Appendix A.52:

Nursery Rd – CPT 17262

Table 1: Site Description for Nursery Rd (CPT 17262).

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 ~1400 m to the SE from the Avon River (the free-face height is ~4.5 m) and ~1600 m to the N from the Heathcote River (the free-face height is ~3.5 m).	NA
Lateral spreading observed during the CES?	No	No	No	No lateral spreading was observed by the mapping team.[1]	NA
Nearby buildings or structures?	Yes	Yes	Yes	Building coverage of the 10-, 20-, and 50-m buffers is 24, 21, and 20%, respectively. Buildings are in the SW q. of the 10-m b. and all q. of the 20-m and 50-m b.	White Fill + Brown Outline
Sloping land?	No	No	No	Flat land, community center + school 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 9% and 16% of the 20-m and 50-m buffers. They are in the NW, NE, and SE q. of the 20-m b. and all q. of the 50-m b.	White Fill + Green Outline
Anthropogenic changes to the site between the LiDAR surveys?	No	No	No	Between Jan 2006 and Mar 2009, vegetation addition in the SE q. of the 50-m b. and renovation of buildings in the NW and SW q. of the 10-m and 20-m b. and the NW, SW, and SE q. of the 50-m b. Concrete pavement removal in all q. of all b. between 26 Feb 2011 and 28 Mar 2011. Construction fence placement around the central building between 28 Mar 2011 and 14-15 Jun 2011. Playground addition in the SW q. of the 50-m buffer between Dec 2011 and Apr 2012. Building removal from the W portion of all buffers between Mar 2014 and Aug 2014.	Pavement Removal: Orange Outline; Building Removal: Orange Crossline; Playground: Yellow Outline + White Fill
Other important factors?	Yes	Yes	Yes	Nursery Rd is in the E portion of the 50-m b. and occupies 1% of the 50-m b. There is a container in the NW q. of the 50-m buffer, speed bump in the E portion of the 20-m and 50-m b., potential speed bump in the NW q. of the 50-m b., gutter in the NW q. of the 20-m and 50-m b. and construction fence in the S portion of all b.	Road: White Fill + Gray Outline; Container: Blue outline + White Fill; Speed Bump: Pink Outline + White Fill; Gutter: Green Outline

Note: Buffer is the area within a circle of a specified radius with CPT investigations done at its center (172.656360°, -43.537748°).

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

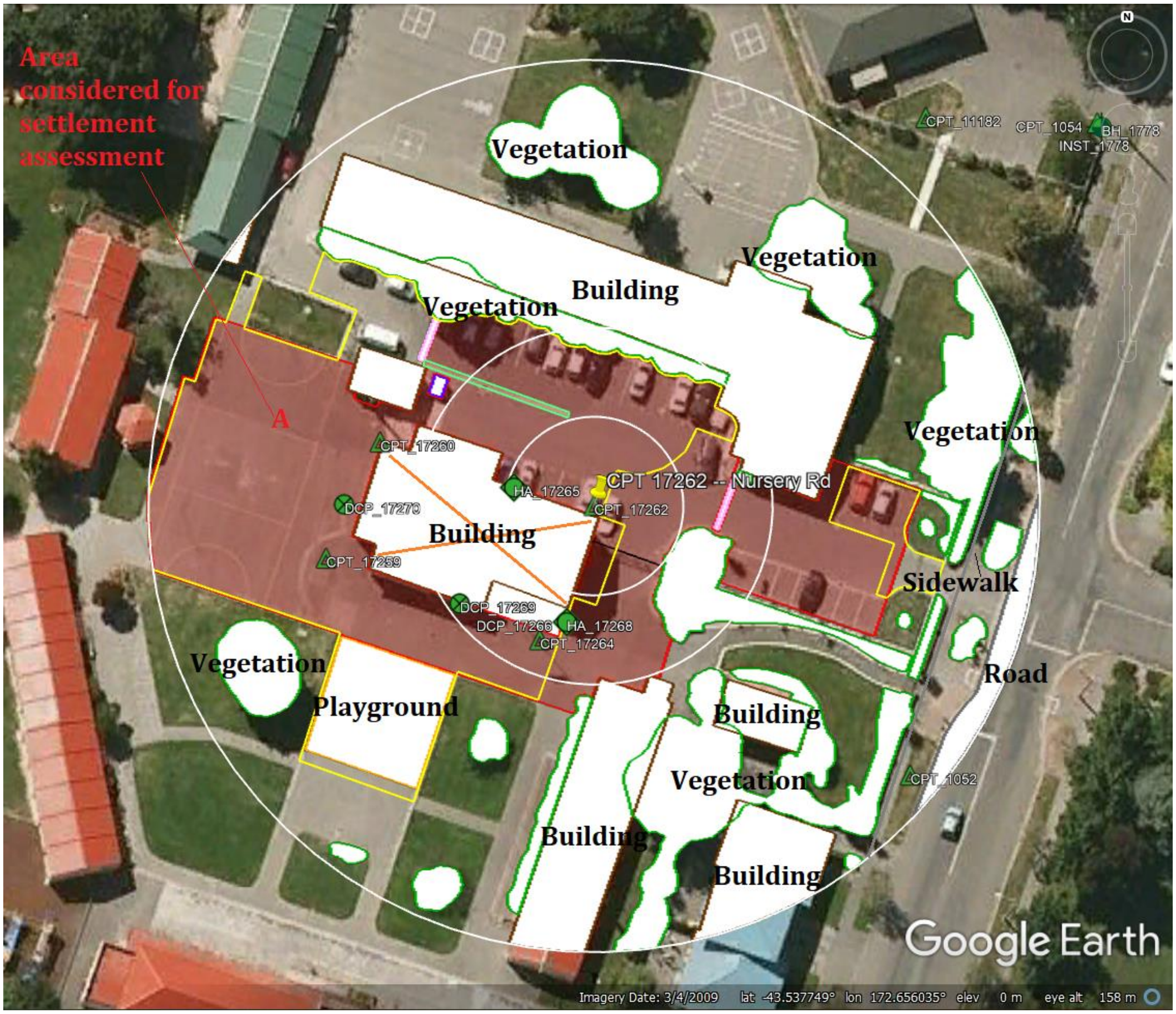

Figure 1: Site plan with areas where ejecta-induced settlement is considered.

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 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 aerial distribution of sediment ejecta. Due to the anthropogenic changes that had the potential to affect all post-Feb-2011 LiDAR surveys (primarily because the concrete pavement was removed and was not replaced), the LiDAR-based settlement analyses for the Feb-11, Jun-11, and Dec-11 EQs were not conducted for this site. Due to the evident absence of ejecta from the site for the Sep-10 EQ, the July 2003 and Sep 2010 LiDAR surveys were not considered either.

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	-100
Jun-11	0	38	-40
Dec-11	0	-65	0
CES	0	-14	-140
Any 2010 LiDAR survey affected by ejecta?			No

Note: 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 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 3a.

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

Earthquake Event(s)	Average Ground Surface Subsidence (mm)		
	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.

Earthquake Event(s)	Average Calculated Ground Surface Subsidence (mm)		
	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 4, but rounded to the nearest 25 mm; Positive overall values indicate ground surface subsidence, while negative overall values indicate ground surface uplift.

