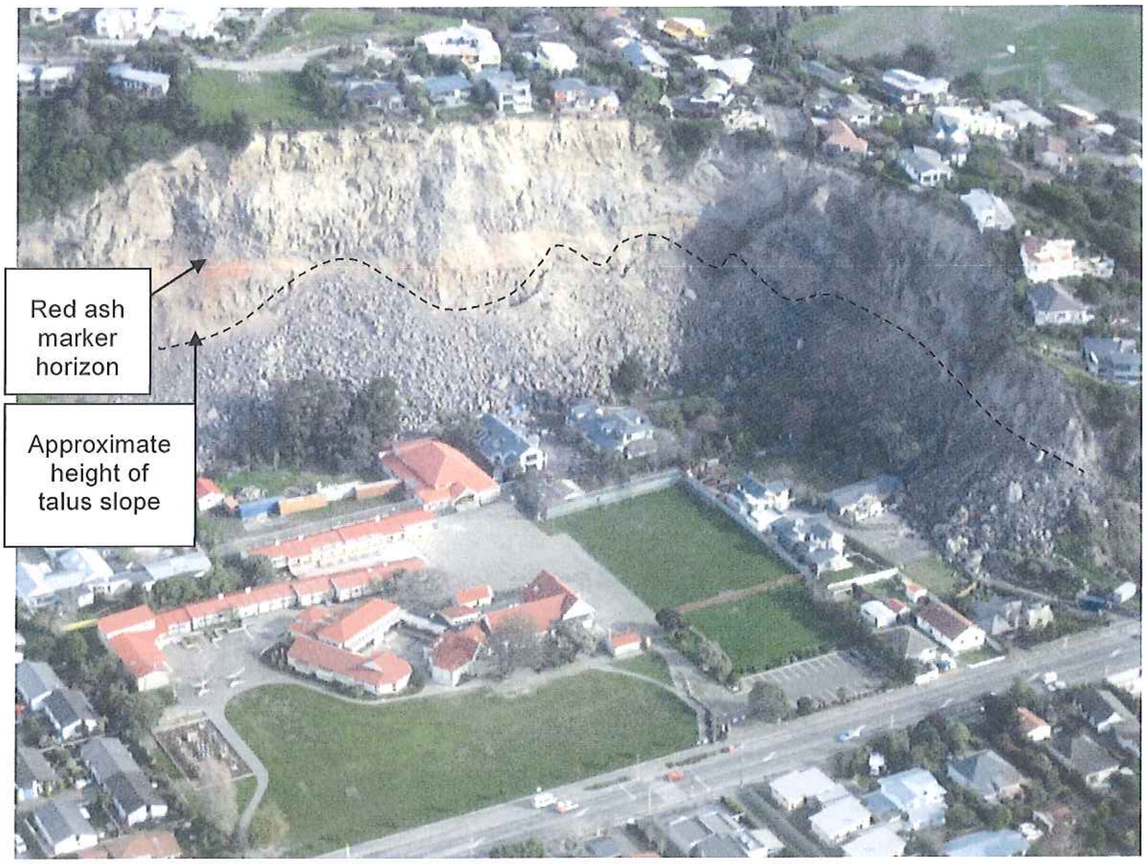
Photo 3-3 – Cliffs above Redcliffs School following February 2011 Earthquake.

Photo 3-4 – Cliffs above Redcliffs School following June 2011 Earthquake.



