Appendix A.43:

Heaton Normal Intermediate School – VsVp 57181

Table 1: Site Description for Heaton Normal Intermediate School (VsVp 57181).

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 center of the site is ~535 m to the NE from the Wairarapa Stream (the free-face height is ~1.5 m) and ~ 400 m to the S from the unnamed stream/pond (the free-face height is ~1.5 m).	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	Building coverage of the 50-m buffer is 12%. Buildings are in the NE, SE, and SW quadrants.	White Fill + Brown Outline
Sloping land?	No	No	No	Flat land, open + residential area	NA
Step changes in the ground surface?	No	No	No	NA	NA
Retaining walls?	No	No	No	NA	NA
Vegetation?	No	Yes	Yes	Trees and bushes cover 7 and 19% of the 20- and 50-m buffers, respectively. They are in the SE and SW quadrants of the 20-m buffer and the NE, SE, and SW quadrants of the 50-m buffer.	White Fill + Green Outline
Anthropogenic changes to the site between the LiDAR surveys?	Yes	Yes	Yes	Building addition in the E portion of the 50-m b. between Apr 2005 and Jan 2006. Access road construction in the NE q. of the 50-m b. between Jan 2007 and Mar 2009. Some anthropogenic changes in the sports field in all q. of all b. between Mar 28, 2011, and Aug 30, 2011 (still evident in Aug). Footpath addition in the NE q. of the 50-m b. between Aug 30, 2011, and Feb 24, 2011. The same footpath was removed between Mar 2013 and Aug 2013. It was then added and removed several times. Between Mar 2014 and Aug 2014: footpath addition in the NE q. of the 50-m b., swimming pool removal in the S portion of all b., and earthwork in the sports field in all q. of all b.	Footpath Addition/ Removal: Gray Outline + White Fill; Building Addition: Orange Crossline; S. Pool Removal: Blue Crossline
Other important factors?	Yes	Yes	Yes	Playground in the N portion of the 50-m buffer. Swimming pool in the S portion of all buffers (covers 11, 14, and 2% of the 10-, 20-, and 50-m buffers). Swimming pool in the SE quadrant of the 50-m buffer (covers ~0% of the 50-m buffer). There is a possibility the sports field was completely re-grassed between July 2003 and Nov 2015.	Playground: Orange Outline + White Fill; Swimming Pool: Blue Outline + White Fill

Note: Buffer is the area within a circle of a specified radius with CPT investigations done at its center (172.614886°, -43.510572°).

[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 areas where ejecta-induced settlement is considered.

Note 1: Patch A (outlined in red) in the free field was selected for settlement assessment as an area free of vegetation and structures. Other important factors considered for the patch selection 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), swimming pool, and aerial distribution of sediment ejecta. The LiDAR-based settlement analyses were not performed for any earthquake event because the Sep 2010 LiDAR survey was affected by ejecta from the Sep-10 EQ and the Sep 2011, Feb 2012, and Oct 2015 LiDAR surveys were affected by anthropogenic changes.

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	0	-3	0
Feb-11	0	16	-50
Jun-11	0	38	-30
Dec-11	0	-65	0
CES	0	-14	-80
Any LiDAR survey affected by ejecta?			Yes*

Note: The negative sign indicates the subtraction from the ground surface subsidence, while the positive sign indicates the addition to the ground surface subsidence; * Ejecta were not removed from Patch A at the time of the Sep 2010 LiDAR survey (subtract ~50 mm from the ground surface subsidence for the Sep-10 EQ and add ~50 mm to the ground surface subsidence for the Feb-11 EQ for the 10-m and 20-m buffers; subtract ~30 mm from the ground surface subsidence for the Sep-10 EQ and add ~30 mm to the ground surface subsidence for the Feb-11 EQ for the 50-m buffer).

Table 3: LiDAR Measurement Error for Patch A.

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

*Standard deviation; ND = Not determined.

[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 for Patch A.

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	ND
Feb-11	56	59	59	ND
Jun-11	59	61	62	ND
Dec-11	61	70	87	ND
CES	158	70	124	ND

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

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

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

Table 6: Corrected liquefaction-related ground surface subsidence using original LiDAR points for Patch A 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	ND	ND	ND
Feb-11	ND	ND	ND
Jun-11	ND	ND	ND
Dec-11	ND	ND	ND
CES	ND	ND	ND

Notes: Plus/minus values are same as those in Table 4a, but rounded to the nearest 25 mm; Positive overall values indicate ground surface subsidence, while negative overall values indicate ground surface uplift; ND = Not determined.

Table 7: Corrected liquefaction-related ground surface subsidence for Patch A 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	<50	<50	50	<50	50	100	<50	50	100
Feb-11	50	100	100	50	100	100	50	100	100
Jun-11	<50	50	50	<50	50	50	<50	50	50
Dec-11	<50	<50	<50	<50	<50	<50	<50	<50	<50
CES	150	150	200	150	200	250	150	250	350

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 Patch A (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	0.21	1.5	ND	71±20	ND
Feb-11	6.2	0.33	1.5	ND	118±50	ND
Jun-11	6.2	0.17	1.0	ND	17±25	ND
Dec-11	6.1	0.19	1.0	ND	26±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), 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}.

Table 8b: Ejecta-Induced settlement for the top 20 m of the soil profile for Patch A (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	0.21	1.5	ND	94±20	ND
Feb-11	6.2	0.33	1.5	ND	158±50	ND
Jun-11	6.2	0.17	1.0	ND	27±25	ND
Dec-11	6.1	0.19	1.0	ND	43±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), 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}.

Table 8c: Ejecta-Induced settlement for the top 20 m of the soil profile for Patch A (50-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	0.21	1.5	ND	94$\pm$20	ND
Feb-11	6.2	0.33	1.5	ND	158$\pm$50	ND
Jun-11	6.2	0.17	1.0	ND	27$\pm$25	ND
Dec-11	6.1	0.19	1.0	ND	43$\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), 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}.

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 Patch A (10-m buffer) using photographs.

Earthquake Event	$A_{E,thick}$ (m^2)	$H_{E,thick}$ (mm)	$A_{E,thin}$ (m^2)	$H_{E,thin}$ (mm)	A_T (m^2)
Sep-10	105	60-80	8.3	10-40	158
Feb-11	48.4	50-70	65	10-30	158
Jun-11	14.7	40-60	22.6	10-30	144*
Dec-11	0	0	1.9	10-30	158

Notes: $A_{E,thick/thin}$ = Coverage area of thick/thin ejecta layers; $H_{E,thick/thin}$ = Lower-upper estimate of height of thick/thin ejecta layers; A_T = Total assessment area of a buffer being considered; Thin and thick layers correspond to light gray and dark gray colors of ejecta observed in aerial photographs; * indicates the reduction in A_T due to the presence of shadows.

Table 9b: Coverage area and height of ejecta estimates for Patch A (20-m buffer) using photographs.

Earthquake Event	$H_{E,thick}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thin}$ (mm)	$A_{E,thin}$ (m^2)	A_T (m^2)
Sep-10	60-80	287	10-40	131	563
Feb-11	50-70	120	10-30	315	563
Jun-11	40-60	52.2	10-30	197	481*
Dec-11	0	0	10-30	36.6	563

Notes: $A_{E,thick/thin}$ = Coverage area of thick/thin ejecta layers; $H_{E,thick/thin}$ = Lower-upper estimate of height of thick/thin ejecta layers; Thin and thick layers correspond to light gray and dark gray colors of ejecta observed in aerial photographs; * indicates the reduction in A_T due to the presence of shadows.

Table 9c: Coverage area and height of ejecta estimates for Patch A (50-m buffer) using photographs.

Earthquake Event	$A_{E,thick}$ (m^2)	$H_{E,thick}$ (m)	$A_{E,thin}$ (m^2)	$H_{E,thin}$ (m)	A_T (m^2)
Sep-10	287	60-80	709	10-40	2731
Feb-11	120	50-70	1446	10-30	2731
Jun-11	40-60	52.2	449	10-30	2628*
Dec-11	0	0	63.6	10-30	2731

Notes: $A_{E,thick/thin}$ =Coverage area of thick/thin ejecta layers; $H_{E,thick/thin}$ = Lower-upper estimate of height of thick/thin ejecta layers; A_T= Total assessment area of a buffer being considered; Thin and thick layers correspond to light gray and dark gray colors of ejecta observed in aerial photographs; * indicates the reduction in A_T due to the presence of shadows/objects.

Note 3: The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photographs (Figures 42-45) and the lower and upper estimates of ejecta height based on geometrical approximations and EQC LDAT property inspection reports. The ejecta-induced settlement using photographs and engineering judgment, $S_{E,P}$, is estimated as

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

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_T is the total assessment area for a buffer being considered (Figure 1).

Table 10: Ejecta-induced settlement estimates for Patch A based on photographs.

Earthquake Event	Patch A (10-m buffer)		Patch A (20-m buffer)		Patch A (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	40	55	33	50	9	19
Feb-11	19	34	16	32	8	19
Jun-11	6	11	8	19	3	6
Dec-11	≈0	≈0	1	2	≈0	1

Note: $S_{E,P,lower}$ and $S_{E,P,upper}$ correspond to lower and upper estimates of $S_{E,P}$, respectively.

Table 11: Best final estimates of ejecta-induced settlement for Patch A.

EQ Event	Patch A (10-m buffer)			Patch A (20-m buffer)			Patch A (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	ND	48±7	50±5	ND	42±8	40±10	ND	14±5	15±5
Feb-11	ND	27±7	25±5	ND	24±8	25±10	ND	14±5	15±5
Jun-11	ND	8.5±2.5	10±5	ND	14±5	15±5	ND	4.5±1.5	5±5
Dec-11	ND	≈0	<5	ND	1.5±0.5	<5	ND	0.5±0.5	<5

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.

Note 4:

- $S_{E,final}$ for is based solely on $S_{E,P}$ for all earthquake events (please see Note 1 for the explanation).
- The Heaton Normal Intermediate School St site is not in the apparent zone of higher or lower ground surface subsidence for the Sep-10 EQ or Feb-11 EQ. The site is in the zone of moderate to severe LPI overprediction of liquefaction severity for the Sep-10 and slight to moderate LPI overprediction for the Feb-11 EQ (Maurer et al. 2014[3]). The LDAT property inspection reports from Oct 2011 are available for nearby properties to the east; the swimming pool and the driveway were uplifted by 150 mm and 100 mm, respectively. No other measurements or ground photographs of ejecta are available.

<u>Summary 1</u>:

The best estimate of the ejecta-induced free-field ground settlement at the Heaton Normal Intermediate School site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 40±10 mm, 25±10 mm, 15±5 mm, and <5 mm, respectively.

[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 2: Location of the site.

Figure 3: Position of the site relative to nearby buildings, vegetation, and free-face features.

Figure 4: Street view of the flat land.

Figure 5: Satellite image of the site taken in Dec 2004.

Figure 6: Satellite image of the site taken in Apr 2005.

Figure 7: Satellite image of the site taken in Jan 2006.

Figure 8: Satellite image of the site taken in Jan 2007.

Figure 9: Satellite image of the site taken in Mar 2009.

Figure 10: Satellite image of the site taken on Sep 3, 2010.

Figure 11: Satellite image of the site taken on Sep 5, 2010.

Figure 12: Satellite image of the site taken on Feb 7, 2011.

Figure 13: Satellite image of the site taken on Feb 26, 2011.

Figure 14: Satellite image of the site taken on Mar 28, 2011.

Figure 15: Satellite image of the site taken on Aug 30, 2011.

Figure 16: Satellite image of the site taken in Apr 2012.