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	ND	ND	ND	ND	ND	ND	ND	ND	ND
Feb-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jun-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dec-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
CES	ND	ND	ND	ND	ND	ND	ND	ND	ND

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	0.22	3.3	ND	37±20	ND
Feb-11	6.2	0.50	2.7	ND	195±50	ND
Jun-11	6.2	0.29	2.5	ND	67±25	ND
Dec-11	6.1	0.22	2.5	ND	15±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 (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	0.22	3.3	ND	31±20	ND
Feb-11	6.2	0.50	2.7	ND	159±50	ND
Jun-11	6.2	0.29	2.5	ND	57±25	ND
Dec-11	6.1	0.22	2.5	ND	14±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 (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	0.22	3.3	ND	37±20	ND
Feb-11	6.2	0.50	2.7	ND	185±50	ND
Jun-11	6.2	0.29	2.5	ND	71±25	ND
Dec-11	6.1	0.22	2.5	ND	17±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 ±20, ±50, ±25, and ±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.

EQ Event	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m^2)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m^2)	$H_{E,thick3}$ (mm)	$A_{E,thick3}$ (m^2)	$H_{E,thin1}$ (mm)	$A_{E,thin1}$ (m^2)	$H_{E,thin2}$ (mm)	$A_{E,thin2}$ (m^2)	A_T (m^2)
Sep-10	0	0	0	0	0	0	0	0	0	0	252
Feb-11	80-120	138	0	0	0	0	10-30	7.3	5-15	99.2	252
Jun-11	0	0	0	0	0	0	10-40	106	0	0	235*
Dec-11	0	0	0	0	0	0	0	0	0	0	252

Notes: $A_{E,thin/thick}$ =Coverage area of thin/thick ejecta layers; $H_{E,thin/thick}$ = Lower-upper estimate of height of thin/thick ejecta layers; A_T= Total assessment area of a buffer being considered; * indicates 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.

EQ Event	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m²)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m²)	$H_{E,thick3}$ (mm)	$A_{E,thick3}$ (m²)	$H_{E,thin1}$ (mm)	$A_{E,thin1}$ (m²)	$H_{E,thin2}$ (mm)	$A_{E,thin2}$ (m²)	A_T (m²)
Sep-10	0	0	0	0	0	0	0	0	0	0	804
Feb-11	80-120	228	40-80	21.8	0	0	10-30	40.0	5-15	376	804
Jun-11	0	0	0	0	0	0	10-40	131	0	0	496*
Dec-11	0	0	0	0	0	0	0	0	0	0	804

Notes: $A_{E,thin/thick}$ =Coverage area of thin/thick ejecta layers; $H_{E,thin/thick}$ = Lower-upper estimate of height of thin/thick ejecta layers; A_T= Total assessment area of a buffer being considered; * indicates 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.

EQ Event	$H_{E,thick1}$ (mm)	$A_{E,thick1}$ (m²)	$H_{E,thick2}$ (mm)	$A_{E,thick2}$ (m²)	$H_{E,thick3}$ (mm)	$A_{E,thick3}$ (m²)	$H_{E,thin1}$ (mm)	$A_{E,thin1}$ (m²)	$H_{E,thin2}$ (mm)	$A_{E,thin2}$ (m²)	A_T (m²)
Sep-10	0	0	0	0	0	0	0	0	0	0	1912
Feb-11	80-120	554	40-80	83.8	20-50	269	10-30	113	5-15	684	1912
Jun-11	0	0	0	0	20-50	504	10-40	131	0	0	1351*
Dec-11	0	0	0	0	0	0	0	0	0	0	1912

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

Note 3: The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photographs (Figures 18, 20, 38, and 39) and the lower and upper estimates of ejecta height based on geometrical approximations. 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, respectively, of a thick ejecta layer;
- $A_{E,thin,j}$ and $H_{E,thin,j}$ are the area and the height, respectively, of a thin ejecta layer;
- 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	0	0	0	0	0	0
Feb-11	46	73	27	45	30	53
Jun-11	5	18	3	11	8	23
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.

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	0	0	ND	0	0	ND	0	0
Feb-11	ND	60±13	60±15	ND	36±9	35±10	ND	42±11	40±10
Jun-11	ND	12±6	10±5	ND	7±4	5±5	ND	16±7	15±5
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.

Note 4:

- $S_{E,final}$ for all buffers is based solely on $S_{E,P}$ for all earthquake events.
- The Nursery Rd site is in the zone of slight to moderate LPI overprediction of liquefaction severity for the Sep-10 and Feb-11 EQs (Maurer et al. 2014[3]). The site is not in the apparent zone of higher/lower ground surface subsidence for the Sep-10/Feb-11 EQ although no LiDAR-based ejecta-induced settlement analyses were performed (please see Note 1 for the explanation). The LDAT property inspection reports and ground photographs are not available.

<u>**Summary 1**</u>**:**

The best estimate of the ejecta-induced free-field ground settlement at the Nursery Rd site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 60±15 mm, 10±5 mm, and 0 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.

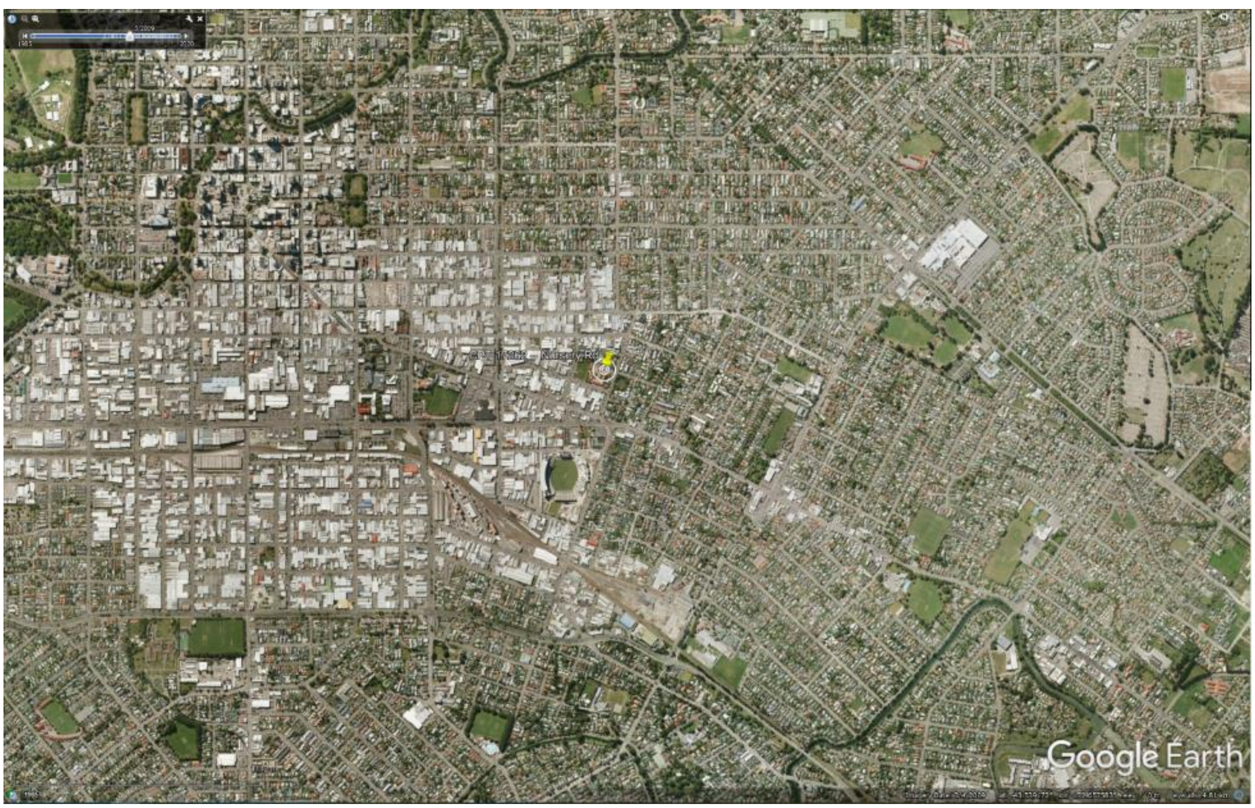

Figure 3: Position of the site relative to the nearest free-face features.