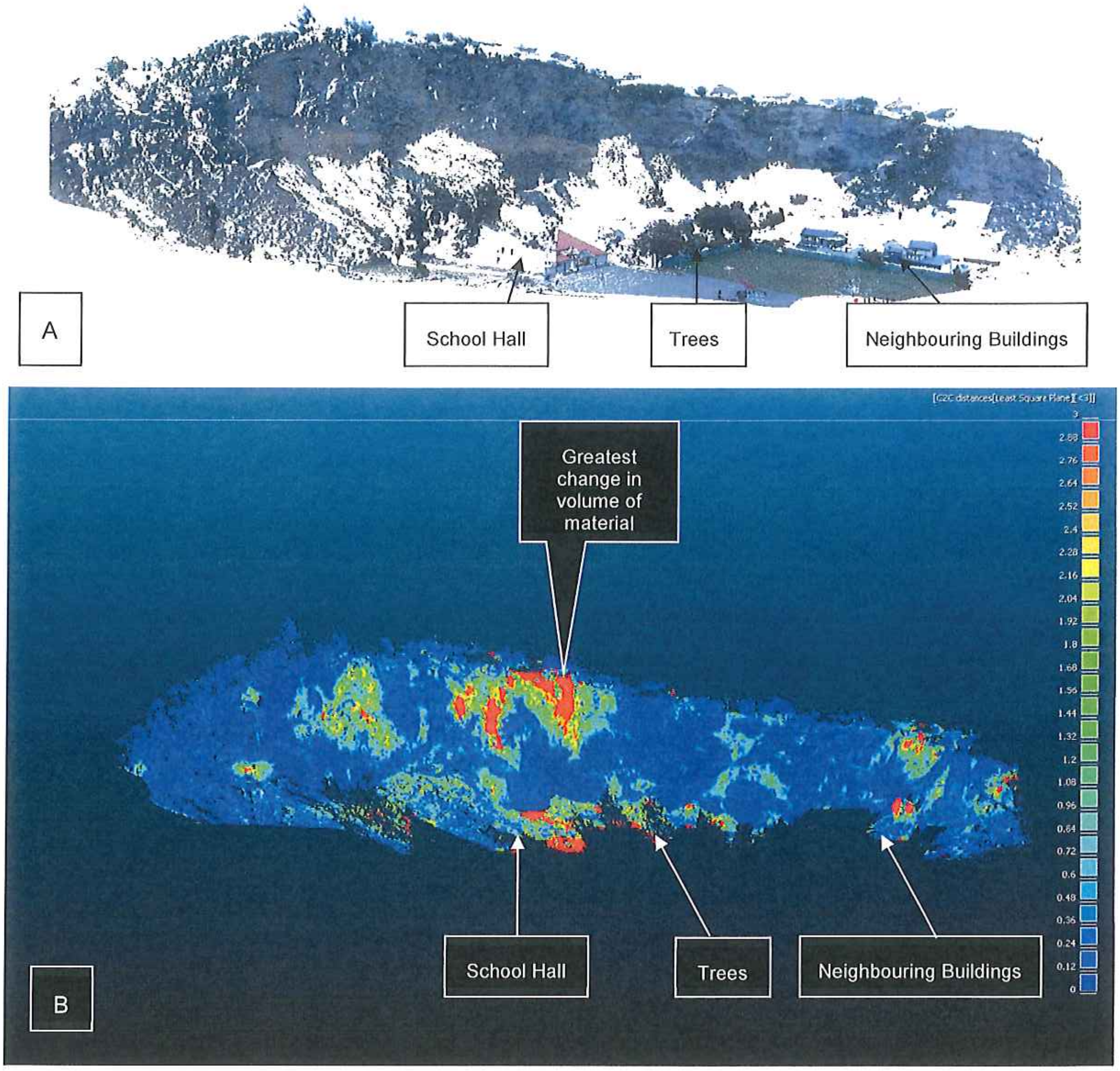


Figure 3-2 : Terrestrial Laser Scan showing A) Coloured Pointcloud Approximating the View and B) Scan from 2 March 2011 versus 15 June 2011 (source GNS).

3.6.2 Other Cliffs

3.6.2.1 Observation

There was extensive rockfall in the Sunmer/Redcliffs area during the June event. We understand that in many cases, slopes that showed no signs of large scale instability prior to the event experienced large scale failures during the June event.

Although almost no rocks penetrated the original protection works installed at Redcliffs School prior to February, it is clear from observations of other cliffs that the potential for larger scale instability on the cliffs behind the School from ongoing aftershocks cannot be discounted. The risk of further rockfalls is highest where there is loose rock on the slopes that failed, especially where there may be cracking along the edge of the cliff face. Although there is no visual evidence to suggest global instability, large scale failures have occurred under similar circumstances at other locations. Hence, as a precautionary approach, further rockfall modelling has been undertaken to determine the likely effects should large scale instability occur with the potential for a larger volume of material to fail. The rockfall re-modelling is described in Section 4.

3.6.2.2 Applicability to Redcliffs School

Data from the February and June events has been collected by GNS and used to develop risk based models for cliff collapse events. These models can be used to help refine the understanding of risk at Redcliffs School and the requirements for long term protection measures.

The GNS modelling and its applicability to Redcliffs School are discussed further in section 4.2.

3.7 Post June 2011

There have been no further major rockfall events since June 2011 although there have been smaller events due to ongoing seismic activity and weather effects on the cliffs. No rocks have been observed to reach the school grounds during this time.

