Appendix A.2:

Rydal Reserve – VsVp 57190

Table 1: Site Description for Rydal Reserve (V_SV_P 57190).

Attribute	Yes/No			Description/Date	Symbol in Figure 1
	10-m Buffer	20-m Buffer	50-m Buffer		
Near a body of surface water or other free face features?	No	No	No	The nearest body of surface water, the Heathcote River, is 230 m from the center of the site toward E.	NA
Lateral spreading observed during the CES?	No	No	No	Lateral spreading was not observed by the mapping team.[1]	NA
Nearby buildings or structures?	No	No	Yes	Buildings are in the NW, NE, and SE quadrants of the 50-m buffer, covering 11% of its area.	White Fill + Brown Outline
Sloping land?	No	No	No	NA	NA
Step changes in the ground surface?	No	No	Yes	Elevated playground (ca. 20 cm above the surrounding ground surface) in the SE quadrant of the 50-m buffer covering 3% of its area.	White Fill + Yellow Outline
Retaining walls?	No	No	No	NA	NA
Vegetation?	Yes	Yes	Yes	Trees and bushes cover 6% of the 10-m buffer, 14% of the 20-m buffer, and 22% of the 50-m buffer. They are in the NE quadrant of the 10-m buffer, the NE and NW quadrants of the 20-m buffer, and all quadrants of the 50-m buffer.	White Fill + Green Outline
Anthropogenic changes to the site between the LiDAR surveys?	Yes	Yes	Yes	Vegetation removal from the E portion of the 20-m and 50-m buffers between Jan 2007 and Mar 2009. Land resurfacing in all quadrants of all buffers between 9 Nov 2011 and 24 Dec 2011.	Vegetation removal: Green Outline
Other important factors?	No	No	Yes	Road is in the SW quadrant of the 50-m buffer and occupies 4% of its area. Table and bench set and light poles near the playground.	Table and Bench: White Fill + Purple Outline; Road: White Fill + Gray Outline

Notes: Buffer is the area within a circle of a specified radius with VsVp investigations done at its center (172.608493, -43.565806).

[1] Canterbury Geotechnical Database. (2012). "Observed Ground Crack Locations", Map Layer CGD0400 - 23 July 2012, retrieved July 09, 2018 from https://canterburygeotechnicaldatabase.projectorbit.com/

Figure 1: Site plan with the area considered for settlement analysis.

Note 1: The area in the free field selected for settlement assessment is free of vegetation and structures. Other factors considered in the patch selection process were its proximity to a CPT, a property subjected to addition and/or demolition of a structure, front yard/backyard alterations (e.g., ploughing, rubble, scrap), and areal distribution of ejecta. The LiDAR-based settlement analyses were not performed for any earthquake event.

Table 2: LiDAR flight error adjustments, global adjustments for the difference between average LiDAR point elevations and benchmark survey elevations, and vertical tectonic movement adjustments.

	Adjustments (mm)		
Earthquake Event(s)	LiDAR Flight Error	Global Offset[2]	Tectonic Vertical Movement
Sep-10	NA	-3	0
Feb-11	NA	16	-50
Jun-11	0	38	-10
Dec-11	NA	-65	0
CES	NA	-14	-60
Any LiDAR survey affected by ejecta?*			Yes

*Ejecta from the Feb-11 EQ remained at the site until the period between 9 Nov 2011and 24 Dec 2011; which affected the Dec-11 EQ; thus, ~20 mm (based on photographs) would need to be subtracted from the ground surface subsidence for the Dec-11 EQ. The presence of ejecta at the site at the time of May 2011 and Sep 2011 LiDAR surveys would not impact the subsidence estimates for the Jun-11 event.

Notes: NA = Not available; The negative sign indicates the subtraction from the ground surface subsidence, while the positive sign indicates the addition to the ground surface subsidence.

Table 3: LiDAR Measurement Error.

Surveys	Buffer	Area Averaged Difference Indicating Repeat Measurement Error (mm)	б*$_{\text{individual LiDAR points}}$ (mm)	%Reduction in б due to Area Averaging of LiDAR Points
Post Feb 2011: Mar 2011 and May 2011	10-m	NA	59	NA
	20-m	NA		
	50-m	NA		
Post Dec 2011: Feb 2012 and Oct 2015	10-m	NA	70	NA
	20-m	NA		
	50-m	NA		

*Standard deviation.

[2] Russell, J., & van Ballegooy, S. (2015). *Canterbury Earthquake Sequence: Increased liquefaction vulnerability assessment methodology*. New Zealand: Tonkin & Taylor Ltd.

Table 4: Ground surface subsidence adjustments due to LiDAR measurement error.

Earthquake Event(s)	$\sigma_{\text{pre-EQ LiDAR survey}}$ (mm)	$\sigma_{\text{post-EQ LiDAR survey}}$ (mm)	σ_{total} (mm)	Area Average Adjusted σ (mm) **
Sep-10	158	56	134	NA
Feb-11	56	59	59	NA
Jun-11	59	61	62	NA
Dec-11	61	70	87	NA
CES	158	70	124	NA

**Based on the highest %Reduction in Table 3.

Table 5: Raw liquefaction-related ground surface subsidence using original LiDAR points.

	Average Ground Surface Subsidence (mm)		
Earthquake Event(s)	10-m Buffer	20-m Buffer	50-m Buffer
Sep-10	NA	NA	NA
Feb-11	NA	NA	NA
Jun-11	ND	ND	ND
Dec-11	ND	ND	ND
CES	ND	ND	ND

NA = Not available; ND = Not determined.

Table 6: Corrected liquefaction-related ground surface subsidence using original LiDAR points with the calculated adjustments in Table 2.

	Average Calculated Ground Surface Subsidence (mm)		
Earthquake Event(s)	10-m Buffer	20-m Buffer	50-m Buffer
Sep-10	NA	NA	NA
Feb-11	NA	NA	NA
Jun-11	ND	ND	ND
Dec-11	ND	ND	ND
CES	ND	ND	ND

Note: Plus/minus values are NA as per Table 4.

Table 7: Corrected liquefaction-related ground surface subsidence using LiDAR DEMs.

	Estimated Ground Surface Subsidence (mm)								
	10-m Buffer			20-m Buffer			50-m Buffer		
Earthquake Event(s)	16th %ile	50th %ile	84th %ile	16th %ile	50th %ile	84th %ile	16th %ile	50th %ile	84th %ile
Sep-10	NA	NA	NA	NA	NA	NA	NA	NA	NA
Feb-11	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jun-11	50	50	50	50	50	50	50	50	50
Dec-11	NA	NA	NA	NA	NA	NA	NA	NA	NA
CES	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note: These percentiles are not the exact statistical measures; they indicate the spatial variability of ground surface subsidence.

Table 8a: Ejecta-Induced settlement for the top 20 m of the soil profile for the 10-m buffer for the 50th %ile PGA, P_L=50%, and C_{FC}=0.13 using BI-2014, ZRB-2002, and I_C cutoff of 2.6.

Earthquake Event(s)	M_W	PGA (g)	Depth to Groundwater (m)	S_T (mm)	S_{V1D} (mm)	$S_{E,L}$ (mm)
Sep-10	7.1	0.25	1.5	NA	48±20	NA
Feb-11	6.2	0.44	1.8	NA	79±50	NA
Jun-11	6.2	0.19	1.8	ND	11±25	ND
Dec-11	6.1	0.14	1.8	ND	1±50	ND

Notes: S_T = Total settlement (Table 6); S_{V1D} = Average vertical settlement due to volumetric compression using Boulanger and Idriss (2014) (BI-2014) and Zhang et al. (2002) (ZRB-2002) procedures and de Greef and Lengkeek (2018) thin-layer correction; $S_{E,L}$ = Ejecta-induced settlement as the difference between the LiDAR-based S_T and S_{V1D}; NA = Not available; ND = Not determined.

Table 8b: Ejecta-Induced settlement for the top 20 m of the soil profile for the 20-m buffer for the 50th %ile PGA, P_L=50%, and C_{FC}=0.13 using BI-2014, ZRB-2002, and I_C cutoff of 2.6.

Earthquake Event(s)	M_W	PGA (g)	Depth to Groundwater (m)	S_T (mm)	S_{V1D} (mm)	$S_{E,L}$ (mm)
Sep-10	7.1	0.25	1.5	NA	53±20	NA
Feb-11	6.2	0.44	1.8	NA	81±50	NA
Jun-11	6.2	0.19	1.8	ND	11±25	ND
Dec-11	6.1	0.14	1.8	ND	1±50	ND

Notes: S_T = Total settlement (Table 6); S_{V1D} = Average vertical settlement due to volumetric compression using Boulanger and Idriss (2014) (BI-2014) and Zhang et al. (2002) (ZRB-2002) procedures and de Greef and Lengkeek (2018) thin-layer correction; $S_{E,L}$ = Ejecta-induced settlement as the difference between the LiDAR-based S_T and S_{V1D}; NA = Not available; ND = Not determined.

Table 8c: Ejecta-Induced settlement for the top 20 m of the soil profile for the 10-m buffer for the 50th %ile PGA, P_L=50%, and C_{FC}=0.13 using BI-2014, ZRB-2002, and I_C cutoff of 2.6.

Earthquake Event(s)	M_W	PGA (g)	Depth to Groundwater (m)	S_T (mm)	S_{V1D} (mm)	$S_{E,L}$ (mm)
Sep-10	7.1	0.25	1.5	NA	52$\pm$20	NA
Feb-11	6.2	0.44	1.8	NA	80$\pm$50	NA
Jun-11	6.2	0.19	1.8	ND	11$\pm$25	ND
Dec-11	6.1	0.14	1.8	ND	1$\pm$50	ND

Notes: S_T = Total settlement (Table 6); S_{V1D} = Average vertical settlement due to volumetric compression using Boulanger and Idriss (2014) (BI-2014) and Zhang et al. (2002) (ZRB-2002) procedures and de Greef and Lengkeek (2018) thin-layer correction; $S_{E,L}$ = Ejecta-induced settlement as the difference between the LiDAR-based S_T and S_{V1D}; NA = Not available; ND = Not determined.

Note 2: The uncertainty for volumetric settlement was derived based on the sensitivity of volumetric settlement to PGA, C_{FC}, and P_L for each earthquake event for VsVp 57203 *Shirley Intermediate School* and CC LIQ 1 – CPT 5586 – *Vivian St* sites. Taking the 50th percentile as the baseline case, the minimum and maximum values corresponding to the difference between the 25th percentile and the 50th percentile and the 75th percentile and the 50th percentile were determined. The arithmetic mean of the range of the minimum and maximum difference was evaluated for each patch at the two sites. The maximum arithmetic mean for each earthquake event was rounded to the nearest five and used as the uncertainty value. Accordingly, the 1-D volumetric settlement uncertainties of $\pm$20, $\pm$50, $\pm$25, and $\pm$50 mm for the Sep-10, Feb-11, Jun-11, and Dec-11 earthquake events, respectively, were used for all sites in this study.

Table 9a: Coverage area and height of ejecta estimates for the 10-m buffer using aerial and/or ground photographs and engineering judgement.

EQ Event	$H_{E,thin}$ (mm)	$A_{E,thin}$ (m^2)	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m^2)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m^2)	$H_{E,cone}$ (mm)	$A_{E,cone}$ (m^2)	A_T (m^2)
Sep-10	0	0	0	0	0	0	0	0	292
Feb-11	80-160	54.6	0	0	5-10	14.5	200-250	5.0	292
Jun-11*	0	0	0	0	0	0	0	0	292
Dec-11	0	0	0	0	0	0	0	0	292

Notes: $H_{E,thick/thin}$ = Lower-upper estimates of height of thick/thin ejecta layers; $A_{E,thick/thin}$ = Coverage area of thick/thin ejecta layers; Thin and thick layers correspond to light gray and dark gray colors of ejecta, respectively, observed in aerial photographs; $A_{E,cone}$ = Lower-upper estimate of conically shaped ejecta; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta layers; A_T= Total assessment area of a buffer being considered; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ and the lack of physical evidence for the Jun-11 EQ.

Table 9b: Coverage area and height of ejecta estimates for the 20-m buffer using aerial and/or ground photographs and engineering judgement.

EQ Event	$H_{E,thin}$ (mm)	$A_{E,thin}$ (m²)	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m²)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m²)	$H_{E,cone}$ (mm)	$A_{E,cone}$ (m²)	A_T (m²)
Sep-10	0	0	0	0	30-60	36.0	0	0	1055
Feb-11	80-160	223	30-50	10.2	5-10	148	200-250	9.9	1055
Jun-11*	0	0	0	0	0	0	0	0	1055
Dec-11	0	0	0	0	0	0	0	0	1055

Notes: $H_{E,thick/thin}$ = Lower-upper estimates of height of thick/thin ejecta layers; $A_{E,thick/thin}$ = Coverage area of thick/thin ejecta layers; Thin and thick layers correspond to light gray and dark gray colors of ejecta, respectively, observed in aerial photographs; $A_{E,cone}$ = Lower-upper estimate of conically shaped ejecta; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta layers; A_T= Total assessment area of a buffer being considered; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ and the lack of physical evidence for the Jun-11 EQ.

Table 9c: Coverage area and height of ejecta estimates for the 50-m buffer using aerial and/or ground photographs and engineering judgement.