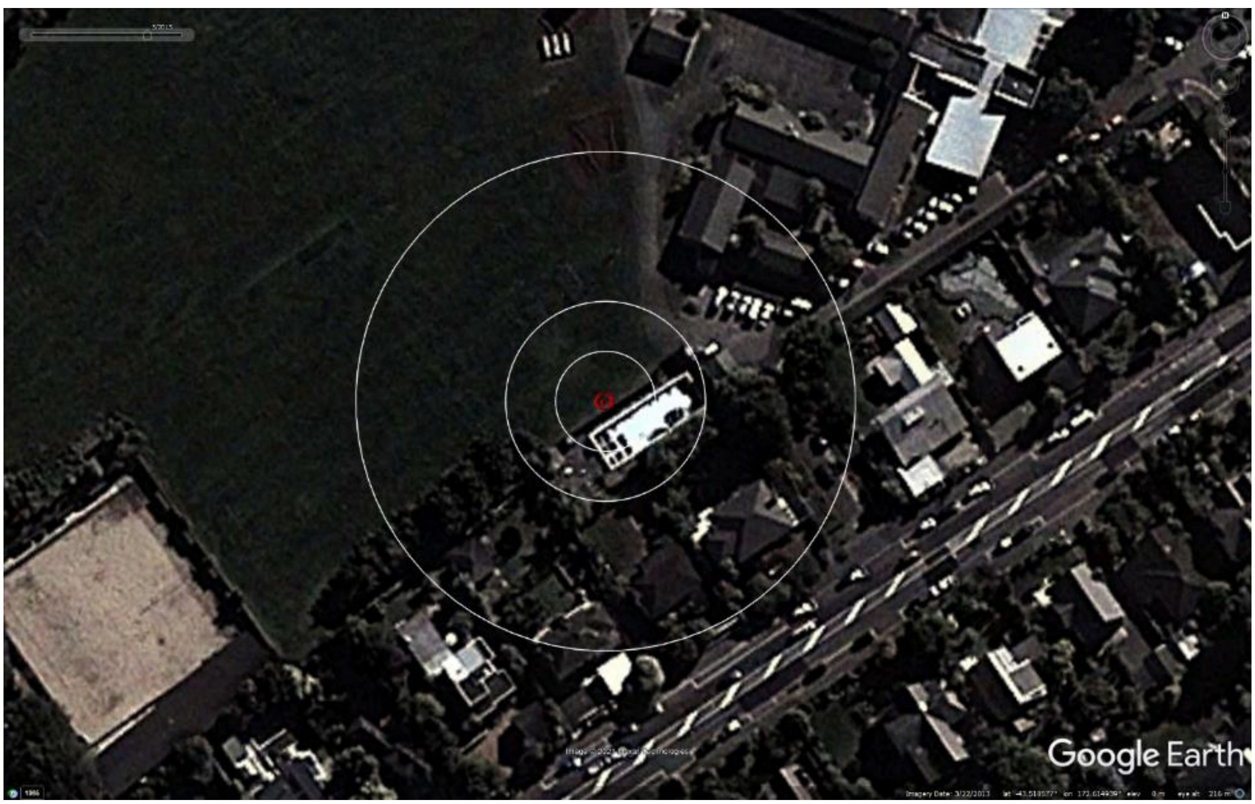

Figure 17: Satellite image of the site taken in Mar 2013.

Figure 18: Satellite image of the site taken in Aug 2013.

Figure 19: Satellite image of the site taken in Mar 2014.

Figure 20: Satellite image of the site taken in Aug 2014.

Figure 21: Satellite image of the site taken in Nov 2015.

Figure 22: Aerial photograph of the site taken on Sep 4, 2010.

Figure 23: Aerial photograph of the site taken on Feb 24, 2011.

Figure 24: Aerial photograph of the site taken on June 14-15, 2011.

Figure 25: Aerial photograph of the site taken on June 16, 2011.

Figure 26: Aerial photograph of the site taken on Dec 24, 2011.

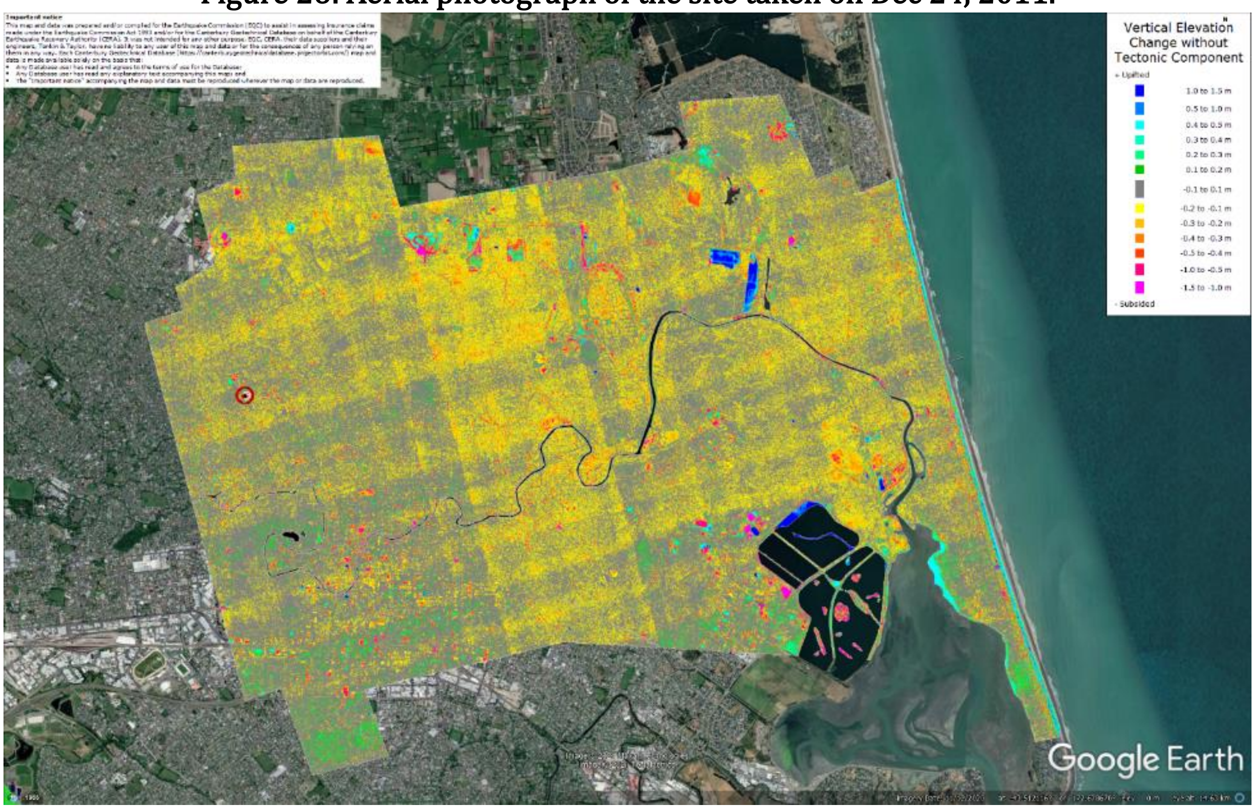

Figure 27: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake – the site is not in the apparent zone of overestimated ground surface subsidence.

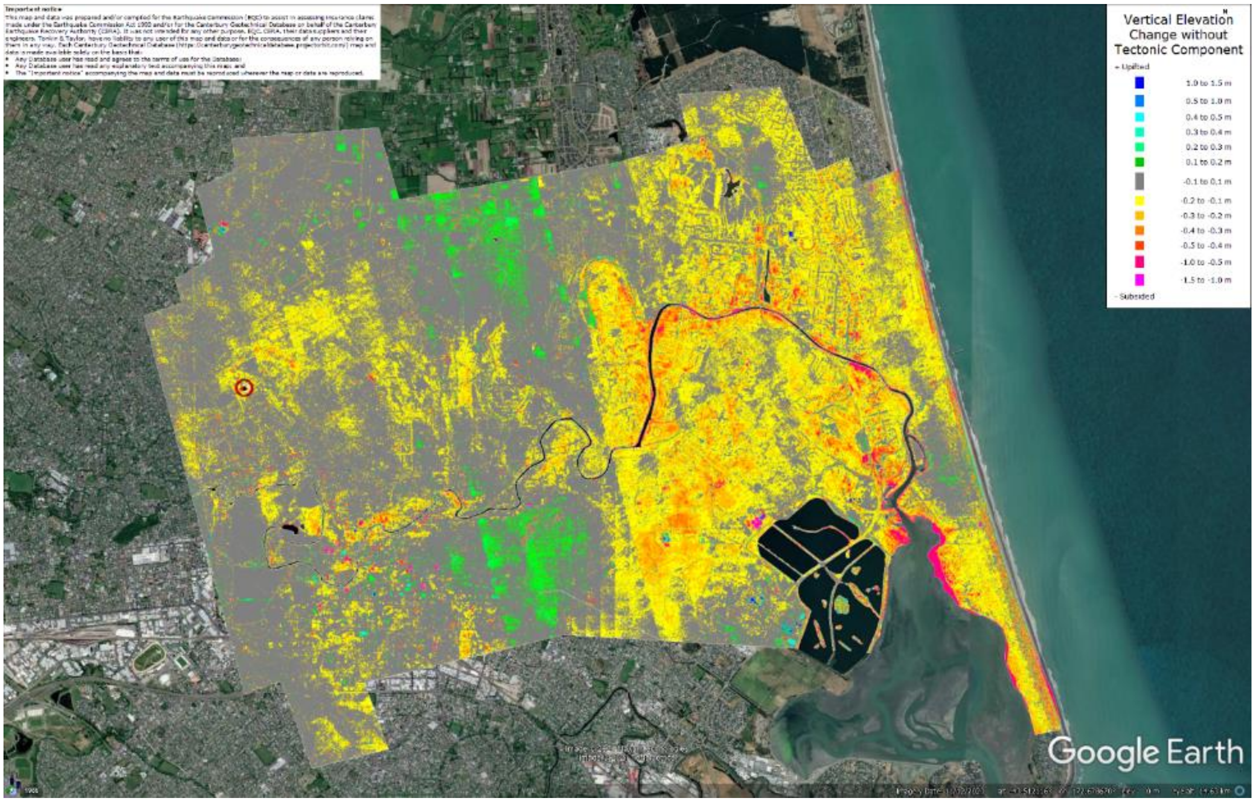

Figure 28: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake – the site is not in the apparent zone of underestimated ground surface subsidence.

