4.2.2 Runout modelling

4.2.2.1 Randomly distributed cliff collapses

For distributed cliff collapses triggered by earthquakes and for non-earthquake cliff collapses, the volume of debris passing through each 2 m by 2 m grid cell was estimated using the volumes of material that passed a given fahrboeschung angle from debris avalanches triggered by the 22 February and 13 June 2011 earthquakes, at Redcliffs. The values contained in Massey et al. (2012a) have been revised based on reassessment of the LiDAR data sets. Results are presented in Figure 31.

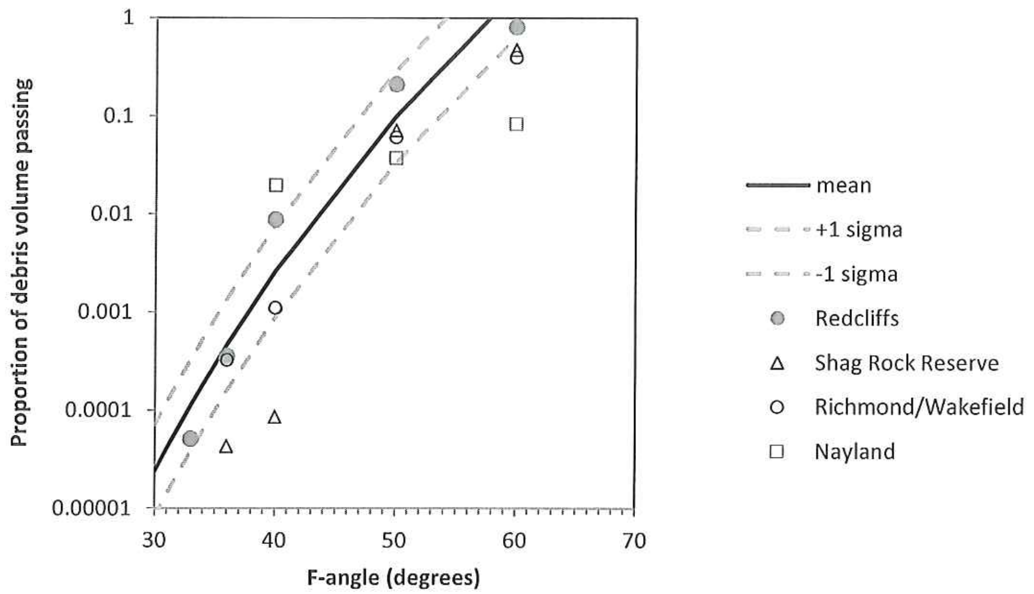


Figure 31 Proportion of debris volume passing a given fahrboeschung angle (F-angle) line, from debris avalanches triggered during the 22 February and 13 June 2011 earthquakes at Redcliffs. Trend lines are fitted to Redcliffs data only. Data from Shag Rock Reserve, Richmond Hill/Wakefield Avenue and Nayland Street are also shown for comparison.

For these randomly distributed cliff collapses, the volume of debris passing through a given 2 m by 2 m grid cell below the slope was derived from the relationship in Figure 31, based on the Redcliffs data only, for each volume estimate (lower, middle and upper). For the risk assessment the volume was converted into an equivalent number of boulders, where 1 m^3 of debris comprised about 15 boulders.

4.2.2.2 Local cliff collapses (assessed source areas 1–3)

The runout of debris from the assessed source areas 1–3 was assessed both empirically and numerically.

For local cliff collapses the maximum volume of debris passing through a given 2 m by 2 m grid cell below the source was derived from the RAMMS model outputs for each assessed source area (1–3) for each volume estimate (lower, middle and upper). For the risk assessment the volume was then converted into an equivalent number of boulders, as per the randomly distributed debris volumes.

The runout distances estimated from RAMMS were checked using empirical runout relationships measured from discrete debris avalanches that occurred in the Port Hills during the 2010/11 Canterbury earthquakes.

Empirical method

The procedure followed for estimating the empirical run-out distance, in terms of the fahrboeschung angle, is detailed in Appendix 1.