EQ Event	$H_{E,thin}$ (mm)	$A_{E,thin}$ (m²)	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m²)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m²)	$H_{E,cone}$ (mm)	$A_{E,cone}$ (m²)	A_T (m²)
Sep-10	0	0	0	0	30-60	36.0	0	0	2642
Feb-11	80-160	437	30-50	24.5	5-10	358	200-250	16.9	2642
Jun-11*	0	0	0	0	0	0	0	0	2642
Dec-11	0	0	0	0	0	0	0	0	2642

Notes: $H_{E,thick/thin}$ = Lower-upper estimates of height of thick/thin ejecta layers; $A_{E,thick/thin}$ = Coverage area of thick/thin ejecta layers; Thin and thick layers correspond to light gray and dark gray colors of ejecta, respectively, observed in aerial photographs; $A_{E,cone}$ = Lower-upper estimate of conically shaped ejecta layers; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta; A_T= Total assessment area of a buffer being considered; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ and the lack of physical evidence for the Jun-11 EQ.

Note 3:

- The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photographs (Figures 33, 34, and 36) and the lower and upper estimates of ejecta height based on EQC LDAT property inspection reports and ground photographs (Figure 52). The ejecta-induced settlement using photograph and engineering judgment, $S_{E,P}$, is estimated as

$$S_{E,P} = \frac{\sum_{i=1}^{a} A_{E,thick,i} * H_{E,thick,i} + \sum_{j=1}^{b} A_{E,thin,j} * H_{E,thin,j} + \frac{1}{3}\sum_{m=1}^{e} A_{E,cone,m} * H_{E,cone,m}}{A_T} + $$

$$= \frac{\sum_{i=1}^{a} V_{E,thick,i} + \sum_{j=1}^{b} V_{E,thin,j} + \sum_{m=1}^{e} V_{E,cone,m}}{A_T}$$

where

- $A_{E,thick,i}$ and $H_{E,thick,i}$ are the area and the height of a thick ejecta layer, respectively;
- $A_{E,thin,j}$ and $H_{E,thin,j}$ are the area and the height of a thin ejecta layer, respectively;
- $A_{E,cone,m}$ and $H_{E,cone,m}$ are the area and the height of a conically shaped ejecta, respectively;

  - A_T is the total assessment area for a buffer being considered (Figure 1).
- It is stated in the LDAT property report that ejecta were not removed at the time of the inspection, on 9 Nov 2011, and that earthwork was required to remediate the entire site. The inspection team reported the undulating land (lawn > 50 mm high). Furthermore, the settlement of LINZ benchmarks near the site due to the Sep-10, Feb-11 and Jun-11 earthquake was evaluated as 58±48 mm, 67±66 mm, and 10±10 mm, respectively. For the Jun-11 EQ, there are no aerial photographs or satellite images of the site. However, liquefaction at nearby sites was interpreted as none from the aerial photograph for the Jun-11 EQ (Figure 35). Thus, it is reasonable to assume no liquefaction ejecta occurred for the Jun-11 EQ. For the Dec-11 EQ, no ejecta are visible in the aerial photograph except for the minor quantum along the curb of the road.
- The high-resolution aerial photograph for the Sep-10 EQ is unavailable and there is uncertainty in estimating the ejecta-induced settlement of the assessment area for the Sep-10 EQ. However, the satellite image reveals the significant quantum of ejecta on the road within the 50-m buffer.

Table 10: Ejecta-induced settlement estimates based on aerial and/or ground photographs.

Earthquake Event	10-m buffer		20-m buffer		50-m buffer	
	$S_{E,P,lower}$ (mm)	$S_{E,P,upper}$ (mm)	$S_{E,P,lower}$ (mm)	$S_{E,P,upper}$ (mm)	$S_{E,P,lower}$ (mm)	$S_{E,P,upper}$ (mm)
Sep-10*	0	0	1	2	≈0	1
Feb-11	16	32	19	36	15	29
Jun-11*	0	0	0	0	0	0
Dec-11	0	0	0	0	0	0

Note: $S_{E,P,lower}$ and $S_{E,P,upper}$ correspond to lower and upper estimates of $S_{E,P}$, respectively; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ and the lack of photographic evidence for the Jun-11 EQ.

Table 11: Best final estimates of ejecta-induced settlement

EQ Event	10-m buffer			20-m buffer			50-m buffer		
	$S_{E,L}$ (mm)	$S_{E,P}$ (mm)	$S_{E,final}$ (mm)	$S_{E,L}$ (mm)	$S_{E,P}$ (mm)	$S_{E,final}$ (mm)	$S_{E,L}$ (mm)	$S_{E,P}$ (mm)	$S_{E,final}$ (mm)
Sep-10	NA	0	0	NA	1.5±0.5	<5	NA	0.5±0.5	<5
Feb-11	NA	24±8	25±10	NA	28±8	30±10	NA	22±7	20±5
Jun-11	ND	0*	0*	ND	0*	0*	ND	0*	0*
Dec-11	ND	0	0	ND	0	0	ND	0	0

Notes: $S_{E,L}$ = Ejecta-induced settlement based on LiDAR data reported in Table 8; $S_{E,P}$ = Median ejecta-induced settlement for the range of values reported in Table 10; $S_{E,final}$ = Best final estimate of ejecta-induced settlement rounded to the nearest 5 mm; Final plus/minus values are also rounded to the nearest 5 mm; * indicates uncertainty due to the lack of photographic evidence for the Jun-11 EQ and the low-resolution satellite image for the Sep-10 EQ; NA = Not available; ND = Not determined.

Note 4:

$S_{E,final}$ is based on $S_{E,P}$ for all earthquake events. The Rydal Reserve site is in the zone moderate to severe overprediction for the Sep-10 EQ and the zone of slight to moderate LPI overprediction of liquefaction severity for the Feb-11 EQ according to Maurer et al. (2014[3]).

<u>Summary 1</u>: The best estimate of the ejecta-induced free-field settlement at the Rydal Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is <5 mm, 30±10 mm, 0 mm, and 0 mm, respectively.

Figure 2: Location of the site.

[3] Maurer, B. W., Green, R. A., Cubrinovski, M., & Bradley, B. A. (2014). Evaluation of the Liquefaction Potential Index for Assessing Liquefaction Hazard in Christchurch, New Zealand. *Journal of Geotechnical and Geoenvironmental Engineering*, 140(7), 04014032-1-11. doi:10.1061/(asce)gt.1943-5606.0001117

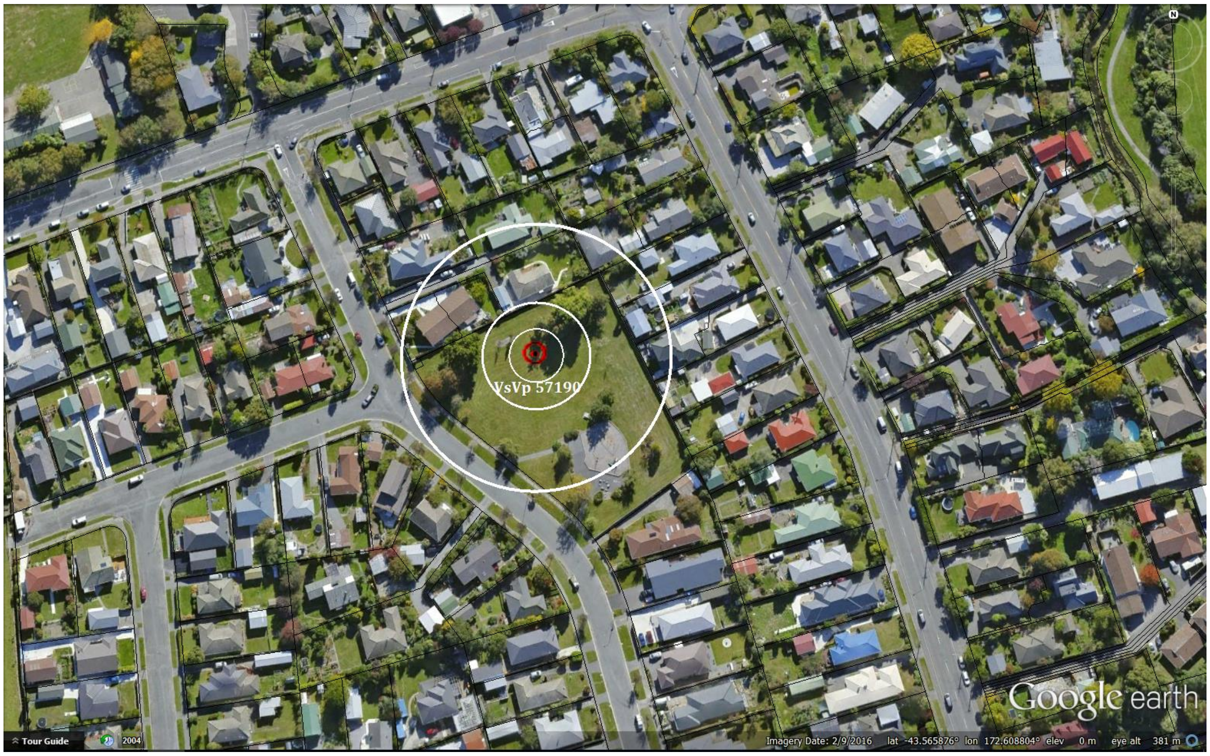

Figure 3: Position of the site relative to nearby buildings, vegetation, and other important features.

Figure 4: Street view of the elevated playground.

Figure 5: Street view of the flat land.

Figure 6: Satellite image of the site taken in Dec 2004.

Figure 7: Satellite image of the site taken in Jan 2007.

Figure 8: Satellite image of the site taken in Mar 2009.

Figure 9: Satellite image of the site taken on 3 Sep 2010.

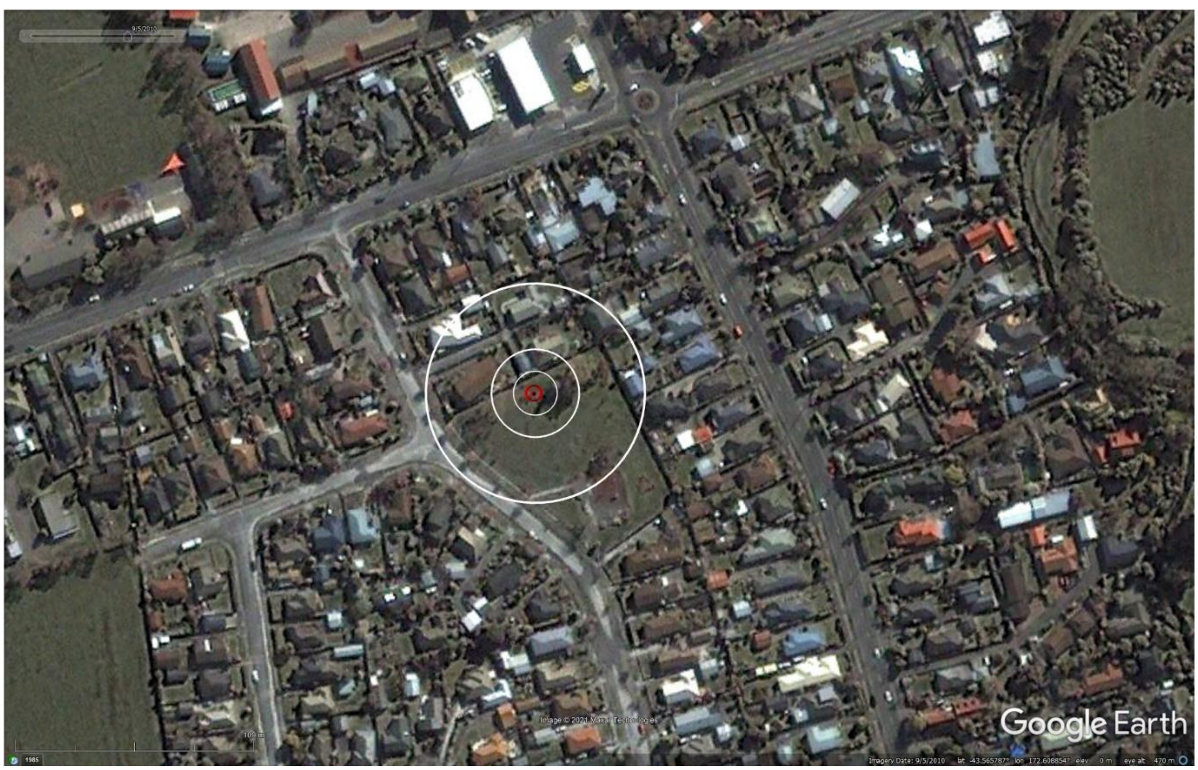

Figure 10: Satellite image of the site taken on 5 Sep 2010.

Figure 11: Satellite image of the site taken on 15 Feb 2011.

Figure 12: Satellite image of the site taken on 26 Feb 2010.

Figure 13: Satellite image of the site taken in Apr 2012.

Figure 14: Satellite image of the site taken in Nov 2015.

Figure 15: EQC Aerial Photograph of the site taken on Feb 24, 2011.