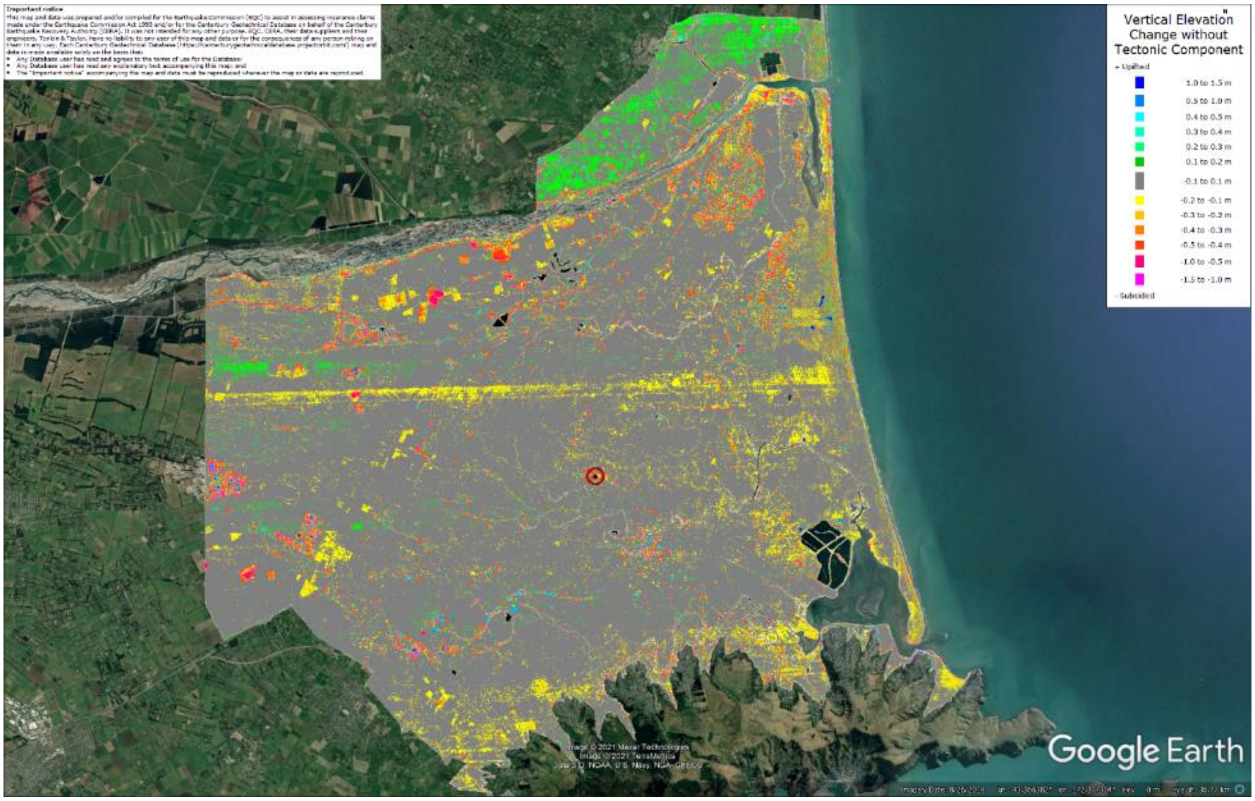

Figure 29: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

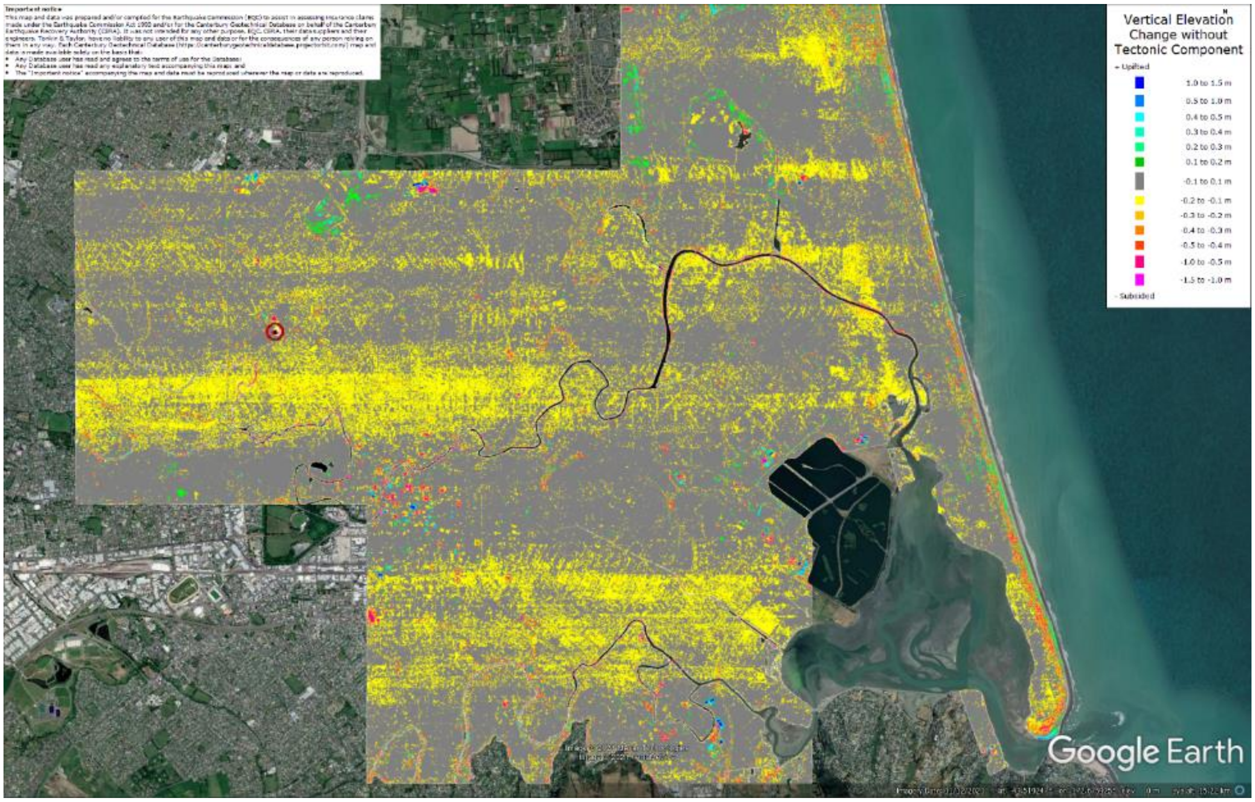

Figure 30: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

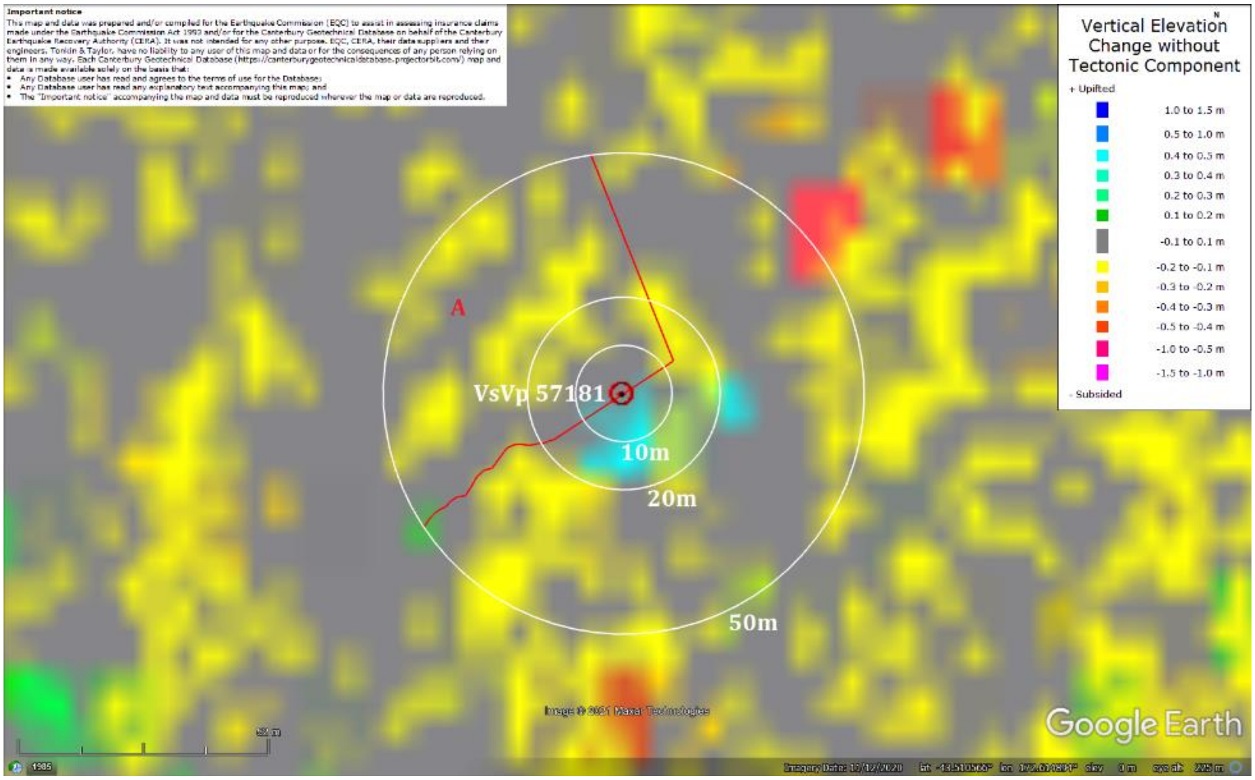

Figure 31: Ground surface subsidence without tectonic component for Sep 2010 Earthquake according to the LiDAR DEM.

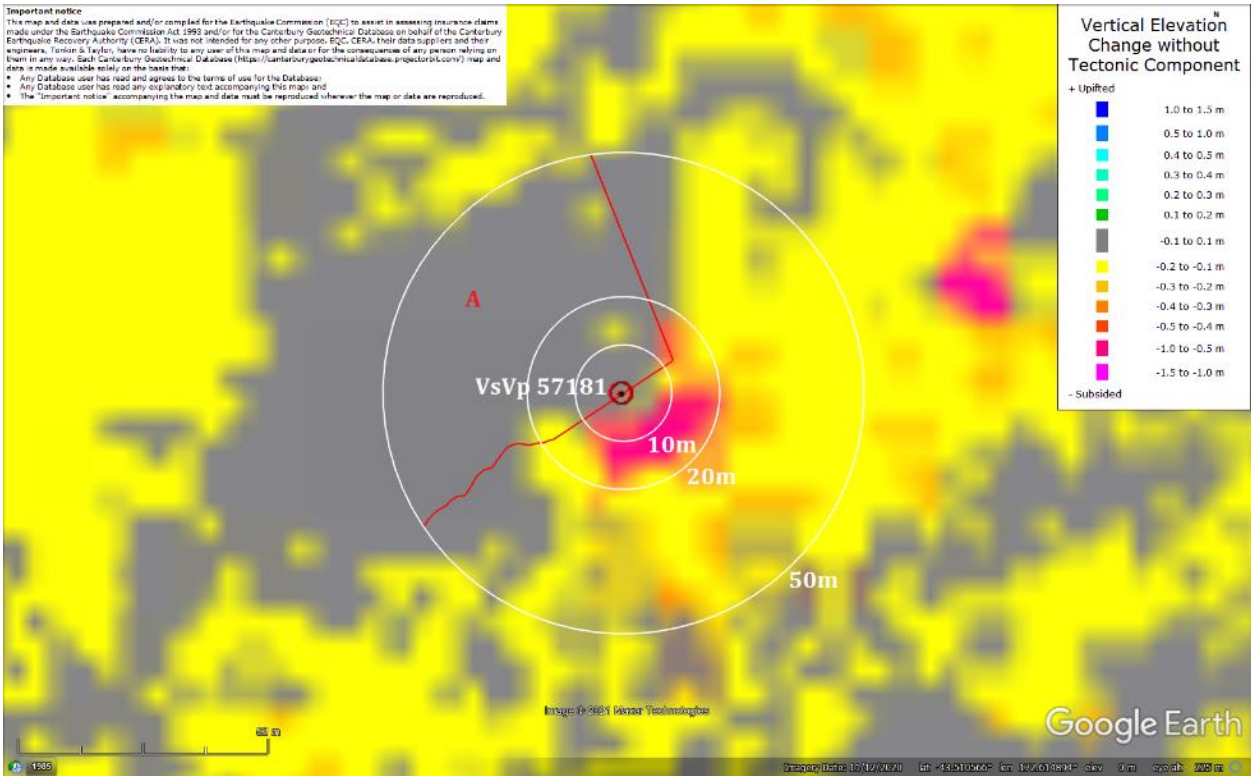

Figure 32: Ground surface subsidence without tectonic component for Feb 2011 Earthquake according to the LiDAR DEM.