A total of 45 sections through specific debris avalanches triggered by the 22 February and 13 June 2011 earthquakes have been assessed. For each section the fahrboeschung for "talus" (where the ground surface is obscured by many boulders) and "boulder roll" (individual boulders) have been defined based on field mapping. The results are shown in Figure 32 as ratios of H/L where H is the height of fall and L is the length, or runout distance, of the mapped rockfalls and debris avalanche deposits (talus).

These fahrboeschung relationships are based on debris avalanches that fell from cliffs in the wider Port Hills area during the earthquakes, and not just from the Redcliffs site. They therefore reflect all of the different types of slope shape that could affect the debris avalanche runout.

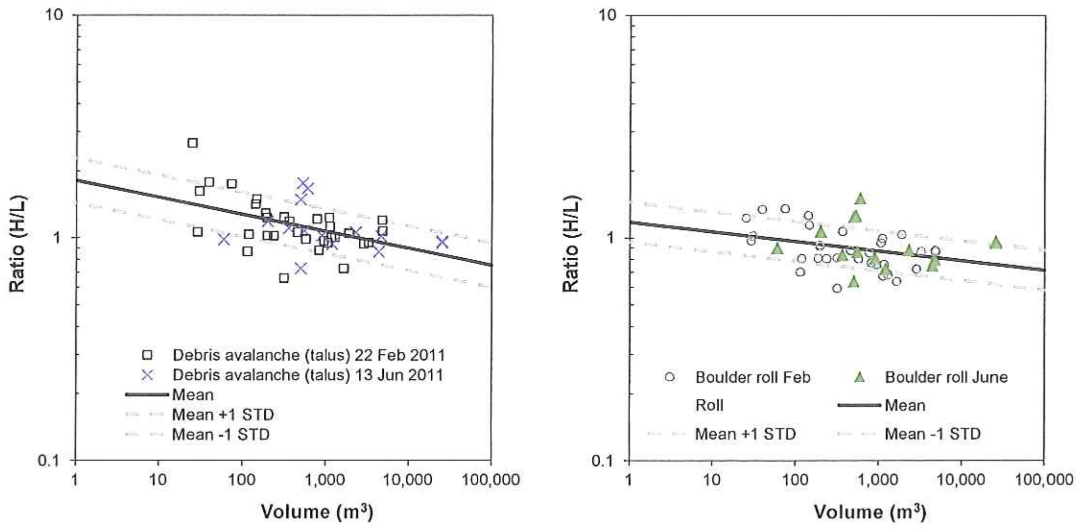


Figure 32 The empirical fahrboeschung relationships, expressed as the ratio of height (H) to length (L) for debris avalanche talus and boulder roll (rockfalls), recorded in the Port Hills. N = 45 sections. Errors are expressed as the mean ± one standard deviation (STD).

The results show that for very large failure volumes, the fahrboeschung angles – and therefore runout distances – are the same for talus and boulder rolls. However, for smaller failure volumes (typically less than 100 m^3) the boulders runout significantly further than the talus.

The main problem with using the fahrboeschung method to predict runout is that it does not take into account the ramping effect caused by the shape of the slope below the source area, which can have a significant effect on debris runout. However, they are useful as comparison tools to compare how credible the RAMMS runout modelling results are.

From the assessment of the debris that fell from the three main cliffs (Redcliffs, Shag Rock Reserve and Wakefield Avenue/Richmond Hill), during the 2010/11 Canterbury earthquakes, no debris passed the 31° fahrboeschung angle line (Massey et al., 2012a).

Numerical method – RAMMS

The RAMMS software (RAMMS, 2011) takes into account the site slope geometry when modelling debris runout. The physical model of RAMMS Debris Flow uses the Voellmy friction law. This model divides the frictional resistance into two parts: 1) a dry-Coulomb type friction (coefficient μ) that scales with the normal stress; and 2) a velocity-squared drag or viscous-turbulent friction (coefficient xi). The RAMMS model parameters were calculated from the back-analysis of 23 debris avalanches (ranging in volume from 200 to 35,000 m^3) that fell from the slopes at Richmond Hill Road, Shag Rock Reserve and Redcliffs during the 22 February and 13 June 2011 earthquakes. The modelled parameters mu (μ) and xi were optimised to obtain a good correlation between the modelled versus actual runout and deposited debris heights (Figure 33).