Figure 4: Position of the site relative to nearby buildings and vegetation.

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 2006.

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

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

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

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

Figure 12: Satellite image of the site taken on Feb 26, 2011.

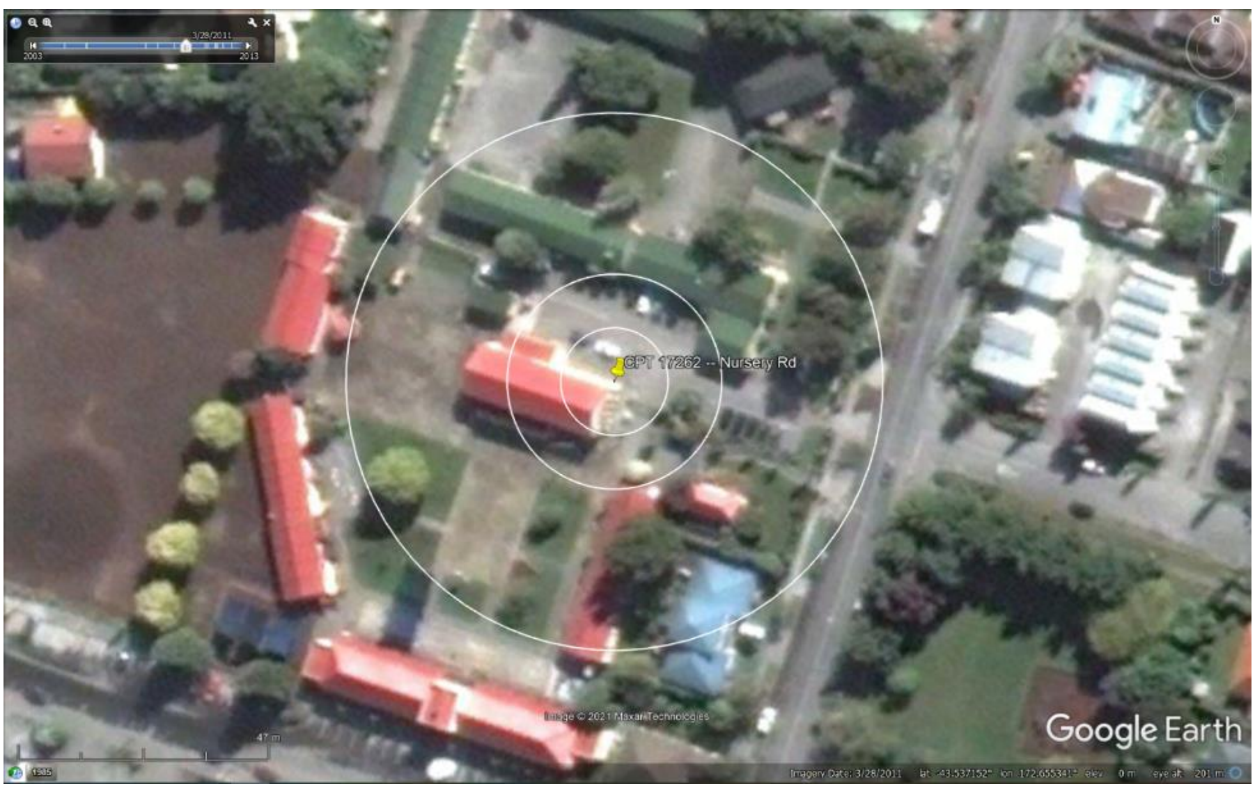

Figure 13: Satellite image of the site taken on Mar 28, 2011.

Figure 14: Satellite image of the site taken in Apr 2012.

Figure 15: Satellite image of the site taken in Mar 2014.

Figure 16: Satellite image of the site taken in Aug 2014.

Figure 17: Satellite image of the site taken in Nov 2015.

Figure 18: Aerial photograph of the site taken on Sep 4, 2010.

Figure 19: Aerial photograph of the site taken on Feb 24, 2011.

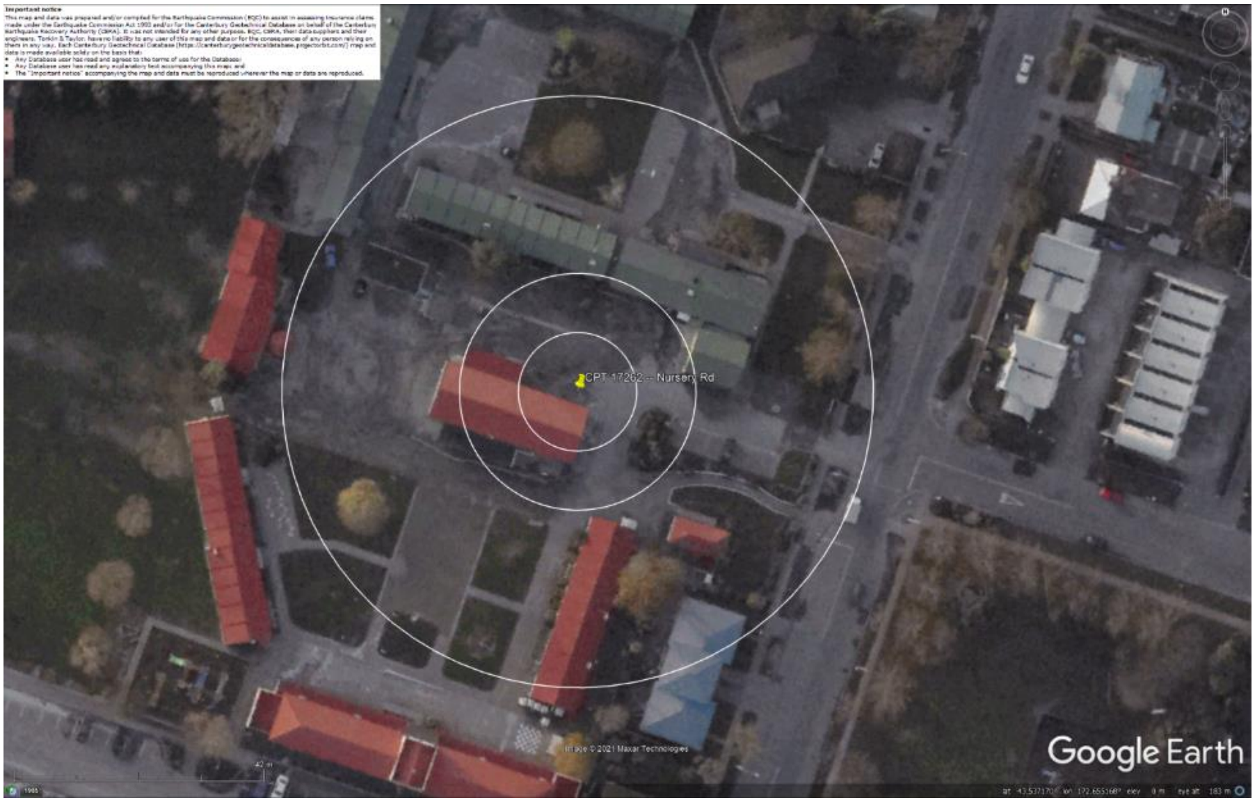

Figure 20: Aerial photograph of the site taken on June 14-15, 2011.