Ongoing research into the cliffs above Redcliffs School has been undertaken and is presented in GNS Consultancy Report 2012/317 dated 1 August 2013. This work involved two large areas of mass movement on the cliffs above the school, one on the southern and one on the western cliffs.

The implications of these mass movement areas on rockfall potential has been modelled by GNS as discussed in section 4.2 of this report.

4 Rockfall Modelling

4.1 Previous Modelling – February 2011

In order to supplement the visual observations of the rockfall characteristics and investigate the adequacy of the proposed mitigation measures a rockfall assessment, using the Colorado Rockfall Simulation Program (CRSP) software, was undertaken following the February 22nd earthquake. A detailed description is presented in the MWH (March 2011) report.

The results indicated that since the area behind the berm (formed after the September 2010 event) had been in-filled with debris, the most significant rockfalls would travel to the base of the slope. There was a possibility that sizeable boulders could bounce over the existing catch fence, which is approximately 2 m high. Therefore additional protection beyond the line of the existing fence was recommended in the form of a line of shipping containers installed 30 m away from the existing fence. The model predicted that boulders rolling along a grass surface would not reach the containers, but may do so rolling along an asphalt surface, albeit at low height.

The proposed protection works were therefore considered adequate to address the potential rockfall mechanisms identified by the computer modelling referred to above. The computer modelling results appeared consistent with rockfall behaviour expected based on site observations following the 22nd February earthquake.

4.2 GNS Modelling

4.2.1 2012 modelling

GNS have published an assessment of life safety risk from cliff collapse (GNS Science Consultancy Report 2012/124) which addresses the cliffs that surround Redcliffs School.

The methodology of the GNS report is to estimate the life safety risk (expressed as an annual individual fatality risk) as a combination of:

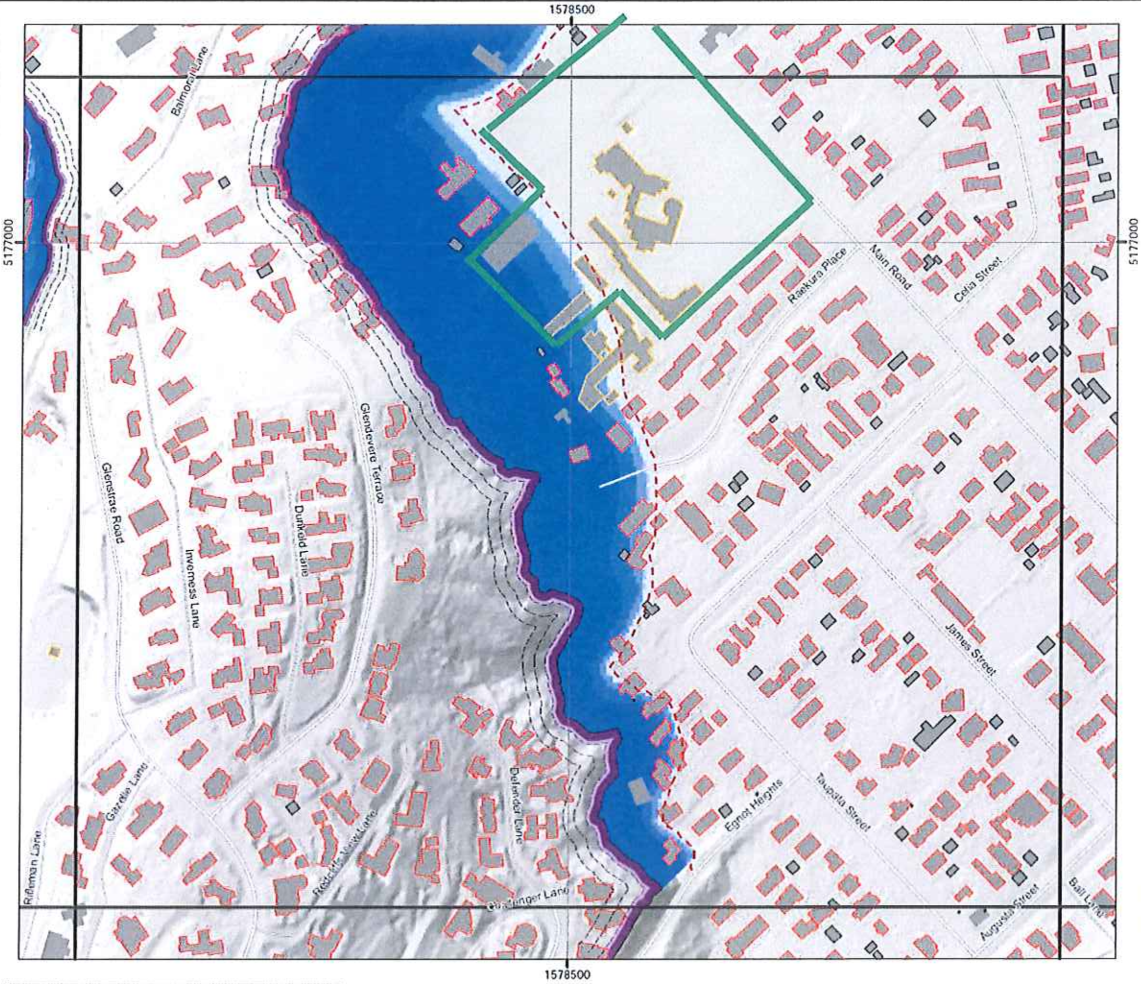
- the probability of an initiating event, times
- the probability of a person being in the path of the falling material, times
- the probability that a person is present during the event, times
- the probability that a person if hit would be killed.

