

## **Author response to comments: Anonymous Referee #1**

**RC1-1:** *This paper is dealing with earth sciences information is used for post-disaster land-use planning decisions during the 2010-2011 Canterbury earthquake sequence (Christchurch, New Zealand). The scope of this paper is limited to mass movements and ground surface fault rupture because authors possess intimate knowledge of those hazards. Unfortunately, just brief comparisons are made for liquefaction.*

**Author response 1:** The utility of liquefaction science and engineering inputs into decision-making has been extensively analysed in our prior work (Quigley et al, 2019 – references 1,2 below) and we do not seek to duplicate that in this paper. We invited other science providers with unpublished knowledge of the liquefaction aspects to contribute to this paper and they declined. As such, the work of Quigley et al. (2019) represents the current authoritative account of liquefaction, and our choice to focus on lesser understood aspects (to-date) in this work is deliberate. Note that we do compare our study findings with those of Quigley et al. (2019 – refs 1,2) and these references are cited at several places in this manuscript. We have added a sentence to the Introduction that explicitly states why liquefaction is not the primary focus of this paper, and directs readers to Quigley et al. 2019 -1,2.

### **REFERENCES:**

1. Quigley, M.C., Bennetts, L.B., Durance, P., Kuhnert, P.M., Lindsay, M.D., Pembleton, K.G., Roberts, M.E., White, C.J., (2019) The provision and utility of earth science to decision-makers: synthesis and key findings, *Environment Systems and Decisions*, doi: <https://doi.org/10.1007/s10669-019-09737-z>
2. Quigley, M.C., Bennetts, L.B., Durance, P., Kuhnert, P.M., Lindsay, M.D., Pembleton, K.G., Roberts, M.E., White, C.J., (2019) The Provision and Utility of Science and Uncertainty to Decision-Makers: Earth Science Case Studies, *Environment Systems and Decisions*, doi: <https://doi.org/10.1007/s10669-019-09728-0>

**RC1-2:** *Manuscript is well structured and clear. However, there are a lot of institutions involved in the research (New Zealand Cabinet, CERA, Christchurch City Council, MfE, MBIE, ECQ, ECan, SDC) so a new section to explain interactions (hierarchy, competences, and so on) among them would be greatly appreciated. I would reduce the number of acronyms used (for readers not familiarised with them), especially those not used more than twice.*

**Author response 2:** We have included a new section (3) on Governance, which includes a table (Table 1) with the various responsibilities of all agencies described in the manuscript. The roles of these agencies are also described in:

*Berryman, K. (2012). "Geoscience as a component of response and recovery from the Canterbury earthquake sequence of 2010–2011." *New Zealand J. Geol. Geophys.*, 55(3), 313–319.*

*Beaven, S., Wilson, T., Johnston, L., Johnston, D., & Smith, R. (2017). Role of boundary organization after a disaster: New Zealand's natural hazards research platform and the 2010–2011 Canterbury Earthquake Sequence. *Natural Hazards Review*, 18(2), 05016003.*

...and we think that interested readers can consult these papers (cited in our paper) for further information. We have further reduced acronym usage where appropriate, particularly for single usage, but have ultimately retained some acronyms in instances where word and page length would be compromised through further reductions.

**RC1-3:** *I would clarify the compulsory regulations, if any, to enforce geotechnical reports.*

### **Author response 3:**

The active fault guidelines (Kerr et al) are non-regulatory; they provide a voluntary framework for managing active faults. Geotechnical reports typically inform decision making within a planning framework, with the 'enforcement' of their content being through conditions of resource consent (if resource consent is required).

**RC1-4:** *A map showing differences in land uses after CES would be appreciated to check the real impact of earth sciences information.*

**Author response 4:** This is already shown in Figures 1B and 1C. Figure 1B shows the location of 'red zoned' areas that were formerly residential areas and are vacated. This is shown for both mass movement (yellow) and liquefaction (red) areas. Figure 1C shows the location of the fault avoidance zone, which was newly mapped following the Darfield earthquake; however no land-use changes were enacted for this area, as clearly described in the text. We turn the reviewer to this figure for the information they request.

**RC1-5:** *Specific comments (a) to (j) and Author responses:*

*a) Line 210 Were domestic dwellings damaged by earthquakes after 16/2/2011 (Table S1)?*

**Author response 5:** We infer this reviewer's question to ask, 'were domestic dwellings damaged by earthquakes after the 22 February 2011 Christchurch earthquake? We see no other clear alternative to this question as stated. If our rephrasing of their question is correct, the answer varies depending on which hazard is being discussed. The text on line 201 refers to damage from fault surface rupture. Only the 4/09/10 earthquake was associated to surface rupture, and so the answer to the question is NO if referring to fault rupture. If the reviewer means to query whether domestic dwellings were damaged by earthquakes post 22 February 2011 from other hazards (rockfall, liquefaction) the answer is yes: e.g., domestic dwellings were also damaged by mass movements in the 16 April, 13 June and 23 Dec 2011 earthquake quakes. The 13 June was the most damaging. As a result of this EQ multiple dwellings were again hit by boulders, many dwellings were also damaged again by liquefaction-induced ground deformation and also shaking damage.