Figure 21: Aerial photograph of the site taken on June 16, 2011.

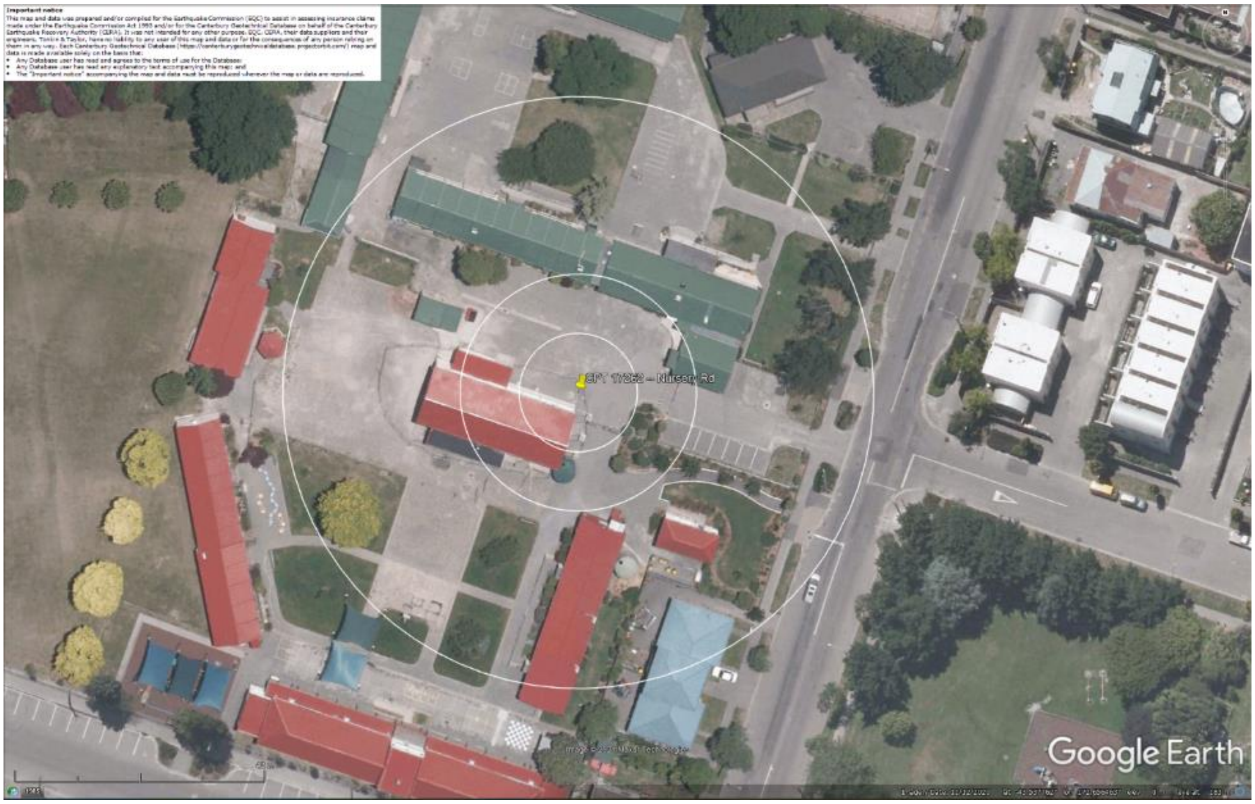

Figure 22: Aerial photograph of the site taken on Dec 24, 2011.

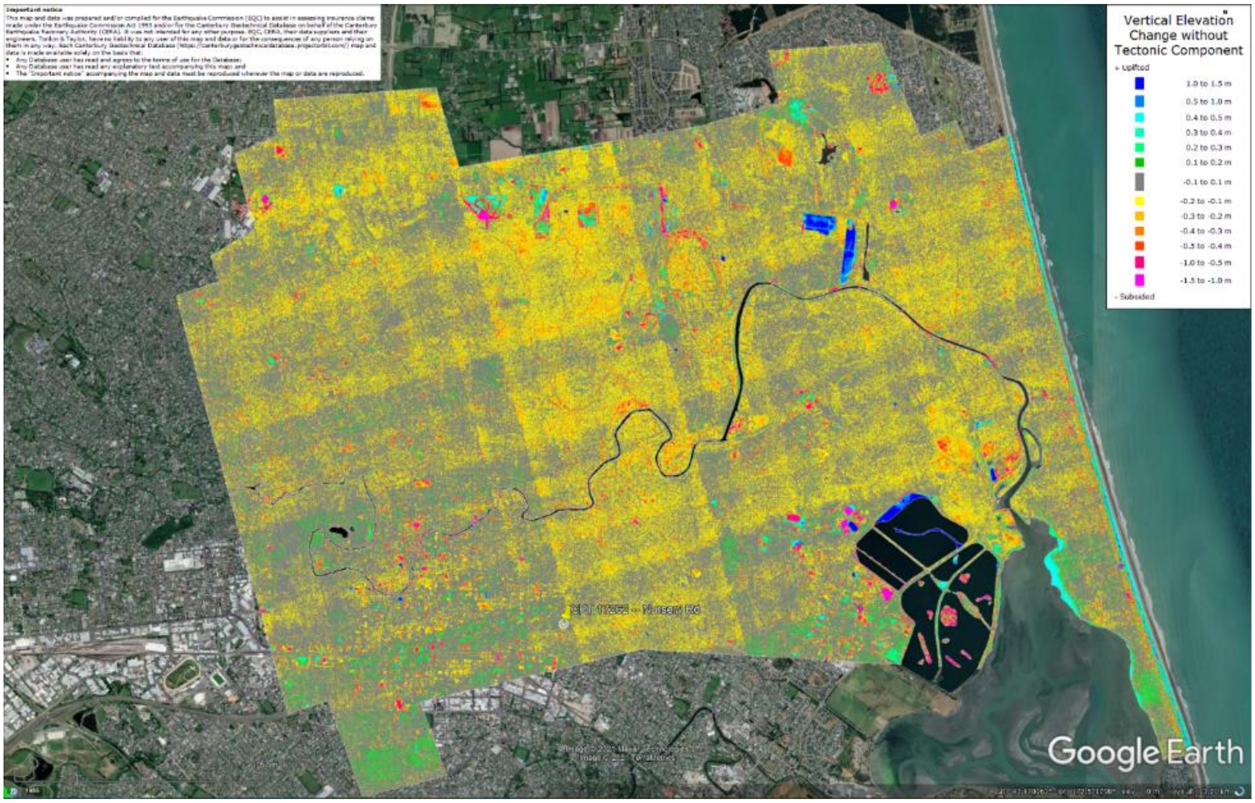

Figure 23: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake – the site is not in the apparent zone of overestimated ground surface subsidence.

