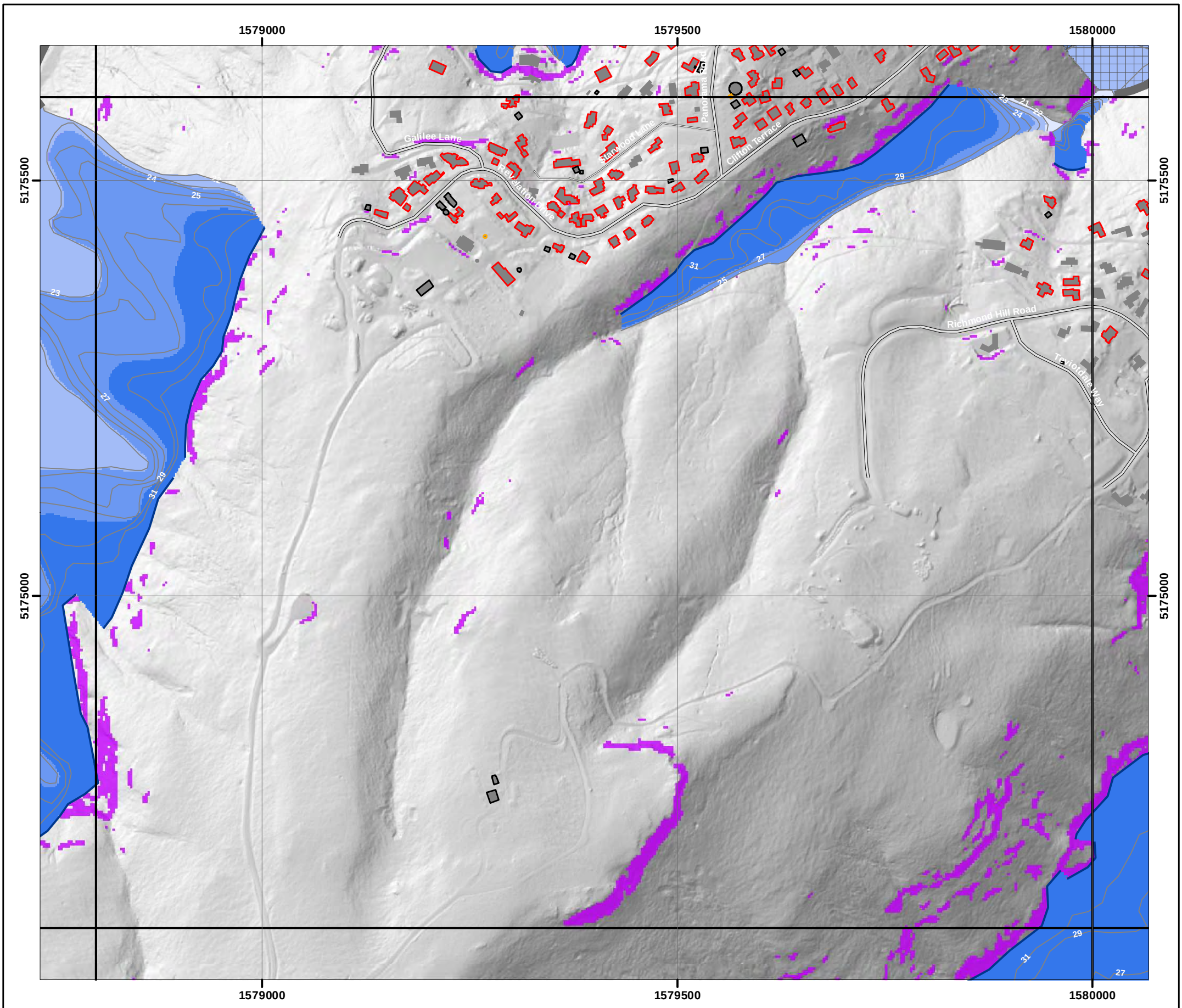
Port Hills Christchurch

APPENDIX C
Map C11

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

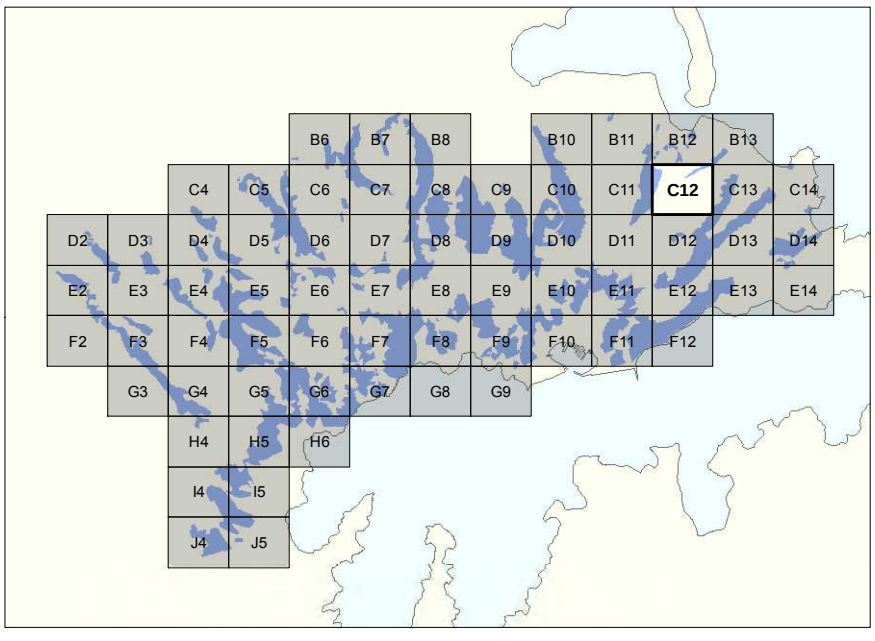
- Areas where the risk decreased
- Areas where the risk increased

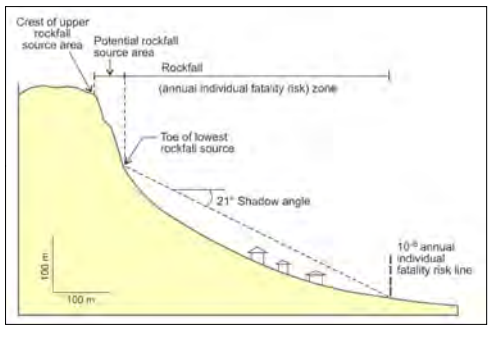
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

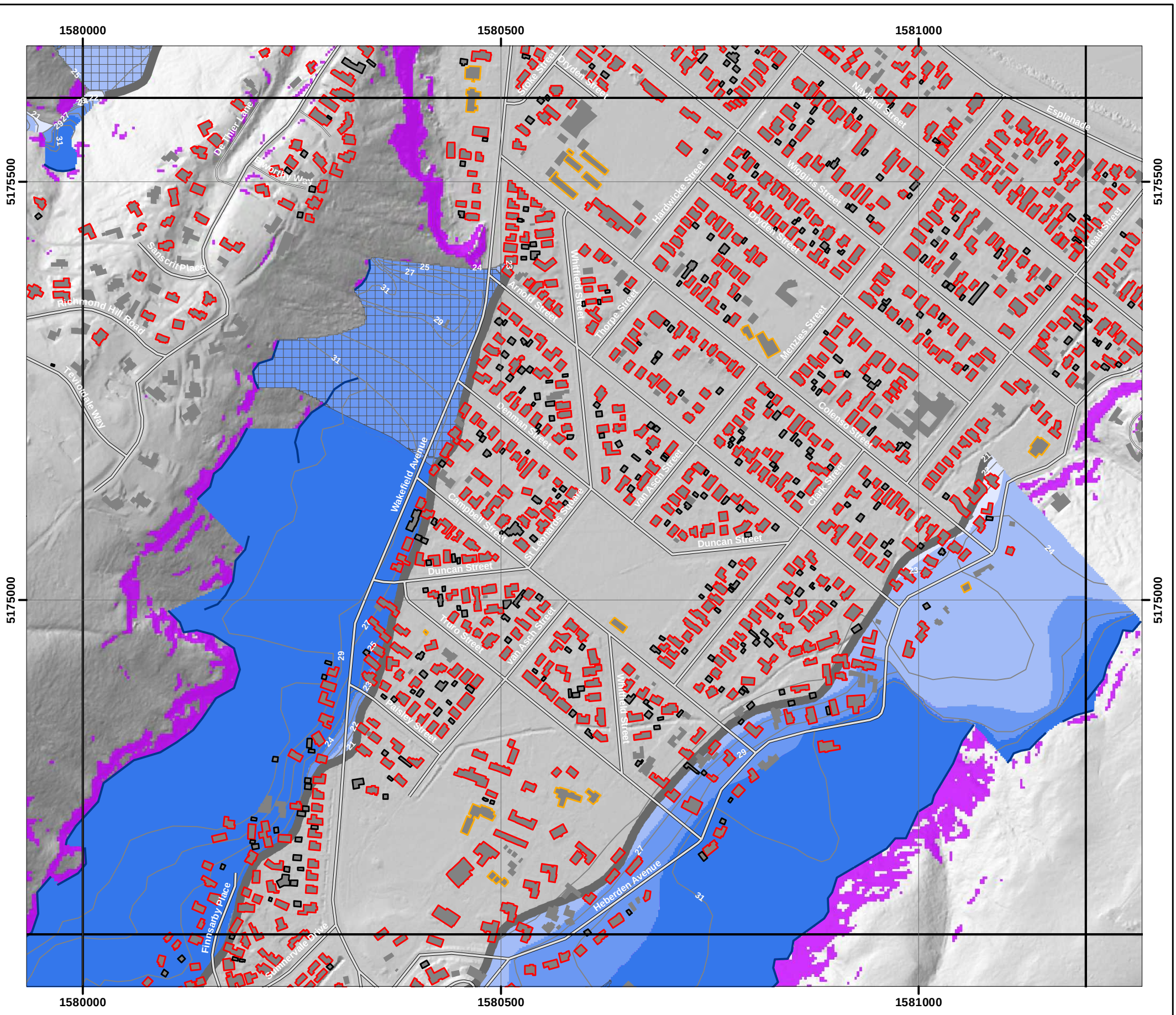
Port Hills Christchurch

APPENDIX C
Map C12

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

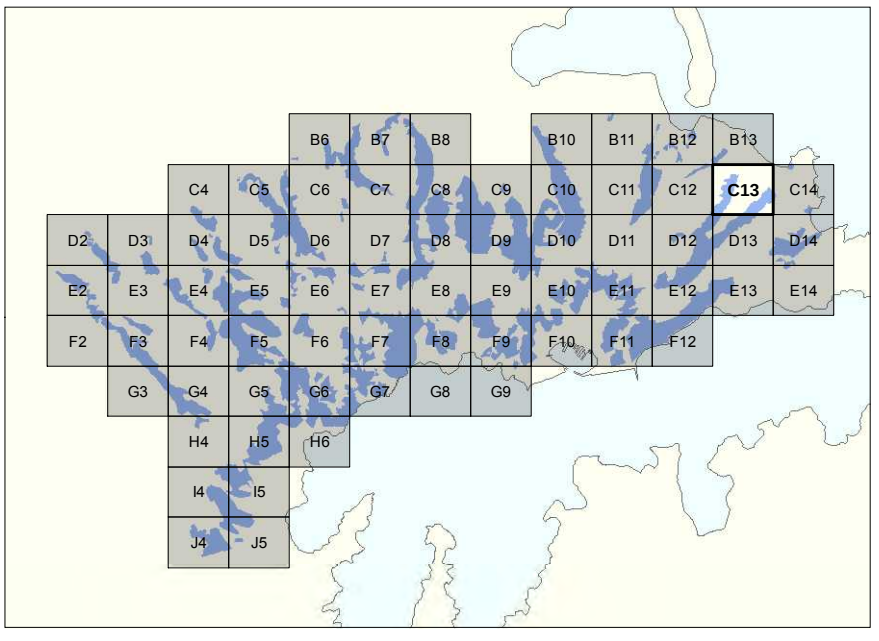
N

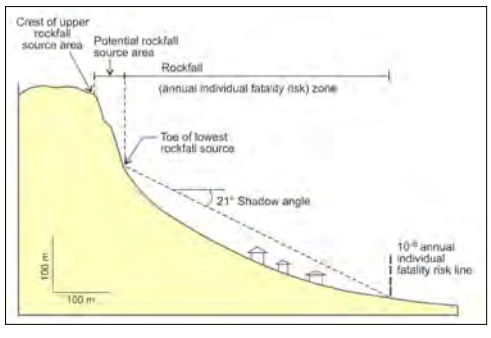
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C13

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1581500 1582000

5175500 5175500

5175000 5175000

Esplanade
Head Street
Hayland Street
Heberden Avenue
Edwin Mouldey Track
Tirohanga Lane
Shuttlers Cove
Appian Lane
Taylors Mistake Road
Scotty Drive
Sunview Lane
Sunrise Lane
Peninsula View
24
29
31
21
23

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

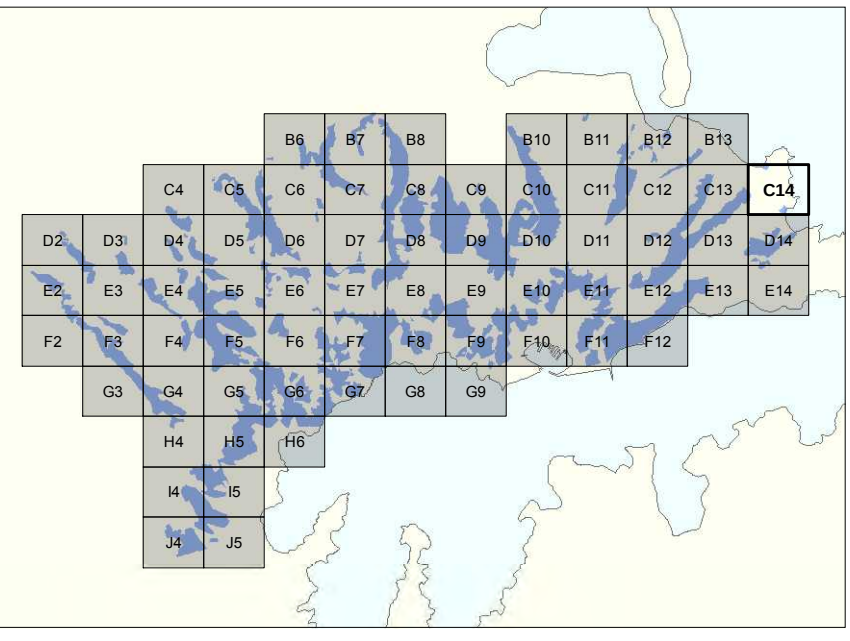
N

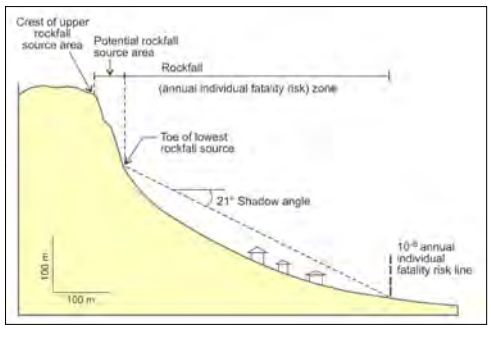
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map C14

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1567000 1567500 1568000

5174500 5174000

Ennerdale Row
Somerton Rise
Highcrest Heights
Rennuddock Rise
Sedbergh Place
Rosthwaite Place
Thirlmere Lane
Blencathra Place
Woodside Common
Mount Pleasant Drive
Cashmere Road
South Hay Valley Road

21 23 25 27 29 31

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

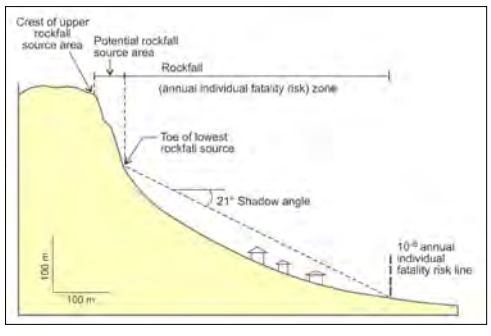
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

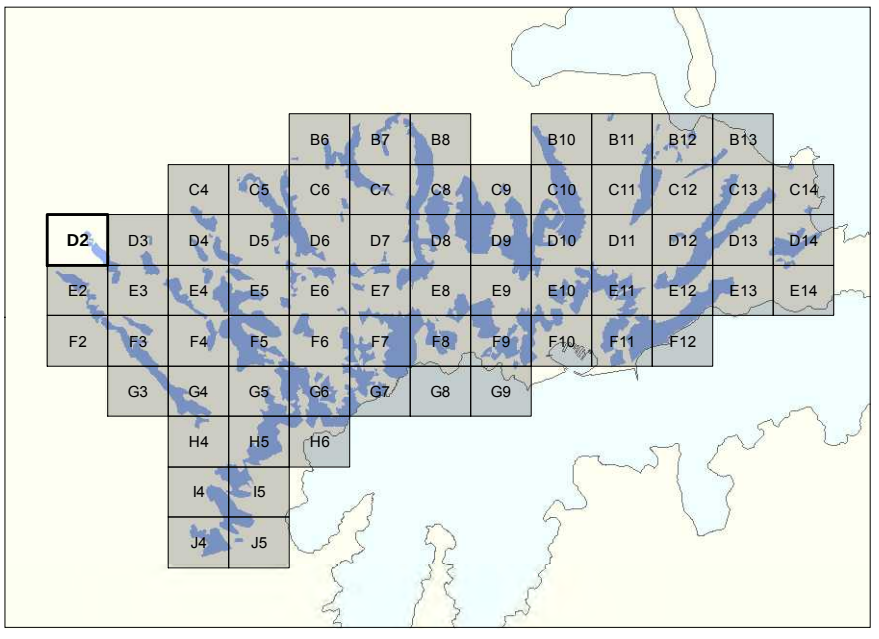
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

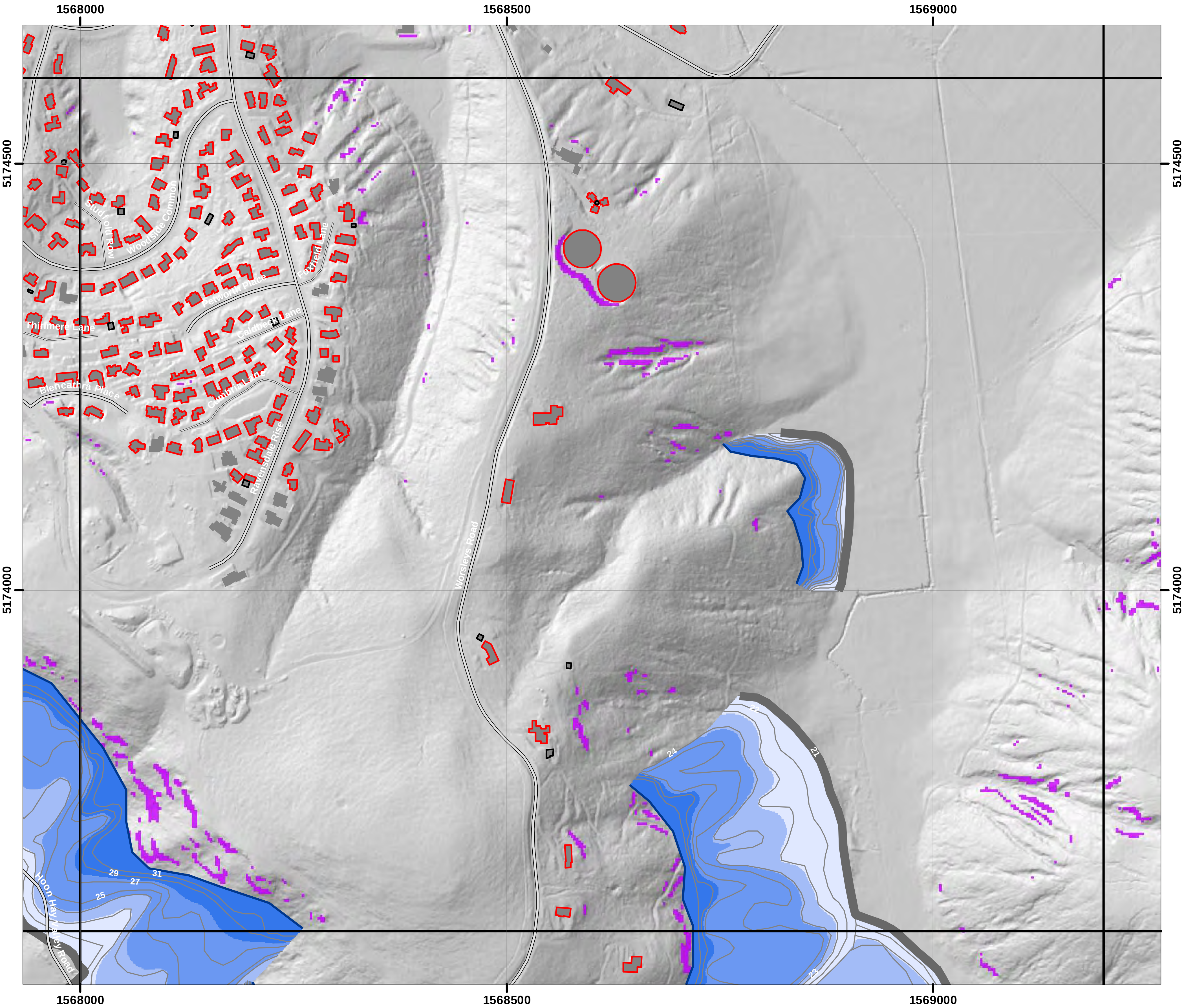
Port Hills Christchurch

APPENDIX C
Map D2

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

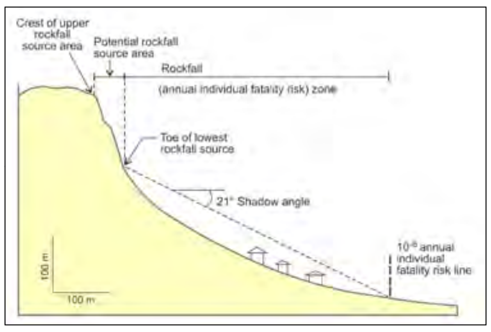
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

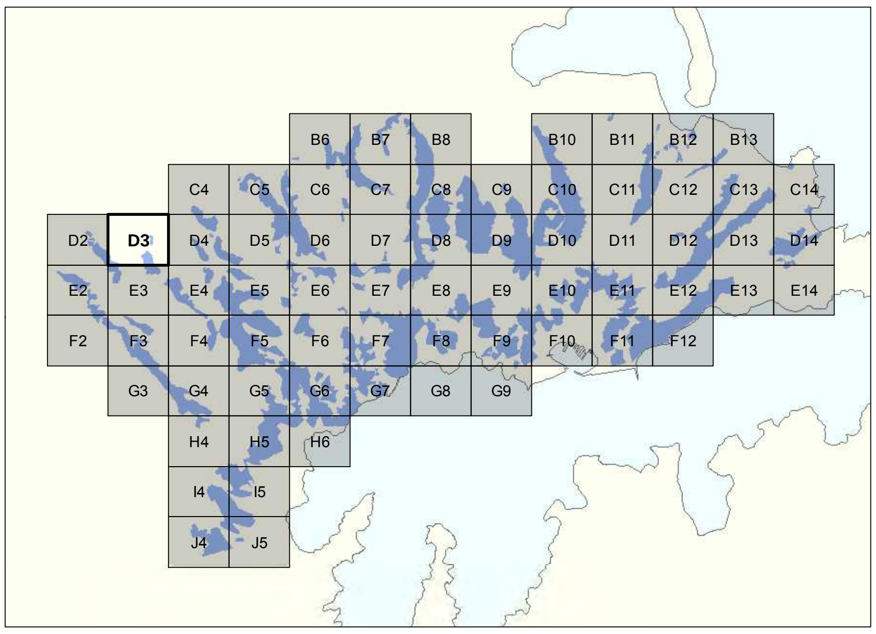
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL
CHK: CM

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D3

FINAL ISSUE 2

REPORT: CR2012/123
DATE: July 2013

1569500 1570000

5174500 5174000

Dyers Pass Road

Pentre Terrace

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

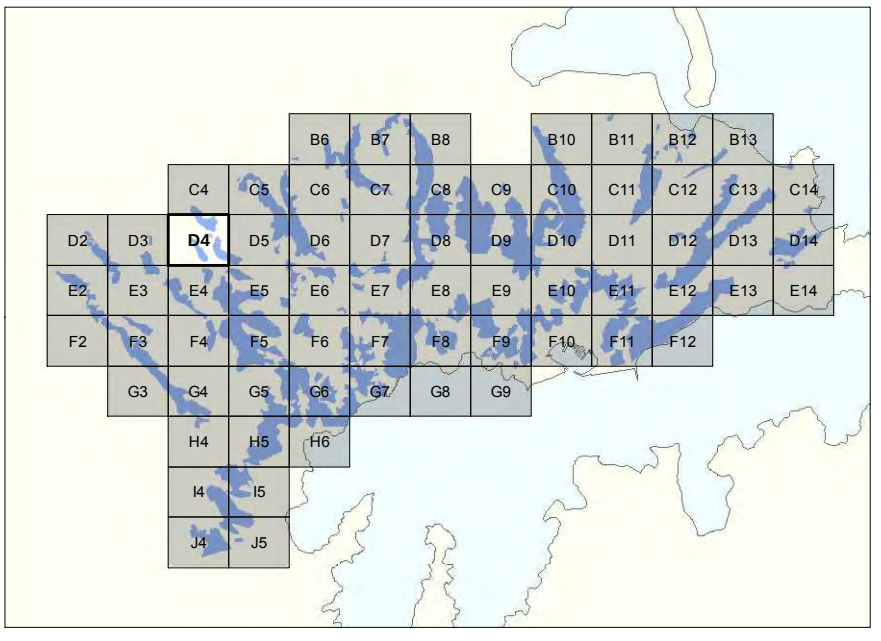
N

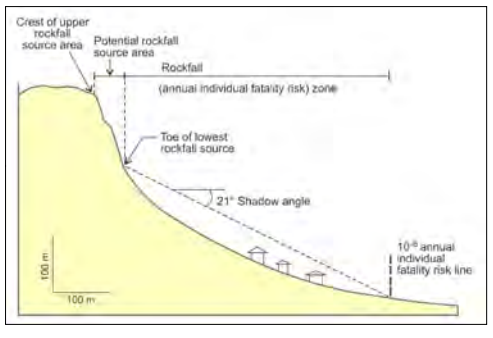
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D4

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1570500 1571000 1571500

5174500 5174000

Dyers Pass Road · Hackthorne Road · Longhurst Terrace · Hillerest Place · Victoria Park Road · Penire Terrace

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

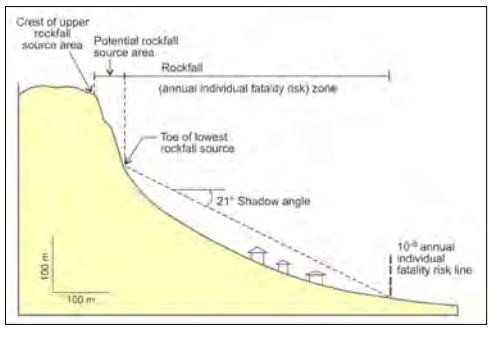
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

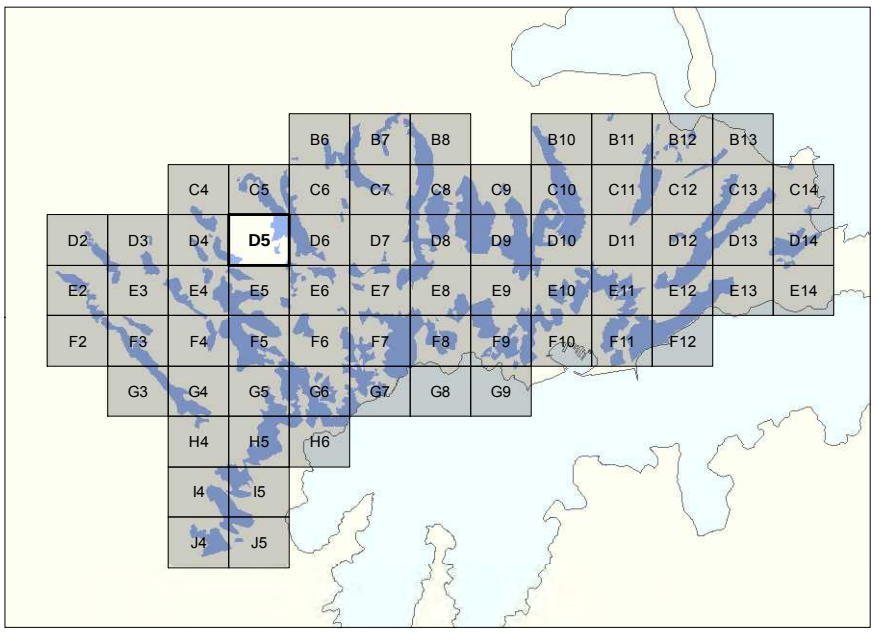
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1572000 1572500