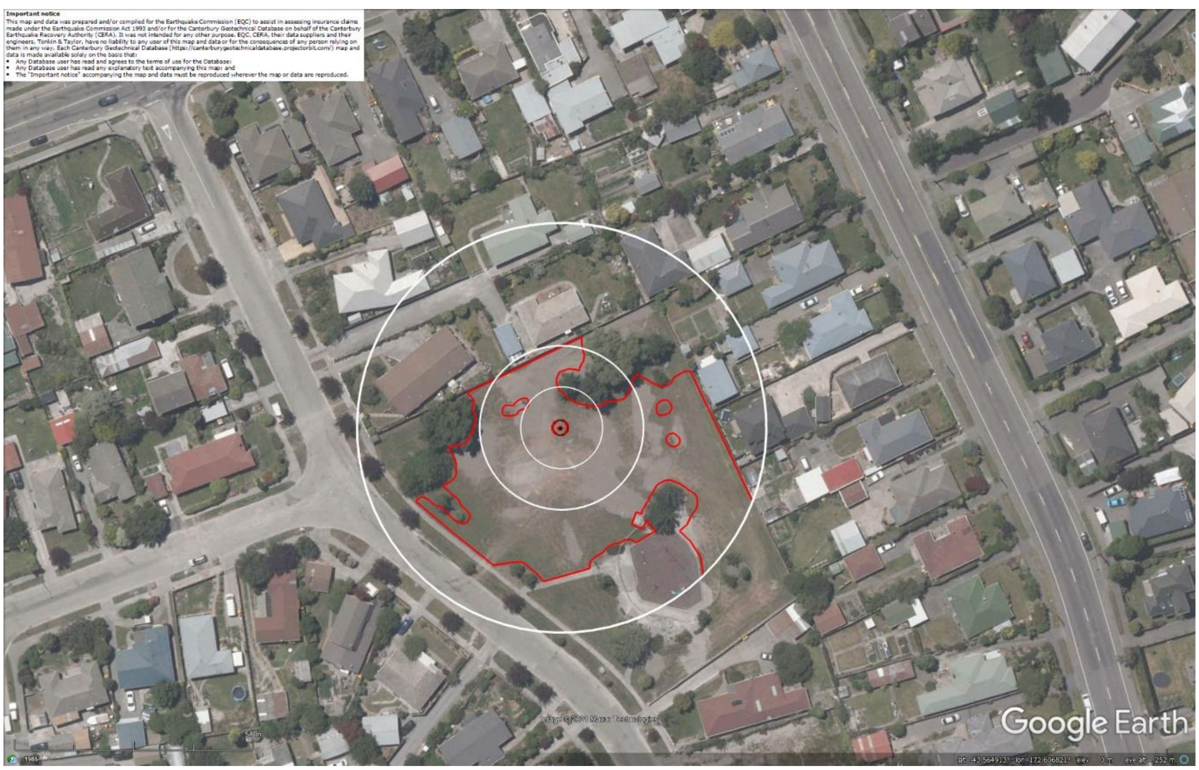

Figure 16: EQC Aerial Photograph of the site taken on Dec 24, 2011.

Note 5: EQC Aerial Photograph is not available for Sep 2010 and Jun 2011 events.

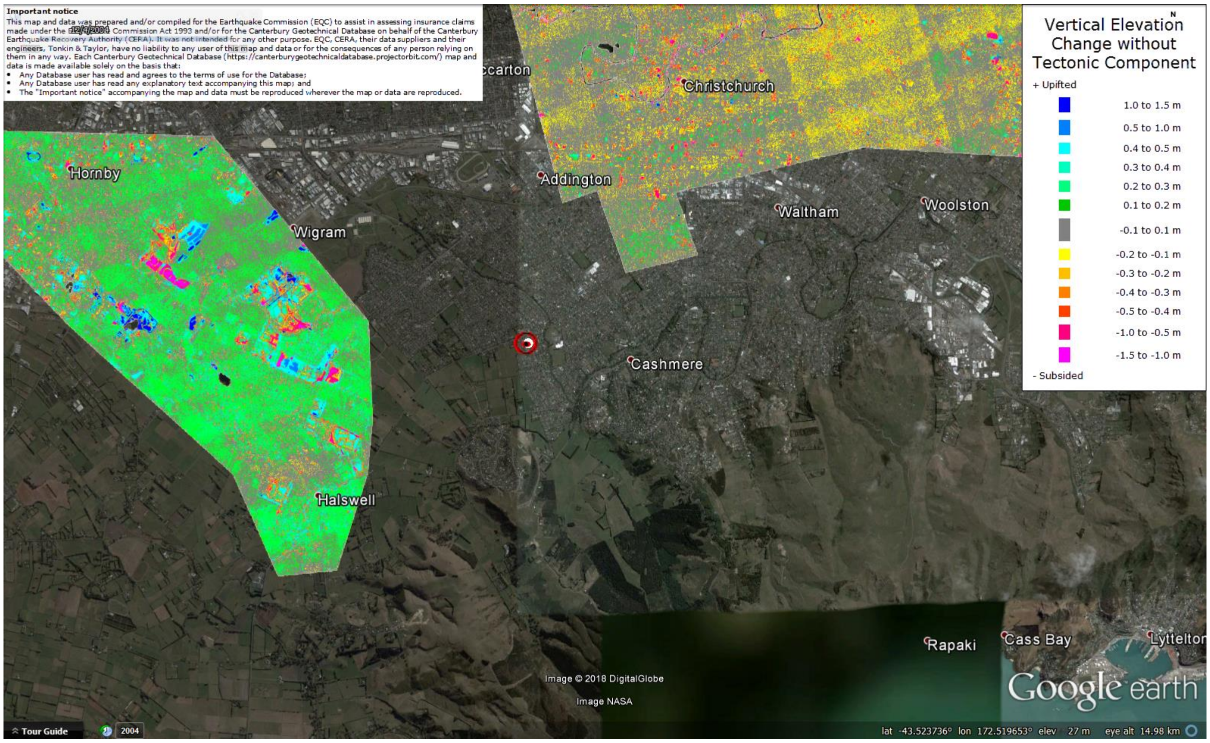

Figure 17: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake for the site are not available.

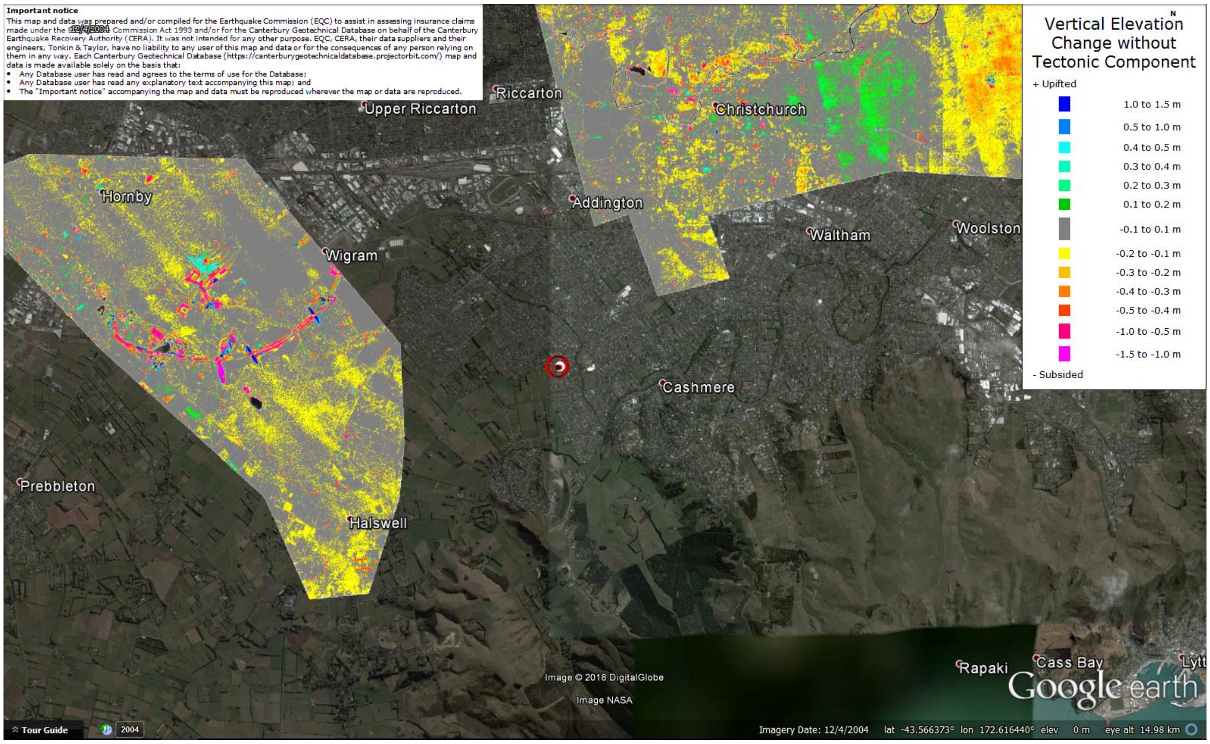

Figure 18: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake for the site are not available.

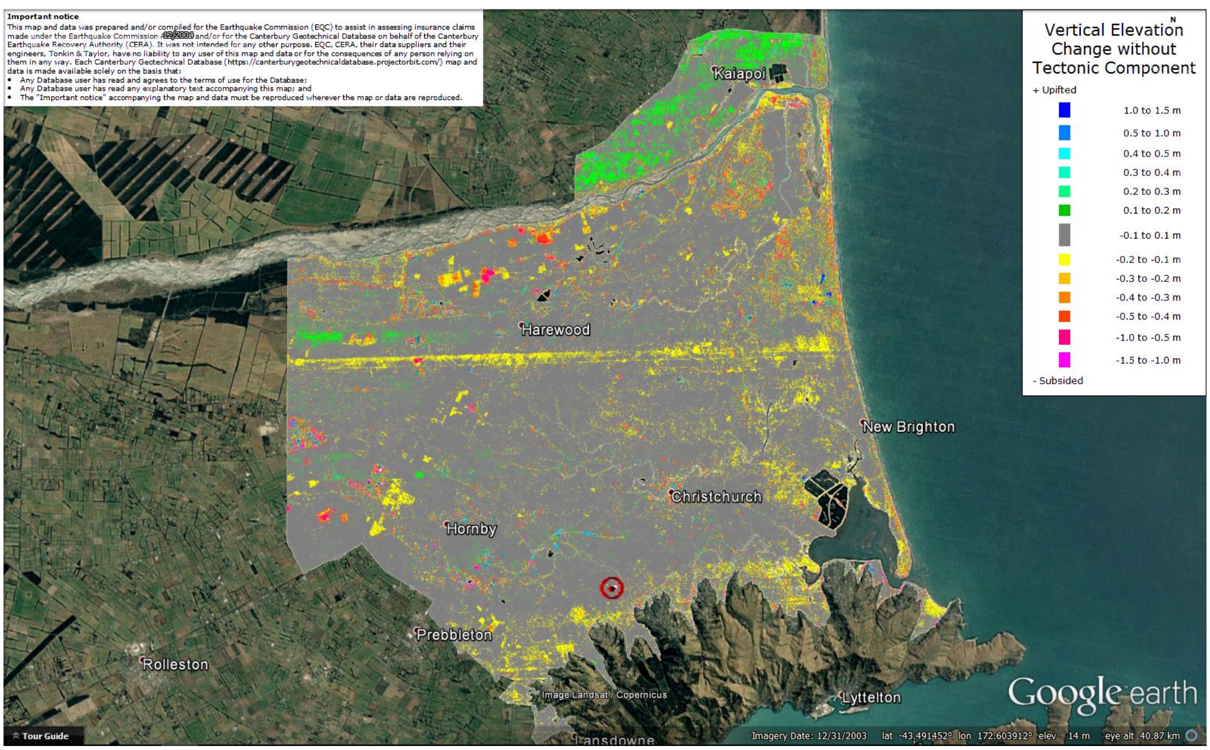

Figure 19: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated or underestimated ground surface subsidence.

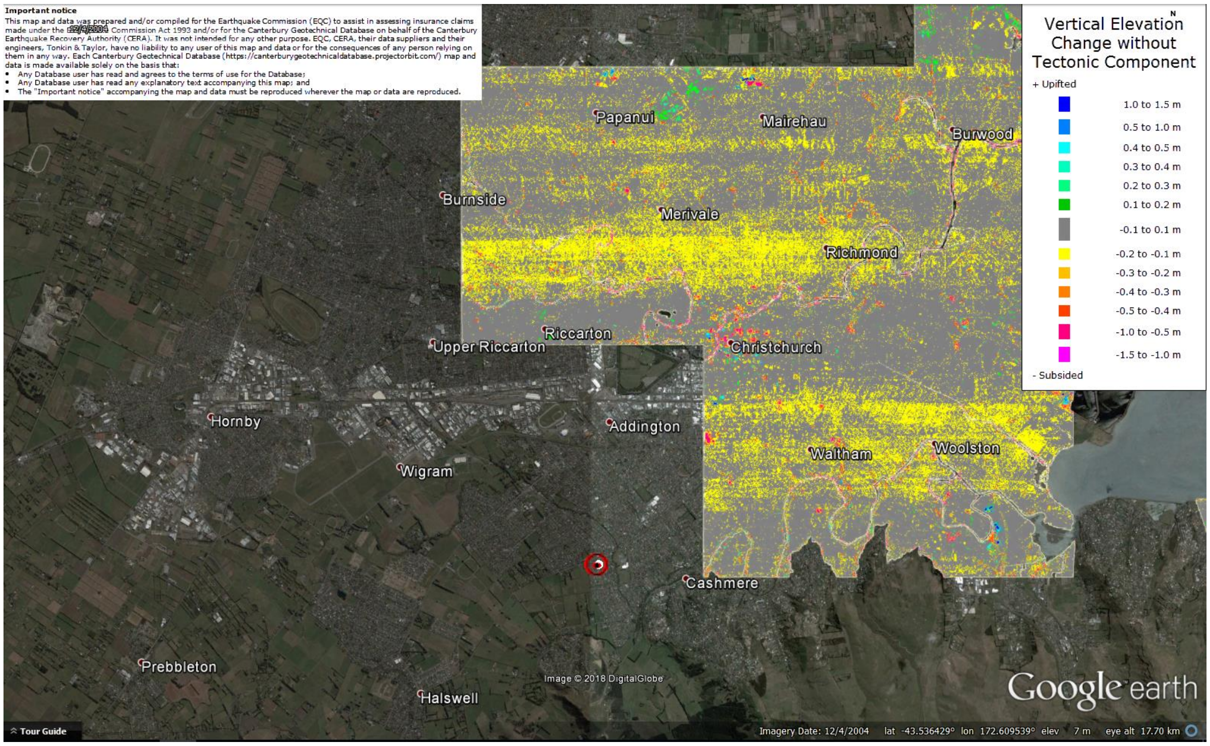

Figure 20: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake for the site are not available.