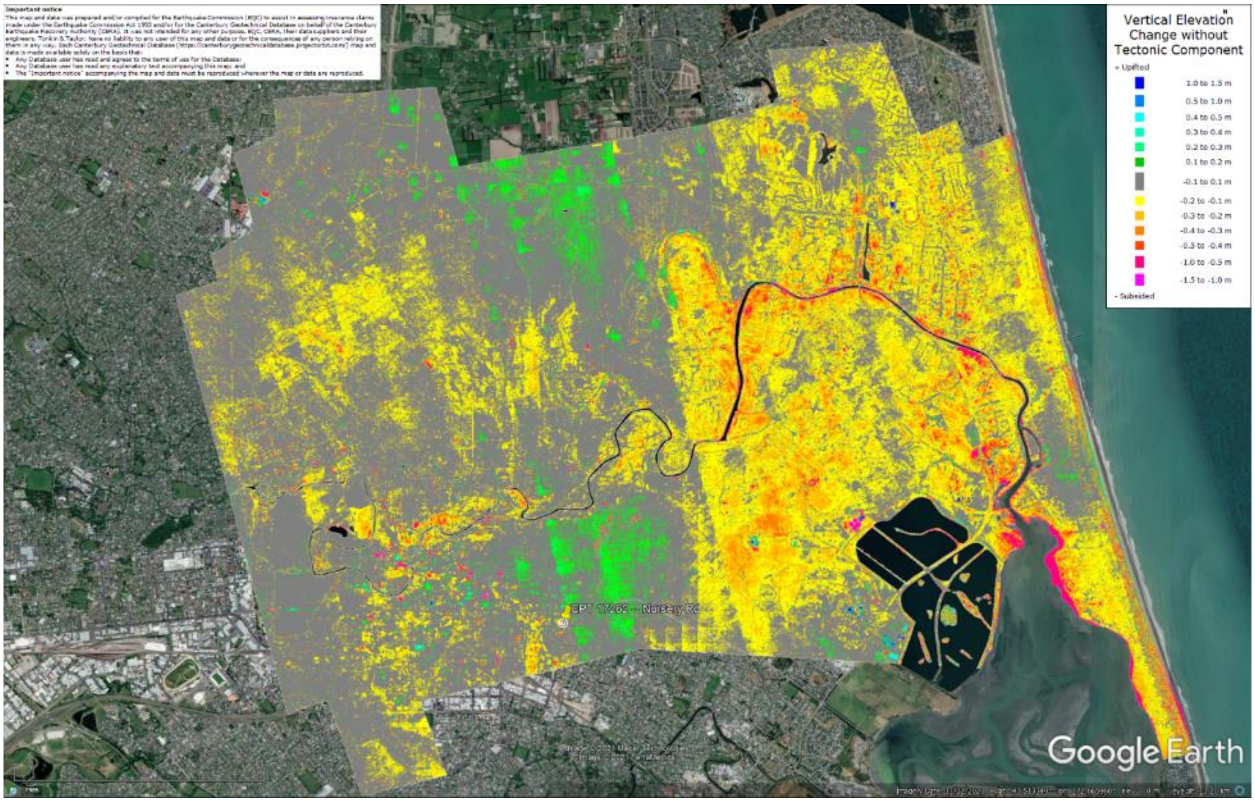

Figure 24: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake – the site is not in the apparent zone of underestimated ground surface subsidence.