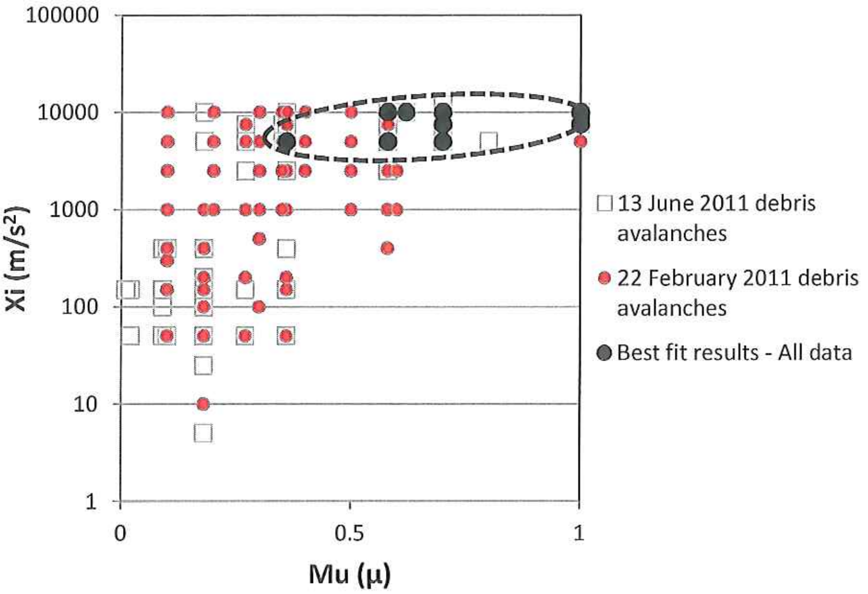


Figure 33 Range of parameters used to back-analyse the runout of debris avalanches in the Port Hills triggered by the recent earthquakes using the RAMMS software (RAMMS, 2011).

The model parameters that gave the "best fits" between modelled and actual runout distances and heights when: $\mu = 0.7$ and xi = 7,500 m/s^2. The xi values are comparable to results from other assessments compiled by Andres (2010) for rockfalls (debris avalanches), but the μ values are larger than those shown by Andres (2010), possibly because the Port Hills debris avalanches are more clast-dominated (Figure 34).

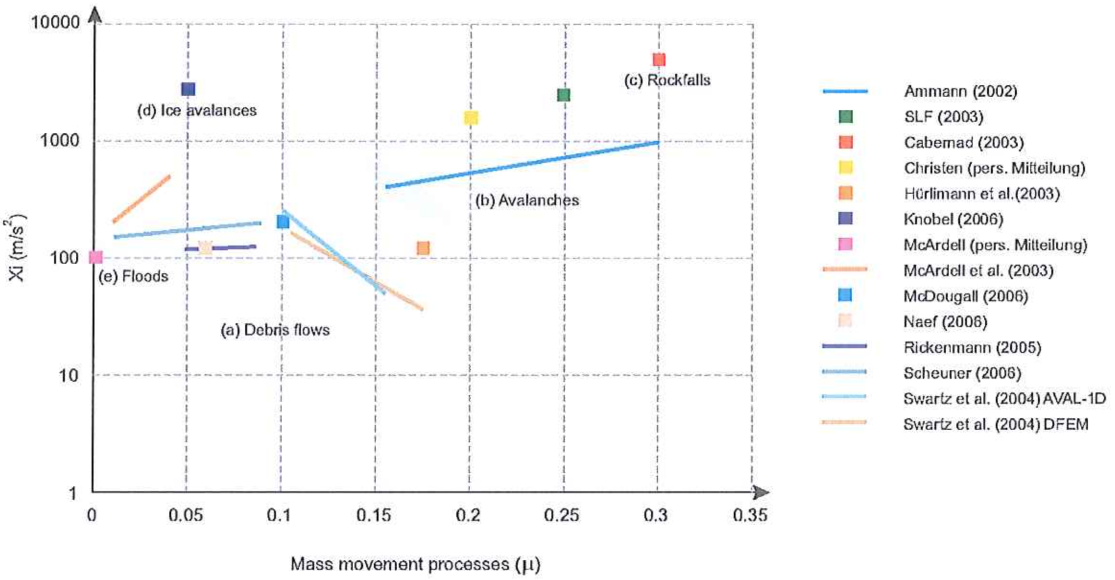


Figure 34 Range of parameters for different mass movement processes: a) debris flows, b) snow avalanches, c) snow avalanches, d) ice avalanches, e) debris floods. Modified from Andres (2010).

