5.3 ROAD USER RISK

The section of Main Road assessed for this report (Figure 42) is broadly similar in terms of traffic and usage to that below Quarry Road which was assessed by GNS Science in (Massey et al., 2014), although the length of road assessed in this report is shorter (81 m).

Individual road user risks per journey and per year are assessed using the same cellular grid as that used for dwellings. Previous assessments have found that the hazard of driving into or swerving to avoid debris contributes very little risk in comparison with that of being directly impacted by or inundated with debris. This assessment therefore considers only the "impacted/inundated by debris" hazard, and not the "drive into/swerve avoiding debris" hazard.

Risk assessments were carried adopting the scenarios A, B and C input parameters (as for the dwellings assessment), for the following road users:

- Motor vehicle users (car, bus and truck occupants), and
- Vulnerable road users (motorcyclists, pedal cyclists and pedestrians).

The risk assessment methodology is described in Appendix 1.

Figure 42, Maps 1 and 2 show the risk per trip for a pedestrian along the outer an inner edge of Main Road from debris avalanches, for the upper and lower volume estimates respectively. Figure 43 and Figure 44 show the results in terms of risk per journey and risk per year for the middle debris volume estimate, in comparison with the average motor vehicle crash risk for an urban New Zealand road of the same length. Results show that:

1. The slope collapse risk on the NEAR (slope) side of the road is very much greater than the motor vehicle crash risk over the same length of road for all road users except motorcyclist, for whom it is comparable;
2. The slope collapse risk on the far (seaward, downhill) side of the road is virtually zero; and
3. The risk is greatest for the slowest moving road users (pedestrians), as it is they who spend most time at risk. However, it should be noted that this section of Main Road is currently closed to pedestrians.

Figure 45 and Figure 46 show the risk per journey for the lower and upper estimates of debris volume generated in seismic events (scenarios C and A respectively). The risk is acutely sensitive to debris volume on the low side, but less sensitive on the high side, because for several road cells the 'middle' debris volume estimates were already large enough to virtually assure death to someone present, so further rockfall makes little difference as a person can only be killed once. For the lower debris volume estimate (scenario C) there is virtually no risk contribution from rockfall, and motor vehicle crash risk outweighs rockfall risk for all road users except bus occupants – whose crash risk is relatively low.

SCALE BAR: 0 50 m

EXPLANATION:

* 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: DH, BL

CHK: CM, FDP

ROAD USER RISK : PEDESTRIAN
Higher estimate

Redcliffs
Christchurch

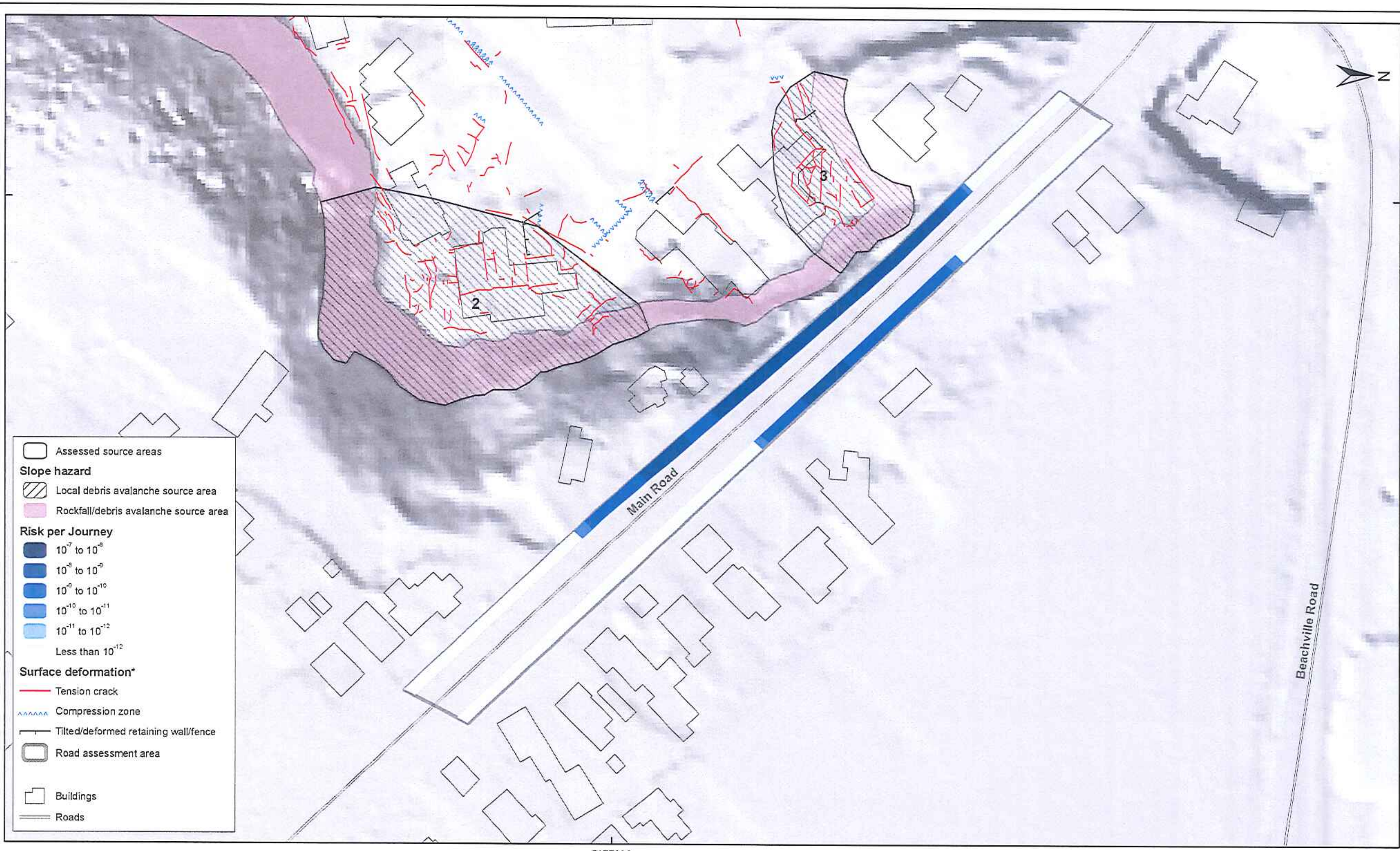
FIGURE 42

Map 1

FINAL

REPORT: CR2014/78

DATE: August 2014



SCALE BAR: 0 — 50 m

EXPLANATION:

* 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: DH, BL

CHK: CM, FDP

GNS SCIENCE TE PŪ AO

ROAD USER RISK : PEDESTRIAN
Lower estimate

Redcliffs
Christchurch

FIGURE 42

Map 2

FINAL

REPORT: CR2014/78

DATE: August 2014

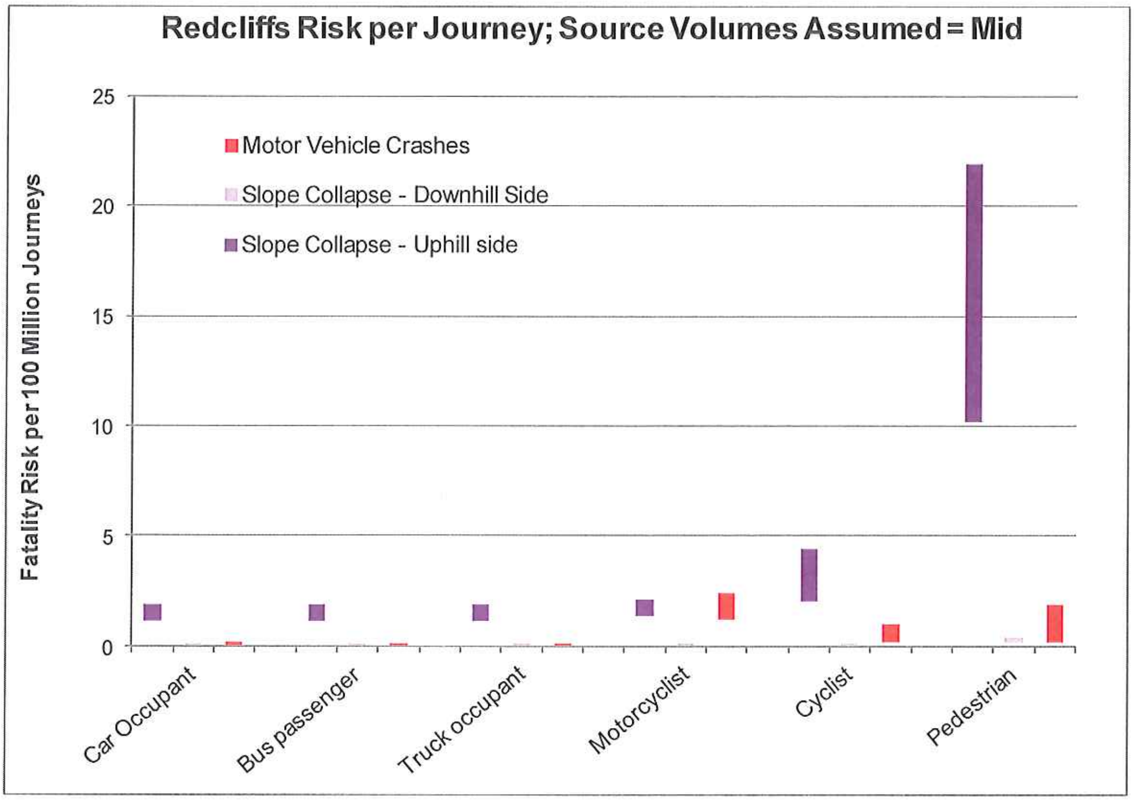


Figure 43 Road user risk per journey, central source volume estimates.