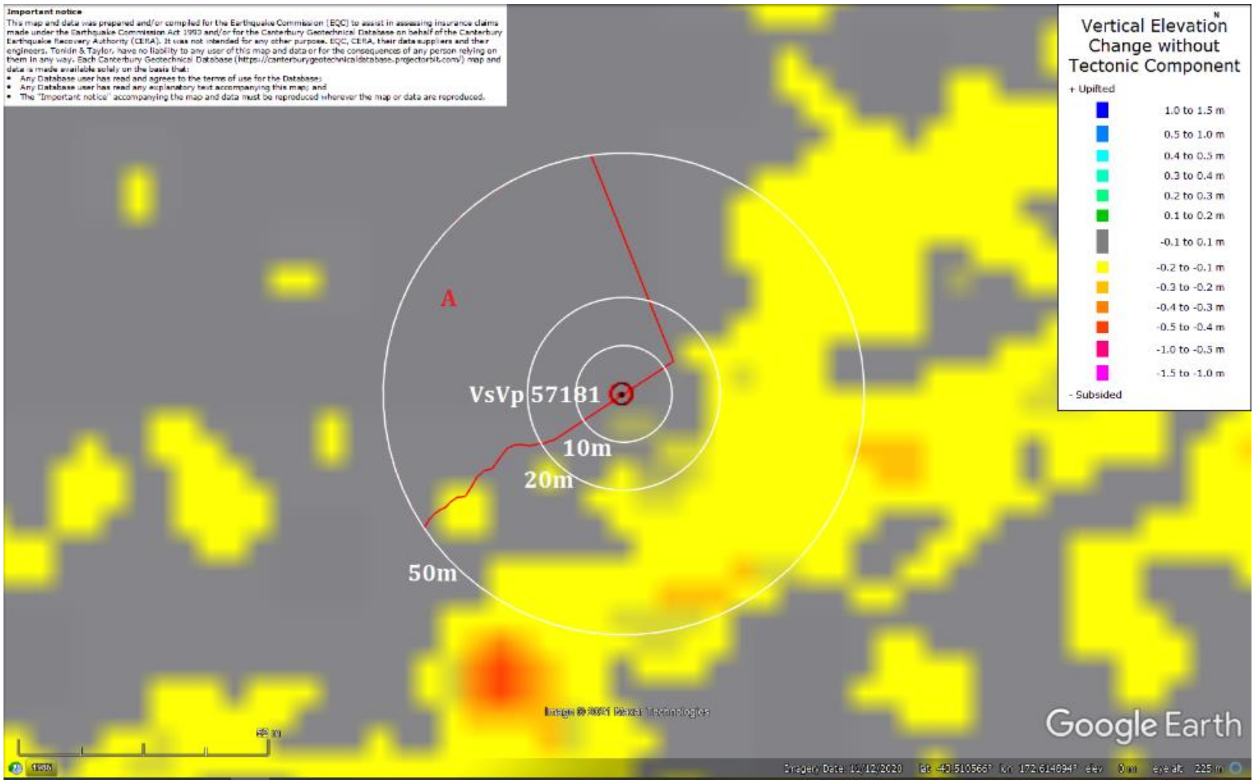

Figure 33: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

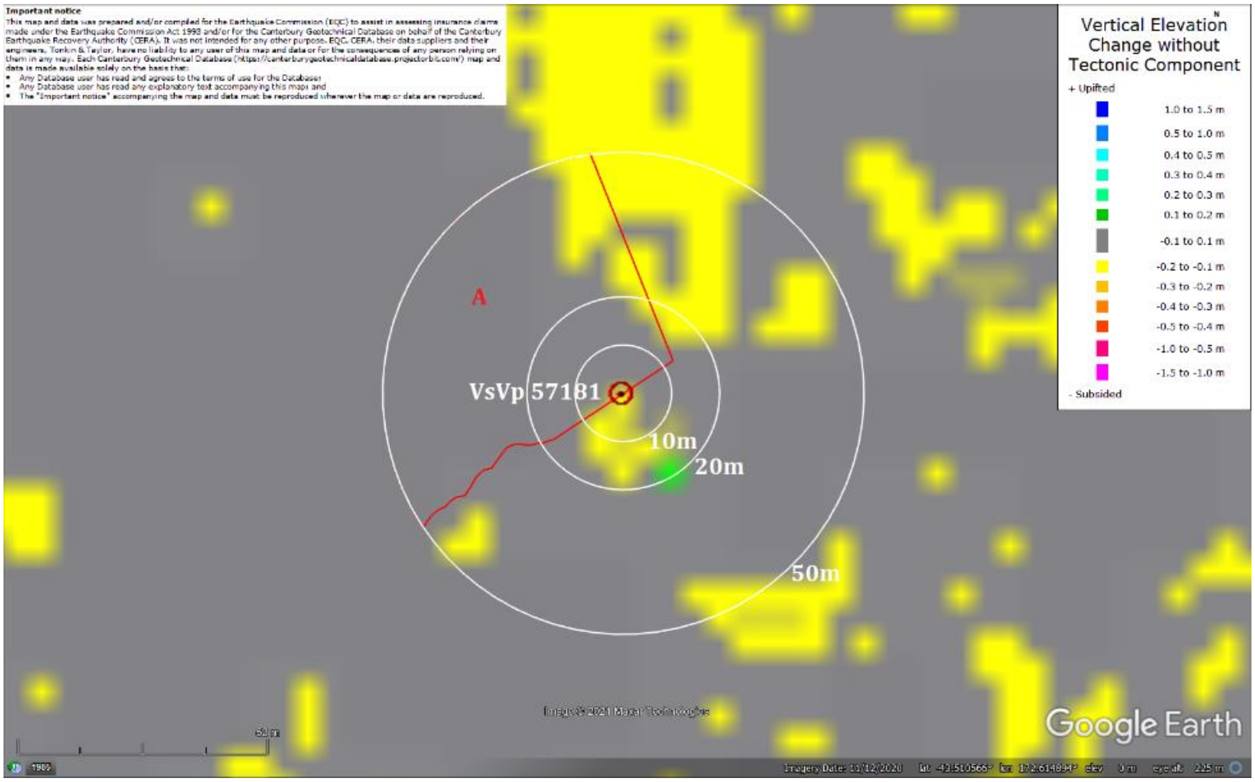

Figure 34: Ground surface subsidence without tectonic component for Dec 2011 Earthquake according to the LiDAR DEM.

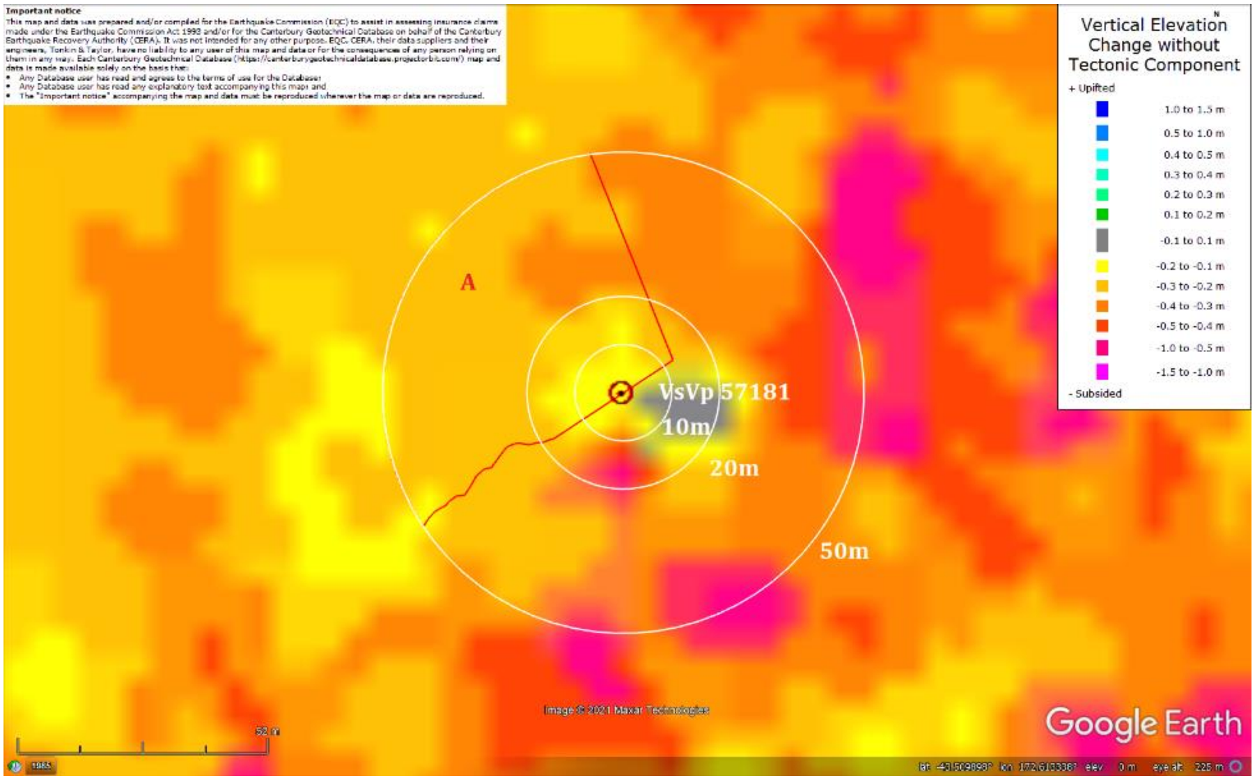

Figure 35: Ground surface subsidence without tectonic component for Canterbury Earthquake Sequence according to the LiDAR DEM.

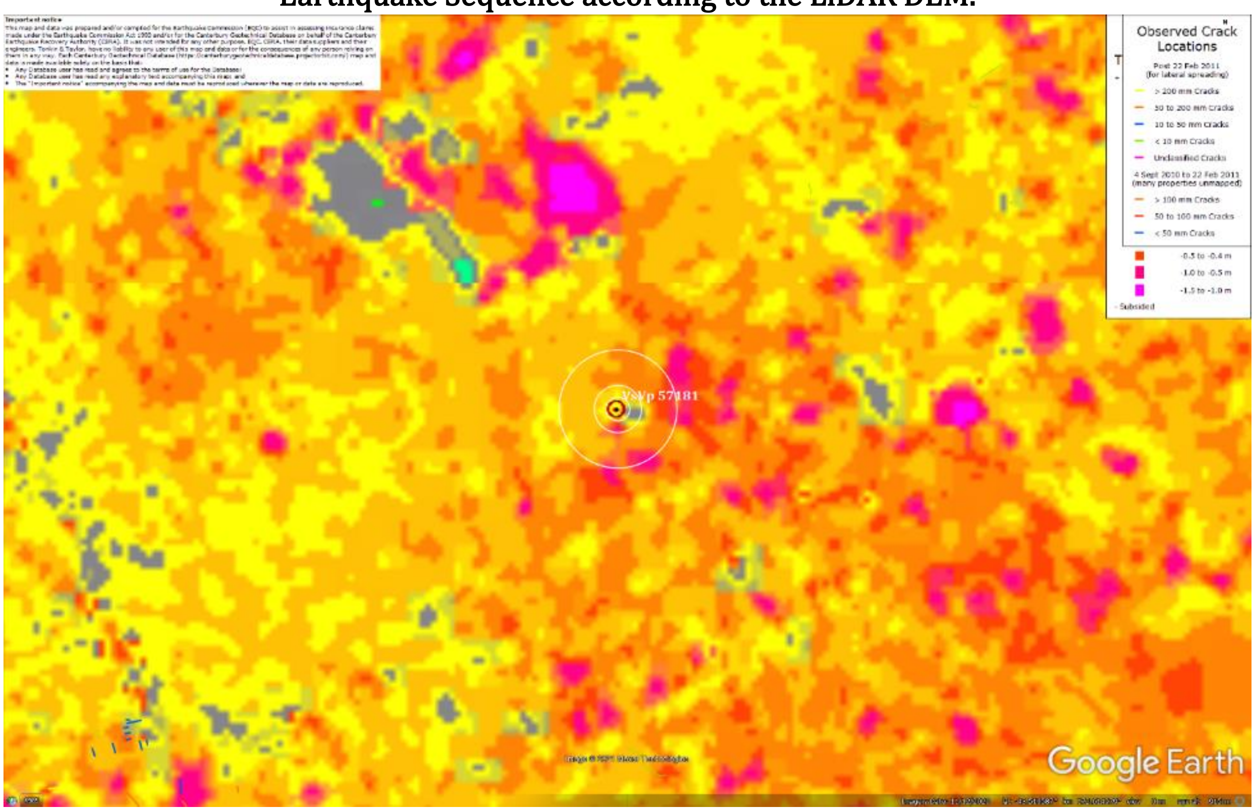

Figure 36: No lateral spreading for Canterbury Earthquake Sequence.