5174500 5174000

Humpsburn Avenue

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

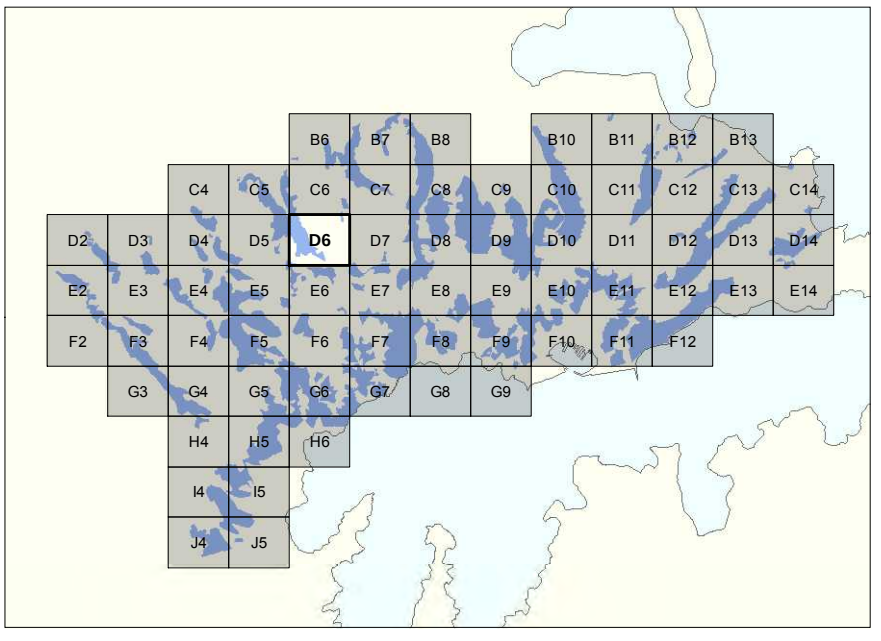
N

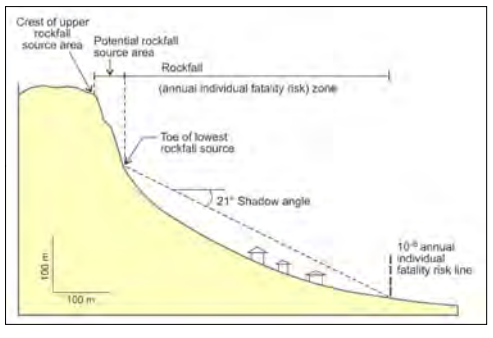
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

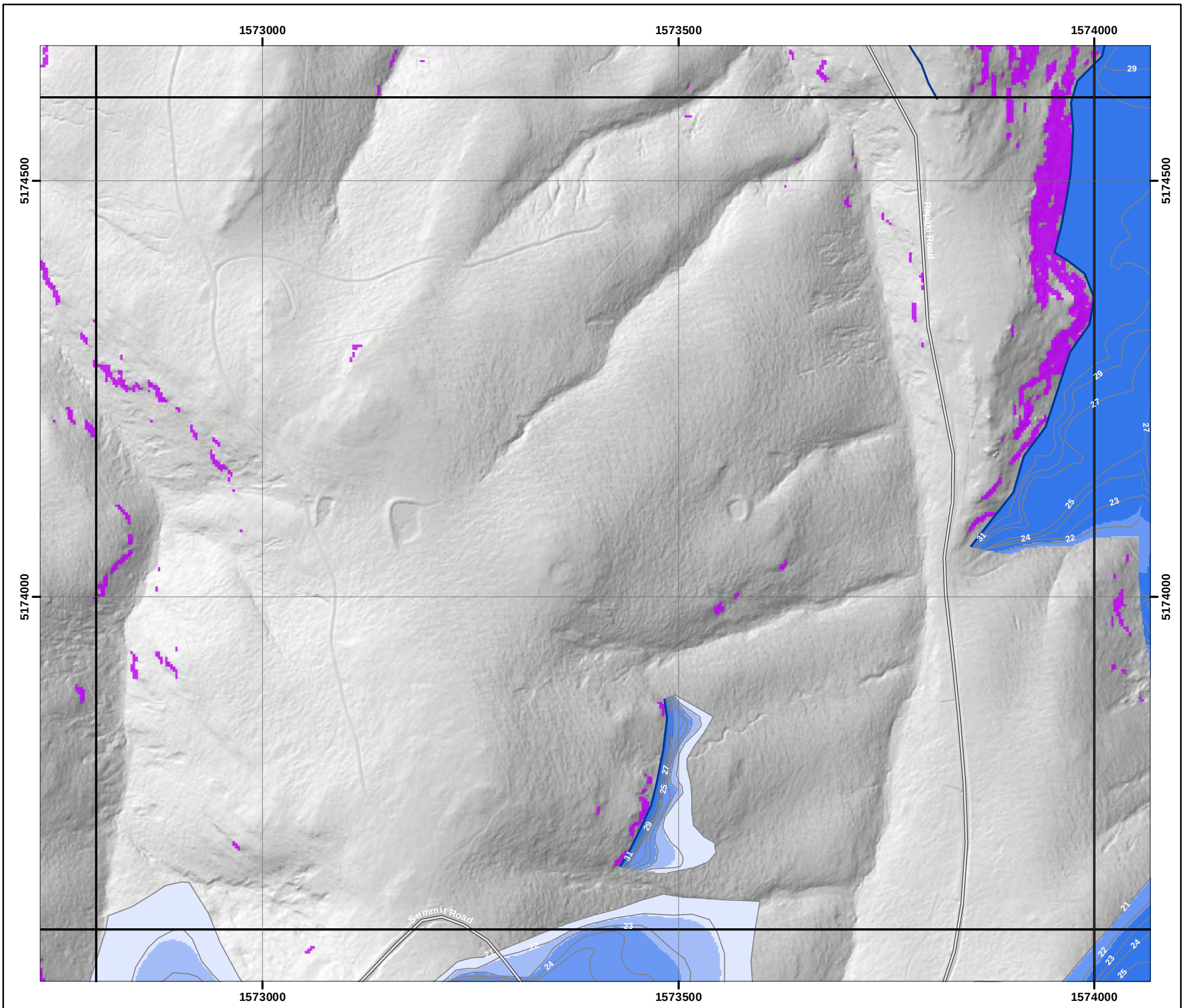
Port Hills Christchurch

APPENDIX C
Map D6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

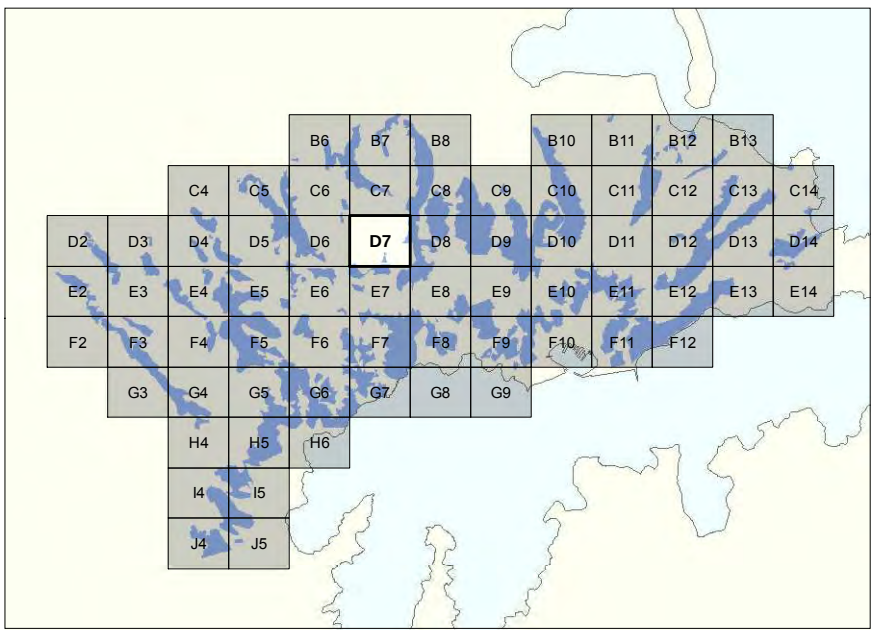
N

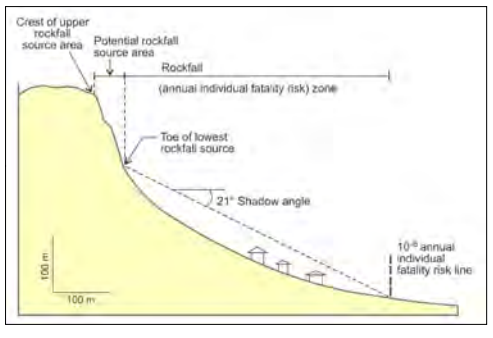
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

GNS SCIENCE TE PŪ AO

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D7

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1574000 1574500 1575000

5174500 5174000

Summit Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

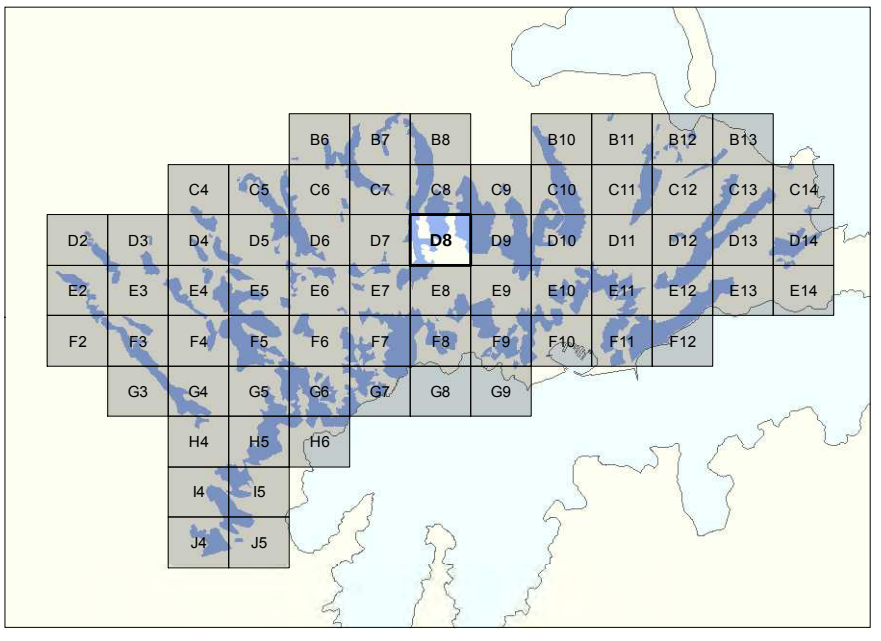
N

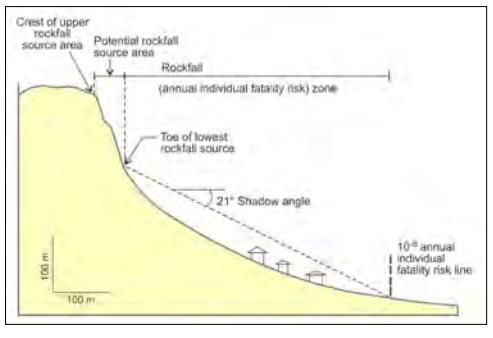
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D8

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1575500 1576000

5174500 5174000

Port Hills Road

Bridle Path Road

Bridle Path

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

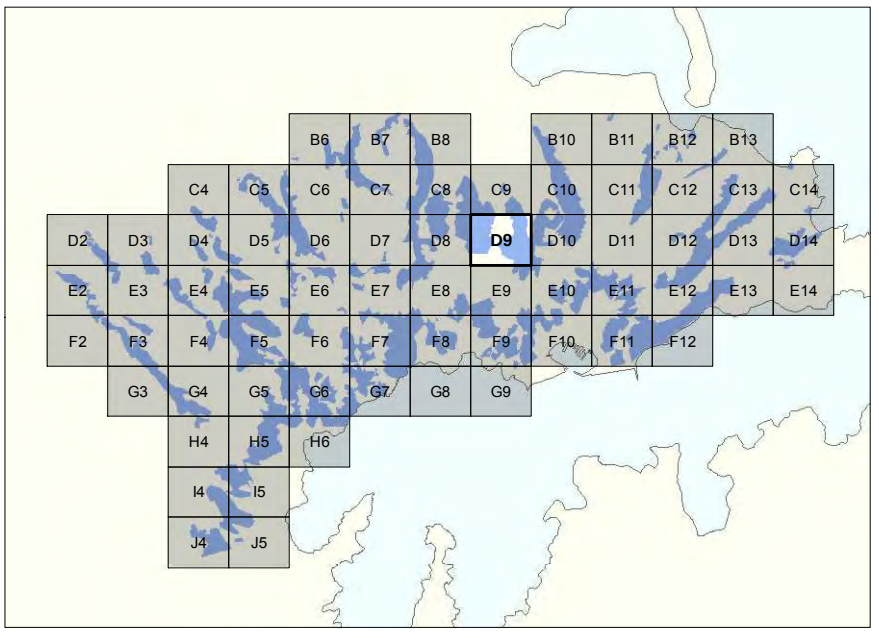
- Areas where the risk decreased
- Areas where the risk increased

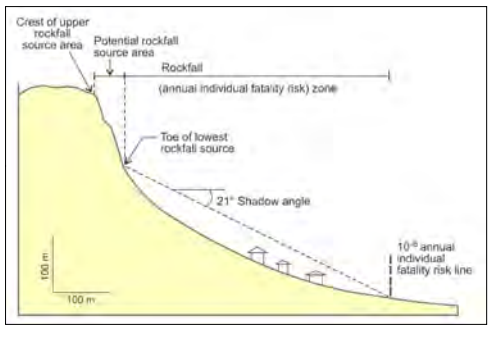
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

N





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

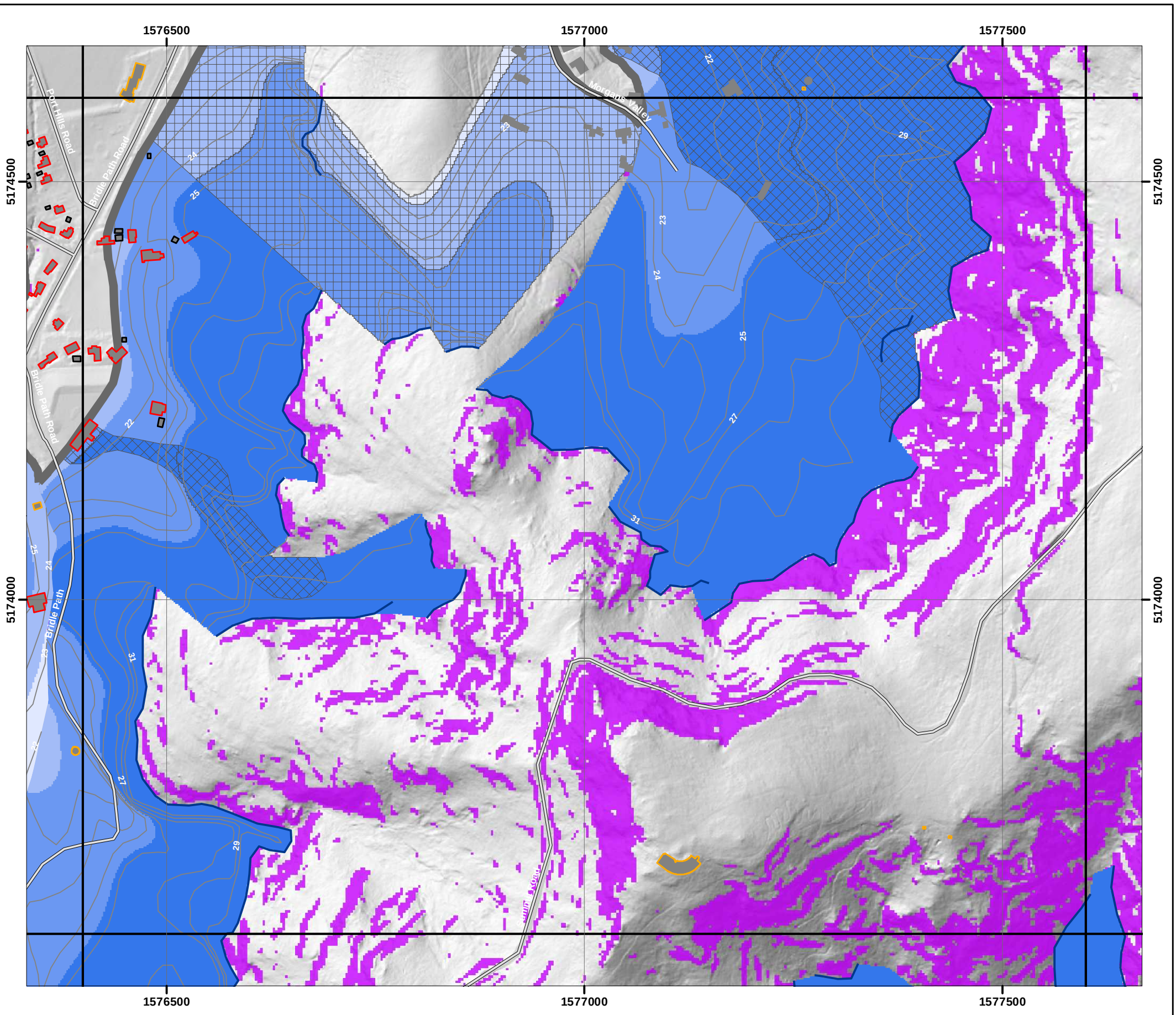
Port Hills Christchurch

APPENDIX C
Map D9

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

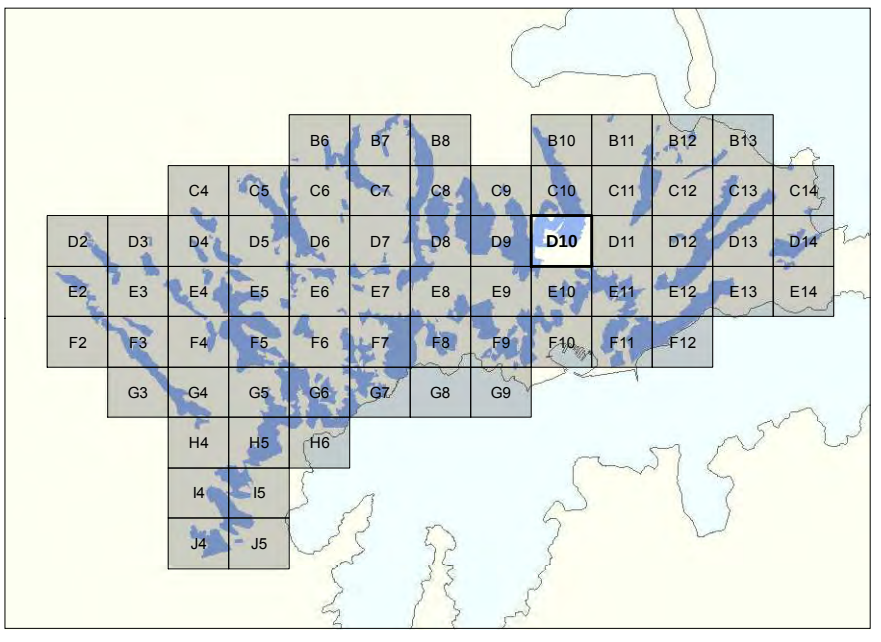
N

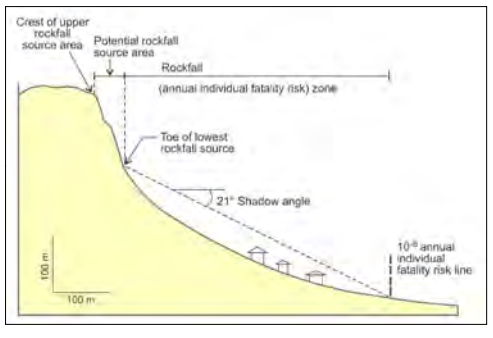
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D10

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1578000 1578500

5174500 5174000

Mt Pleasant Road

Broadleaf Lane

Summit Road

27 29 29 31 31

1578000 1578500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

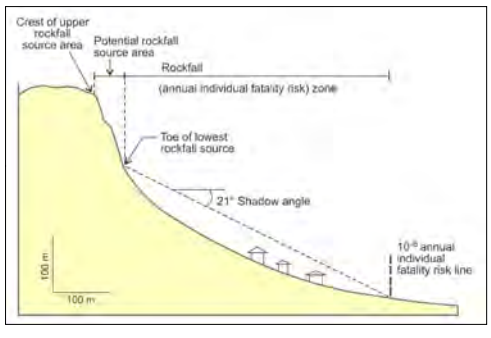
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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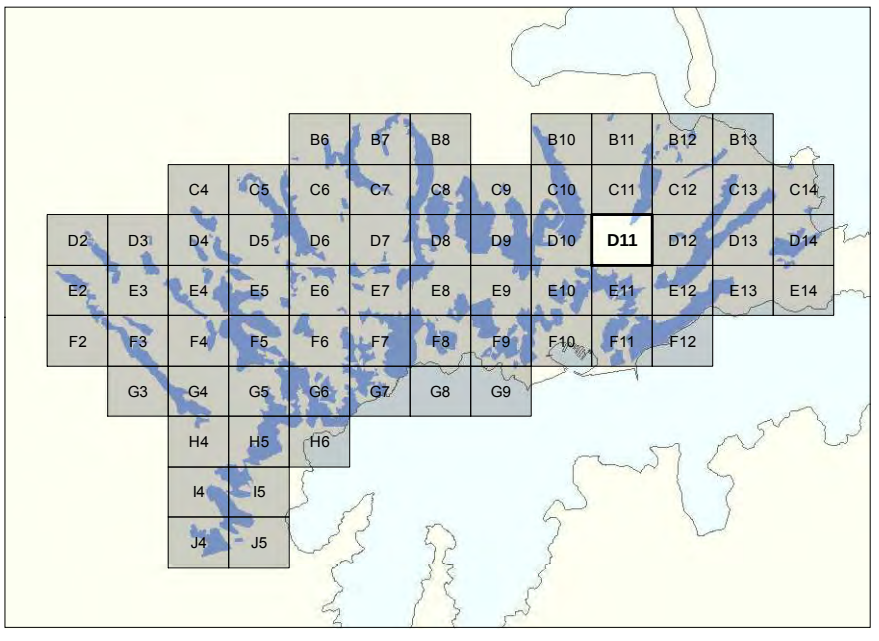
10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

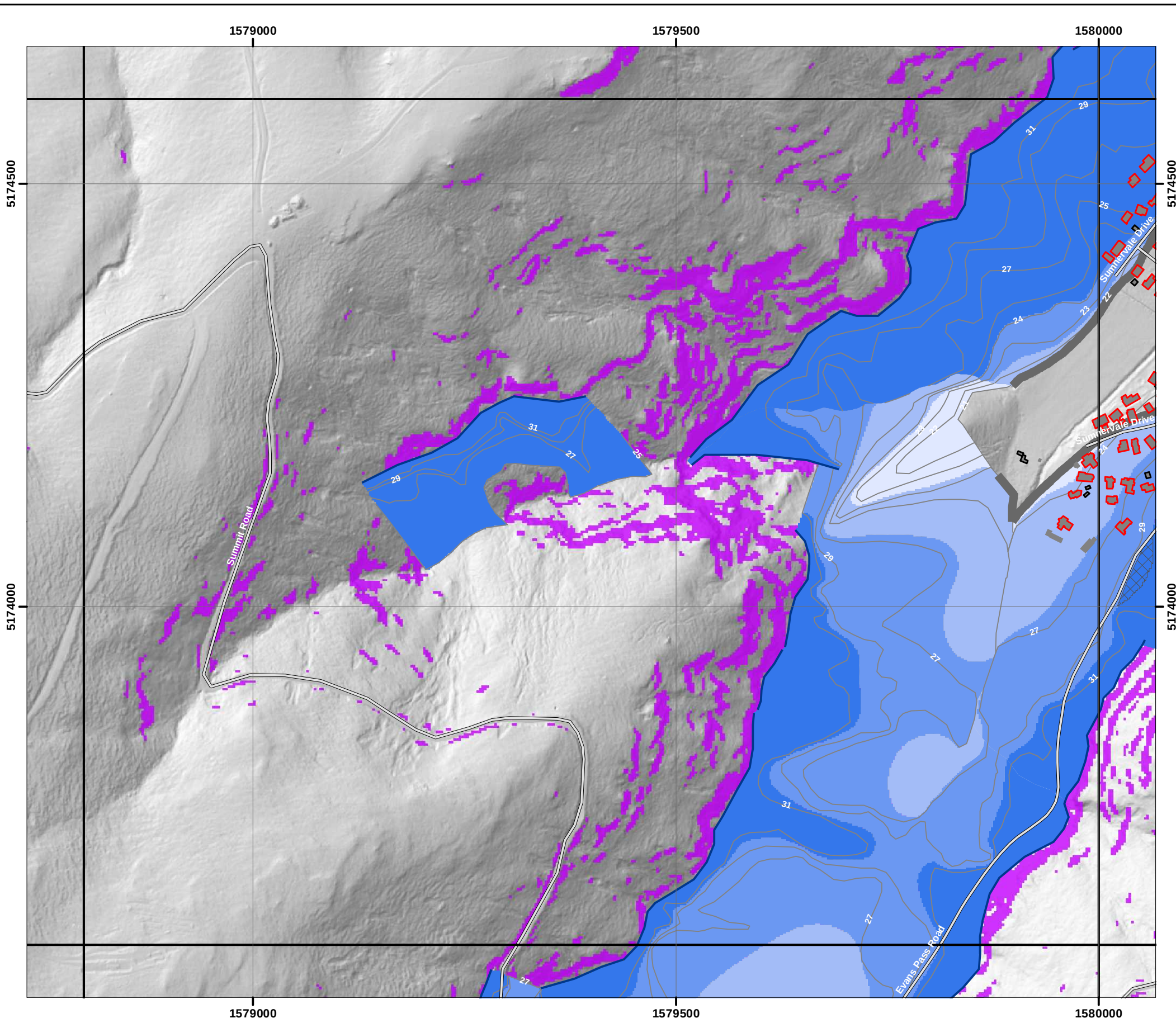
Port Hills Christchurch

APPENDIX C
Map D11

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

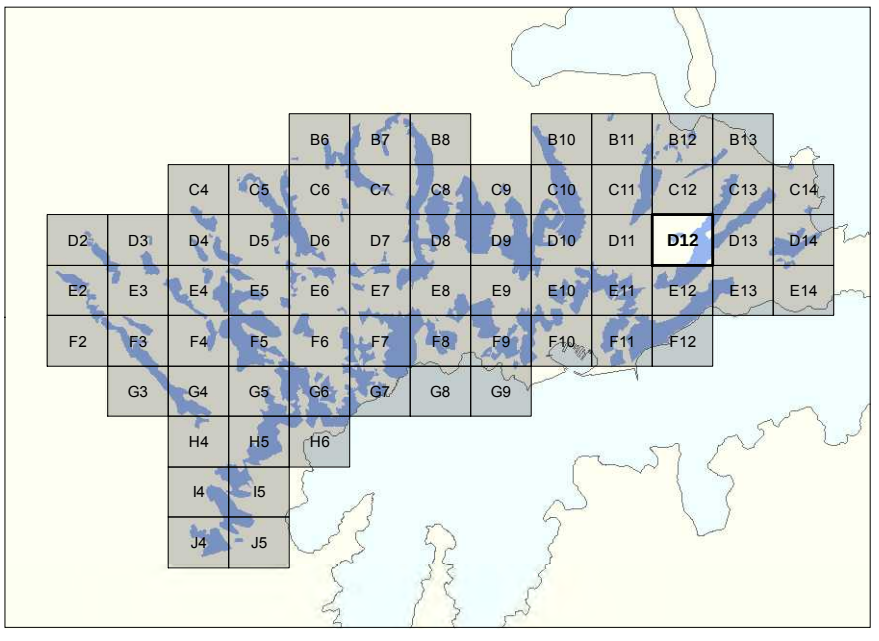
- Areas where the risk decreased
- Areas where the risk increased

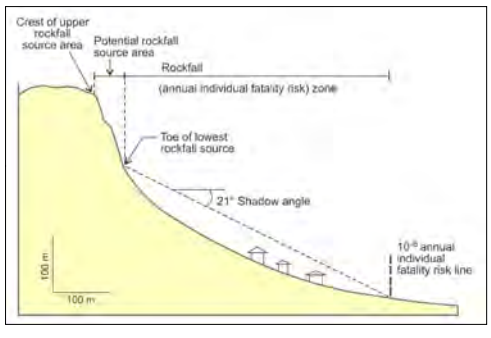
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

