Appendix 8

Redcliffs School: Rockfall Hazard Mitigation

Prepared for Redcliffs School Board of Trustees

412368

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Redcliffs School: Rockfall Hazard Mitigation

On behalf of Redcliffs School Board of Trustees

Quality Control Certificate

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Limitations
This report has been prepared for Redcliffs School Board of Trustees according to their instructions and for the particular objectives described in this report. The information contained in this report should not be used by anyone else or for any other purposes.

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Executive Summary

Eliot Sinclair has been commissioned by the Redcliffs School Board of Trustees to provide expert technical advice to:

- Specifically address the Ministry of Education's concerns (Education Report, Nov 2015) regarding rockfall hazard management;
- Explore rockfall mitigation measures that provide assurance of minimised disruption to education, appropriate levels of safety, and minimised uncertainty; and
- Provide substantially new information regarding rockfall hazard management and disruption mitigation.

Eliot Sinclair has reviewed the MWH's preliminary rockfall mitigation works design (Aug 2014), the Board of Trustees' June 2015 submission, the MoE's experts' reviews of that submission and the subsequent MoE Education Report (Nov 2015), the latter recommending closure of the school.

The MWH design does not address the MoE's key concerns regarding disruption to education that could potentially occur, for example, following a large rockfall event. The site would be at low risk in the context of rockfall risk for that event, but it is the Ministry's concern that uncertainty would remain regarding the time taken to reassess the on-going risk presented by the cliff.

In this regard, performance criteria to minimise disruption to education due to rockfall are necessarily more stringent than those required for safety – in that measures to minimise disruption need to provide assurances in the long-term (over a duration where there could be multiple large rockfall events) without the need for detailed reassessment of the cliff face each time.

We have undertaken a thorough review of the mitigation works design and present a new design that has higher performance requirements, and achieves those requirements via minimisation and, in some instances, elimination of elements of risk that form the basis of the MoE concerns.

The revised design relies on retreating the operational school boundary further from the rockfall source and providing a 2m high bund. With the revised mitigation measures in place there is negligible risk of disruption at Redcliffs School due to rockfall. Another notable benefit is that the maintenance and monitoring requirements are minimised to a very low level with minimal burden on the Board regarding diversion of resources.

There is a strong case for the MoE to review the new information provided in this report and reconsider its decision regarding the future of Redcliffs School, where those parts of its decision relate to rockfall hazard mitigation and minimisation of disruption.

1 Introduction

Eliot Sinclair has been commissioned by the Redcliffs School Board of Trustees to provide technical advice regarding rockfall hazard mitigation measures at the school's site (136 Main Road, Redcliffs, Christchurch).

As a result of rockfall hazard associated with the 2010-2011 Canterbury Earthquakes Sequence the school has been relocated to a site in Sumner. In March 2015 the Education Minister began consultation with the Board of Trustees about the possible closure of the school because of concerns about the long-term safety of the Redcliffs site due to rockfall hazard[1]. In June 2015 the Board of Trustees presented a submission to support the school returning to its Redcliffs site[2]. The submission included technical reporting addressing rockfall hazard management.

In November 2015 the Education Minister made an interim decision to close Redcliffs School because of on-going concern about the unstable cliff behind the school[3,4]. Of critical concern to the Ministry of Education (MoE) was uncertainty regarding the potential for disruption to education due to rockfall.

The Board of Trustees has the opportunity to provide a follow-up submission to the MoE to present new information supporting their case to save the school from closure.

This report addresses technical matters associated with rockfall hazard management and disruption mitigation. It specifically provides new information as part of the technical reporting for the Board of Trustees' submission to inform the MoE's final decision making, where those considerations relate to rockfall hazard management and disruption mitigation.

The subject of rockfall hazard management at the site covers complex matters requiring competency and familiarity with the subject matter and a suite of comprehensive technical reports on which the Eliot Sinclair report is based. References to relevant reports are provided throughout.

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[1] The various Redcliffs reports and submission documents are available at http://shapingeducation.govt.nz/read-more-2/recent-announcements under the *23 March 2015* and *25 November 2015* headings.

[2] Appendix 1 under the *25 November 2015* heading.

[3] *Education Report: Consideration of Closure of Redcliffs School, Christchurch*; 9 November 2015 http://shapingeducation.govt.nz/read-more-2/recent-announcements

[4] *Interim Redcliffs decision announced*; 25 November 2015 https://www.beehive.govt.nz/release/interim-redcliffs-decision-announced

2 Objectives

The objectives of the Eliot Sinclair report are as follows:

1 To review the suite of existing documents and reports relating to rockfall hazard management at Redcliffs School.

2 To provide technical assessment and recommendations regarding rockfall hazard assessment and management at the Redcliffs School site.

3 To provide new information for the MoE to take into account in its decision regarding the future of Redcliffs School.

4 To review the key MoE concerns of <u>safety</u> and <u>disruption to education</u> associated with rockfall hazard management.

5 To provide a rationale for the development of management measures to address safety and to minimise disruption to education.

3 Scope of work

The scope of work was developed to address the Board of Trustees' requirements for their submission, and to address particular topics and provide new information, where appropriate. An outline of our scope of work is as follows:

1 Briefing meeting with members of the Board of Trustees

2 Site inspections

3 Review of existing documents and reports, including the basis of the MoE's interim decision and reports by technical experts commissioned by MoE. The MoE commissioned the following experts to provide their technical advice:

- Mr. Steve Woods, MWH (author of MoE's technical reporting regarding rockfall hazard management at the school site. The MWH 2015 report presents a bund design that addresses safety requirements).
- Dr. Jan Kupec, CERA (provided comments on the Board of Trustees' June 2015 submission).
- Dr. Ian Wright, CCC (provided comments on the Board of Trustees' June 2015 submission).

4 Reporting to provide solutions to the MoE's concerns and the concerns of their technical experts. Following our review of the MoE's and their experts' reports, topics of particular relevance that warranted specific review and comment are:

- Disruption mitigation
- The definition of "safety" as it relates to rockfall hazard management and occupancy of the school site. This topic is linked to an assessment of risk.
- Risk assessment
- Uncertainty mitigation

4 Existing Information

The two main sources of relevant existing information are:

1 The reports and other documents catalogued on the MoE's Shaping Education website http://shapingeducation.govt.nz/read-more-2/recent-announcements under the headings of the 23 March 2015 and 25 November 2015 decisions.

Key documents include:

- Education Minister's Nov 2015 press release
- MoE Education Report (Nov 2015)
- Board June 2015 submission, including June 2015 AECOM report
- MWH 2014 report
- CERA, CCC and MWH review comments on the Board's submission
- May 2015 Experts' meeting minutes

2 The suite of GNS Port Hills geotechnical reports catalogued on the Christchurch City Council's website http://www.ccc.govt.nz/environment/land/slope-stability/port-hills-gns-reports/

GNS' portfolio of reports[5] developed as part of the CCC's response to land stability management, District Plan recommendations regarding natural hazards, and CERA's decisions regarding land zoning[6].

Key documents include:

- Risk Assessment for Redcliffs (2014/78); Massey et al. 2014
- Principles and Criteria for the Assessment of Risk from Slope Instability in the Port Hills, Christchurch (2011/319); Taig et al. 2012
- Pilot study for assessing life-safety risk from cliff collapse (2012/57); Massey et al. 2012

We inspected a suite of other existing reports dating back to rockfall technical advice following the 4 September 2010 earthquake, where rockfall hazard became evident at the school site. Several other reports followed by various authors and their peer reviewers, but of primary relevance to the current risk assessment are those items listed above.

[5] Refer to http://www.ccc.govt.nz/environment/land/slope-stability/port-hills-gns-reports/

[6] Refer to http://cera.govt.nz/port-hills

5 New information

New information presented in this report includes:

1 Eliot Sinclair's independent expert review and assessment of MoE's and their experts' technical concerns. We have reviewed the MoE's Education Report (Nov 2015) and associated documents and identified their key concerns with regard to disruption to education.

2 Clarification of the MoE experts' comments and concerns via meetings with MoE expert advisors. We have reviewed the MoE experts' reports and, where warranted, met with them to specifically understand the background to their comments[7].

3 Definition of safety appropriate for rockfall risk management at the school site

4 Definition of risk levels and their relevance to the school site

5 Modelling and verification of rockfall hazard

6 Revised rockfall hazard mitigation works specifically tailored to address MoE's concerns. These measures include the definition of a revised operational school boundary beyond which the risk of disruption is negligible.

7 On the basis of the definition of risk and safety at the school it is possible to provide assurances of safety and minimisation of disruption to as low as practically possible within the school site.

[7] Meeting between Ian Wright and Nick Harwood; 19 February 2016. Meeting between Jan Kupec and Nick Harwood; 1 March 2016. Meeting between Stephen Woods and Nick Harwood; 23 March 2016

6 Ministry of Education's concerns

6.1 Introduction

The MoE's concerns are expressed in their Education Reports (March 2015 & November 2015) and the associated media releases (25 March 2015[8] & 25 November 2015[9], respectively).

The MoE concerns fall into three main categories:

- Disruption to education
- Planning for return to site
- Local schooling policy e.g. Redcliffs closing and other schools absorbing the pupils
- This report addresses the technical matters associated with rockfall hazard management, which we have categorised as relating to disruption to education, safety and uncertainty. Disruption to education is the primary MoE concern and is interlinked with the topics of safety and uncertainty.

The new information particularly relates to topics and issues raised by the MoE and its expert advisors. We met with the MoE's experts to get a better understanding of their reported comments. These meetings helped inform the scope of work to be addressed in our reporting. Rather than picking out individual items from the MoE report and their experts' reports we present a review of key topics, then a solution to those concerns by way of a revised operational school boundary and a revised bund location and design.

The Ministry response has emphasised risk as the key decision influence, without specifying what level of risk they are willing to accept. The MoE infers they are not willing to accept any disruption, but this not achievable for a school in New Zealand given our exposure to multiple natural hazards. We discuss this topic further in the report.