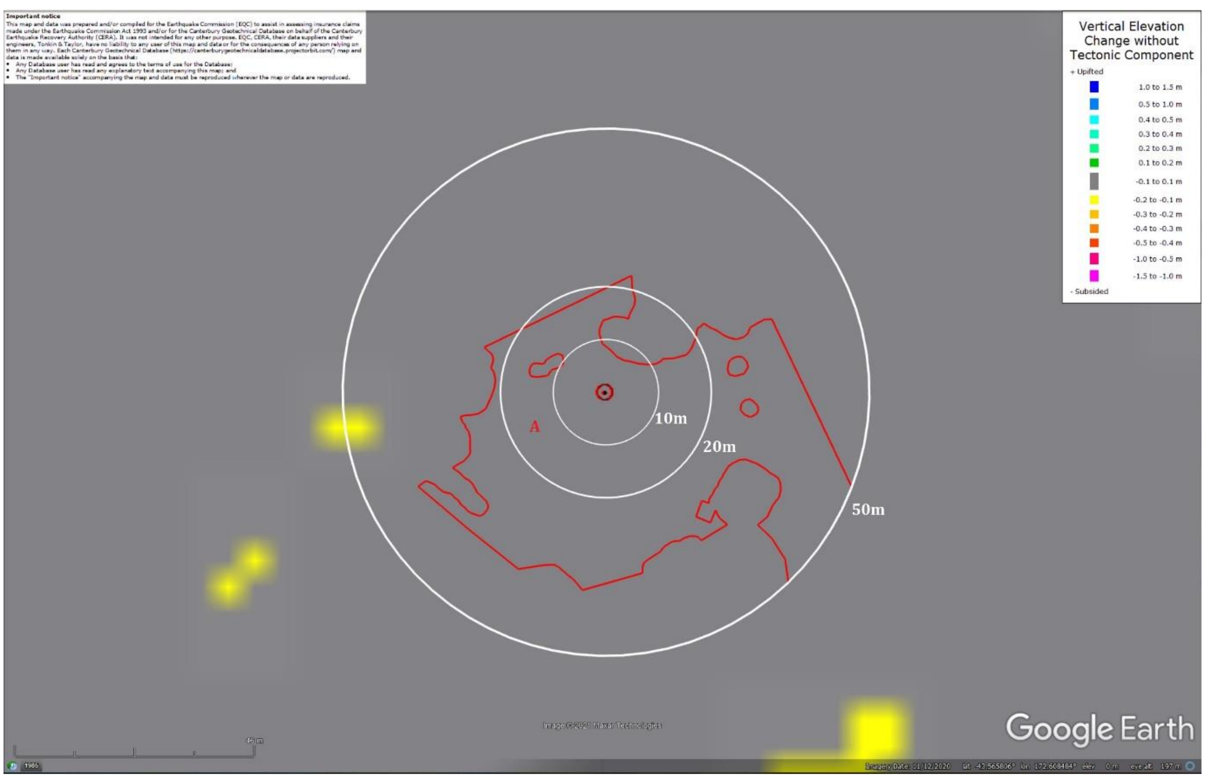

Figure 21: LiDAR DEM-based ground surface subsidence without tectonic component for Jun 2011 Earthquake.

Note 6: The LiDAR DEM-based ground surface subsidence without tectonic component is not available for the Sep 2010, Feb 2011, and Dec 2011 Earthquakes and Canterbury Earthquake Sequence. The only available LiDAR surveys for this site are from July 2003, May 2011, and Sep 2011. The LiDAR survey conducted in Oct 2015 is available, but was not utilized for the development of LiDAR DEMs.

Figure 22: Absence of ground cracks indicating no lateral spreading for Canterbury Earthquake Sequence.

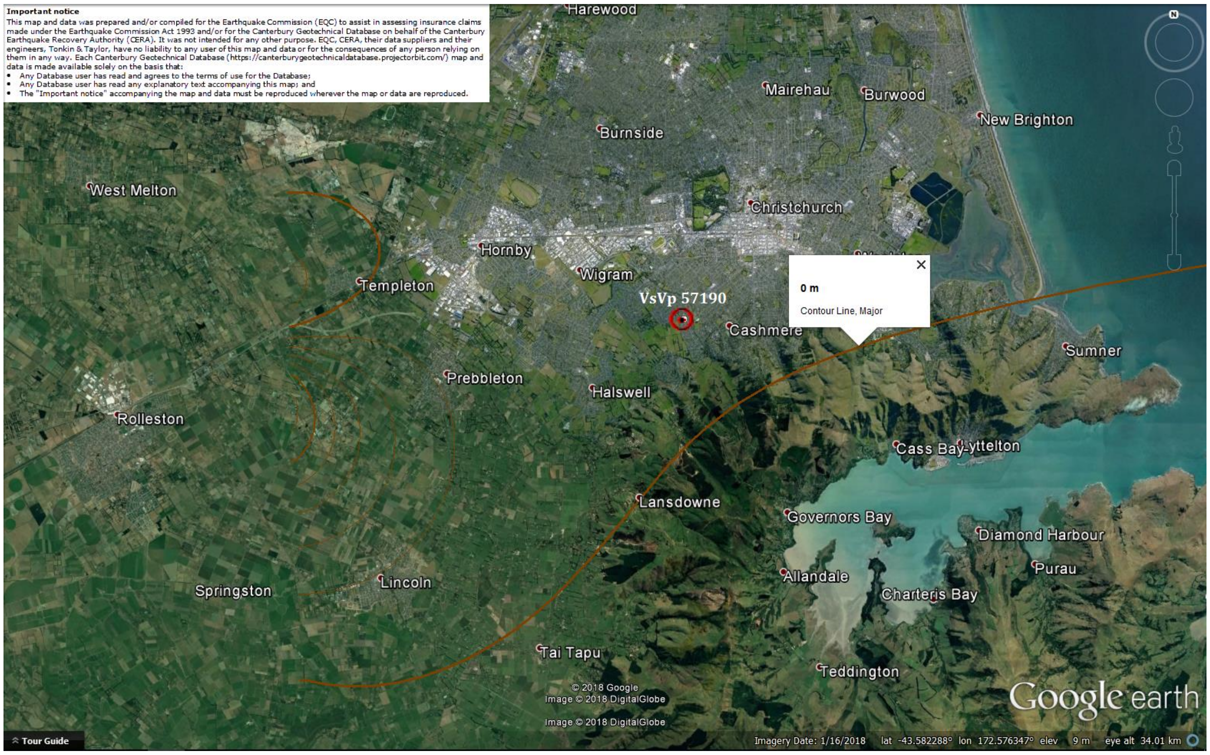

Figure 23: Vertical tectonic movements for Sep 2010 Earthquake.

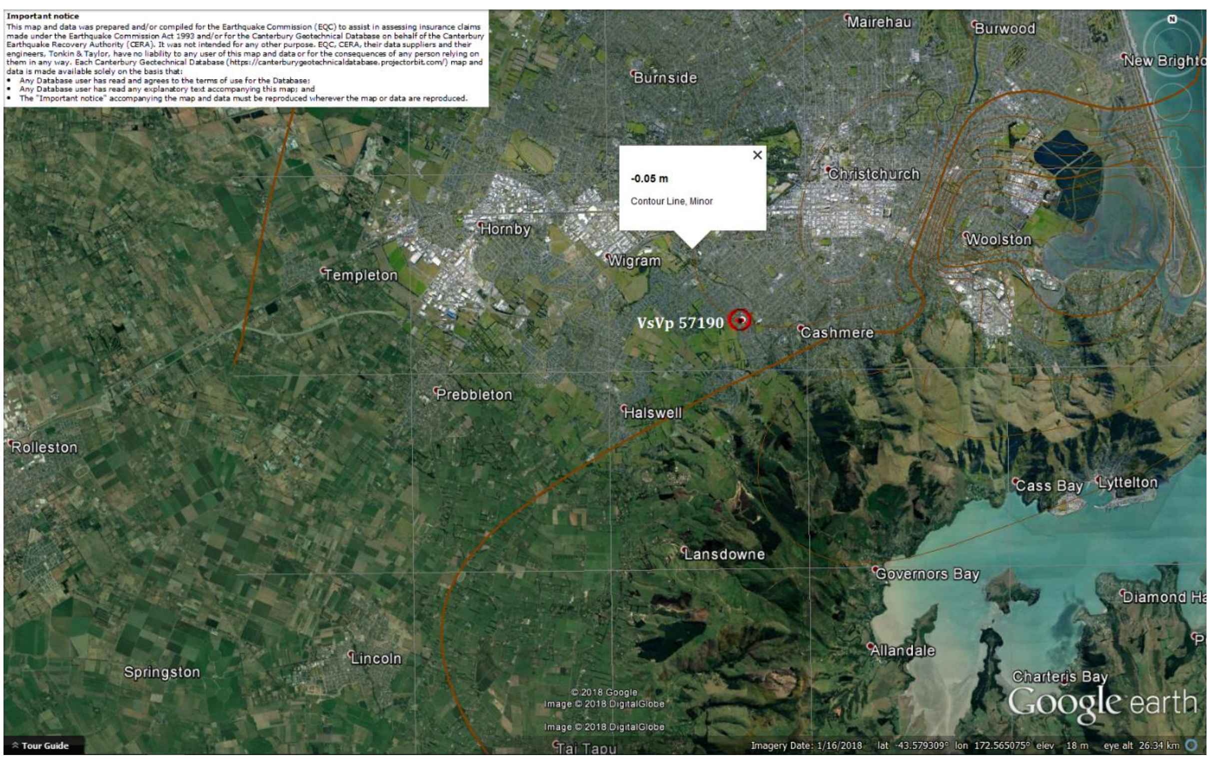

Figure 24: Vertical tectonic movements for Feb 2011 Earthquake.

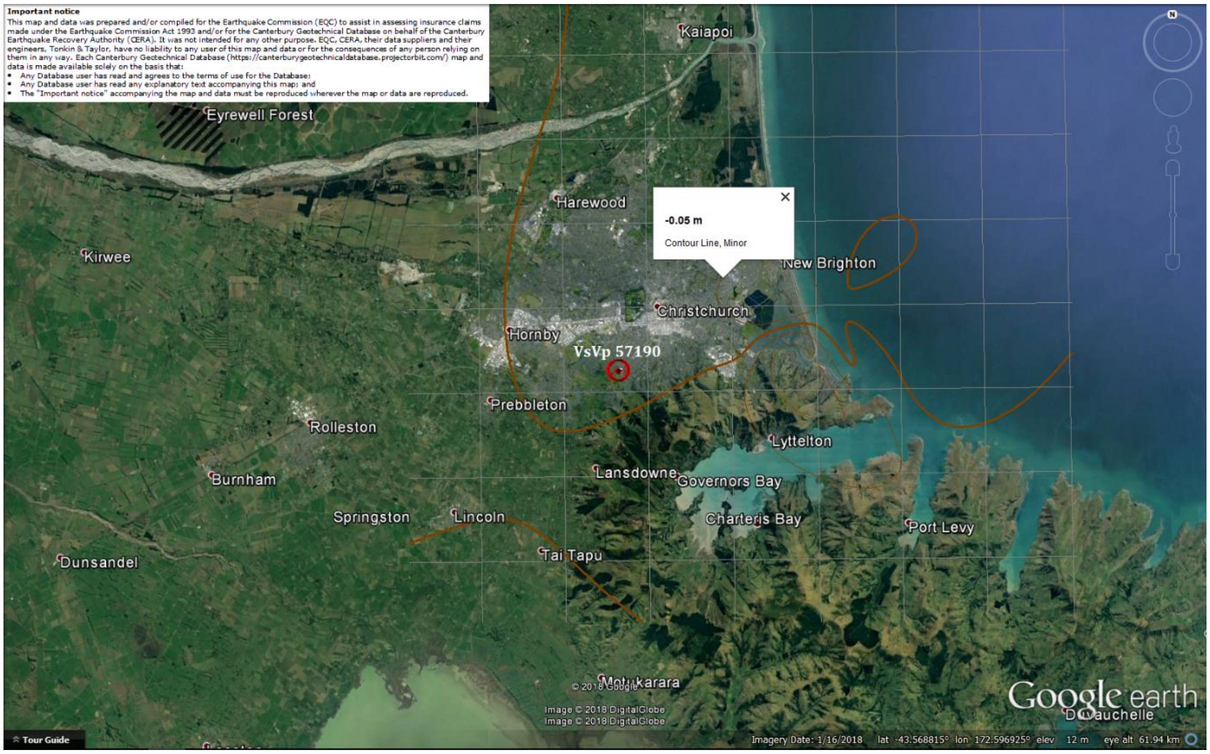

Figure 25: Vertical tectonic movements for June 2011 Earthquake.