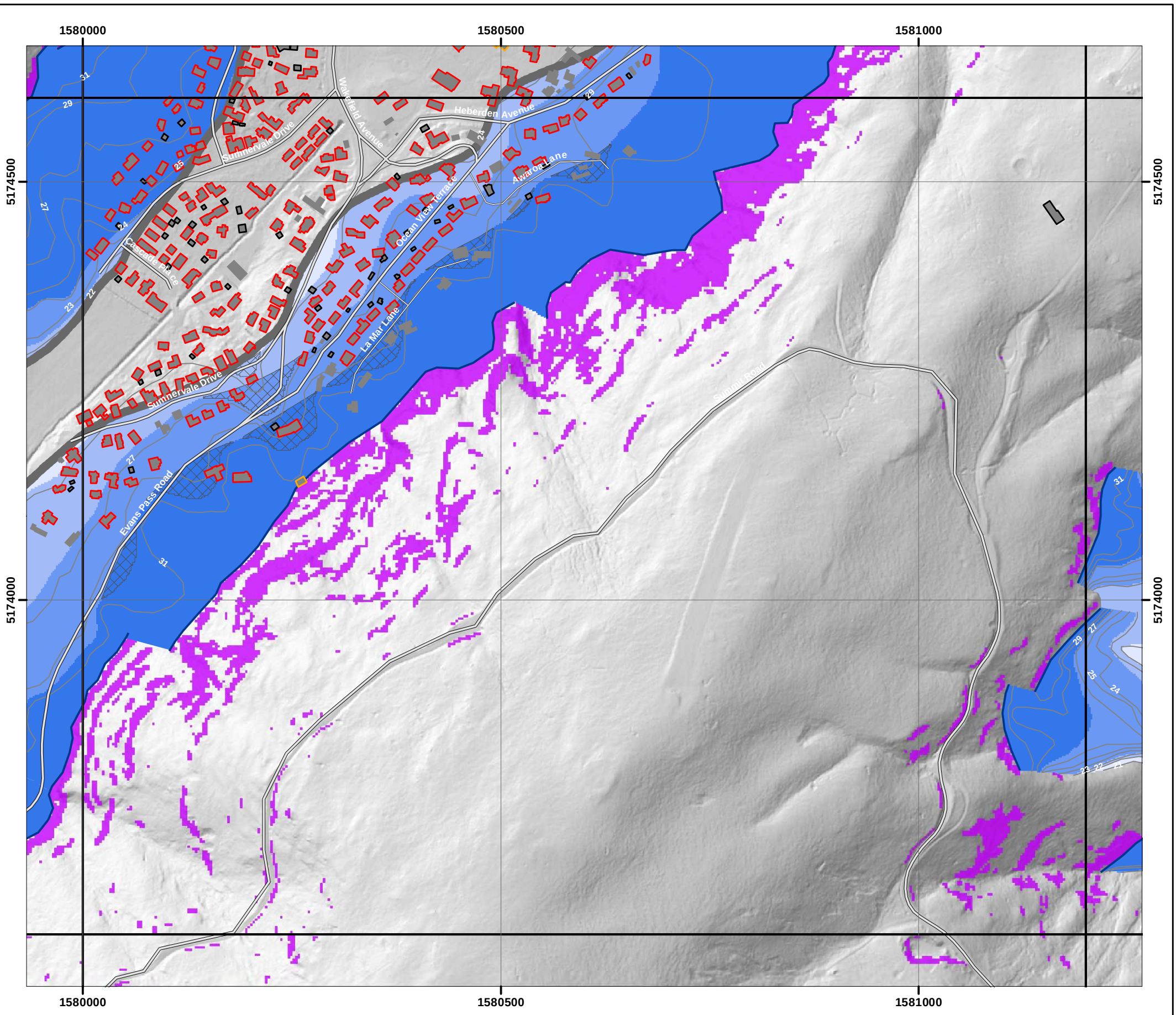
Port Hills Christchurch

APPENDIX C
Map D12

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

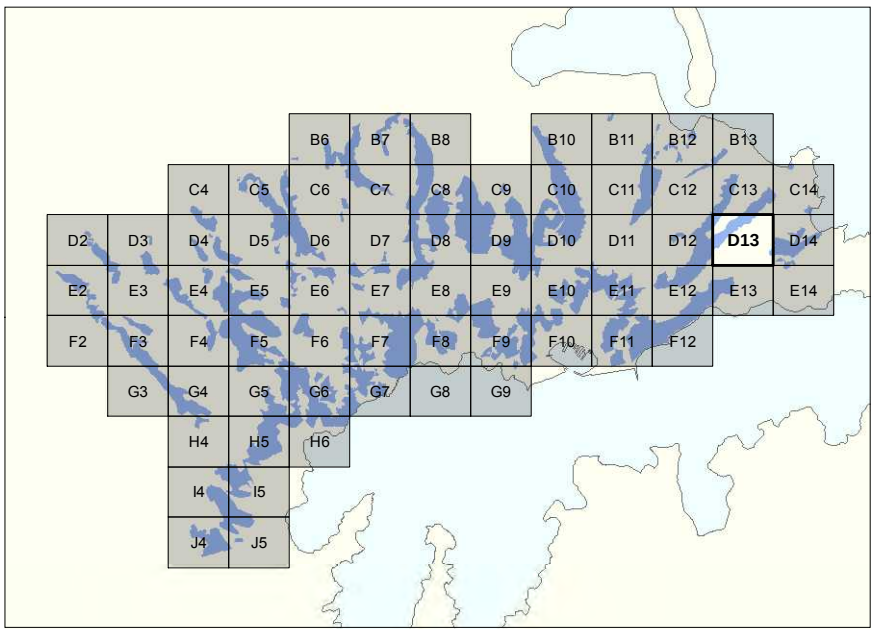
N

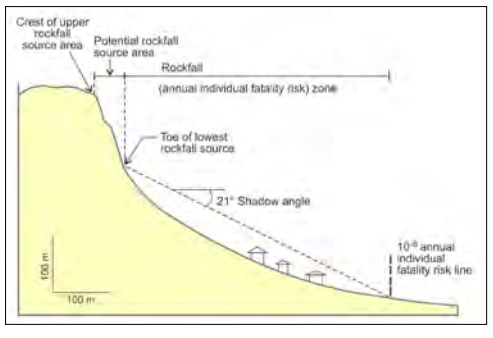
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D13

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1581500 1582000

5174500 5174500

5174000 5174000

Taylors Mistake Road

Rotten Row

Summit Road

1581500 1582000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

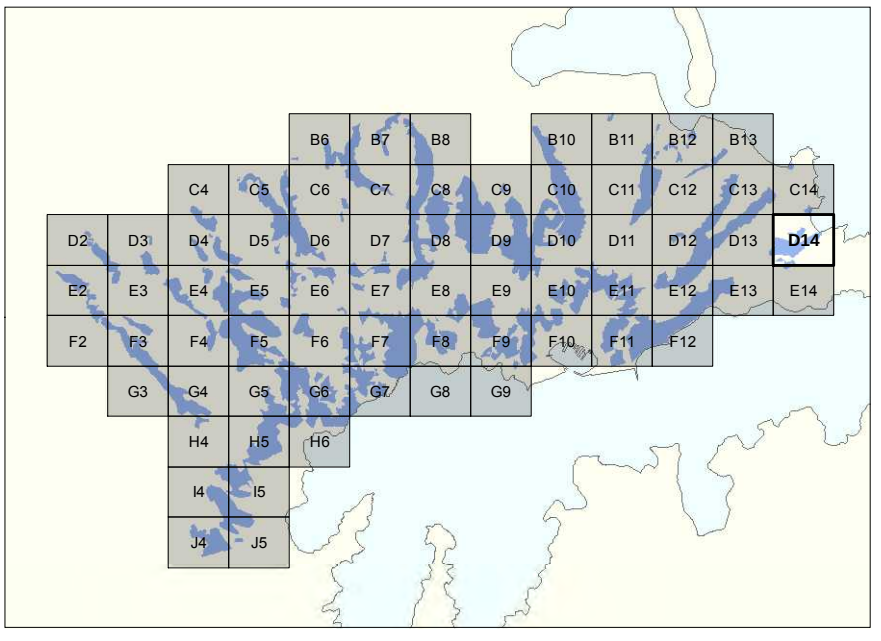
N

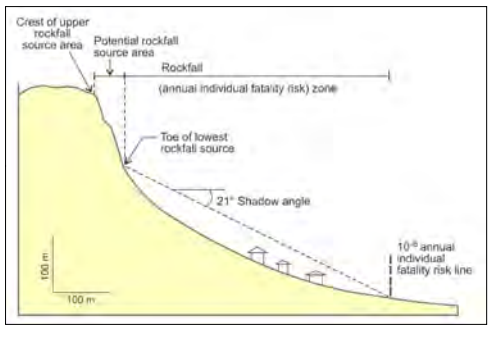
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map D14

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1567000 1567500 1568000

5173500 5173000

Hoon Hay Valley Road

29 31 27 25 24 22

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

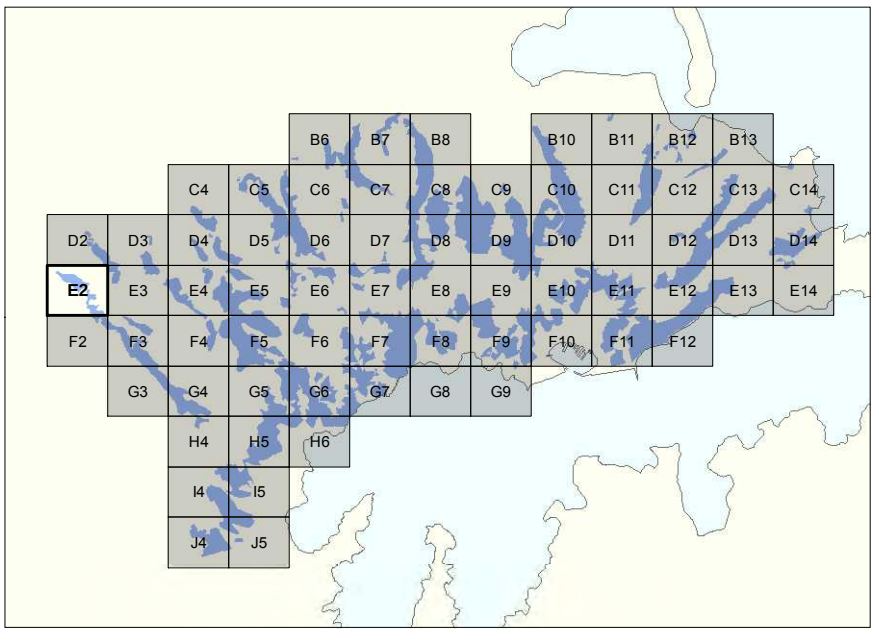
N

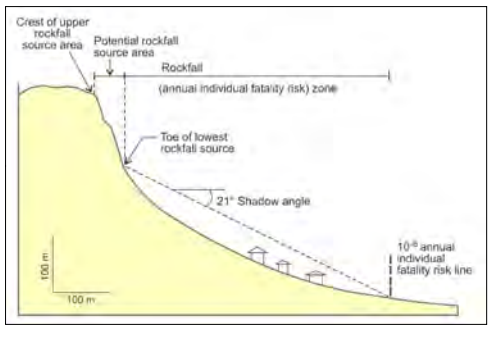
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

GNS SCIENCE TE PŪ AO

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E2

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1568000 1568500 1569000

5173500 5173000

Tisbury Lane
Worsleys Road
Aglaia Place
Hoon Hay Valley Road

1568000 1568500 1569000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

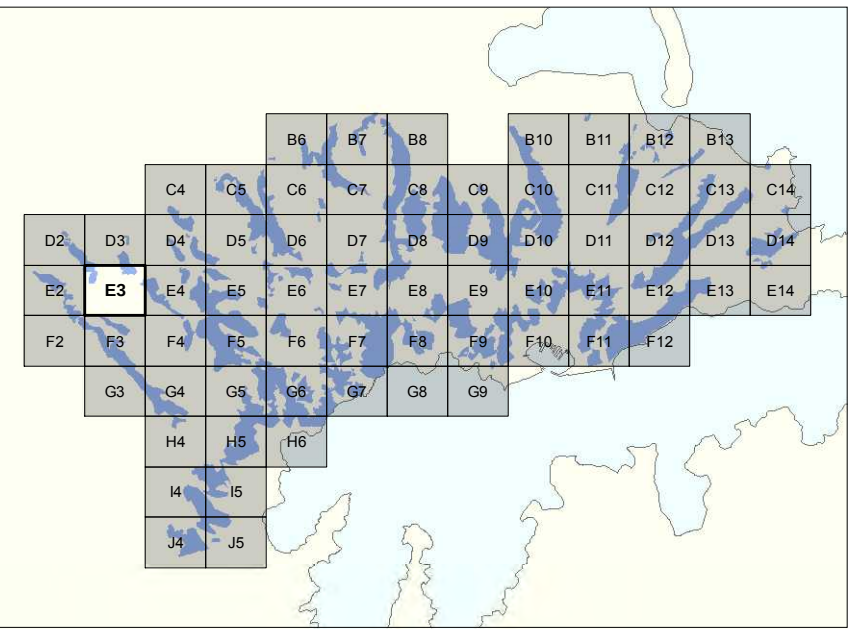
N

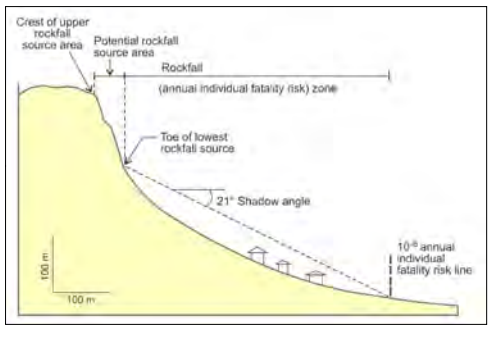
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

GNS SCIENCE TE PŪ AO

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E3

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1569500 1570000

5173500 5173500

5173000 5173000

1569500 1570000

Wesleys Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

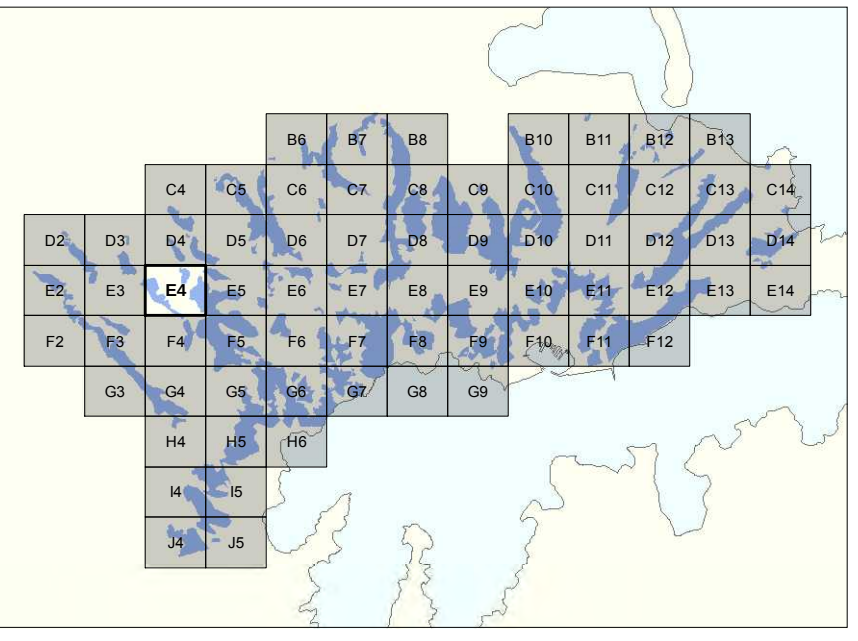
N

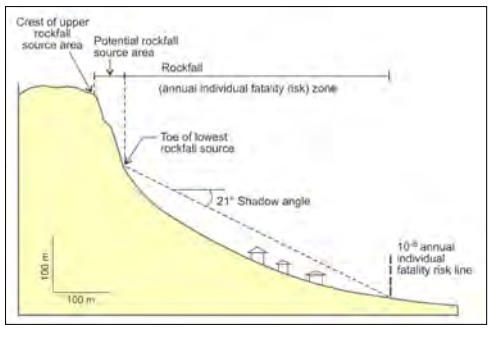
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

GNS SCIENCE TE PŪ AO

ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

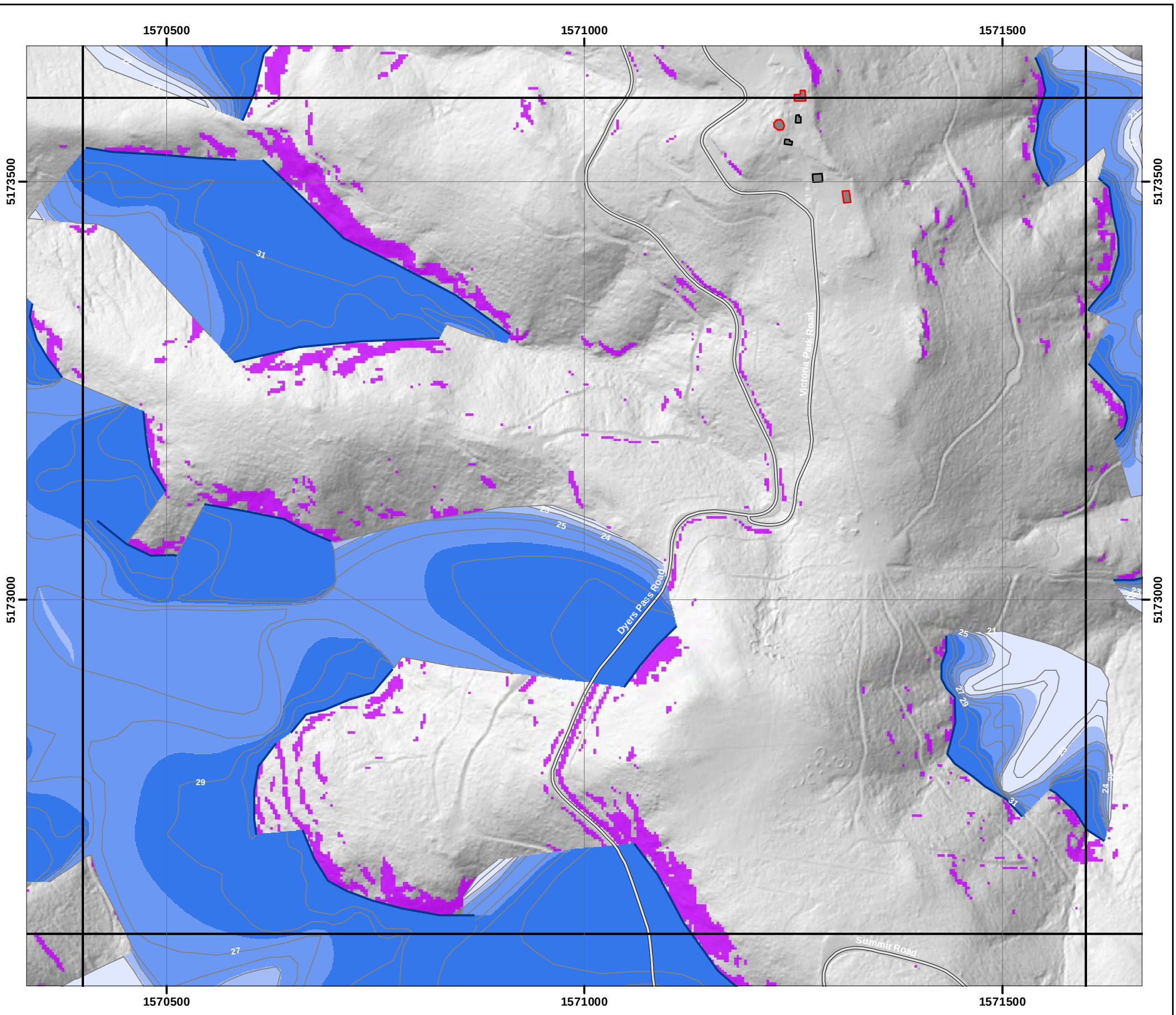
Port Hills Christchurch

APPENDIX C
Map E4

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

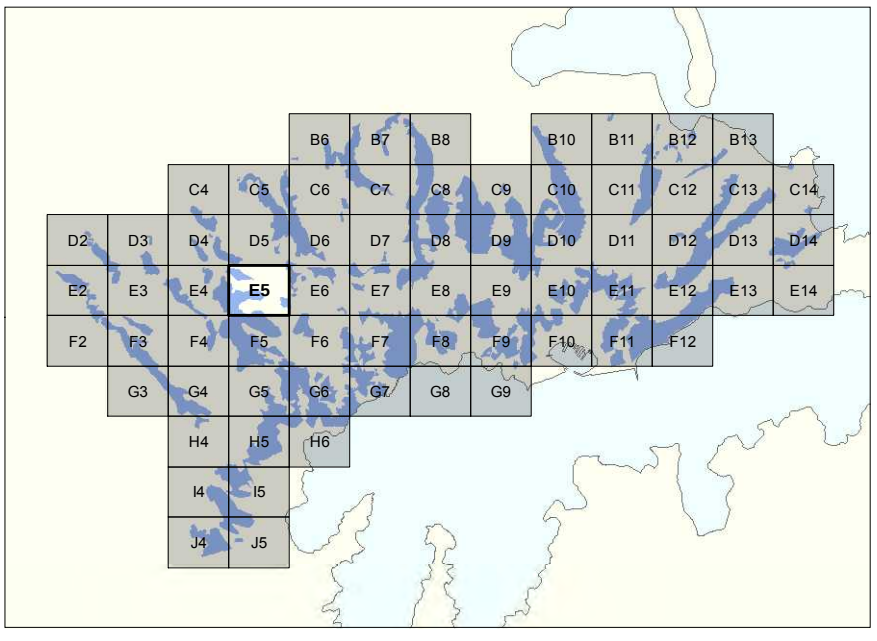


Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

N

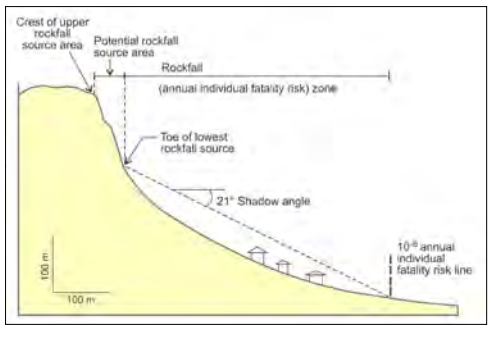


Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1572000 1572500

5173500 5173000

Huntsbury Avenue

Summit Road

1572000 1572500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

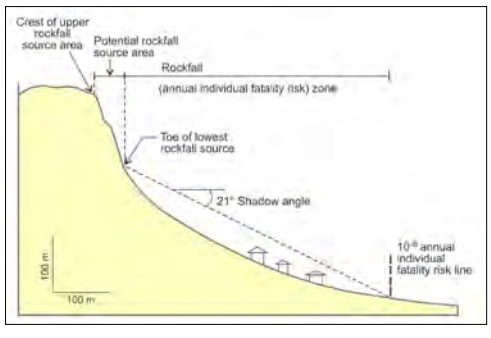
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

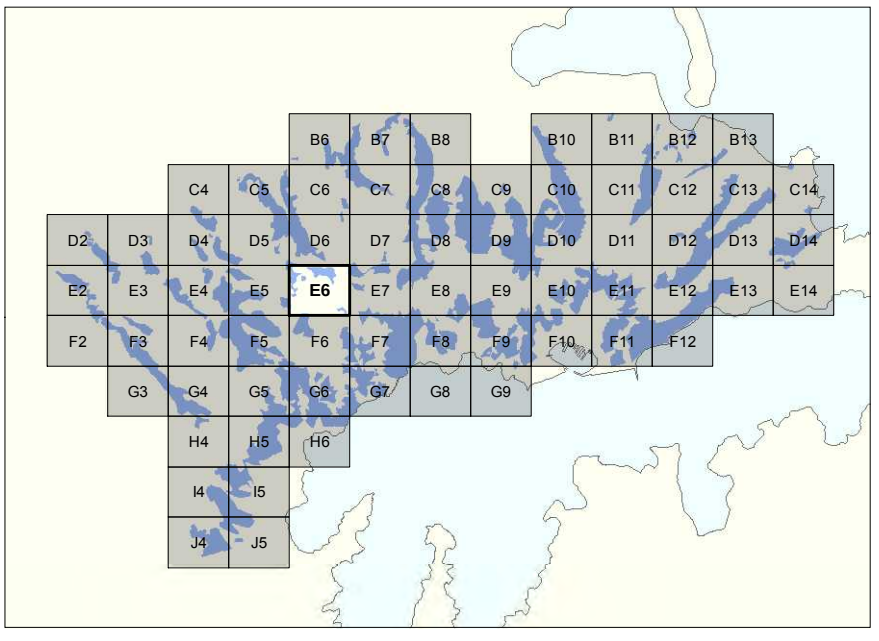
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1573000 1573500 1574000

5173500

5173000

Summit Road

Rapaki Road

Huntsbury Avenue

1573000 1573500 1574000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

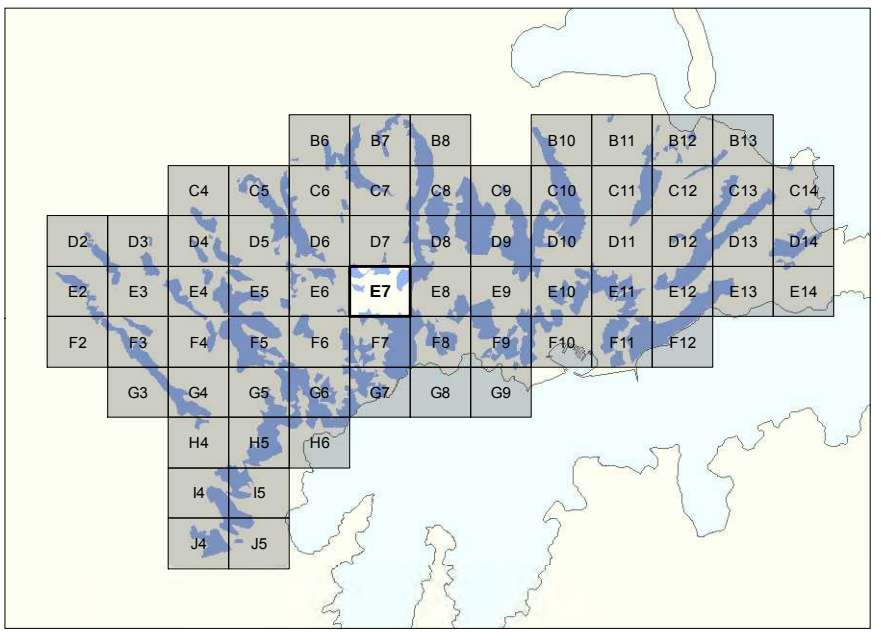
N

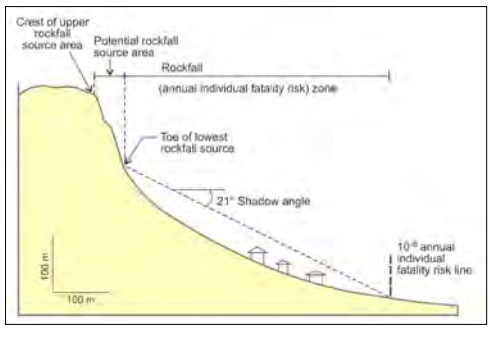
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

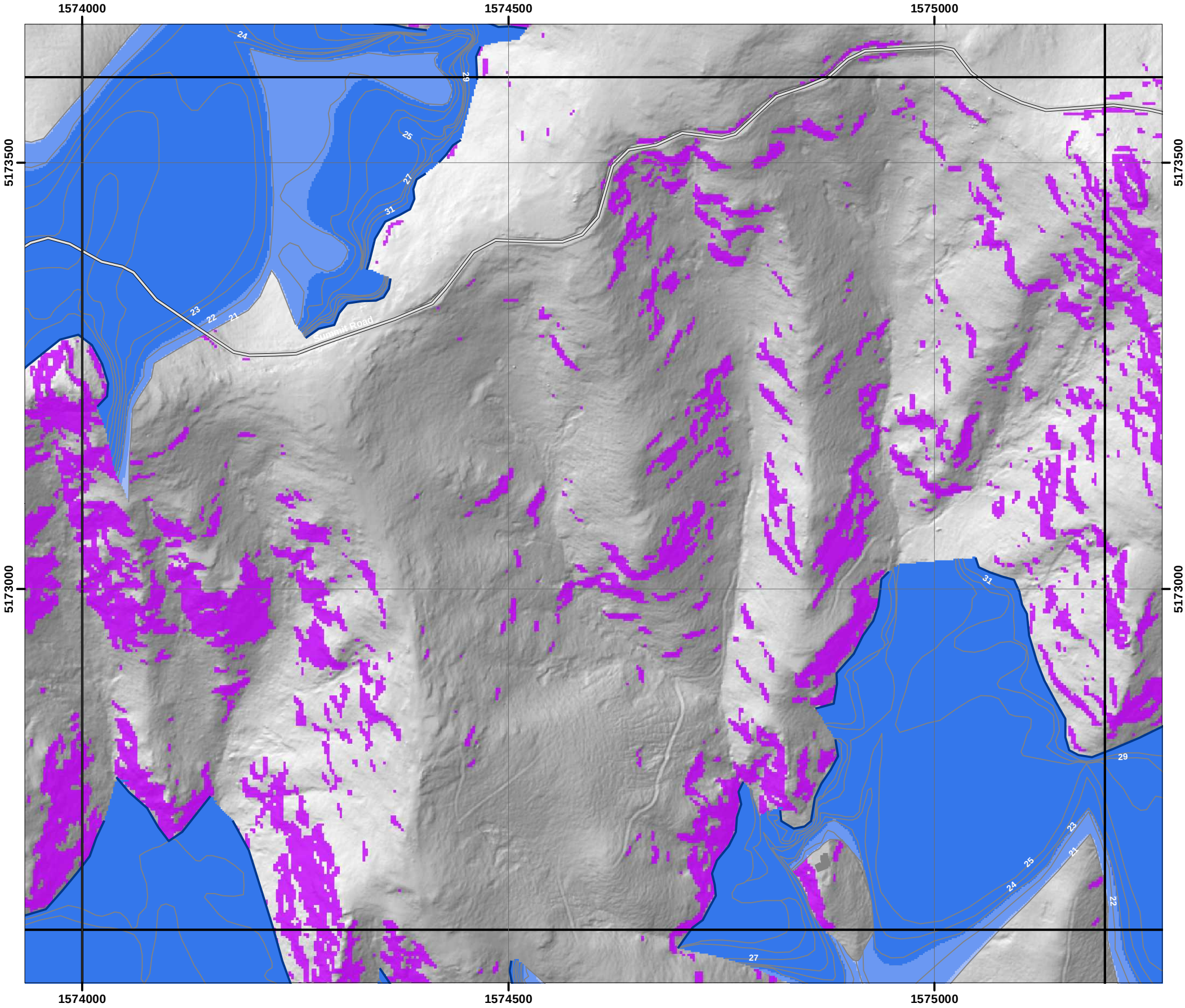
Port Hills Christchurch

APPENDIX C
Map E7

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

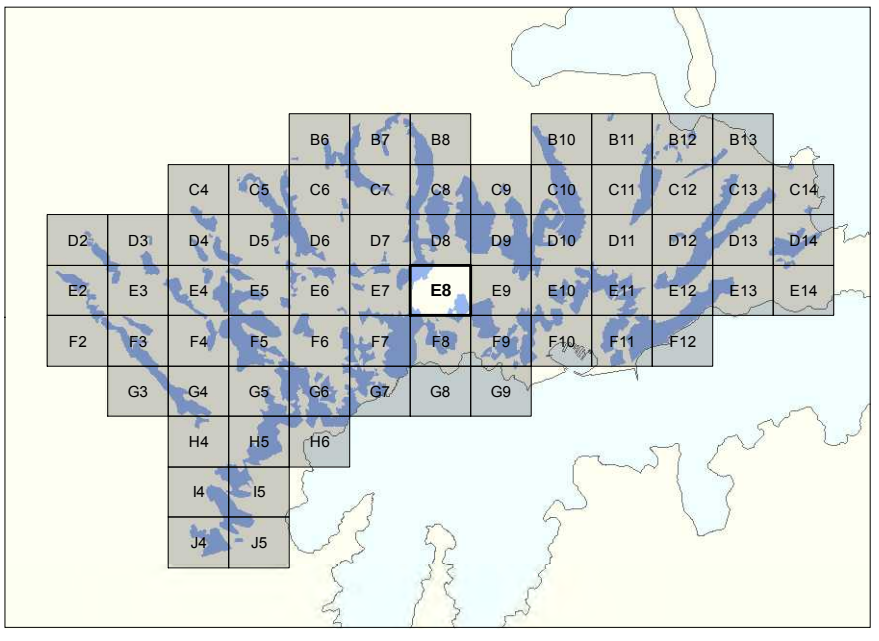
N

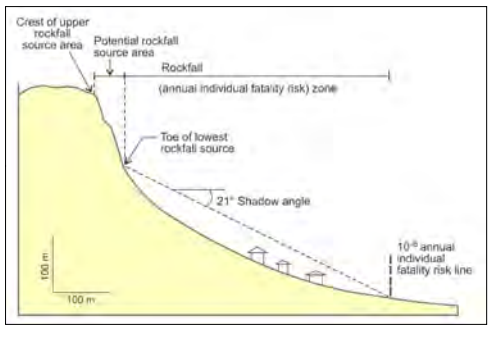
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E8