6.2 MoE concerns - details

A Beehive press release[10] gives a succinct account of the Education Minister's concerns. We present an extract of Education Minister Hekia Parata's 25 Nov 2015 press release below. We have added reference numbers to identify the specific concerns, which provide the basis for the Eliot Sinclair reassessment and provision of technical advice to the Board of Trustees. Greater detail is provided in the MoE Education Report (Nov 2015), but the essence of the concerns is presented in the press release.

Comments by the Education Minister regarding the Board's June 2015 submission:

"...I have considered the submissions, including expert advice, and I remain concerned about **(1)** the potential for future disruption to education provision if the school returns to the Main Road site".

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[8] 23 March 2015 media release at http://shapingeducation.govt.nz/read-more-2/recent-announcements.

[9] 25 November 2015 media release at https://www.beehive.govt.nz/release/interim-redcliffs-decision-announced.

[10] 25 November 2015 Beehive press release at: https://www.beehive.govt.nz/release/interim-redcliffs-decision-announced

"While the school's board has argued that **(2)** circumstances that could give rise to potential disruption are extremely unlikely, advice from technical experts has shown these concerns cannot be ruled out."

"The situation is further complicated by uncertainty over **(3)** which agency or agencies would be responsible for deciding on a return to the site following a significant event, **(4)** the private ownership of the land behind the school and **(5)** the fact that no agency is currently monitoring the cliff face"

"Although not the primary reason for my decision, I am also concerned about the uncertainty of **(6)** the likely timing of a return to the Main Road site. As I understand it, there is still no timeframe set for the removal of the houses from the cliff-top and no work can begin until this happens.

"**(7)** It has already been five years since the school was on its site. It could be several more years".

The numbering of these concerns cross-references to our responses in Section 13.2 that follow our assessment of risk and safety, and the presentation of the revised mitigation measures.

7 Review of existing proposed mitigation measures

The MoE commissioned MWH to provide expert advice regarding rockfall mitigation measures at the site. MWH's latest report (dated Aug 2014)[11] presents a rockfall bund solution. The preliminary design is for a 4m high rockfall barrier along the southwest and northwest boundaries of the school site (excluding the area of the former school hall). Refer to Figure 1, below (extract from MWH, 2014; Appendix A).

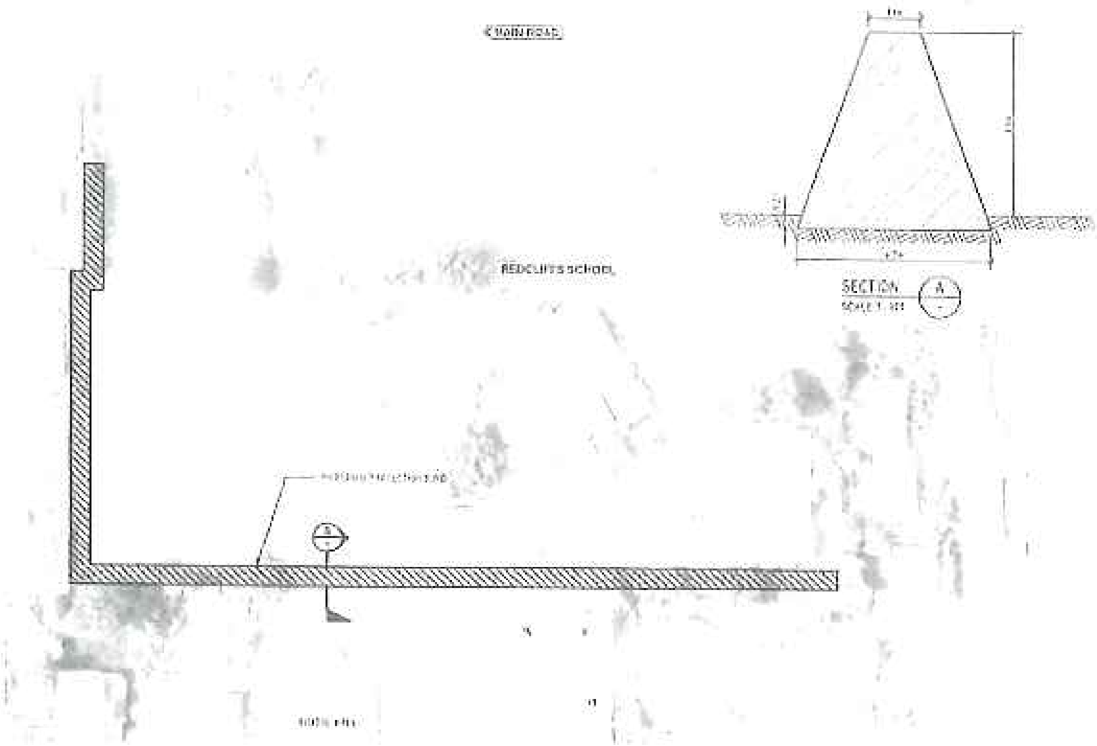

Figure 1 Location and preliminary design of bund (extract from MWH, 2014)

There is consensus with MoE and its experts that the preliminary MWH bund design is conservative and provides a suitably low risk environment for the school grounds and its occupants. Safety with this design is related to protection against a large rockfall event, but such an event would then require a detailed reassessment of the cliff face – which would be of uncertain duration to undertake, and requiring the school to be unoccupied whilst the review was undertaken.

Performance criteria to minimise disruption to education due to rockfall are necessarily more stringent than those required for safety – in that measures to minimise disruption need to provide assurances in the long-term (over a duration where there could be multiple large rockfall events) without the need for detailed reassessment of the cliff face each time.

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[11] Appendix1 to the MoE March 2015 Education Report http://shapingeducation.govt.nz/read-more-2/recent-announcements

Disruption mitigation and **safety** would be the primary objectives for rockfall mitigation measures to address yet from reading MWH's report they only address safety.

8 Disruption to education

"Uninterrupted education" cannot be provided in any part of New Zealand, largely due to our exposure to multiple natural hazards, including earthquakes, floods and storms. In recognition of this MoE[12], MCDEM[13] and CCC[14] disaster planning advice specifically covers planning and preparedness for multiple types of disruptive events.

The MoE guidance identifies the following potential causes of disruption: fire, earthquake, tsunami, flooding, volcanic eruption & ashfall, gas leak, chemical spill, dealing with suspicious letter or package, bomb threats, trespasser on the school grounds and violent intruder.

Additionally, the MoE's school design guidance[15] has as a design principle requirement: "To ensure that all occupants are adequately protected from injury in the event of a significant natural hazard or man-made disaster event". The requirement is specifically in recognition of the potential for disruptive events that are a reality of living in New Zealand.

CCC provides an education programme called 'Stan's Got a Plan' to supplement the delivery of CDEM education in the classroom. The CCC advice states:

Take your pick from the following 5 disasters, most likely to affect us here in Canterbury, to focus your 'Stan's Got a Plan' experience:

- *Earthquakes*
- *Flooding*
- *Pandemic*
- *Tsunami*
- *Storms*

Setting an expectation or a threshold requiring "uninterrupted education" as a performance threshold for Redcliffs School is not a realistic or achievable performance target.

It is inconsistent with planning and preparedness advice for schools recommended by central and local government agencies. Also, it is inconsistent with the provisions of the NZ Building Code (Clause B1 Structure[16]) and the MoE's school design guidance[17], which cites the NZBC as a minimum standard.

[12] MoE guidance Preparing for and dealing with emergencies and traumatic incident: http://www.education.govt.nz/school/student-support/emergencies/

[13] MCDEM disaster guidance for schools: http://www.civildefence.govt.nz/get-ready/at-school/

[14] CCC disaster preparedness guidance for schools: http://www.ccc.govt.nz/services/civil-defence/being-prepared/school-education-programmes/

[15] MoE Structural and Geotechnical Guidelines for School Design: http://www.education.govt.nz/school/property/state-schools/design-standards/structural-and-geotechnical-guidelines/

[16] Building Code Clause B1 Structure: http://www.building.govt.nz/compliance-documents#B1

[17] MoE Design standards for school property: http://www.education.govt.nz/school/property/state-schools/design-

The rockfall protection works may require a Building Consent as would the construction of school buildings, and hence, both types of work (rockfall protection works and school buildings) must satisfy provisions of the Building Act 2004[18].

For school buildings the performance requirements of Clause B1 Structure[19] are stated as a *low probability* threshold for non-compliance for life-safety and amenity functions – not a requirement to "guarantee" the uninterrupted function of a building, largely because this is not achievable, or cost-effective, and at odds with a principle of risk management practice to mitigate risks to acceptability low levels – as per the CCC programme for residential land stability risk management.

The MoE design standard can require compliance "above and beyond the Building Code requirements" (ref. Section 1.3, page 6). The normal course to require a higher performance standard is to increase the NZS1170.0 *Importance Level* of the structure, such that it must comply with the performance requirements at increased load demands due to wind, snow, and earthquake[20].

A principle of the proposed rockfall mitigation works is that they function and comply with their performance requirements (safety, rockfall storage and minimise disruption risk) under seismic demand well in excess of the load actions that the school buildings would be designed to (assumed to be IL3[21]).

The indicative peak ground acceleration (PGA) for geotechnical design of buildings at the site is ULS IL3 is 0.5g. The rockfall mitigation works are designed to function and comply with their safety and storage requirements at earthquake demand in excess of 1.0g, and for multiple earthquake events of this severity (refer to Appendix B).

With regard to the rockfall mitigation works instead of expecting "uninterrupted education" we suggest the achievable alternative requirement, which is to undertake robust risk management to reduce risks to acceptable levels. This is what we have undertaken. This approach is consistent with the Building Act's performance requirements and also consistent with the new Health and Safety at Work Regulations[22] approach to risk management.