Figure 37: Vertical tectonic movements for Sep 2010 Earthquake.

Figure 38: Vertical tectonic movements for Feb 2011 Earthquake.

Figure 39: Vertical tectonic movements for June 2011 Earthquake.

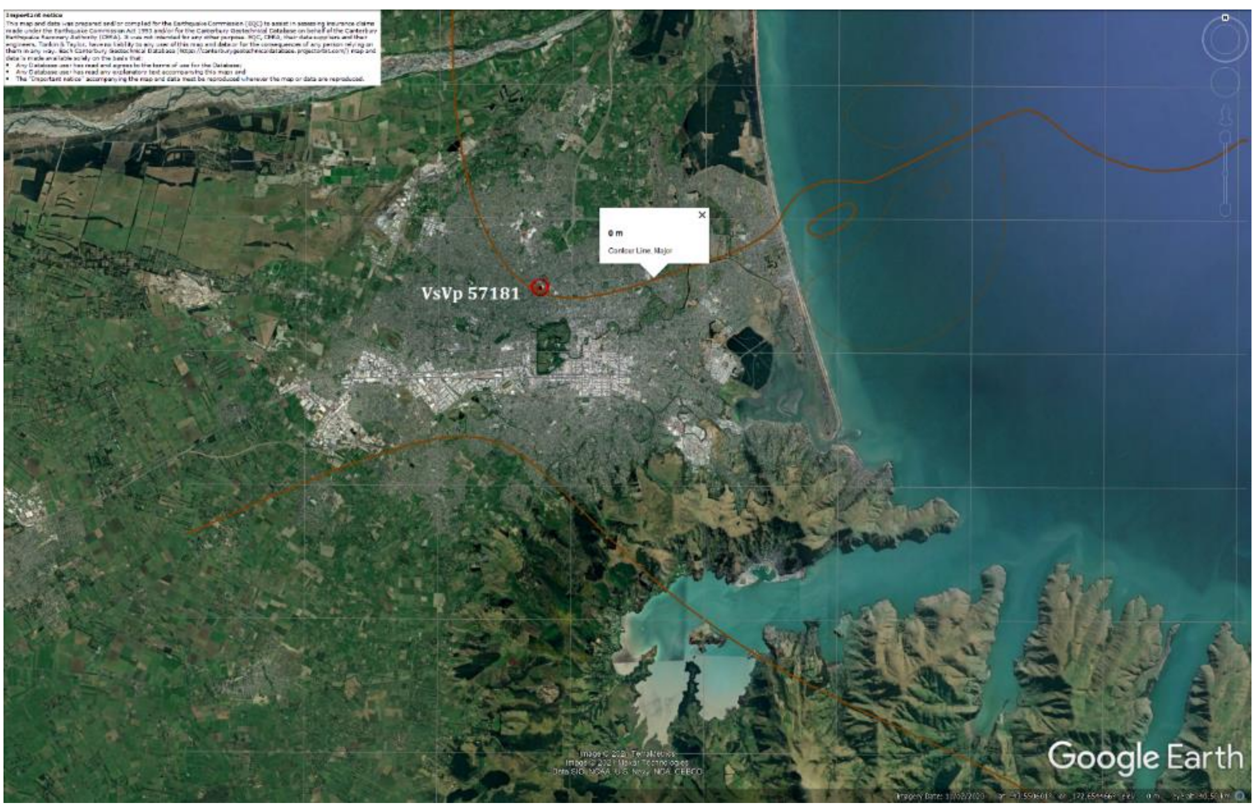

Figure 40: Vertical tectonic movements for Dec 2011 Earthquake.

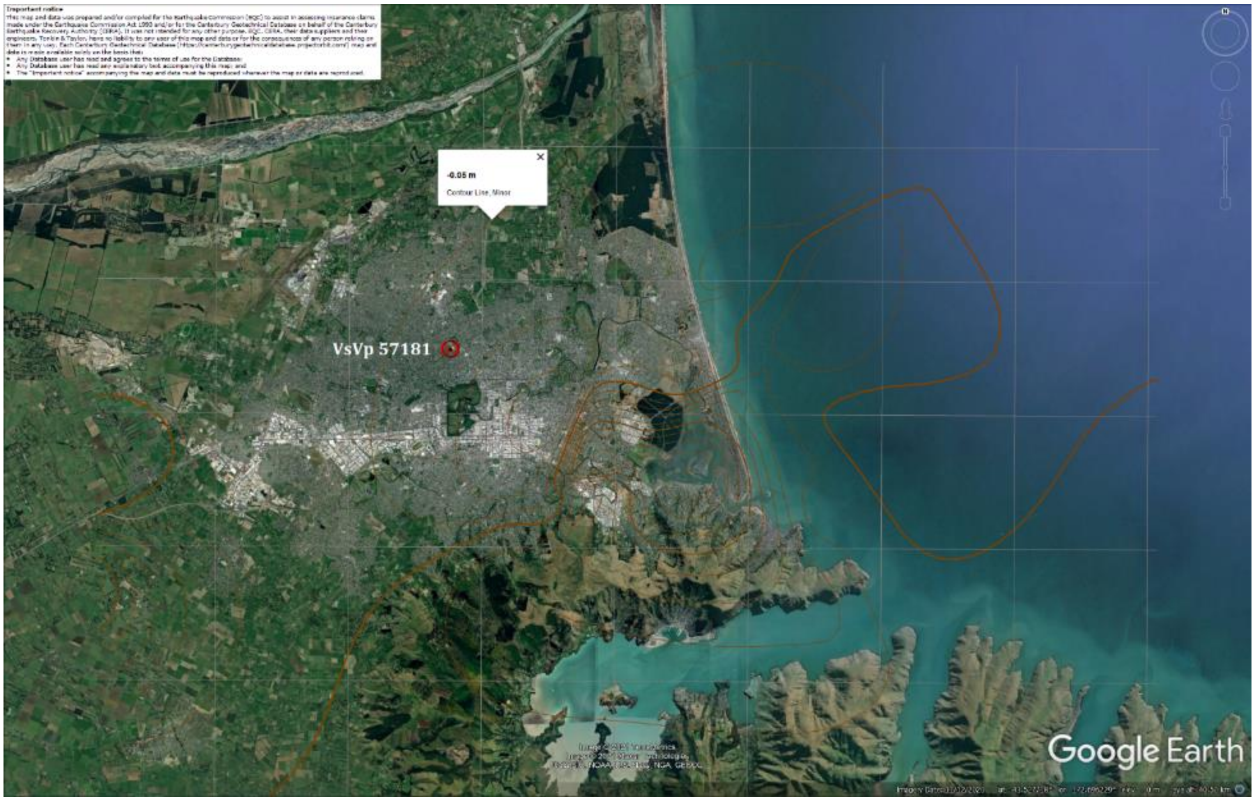

Figure 41: Vertical tectonic movements for Canterbury Earthquake Sequence.

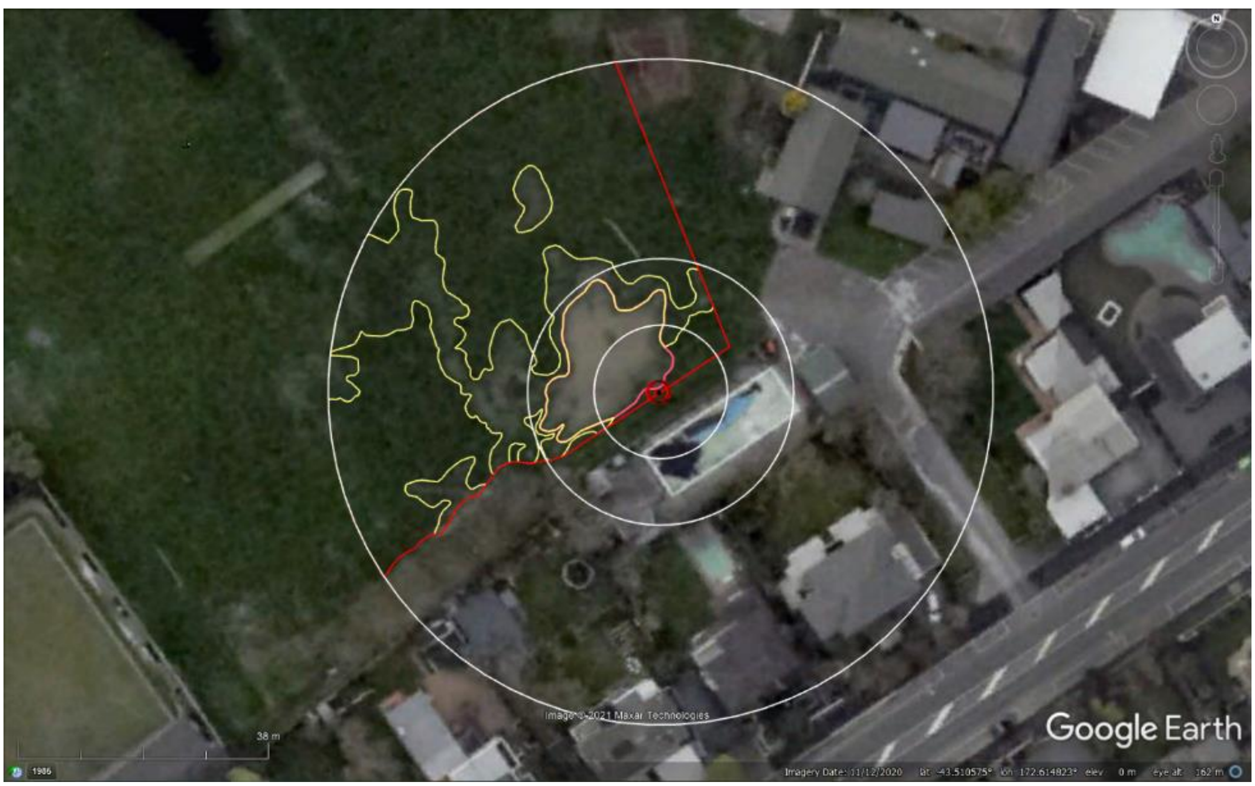

Figure 42: Aerial photograph showing no ejecta at the site for Sep-10 EQ.

Figure 43: Aerial photograph showing the ejecta outline at the site for Feb-11 EQ.