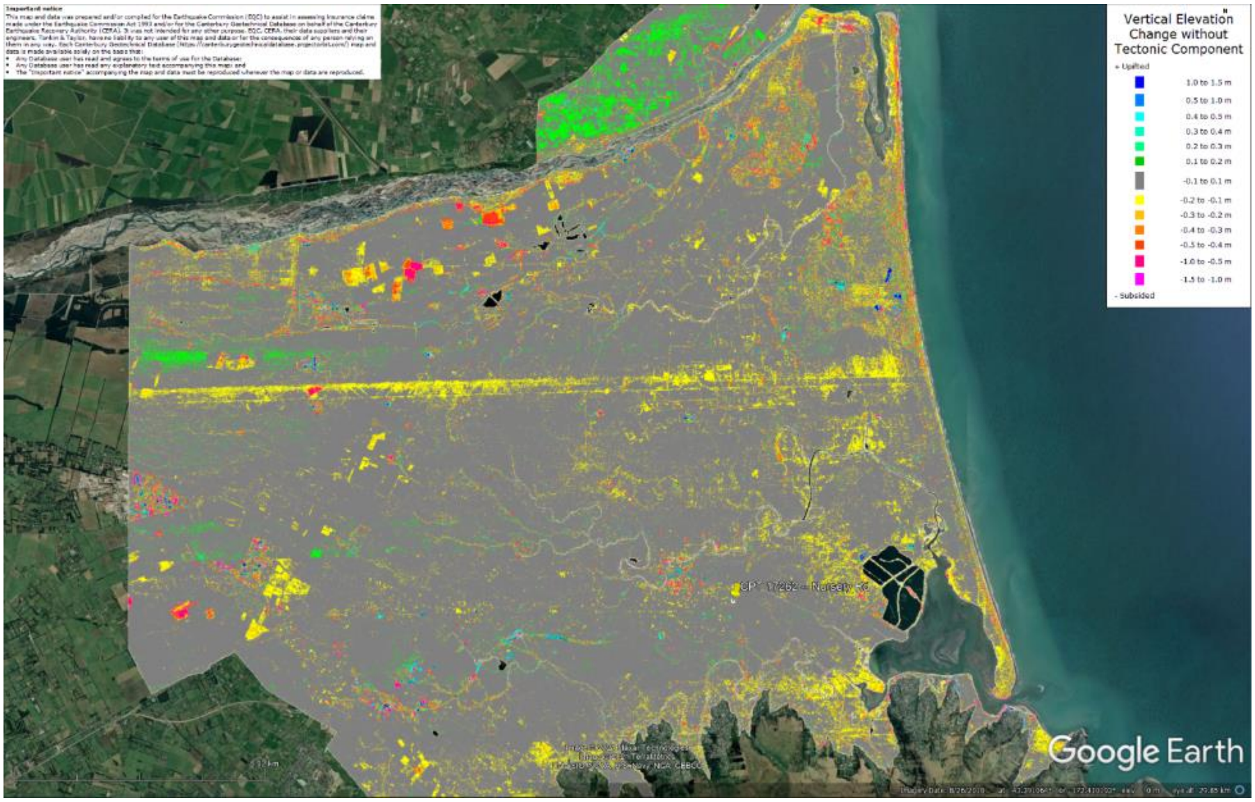

Figure 25: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

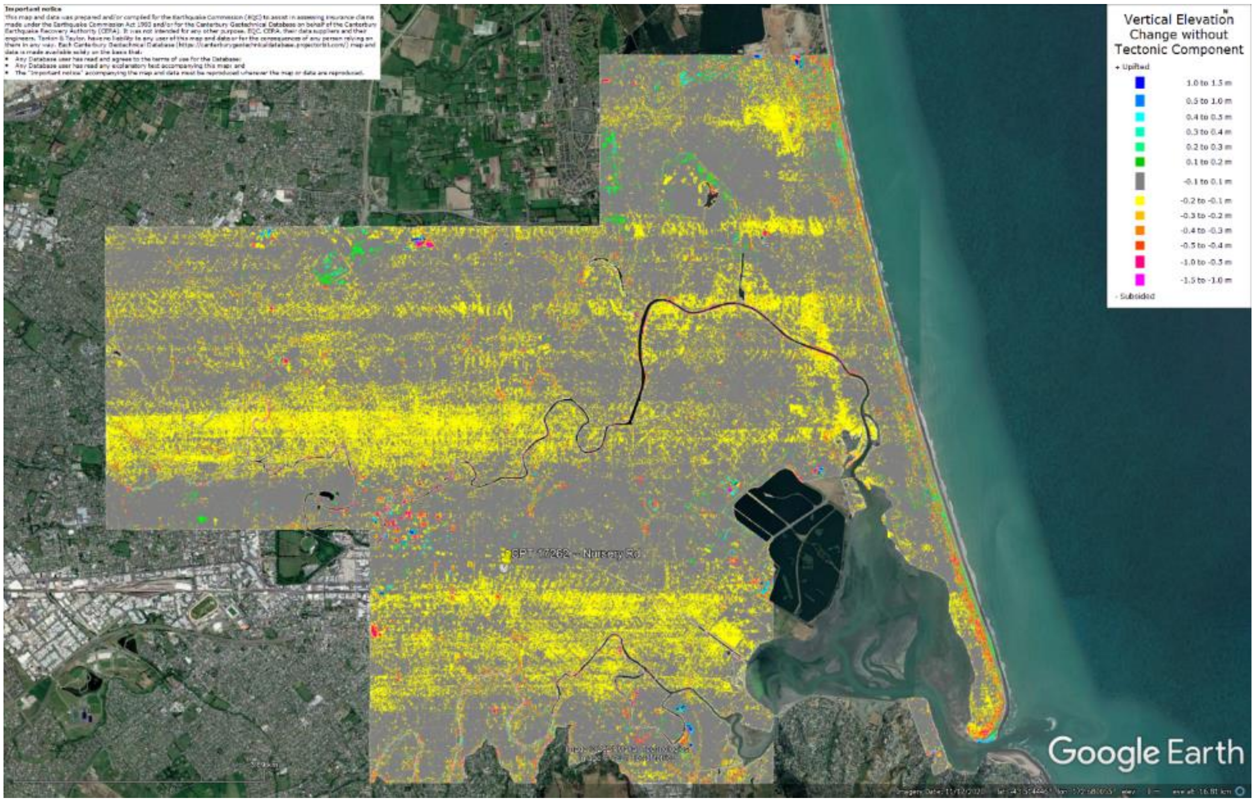

Figure 26: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

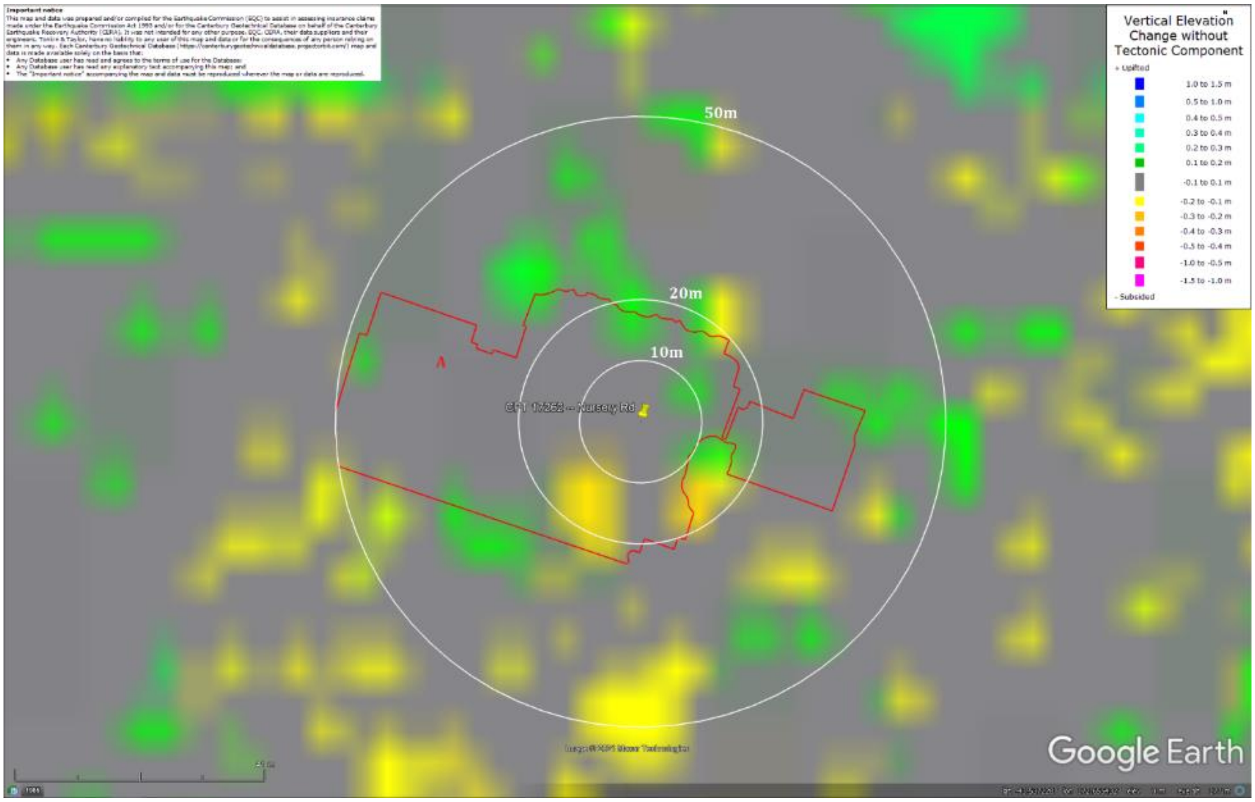

Figure 27: Ground surface subsidence without tectonic component for Sep 2010 Earthquake according to the LiDAR DEM.