The report provides a commentary on the definition of acceptable risk level. The commentary is based on GNS's comprehensive risk assessment work[23] that informed local and central government agencies (CCC & CERA, respectively) in their decision making regarding residential land stability risk in the Port Hills, which is of direct relevance to Redcliffs School albeit requiring interpretation relevant to a school site, which we present below.

standards/

[18] http://www.legislation.govt.nz/act/public/2004/0072/latest/DLM306036.html

[19] Clause B1.3.1 (life-safety) and B1.3.2 (amenity)

[20] Ref Section 3; NZS1170.0 Structural Design Actions

[21] Load levels for seismic design of school buildings are provided in Section 2.3 of the MoE design standards. Importance Level 3 (IL3) is the highest design standard applicable to school buildings. http://www.education.govt.nz/school/property/state-schools/design-standards/structural-and-geotechnical-guidelines/

[22] Health and Safety at Work (General Risk and Workplace Management) Regulations 2016 http://www.business.govt.nz/worksafe/hswa/legislation/hswa-regulations

[23] GNS reports 2014/78 & 2011/319 at http://www.ccc.govt.nz/environment/land/slope-stability/port-hills-gns-reports/

9 Risk assessment

9.1 Introduction

The topics of risk and safety are inextricably linked and both have been raised as topics of concern by the MoE[24] and its expert advisors. We infer that the experts' comments are likely to have influenced the MoE's perception of the engineering risk associated with the proposed rockfall mitigation works, so we have specifically addressed these comments.

The rationale for a definition of safety is presented below. A pre-requisite of the discussion is familiarity and competency in the comprehensive risk assessment reports undertaken by GNS, and other relevant industry documents used and referred to by the engineering community in our routine practice.

9.2 Safety for a school site

9.2.1 Rationale

Necessarily, the definition of *safety* starts with reference to reporting on safety and risk associated with occupancy of residential properties in land stability risk areas on the Port Hills. It is recognised that the CCC's Rockfall Protection Structure design guidance and the GNS reports were specifically tailored for residential risk assessment, but they can be appropriately used to derive significant and valuable information relevant to the Redcliffs School site.

The derivation of a suitable definition of *safety* is as follows:

1. "Council requires that any Rockfall Protection Structure (RPS) demonstrably reduces the Annual Individual Fatality Risk (AIFR) at the dwelling or structure to be protected to below the adopted tolerable risk limit of 10^{-4} announced by the Minister for CER on 29 June 2012." This statement is a key design consideration stated in the CCC's Rockfall Protection Structure Design guidelines, 2013; page 5, section 3.2. It is consistent with the recommendations of GNS report 2011/319; page 35.

2. GNS (Report 2011/319; page 36) recommends that for a school site the acceptable AIFR should be 100x lower than for residential land use. This is on the basis of a school having a higher number of occupants than a house, a greater societal sensitivity to a school than a house, and thus a more stringent relative threshold of tolerable risk is warranted. As 10^{-4} has been adopted by local and central government agencies (CCC and CERA, respectively) as their decision threshold for residential properties on the Port Hills, we suggest that 10^{-6} is a suitable starting point as to where to set an equivalent threshold for Redcliffs School.

3. From GNS Report 2014/78 (Fig. 38, page 99) the outer limit of the modelled 10^{-5} AIFR contour (i.e. modelled as *less than* 10^{-5}) is essentially at the existing school boundary (excluding the area with the existing school hall). The AIFR *less than* 10^{-5} line is also the modelled fly-rock limit line (Fahrboeschung angle, F = 31°) i.e. the outer limit to which small rock fragments are expected to travel.

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[24] MoE Education Report executive summary para. 2; 9 Nov 2015.

5. GNS (Report 2012/57, page 98) concludes the risk beyond the 31° fly-rock angle is <u>less than AIFR 10^{-6}</u> i.e. any land beyond the F = 31° line has an AIFR **at least 100x less than** that adopted for residential zoning purposes, and at a threshold consistent with the GNS recommendation for land used for school purposes. Also, the Port Hills Geotechnical Group (PHGG) states [in GNS Report 2012/57; Appendix E, page 110] *"GNS have indicated that the 31° Fahrboeschung (F) Angle represents the maximum observed run out distance for flyrock associated with debris below a collapsed cliff. This represents the "negligible rockfall risk line"*

6. In its appraisal of risk assessment sensitivity to uncertainties GNS (2014/78; Section 6.3.3, page 113) states with regard to debris run out *"...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 run out to Fahrboeschung angles of 30°, the likelihood of them doing so is relatively low (as demonstrated by the past run out of debris at the site)".* GNS is referring to uncertainties in the empirical and modelled debris run-out (rock roll) distances at the extremities (distal extent) of a debris avalanche.

9.2.2 Definition

On the basis that land beyond the F = 31° line has an AIFR **at least 100x less than** that adopted for residential zoning purposes, and at a threshold consistent with the GNS recommendation for land used for school purposes we define <u>land beyond the F = 31° line as being safe for school use in the context of rockfall hazard management</u>.

In Section 10 we present our revised mitigation measures and their stringent performance requirements, that define a revised operational school boundary even further beyond the F = 31° line.

9.3 Tolerable risk for a school site

The commentary presented above is based on the assumption of their being an acceptably low risk of fatality, which is based on the risk profile adopted for a residential building.

Using the GNS risk criteria for residential thresholds we define land beyond the F = 31° contour (AIFR *less than* 10^{-6}) as *safe* for school purposes without the need for a physical barrier (bund) i.e. the separation distance from the hazard (rockfall source) is the primary means of minimising risk. However, there are a number of important considerations we have taken account of in our risk assessment of the school land, as follows:

- There is uncertainty in the debris run-out modelling, although at the extremities of the observed debris avalanches reported by GNS there is strong evidence that the risk of debris exceeding the F = 31° line is very low (it can occur, but the risk is very low);
- Although there is sound science and a rich database of observations to rely on, non-technical people may not be able to grasp the science and accept the low level of risk without the presence of some form of physical protection measures. Also, the lay-person may not be able to relate to the relative risks they are exposed to on a daily basis that can exceed the risk to their well-being presented by rockfall at the Redcliffs site (this comment is in recognition of the topics of "perceived risk" and "societal risk");

- In our opinion the measure of an acceptable risk of fatality is not appropriate for a school setting. We would expect a school to be able to demonstrate protection to a level that leaves negligible doubt as to the risk of fatality due to rockfall whilst present on the school site.

For these reasons, we recommend that although the school boundary could be retreated into the school land (see comments below) to provide a negligible exposure to life safety risk, it is prudent and warranted to construct a physical barrier to provide a heightened sense of protection and safety within the school's grounds.

With the revised mitigation measures in place there is negligible (virtually nil) risk of harm due to rockfall at the Redcliffs School site. At such a low level of risk we adopt this level as tolerable for the school.

9.4 Societal risk

The question of societal risk has been raised and was touched upon by GNS in their Port Hills risk review (GNS Report 2011/319; Section 3.1.2). The UK's Health and Safety Executive[25] defines societal risk as:

The relationship between frequency and the number of people sustaining a specified level of harm in a given population due to the realisation of specified hazards. This factor can help to reflect societal concerns that arise (e.g. when multiple fatalities or injuries occur) in planning advice.

With the revised mitigation measures in place there is negligible (virtually nil) risk of harm even to an individual due to rockfall within the revised operational school boundary. Consequently, the "societal risk" of returning to the Redcliffs site is also negligible (virtually nil).

[25] HSE (2009) Societal Risk: Initial briefing to Societal Risk Technical Advisory Group http://www.hse.gov.uk/research/rrpdf/rr703.pdf

10 Revised mitigation measures

10.1 Overview

We have undertaken a thorough review of the MWH preliminary design and present a new design that has higher performance requirements, and achieves those requirements via minimisation and, in some instances, elimination of elements of risk that form the basis of the MoE concerns.

Figures presenting the revised operational school boundary, the bund location and the service road location are presented in Appendix A.

The assessment of the location of the revised operational school boundary is presented in Appendix B. The revised boundary is based on the highly conservatively established F=26° fahrboeschung angle line. There is ample rock debris catch capacity, no need for monitoring or risk reassessment of the cliff would be required and no requirement to enter 3rd party land should rock need to be removed (which is highly unlikely).

The assessment of the bund design is presented in Appendix C. The bund is a 2m high gabion basket wall that is no higher than a typical wood paling boundary fence. At the distant location of the bund from the cliff face there is no need for a flyrock fence.

10.2 Performance criteria

Our assessment of a revised operational school boundary to (i) maintain safety to a high level, and (ii) minimise disruption to as low as practically possible, is based on GNS's slope stability modelling and runout modelling (GNS 2014/78; Sections 4.1 & 4.2, respectively).

To achieve the aims to minimise disruption, maintain safety and minimise uncertainty we set the following performance objectives:

- Risk of fatality within the school grounds shall be nil
- Establish a revised operational school boundary at a conservatively located set-back
- No rock shall cross the revised boundary
- Minimise risk of rock impacting or damaging the bund
- Minimise risk of rock requiring clearance from behind the bund (in the catch area)
- Minimise maintenance and monitoring requirements
- Provide conservatively established ample storage capacity such that in the event of multiple large volume rockfall events, the rock is well contained in the catch area, and there be no need for detailed reassessment of the slope stability.
- Avoid the need for 3rd party land access

As noted previously, performance criteria to minimise disruption to education due to rockfall are necessarily more stringent than those required for safety – in that measures to minimise disruption need to provide assurances in the long-term (over a duration where there could be multiple large rockfall events) without the need for detailed reassessment of the cliff face each time.

We note that whereas "safety" can be defined in terms of the AIFR metric, there is no performance criteria in terms of a "disruption tolerance". In the absence of performance criteria or a tolerance threshold for disruption, we have considered whether it is possible to eliminate or reduce the risk of disruption to *negligible* in the long-term (over a duration where there could be multiple large rockfall events). This involves a bund design that avoids the need for detailed reassessment of the cliff face each time there is a rockfall.

The revised rockfall mitigation measures will reduce the rockfall risk to the pupils and staff to negligible levels, and will at the same time provide the added benefit of reducing the risk of disruption to learning to negligible levels (as far as is practicable with engineering works). The proposed works address the inherent uncertainty in the GNS risk assessment and stability modelling, and recognise the need for elevated protection and safety assurance for a school site.

10.3 Revised operational school boundary

The proposed works comprise two forms of protection, the components of which are as follows (in order of priority):

1 Horizontal **separation distance** from rockfall source to a revised school boundary referred to as the operational school boundary. The legal boundaries do not change. It is the operational area that is changed being defined by revised operational school boundaries.

The revised school boundary is approx. 100m from the cliff face (at its nearest point), which provides the primary hazard mitigation – physical separation from the rockfall source zone.