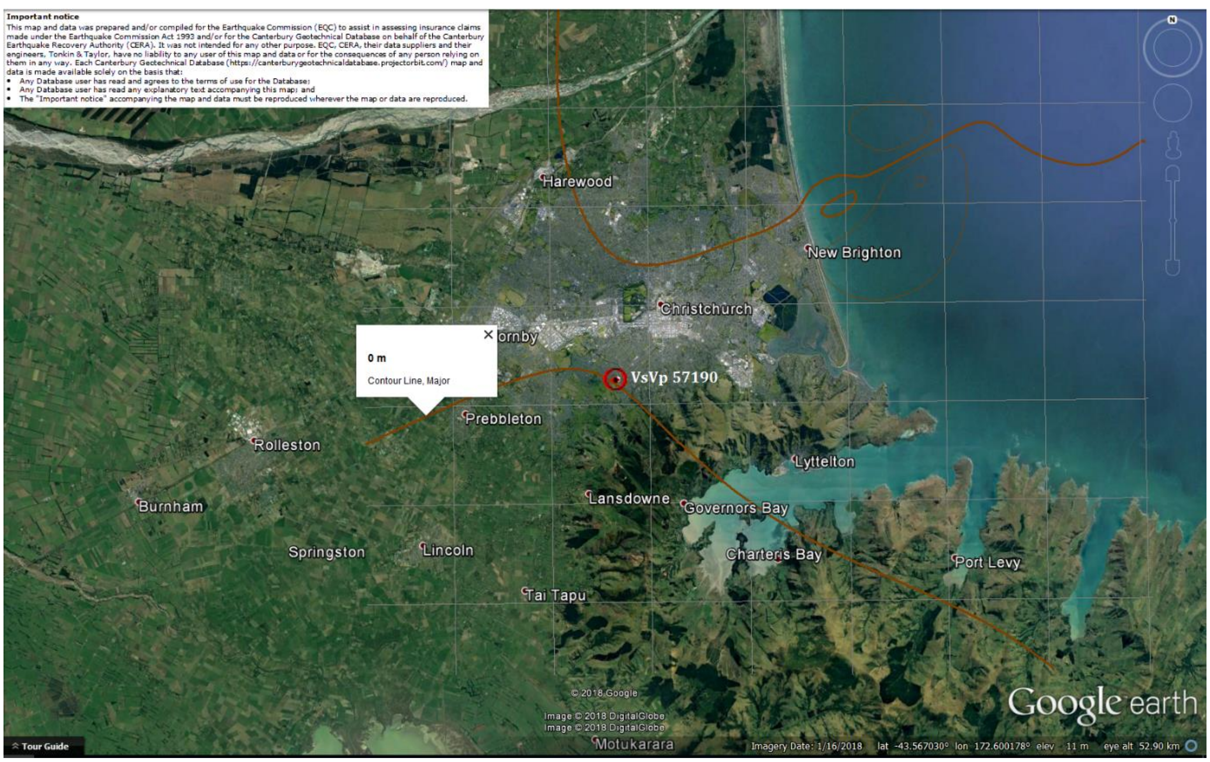

Figure 26: Vertical tectonic movements for Dec 2011 Earthquake.

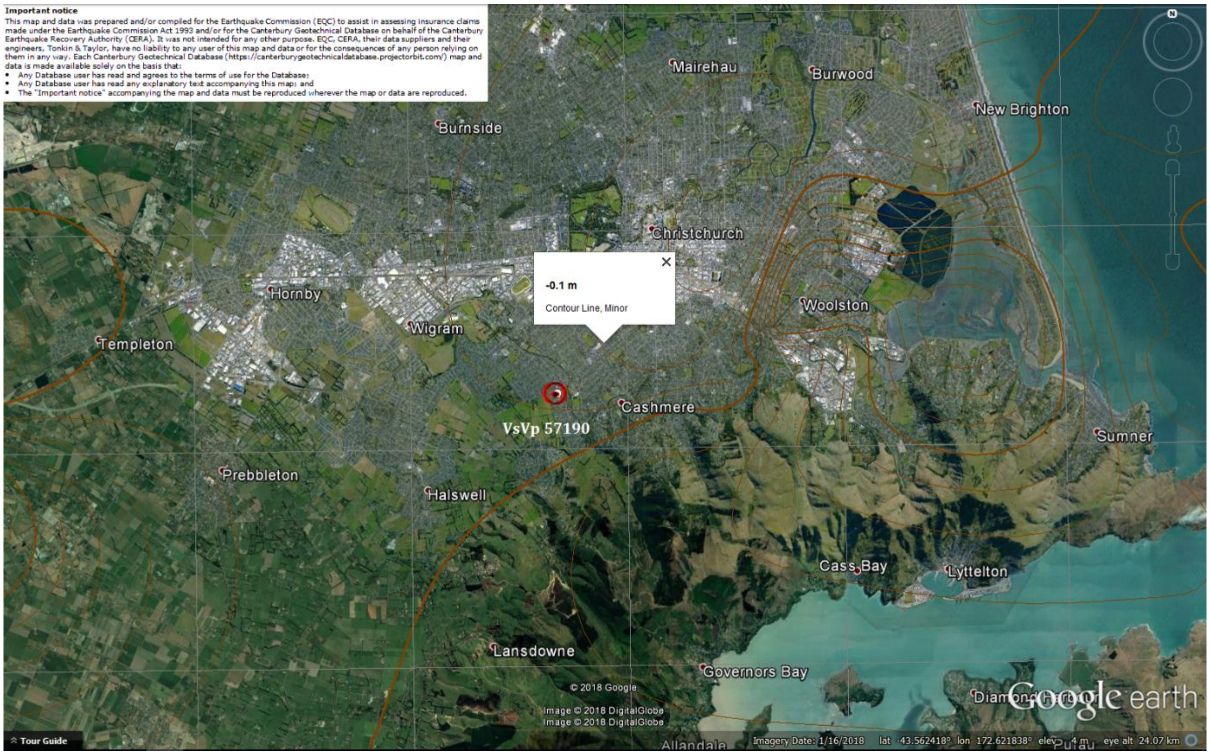

Figure 27: Vertical tectonic movements for Canterbury Earthquake Sequence.

Note 7: The Sep 5, 2010, Mar 2011, and Feb 2012 LiDAR surveys are not available.

Figure 28: EQC liquefaction and lateral spreading observations for Sep 2010 Earthquake to determine ejecta quantum.

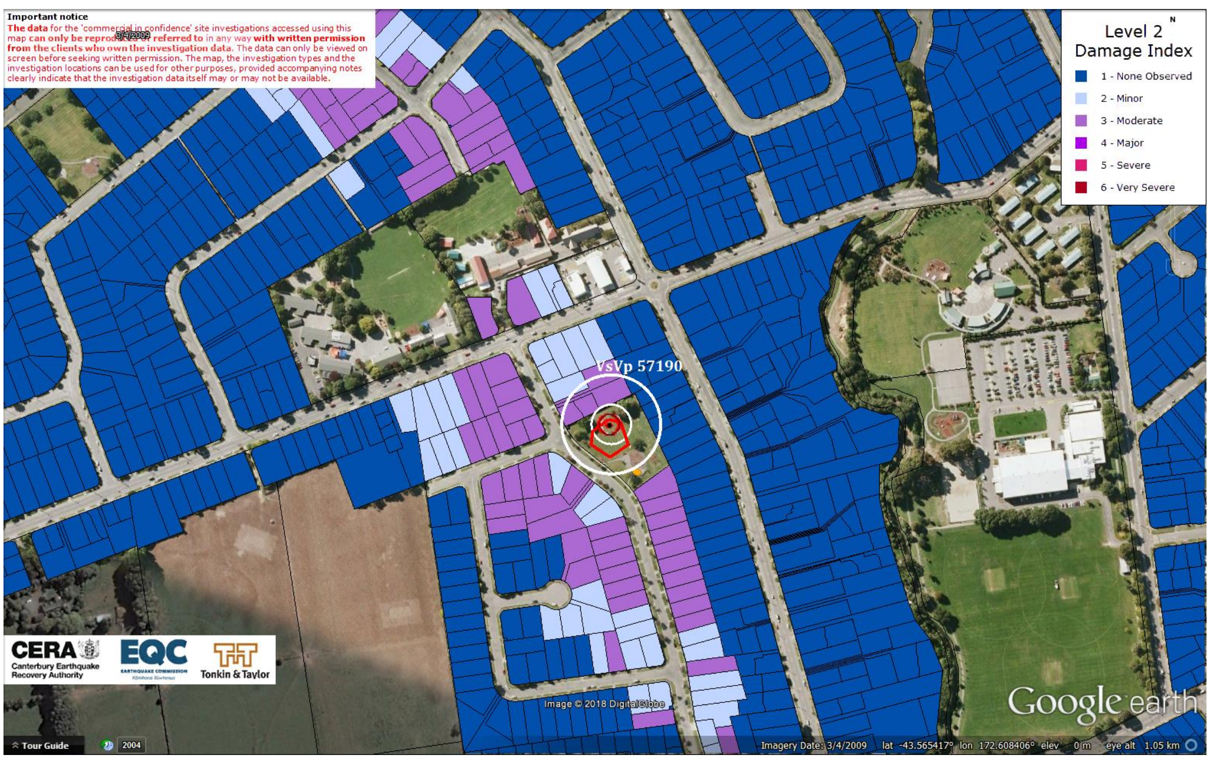

Figure 29: EQC Level 2 Damage Index map for Sep 2010 Earthquake to determine ejecta quantum.

Figure 30: EQC Level 2 Damage Index map for Jun 2011 Earthquake to determine ejecta quantum.

Figure 31: EQC liquefaction and lateral spreading observations for Jun 2011 Earthquake to determine ejecta quantum.

Figure 32: EQC Level 2 Damage Index map for Dec 2011 Earthquake to determine ejecta quantum.

Figure 33: Outline of ejecta for Sep-10 EQ.

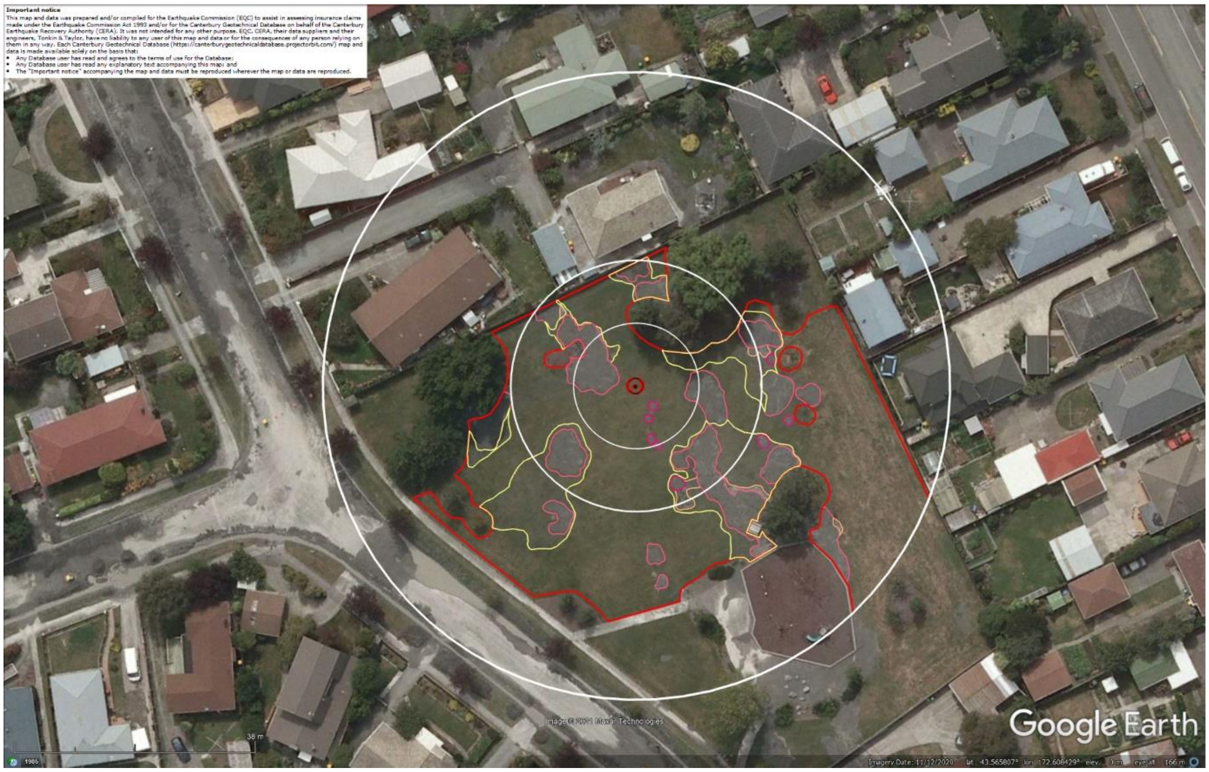

Figure 34: Outline of ejecta for Feb-11 EQ.