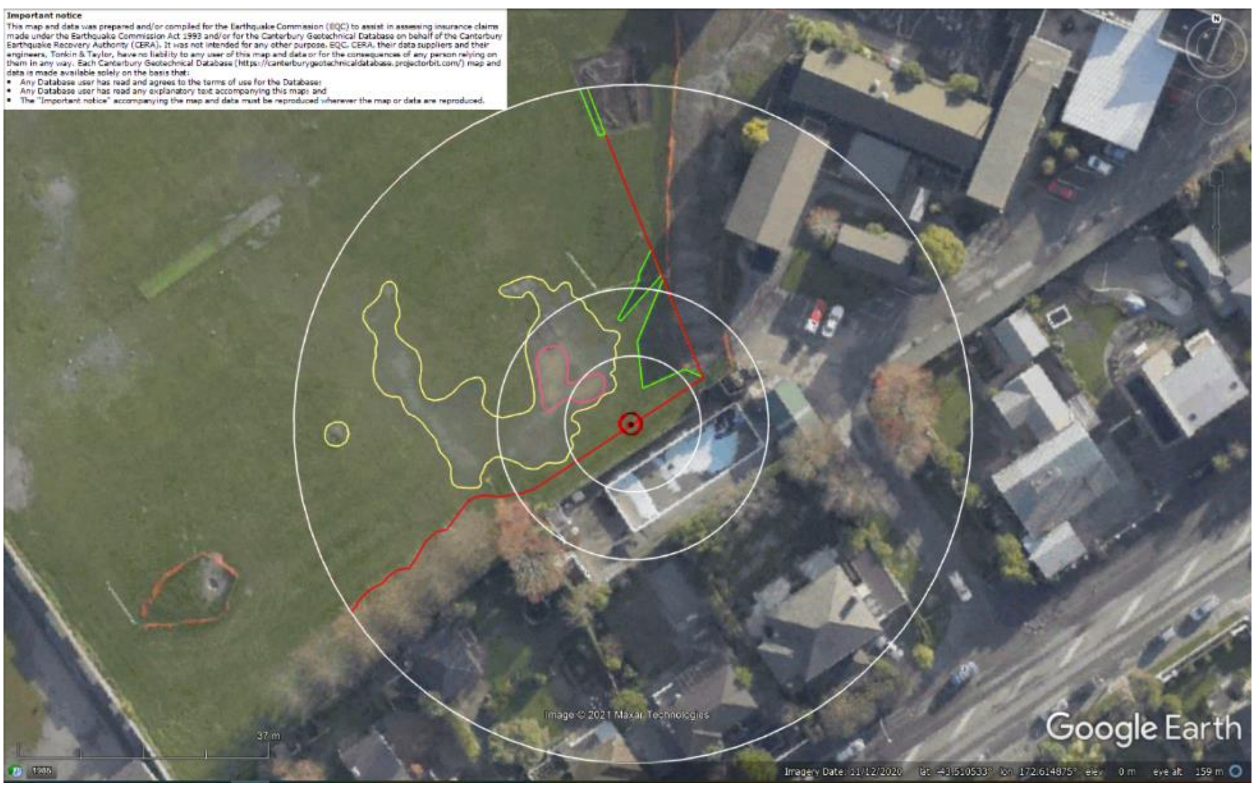

Figure 44: Aerial photograph acquired on 14-15 Jun 2011 showing the ejecta outline at the site for Jun-11 EQ.

Figure 45: Aerial photograph showing the ejecta outline at the site for Dec-11 EQ.

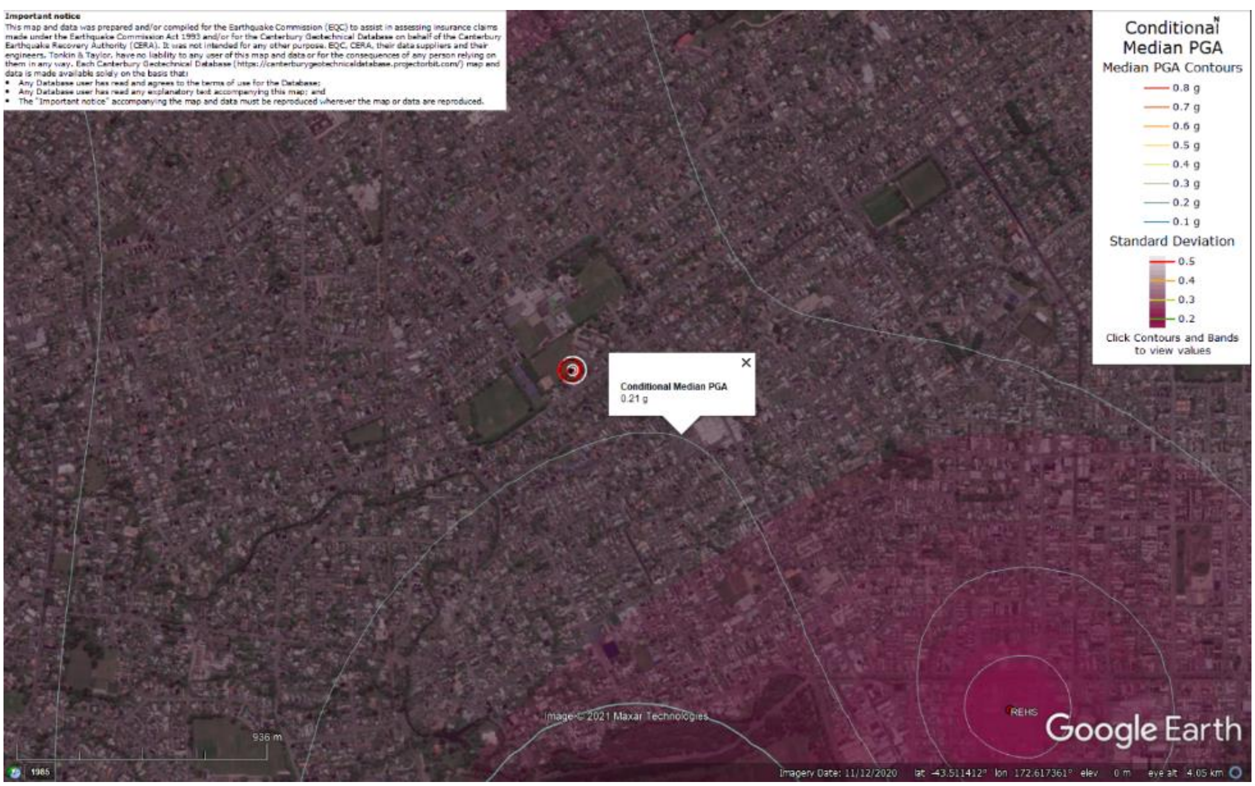

Figure 46: PGA for Sep-10 EQ (st. dev. = 0.300-0.350 ln units).

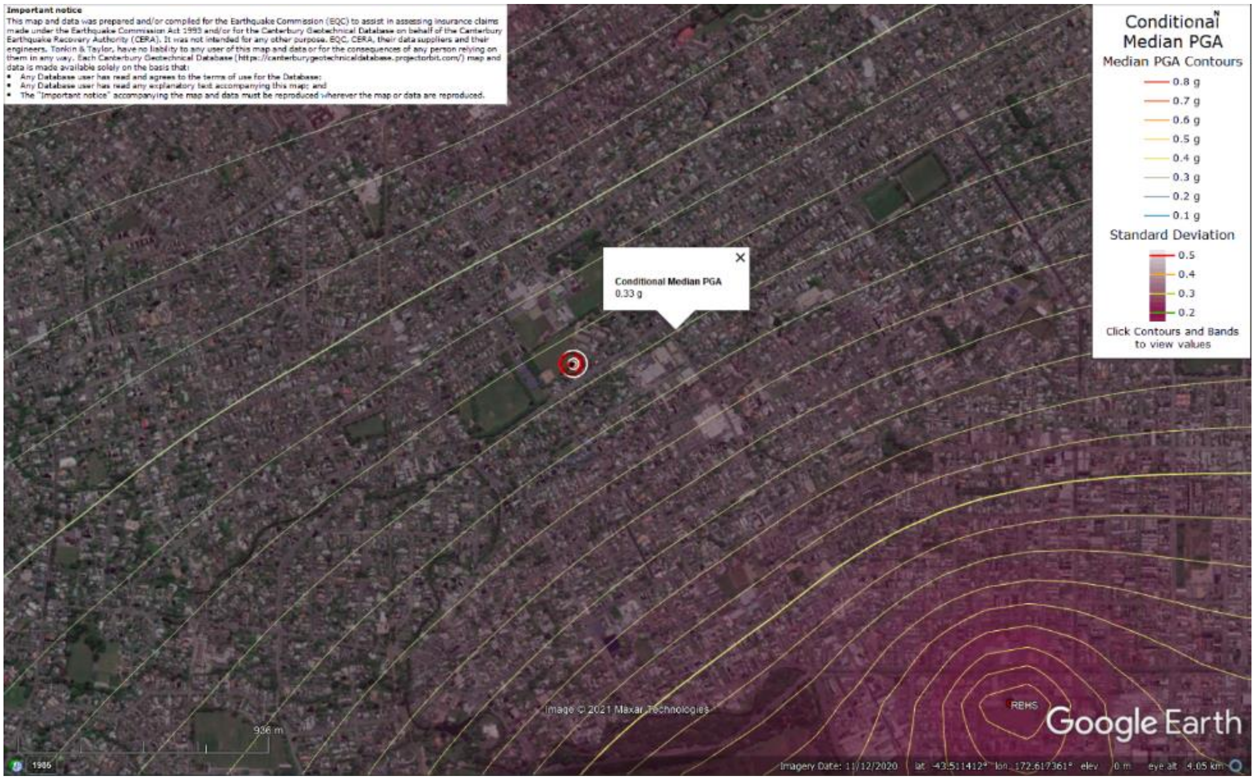

Figure 47: PGA for Feb-11 EQ (st. dev. = 0.350-0.375 ln units).

Figure 48: PGA for Jun-11 EQ (st. dev. = 0.350-0.375 ln units).

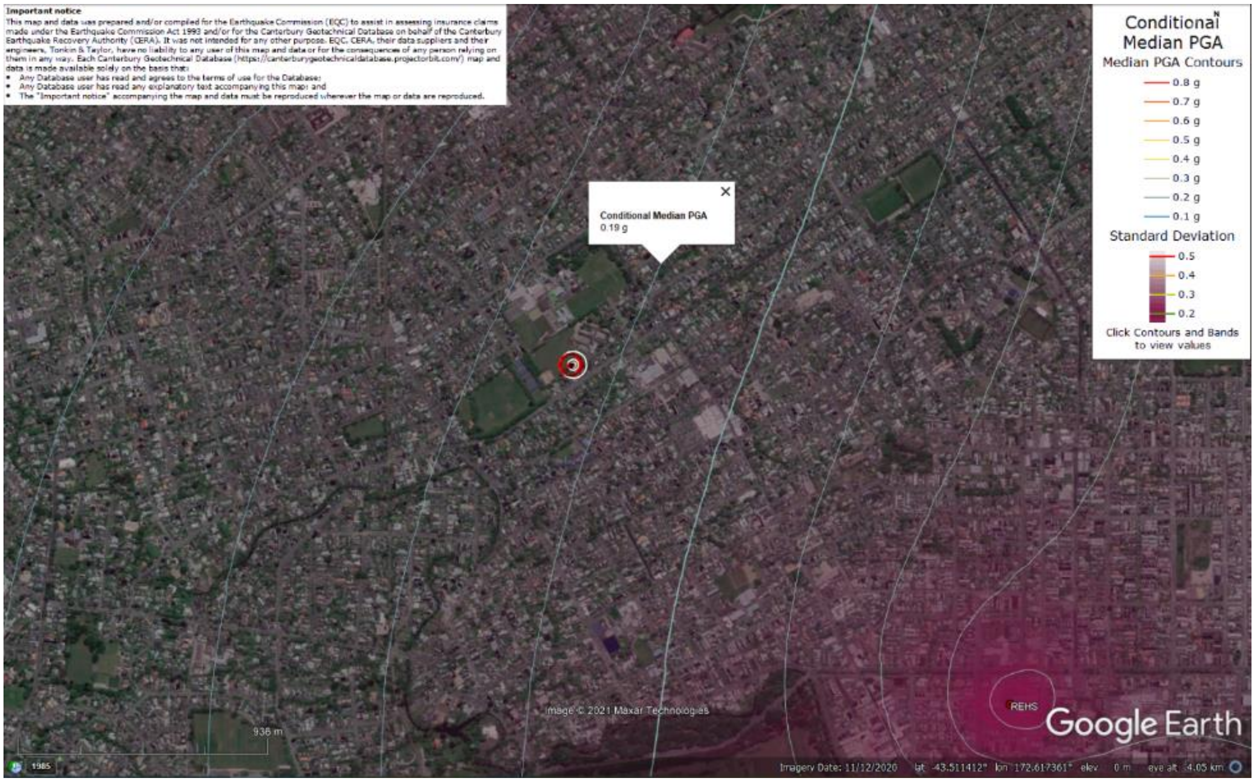

Figure 49: PGA for Dec-11 EQ (st. dev. = 0.375-0.400 ln units).