The figures in Appendix A show the proposed bund location. The revised operational area of the school is approx. 14,400m^2, with the balance land measuring approx. 8,500m^2 (refer to Sheet 2).

2 A 2m high engineered **bund** provides a physical barrier to prevent runout crossing the revised operational boundary, in the highly unlikely event rocks travel beyond the limits of expected and observed runout.

The bund is a low-tech barrier with high resilience to multiple impacts. Is it unlikely the bund would be impacted in rockfall events of similar magnitudes to those experienced in the Canterbury Earthquakes, so the risk of damage warranting repair is accordingly low. In addition, the bund location allows for storage of a large volume of rock debris; the area between the bund and the cliff is more than capable of holding worse-case rockfall events with negligible risk of disruption to the school.

10.4 Maintenance

With regards to on-going maintenance the bund is a low-tech structure requiring negligible maintenance.

It is proposed to use gabion baskets (e.g. Geofabrics®[26] or similar approved) to build the bund. The gabion baskets are a rectangular wire mesh box made from double twisted hexagonal mesh of steel wire, additionally reinforced by selvedges of heavier wire. Gabions are available with different levels of coating protection for durability in a wide range of environments and climatic conditions. Gabions are manufactured from Galmac (Zn-5%AL MM alloy) coated wire that offers around three times greater protection than zinc coated wire gabions. Where gabion baskets come in contact with more aggressive environments, then an additional polymer protective coating is applied over the Galmac coating to maximise the level of protection.

The bund's location at (or beyond) the F=26° contour (refer to Appendix A) means that it is highly unlikely to be impacted or damaged should rockfall occur during its design life. In the unlikely event that damage occurred this is likely to be localised indentation of the bund. Repairs would be straight-forward.

Additionally, rock removal behind the bund is unlikely to be required, but access is provided should the need arise. These considerations have been taken into account in the design and location of the bund to specifically limit the requirement for maintenance. Concerns regarding on-going maintenance are effectively eradicated due to bund's location and its low-tech form of construction and materials.

[26] http://www.geofabrics.co.nz/products/double-twist-mesh/gabion-baskets/

10.5 Compliance monitoring

With regards to monitoring the bund may need a Building Consent and as such would require *compliance monitoring* consistent with the CCC's requirements for other similar protection structures[27]. An indication of the form of compliance monitoring that might be required is as follows (extract from Appendix 5 of the CCC's guidance):

STRUCTURE	Maintenance Inspection	Trigger3 Event	Engineering Inspection
Bund	Annual check, rock clearance and certificate – by Engineer[1]	Inspection required post trigger event - by Engineer[1]	10 yearly check with cert signed by Engineer[1] unless otherwise specified by the Designer
Fence	Annual check, rock clearance and certificate – by Engineer[1]	Inspection required post trigger event - by Engineer[1]	5 yearly check with cert signed by Engineer[1] unless otherwise specified by the Designer
Source Rock Fixing (e.g. cable, bolt, mesh)	Annual check, rock clearance and certificate – by Engineer[1]	Inspection required post trigger event - by Engineer[1]	5 yearly check with cert signed by Engineer[1] unless otherwise specified by the Designer
Source Rock Zone	As advised by Geoprofessional or if rockfall has been observed in the immediate area	Inspection required post trigger event - by Engineer[1]	5 yearly check with cert signed by Engineer[1] unless otherwise specified by the Designer

Notes:

1. Engineer must be a qualified approved Geoprofessional (with required specified insurances). A list of Approved Geoprofessionals is available on the Council's web page at www.ccc.govt.nz/business/constructiondevelopment/approvedcontractors.aspx
2. Responsibility for all compliance checks, submission of documentation and the costs associated with these, rests with the owner of the RPS.
3. Trigger events will be defined in conjunction with GNS. Trigger events will include non-seismic factors e.g. rainfall, fire

There are several approved Geoprofessionals who can undertake the compliance monitoring, which would be consistent with the monitoring required for other recently constructed similar structures in Christchurch. The details of the monitoring would be developed at the time of Building Consent and be tailored for the site and the final design and layout of the mitigation measures.

[27] CCC Technical Guideline for Rockfall Protection Structures: http://www.ccc.govt.nz/assets/Documents/Consents-and-Licences/construction-requirements/approved-contractors/techguidelinerockfallprotectionstructures-mar2013.pdf

It is important to recognise that the bund is located at a deliberately far distant location from the rockfall source (at or beyond the F=26° contour) with many benefits relating to rockfall hazard mitigation and disruption mitigation compared to the MWH design (see Section 7).

The highly conservative design and layout is such that even for large volume rockfall events the material will be amply contained and the requirement to undertake detailed, time-consuming, costly rock source monitoring is not warranted.

The monitoring plan would be developed in conjunction with the CCC and specifically tailored for the school site and the rockfall source, taking into account the highly conservative design and bund layout.

Our recommended monitoring plan is presented below (Table 1). This maintenance and monitoring plan would be appropriate for the mitigation works whether a Building Consent is needed or not - as part of the school's administrative management systems.

Key benefits of the monitoring plan include:

- It recognises that the mitigation measures are so conservative that (in lay terms) "it does not matter" if there is a large rockfall, or a series of large rockfalls. The risk of disruption to education due to rockfall is negligible, and safety is not compromised.
- The Board holds the authority to allow occupation of the school as it does for other potentially disruptive events for which there are MoE, CCC and MCDEM recommendations and requirements for emergency management. The risk presented by the rockfall hazard has been reduced to such a low level (negligible) that other potential hazards (notably the background Canterbury earthquake hazard that governs building design) is a higher risk to be managed.
- It minimises the cost burden on the Board to as low as practically possible as it is highly unlikely that the Engineer would need to be called out, and it is highly unlikely rock debris would need to be removed from the catch area behind the bund.

Table 1: Recommended monitoring plan with the revised mitigation measures in place

Structure	Maintenance inspection	Trigger event	Engineering inspection
Bund	Annual check by caretaker or authorised school management representative	No **earthquake** or **rainfall** trigger event criteria required. Efficacy of the mitigation measures is not dependent on the condition of the source zone. Engineering inspection required if there is **fire** damage to bund wire mesh e.g. due to scrub fire in catch area (highly unlikely).	10 yearly check with certificate signed by Engineer or At any time rock debris is observed to have reached the bund. Requires certificate signed by Engineer. (Rock debris is likely not required to be removed). or Fire damage to bund wire mesh. Requires certificate signed by Engineer to cover suitable low-tech repairs.
Fence (School perimeter fence)	Annual check by caretaker or authorised school management representative.	Not applicable.	Not applicable.
Source rock fixing	Not applicable. There is no rock source fixing.	Not applicable.	Not applicable.
Source rock zone	Not applicable. Efficacy of the mitigation measures is not dependent on the condition of the source zone.	Not applicable.	Not applicable.

Notes:

The fence (if required) would be on the school side of the bund and is there to prevent pupils climbing of the bund. The fence is not part of the mitigation works – it is part of normal school perimeter security fencing.

11 Peer review

We held meetings with the MoE's experts to discuss their review comments[28] and also to present our revised mitigation measures for their comment. We were also interested to understand the scope of each expert's review of relevant technical reports, including:

- Experts' meeting minutes (May 2015)
- MWH (2014) report
- AECOM (2015) report – this report is Appendix A to the Board's June 2015 submission.

11.1 Mr. Stephen Woods, MWH

We met with Mr. Woods on 23rd March 2016 to discuss the MWH preliminary design, discuss his comments to MoE (Appendix 5 to the MoE Nov 2015 Education Report) and present the revised mitigation works.

Mr. Woods commented that the revised design probably added little increase in effective safety requirements as the MWH preliminary design was already conservative.

We discussed that the revised design goes beyond the requirements to address safety, and that the performance criteria to minimise disruption we more stringent. Mr. Woods concurred and we then discussed that with such a high degree of conservatism in the revised design that it was not warranted to monitor the cliff face..

On review of Mr. Woods' comments to MoE we are satisfied that we have suitably addressed those via our risk assessment and revised mitigation works. Notably -

1 The issue of approving continued use of the school site following a large rockfall has been resolved. The proposed maintenance and monitoring plan presented in the report sets out the simplified process, and identifies the Board as the party responsible. Monitoring can now be done as a simple exercise without placing undue expectations on the Board.

   There are identified events where an Engineer's opinion should be sought, but these are unlikely events and the risk of disruption due to rockfall is negligible.

2 The requirement to assess the cliff hazard and risk following a large rockfall has been eradicated, and so has any concern regarding regulatory requirements to do an assessment and the timeframe for such work.

11.2 Dr. Ian Wright, CCC

We initially met with Dr. Wright on 19th February 2016 to discuss his expert advice to MoE (Appendix 6 to the MoE Nov 2015 Education Report), and we also conversed via subsequent emails.

Dr. Wright has confirmed:

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[28] The experts' commentaries are available at http://shapingeducation.govt.nz/read-more-2/recent-announcements ; 25 Nov 2015. Dr. Jan Kupec, CERA (Appendix 4); Mr. Stephen Woods, MWH (Appendix 5); Dr. Ian Wright, CCC (Appendix 6).

- Following the Board's June 2015 submission MoE sought his "follow up comment on that expert advice".
- He has only provided comments on the Board's June 2015 commentary.
- He has not reviewed the MWH or AECOM reports.
- He acknowledged the experts' meeting minutes are a fair reflection of the meeting.
- CCC staff have not been involved in the second (March 2016) submission and nor will CCC be providing any comment to the Ministry of Education.

We note that the Board's June 2015 commentary is a lay-person's commentary, which we would not regard as "expert advice".

We sought Dr. Wright's comment on the revised mitigation works but he declined stating CCC staff had ceased commenting on the Redcliffs School topic.

On review of Dr. Wright's comments to MoE we are satisfied that we have suitably addressed those via our risk assessment and revised mitigation works. Notably -

1 Our report is the primary source of technical content for the Board's March 2016 submission to MoE. The Board has undertaken to refer directly to our report in their submission without further interpretation. Any comment on technical matters should be directed to us.