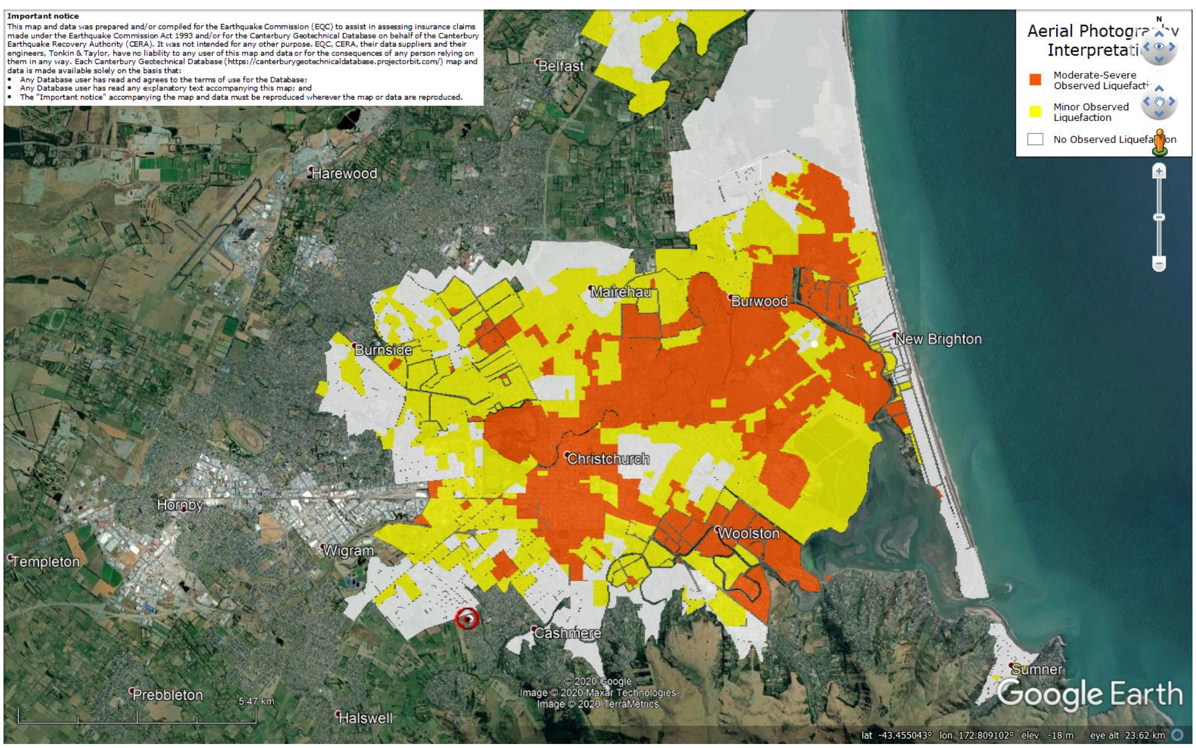

Figure 35: Interpretation of liquefaction for Jun-11 EQ using aerial photographs; liquefaction ejecta were not observed near the site for Jun-11 EQ.

Figure 36: Absence of ejecta at the site for Dec-11 EQ. (The yellow arrow is pointing to the only place with fresh ejecta.)

Figure 37: Ground photographs of the site taken on 9 Nov 2011.

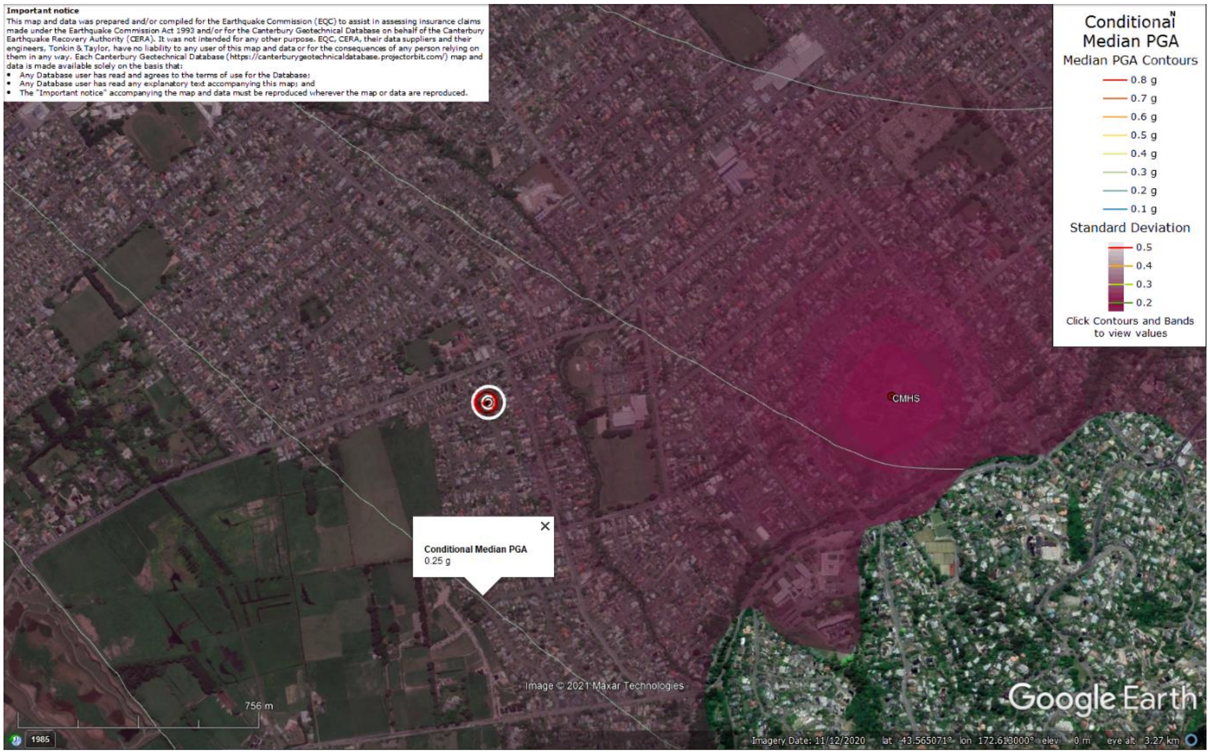

Figure 38: PGA for Sep-10 EQ (st. dev = 0.325-0.350 ln units).

Figure 39: PGA for Feb-11 EQ (st. dev = 0.350-0.375 ln units).

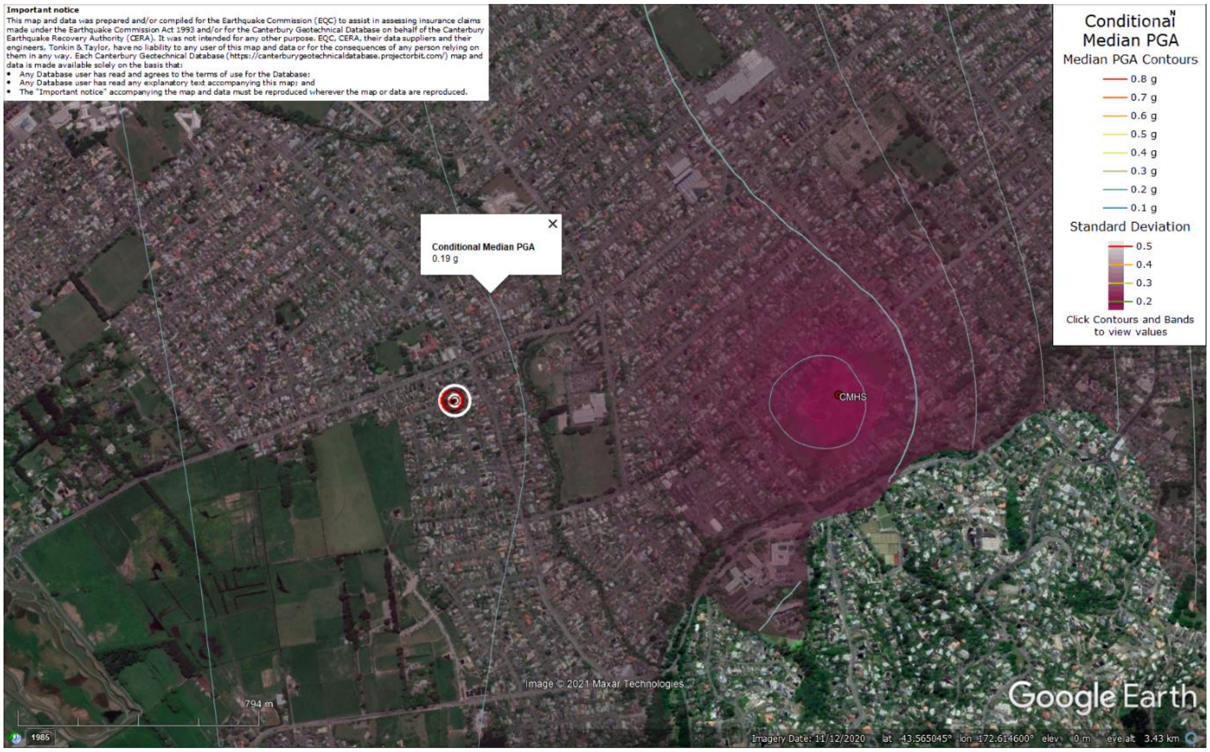

Figure 40: PGA for Jun-11 EQ (st. dev = 0.375-0.400 ln units).

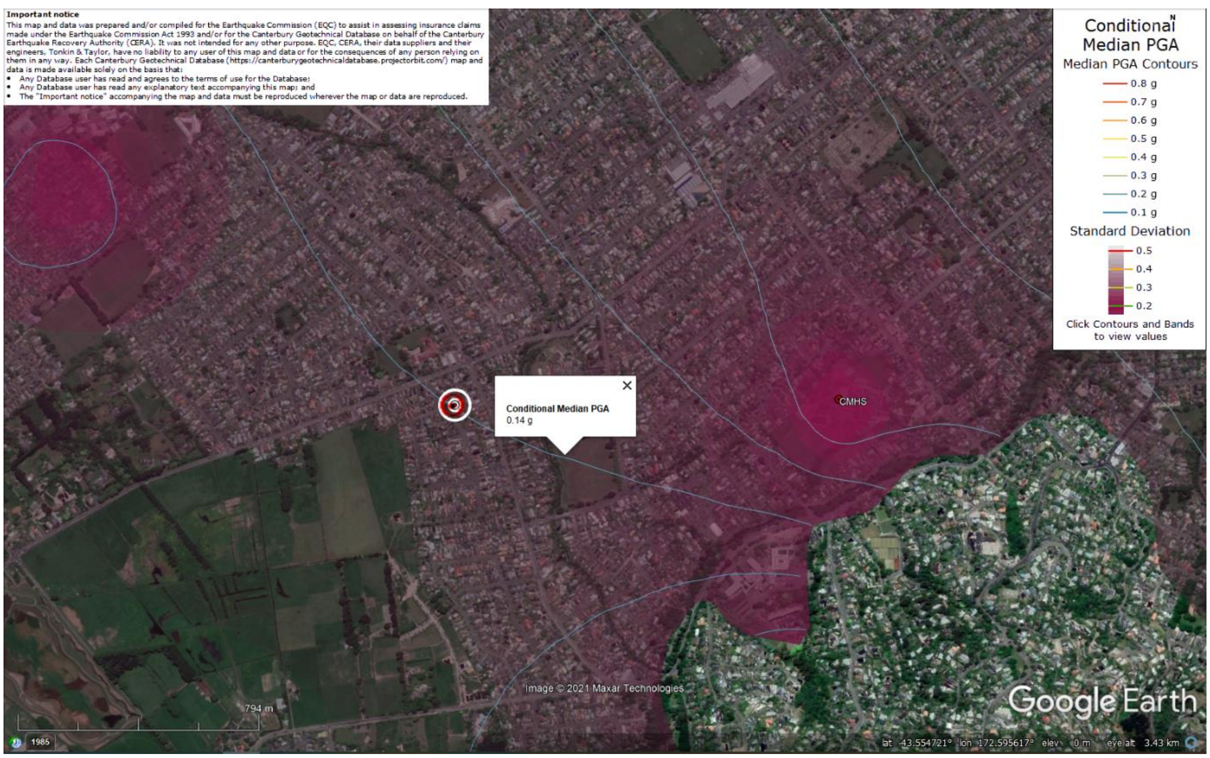

Figure 41: PGA for Dec-11 EQ (st. dev = 0.325-0.350 ln units).