*b) Line 230 Do you mean the revised Selwyn District Plan?*

**Author response:** No, we refer here to the **current** Selwyn District Plan. The Plan is currently being reviewed (its normal 10-yearly review) and is likely to be notified to the public for submissions by late 2020. The reviewed Plan proposes restrictions on new Building Importance Category 4 and 5 buildings within the fault avoidance zone. The text has been updated to clarify this.

*c) Line 239 I suppose that buffer zone is 20 m. according to Kerr et al, 2003. Is that buffer considered in fig. 1C?*

**Author response:** The buffer zone contains the deformation zone **and** the 20 m setback. The polygon surrounding the lines on the figure (e.g., the fault avoidance zone) contains both the deformation zone and the 20 m setback. To avoid confusion, we have replaced the word 'buffer' (which we think the reviewer associated only with the 20 m setback) and use the more precise nomenclature of "fault avoidance zone". We have made changes to the text to reflect this.

*d) Lines 285 Are Kerr et al, 2003 and Building Act the pre-disaster geotechnical guidelines?*

**Author response:** The Kerr et al, 2003, is the pre-disaster land use planning guideline for managing surface fault rupture hazard. This reference has been added to the text.

*e) Line 305 Which is the percentage of fault avoidance zones in current district plans considering maps of past surface rupture faults?*

**Author response:** Unfortunately this is beyond the scope of this paper. Many councils in New Zealand are in the process of incorporating fault information and provisions into their district plans through their 10-yearly Plan review process, but we have not done a full analysis of this; to do so would be a huge endeavour and we choose to retain the primary focus of this manuscript on to the Canterbury earthquake sequence. Our quick analysis of some District Plans indicates n=8 Operative District Plans with fault avoidance zones, n=3 Operative District Plans with active fault traces, n=2 Draft plans with fault avoidance zones. However, you can't see all the Draft Plans and we cannot check them all.

*f) Do you have the information for revising plans? Have the results improved when compared to those published by Saunders, W.S.A., Beban, J.C. and Coomer, M.A. (2014). Analysis of natural hazard provisions in regional policy statements, territorial authority plans, and CDEM Group Plans. GNS Science report 2014/28. Lower Hutt: GNS Science?*

**Author response:** Please see the above comment. While an analysis of this type was outside the scope of this paper, as a result of the CES and planning reviews, liquefaction and slope instability are now incorporated in a far more comprehensive way than in previous plans. This paper describes how the science was incorporated into the plans, which provides a more detailed planning response for existing and future activities in these zoned locations.

*g) Line 360 Was the reduction of dwellings to be evacuated due to the 13 June 2011 Mw 6.0 earthquake damages?*

**Author response:** After the 22 February 2011, earthquake the Port Hills Geotechnical Group (PHGG) of consultants undertook a review of all 560 Red Placards on residential properties and recommended that 104 of these should not be reinstated because the life-safety risk was judged to no longer remain or be tolerable, for occupants of these dwellings, e.g., the dwelling had been demolished, or the hazard removed or the hazard and associated risk was reassessed as being low.

*h) Line 426 Has reforestation been proposed as solution for rockfall hazard?*

**Author response:** Reforestation was proposed in some areas as a solution for rockfall hazard and existing forests were considered in the risk analyses. In some areas of the Port Hills, vegetation – mainly mature trees planted close together in rows to form shelterbelts (sometime in the 1970s) – stopped boulders. Dense native forest in Lyttelton was effective at reducing the runout distances of rockfalls. However, for planning and regulatory purposes, it was decided (by CCC on advice from PHGG and GNS Science) that the inclusion of such local factors in risk assessment were problematic as in many cases the vegetation providing the mitigating effect (or land on which the forest needed to be planted) was not owned by the property it would be protecting, and neither these land owners nor the council had control over vegetation (existing or new) on private property. There was also the significant doubt locally and internationally about how effective vegetation is at stopping rockfall. There was also the issue of vegetation being susceptible to fire and storms, and ephemeral in the long-term which would render it ineffective during times of renewal. Therefore, it was decided to use reforestation as a mitigation option, where possible, but only to compliment other engineered mitigation solutions.

*i) Line 784. Are hazard maps legally binding?*

**Author response:** In general, hazard maps are only legally binding if they have been incorporated, with accompanying provisions, into a District Plan or other statutory plan through a process involving the consideration of all aspects of using the information by the council, and the opportunity for the public to provide feedback. Prior to the CES there were few District Plan provisions for liquefaction, mass movement or surface fault rupture hazards in Christchurch City, Selwyn District or Waimakariri District. We have added some clarification in lines 797-798.