2 We have addressed the topic of "safety" and provide a definition appropriate for the site in terms of rockfall hazard management at a school site. The definition is based on GNS's residential risk assessment work, but specifically acknowledges the school usage of the land i.e. a more sensitive use than for residential land. The revised operational boundary is far removed from the hazard source such that the risk of harm from rockfall is negligible whether the land has residential or school use. Based on our risk assessment we consider the site is safe and suitable for school use. As to who accepts the residual risk (i.e. the remaining risk once the mitigation measures are in place), it is now a non-governing question as the risk is negligible. With the mitigation in place it is far more likely school buildings in Canterbury would be damaged by earthquake shaking, than Redcliffs School would be disrupted by rockfall. The rockfall risk at the Redcliffs School site has been mitigated and suppressed.

3 We have specifically acknowledged and catered for uncertainty in our assessment and design of mitigation measures. There is a high degree of conservatism in our design and we have specifically addressed the sensitivities GNS identifies in its reporting.

4 We have addressed the topic of "guarantee" regarding damage to the bund – the risk of debris impact is negligible, therefore the risk of bund damage is less so. We have avoided discussions on what could be "possible" and rather concentrated on the likelihood and consequences (i.e. the risk) of certain events, and have addressed these events and risks.

5 We have addressed the topic of "societal risk". With the mitigation measures in place there is negligible societal risk due to rockfall at the school site.

6 The "post emergency decision" to occupy the site resides with the Board of Trustees. However, the likelihood that such a decision relates to rockfall is negligible.

The proposed maintenance and monitoring plan presented in the report sets out the simplified process, and identifies the Board as the party responsible. Monitoring can now be done as a simple exercise without placing undue expectations on the Board.

There are identified events where an Engineer's opinion should be sought, but these are unlikely events and the risk of disruption due to rockfall is negligible.

7 The revised layout of the site means that there is no need to seek 3rd party land entry permission.

8 Regarding the time taken to date to reach a resolution, we note the following:

- It has taken a number of years for the combined local and central government agencies to establish investigation programmes and report on complex earthquake-related land stability issues across the Port Hills – an unprecedented feat in New Zealand. The fruit of the that work is we have a far deeper and broader understanding of the technical, legal and policy issues associated with land stability risk and future occupancy of land for residential, commercial and other land uses.
- We are in a far better position now to be undertaking assessments and making decisions regarding the long-term risk profile of the Redcliffs School site than we were prior to the detailed GNS reporting (August 2014). Instead of seeing the time taken as a harbinger of potential future delays, the time should be taken as an assurance that we are all wiser and are much better informed.
- The MoE's experts' comments have provided a broad ranging review and highlighted issues that we have accommodated in the revised mitigation works that are a simple, resilient solution to the many concerns raised, and that provide long-term assurances of rockfall safety and mitigation of disruption to enable a confident decision to return to site.

9 The "huge amount of issues" that Dr. Wrights alludes to are effectively eradicated by the revised mitigation works. We believe that the "long process, possibly protracted with legal issues" has been averted.

11.3 Dr. Jan Kupec, CERA

We initially met with Dr. Kupec 1st March 2016 to discuss his expert advice to MoE (Appendix 4 to the MoE Nov 2015 Education Report). We latterly met on 30th March 2016 to discuss the revised mitigation works.

Dr. Kupec is in general agreement with the experts' meeting minutes. His commentary to the MoE is a review of the Board's June 2015 lay-person's commentary.

On review of Dr. Kupec's comments to MoE we are satisfied that we have suitably addressed those via our risk assessment and revised mitigation works. Dr. Kupec has several similar concerns to Dr. Wright's so we have not reiterated those. Additional concerns and our comments are as follows:

1 Our revised assessment accepts that rockfall can occur at any time so we are not concerned with likelihood of a certain earthquake severity or likelihood of a certain rockfall event. The high degree of conservatism in the revised mitigation works is such that the works are not sensitive to defining these events.

2 The design is such that we are not concerned with changes to the condition of the cliff over time. The revised operational boundary set at or beyond the F=26° contour line provides ample storage capacity and a negligible risk of rock debris impact or bund damage. Conditions can and will change in the cliff face and the revised works cater for this.

3 Given the negligible risk environment afforded by the revised design we are able to provide a professional opinion on assurance of safety as defined in the report. Our professional indemnity insurance covers this nature of advice.

4 Decision-making during a rockfall response inspection has been greatly simplified as per our recommended maintenance and monitoring programme. The authority to re-occupy the site following an emergency resides with the Board – but such an emergency is highly unlikely to be related to rockfall hazard.

5 The visual impact of the revised bund is minor as it is now only 2m high and would have an appearance comparable to a normal school perimeter fence.

6 Only one house remains for demolition on the cliff-top and this in not governing for construction of the revised bund at its distant location from the cliff, or return of the school to the site.

7 Regarding Crown policy on area-wide mitigation works we noted following: (i) the policy does not relate to school land, and (ii) the primary mitigation measure is the separation distance from the cliff, such that the bund has very little role as a true "area-wide mitigation measure" (the school as located on or beyond the F=26° contour has an AIFR far less than 10^{-6} even without the bund).

Regarding the revised mitigation works Dr. Kupec remarked that the revised design was very different to MWH's (i.e. a different design approach), was suitably conservative and fit-for-purpose in terms of safety mitigation and disruption management. He also concurred that monitoring of the cliff would not be warranted as it was highly unlikely rock would reach the bund even in a large rockfall event.

12 Addressing uncertainty

One of the key strengths of the GNS reports is their recognition and appraisal of uncertainties in its knowledge and methods, which give insights into the sensitivity of results obtained. We have been very cognisant of these uncertainties in our assessment and heed GNS' advice, where relevant. Specific comments on uncertainty management and addressed below.

Our review of sensitivity to uncertainties is made with reference to GNS 2014/78 Section 6.3 (page 112). GNS assess sensitivity to changes in debris volumes, area of cliff-top lost, debris run-out, and level of seismicity. They then consider potentially significant uncertainties and their likely implications for risk in their Table 31, which we reproduce below with our comments on the relevance to our assessment.

Our comments regarding items in Table 31:

a) We have adopted the upper-bound estimates of rockfall volumes, and catered for very large volumes. Additionally, our recommended set-back distance is based on a conservatively established F=26° contour.

b) Our assessment is not sensitive to which seismic model is used. We have catered for long-term multiple rockfalls. Additionally, our recommended set-back distance is based on a conservatively established F=26° contour.

c) Our assessment is not sensitive to this issue. We have adopted the upper-bound estimates of rockfall volumes. The two orders of magnitude referred to relate to relative position of the AIFR risk contours inside the F=31° contour limit line (refer to GNS 2014/78, Figure 38, page 99-102). Beyond the F=31° contour the residential AIFR is $<10^{-6}$ and outside of the dataset i.e. no rock passed beyond F=31°, so risk is negligible for any site use. Additionally, the upper-bound modelling (25,000m^3) of the large Local Source 1 does not pass the F=33° line (refer to GNS 2014/78, Appendix 7).

d) We have adopted the upper-bound estimates of rockfall volumes, so are not concerned with *rates* of non-seismic events. Additionally, our recommended set back distance is based on a very conservatively established F=26° contour.

e) This relates to cliff-top recession risk, which we are not concerned with.

f) We have adopted the upper-bound estimates of rockfall volumes, and catered for very large volumes. Additionally, our recommended set-back distance is based on a conservatively established F=26° contour.

g) Our assessment is not sensitive to this issue. We are not attempting to assess risk within the body of the potential rockfall zone or assess relative risk contours, but instead have used a very conservative method to establish the outer limits of possible boulder roll (not bounce), and then protecting that outer limit with a bund.

h) Our assessment is not sensitive to this issue. See comments for (g), above. In addition to establishing a highly conservative revised school boundary location at the F=26° contour we recommend the addition of a bund, the design principle being having established a suitably conservative set-back distance we do not accept any risk of rock rolling across the school boundary. With these measures in place the risk of rock roll beyond the revised school boundary is negligible. The risk of fatality is nil.

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.

13 Addressing the MoE's concerns

13.1 Overview

With the preliminary MWH rockfall mitigation design their considerations did not include the time taken to reassess the risk profile following a large rockfall. The key benefits of the revised bund location and design are:

1. The location is based on a rational assessment of rockfall hazard to provide a margin of redundancy in run-out distance and storage capacity to cater for large rockfall events and long-term catchment requirements.
2. Additionally, the location provides a high degree of surety (as close to "certainty" as is able to be stated in practical engineering terms) that even in the event of a major rockfall event (e.g. GNS's Local source 1 at its upper-bound volume of 25,000m^3) that rock will be highly unlikely reach the bund, and that a series of similar rockfalls will be amply contained well inside the catch area.
3. Compared to the MWH preliminary design the revised location significantly reduces the cost burden on the Board of Trustees with regards to minimal provision of on-going monitoring, maintenance and clearance/removal of rocks in the catch area. Maintenance and clearance/removal of rocks would likely be an exception rather than an on-going / scheduled requirement.
4. The MWH design already provides a high degree of safety but was not required to address concerns regarding the potential for disruption to education in the long-term. The revised bund design addresses the uncertainty regarding disruption to education as well has giving a heightened perception of safety.

The risk assessment specifically provides commentary on acceptable risk (Section 9). The revised rockfall mitigation design specifically addresses the MoE's concerns regarding uncertainty and disruption management principally by relocating the bund further away from the cliff to provide:

1. Significantly increased separation distance between the bund and cliff such that even a very large rockfall (or series of large rockfalls) would be very unlikely reach the bund. The bund is to be located at the distal margin of rockfall runout modelled from an extreme rockfall event.
2. A shorter bund due to geometry of the site and the separation distances from the cliff.
3. Large redundancy in the storage capacity such that there is ample storage in the long-term thus limiting the expectation that rock would need to be removed from the catch area.
4. Wide access behind the bund within school-owned land should the need arise to move or remove rocks i.e. no reliance on 3rd party land access. It is very unlikely that rocks would have to be removed.
5. Increased run-out distance thus reducing the risk of impact or damage to the bund – to a level of very low likelihood; therefore, maintenance requirements would be minimal.

