EXECUTIVE SUMMARY

ES 1 INTRODUCTION

This report brings together recent field information on the Redcliffs site and uses numerical models of slope stability to assess the risk to people in dwellings and users of Main Road from cliff-collapse hazards (debris avalanches and cliff-top recession) at the site, over and above those assessed in an earlier cliff collapse study (Massey et al., 2012a).

Following the 22 February 2011 earthquakes, extensive cracking of the ground occurred in some areas of the Port Hills. In many areas, the cracks were thought to represent only localised relatively shallow ground deformation in response to shaking. In other areas, however, the density and pattern of cracking and the amounts of displacement across cracks clearly indicated large mass movements.

Christchurch City Council contracted GNS Science to carry out further detailed investigations of these areas of systematic cracking, in order to assess the nature of the hazard, the frequency of the hazard occurring, and whether the hazard could pose a risk to life, a risk to existing dwellings and/or a risk to critical infrastructure. This work on what are termed mass movements is being undertaken in stages. Stage 1 is now complete (Massey et al., 2013) and stages 2 and 3 are detailed investigations of mass movements from highest to lowest priority.

The Stage 1 report identified 36 mass movements of concern in the Port Hills project area. Four of these were further subdivided based on failure type, giving a total of 46 mass movements including their sub areas. Fifteen of these were assessed as being in the Class I (highest) relative hazard-exposure category. Mass movements in the Class I category could cause loss of life, if the hazard were to occur, as well as severe damage to dwellings and/or critical infrastructure, which may lead to the loss of services for many people.

Redcliffs mass movement area was assessed in the Stage 1 report (Massey et al., 2013) as being in the highest relative hazard exposure category (Class I, involving potential risk to life). Following the 22 February 2011 earthquakes significant localised cracking was noted in the loess (soil) mantling the steep rock slope and in the cliff face at the Redcliffs mass movement.

This report, as part of the Stage 2 investigations, presents the revised risk assessment results for the Redcliffs Class I mass movement.

ES 2 INVESTIGATION PROCESS AND FINDINGS

Detailed investigations of the site and its history were carried out by GNS Science. These investigations have identified several relict landslides (up to 10,000–15,000 m^3 in volume) at the site that appear to date from before the time of European settlement (about 1840 AD). Rockfalls are also apparent from the steep rock slope in aerial photographs covering the period 1946–1984. The areas of past failures from the slope coincide with the same areas that failed during the 2010/11 Canterbury earthquakes.

The slopes at Redcliffs were significantly cracked during the 22 February, 16 April, 13 June and 23 December 2011 earthquakes. Up to 24,000 m^3 of debris fell from the slope during the 22 February 2011 earthquake and the cliff top recessed by up to 7 m during the 13 June 2011 earthquake.

The relative ground displacements at this site through the 2010/11 Canterbury earthquakes are constrained by the mapping of crack apertures, measured before and after the main earthquakes. The bulk strength of the rock mass forming the slope was weakened by cracking, and in particular, the presence of open surface cracks have made the slope more susceptible to the ingress of run-off water.

The main types of landslide hazard identified at the site are debris avalanches and cliff-top recession, which are a relatively rapid type of landslide involving many hundreds to thousands of boulders. The risk to life of people in dwellings from debris avalanches and cliff top recession hazards associated with the steep rock slope has already been estimated by Massey et al. (2012a).

Further investigation of the site has involved field mapping, ground investigation (comprising subsurface drilling and trenching), laboratory testing, numerical modelling and monitoring (of the features in the field and how they have responded to earthquakes and rain).

The further investigation has identified an additional three potential source areas, where local larger volumes of rock may fall from the cliff, during a triggering event, as single or multiple failures, with the resultant debris travelling further on the valley floor than occurred in the 2010/11 Canterbury earthquakes. This is the reason for the Redcliffs mass movement being included in the Class I (high priority for further investigation) mass movements.