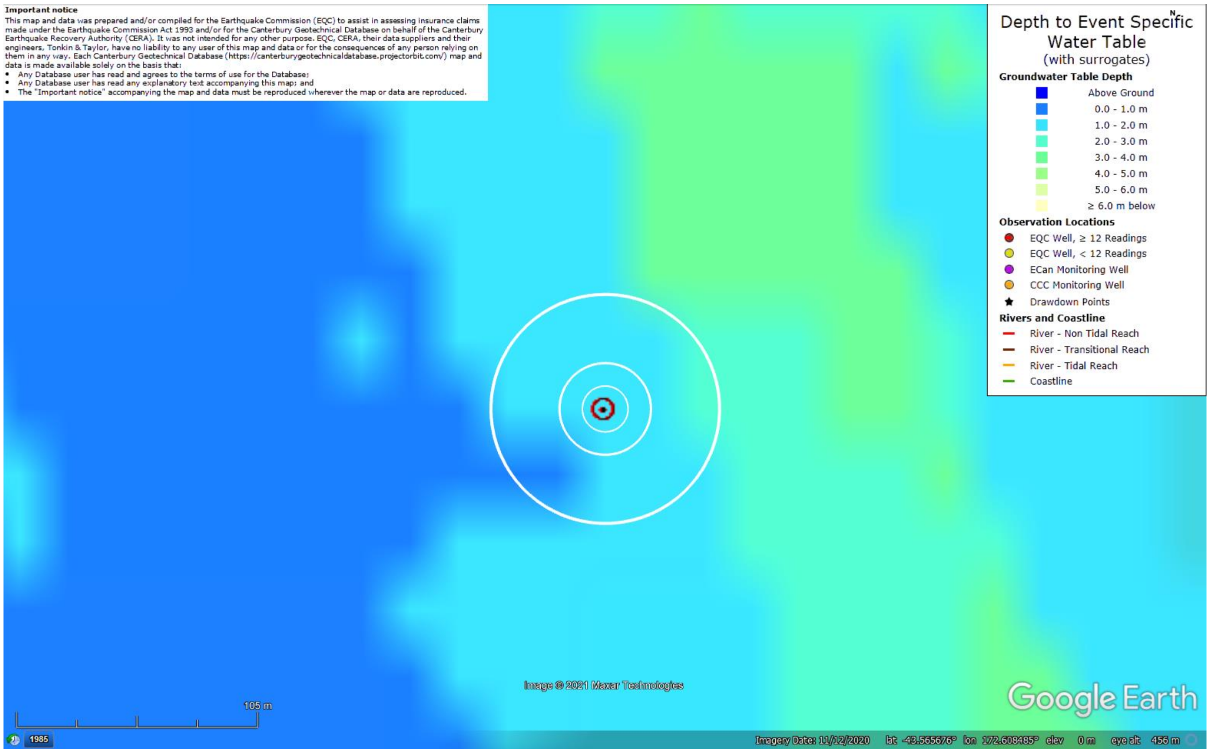

Figure 42: Depth to groundwater table for Sep-10 EQ.

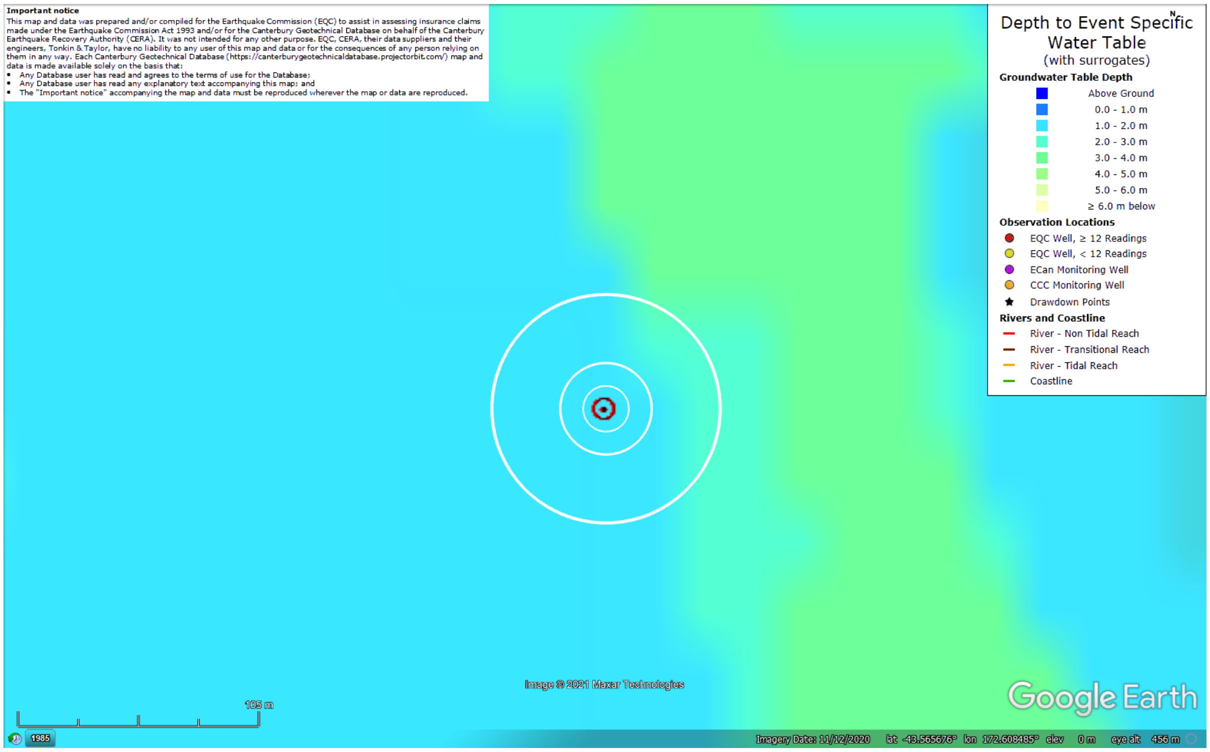

Figure 45: Depth to groundwater table for Feb-11 EQ.

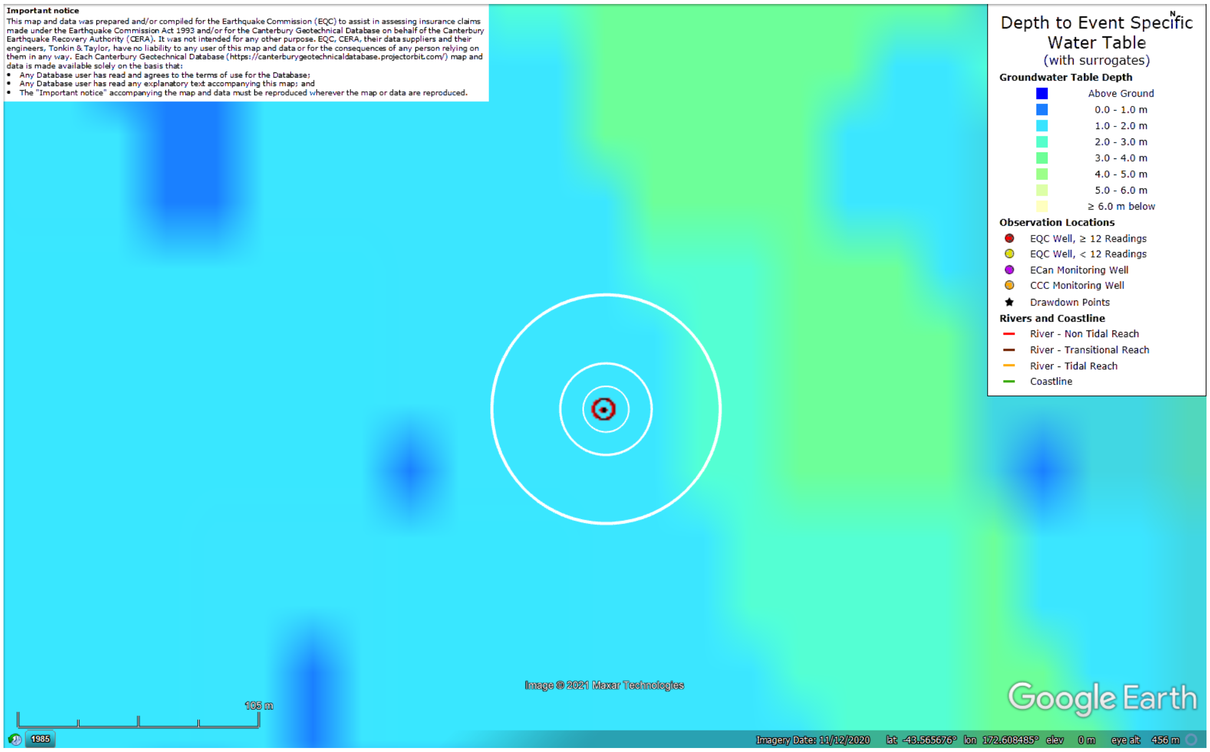

Figure 44: Depth to groundwater table for Jun-11 EQ.

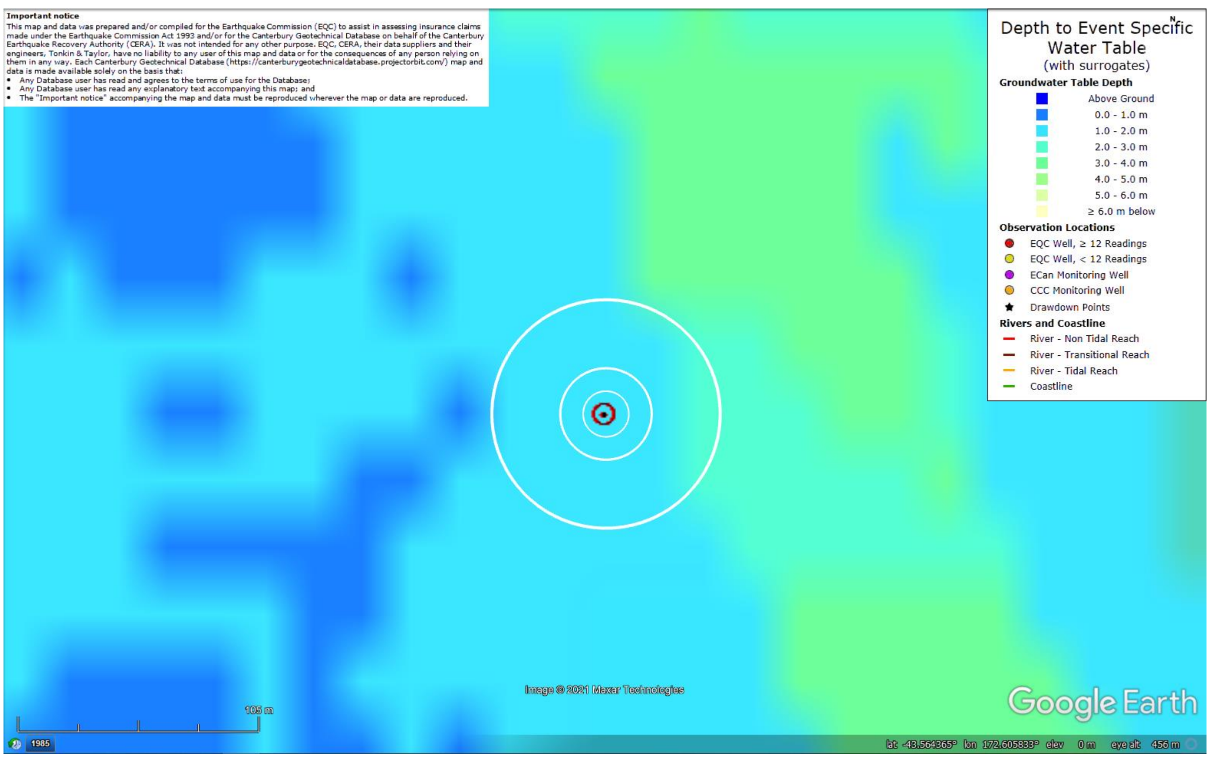

Figure 45: Depth to groundwater table for Dec-11 EQ.

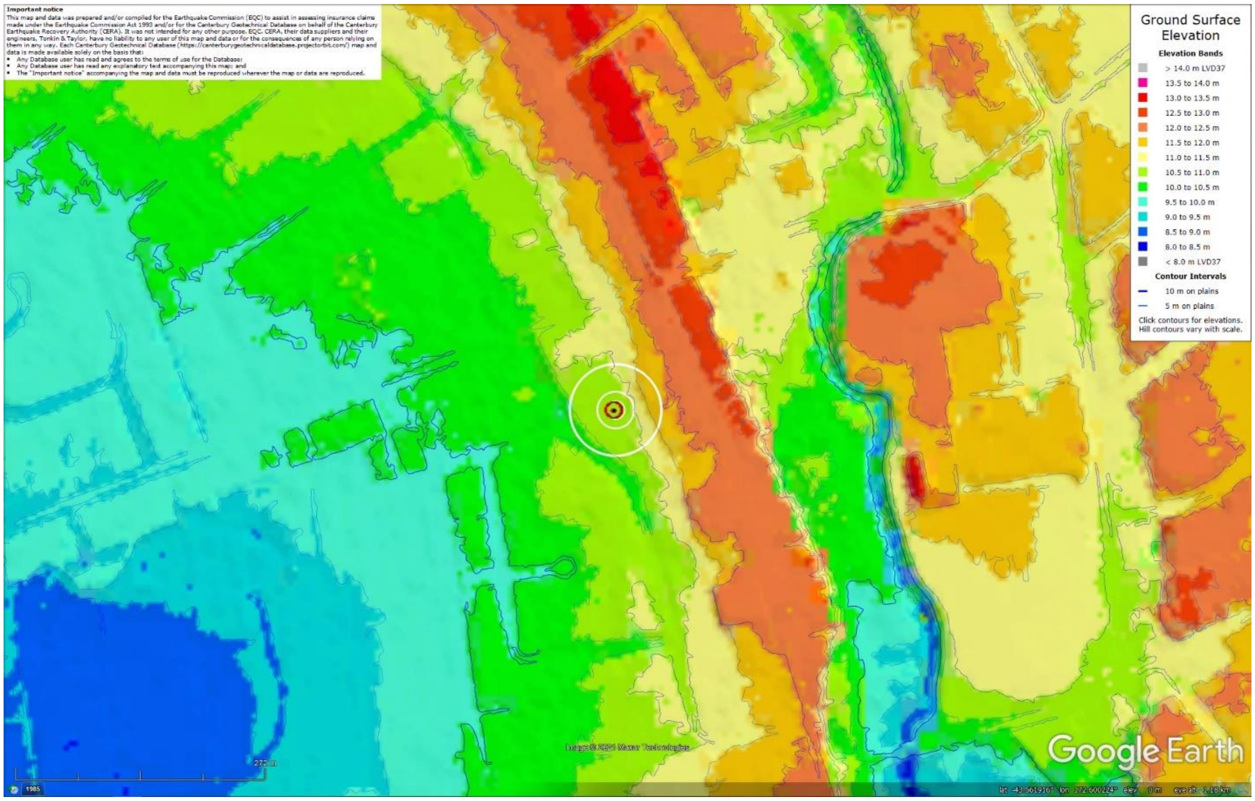

Figure 46: Ground surface elevation according to the Sep-11 LiDAR survey.