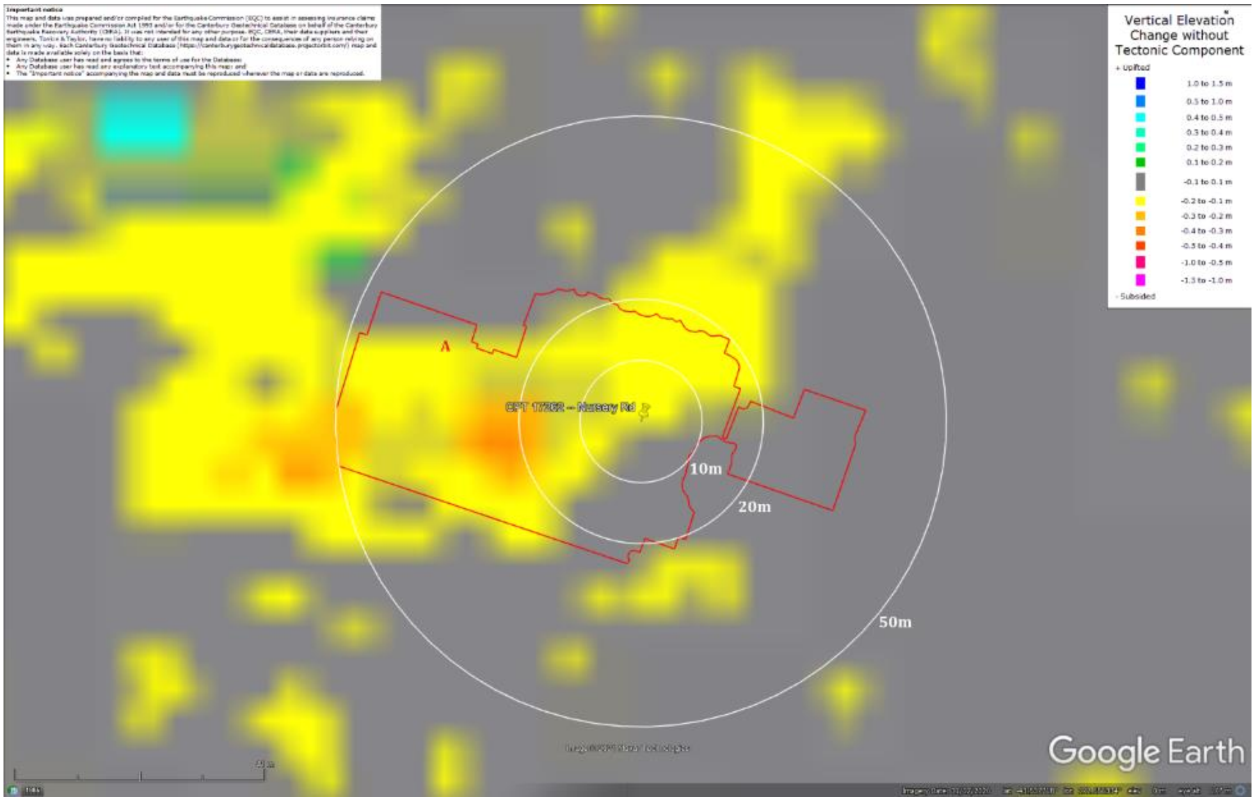

Figure 28: Ground surface subsidence without tectonic component for Feb 2011 Earthquake according to the LiDAR DEM.

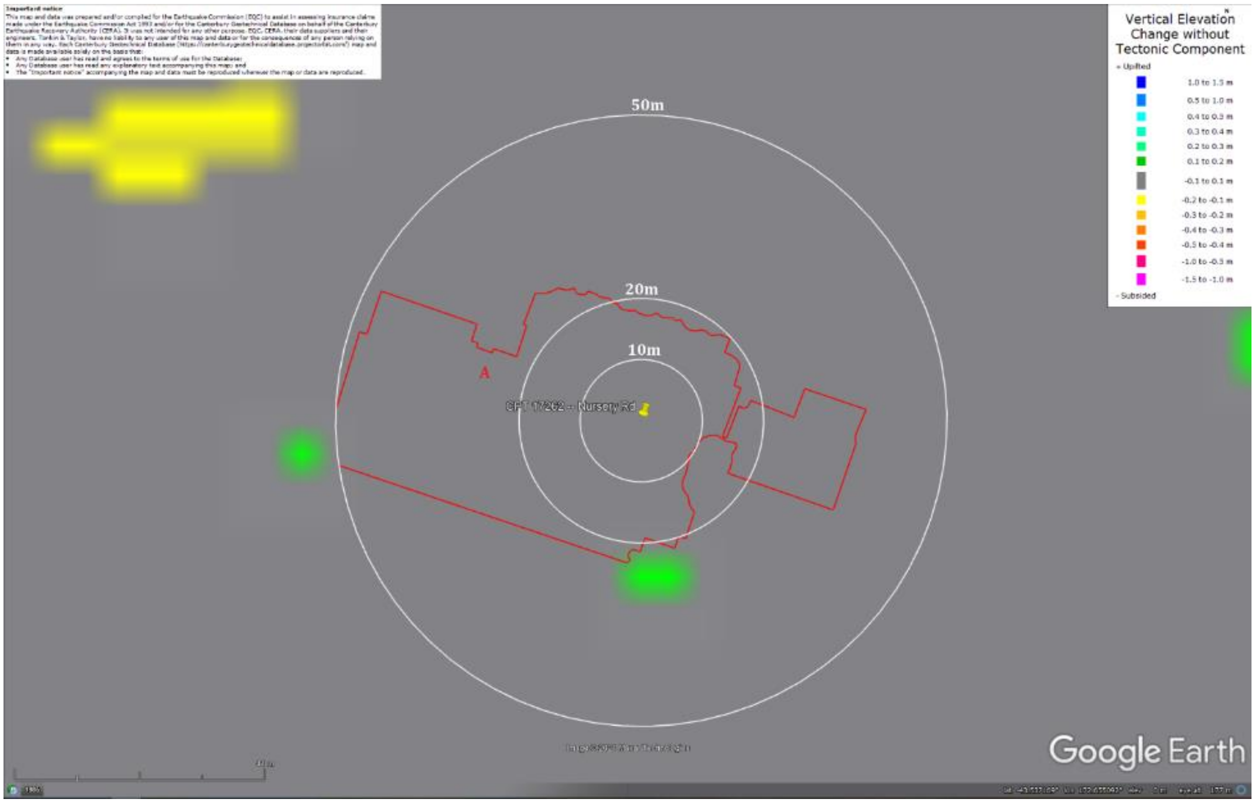

Figure 29: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

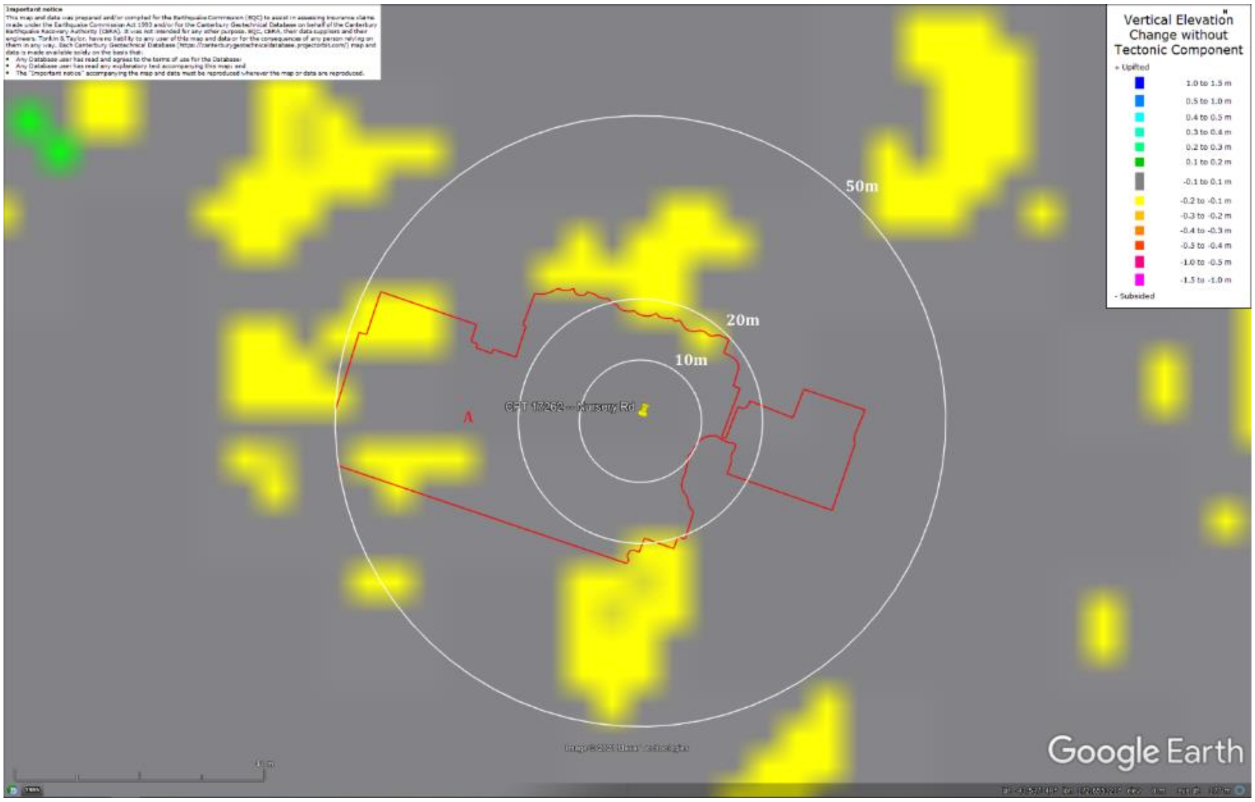

Figure 30: Ground surface subsidence without tectonic component for Dec 2011 Earthquake according to the LiDAR DEM.