This assessment improves on the original work in Massey et al. (2012a) by taking into account:

1. Large localised failures from three assessed source areas; and
2. Other failures, randomly distributed across the slope.

These three assessed source areas are in addition to the randomly distributed source areas, from which debris could fall from anywhere along the cliff. Numerical models have been used to assess the stability of the Redcliffs slopes, in particular the three potential landslide sources. Analyses have considered both:

- static (without earthquake shaking); and
- dynamic (with earthquake shaking) conditions.

Cliff-collapse hazards

Cliff-top recession and associated debris avalanches pose the greatest landslide hazards and landslide risk to people on the cliff top (Glendevere Terrace) and cliff toe. These slope-instability processes form the basis of the hazard and risk assessments contained in this report.

Under current conditions, it is possible for failure of the slope to occur under either static or dynamic conditions. However, it should be noted that material strengths – and therefore the slope factors of safety – may reduce with time (weathering), water content, and further movement of the slope under either static or dynamic conditions.

For non-earthquake triggers, given the relatively low static factors of safety, an increase in pore water pressures in open tension cracks within the overlying loess and joints within the underlying rock mass could lead to instability of the slope under static conditions (i.e., short duration, high intensity rain) especially where antecedent rainfall has been high.

For earthquake triggers, given the relatively low yield acceleration of the slope, it is likely that future earthquakes could generate permanent displacements that could be quite large, and potentially lead to large volumes of debris falling from the slope. Earthquake-induced failures are likely to be larger in volume and the debris travel further, due to the larger volume, than rainfall-induced failures.

Parts of the slope crest have already undergone more than one metre of permanent slope displacement, during the 2010/11 Canterbury earthquakes and this displacement may have reduced the shear strength of critical materials in the slope, making the slope more susceptible to future earthquakes.

Failure volumes and triggering frequencies

The volumes of rock that could fall from the cliff under dynamic (earthquake) and static (non-earthquake, e.g., rain) conditions have been assessed.

The original cliff-collapse risk assessment by Massey et al. (2012a) was based on future failures that were all randomly distributed across the slope face. The results of the engineering geological assessments identified that although many failures were randomly distributed across the slopes, these failures only accounted for a relatively small proportion of the total volume of rock leaving the slopes. Much of the debris leaving the Redcliffs slope (and other similar slopes in the Port Hills), derived from a few non-random (local) failures that involved larger volumes of rock, particularly in areas where the rock mass strength had been weakened as a result of earthquake-induced cracking.

The volumes of material involved in, and the frequency of, cliff collapse from the slopes are assessed. Three source-volume ranges (upper, middle and lower volumes), and seven earthquake event annual frequencies (representing different ranges of peak ground acceleration), and four non-earthquake event band annual frequencies (representing mainly rainfall triggers) have been modelled. All are uncertain and the frequency of the triggering events is particularly uncertain.

Three scenarios have been adopted for modelling the risk to dwelling occupants and users of Main Road to provide an indication of the range of uncertainty associated with the risk estimates. The three scenarios span reasonable ranges of: 1) the assessed total volume that could be generated in a representative event; and 2) the volume of debris that passes a given distance down the slope.

ES 3 CONCLUSIONS

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

ES3.1 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.

ES3.2 Risk

ES3.2.1 Dwelling occupant

1. There are very few additional dwellings in the revised debris avalanche or cliff recession zones, within the assessment area, 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.

ES3.2.2 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.

ES 4 RECOMMENDATIONS

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

ES 4.1 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.

ES4.2 Short-term actions

ES4.2.1 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 changes in 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.

ES4.2.2 Monitoring alerts and early warning

Monitoring the slope for early warning of potentially dangerous trends in groundwater or slope movement as part of a hazard warning system is not recommended. 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.

ES4.2.3 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.

ES4.2.4 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".

ES4.3 Long-term actions

ES4.3.1 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 taken into account in any road design (or in the design of modifications to the road).

ES4.3.2 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.