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1575500 1576000

5173500 5173500

5173000 5173000

1575500 1576000

Bridle Path

Summit Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

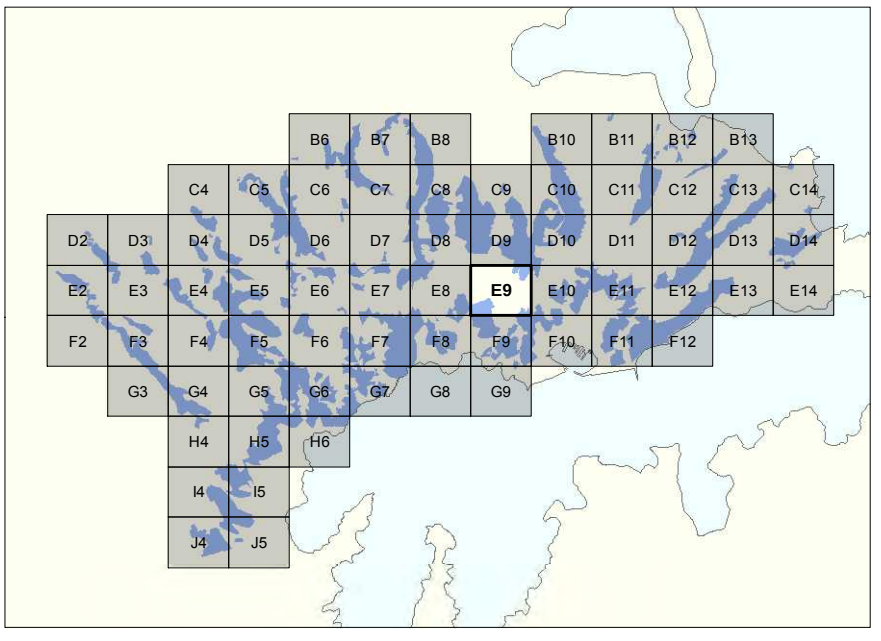
N

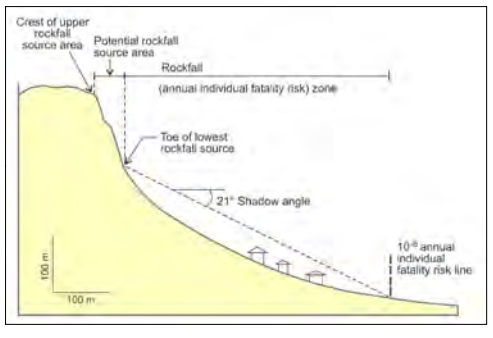
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

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SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

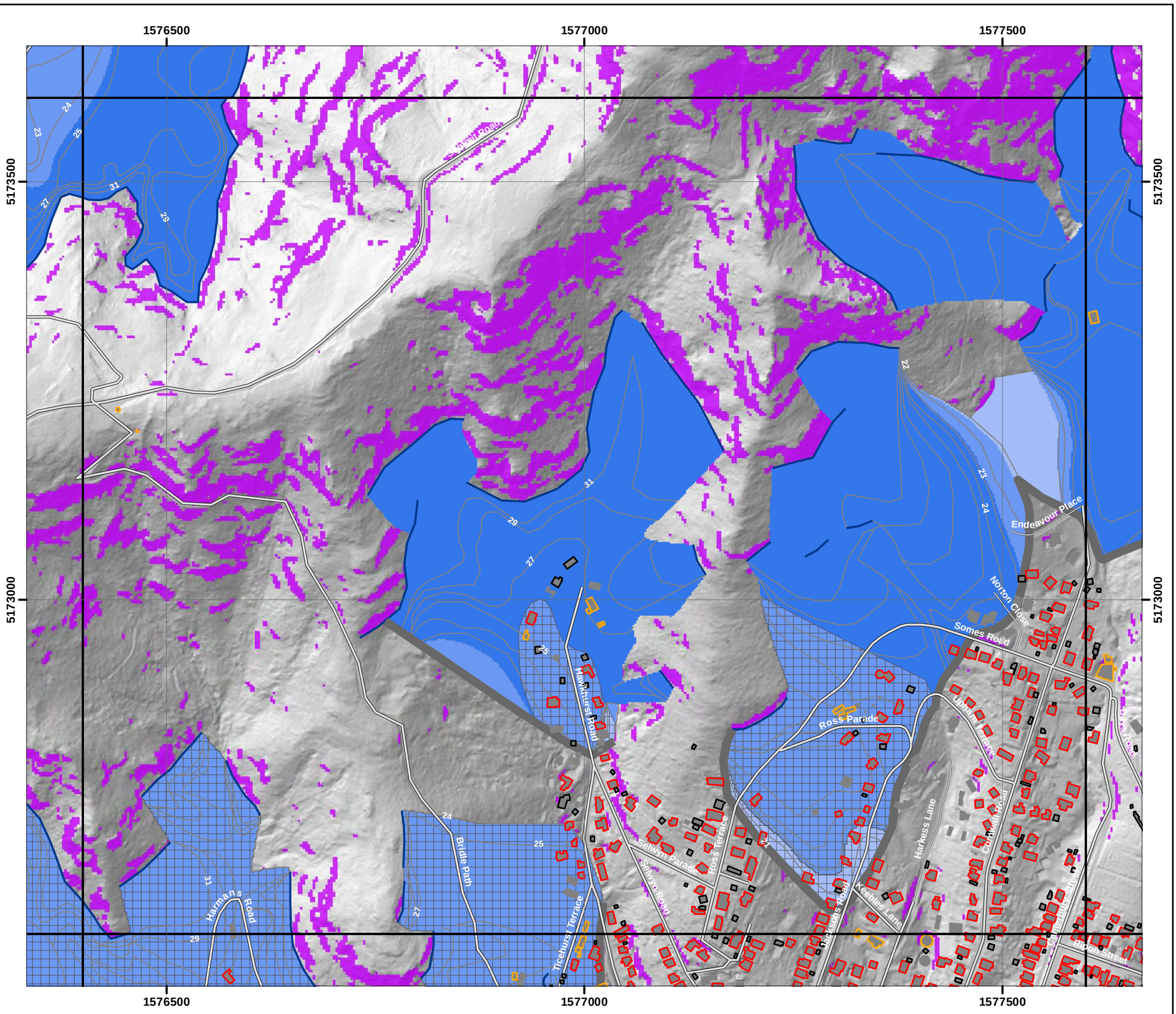
Port Hills Christchurch

APPENDIX C
Map E9

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

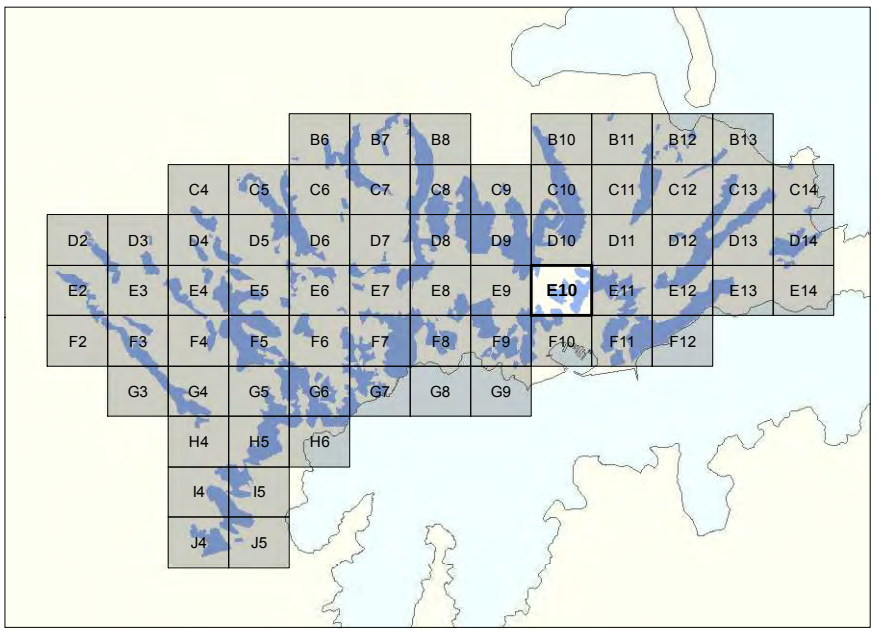
N

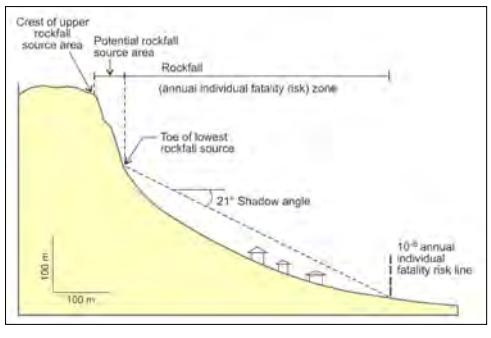
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

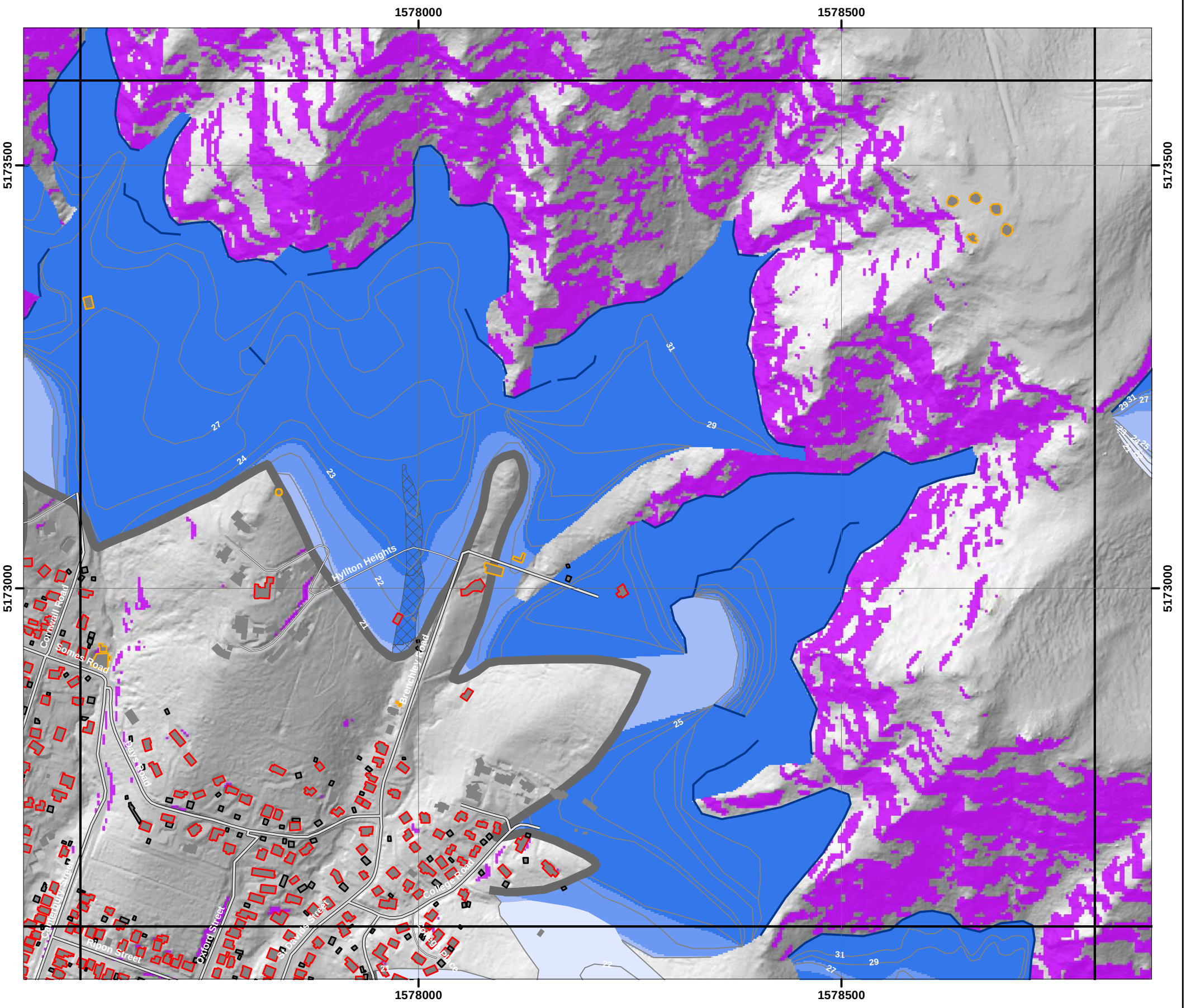
Port Hills Christchurch

APPENDIX C
Map E10

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

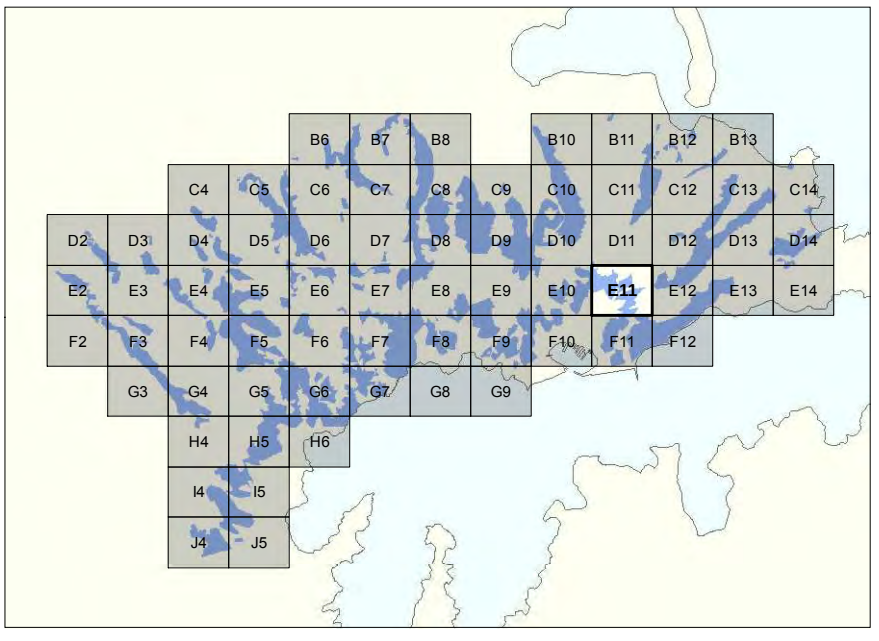
- Areas where the risk decreased
- Areas where the risk increased

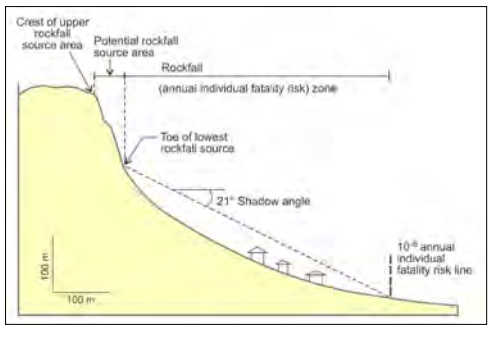
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

N





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

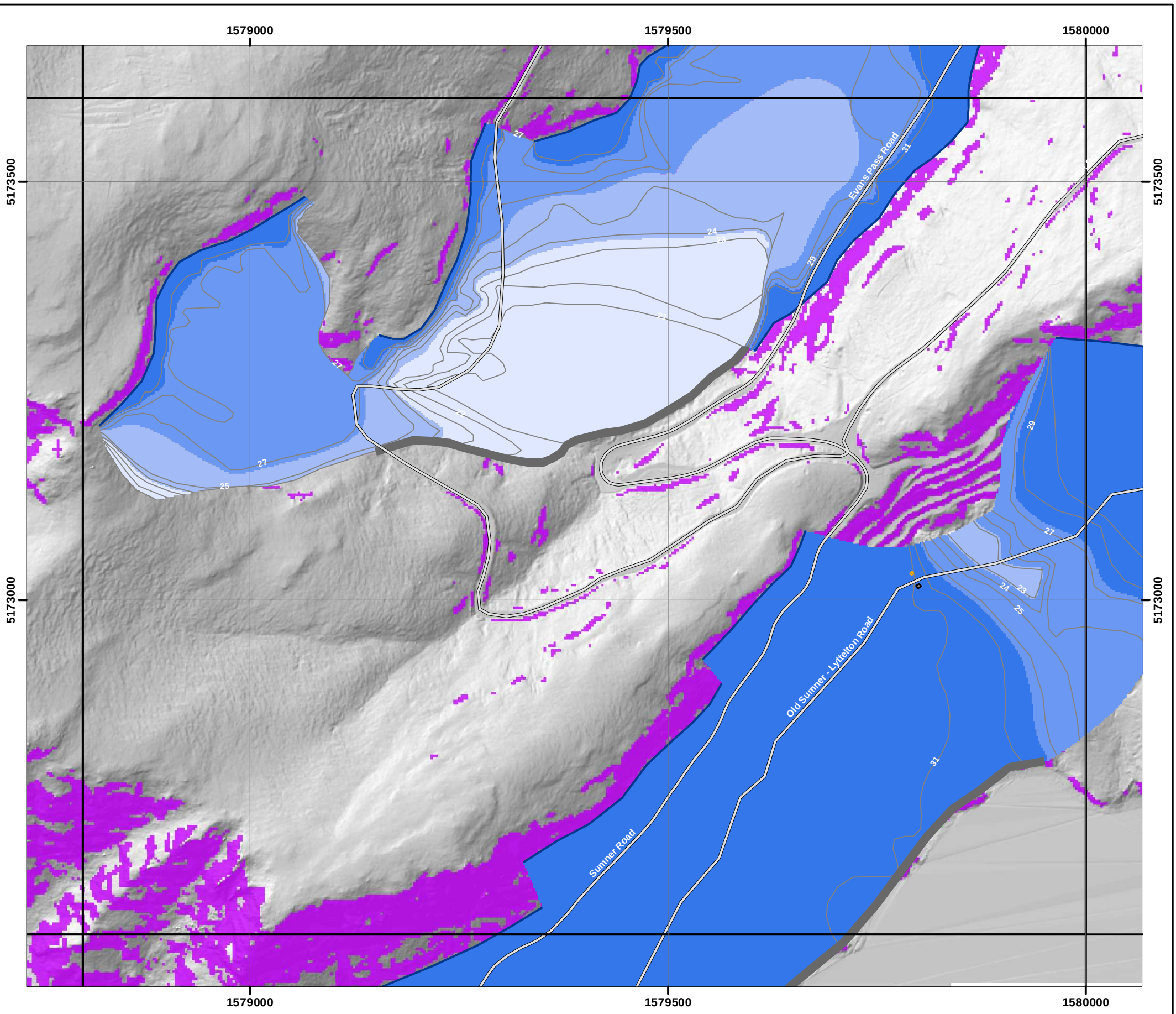
Port Hills Christchurch

APPENDIX C
Map E11

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

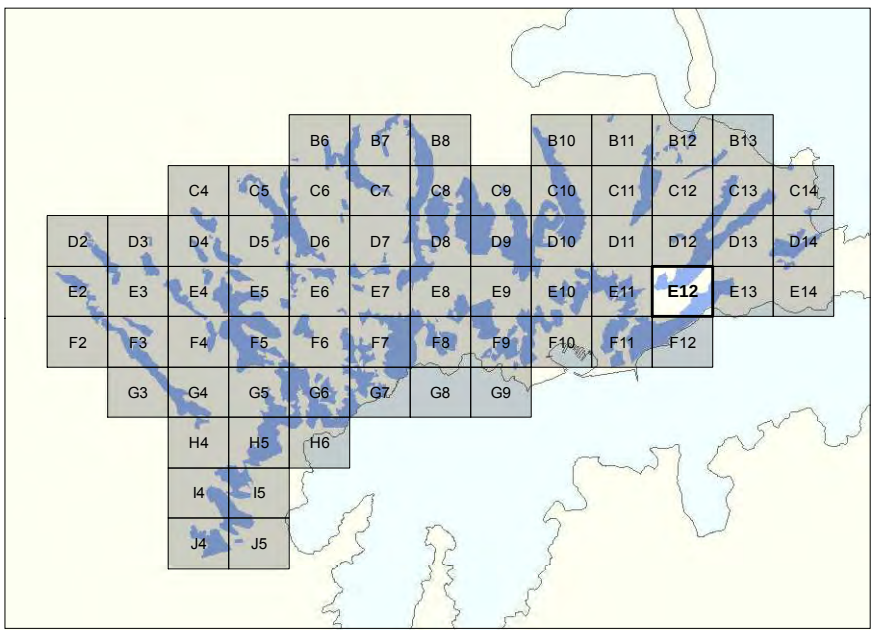
N

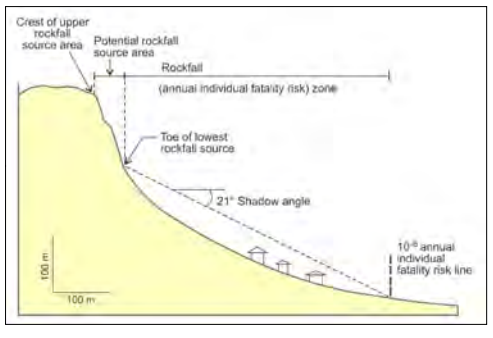
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

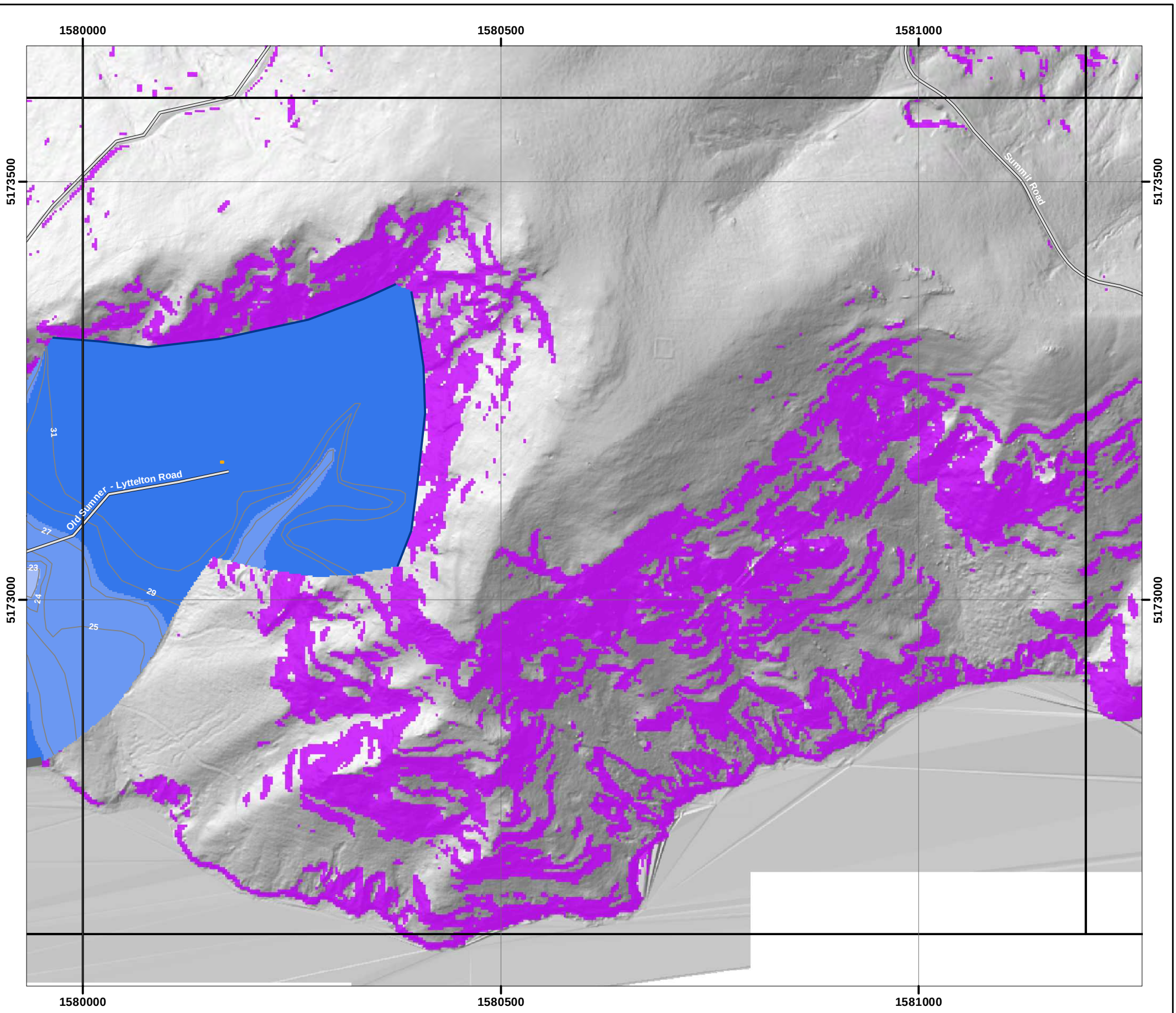
Port Hills Christchurch

APPENDIX C
Map E12

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

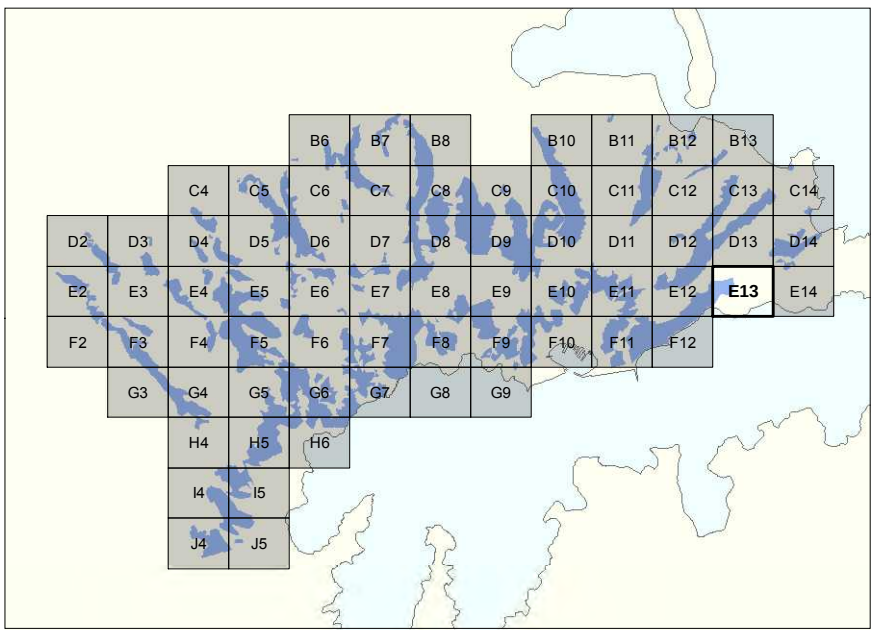
N

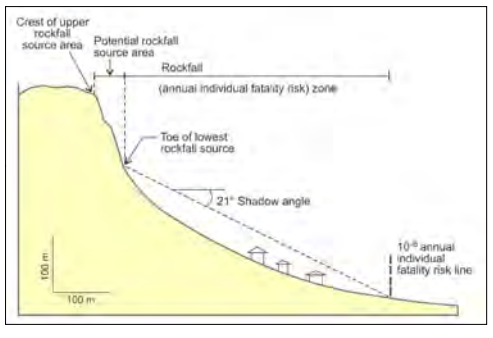
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