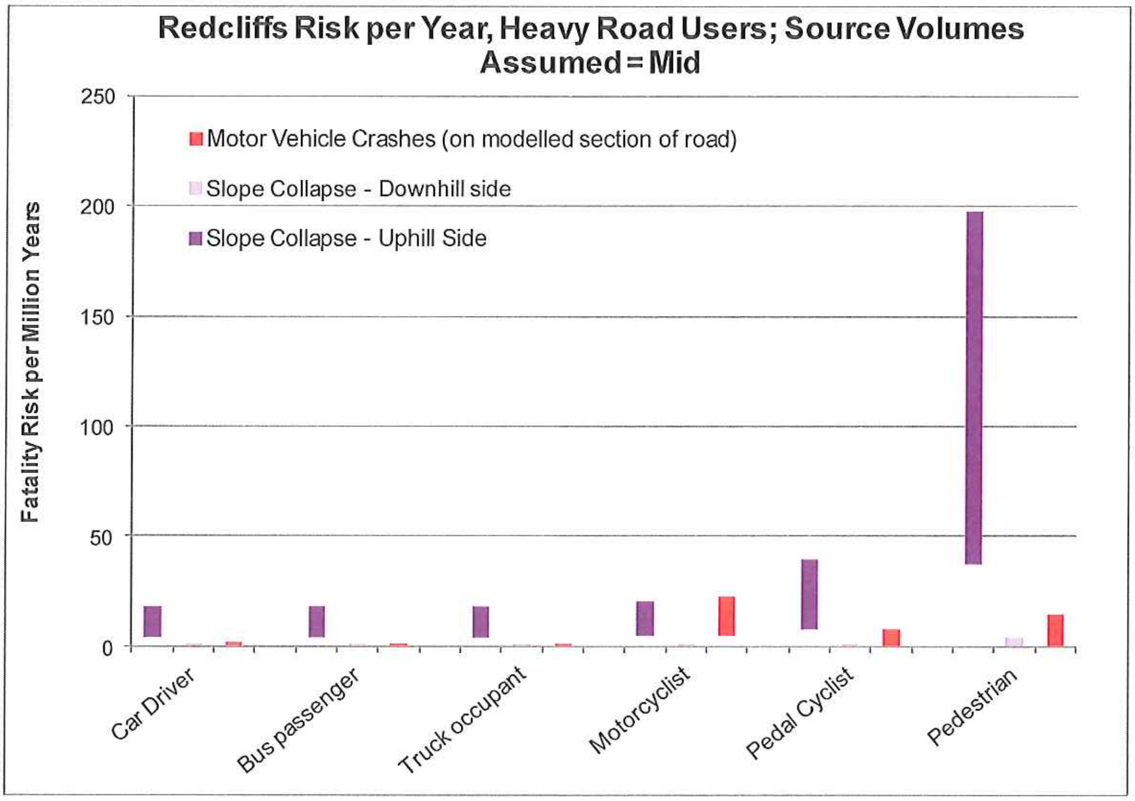


Figure 44 Road user annual fatality risk, central source volume estimates.

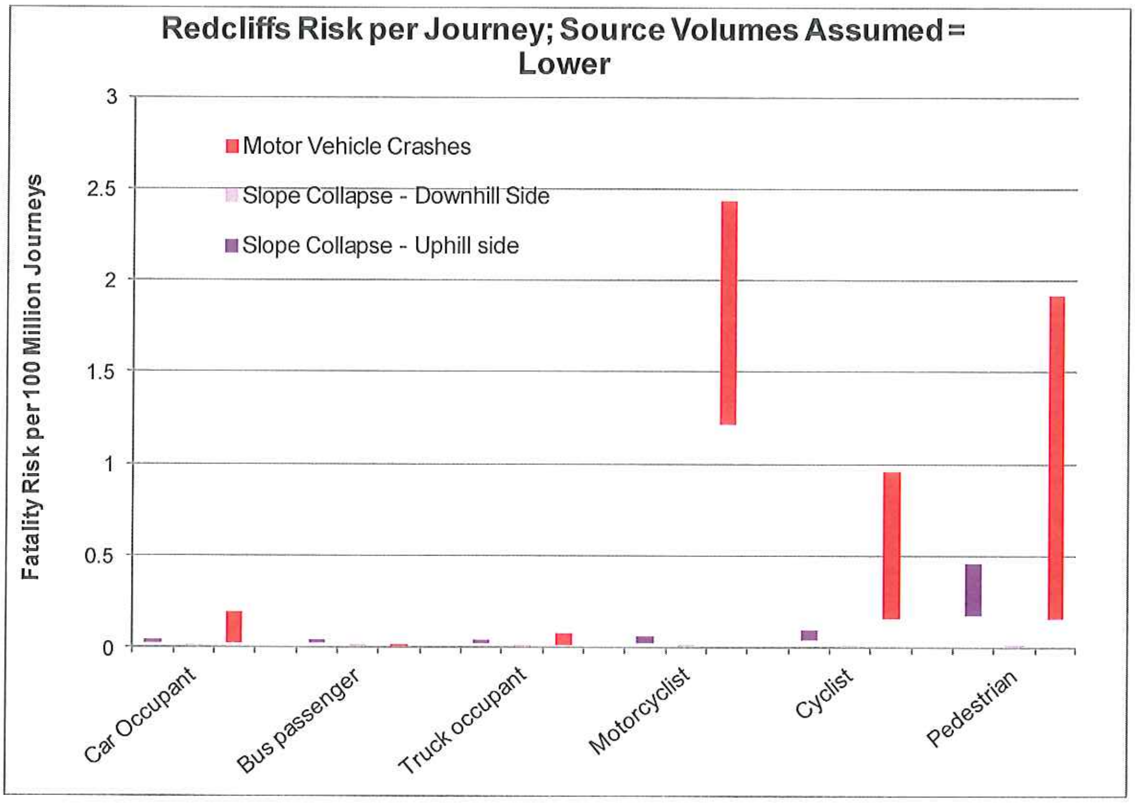


Figure 45 Risk per journey; lower assumed debris source volumes.