*j) Line 801 Is District Plan including liquefaction and ground rupture?*

**Author response:** Yes, liquefaction and surface fault rupture can both be addressed through the District Plan. Neither the Selwyn District Plan nor the Christchurch City Plan contained provisions for surface fault rupture prior to the CES (the Christchurch City Plan still does not, because there are no fault traces at the ground surface in Christchurch). The Greendale Fault was unmapped prior to the CES, so even if there had been surface rupture hazard provisions in the Selwyn District Plan prior to the CES they would not have prevented development in the surface rupture area. Neither Selwyn District or Christchurch City had specific liquefaction provisions in their District Plans prior to the CES, although Waimakariri District did. All now have, or are proposing to have, liquefaction-specific provisions in their District Plans. We have included further wording to clarify this.

**RC1-6:** *Figure 1. I would have considered one figure for each hazard in order to enlarge some small figures.*

**Author response 6:** We value the reviewer's opinion but the figures are provided in high resolution and can be digitally enlarged to whatever scale the reader wishes. We have also undertaken this research without a formal budget and thus do not have the funding to expand our page charges by disseminating this figure into multiple figures.

**RC1-7:** *Fig. 1A. I suppose that SDC corresponds to 1C. I have missed buildings (and specifically damaged buildings mentioned in Lines 163-166, Lines 243-245) in fig. 1C. Is the fault avoidance zone restricted to one type of deformation (well defined, distributed or uncertain) or to all of them? Is the buffer already considered?*

**Author response 7:** Fault avoidance zones were created for well defined, distributed or uncertain types, i.e. all types. Perhaps the confusion for the reviewer was that he/she cannot see 2 polygons (one associated with the deformation zone and another one the 20 m setback). This has now been explained in the figure caption

**RC1-8:** *Fig. 2 Too much information. Table S1 is more clear. Table S2 would be better with landscape orientation.*

**Author response 8:** Table S1 has been revised and inserted into the main manuscript as Table 2. Table S2 has been converted to landscape orientation, as per the reviewer's request.

**RC1-9:**

*(a) Line 120, 129, 146 and 148. Reference of Berryman 2012 is missing*

- REFERENCE ADDED

- (b) *Line 280. Ordinances instead of ordnances*
- *CHANGE MADE*
- (c) *Lines 250, 251, 253 and 638. Hornblow et al, 2014 should be 2014a or 2014b?*
- *CLARIFIED THROUGHOUT (a) or (b)*
- (d) *Lines 447 and 813. Building Act is not included in references.*
- *NOW INCLUDED*
- (e) *Lines 490 and 682. Reports are not included in references*
- *Included missing one; one was under Massey et al, so have changed citation*
- (f) *Line 518. 5.2.3 should be 5.2.2*
- *REVISED*
- (g) *Line 616. Reference of Drabek 2007 is missing*
- *DELETED REFERENCE FROM TEXT*
- (h) *Line 669. “Replacement Christchurch District Plan (RCDP)“ instead of “Replacement Christchurch District Plan”*
- *CHANGED TO REDUCE ACRONYMS*
- (i) *Line 783. Reference of Gerstenberger et al, 2104 (probably 2014) is missing*
- *NOW INCLUDED IN REFERENCES*
- (j) *Line 814 Local Government Act 2002 should be included in references*
- *NOW INCLUDED IN REFERENCES*
- (k) *Lines 821 to 825. Sentence is repeated (lines 770 to 774). Please, rewrite it.*
- *SENTENCE REVISED*
- (l) *Line 845. Correct ”and liquefaction hazards are the be applied”*
- *CORRECTED TO “liquefaction are to be applied”*
- (m) *Author contribution: W.S. contribution is missing*
- *INCLUDED AND SPECIFIED*

#### **RC1-10: References**

- (a) *Line 901 Cubrinonovski et al, 2010 is not in alphabetical order*
- *FIXED*
- (b) *Line 955 Hornblow et al, 2014 should be 2014a?*
- *YES, FIXED*
- (c) *Line 1022 Massey et al, 2011 are not cited*
- *REVISED*

- (d) *Line 1044 Mileti, 1999 is not cited*
  - *REFERENCE REMOVED*
- (e) *Line 1047 Neth, 2016 is not cited*
  - *REFERENCE REMOVED*
- (f) *Line 1064 2010a instead of 2010?*
  - *REVISED TO 2010a*
- (g) *Line 1097 Saunders and Beban, 2014 are not cited*
  - *Reference added to manuscript - line 73*
- (h) *Line 1107 Stahl et al., 2013 should be Stahl et al, 2014*
  - *CHANGED TO 2014*