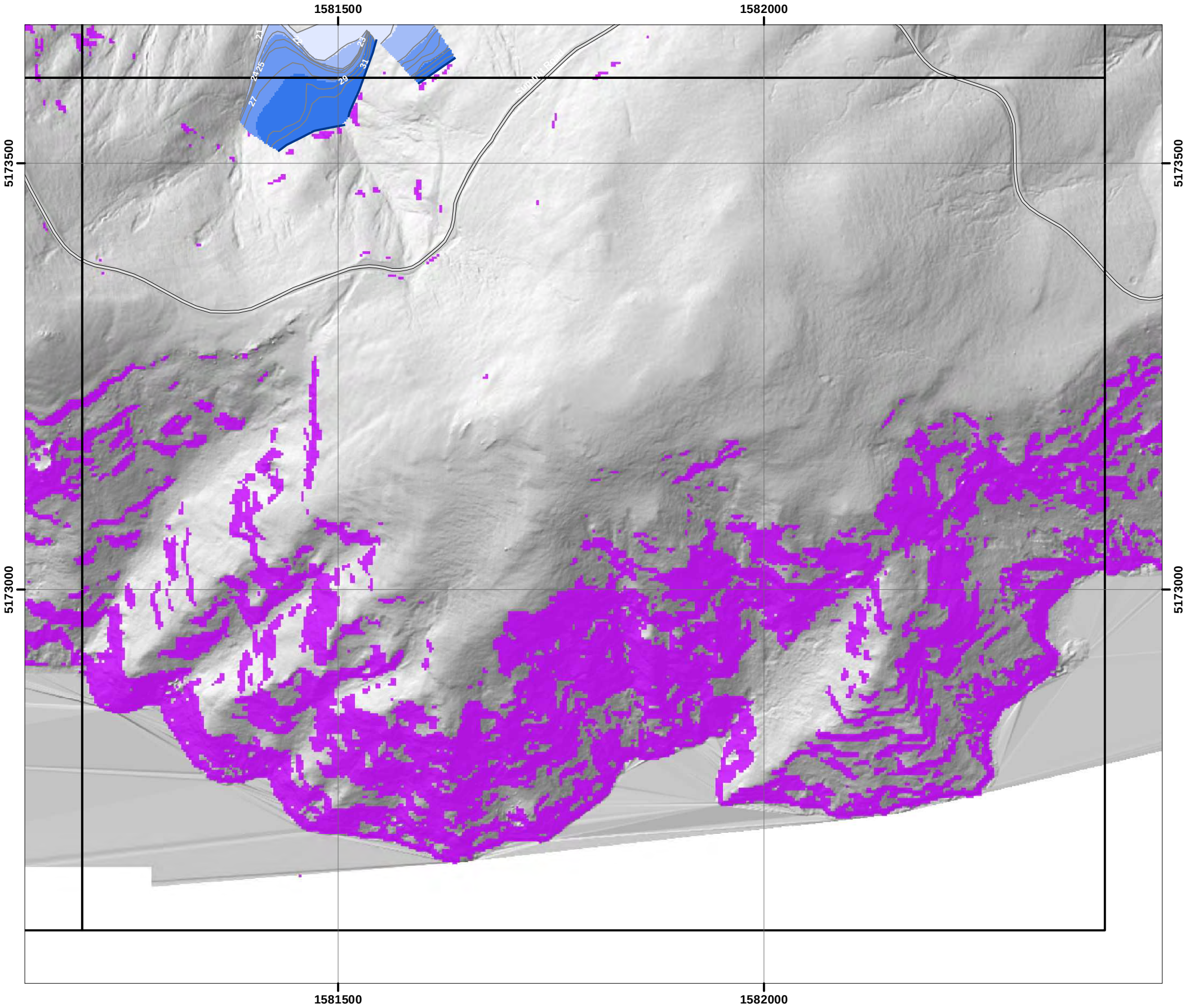
Port Hills Christchurch

APPENDIX C
Map E13

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

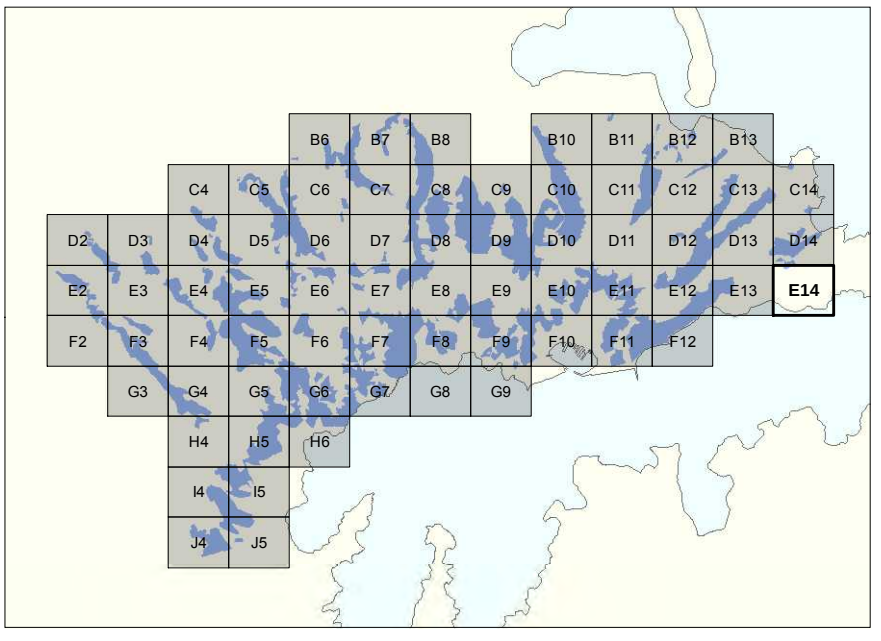
N

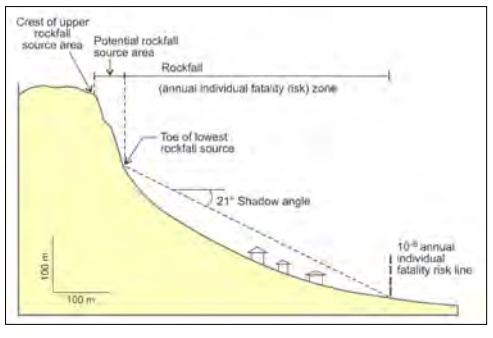
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map E14

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1567000 1567500 1568000

5172500

5172000

Rock Hill Drive
Sunny Hill Terrace
The Ridge
Kennedys Bush Road

21 25 24 27 31 29

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

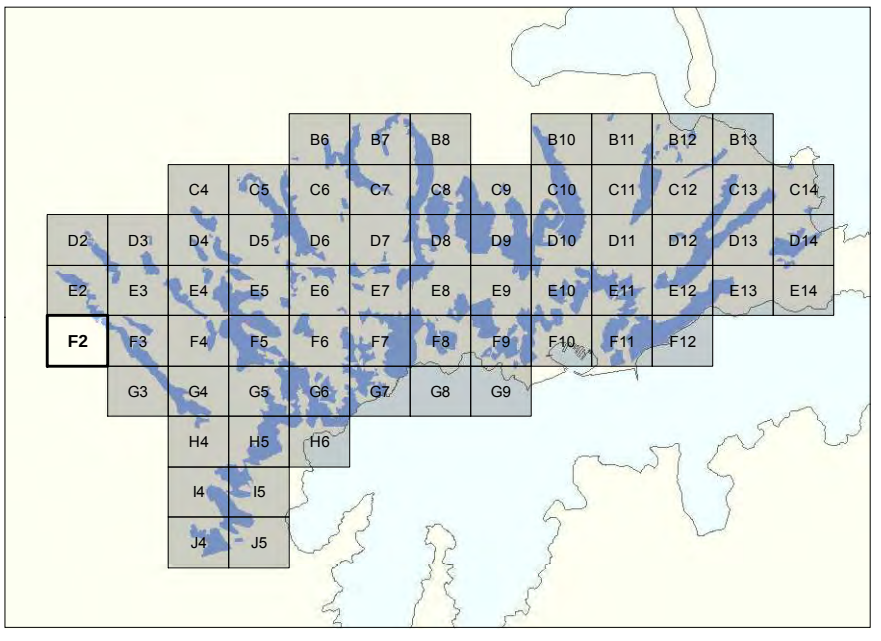
N

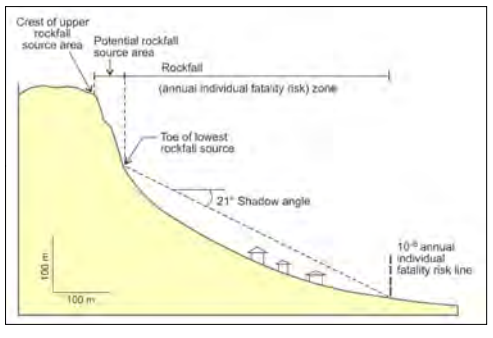
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

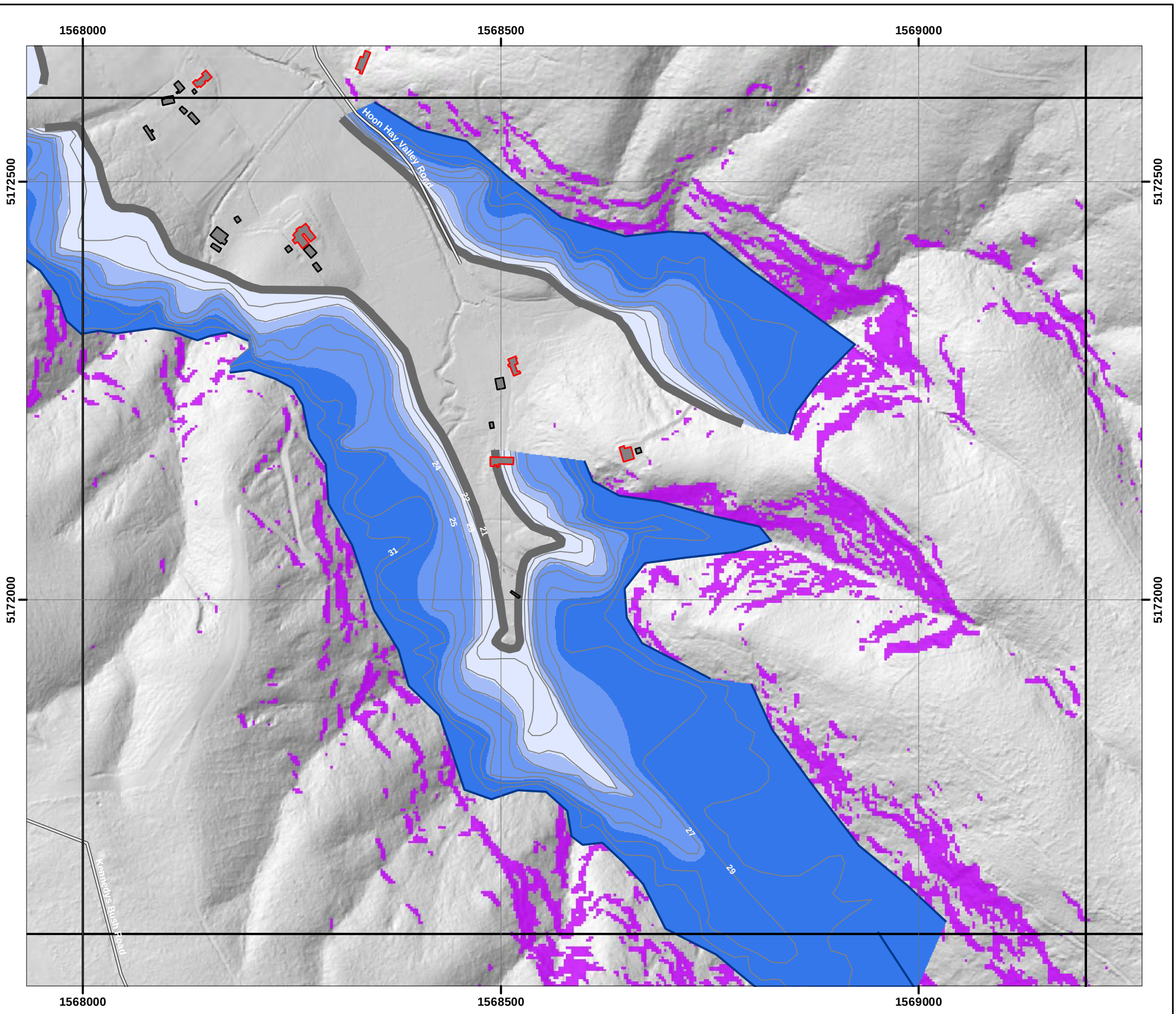
Port Hills Christchurch

APPENDIX C
Map F2

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

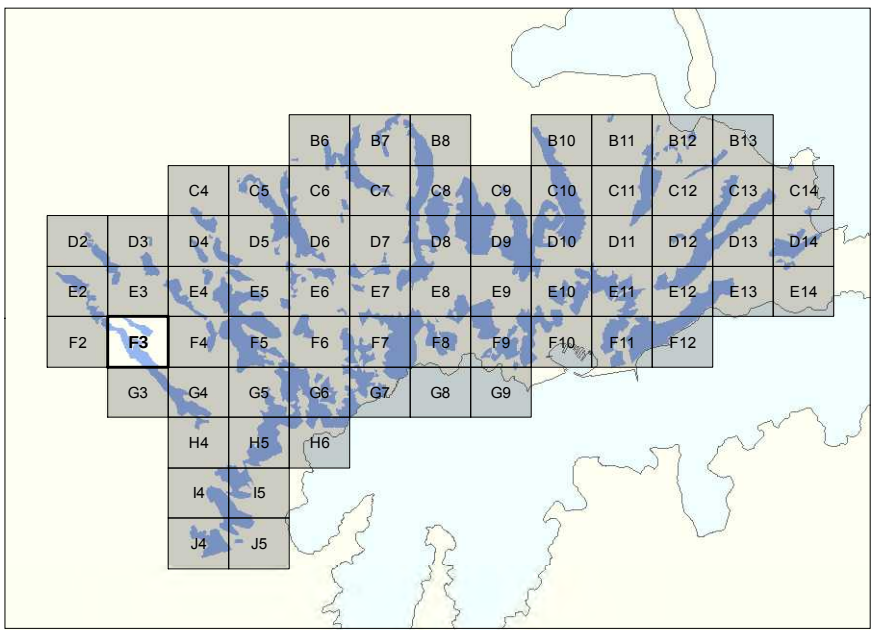
N

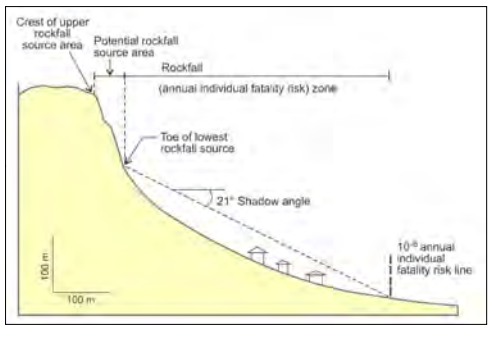
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

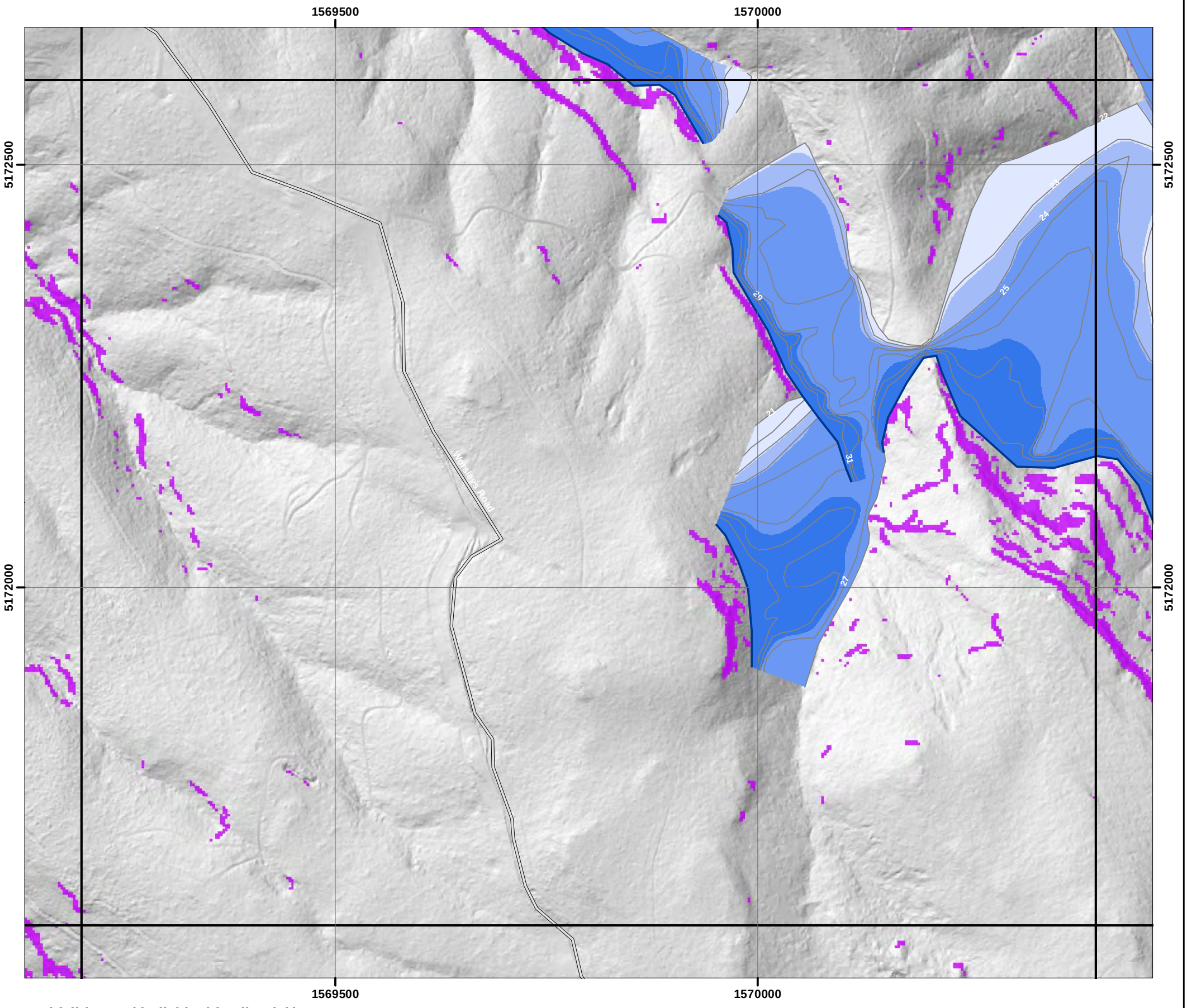
Port Hills Christchurch

APPENDIX C
Map F3

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

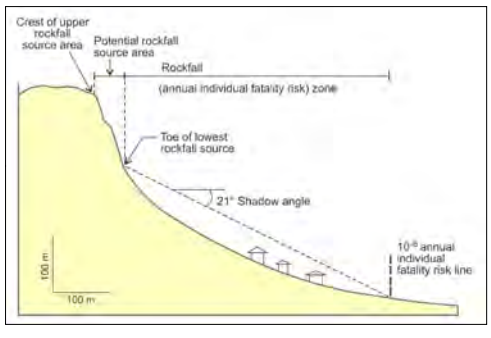
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

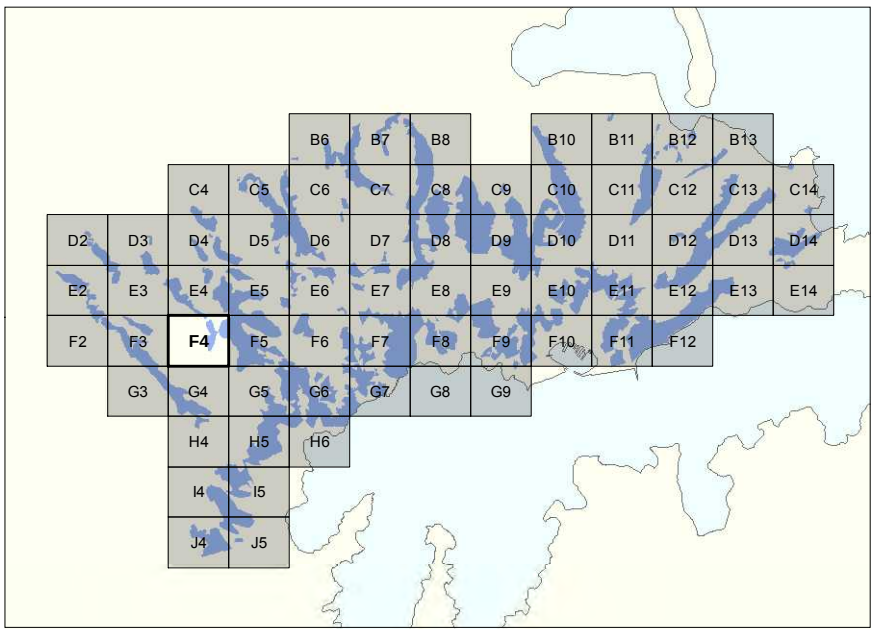
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map F4

FINAL ISSUE 2

REPORT: CR2012/123

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1570500 1571000 1571500

5172500

5172000

Dyers Pass Road

Summit Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

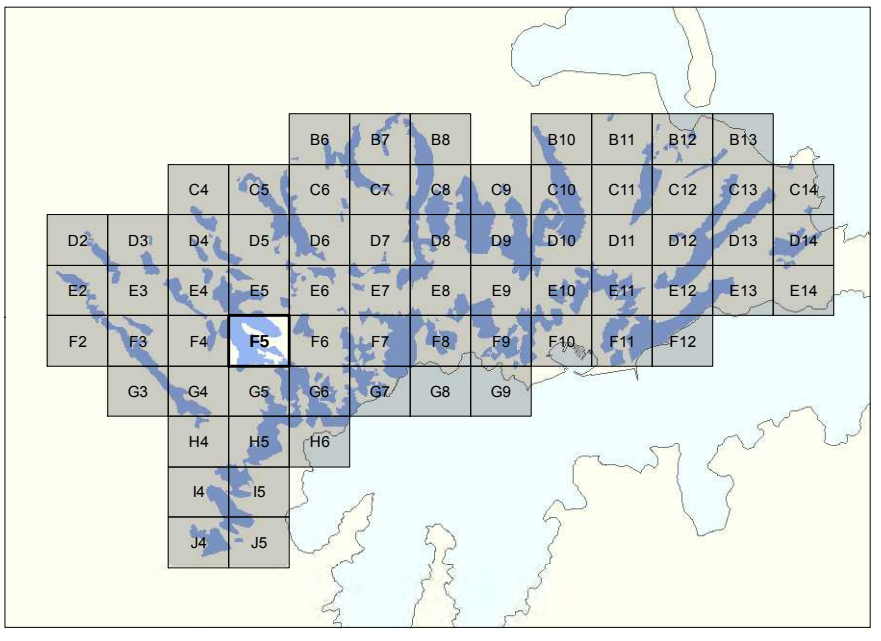
N

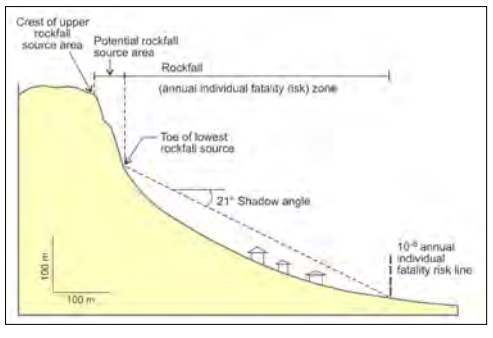
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

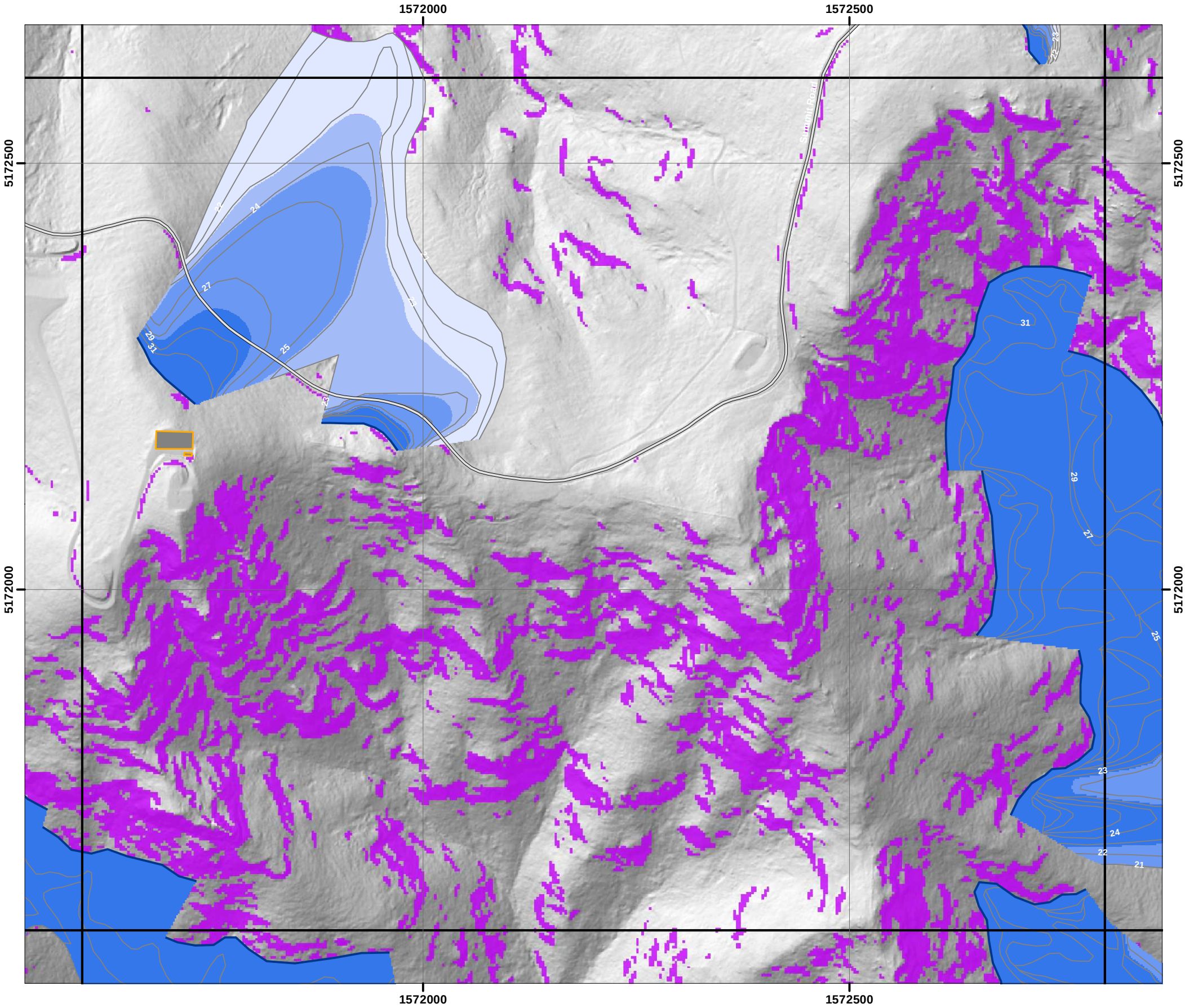
Port Hills Christchurch

APPENDIX C
Map F5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

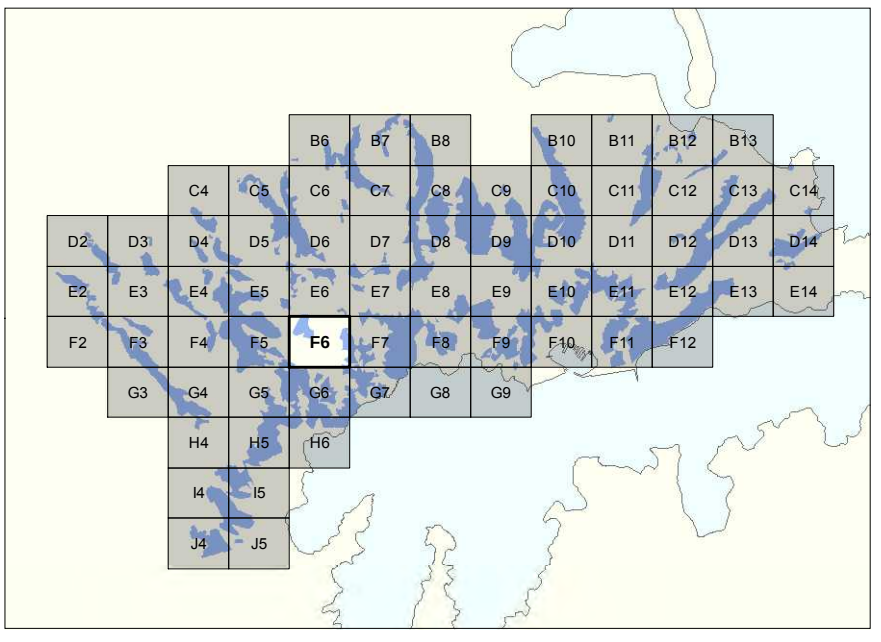
N

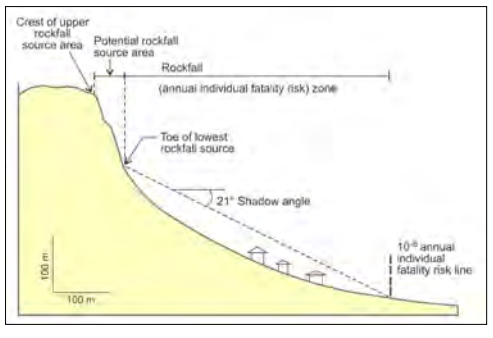
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