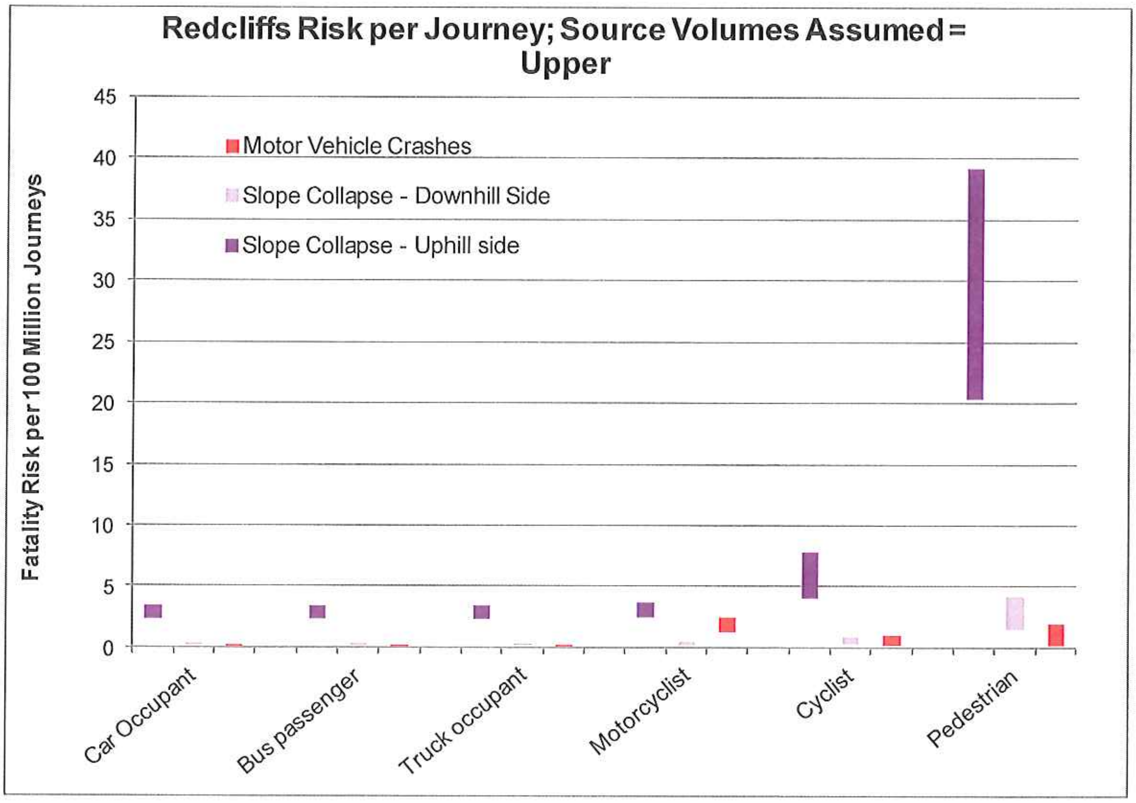


Figure 46 Risk per journey; upper assumed debris source volumes.

6.0 DISCUSSION

6.1 DWELLING OCCUPANT RISK

Important points of note from the results of the hazard and risk assessment undertaken in this study include:

1. Earthquake-triggered debris avalanches contribute most to the risk.
2. The inclusion of the assessed source areas 1–3 in the risk assessment increases the runout and hence the risk farther out from the toe of the slope, compared with the risk estimated assuming that the debris is randomly distributed across the slope. This can be seen in the risk estimates adopting scenario C input parameters (Figure 38, Map 3), which give the risk contours a more irregular shape.
3. For scenarios A and B (upper and middle volume and runout estimates), there is little difference between the risk estimates including the local source areas 1–3 (Figure 38, Map 2), and those without source areas 1–3 where the entire debris is distributed randomly across the slope (Figure 39). This is because the volume of debris and therefore risk is already high in these areas from distributed failures alone, and so the inclusion of additional debris from source areas 1–3 does not significantly increase the risk.
4. 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. This Indicates that the rapid, mainly empirically-based risk assessment, carried out soon after the 22 February and 13 June 2011 earthquakes, provided robust estimates of the risk that were "fit for purpose".
5. The largest difference between the original risk estimates (Massey et al., 2012a) and those presented in this report is at the cliff crest. The inclusion of earthquake triggered source areas 1–3, increases the width of the cliff top recession risk zone.
6. The effects of source areas 1–3 on the cliff-top recession risk have been distributed across the entire cliff top and not just in the assessed source area locations; although this is the most likely location they could occur.