For each back-analysed debris avalanche, the modelled final debris thicknesses were compared to the actual deposit thicknesses interpolated from difference models derived from the airborne LiDAR surveys using a 1 m grid. For debris avalanches triggered by the 22 February 2011 earthquakes the deposit thicknesses were estimated from differences between the 2011a (March 2011) LiDAR survey and the 2003 LiDAR survey. For debris avalanches triggered by the 13 June 2011 earthquakes the 2011c (July 2011) and 2011a LiDAR surveys were used. Statistics from the comparison give a mean difference of 0.5 (±0.4) m^3, with a mode of 0.2 m^3 (Figure 35) for the 1 m^2 grid cells.

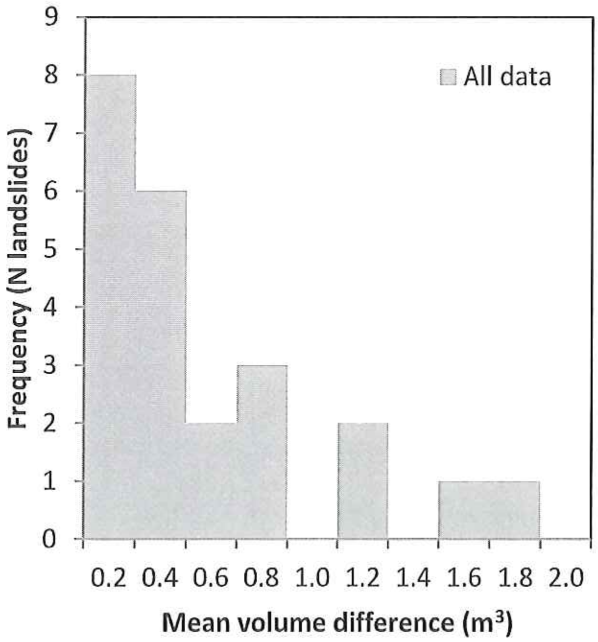


Figure 35 Mean volume difference between the RAMMS modelled volumes and the actual recorded volumes per 1 m^2 grid cell. N = 23 debris avalanches triggered by 22 February and 13 June 2011 earthquakes.

For the 23 debris avalanches, the performance of the RAMMS and fahrboeschung models (based on the compiled 45 sections shown in Figure 32) were assessed against the actual field mapped runout distances. The RAMMS model performed well with a gradient of 1.01 (±0.04) at one standard deviation and coefficient of determination (R^2) of 0.3 indicating the data are scattered. The empirical fahrboeschung model performed about the same as the RAMMS model, where the gradient was 1.06 (±0.05) at one standard deviation but the coefficient of determination (R^2) of 0.5 indicates less scatter (Figure 36).