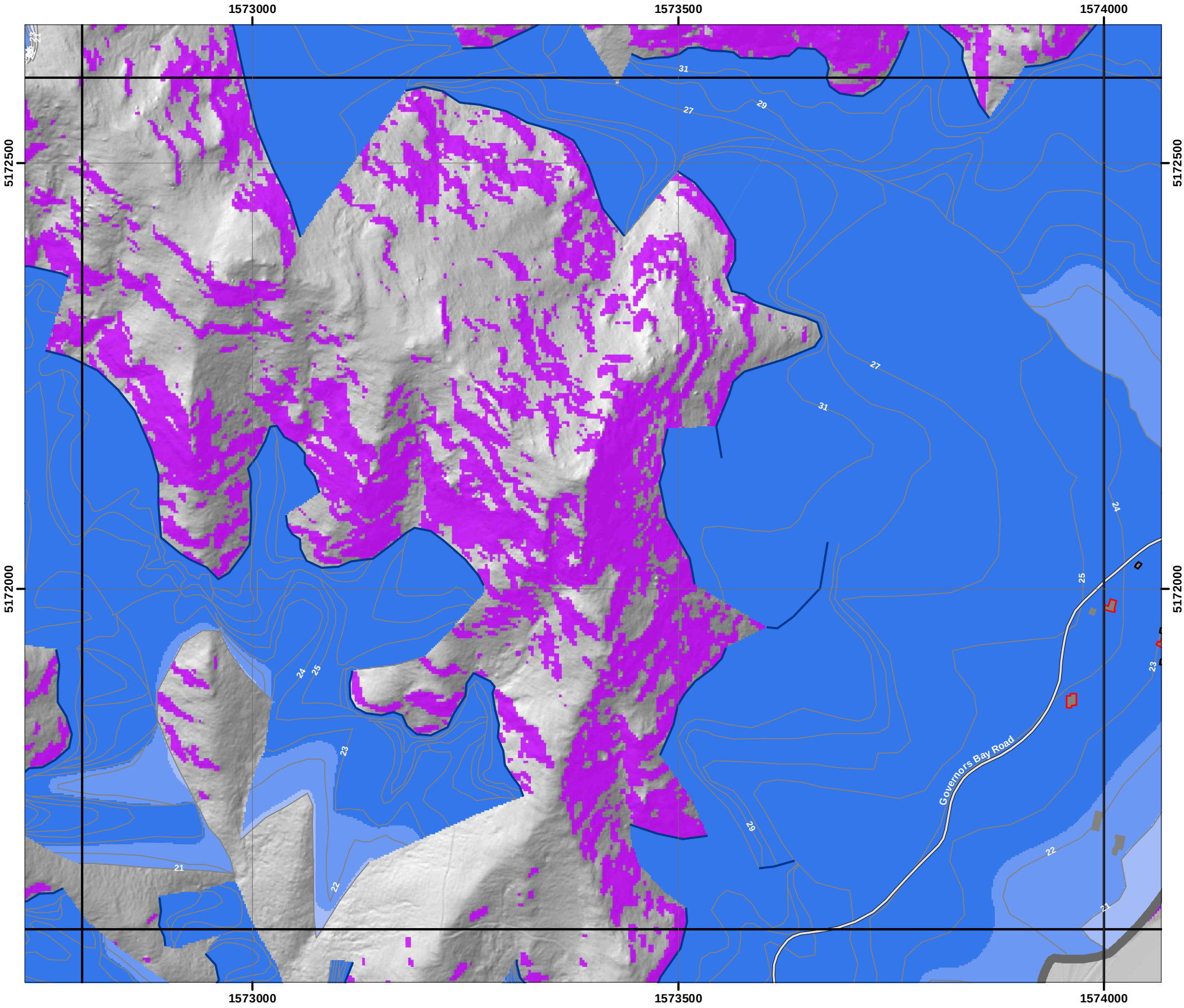
Port Hills Christchurch

APPENDIX C
Map F6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

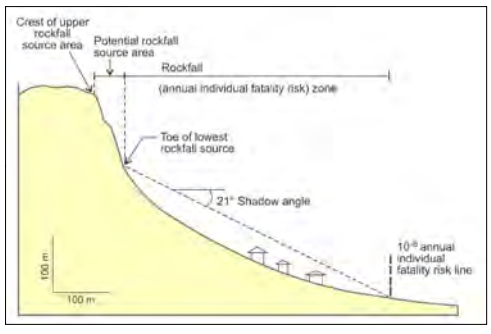
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

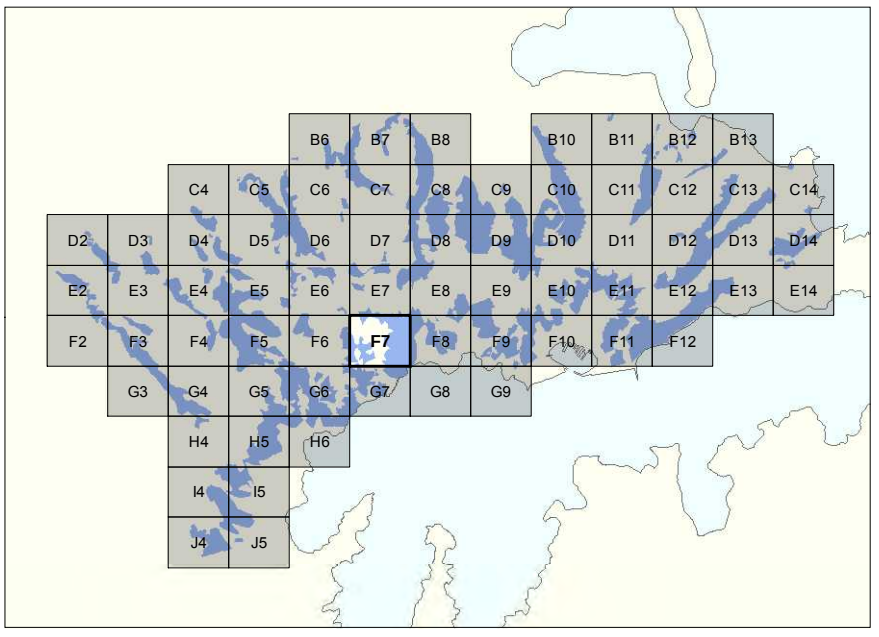
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

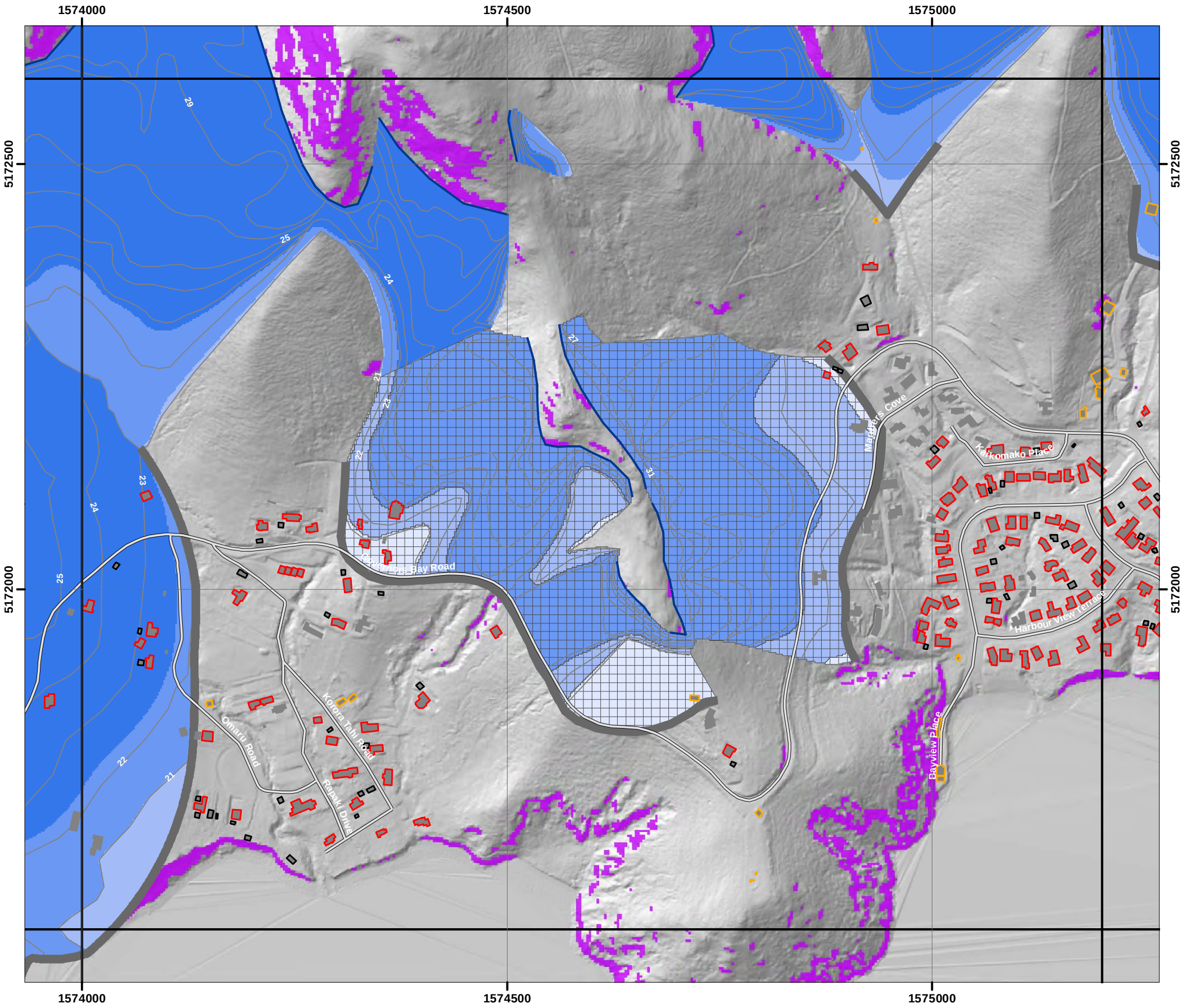
Port Hills Christchurch

APPENDIX C
Map F7

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

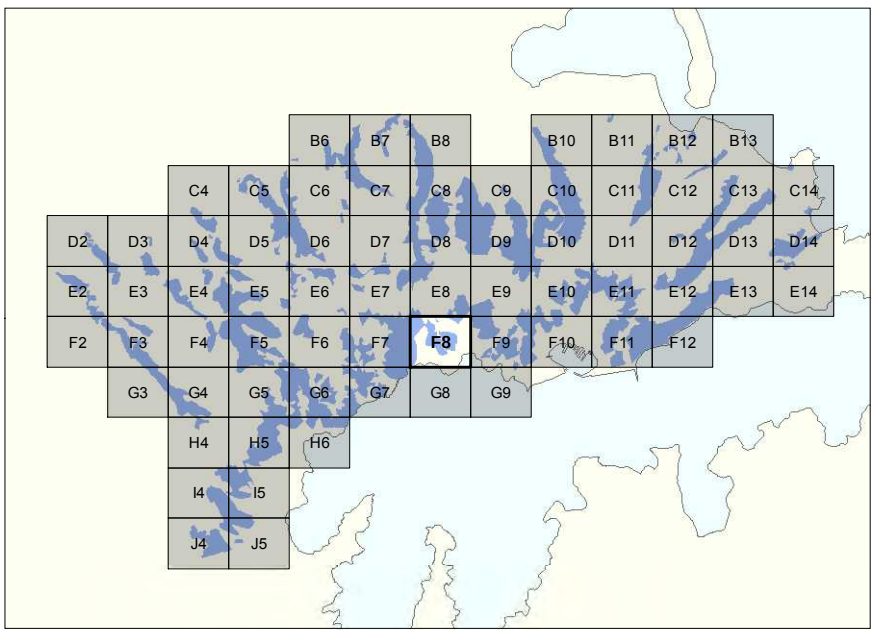
N

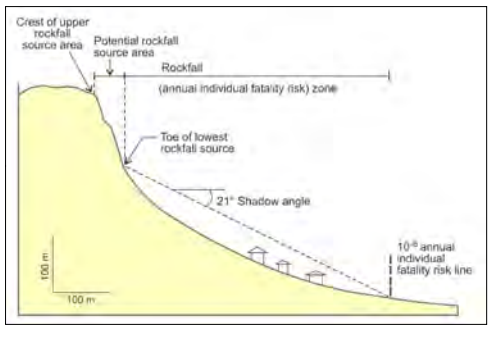
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

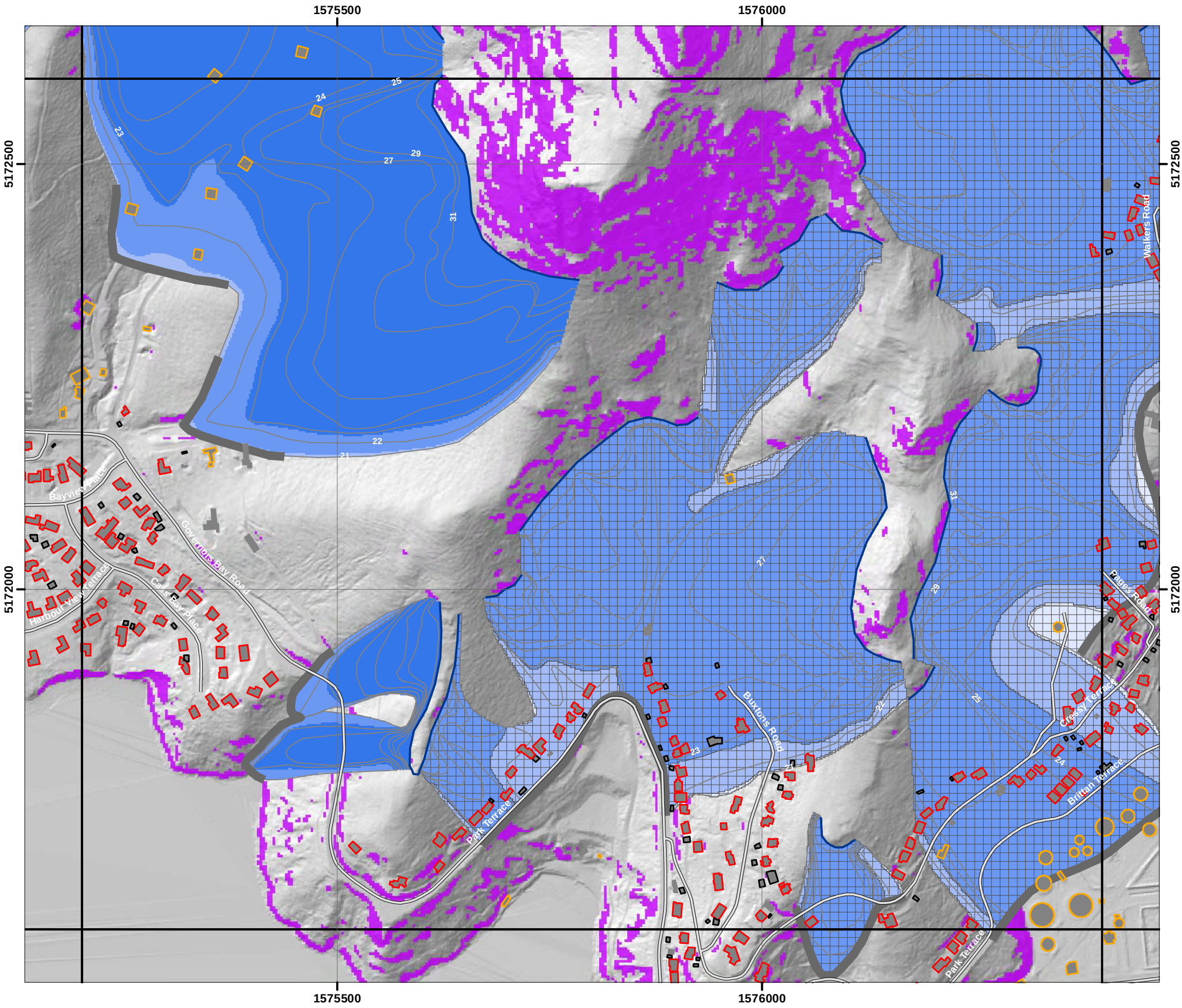
Port Hills Christchurch

APPENDIX C
Map F8

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

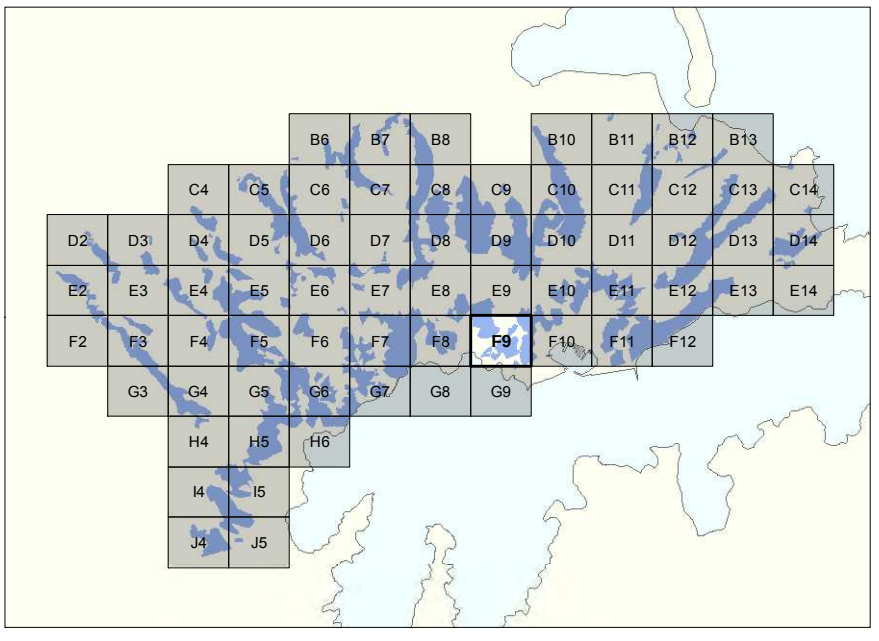
- Areas where the risk decreased
- Areas where the risk increased

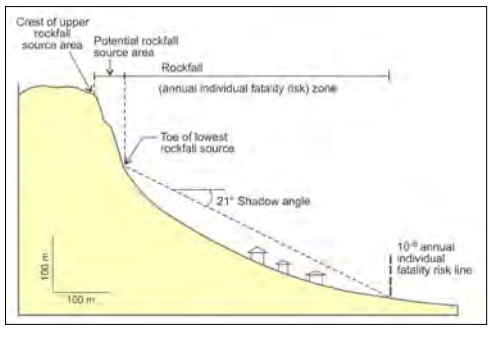
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map F9

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1576500 1577000 1577500

5172500 5172000

Harmans Road · Voelas Road · Walkers Road · Webb Lane · Dudley Road · Cunningham Terrace · Simeon Quay · Godley Quay · Britten Terrace · Pages Road · Seaview Terrace · Cressy Terrace · Bridle Path · Tichehurst Terrace · Tichehurst Road · Selwyn Road · Jackson Road · Tenners Lane · Coleridge Terrace · Hawkhurst Road · Dublin Street · Exeter Street · Colombo Street · Canterbury Street · Winchester Street · Rhodes Street · London Street · Sutton Quay · Norwich Quay · Oxford Street · Bonnington Street · Cyrus Williams Quay · George Seymour Quay · Charlotte Jane Quay · Marina Access

21 22 23 24 25 27 29 31

1576500 1577000 1577500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

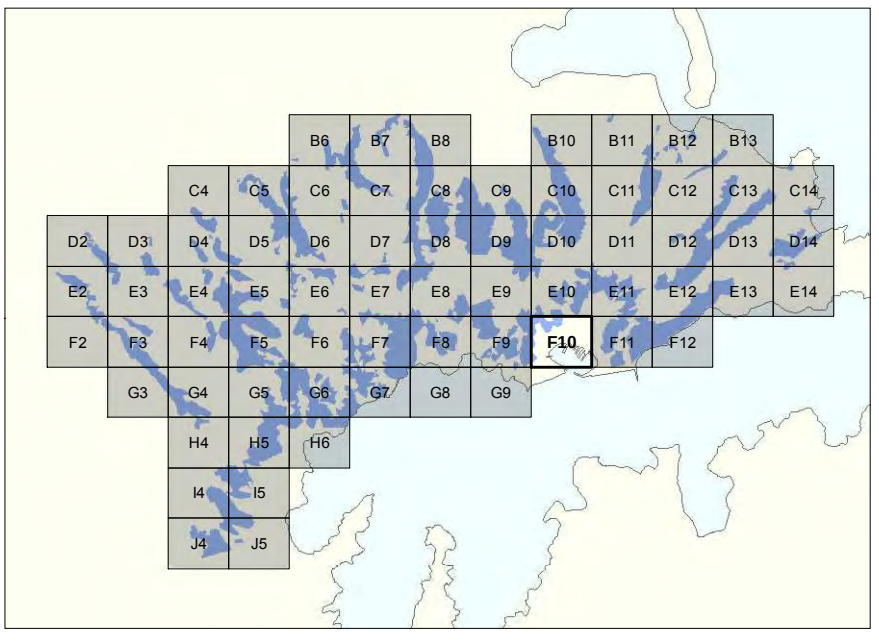
N

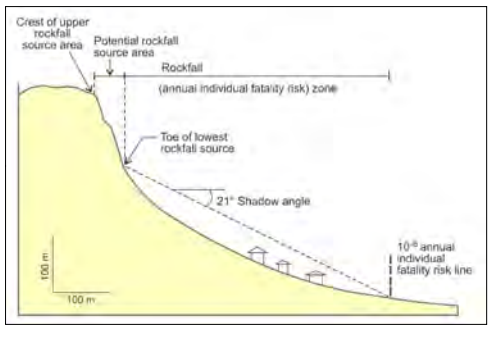
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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"), which is one chance in 10,000 of being killed in any one year.

10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

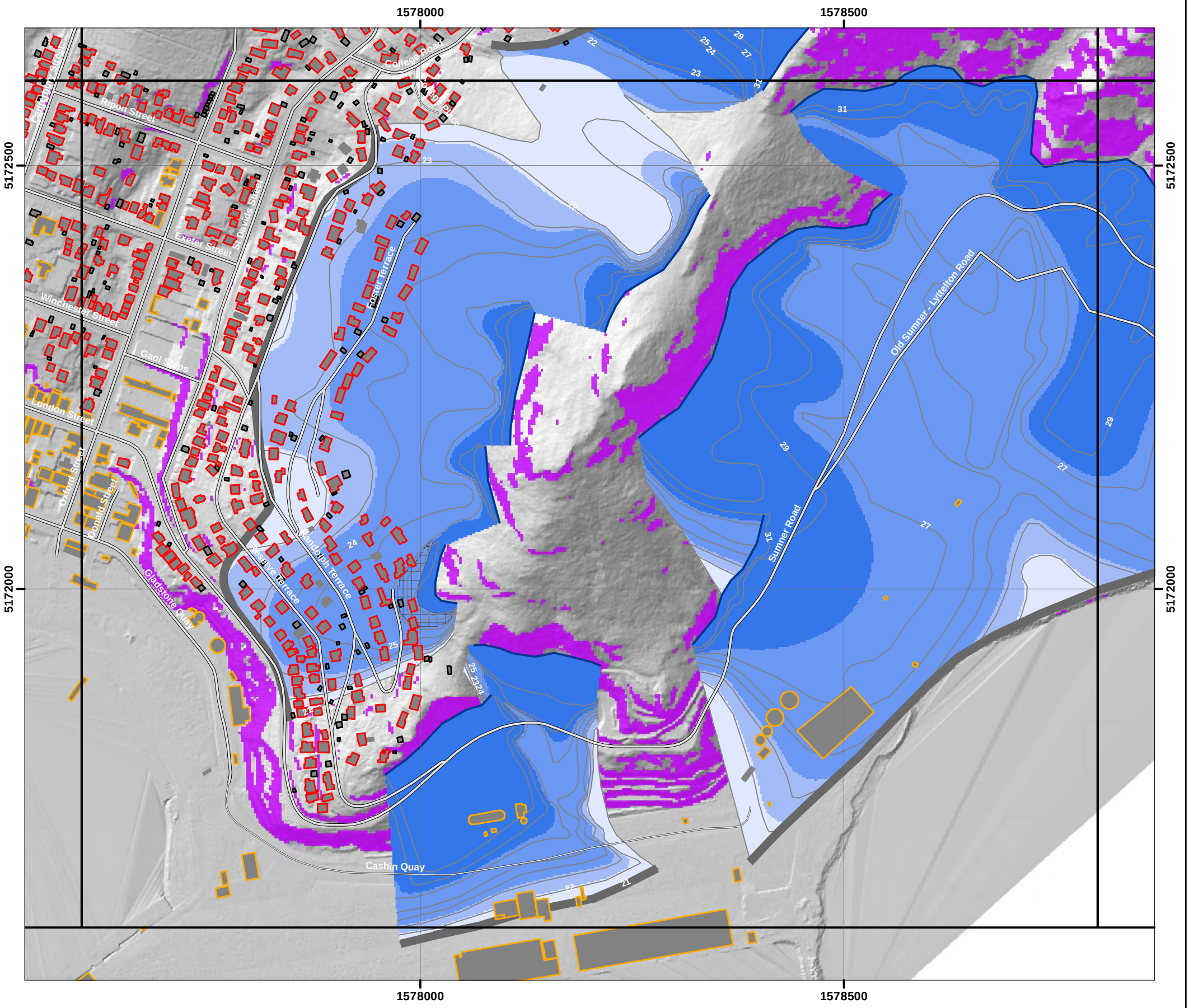
Port Hills Christchurch

APPENDIX C
Map F10

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

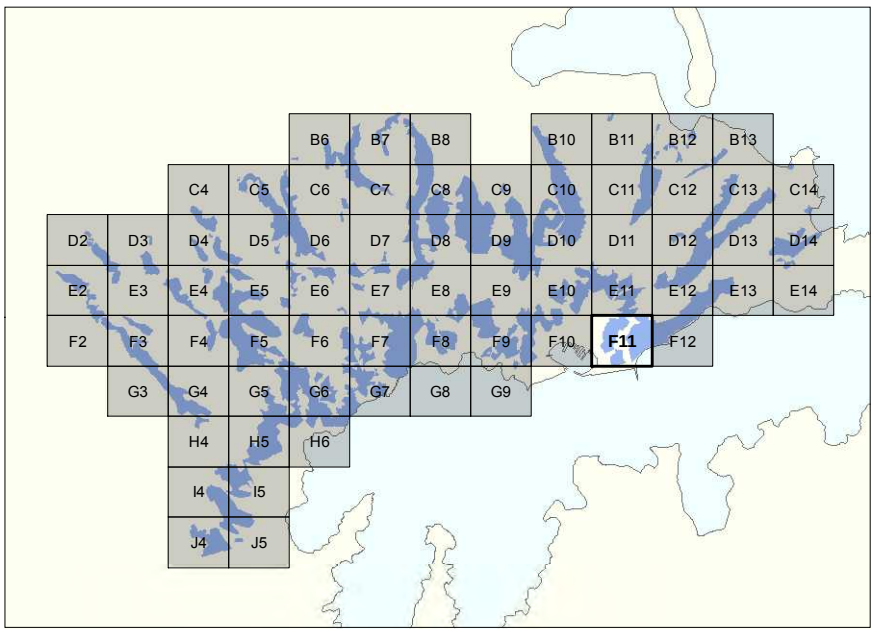
N

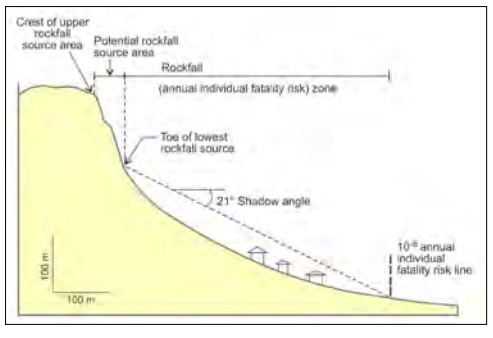
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map F11