6.2 RISK TO THE ROAD USER

Important points of note from the risk assessment results for road users along Main Road at Redcliffs include:

1. The rockfall risk is greatest for the slowest road users (pedestrians, then cyclists), because their slower travel exposes them to risk for longer on each journey;
2. The rockfall risk is significantly higher on the portion of road closer to the slope (west) than on the opposite (east) side of the road; and
3. Within the range of estimated debris volumes (upper, middle and lower), the risk from debris avalanches ranges from being comparable with or smaller than the risk of "ordinary" road accidents, for the lower debris volume estimates, to substantially larger than the risk of "ordinary" road accidents for most road users.

Based on middle debris volume estimates, individual risk to road users of Main Road at Redcliffs, for the section of road assessed, is among the highest per journey assessed for Port Hills roads and comparable to the road risks assessed for the Deans Head mass movement. This is because of the potential for even a relatively frequent event, such as a Band 1 (0.1–0.3 g; Table 27) earthquake, to generate sufficient rockfall volume to cause a high risk of death for any road user present on the near side of the road at the time of the event. This high risk is because this part of the road is at the very bottom of the steep rock slope, within a fahrboeschung angle of about 60°.

The rockfall risk is about zero on the far side of the road, and nearly zero using the lower debris volume estimates modelled in this assessment.

Inclusion or exclusion of localised debris specific sources makes little difference to the results for road users. The risk is dominated by the contribution from earthquakes in Bands 1 and 2 (Table 27). Even the smallest earthquake band considered generates sufficient rockfall volume reaching the near side of the road (under the middle debris volume scenario) to give a high risk of death to any road user present in this section of road when such an event occurs.

6.3 RISK ASSESSMENT SENSITIVITY TO UNCERTAINTIES

In this section the sensitivity of the risk model to key uncertainties and reliability of the assessments are identified. The three sets of assumptions (used for scenarios A–C) are discussed, along with other variations in the input parameters not included in scenarios A–C.

The sensitivity of the estimated risk has been assessed to changes in the following:

6.3.1 Debris volumes

Volumes of debris triggered by the representative events for both seismic and non-seismic triggers:

a. For seismically-triggered debris avalanches three volume ranges have been used to account for any uncertainty in the relationship between peak ground acceleration and volume leaving the slope.

b. For non-seismically-triggered debris avalanche volumes a scale factor of two has been used to allow for a possible increased "long-term" rate of debris avalanches due to the now-dilated and highly disturbed nature of the cliffs.

6.3.2 Area of cliff-top lost

Area of cliff top lost as a result of the occurrence of the representative event for both earthquake and non-seismic triggers:

a. For earthquake triggered recession, the variable debris volume estimates take into account the uncertainty in the relationship between peak ground acceleration and volume leaving the slope and the ratio of volume to cliff top area lost.

b. For non-seismically triggered recession the scale factor (of two on the annual debris production rate) considers the likely "long-term" increased rates of cliff collapse due to the now dilated and highly disturbed nature of the cliffs.

c. The relationship between the volume leaving the cliffs and the area of cliff top lost is varied from a ratio of 0.019 to a ratio of 0.025, i.e., for 100 m^3 of debris leaving the cliff face the area lost would increase from 1.9 to 2.5 m^2.

6.3.3 Debris runout

Volume of debris passing a given distance down the slope:

a. For randomly distributed failures the variation in the relationship between the volume passing a given fahrboeschung angle has been used.

b. For earthquake triggered local debris avalanches the volume of material passing a given distance – estimated using the RAMMS model – has been assessed using different source volumes in the model (upper, middle and lower volume estimates).

The results (Figure 38) show that the largest impact on the risk is from the uncertainty in the volumes of material that could be generated at different bands of peak ground acceleration.