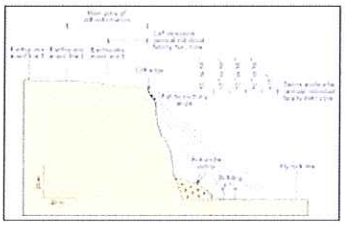
The probability of a number of potential initiating events and boulder roll distances are combined to give the overall fatality probability. This model was developed specifically for residential occupation and therefore the probability functions, such as number of hour's people are present during a day, is based on a typical residential situation. The risk calculations are therefore not directly applicable to the school, but provide an overall level of understanding around risk levels.

A key part of the risk model is the assessment of how far individual rocks may roll from the cliffs. GNS have assessed this based on a statistical analysis of measurements from the February and June 2011 earthquake events. The roll distance is defined in terms of the angle from horizontal of a line projected from the top of the cliff to the point where the boulder stops rolling (the Fahrboeschung angle). The furthest a boulder was found to have rolled during the seismic events produced a Fahrboeschung angle of 31 degrees. This is therefore the limit of the model, i.e. no risk calculation is undertaken beyond a Fahrboeshung angle of 31 degrees.

The calculated probabilities are summarised by GNS as a set of risk contours. The contours around the school site are shown on the following figure. The approximate extent of the school site is outlined in green on this figure.

Figure 4-1 – Risk Contours around Redcliffs School.



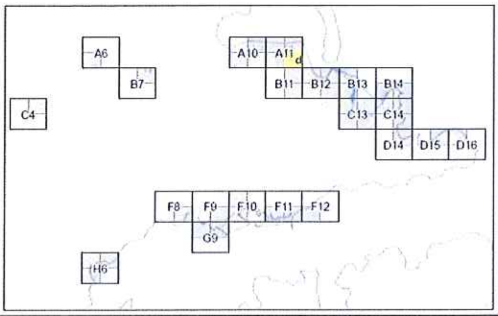


Debris Avalanche
(annual individual fatality risk)
- 10^{-1} to 10^{-2}
- 10^{-2} to 10^{-3}
- 10^{-3} to 10^{-4}
- 10^{-4} to 10^{-5}
- Less than 10^{-5}
- Fly-rock line (31 degrees)

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

Buildings (20/02/2012)
- Dwelling
- Commercial-Industrial
- Accessory building
- Unknown

N



Annual individual fatality risk bands (e.g. 10^{-1} to 10^{-5}) – The risk of being killed in any one year is expressed as a number such as 10^{-4} ("ten to the minus four"). 10^{-4} can also be expressed as one chance in 10,000 of being killed in any one year.

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

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

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

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

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

SCALE BAR: 0 20 40 60 80 100 m		GNS SCIENCE	CLIFF COLLAPSE ANNUAL INDIVIDUAL FATALITY RISK	APPENDIX B Map A11d
EXPLANATION: Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution. Roads and building footprints and types provided by Christchurch City Council (20.02.2012). PROJECTION: New Zealand Transverse Mercator 2000	DRW: DH CHK: CM		Port Hills Christchurch	FINAL REPORT: CR2012/124 DATE: May 2012