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1579000 1579500 1580000

5172500

5172000

Sumner Road

Old Sumner - Lyttelton Road

29 31 24 25 27 22 23

1579000 1579500 1580000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

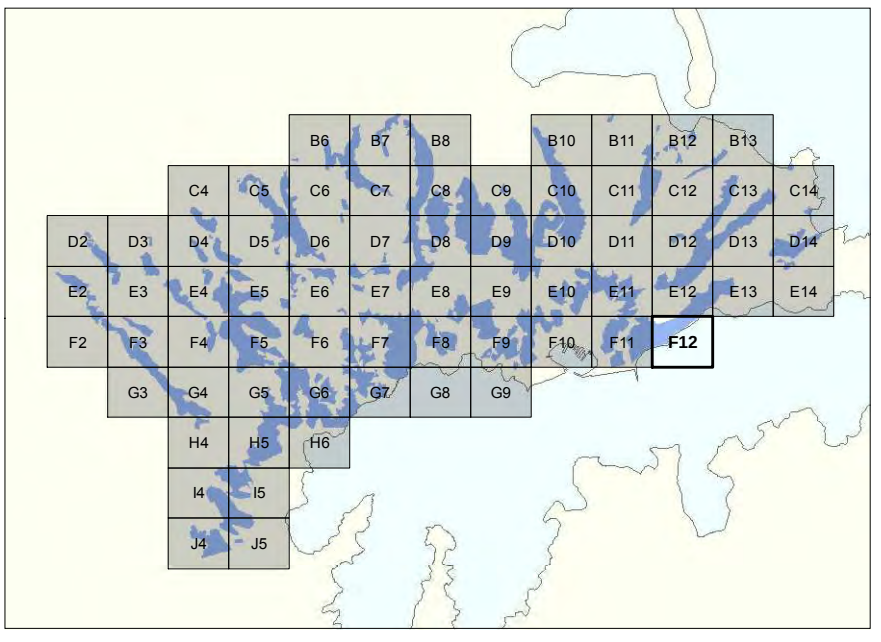
N

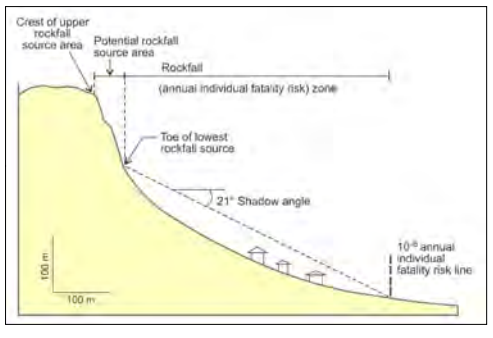
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

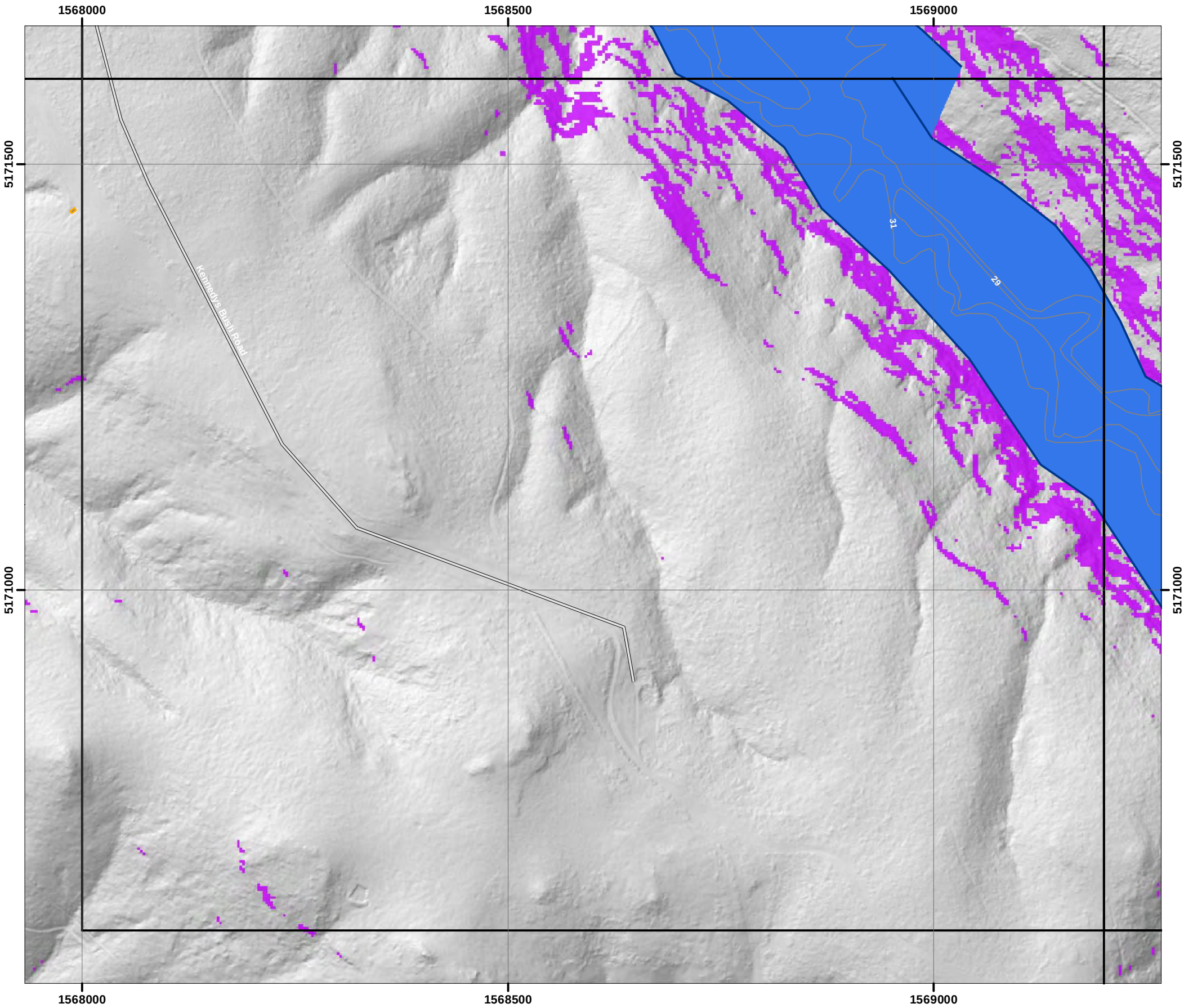
Port Hills Christchurch

APPENDIX C
Map F12

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

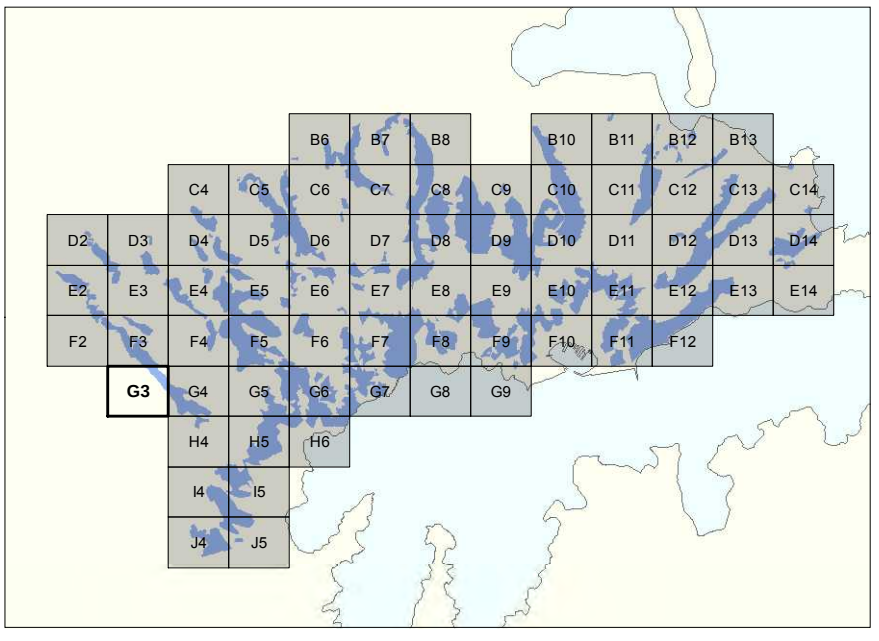
- Areas where the risk decreased
- Areas where the risk increased

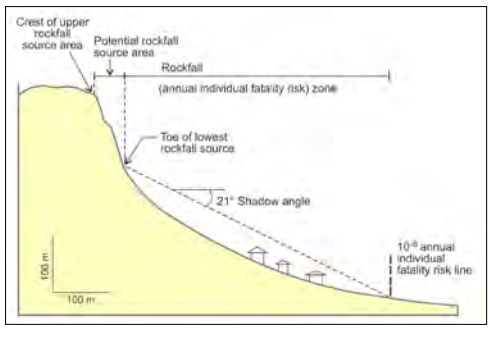
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

N





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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map G3

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1569500 1570000

5171500 5171500

5171000 5171000

1569500 1570000

Worsleys Road

Summit Road

31 29 27 25 24

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

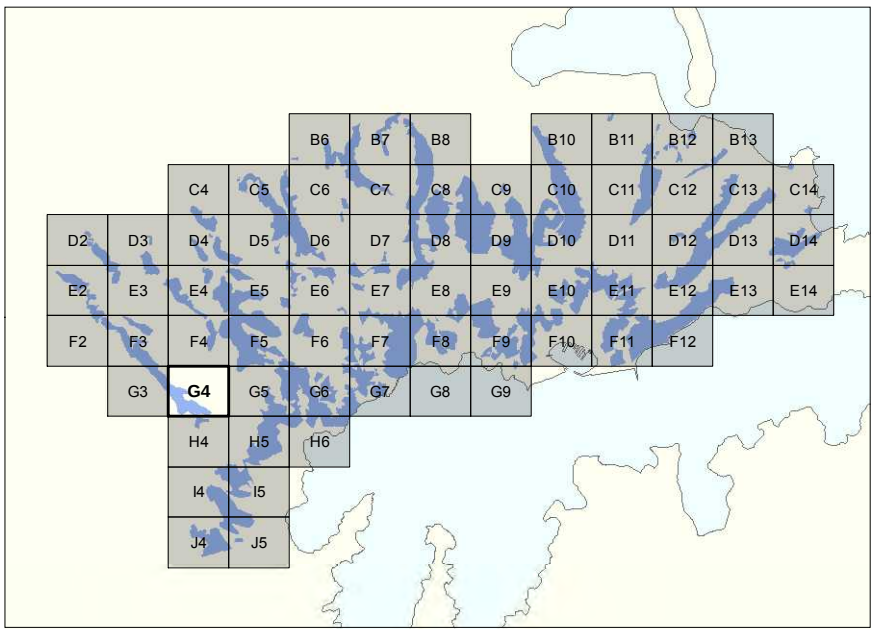
N

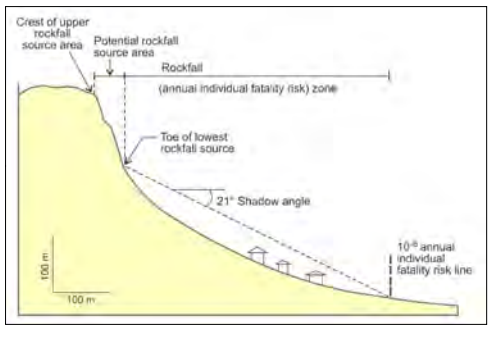
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map G4

FINAL ISSUE 2

REPORT: CR2012/123

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1570500 1571000 1571500

5171500 5171000

Summit Road
Dyers Pass Road
Worsleys Road

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

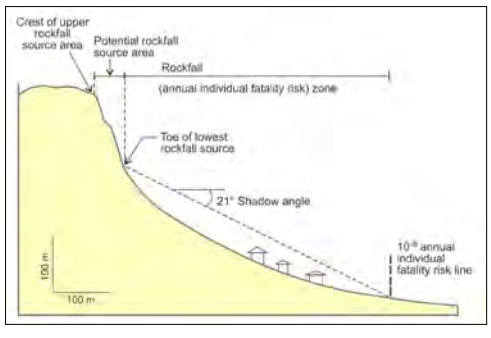
N

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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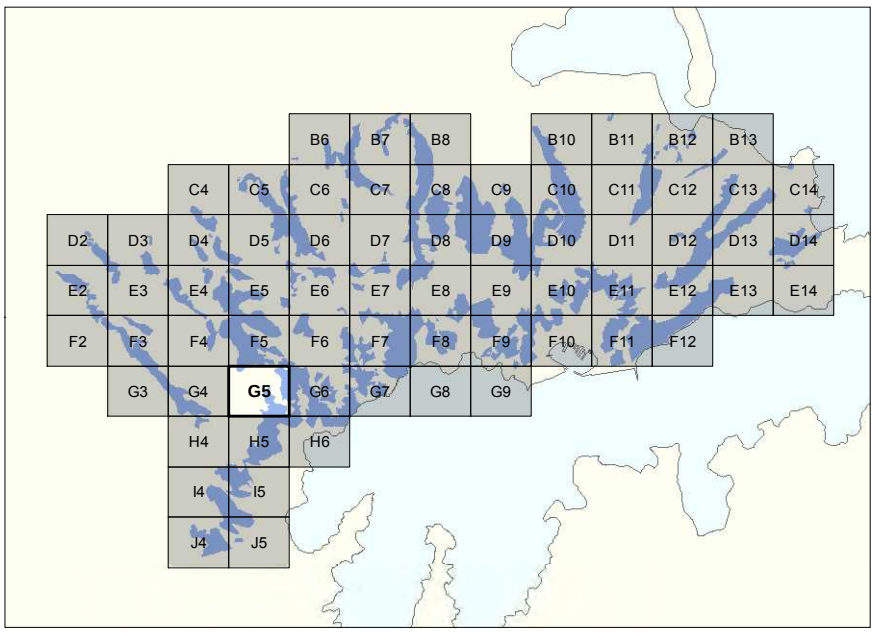

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

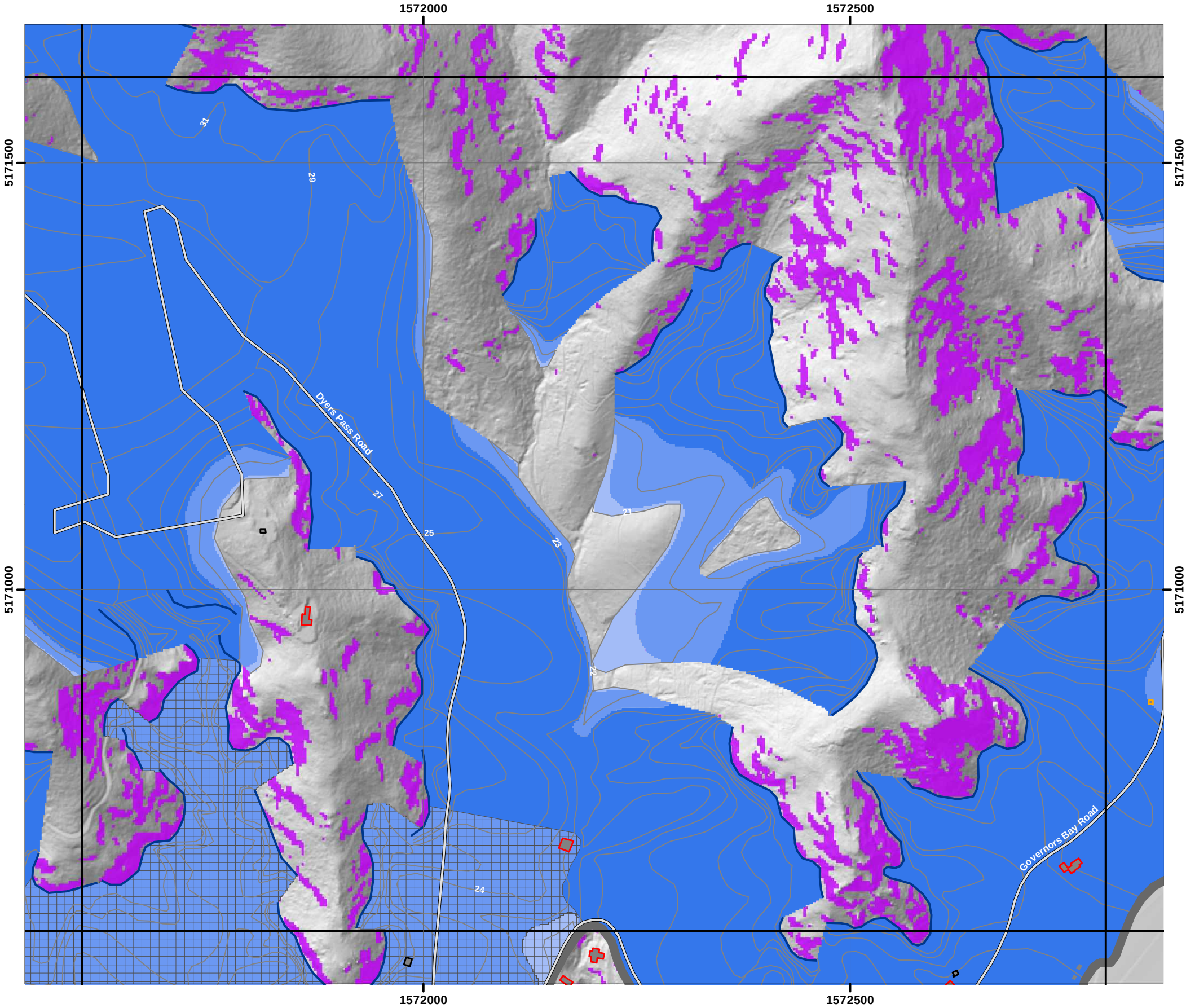
Port Hills Christchurch

APPENDIX C
Map G5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

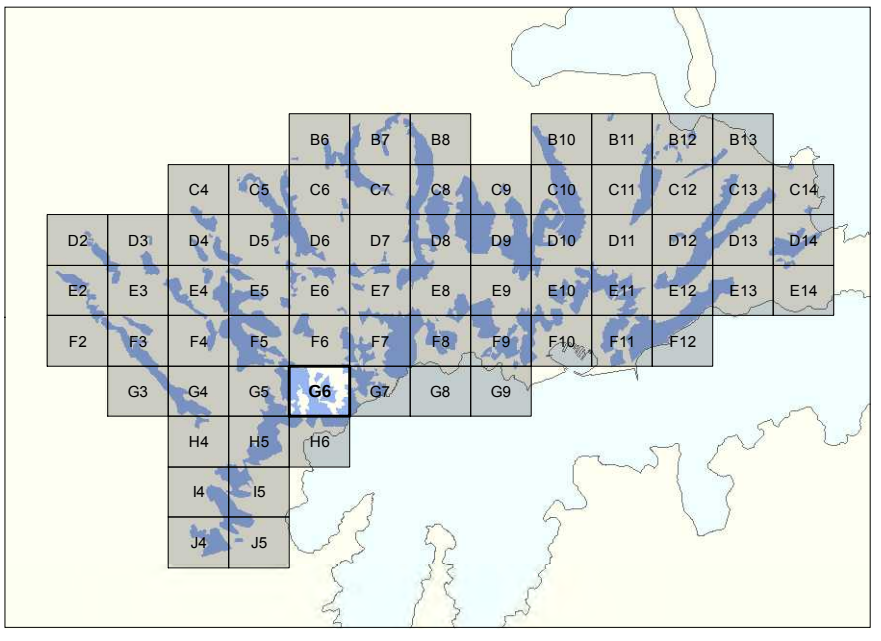
N

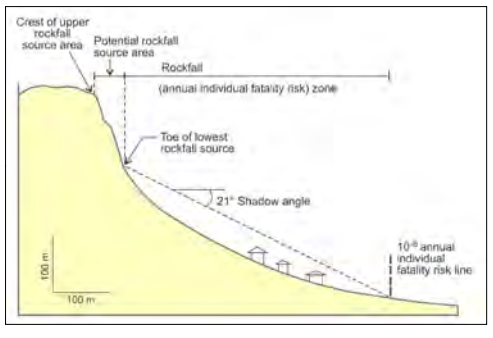
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

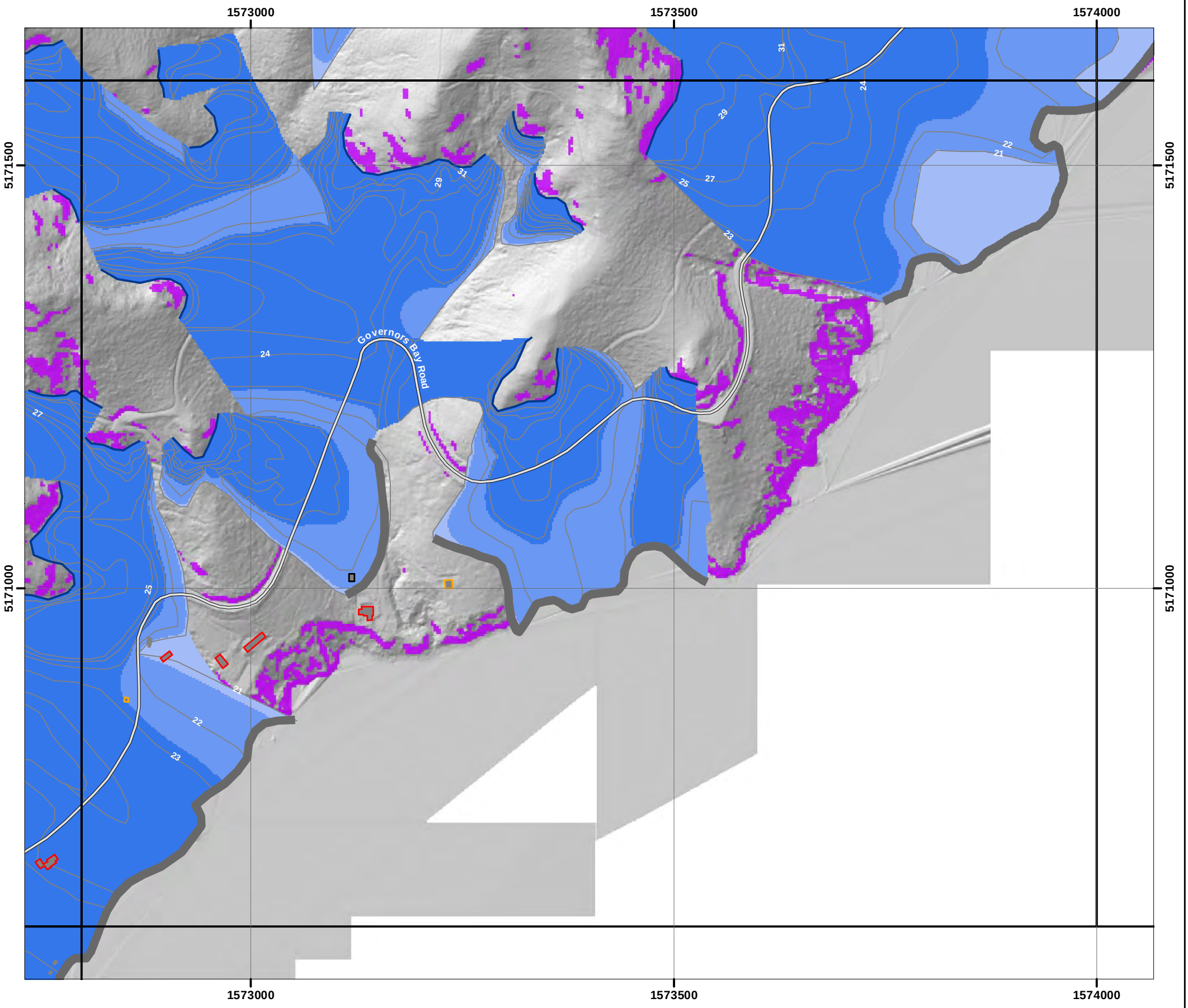
Port Hills Christchurch

APPENDIX C
Map G6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

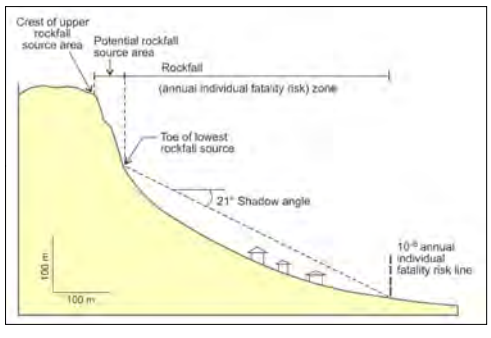
N

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased



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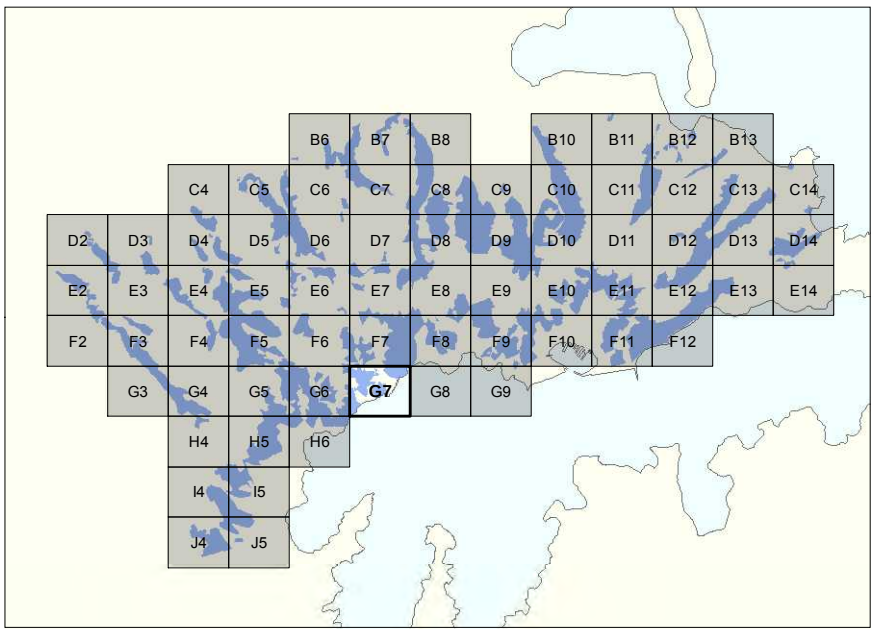

SCALE BAR: 0 100 200 m

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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map G7

FINAL ISSUE 2

REPORT: CR2012/123

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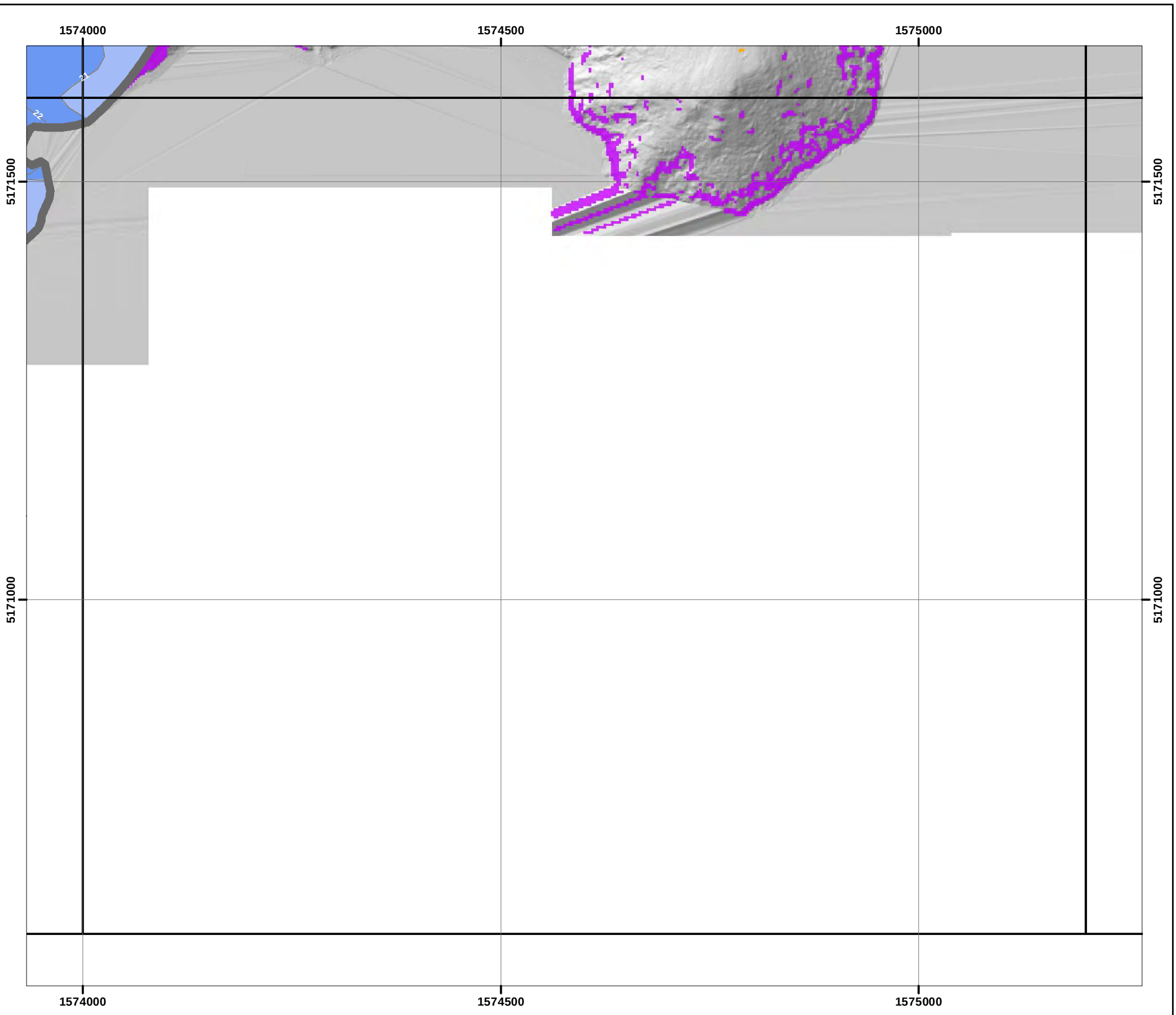


Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

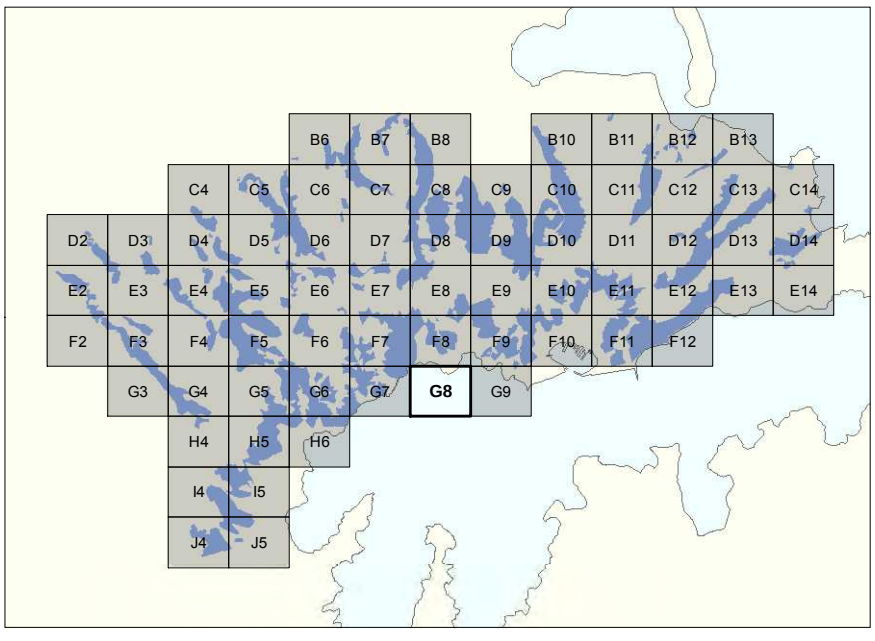
- Areas where the risk decreased
- Areas where the risk increased

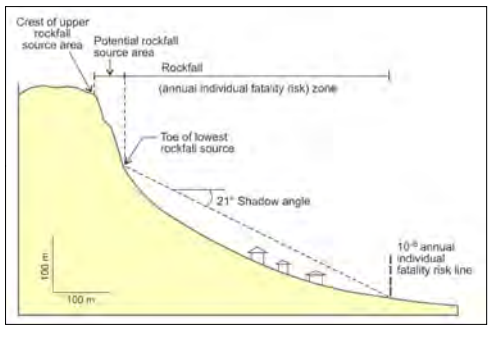
Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

Only those areas with dwellings have been field verified and modified accordingly

N





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10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

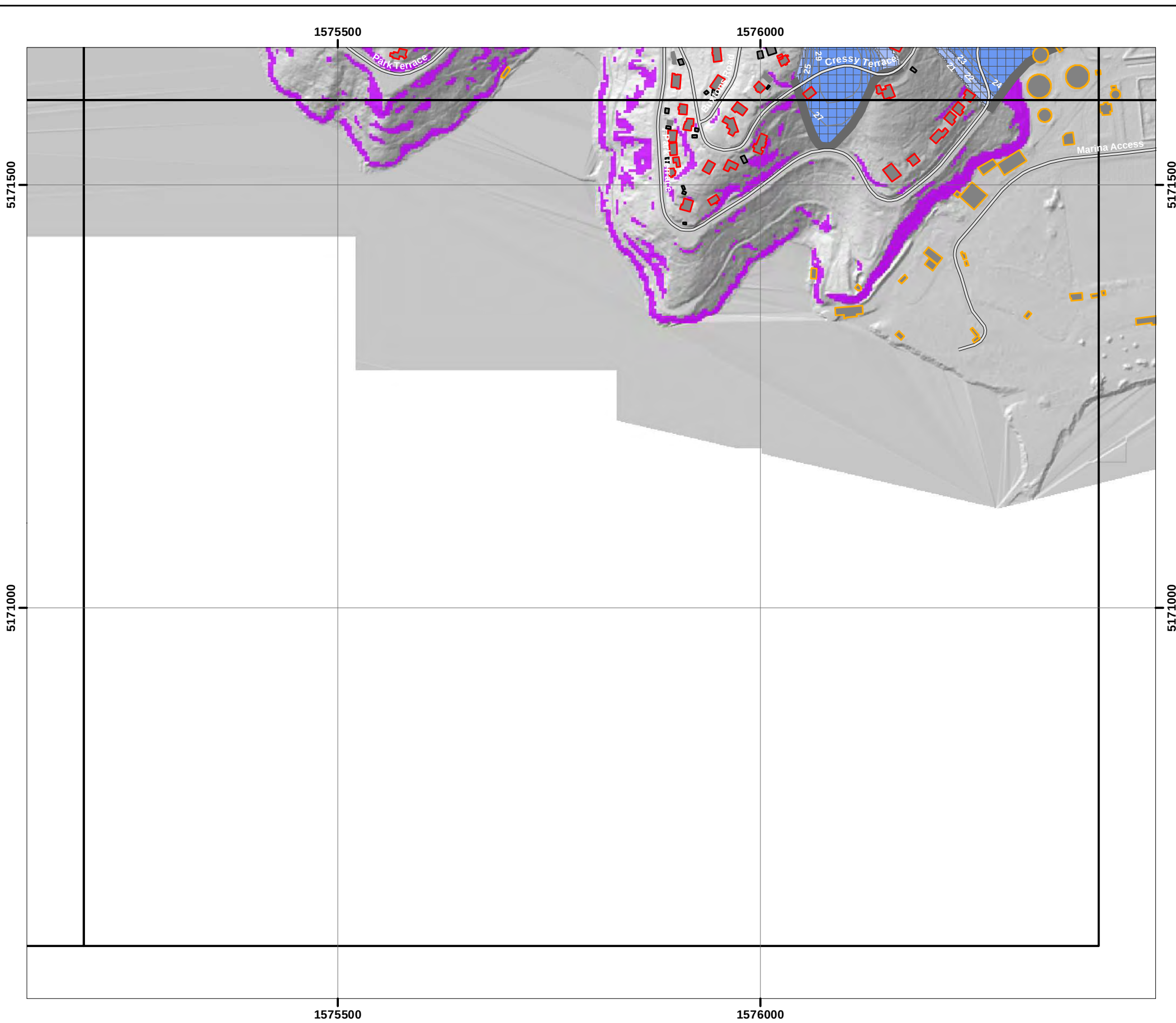
Port Hills Christchurch

APPENDIX C
Map G8

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map G9

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1569500 1570000

5170500 5170500

5170000 5170000

Summit Road

1569500 1570000

Rockfall (annual individual fatality risk)

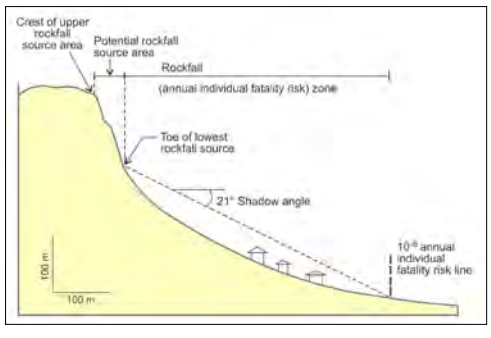
- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line
- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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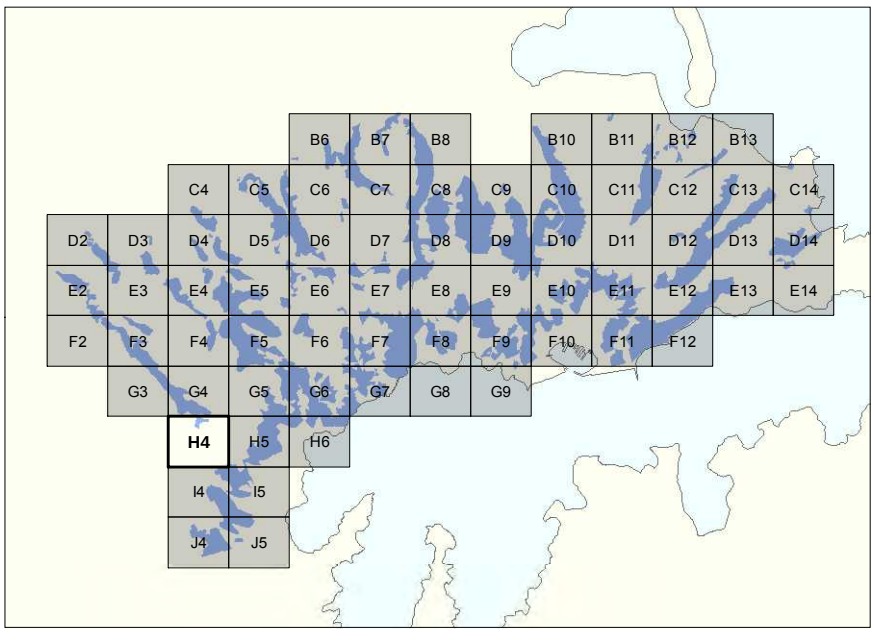
10^{-6} risk line – Defined as the line beyond which rockfall risk is assessed to be less than an annual individual fatality risk of 10^{-6}. This line represents the furthest distance that rockfalls are likely to reach.

Only those areas with dwellings have been field verified and modified accordingly

N



SCALE BAR: 0 100 200 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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

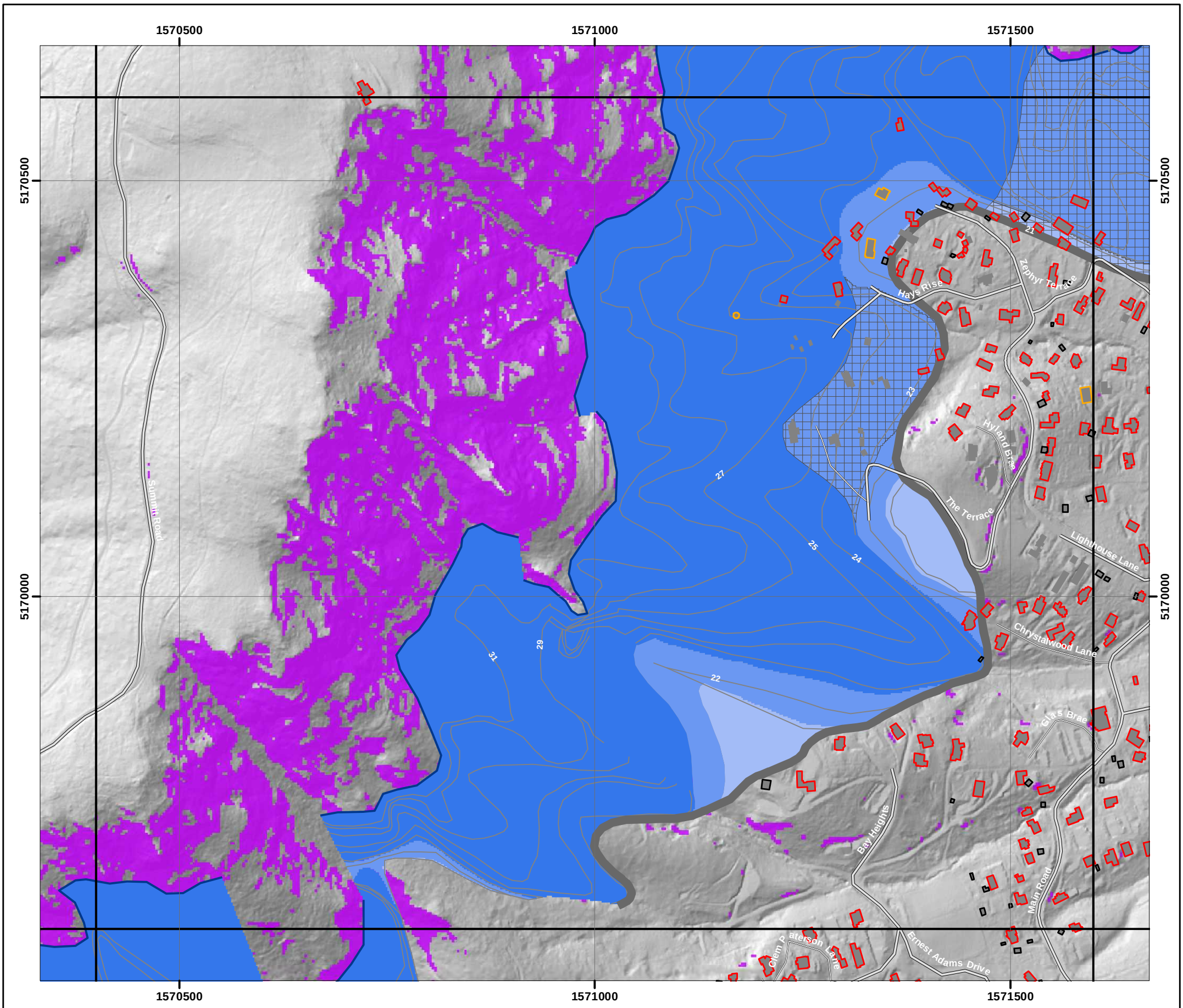
Port Hills Christchurch

APPENDIX C
Map H4

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013



Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

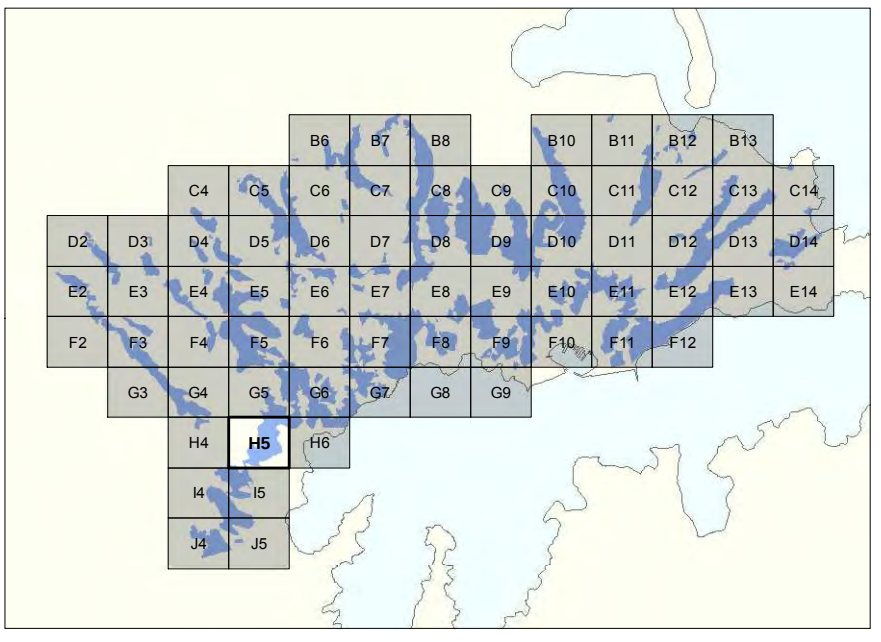
N

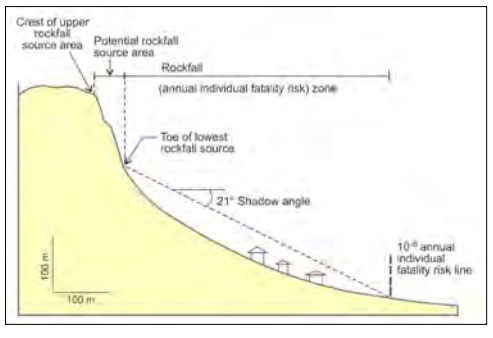
Modifications to modelled risk zones:
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 m

EXPLANATION:

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map H5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1572000 1572500

5170500 5170000

Governors Bay Road
Zephyr Terrace
Dyers Pass Road
Sandy Beach Road
Main Road
Lighthouse Lane
Jetty Road
Cresswell Avenue
Glass Brae
Merlincote Crescent

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
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- Shadow angle with values (for example 21 degrees)

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N

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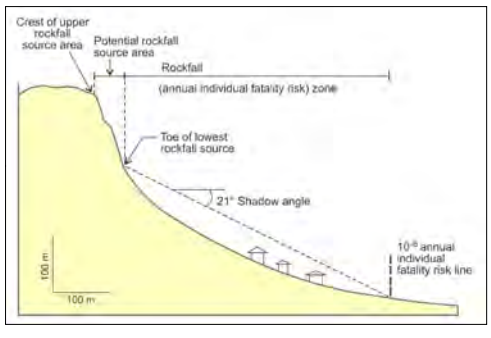
The hatched areas are where modelled risk values were changed following field verification

- Areas where the risk decreased
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown



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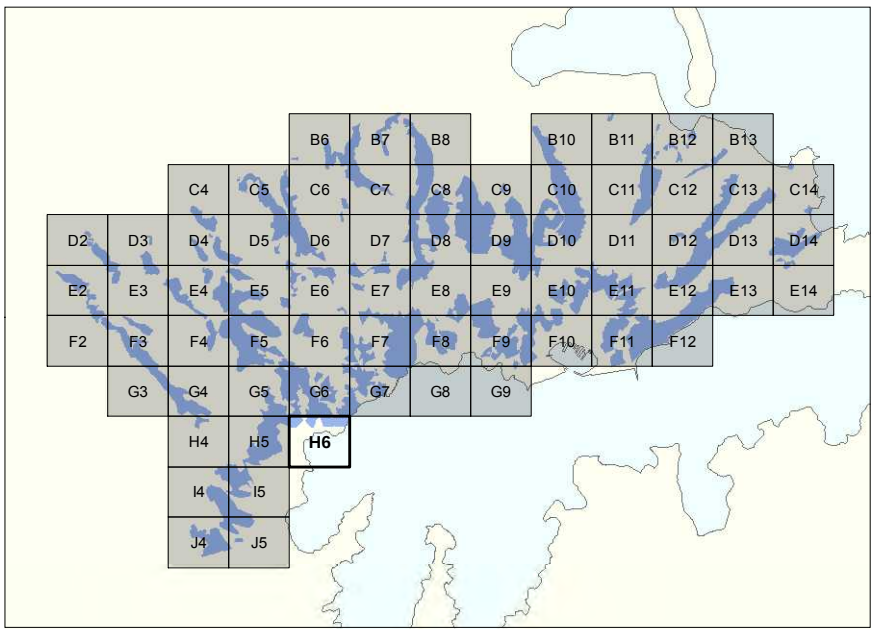

SCALE BAR: 0 100 200 m

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: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map H6

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1569500 1570000

5169500 5169500

5169000 5169000

1569500 1570000

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

- Potential rockfall source areas (slopes > than 35 degrees)
- Toe of lowest rockfall source area
- Shadow angle with values (for example 21 degrees)

Only those areas with dwellings have been field verified and modified accordingly

N

Modifications to modelled risk zones:
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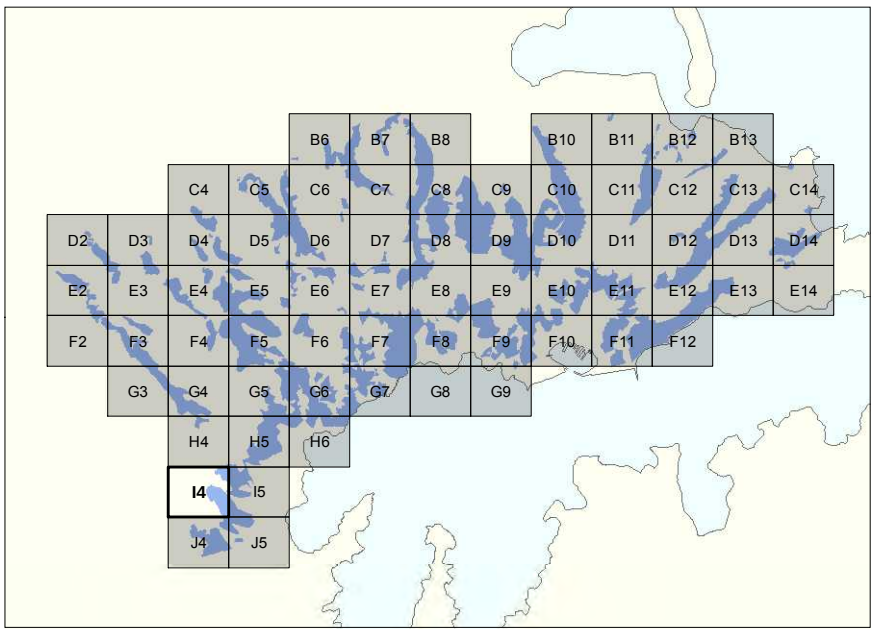
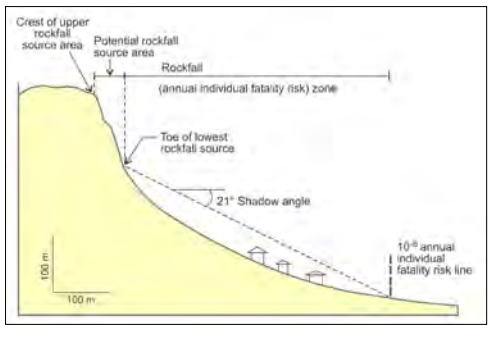
- Areas where the risk increased

Buildings (20/02/2012)

- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown





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SCALE BAR: 0 100 200 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map I4

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1570500 1571000 1571500

5169500 5169000

Bay Heights
Clem Paterson Lane
Lachie Griffen Rise
Ernest Adams Drive
Main Road
Main Road
Governors Bay - Teddington Road
Church Lane

29 31 27 25 23 22 21 24

1570500 1571000 1571500

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

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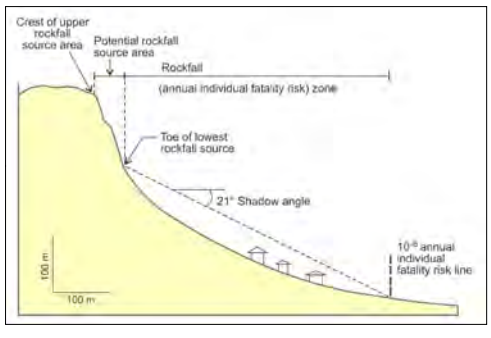
- Accessory building
- Unknown



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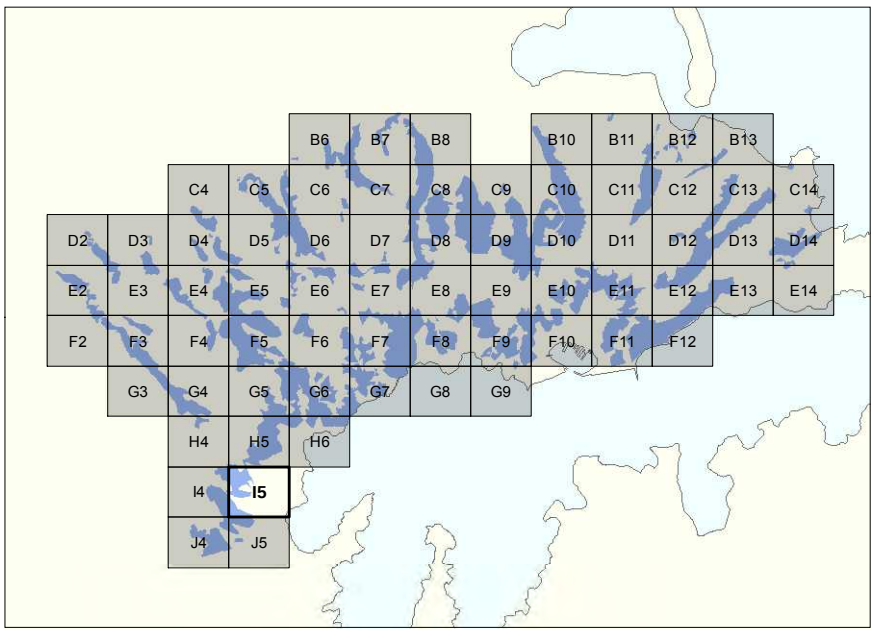

SCALE BAR: 0 100 200 m

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PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map I5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1569500 1570000

5168500 5168500

5168000 5168000

1569500 1570000

31 22 24 23 21 29 25 27

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- 10^{-6} annual individual fatality risk line

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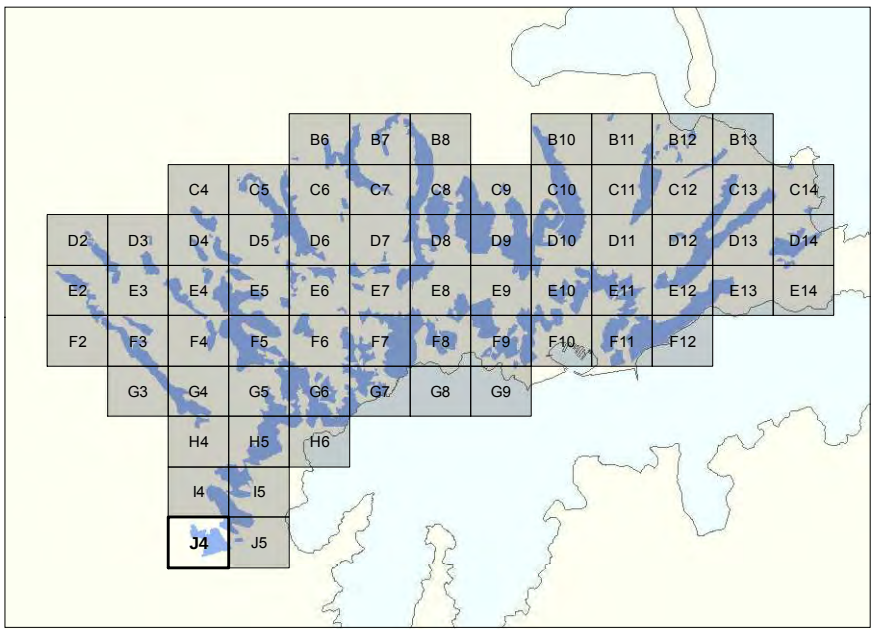
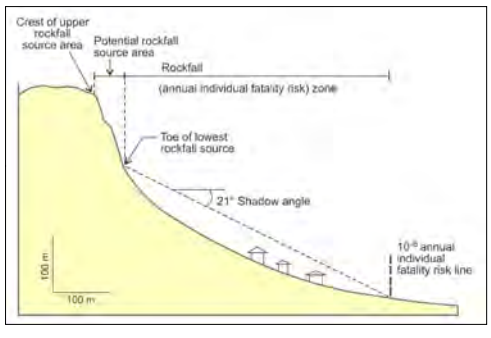
- Accessory building
- Unknown





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CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map J4

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

1570500 1571000 1571500

5168500

5168000

Governors Bay - Teddington Road

24 27 25 22 23 21 29 31

Rockfall (annual individual fatality risk)

- Greater than 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
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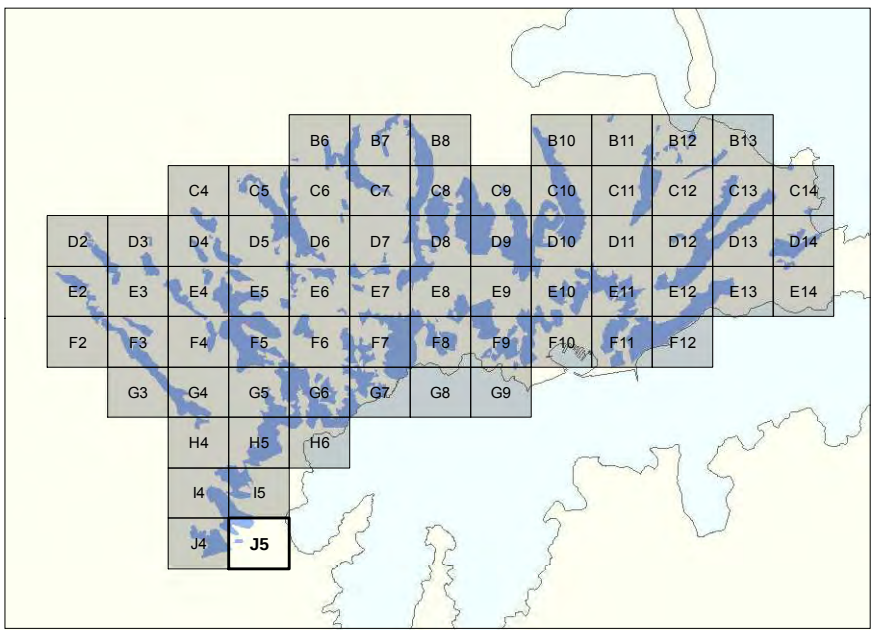

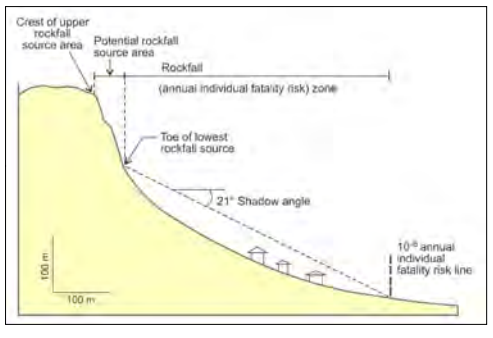

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CHK: CM

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ROCKFALL ANNUAL INDIVIDUAL FATALITY RISK

Port Hills Christchurch

APPENDIX C
Map J5

FINAL ISSUE 2

REPORT: CR2012/123

DATE: July 2013

www.gns.cri.nz

Principal Location

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F +64-3-477 5232

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F +64-4-570 4657