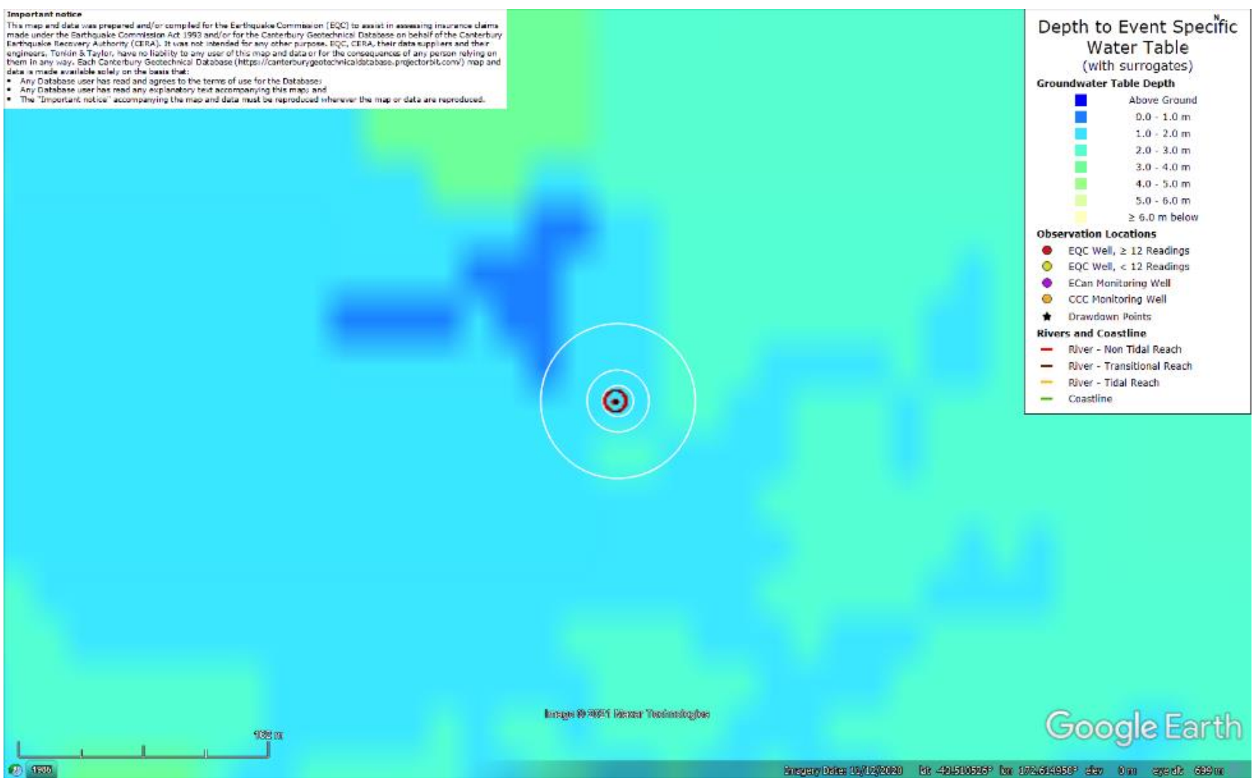

Figure 50: Depth to groundwater table for Sep-10 EQ.

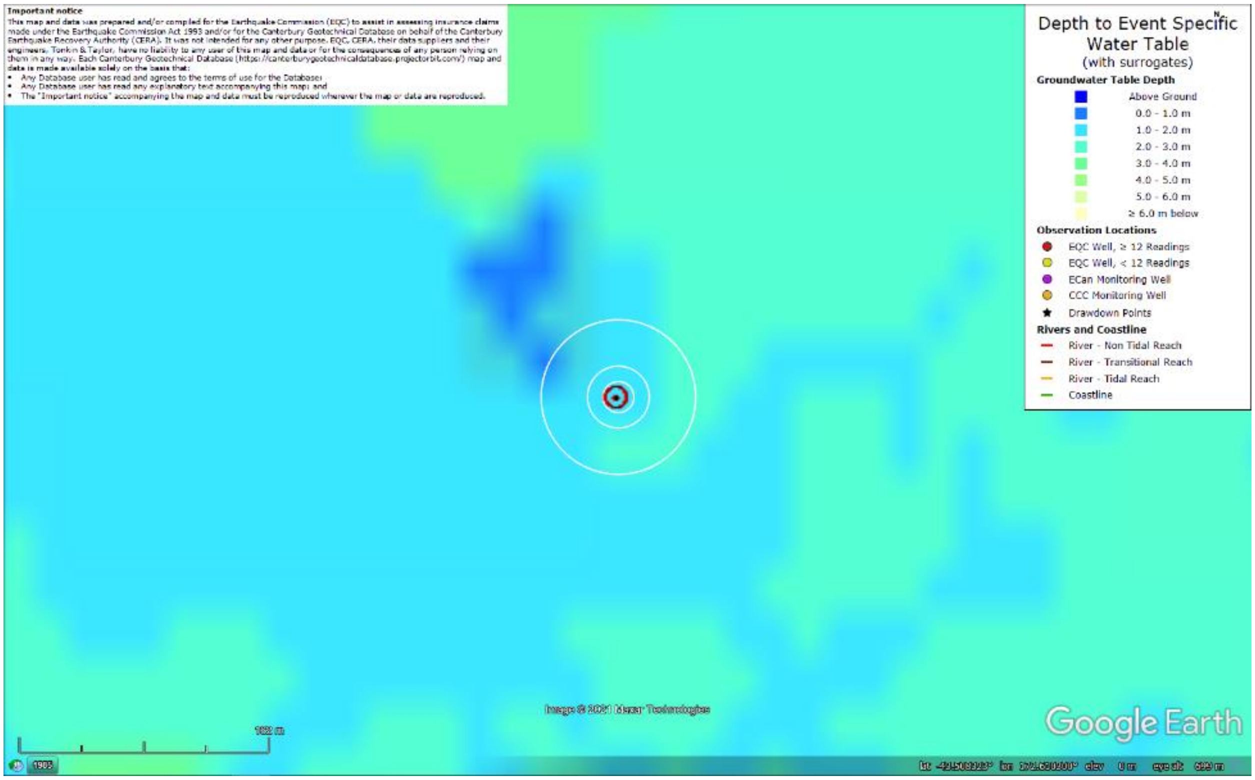

Figure 51: Depth to groundwater table for Feb-11 EQ.

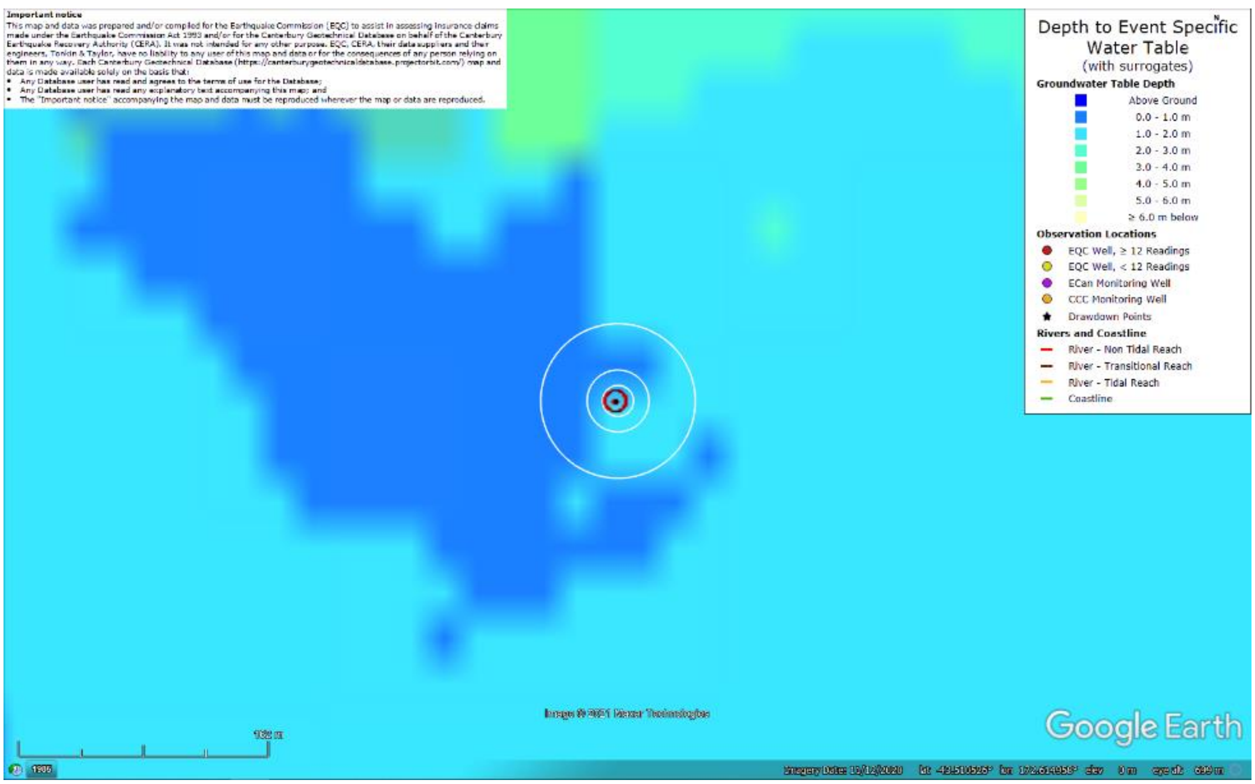

Figure 52: Depth to groundwater table for Jun-11 EQ.

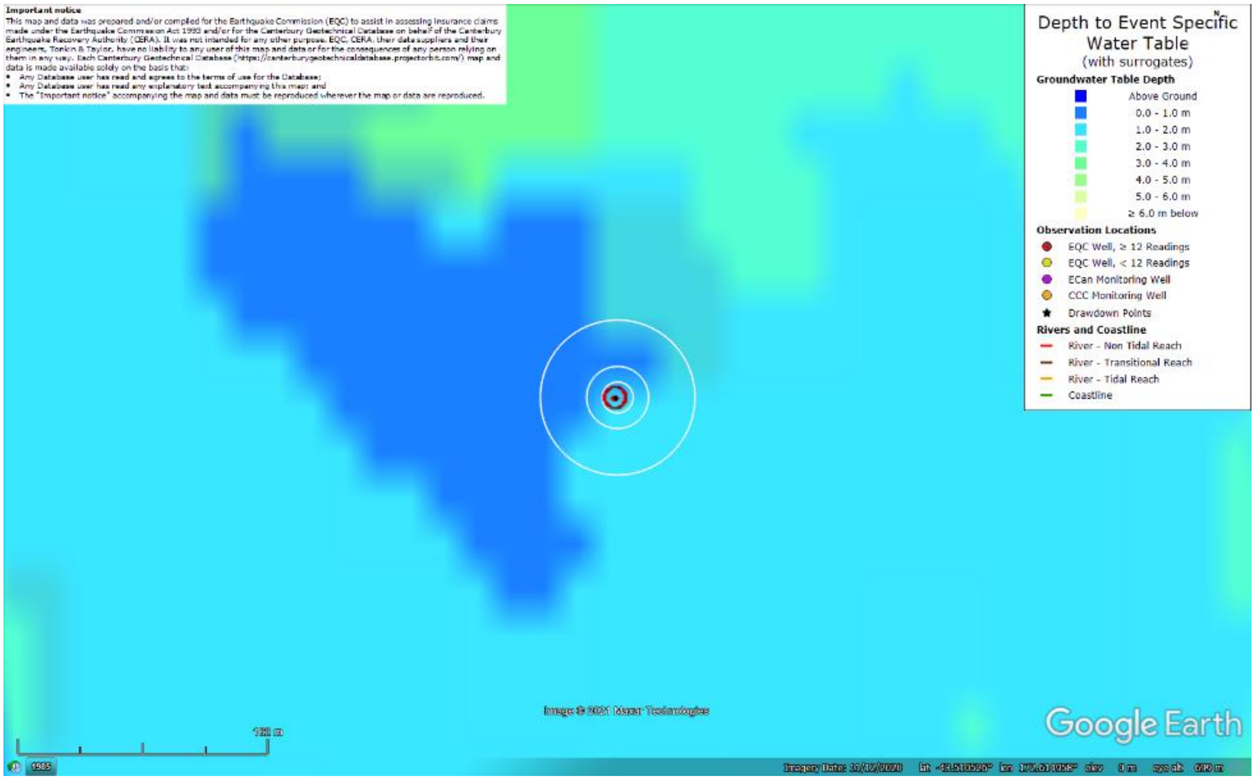

Figure 53: Depth to groundwater table for Dec-11 EQ.

