1.0 INTRODUCTION

This report uses results from recent field investigation and numerical models of slope stability for the Redcliffs site to assess the risks to people in dwellings and users of Main Road from cliff-collapse hazards (debris avalanches and cliff-top recession. This report provides an update from the original risk assessment for Redcliffs presented by Massey et al. (2012a).

1.1 BACKGROUND

Following the 22 February 2011 earthquakes, members of the Port Hills Geotechnical Group (a consortium of geotechnical engineers contracted to Christchurch City Council to assess slope instability in the Port Hills) identified some areas in the Port Hills where extensive cracking of the ground had occurred. In many areas, 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 that larger areas had moved systematically *en masse* as a mass movement.

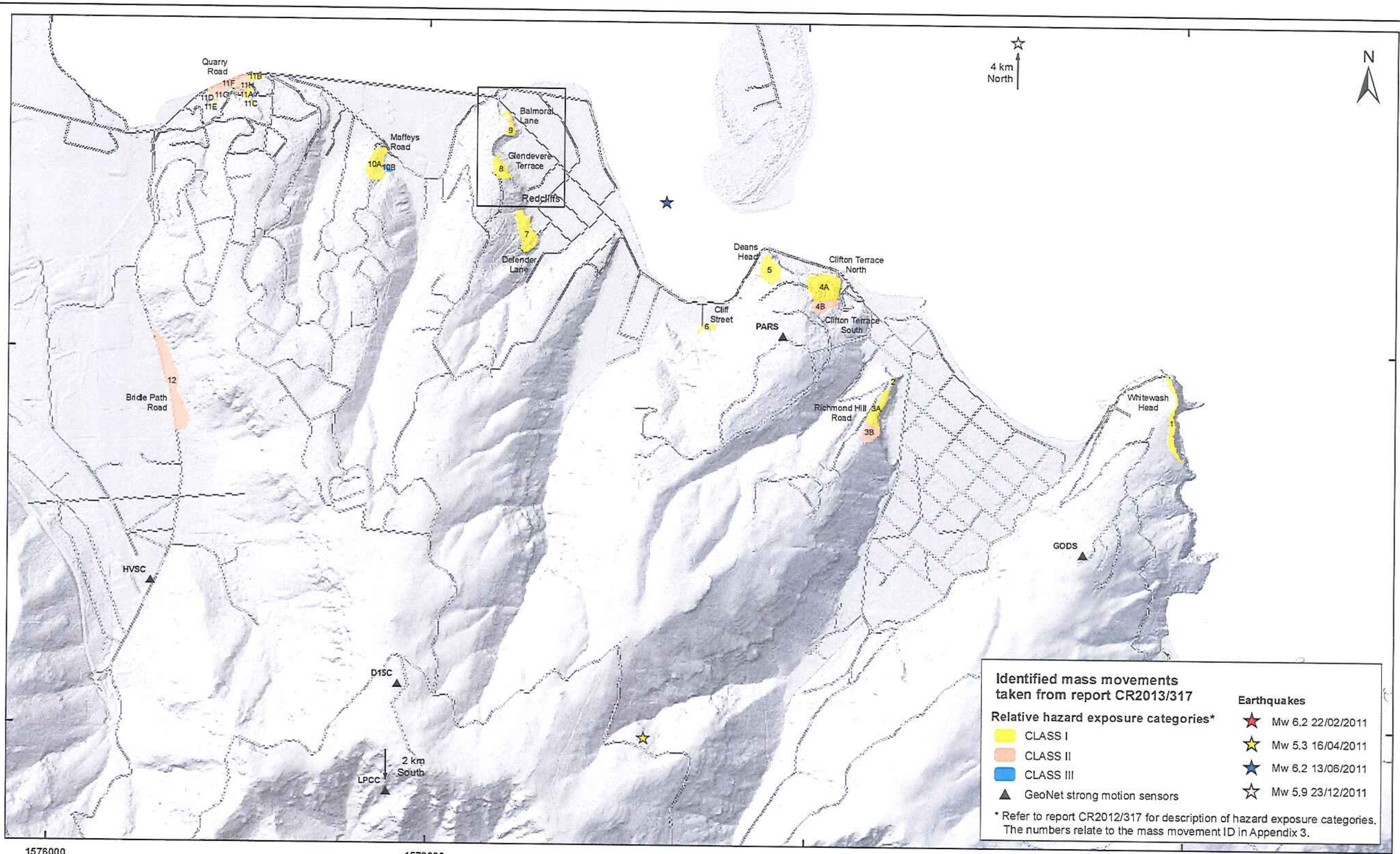
Christchurch City Council contracted GNS Science to carry out detailed investigations of the identified areas of mass movement, in order to assess the nature of the hazard, the frequency of the hazard occurring, and whether the hazard could pose a risk to life, a risk to existing dwellings and/or a risk to critical infrastructure (defined as water mains, sewer mains, pump stations, electrical substations and transport routes). This work is carried out under Task 4 of contract No. 4600000886 (December 2011).