There are approximately two orders of magnitude difference (a factor of 100 times) in the risk between scenarios A and C, for the same location in the more distal areas of the debris runout zone (Figure 38, Maps 1 and 3). The risk in the zones closest to the slope toe does not change much between the scenarios.

Based on the results of the two-dimensional rockfall modelling (Appendix 9), it is possible that individual boulders (rockfalls) could exceed the runout limits of the empirical and numerical RAMMS models used to estimate the risk from debris avalanches in the study area. However, it is not possible to quantify the risk in these distal areas as there is no precedent on which to base them, indicating that although boulders could runout to fahrboeschung angles of 30° (cross-section 6), the likelihood of them doing so is relatively low (as demonstrated by the past runout of debris at the site).

6.3.4 Other sensitivities and uncertainties

Another impact on the risk is from the National Seismic Hazard Model. The annual frequency of a debris avalanche-triggering earthquake occurring is much higher in the next few years, and will decrease over the next decade. The time-varying nature of the seismic hazard has been considered by comparing the differences in risk associated with the year 2016- and 50-year seismic hazard model results (50-years being consistent with the design life used in typical seismic hazard analysis for residential building construction).

The risk estimates reduce by a factor of between two and three – for the same location in the more distal ends of the debris runout zone – when adopting the 50-year average annual frequencies compared to the year 2016 annual frequencies. There is little difference to the risk closer towards the slope toe.

6.3.5 How reliable are the results?

Potentially significant uncertainties noted and their likely implications for risk are summarised in Table 31.

Table 31 Uncertainties and their implications for risk.

Issue	Direction and scale of uncertainty	Implications for risk
a. Under-prediction of annual frequency for a given peak ground acceleration by the composite seismic hazard model.	Increasing, potentially considerable – but geomorphological evidence in the Port Hills suggests there is a sensible cap that can be placed on the upward uncertainty, which is about an order of magnitude.	Risk due to earthquakes could be systematically under- or over-estimated.
b. Choice of whether to use average earthquake annual frequencies for next 50-years, or higher frequencies (year 2016).	Moderate uncertainty between the use of the year 2016 and 50-year average annual frequencies. Refer to Massey et al. (2012a) for details. The magnitude of uncertainty depends on the location of the dwelling within the risk zones. The distal ends are more uncertain than the zones closer to the toe of the slope.	Longer term risk is potentially 5 times lower in the distal runout zone.
c. Volume of debris produced in each peak ground acceleration band, upper, middle and lower debris volume estimates.	Largest uncertainty in either direction, especially between the lower (scenario C) and upper (scenario A) debris volume estimates.	There are two orders of magnitude uncertainty (factor of 100) between the risk estimates from the lower and upper debris volumes
d. Volume of debris produced by other (non-seismic) events.	Large uncertainty either way in the annual frequency, but constrained by the geomorphology suggesting such extreme events (that dominate the risk) are at the medium and low frequency end. However, current frequency of debris production is higher due to the disturbed nature of the rock masses. It may take many years for the frequency to drop back to pre-earthquake rates.	Factor of 2 to 5 uncertainty in the upward direction between current rates of rockfall and the assumed longer term historical rates.
e. Ratio between the volume leaving the face and area of cliff top recessing.	Moderate uncertainty either way. However, ratios may increase as the rock mass become more disturbed as the earthquakes continue.	Factor of about 1.2 uncertainty in the upward direction, but lower in the downward direction.
f. Volume of debris travelling downslope and the number of boulders per m^3 of debris.	Quite well constrained and could be considerable but linked to the total volume of material leaving the slope.	Factor of about 1.4 uncertainty in the upward direction, but lower in the downward direction.
g. Occupancy (proportion of time people are at home)	Assumption of 100% occupancy instead of 67% would modestly increase the estimated risk.	Would increase by a factor of about 1.4.
h. Probability person killed if struck by debris.	Uncertainty potentially reducible but unlikely to make large difference – will always be fairly large given the volumes of debris involved or height of fall.	A change in the vulnerability from 70 to 100% would increase the risk by a factor of about 1.8.