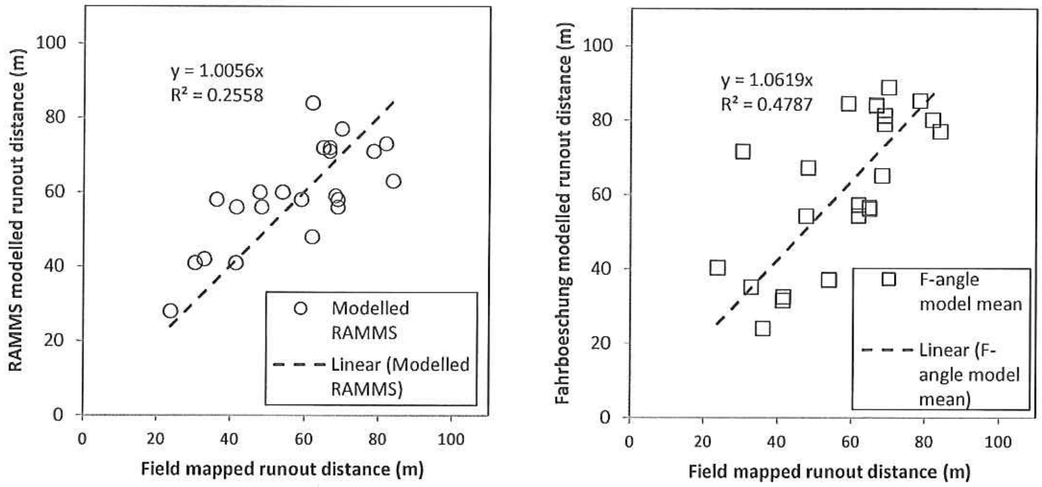


Figure 36 Comparison between the RAMMS modelled and the empirical-modelled debris runout (Figure 32, and the actual recorded runout for debris avalanches triggered by the 22 February and 13 June 2011 earthquakes. N = 23 debris avalanches.

Numerical method – RocFall

In order to better define the debris velocities and to check the RAMMS runout distances in the distal runout zone, the two-dimensional rockfall modelling software RocFall, developed by RocScience has been used, as RocFall treats the debris as individual particles, while RAMMS treats the debris as an aggregated flow. The results of Rockfall run out simulations for Redcliffs cross-sections 2, 4 and 6 are shown in Appendix 9 with the corresponding "end-points" histograms indicating the farthest point reached by the simulation. Cross-sections 2, 4 and 6 have been modelled, adopting the parameters detailed in Massey et al. (2012b). Results are shown in Appendix 9.

The RocFall software program was used by Massey et al. (2012a) to analyse the runout limits of individual boulders that fell during the 2010/2011 Canterbury earthquakes. This was done to derive material parameters by back-analysis of the observed rockfall runouts, which were then subsequently used for forecasting rockfall runout in areas where little rockfall data were available.

Results for cross-sections 2, 4 and 6 show that boulders could reach fahrboeschung angles of 32°, 34° and 30° respectively. The fahrboeschung angle of 30° for cross-section 6, is slightly less than the lowest fahrboeschung angle recorded at Redcliffs (and other similar cliffs in the Port Hills), which was 31°, based on back analysis of the debris that fell from these cliffs during the 2010/11 earthquakes. In general the results from the methods used are similar (within the uncertainties of the methods).