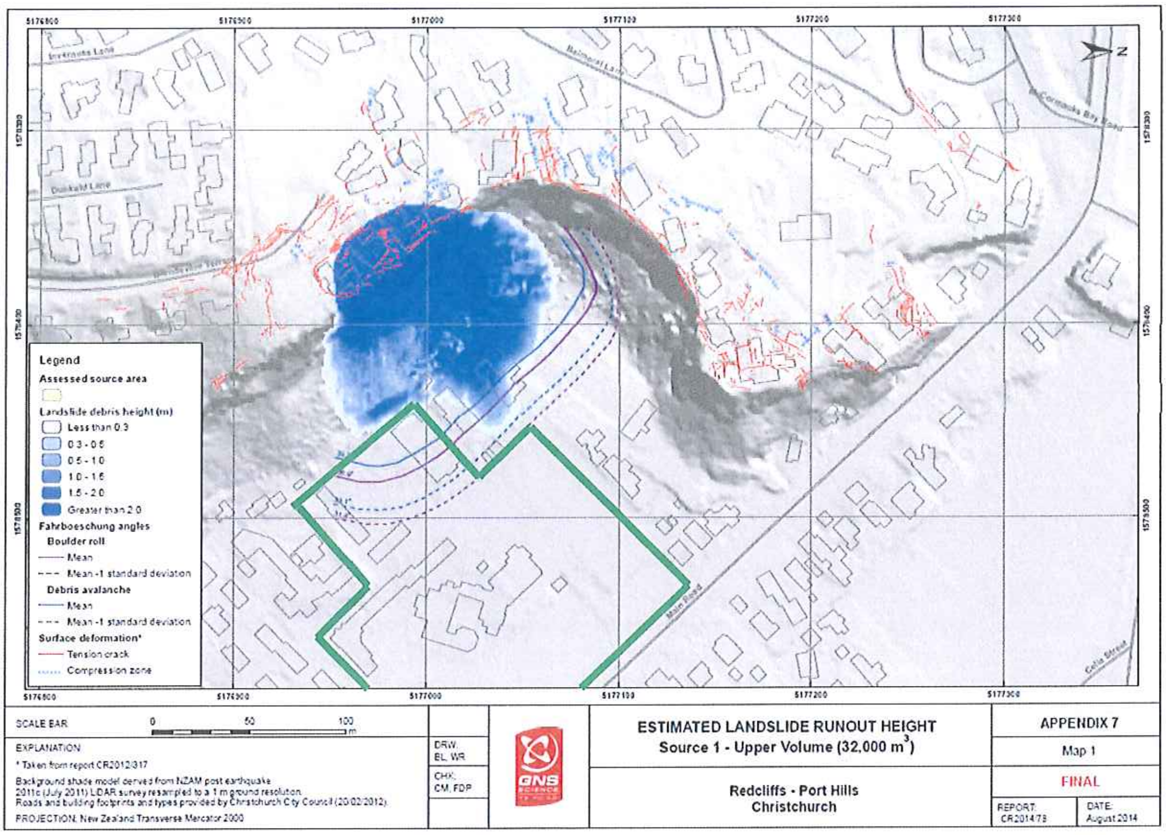
Each band of the contours represents one order of magnitude variation in risk, down to a lowest band of less than 10^{-5} i.e. less than one in one hundred thousand annual individual fatality risk. No risk figure is calculated beyond the red dashed 31 degree line as the model does not allow for any boulders to roll beyond this point. It can be seen that most of the school is located beyond the 31 degree limit of the GNS risk model. The exception is the south-western corner, where the school grounds are closest to the cliffs. In this area the school hall and classrooms have been abandoned or relocated and protection works in the form of shipping containers erected following the February 2011 event.

4.2.2 2014 Modelling

The 2012 GNS model was limited in its ability to estimate risk levels on the school site by its reliance on statistical data from previous events and that it does not attempt to estimate whether a future more adverse event may occur. Ongoing work by GNS and others has also identified potential large scale mass movement in the cliffs above Redcliffs School and significant fracturing of the rock mass. The potential for larger scale cliff collapse events than experienced to date cannot therefore be discounted.

The potential for larger scale cliff collapses has been considered in updated modelling work by GNS and published in their August 2014 report. Run out distances based on a debris flow model ("RAMMS") and accounting for large scale cliff failures of tens of thousands of cubic metres were compared to the empirical data from the 2012 modelling. The results of the RAMMS model are summarised in the following figure, which shows the extent of rock run out from failure of the mass movement area directly behind the school hall, for the most conservative of the three scenarios modelled.

