7.0 CONCLUSIONS

With reference to the assessment area boundary as shown in Figure 2, the conclusions of this report are:

7.1 HAZARD

1. The strength of the rock mass forming the slope at Redcliffs has been reduced by earthquake-induced fractures and movement and it will continue to weaken over time due to factors such as physical and chemical weathering, wetting and drying and further ground movement. Failures, of volumes of rock greater than those that failed during the 2010/11 Canterbury earthquakes, from the cliff are now more likely to be triggered by future earthquakes or by non-earthquake triggers such as rain. Failure volumes triggered by earthquakes may now be larger than any that fell during the 2010/11 Canterbury earthquakes; they could be more similar in size to past failures (from the same slope) identified from pre-1940 aerial photographs and pre-2010/11 earthquakes slope geometry.
2. Revised debris-avalanche dwelling risk maps (revised from those by Massey et al., 2012a) – incorporating local larger source volumes, and both physically and empirically based debris runout models – have little effect on the original risk estimates.

7.2 RISK

7.2.1 Dwelling occupant

1. There are very few additional dwellings in the debris avalanche or cliff recession zones that do not already have "red zone" offers made by the Canterbury Earthquake Recovery Authority and based on the previously assessed cliff-collapse risk.
2. Earthquake-triggered cliff collapses contribute most to the risk.
3. The results show that the most critical uncertainty in the risk assessment is the volumes of material that could be generated at different bands of peak ground acceleration. There is approximately two orders of magnitude difference (a factor of 100 times) in the risk estimates between the upper and lower failure volume estimates (scenarios A and C respectively).
4. The inclusion of the assessed source areas 1–3 in the risk assessment increases the runout and hence the risk further out from the toe of the slope. However, there is little difference between the risk estimates including the local source areas 1–3 and those where the entire debris is distributed randomly across the slope. 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 area where people are exposed to high levels of risk.
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 because the annual individual fatality risk bands have widened.

7.2.2 Road user

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.
    a. The rockfall risk is significantly higher on the side nearest the slope than on the opposite side of the road.
    b. 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.
    c. The rockfall risk falls to virtually zero on the far side of the road, and to virtually zero using the lower debris volume estimates modelled in this assessment.
2. The most pressing issue appears to relate to the section of Main Road within the risk zone. This section of Main Road currently has containers placed along the inside of the road, nearest the slope, to protect road users from falling debris. These measures are temporary. The footpath along this section of road is also closed.

8.0 RECOMMENDATIONS

GNS Science recommends that based on the results of this study, Christchurch City Council:

8.1 POLICY AND PLANNING

1. Decide what levels of life risk to dwelling occupants and road users will be regarded as tolerable.
2. Decide how Council will manage risk on land where life risk is assessed to be at the defined threshold of intolerable risk and where the level of risk is greater than the threshold.
3. Prepare policies and other planning provisions to address risk lesser than the intolerable threshold in the higher risk range of tolerable risk.

8.2 SHORT-TERM ACTIONS

8.2.1 Hazard monitoring strategy

1. Include the report findings in a slope stability monitoring strategy with clearly stated aims and objectives, and list how these would be achieved, aligning with the procedures described by McSaveney et al. (2014). In the meantime, extend the current survey network (by increasing the number of slope monitoring marks) further up the slope (particularly into source area 1), so as to maintain awareness of the behaviour of the slope.
2. Ensure that the emergency management response plan for the area identifies the dwellings that could be affected by movement and runout, and outlines a process to manage a response.

8.2.2 Monitoring alerts and early warning

Recognise the fact that monitoring alerts for slope deformation and groundwater changes cannot be relied upon to provide adequate early warning as experience from Port Hills and elsewhere shows that deformation and groundwater changes can occur rapidly, with little warning.

8.2.3 Surface/subsurface water control

Reduce water ingress into the slopes, where safe and practicable to do so, by:

a. Identifying and relocating all water-reticulation services (water mains, sewer pipes and storm water) inside the identified mass-movement boundaries (at the slope crest) to locations outside the boundary, in order to control water infiltration into the slope. In particular, a storm water main currently traverses the crest of source area 1; and

b. Filling the accessible cracks on the slope and providing an impermeable surface cover to minimise water ingress.

c. Control surface water flow and direct away from mass movement area and into the appropriate storm water system.

8.2.4 Pavement closure

1. Maintain the closure of the pavement on the slope-side of the road, and continue to divert pedestrians onto the footpath on the seaward side of the road.
2. It is not known how effective the current temporary containers would be if impacted by a sizable debris avalanche (as per those discussed in this report). The effectiveness of such temporary risk management measures should be reassessed to ensure they are "fit-for-purpose".

8.3 LONG-TERM ACTIONS

8.3.1 Engineering measures

1. There appears to be reasonable scope to realign the at-risk section of Main Road further away from the bottom of the slope, outside the debris avalanche risk zone.
2. For the section of Main Road within the risk zone, liaise with whoever is responsible for roading in this area to ensure that the debris avalanche risk is fully taken into account in any road design (or in the design of modifications to the road).

8.3.2 Reassessment

Reassess the risk and revise and update the findings of this report in a timely fashion, for example:

a. in the event of any changes in ground conditions; or

b. in anticipation of further development or land use decisions.

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