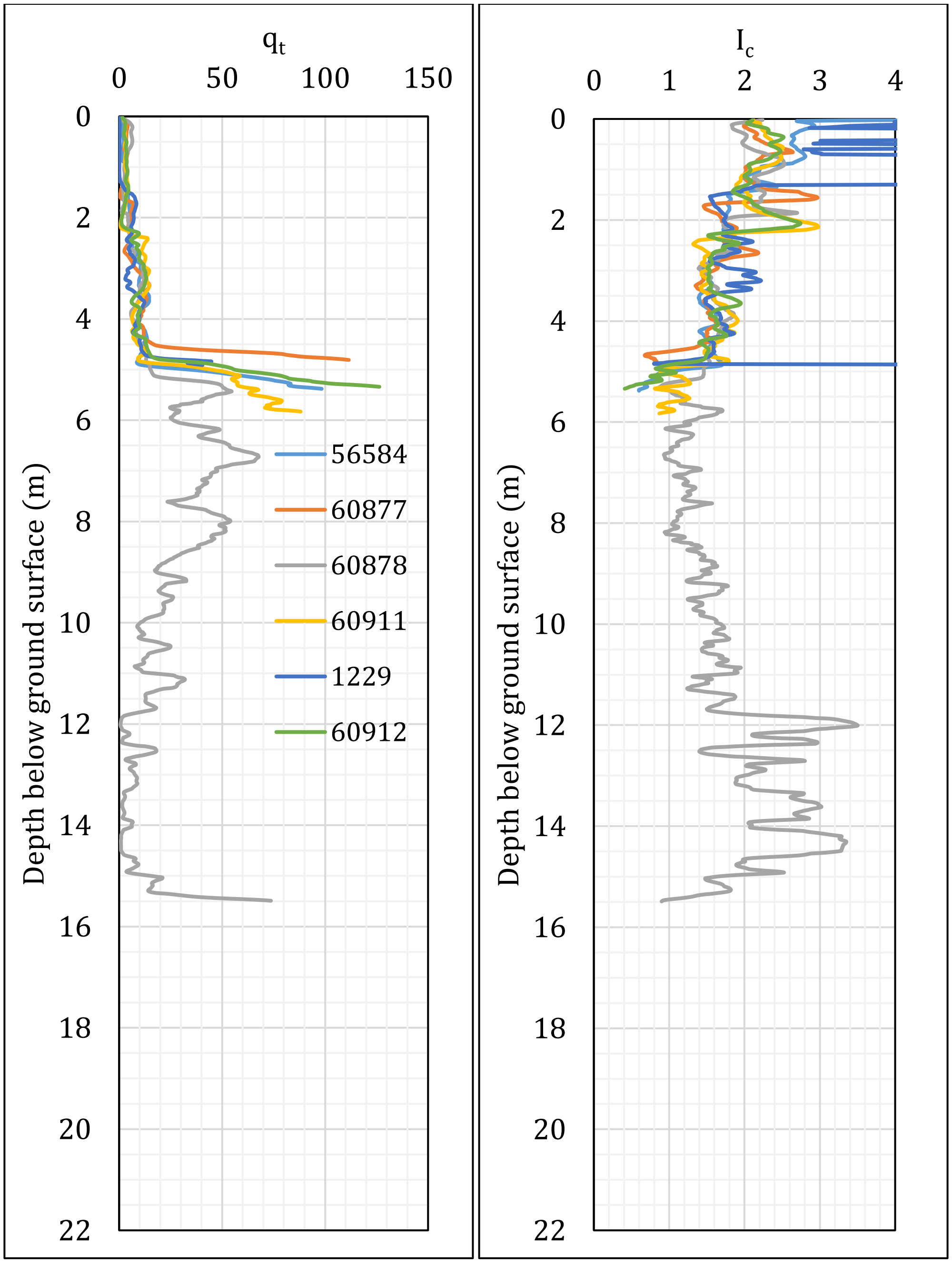

Figure 47: q_t and I_c profiles.

Note 8: The selection of CPTs for the area considered for settlement assessment (Figure 1) is based on the proximity of the CPTs to the considered areas. In accordance with that, the following table shows CPTs that were used for the volumetric settlement analysis in *Cliq v.3.0.3.2*, a CPT soil liquefaction software developed by GeoLogismiki. (The average volumetric settlements were reported in Table 8.)

Table 12: CPT profiles used in volumetric settlement analysis for areas selected for settlement assessment.

CPT ID No.	10-m buffer	20-m buffer	50-m buffer
57344 (56584)	✓	✓	✓
62762 (60877)		✓	✓
62763 (60878)		✓	✓
62764 (60911)		✓	✓
62765 (60912)			✓
1229			✓

Notes: The volumetric settlement for a depth range from 5.2 m to 15.5 m, calculated using CPT 60878, was added to the volumetric settlement computed using the other five CPTs; It is assumed the volumetric settlement below the 15.5-m depth is negligible.

Table 13: CPT-based results.

		CPT ID						
EQ Event	Parameter	57344	62762	62763	62764	62765	1229	$\Delta_{5.2m\text{-}15.5m}$
Sep-10	S_{V1D} (mm)	8	13	61	11	9	7	40
	LSN	4	6	11	4	4	3	4
	LPI	0	0	2	0	0	0	2
	LPI_{ish}	0	0	1	0	0	0	--
	$D_{FS<1}$ (m)	undet	2.6	1.98	4.26	undet	undet	--
Feb-11	S_{V1D} (mm)	25	27	90	21	21	23	54
	LSN	10	11	17	7	8	8	5
	LPI	3	3	8	2	2	2	4
	LPI_{ish}	0	3	6	2	2	0	--
	$D_{FS<1}$ (m)	1.82	1.82	1.94	3.8	3.86	2.38	--
Jun-11	S_{V1D} (mm)	0	0	10	1	0	0	11
	LSN	0	0	1	0	0	0	1
	LPI	0	0	0	0	0	0	0
	LPI_{ish}	0	0	0	0	0	0	--
	$D_{FS<1}$ (m)	undet.	undet.	undet.	undet.	undet.	undet.	--
Dec-11	S_{V1D} (mm)	0	0	1	0	0	0	1
	LSN	0	0	0	0	0	0	0
	LPI	0	0	0	0	0	0	0
	LPI_{ish}	0	0	0	0	0	0	--
	$D_{FS<1}$ (m)	undet.	undet.	undet.	undet.	undet.	undet.	--

Notes: $D_{FS<1}$ = Depth to the first liquefiable layer (FS_L<1) that is at least 200-mm thick, as determined by the Boulanger and Idriss (2016) liquefaction-triggering procedure (P_L=50%, C_{FC}=0.13, and $I_{c,cutoff}$ =2.6), and exported from *Cliq v.3.0.3.2*; undet. = the specified soil layer was not detected; $\Delta_{5.2m\text{-}15.5m}$ indicates the amount of S_{V1D}, LSN, and LPI to be added to CPTs 56584, 60877, 60911, 60912, and 1229 due to their penetration depths being shallower than 20 m.

Note 9: Based on the borehole log (BH 57239, Figure 1), the groundwater table is at a depth of 1.6 m below the ground surface. The soil profile consists of (1) topsoil to a depth of 0.4 m, (2) (sandy) silt, ML, the Yaldhurst member of the Springston formation, to a depth of 1.5 m, (3) poorly graded fine sand, SP, the Yaldhurst member of the Springston formation, to a depth of 5.35 m, (4) sandy fine to coarse gravel, GW, the Yaldhurst member of the Springston formation, to a depth of 8.9 m, and (5) poorly graded sand, SP, the Yaldhurst member of the Springston formation, to a depth of 9.55 m (the end of the borehole). The nearby borehole log (BH 38157, Figure 1) suggests that a silty, ML, layer of the Springston formation follows to a depth of roughly 15 m and is succeeded by a layer of poorly graded gravel, GP, of the Springston formation to an approximate 17-m depth. The following silty, ML, layer of the Springston formation extends to a 20-m depth (the end of the borehole). Trace roots and organics are present within the first 1.5 m of the soil profile.

Note 10: The ejecta-induced free-field settlement provided in Table 11 is an areal average settlement due to ejecta, which is based on the total settlement assessment area, A_T (provided in Table 9 and repeated in Table 14). However, the considered area was not always covered completely with ejecta; thus, it is important to provide the localized ejecta-induced settlement, too. The localized settlement due to ejecta is estimated using photographic evidence only as

$$S_{E,P\_localized} = \frac{V_E}{A_E}$$

where V_E is the total volume of ejecta within A_T and A_E is the total coverage area of ejecta within A_T. Please note that the areal ejecta-induced settlement provided in Table 14 as S_{E,P_areal} is the same as $S_{E,P}$ in Table 11, which was estimated as

$$S_{E,P\_areal} = S_{E,P} = \frac{V_E}{A_T}$$

where V_E is the total volume of ejecta within A_T and A_T is the total settlement assessment area.

Table 14a: Areal and localized ejecta-induced settlement estimates for Patch A (10-m buffer) based on photographic evidence.

Earthquake Event	A_T (m²)	A_E (m²)	V_E (m³)	S_{E,P_areal} (mm)	$S_{E,P\_localized}$ (mm)
Sep-10*	292	0	0	0	0
Feb-11	292	74.1	4.8-9.3	25±10	95±30
Jun-11*	292	0	0	0	0
Dec-11	292	0	0	0	0

Notes: S_{E,P_areal} = $S_{E,P}$ reported in Table 11 = areal ejecta-induced settlement; $S_{E,P\_localized}$ = localized ejecta-induced settlement; A_T = total settlement assessment area; V_E = total volume of ejecta within A_T; A_E = total area of ejecta within A_T; The estimates of both areal and localized ejecta-induced settlement are rounded to the nearest 5; Final plus/minus values are also rounded to the nearest 5; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ (no high-resolution aerial photograph is available) and the lack of photographic evidence for the Jun-11 EQ.

Table 14b: Areal and localized ejecta-induced settlement estimates for Patch A (20-m buffer) based on photographic evidence.

Earthquake Event	A_T (m^2)	A_E (m^2)	V_E (m^3)	S_{E,P_areal} (mm)	$S_{E,P\_localized}$ (mm)
Sep-10*	1055	36.0	1.1-2.2	<5	45±15
Feb-11	1055	390	19.5-38.4	30±10	75±25
Jun-11*	1055	0	0	0	0
Dec-11	1055	0	0	0	0

Notes: S_{E,P_areal} = $S_{E,P}$ reported in Table 11 = areal ejecta-induced settlement; $S_{E,P\_localized}$ = localized ejecta-induced settlement; A_T = total settlement assessment area; V_E = total volume of ejecta within A_T; A_E = total area of ejecta within A_T; The estimates of both areal and localized ejecta-induced settlement are rounded to the nearest 5; Final plus/minus values are also rounded to the nearest 5; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ (no high-resolution aerial photograph is available) and the lack of photographic evidence for the Jun-11 EQ.

Table 14c: Areal and localized ejecta-induced settlement estimates for Patch A (50-m buffer) based on photographic evidence.

Earthquake Event	A_T (m^2)	A_E (m^2)	V_E (m^3)	S_{E,P_areal} (mm)	$S_{E,P\_localized}$ (mm)
Sep-10*	2642	36.0	1.1-2.2	<5	45±15
Feb-11	2642	836	38.6-76.1	20±5	70±20
Jun-11*	2642	0	0	0	0
Dec-11	2642	0	0	0	0

Notes: S_{E,P_areal} = $S_{E,P}$ reported in Table 11 = areal ejecta-induced settlement; $S_{E,P\_localized}$ = localized ejecta-induced settlement; A_T = total settlement assessment area; V_E = total volume of ejecta within A_T; A_E = total area of ejecta within A_T; The estimates of both areal and localized ejecta-induced settlement are rounded to the nearest 5; Final plus/minus values are also rounded to the nearest 5; * indicates uncertainty due to the poor quality of the satellite image for the Sep-10 EQ (no high-resolution aerial photograph is available) and the lack of photographic evidence for the Jun-11 EQ.

Summary 2:

The best estimate of the localized ejecta-induced free-field ground settlement at the Rydal Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 45±15 mm, 75±25 mm, 0 mm, and 0 mm, respectively.