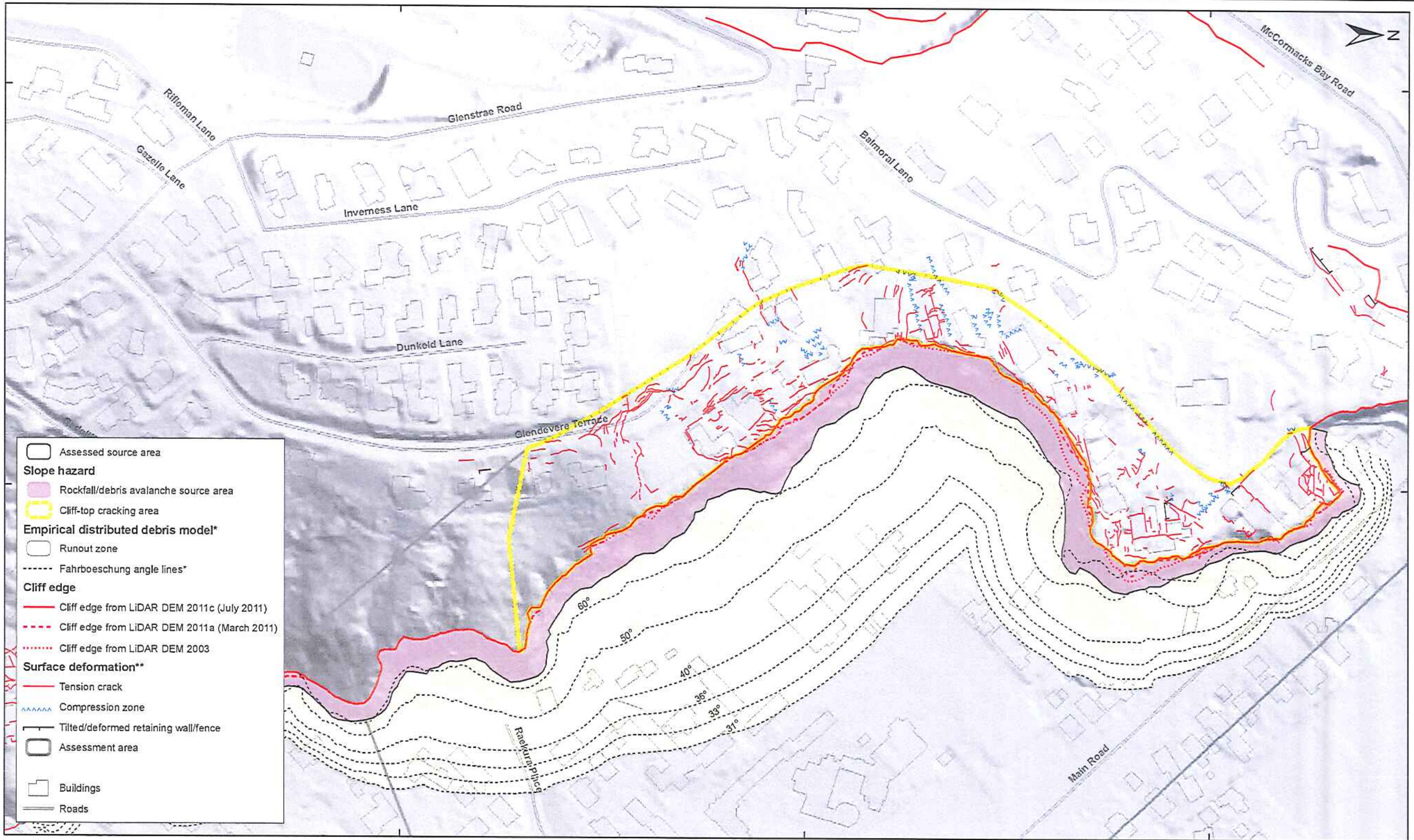
4.2.2.3 Forecast runout modelling

A hazard map (Figure 37) presents the empirical and numerical runout limits from the modelling. Figure 37, Map 1, shows the cliff collapse hazard map for the randomly distributed source areas, and the fahrboeschung angles from 60° to 31°. The 31° fahrboeschung angle is the runout limit of rocks from debris avalanches triggered by the 2010/11 earthquakes from the assessed cliffs (Redcliffs, Shag Rock Reserve, and Richmond Hill/Wakefield Avenue) in Massey et al. (2012a).