The main purpose of the Task 4 work is to provide information on slope-stability hazards in the Port Hills. This is to assist Christchurch City Council land-use and infrastructure planning and management in the area, as well as to establish procedures to manage on-going monitoring and investigation of the hazards.

The Task 4 work is being undertaken in stages. Stage 1 is now complete (Massey et al., 2013; hereafter referred to as the Stage 1 report) and comprised: 1) a list of the areas susceptible to significant mass movement; 2) the inferred boundaries of these areas (as understood at the time of reporting); and 3) an initial "hazard-exposure" assessment (Table 1) intended only to prioritise the areas with regards to future investigations.

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 (Figure 1). Fifteen of these were assessed as being in the Class I (highest) relative hazard-exposure category. The results of their detailed investigation and assessment are presented in Stages 2 and 3, which includes this (Stage 2) report on the Redcliffs mass movement. The Redcliffs study area includes the Glendevere Terrace (8) and Balmoral Lane (9) mass movements shown on Figure 1. Mass movements assessed as being in the Class I category may cause fatalities severe damage to dwellings and/or damage critical infrastructure leading to loss of services for many people if the hazard were to occur.

The Stage 1 report recommended that mass movements in the Class I relative hazard-exposure category be given high priority by Christchurch City Council for detailed investigations and assessment.



SCALE BAR: 0 0.5 1 km

EXPLANATION:

Refer to Appendices 2 and 3 of report CR2012/317 for maps and more details of each mass movement.

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution.
Roads provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM

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LOCATION MAP

Port Hills
Christchurch

FIGURE 1

Map 1

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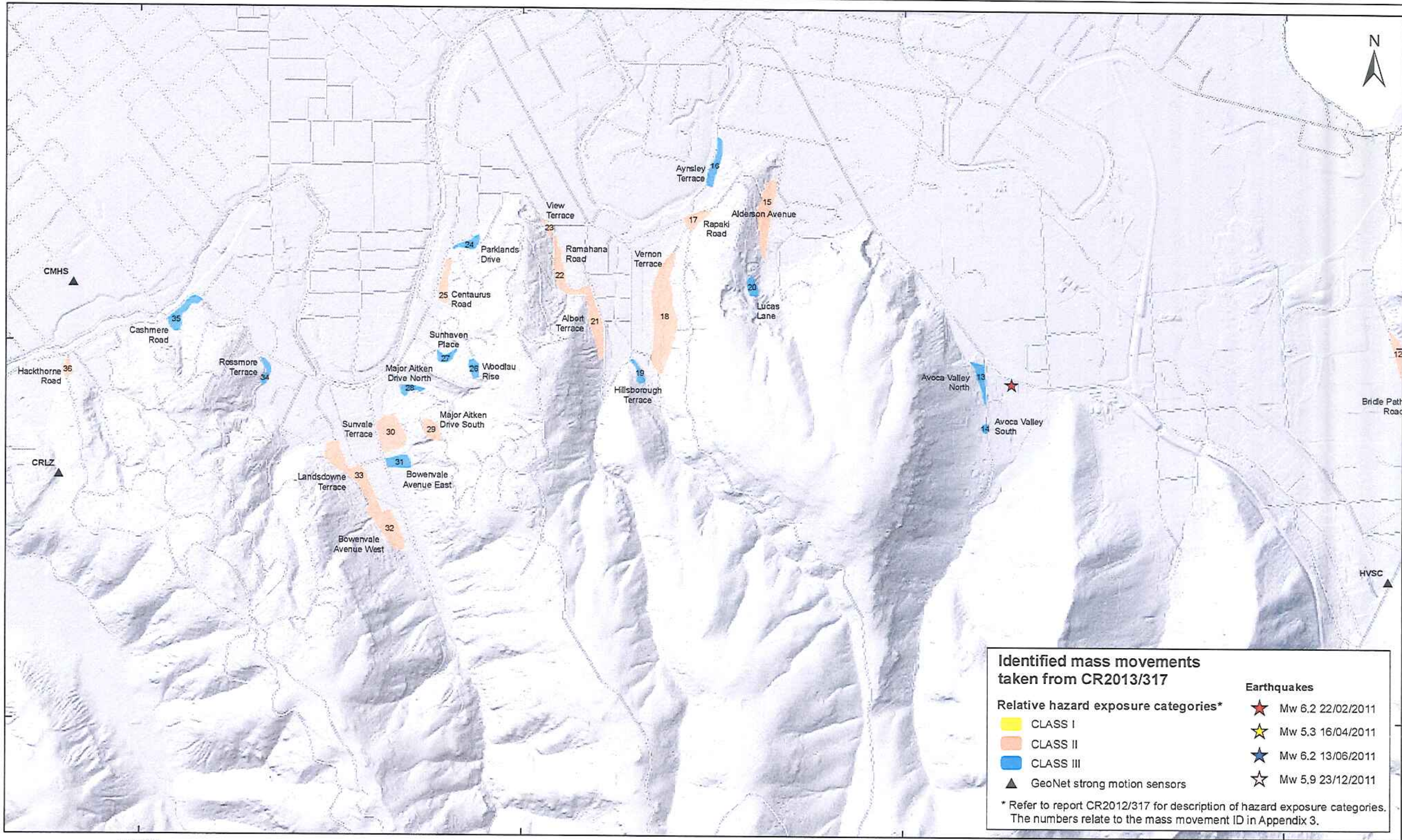

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LOCATION MAP

Port Hills Christchurch

FIGURE 1

Map 2

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Table 1 Assessed mass movement relative hazard exposure matrix (from the Stage 1 report, Massey et al., 2013).

		Hazard Class		
		1. Displacement* greater than 0.3 m and debris runout	2. Displacement* greater than 0.3 m; no runout	3. Displacement* less than 0.3 m; no runout
Consequence Class	1. Life – potential to cause loss of life if the hazard occurs	CLASS I	CLASS III	CLASS III
	2. Critical infrastructure[1] – potential to disrupt critical infrastructure if the hazard occurs	CLASS I	CLASS II[2]	CLASS II
	3. Dwellings – potential to destroy dwellings if the hazard occurs	CLASS I	CLASS II	CLASS III

*Note: Displacements for each assessed mass movements are inferred by adding together the mapped crack apertures (openings) along cross-sections through the assessed mass movements. They are a lower bound estimate of the total displacement, as no account is given for plastic deformation of the mass and not every crack has been mapped.