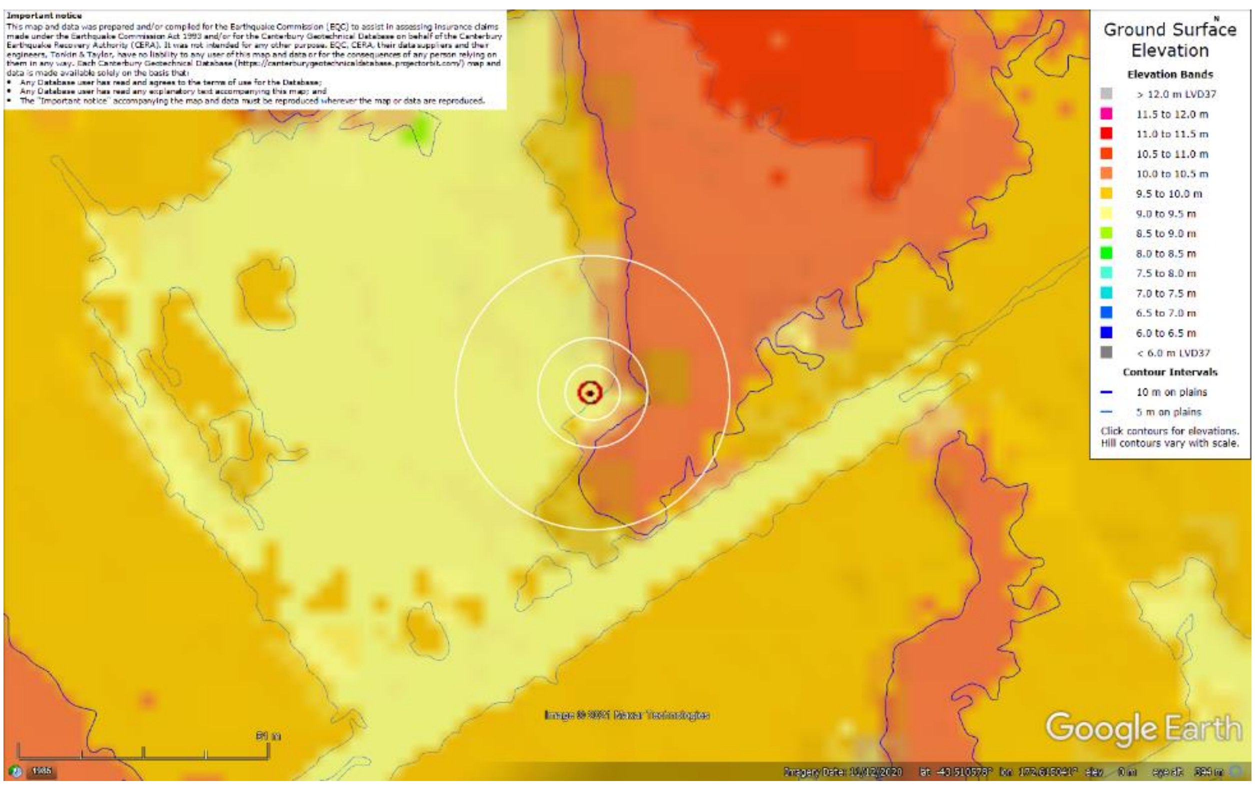

Figure 54: Ground surface elevation according to the Sep-11 LiDAR survey.

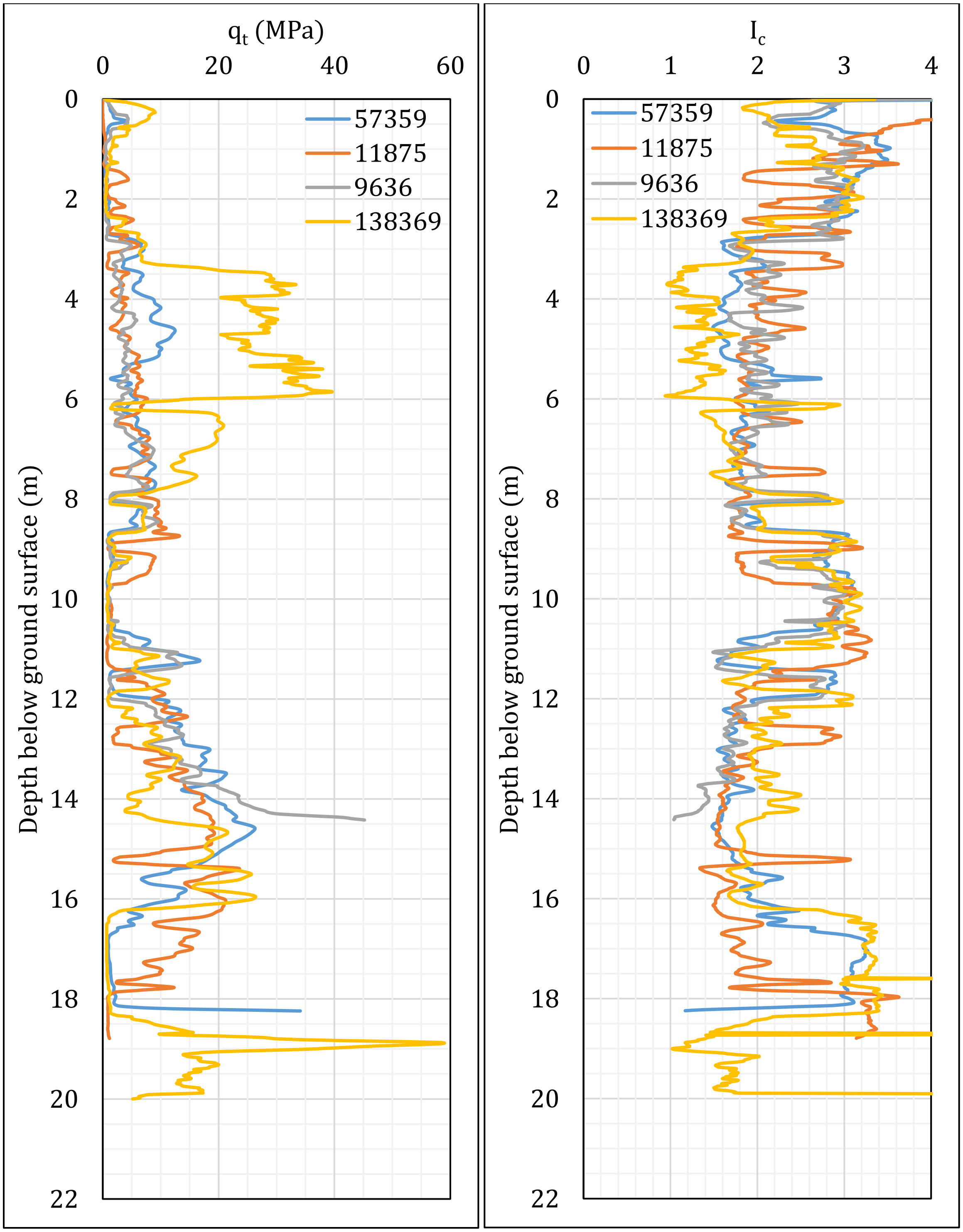

Figure 55: q_t and I_c profiles.

Note 5: 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
57359 (56737)	✓	✓	✓
11875		✓	✓
9636			
138369 (155137)			

Notes: CPT 138369 was used to compute the volumetric settlement for CPTs 57359, 11875, and 9636 for the respective depth ranges: 18.2-20 m, 18.8-20m, and 14.4-20 m; CPT 138369 is ~95 m to the NW from the center of the site.

Table 13: CPT-based results.

		CPT ID					
EQ Event	Parameter	57359	11875	9636	138369	$\Delta_{CPT57359/9636}$	$\Delta_{CPT11875}$
Sep-10	S_{V1D} (mm)	63	114	129	47	8	3
	LSN	9	18	22	4	1	0
	LPI	2	5	7	1	0	0
	LPI_{ish}	0	0	0	0	--	--
	$D_{FS<1}$ (m)	5.84	3.51	2.89	11.23	--	--
Feb-11	S_{V1D} (mm)	113	184	170	72	5	13
	LSN	18	31	29	8	0	1
	LPI	9	16	18	3	0	0
	LPI_{ish}	0	6	11	0	--	--
	$D_{FS<1}$ (m)	2.72	2.74	2.83	2.47	--	--
Jun-11	S_{V1D} (mm)	17	36	52	10	0	0
	LSN	2	7	9	1	0	0
	LPI	0	0	1	0	0	0
	LPI_{ish}	0	0	0	0	--	--
	$D_{FS<1}$ (m)	undet.	4.44	6.03	undet.	--	--
Dec-11	S_{V1D} (mm)	26	58	82	16	0	2
	LSN	4	11	15	2	0	0
	LPI	0	1	3	0	0	0
	LPI_{ish}	0	1	0	0	--	--
	$D_{FS<1}$ (m)	undet.	3.73	3.09	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; $\Delta_{CPT57359/9636}$ and $\Delta_{CPT11875}$ indicate the amount of S_{V1D}, LSN, and LPI added to CPTs 57359/9636 and 11875, respectively.

Note 6: Based on the borehole log (BH 57224, Figure 1), the groundwater table is at a depth of 1.2 m below the ground surface. The soil profile consists of (1) organic silty, OL, fill to a depth of 0.95 m, (2) amorphous peat, Pt, as topsoil to a depth of 1.2 m, (3) silt, ML, with some organics as topsoil to a depth of 1.5 m, (4) silt, ML, the Yaldhurst member of the Springston formation, to a depth of 3.8 m, (5) fine sand, SP, the Yaldhurst member of the Springston formation, to a depth of 5.75 m, (6) silt, ML, the Yaldhurst member of the Springston formation, to a depth of 6.75 m, (7) fine sand, SP, the Yaldhurst member of the Springston formation, to a depth of 7.75 m, (8) silt, ML, the Yaldhurst member of the Springston formation, to a depth of 12.15 m, (9) silty fine sand, SM, of the Christchurch formation, to a depth of 12.85 m, (10) fine to medium sand, SP, of the Christchurch formation, to a depth of 15.65 m (the end of the borehole). According to BH 12035, the SP layer continues to a depth of ~17.5 m and is followed by sandy silt, ML, of the Christchurch formation, to a depth of ~20.5 m, which is underlain by Riccarton gravel.

Note 7: 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 (m^2)	A_E (m^2)	V_E (m^3)	S_{E,P_areal} (mm)	$S_{E,P\_localized}$ (mm)
Sep-10	158	113	6.4-8.7	50±5	65±10
Feb-11	158	113	3.1-5.3	25±5	35±10
Jun-11	144	37.3	0.8-1.6	10±5	30±10
Dec-11	158	1.9	0.02-0.06	<5	20±10

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.

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	563	418	18.5-28.2	40±10	55±10
Feb-11	563	435	9.2-17.8	25±10	30±10
Jun-11	481	249	4.1-9.0	15±5	25±10
Dec-11	563	36.6	0.4-1.1	<5	20±10

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.

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	2731	996	24.3-51.3	15±5	40±15
Feb-11	2731	1566	20.5-51.8	15±5	25±10
Jun-11	2628	501	6.6-16.6	5±5	25±10
Dec-11	2731	63.6	0.6-1.9	<5	20±10

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.

<u>Summary 2:</u>

The best estimate of the <u>localized</u> ejecta-induced free-field ground settlement at the Heaton Normal Intermediate School site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 55±10 mm, 30±10 mm, 25±10 mm, and 20±10 mm, respectively.