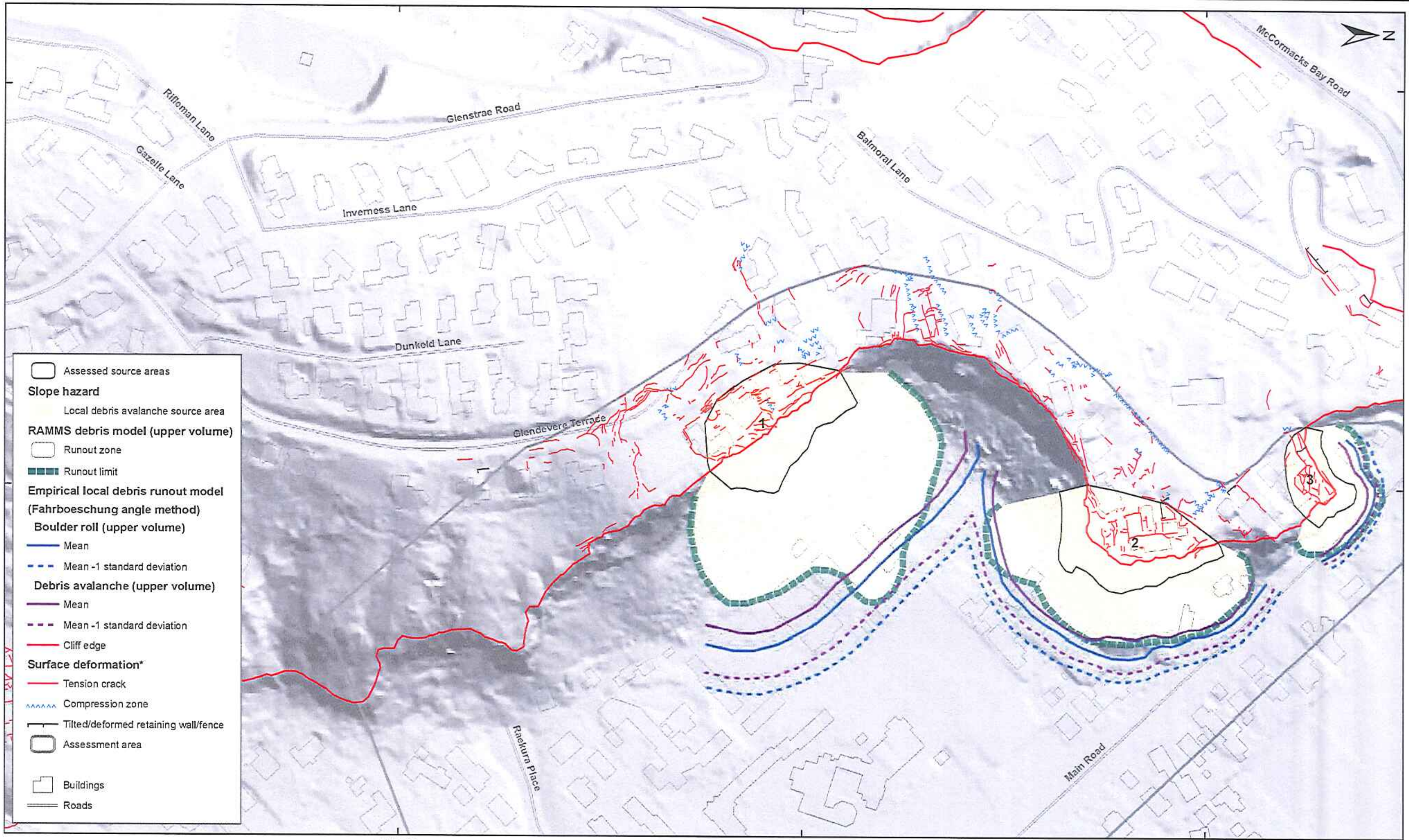
Figure 37, Map 2, shows the cliff collapse hazard map for the localised source areas 1–3 for the upper volume estimates (Scenario A). The mean and mean minus one standard deviation fahrboeschung angles for each source area assuming the upper volume estimates, are also shown. The estimated runout distances from the RAMMS modelling for the same source areas are also shown for the upper volume estimates. These show the likely runout limits of the debris from the assessed debris avalanche source areas.

RAMMS runout models are contained in Appendix 6 (debris height) and Appendix 7 (debris velocity), for source areas 1–3 (upper, middle and lower source volume estimates), along with the corresponding mean and mean minus one standard deviation fahrboeschung angles.

In general, there is a good correlation between the fahrboeschung angles and RAMMS runout limits for the assessed source areas.



SCALE BAR: 0 50 100 m			CLIFF COLLAPSE HAZARD MAP (Randomly distributed debris)	FIGURE 37
EXPLANATION: * Modified from report CR2012/57 ** Taken from report CR2012/317 Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: BL CHK: CM, FDP	GNS SCIENCE TE PŪ AO	Redcliffs Christchurch	Map 1 FINAL REPORT: CR2014/78 DATE: August 2014



SCALE BAR: 0 50 100 m			
EXPLANATION:	DRW: BL	**DEBRIS AVALANCHE HAZARD MAP (Source areas 1, 2 and 3)**	**FIGURE 37**
* Taken from report CR2012/317	CHK: CM, FDP		Map 2
Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints provided by Christchurch City Council (20/02/2012). PROJECTION: New Zealand Transverse Mercator 2000		**Redcliffs Christchurch**	FINAL
			REPORT: CR2014/78 — DATE: August 2014

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