1 Critical infrastructure is defined, for the purpose of this report, as infrastructure vital to public health and safety. It includes transport routes (where there is only one route to a particular destination), telecommunication networks, all water related mains and power networks (where there is no redundancy in the network), and key medical and emergency service facilities. Networks include both linear features such as power lines or pipes and point features such as transformers and pump stations.

2 This relative hazard exposure category is based largely on an assumption that 'critical infrastructure' exists within these areas. Until further assessments are made on the nature of toe slumps and the existence of critical infrastructure in these areas, the relative hazard exposure category of these assessed mass movements has been appropriately assessed as "Class II". It is likely that many of the assessed mass movements in the Class II relative hazard exposure category (where the hazard class is 2 and the consequence class is 2) would be more appropriately classified as "Class III" following further assessments.

1.2 THE REDCLIFFS MASS MOVEMENTS

The Redcliffs mass movement area is shown in Figures 1 and 2. This 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). During the 22 February 2011 earthquake, two people were killed from falling rock at Redcliffs; one person was inside a dwelling and another was in their garden, both at the bottom of the slope in the debris runout zone. The risk to life of people in dwellings at the slope crest and toe from debris avalanche and cliff top recession hazards (collectively termed cliff collapse) presented in this report provides an update from the original risk assessment for Redcliffs presented by Massey et al. (2012a).

1.2.1 Context and terminology

This report uses the terms: "cliff-top recession" to describe the result of landslides from the top and face of cliffs, and "debris avalanche" to describe the landslide process that inundates land at the cliff foot (referred to as "toe") with countless boulders. The two are collectively referred to as cliff collapse.

Debris avalanche refers to a type of landslide comprising many boulders falling simultaneously from a slope. The avalanching mass starts by sliding, toppling or falling before descending the slope rapidly (>5 m/sec) (following Cruden and Varnes, 1996) by any combination of falling, bouncing and rolling.