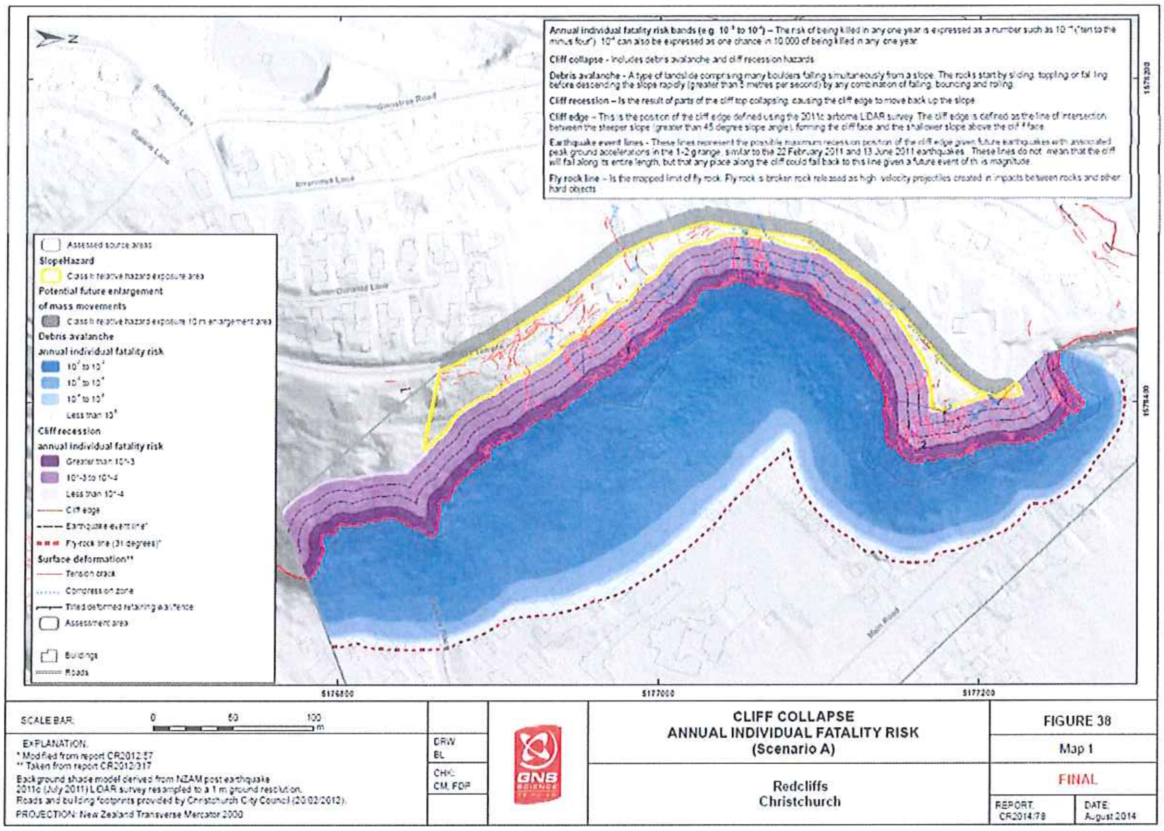
Figure 4-2 GNS RAMMS model output



In the vicinity of the school site (shown by the green lines above) the rockfall run out does not extend further than the previous statistically derived value.

The RAMMS modelling has been incorporated by GNS in their risk mapping and revised risk contours (i.e. revision to the risk contours shown in figure 4-1) are shown in Figure 4-3 below. This figure shows the risk calculation for the most conservative of the three mass movement failure scenarios (Scenario A) modelled.

Figure 4-3 – Revised risk contours



Comparison of figures 4-1 and 4-3 indicates that, even in the event of a large scale collapse of the cliffs behind the school, the extent of the calculated risk contours has not changed in the vicinity of the school site (noting that the red dashed line in both figures is the same). In their August 2014 report GNS note "There is also little difference between the debris avalanche risk maps presented by Massey et al (2012a) and the revised risk maps presented in this report".

4.2.3 Zoning Decisions

The GNS risk modelling has been used as the basis of zoning decisions of residential properties around the Port Hills. Red zoned properties (shown in red on the following figure) are those where the risk is considered too high for ongoing occupation.

Figure 4-4 shows the zoning of properties immediately adjacent to the school. It can be seen that the properties on the western and southern (cliff facing) boundaries have been red zoned, except for the two properties on Main Road which will remain occupied. The parcel of land that is part of the school grounds and closest to the southern cliffs (shown in red stripes on Figure 4-4) has also been red zoned.

Figure 4-4 – Residential Zoning around Redcliffs School.