6. Removing the need for a fly-rock fence on top of the bund, although a fence will still be required to restrict access to the catch area – but no different to a perimeter fence around the school.
7. A lower bund (2m high) - significantly less cost to build than the current bund design.
8. No requirement to provide detailed reassessment of the cliff stability hazard following a large event due to the ample storage capacity and separation distance from the cliff. A large rockfall would be of little consequence to the mitigation works or the on-going safety of the site – in lay terms, "it does not matter" if a large rock fall occurs and that another one could follow. Should the bund require inspection (see Monitoring Plan) the risk of disruption to education would be negligible. Monitoring requirements would be agreed with the CCC as part of the compliance monitoring requirements of the Building Consent. We have presented our recommendations for monitoring and they are minimal.

Note: to cause a large rockfall event requires a significant earthquake that would have city-wide if not regional-scale repercussions and disruption (i.e. disruption to education would likely be governed by off-site issues such as damaged homes and infrastructure). However, the revised mitigation works are such that the school grounds remain protected from large volume cumulative rockfall.

13.2 Education Minister's concerns

Having worked through and presented our assessment we can now return to and address the Education Minister's key concerns presented in the Nov 2015 Beehive press release (presented in Section 6). The concerns and our responses are presented below:

(1) The potential for future disruption to education due to rockfall hazard

A revised operational school boundary with the inclusion of a 2m high bund is proposed. With these mitigation measures in place the risk of disruption due to rockfall is negligible. Drawings of the revised mitigation measures are presented in Appendix A.

(2) Circumstances that could give rise to potential disruption...cannot be ruled out.

With the proposed mitigation measures in place the risk of circumstances that could give rise to disruption due to rockfall is negligible. We have diligently assessed the risk of disruption (i.e. considering likelihood and consequences). Rather than considering whether something is possible, we have considered whether it is probable, and provided a commentary on disruption mitigation in the context of New Zealand's natural hazard exposure and MoE, CCC & MCDEM guidance on preparedness, and also a commentary on risk assessment.

We have presented our revised mitigation measures to two of MoE's expert advisors (Dr, Kupec, CERA and Mr. Woods, MWH), who concur that the proposed measures suitably address mitigation of disruption due to rockfall.

(3) Which agency or agencies would be responsible for deciding on a return to the site following a significant event?

Eliot Sinclair
surveyors | engineers | planners

With the proposed mitigation measures in place the maintenance and monitoring requirements are greatly simplified compared to those previously required under the preliminary MWH design.

Following a significant (i.e. large volume) rockfall event it is highly unlikely that rock debris will have reached the revised bund location, and there is no need to be monitoring the cliff face for changes in its condition, nor is there a need to undertake detailed re-evaluation of the cliff hazard.

The "post emergency decision" to occupy the site resides with the Board of Trustees. However, the likelihood that such a decision relates to rockfall is negligible. The Board holds the authority to allow occupation of the school as it does for other potentially disruptive events for which there are MoE, CCC and MCDEM recommendations and requirements for emergency management. The risk presented by the rockfall hazard has been reduced to such a low level (negligible) that other potential hazards (notably the background Canterbury earthquake hazard that governs building design) is a relatively higher risk to be managed. The background earthquake hazard is managed through the provisions of the Building Act.

(4) The private ownership of the land behind the school

The revised layout of the site means that there is no need to seek 3rd party land entry permission.

(5) No agency is currently monitoring the cliff face

With the proposed mitigation measures in place the maintenance and monitoring requirements are greatly simplified and there is no need to be monitoring the cliff face for changes in its condition, nor is there a need to undertake detailed re-evaluation of the cliff hazard.

(6) The likely timing of a return to the Main Road site re removal of the houses from the cliff-top

Only one house remains for demolition on the cliff-top and this in not governing for construction of the revised bund at its distant location from the cliff, or return of the school to the site.

(7) It has already been five years since the school was on its site. It could be several more years.

It has taken a number of years for the combined local and central government agencies to establish investigation programmes and report on complex earthquake-related land stability issues across the Port Hills – an unprecedented feat in New Zealand. The fruit of the that work is we have a far deeper and broader understanding of the technical, legal and policy issues associated with land stability risk and future occupancy of land for residential, commercial and other land uses.

We are in a far better position now to be undertaking assessments and making decisions regarding the long-term risk profile of the Redcliffs School site than we were prior to the detailed GNS reporting (August 2014). Instead of seeing the time taken as a harbinger of potential future delays, the time should be taken as an assurance that we are all wiser and are much better informed.

The MoE's experts' comments have provided a broad ranging review and highlighted issues that we have accommodated in the revised mitigation works that are a simple, resilient solution to the many concerns raised, and that provide long-term assurances of rockfall safety and mitigation of disruption to enable a confident decision to return to site.

14 Conclusions

The revised mitigation works are consistent with the MoE's design standard for schools that cite the amenity and life-safety performance requirements contained within the Building Code as a minimum standard. Performance requirements for school buildings are based on a *low probability* of non-compliance of those requirements, and not requiring guarantees or certainty.

There is no compromise on safety in the new design that goes substantially beyond the already conservative and safe design of the preliminary MWH bund design. Performance criteria to minimise disruption to education in the long-term are necessarily more stringent than those required for safety. In its simplest terms, the substantially higher performance criteria are achieved via the operational school boundary and bund having a greater set-back from the cliff.

We have relied upon the best risk assessment and slope stability assessment reporting available, adopted conservative parameters in our assessment, and verified critical aspects of the rockfall hazard (location of F angle lines and undertaken rockfall runout modelling).

GNS's comprehensive risk assessment and stability assessment reports specifically recognise and explore the effect of uncertainties on their findings. We have taken heed of their commentary on these matters.

Maintenance and monitoring requirements are minimal. There is no requirement to seek 3rd party land access permission. Cliff-top house demolition is no longer a relevant concern.

We believe the revised mitigation works amply address the MoE's concerns regarding uncertainty and disruption mitigation. We have presented our revised mitigation measures to two of MoE's expert advisors (Dr. Kupec, CERA and Mr. Woods, MWH), who concur that the proposed measures suitably address mitigation of disruption due to rockfall.

The potential for disruption to education due to rockfall hazard has been reduced to as low as practically possible (negligible), and also leaves space within the balance of the school land for the new school layout.

15 Recommendations

1 We recommend adoption of the revised mitigation works (revised operational school boundary on or beyond the F = 26° line and 2m high bund) as the basis for reconsidering the rockfall hazard concerns that led to the decision to close Redcliffs School - refer to figures in Appendix A.

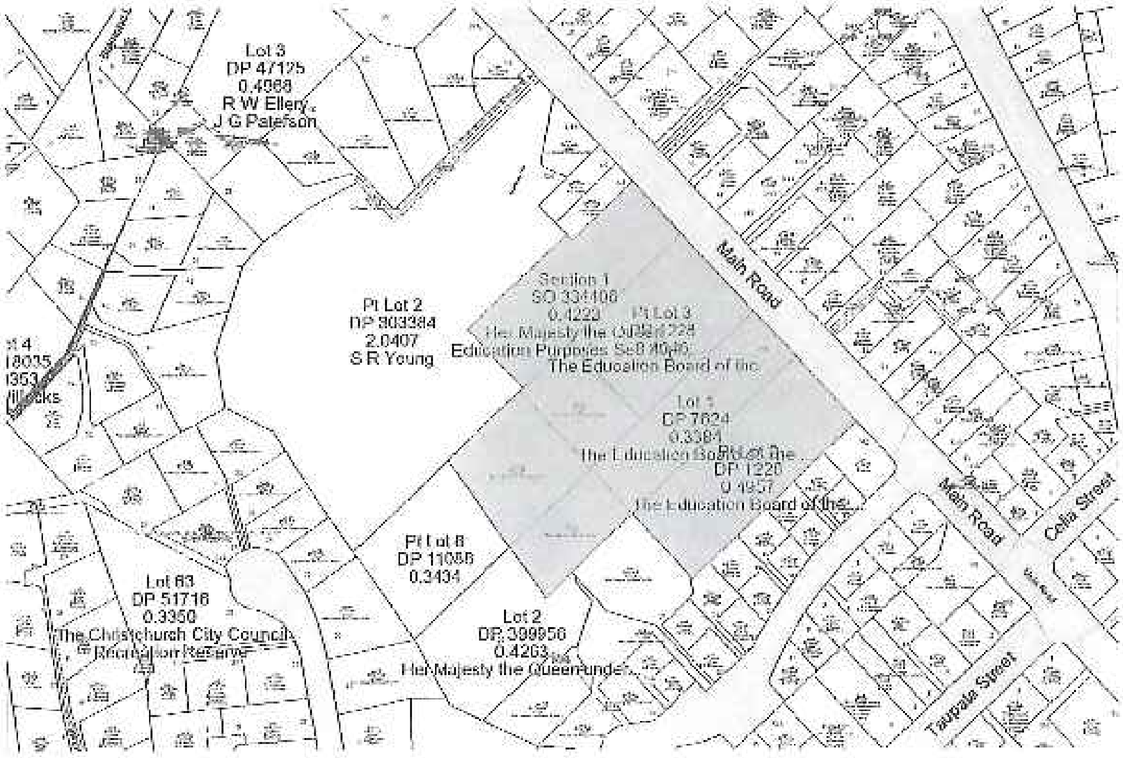
2 We believe the revised measures suitably address the MoE's concerns regarding rockfall hazard management, but they are not a *final design*. There is flexibility in the design to cater for modifications, for example: (i) locally modifying the alignment of the bund where it passes along the rear of the existing school buildings – the design is not sensitive to relocation of the bund by a few metres or so, or (ii) the bund could be relocated onto the F=28° contour, thus providing more school land, though potentially requiring a larger bund. An economic assessment could yield benefits of providing more school land verses the cost of a larger bund. The important point is that a simple, resilient solution has been found, and that bund design can be refined and modified during the *detailed design review* if the MoE or Board had any questions regarding its location (and still meet the performance criteria).

3 If this report is formally reviewed as part of the MoE's assessment process we recommend that the reviewing party/ies observe the IPENZ Code of Ethics re Peer Review; notably that there is a professional obligation to "investigate the matters concerned before commenting"[23] i.e. liaise with Eliot Sinclair during the review process.