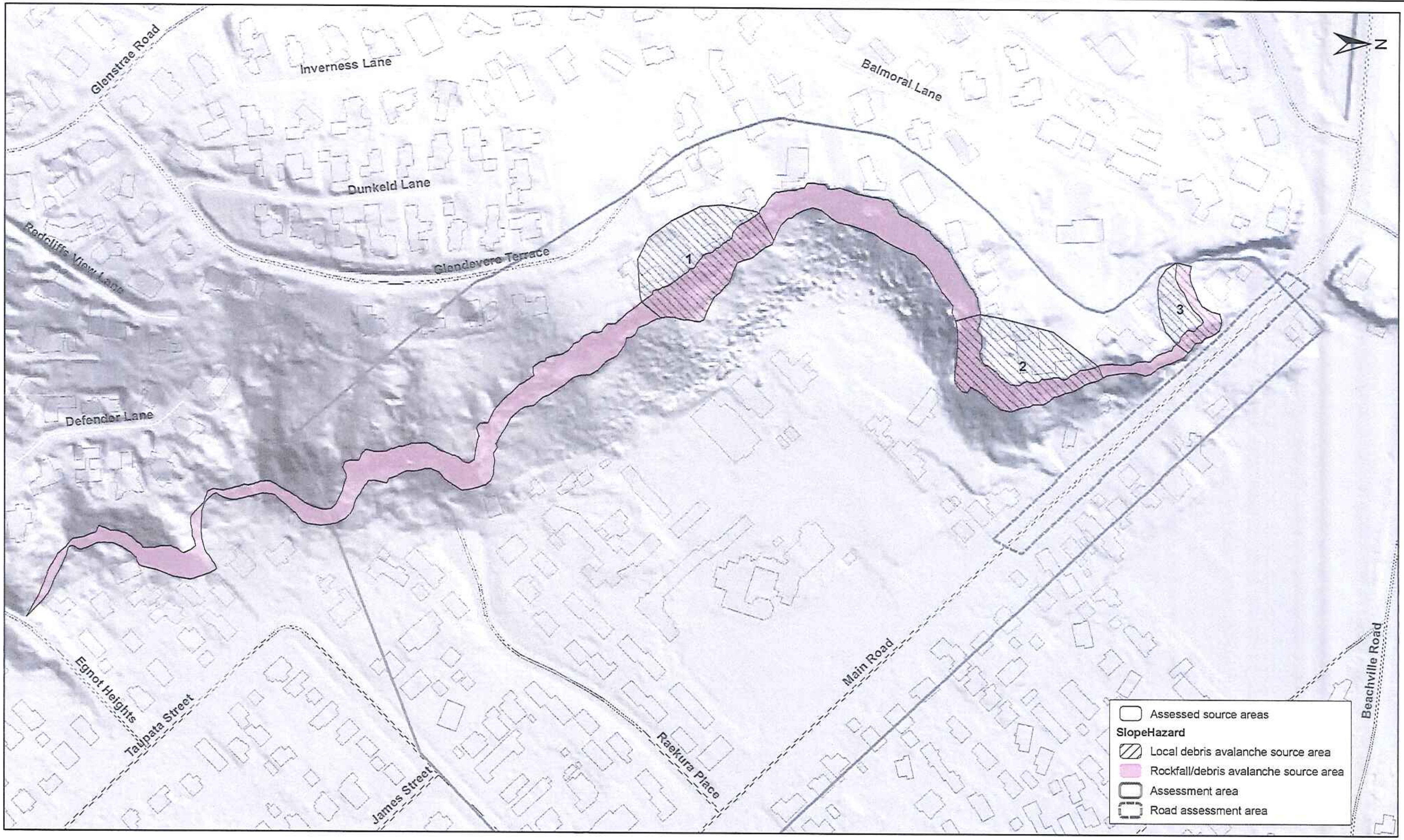
Cliff collapses have been considered separately from the failure and runout of individual boulders, referred to as "boulder rolls". Although cliff collapses and boulder rolls both can be classified as rockfalls (Cruden and Varnes, 1996), the risk analysis for boulder rolls uses information on the location of each fallen boulder. Mapping individual boulder locations in a cliff collapse is impractical because of the large number of boulders involved. The main reason for the difference is that in a debris avalanche the boulders interact with one another, for rockfalls, involving individual boulders, the boulders behave more or less independently.

1.2.2 Local and random cliff collapse source areas

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). During the 2010/11 Canterbury earthquakes many rocks fell from these slopes, forming debris avalanches. The majority of failures involved relatively small volumes of debris, which fell from locations distributed randomly over the cliff face. The larger proportion of the total volume of debris that fell from the slopes however, came from a few much larger volume debris avalanches that were localised "discrete" failures of weaker parts of the rock mass.

The original assessment by Massey et al. (2012a) treated all of the debris avalanches as occurring from random locations anywhere on the slope. The original assessment is now superseded by this assessment, which identifies three specific areas (defined as assessed source areas 1–3) on the slope where local cracking and rock-mass deformation has been focused. These areas are potentially more susceptible to failure during a future triggering event, and could result in local larger volumes of debris leaving the cliff, as single or multiple failures, with the resultant debris travelling further on the valley floor than occurred in the 2010/11 Canterbury earthquakes. These three assessed cliff-collapse source areas are additional to the randomly distributed cliff collapse sources, from which debris could fall from anywhere along the cliff during a future event.

This is the reason for the Redcliffs mass movement being included in the Class I (high priority for further investigation) mass movements. The Redcliffs assessment area is shown on Figure 2 and this report presents: 1) annual individual fatality risks for given users of Main Road; and 2) revised annual individual fatality risks for dwelling occupants, within the given assessment area, which take into account the assessed source areas 1–3. Recommendations are provided to assist Christchurch City Council in considering potential options to mitigate the risk.



SCALE BAR: 0 50 100 m

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 provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM, FDP

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MASS MOVEMENT LOCATION MAP

Redcliffs
Christchurch

FIGURE 2

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