[23] https://www.ipenz.nz/home/professional-standards/code-of-ethics

Appendix A Figures

Redcliffs School and its neighbourhood. Legal boundaries shown in yellow. North at top.



Details of cadastral (legal) boundaries showing layout of lots within the school site (shaded green). North at top. [Source: QuickMap]

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Orientation image showing viewpoints for Figures A1 to A5

Notes re Figure A1 to A5

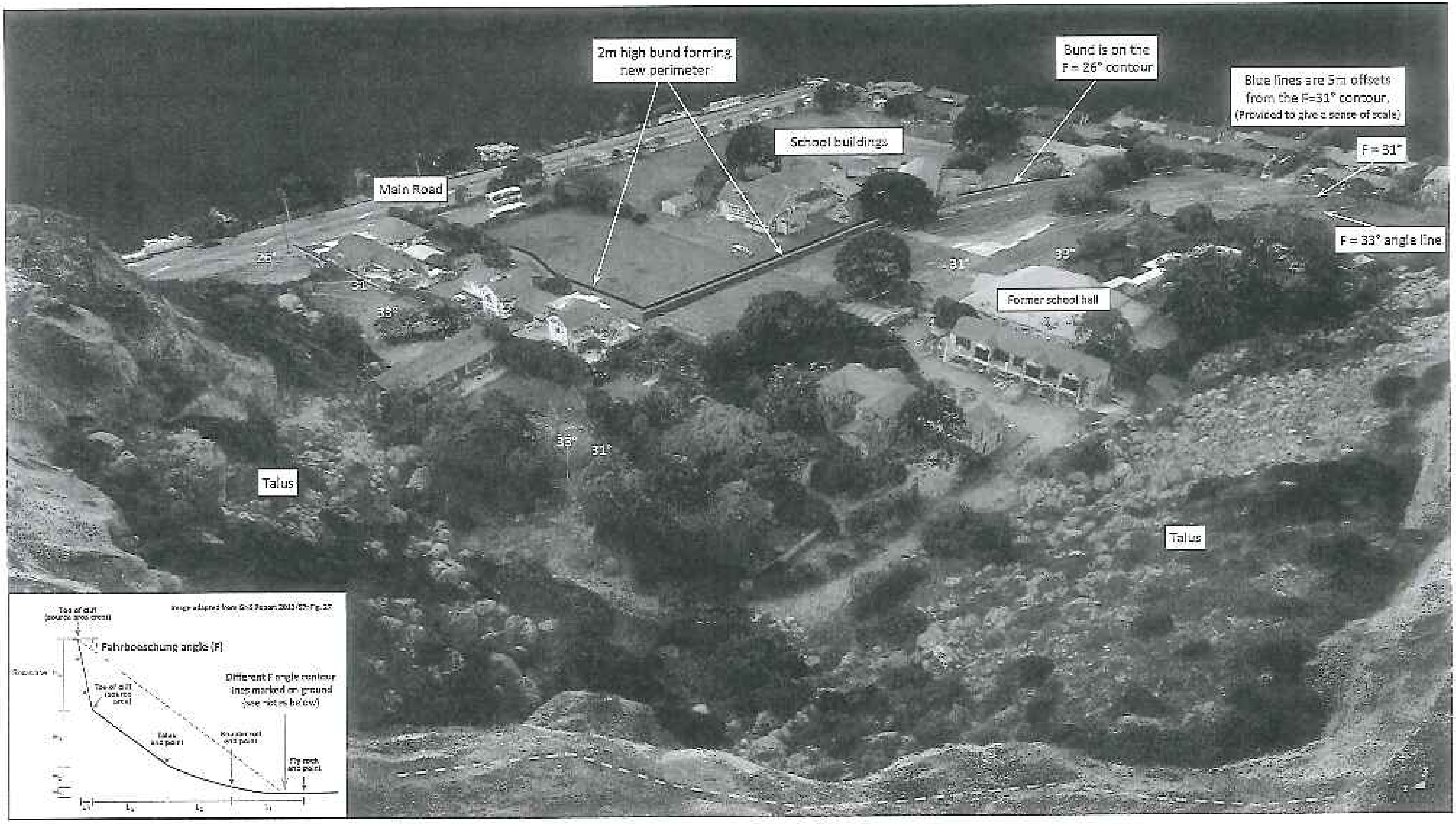
The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crown) and the furthest point of travel of rock debris.

For the purposes of GNS's analysis (GNS Report 2012/57) and Figures A1 to A5, the starting point of the failure is assumed to be the cliff top edge (the source area crown). The orange contours projected onto the ground are referred to as *F angle lines.*

From the assessment of the debris that fell from the three main cliffs (Redcliffs, Shag Rock Reserve and Wakefield Avenue/Richmond Hill), during the 2010/11 Canterbury earthquakes, no debris passed the 31° Fahrboeschung angle line (GNS Report 2011/311).

Boulder roll debris did not pass the F=33° angle line. Fly rock debris did not pass the F=31° angle line.

The rationale for adoption of the F=26° line as the basis for the revised operational school boundary is presented in Appendix B.



Notes

The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crest) and the furthest point of travel of rock debris. For the purposes of GNS's analysis (GNS Report 2012/57) and the image above, the starting point of the failure is assumed to be the cliff top edge (the source area crest). The orange contours projected onto the ground are referred to as *F angle lines*.

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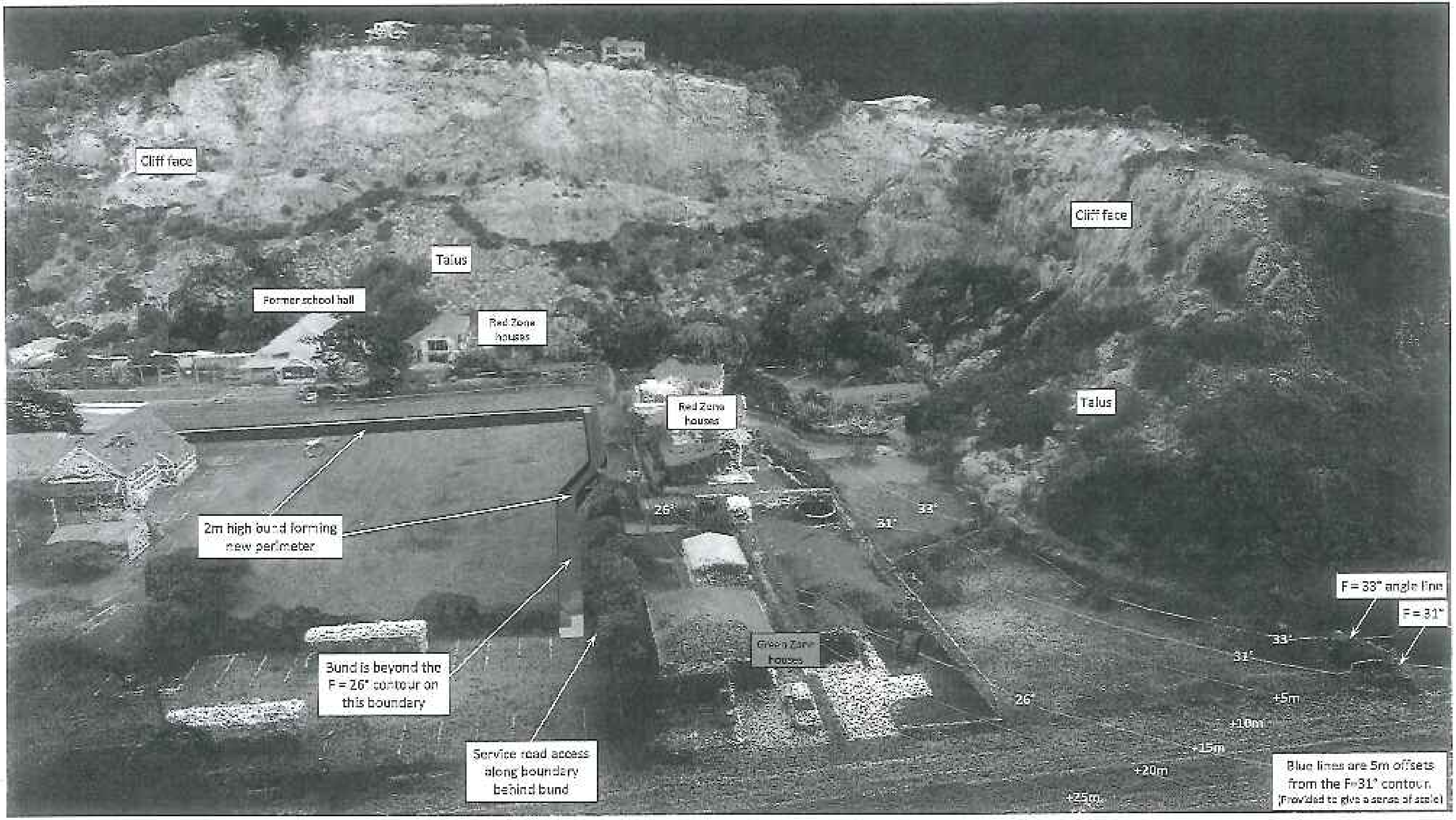
PROJECT	TITLE	SCALE	DRAWING SET	SHEET	
Redcliffs School Rockfall Hazard Review	Revised bund location	N.T.S. DATE CREATED March 2018	412356	Figure A1	Eliot Sinclair surveyors | engineers | planners



Notes

The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crest) and the furthest point of travel of rock debris. For the purposes of GNS's analysis (GNS Report 2012/57) and the image above, the starting point of the failure is assumed to be the cliff top edge (the source area crest). The orange contours projected onto the ground are referred to as *F angle lines*.

From the assessment of the debris that fell from the three main cliffs (Redcliffs, Shag Rock Reserve and Wakefield Avenue/Richmond Hill), during the 2010/11 Canterbury earthquakes, no debris passed the 31° Fahrboeschung angle line (GNS Report 2011/311). Boulder roll debris did not pass the F=32° angle line. Fly rock debris did not pass the F=31° angle line.

PROJECT	TITLE	SCALE / DATE CREATED	DRAWING SET	SHEET	
Redcliffs School Rockfall Hazard Review	Revised bund location	N.T.S. / March 2016	412368	Figure A2	Eliot Sinclair surveyors | engineers | planners

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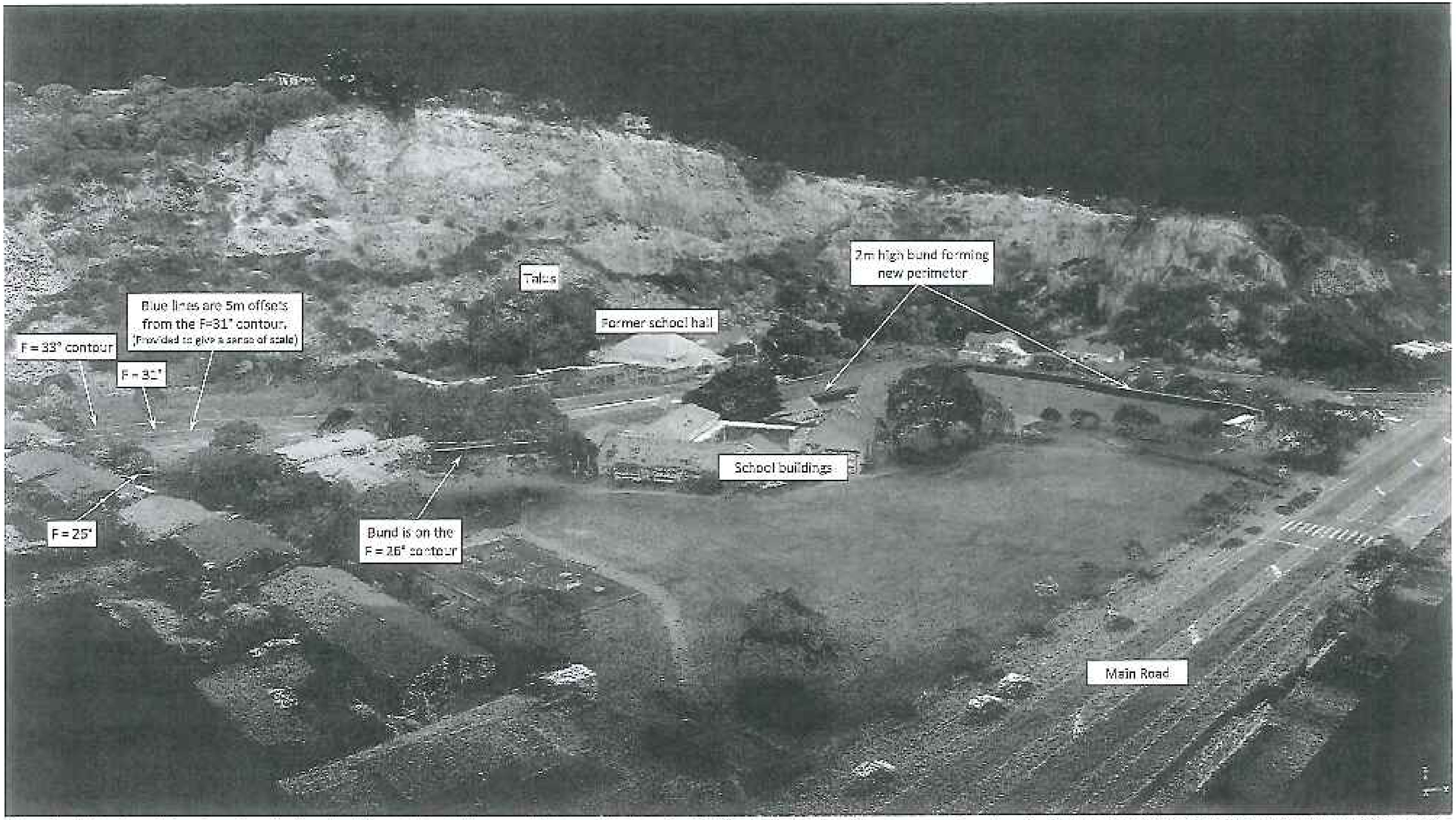

Notes: The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crest) and the furthest point of travel of rock debris. For the purposes of GNS's analysis (GNS Report 2012/57) and the image above, the starting point of the failure is assumed to be the cliff top edge (the source area crest). The orange contours projected onto the ground are referred to as *F angle lines*.

From the assessment of the debris that fell from the three main cliffs (Redcliffs, Shag Rock Reserve and Wakefield Avenue/Richmond Hill), during the 2010/11 Canterbury earthquakes, no debris passed the 31° Fahrboeschung angle line (GNS Report 2011/311). Boulder roll debris did not pass the F=33° angle line. Fly rock debris did not pass the F=31° angle line.

PROJECT	TITLE	SCALE / DATE CREATED	DRAWING SET	SHEET
Redcliffs School Rockfall Hazard Review	Revised bund location	N.T.S. March 2016	412368	Figure A3

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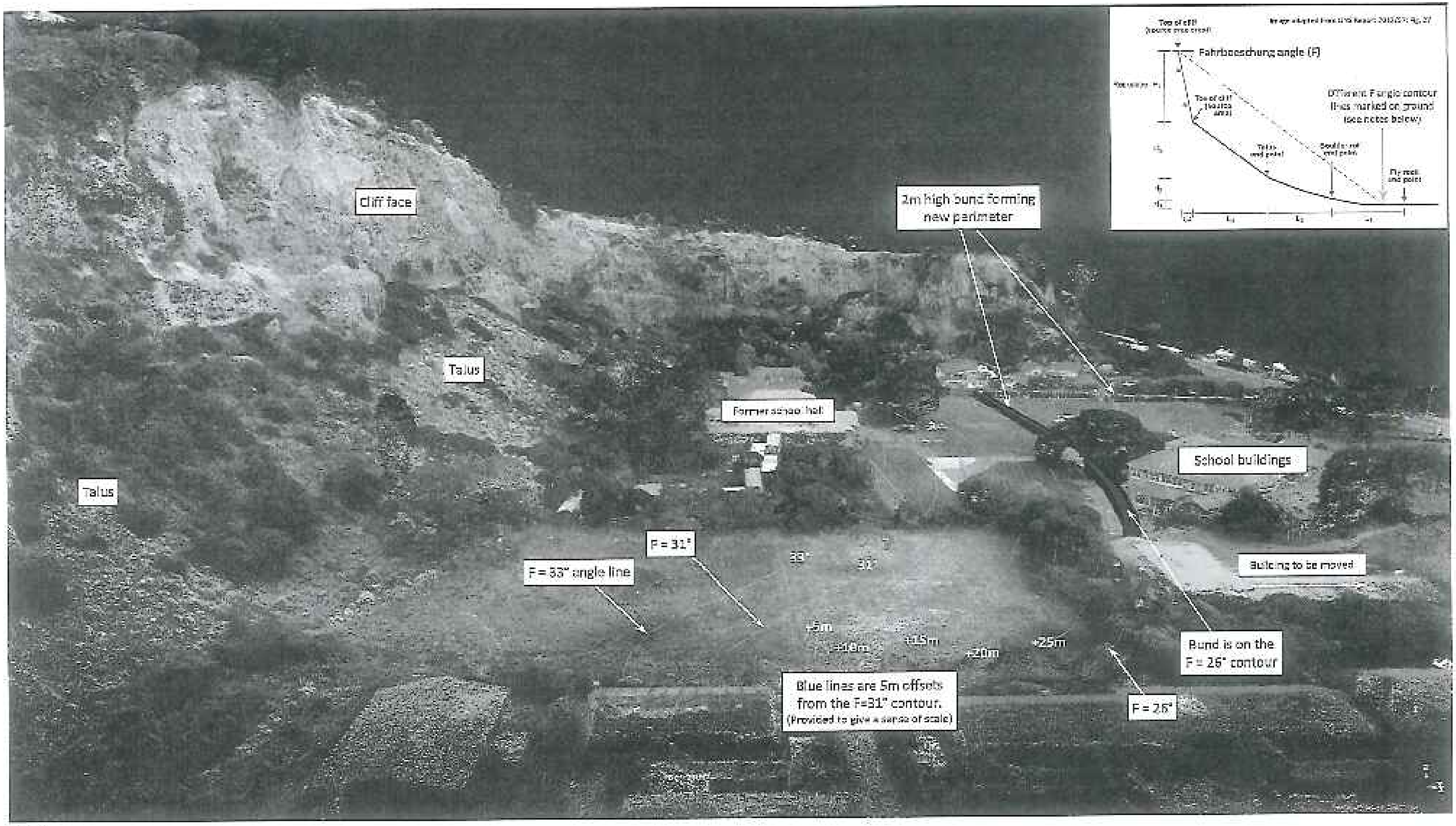

Notes

The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crown) and the furthest point of travel of rock debris. For the purposes of GNS's analysis (GNS Report 2012/57) and the image above, the starting point of the failure is assumed to be the cliff top edge (the source area crown). The orange contours projected onto the ground are referred to as *F angle lines*.

From the assessment of the debris that fell from the three main cliffs (Redcliffs, Shag Rock Reserve and Wakefield Avenue/Richmond Hill), during the 2010/12 Canterbury earthquakes, no debris passed the 31° Fahrboeschung angle line (GNS Report 2011/311). Boulder roll debris did not pass the F=33° angle line. Fly rock debris did not pass the F=31° angle line.

PROJECT	TITLE	SCALE	DRAWING SET	SHEET
Redcliffs School Rockfall Hazard Review	Revised bund location	N.T.S. DATE CREATED March 2016	412368	Figure A4

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Notes

The Fahrboeschung (often referred to as the "travel angle") method for landslide runout studies uses the slope of a straight line between the top of the source area (the crest) and the furthest point of travel of rock debris. For the purposes of GNS's analysis (GNS Report 2012/57) and the image above, the starting point of the failure is assumed to be the cliff top edge (the source area crest). The orange contours projected onto the ground are referred to as F angle lines.

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PROJECT	TITLE	SCALE / DATE CREATED	DRAWING SET	SHEET	
Redcliffs School Rockfall Hazard Review	Revised bund locations	N.T.S / March 2016	412368	Figure A5	Eliot Sinclair surveyors | engineers | planners