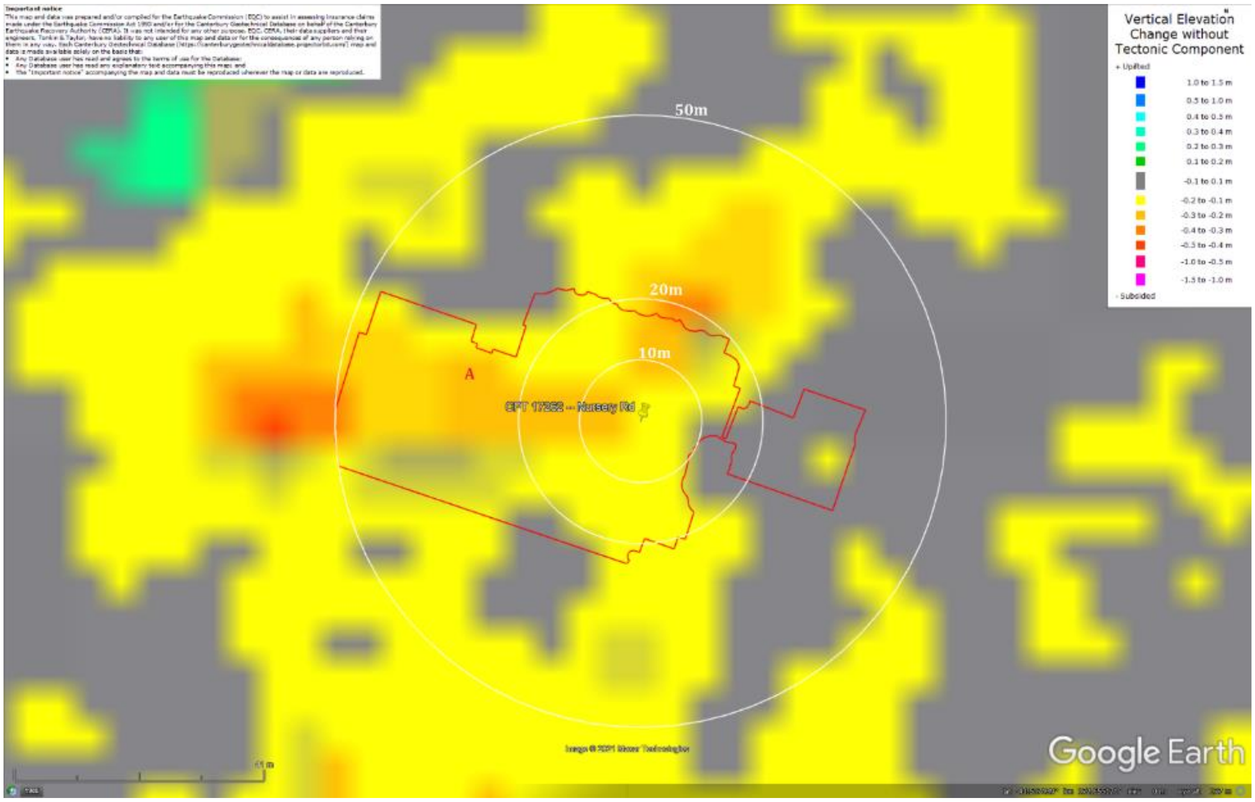

Figure 31: Ground surface subsidence without tectonic component for Canterbury Earthquake Sequence according to the LiDAR DEM.

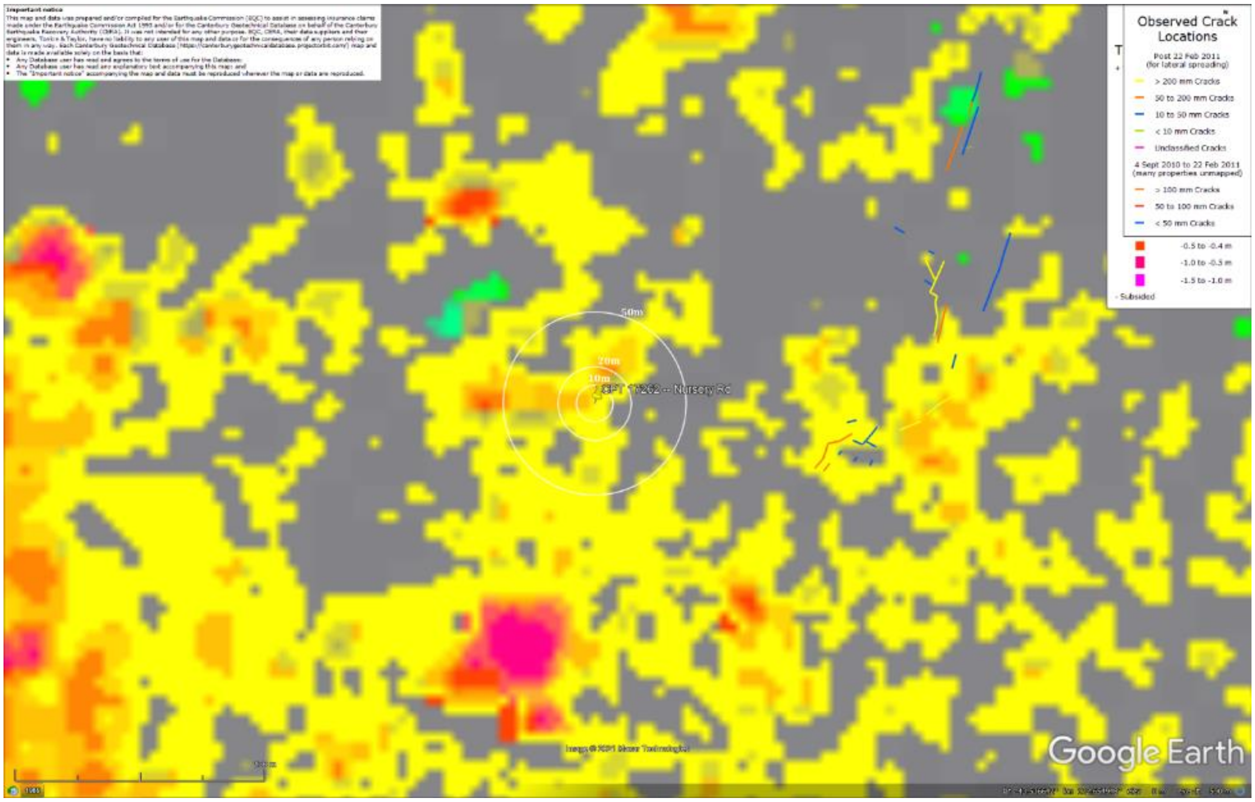

Figure 32: No lateral spreading for Canterbury Earthquake Sequence.

Figure 33: Vertical tectonic movements for Sep 2010 Earthquake.

Figure 34: Vertical tectonic movements for Feb 2011 Earthquake.

Figure 35: Vertical tectonic movements for June 2011 Earthquake.

Figure 36: Vertical tectonic movements for Dec 2011 Earthquake.

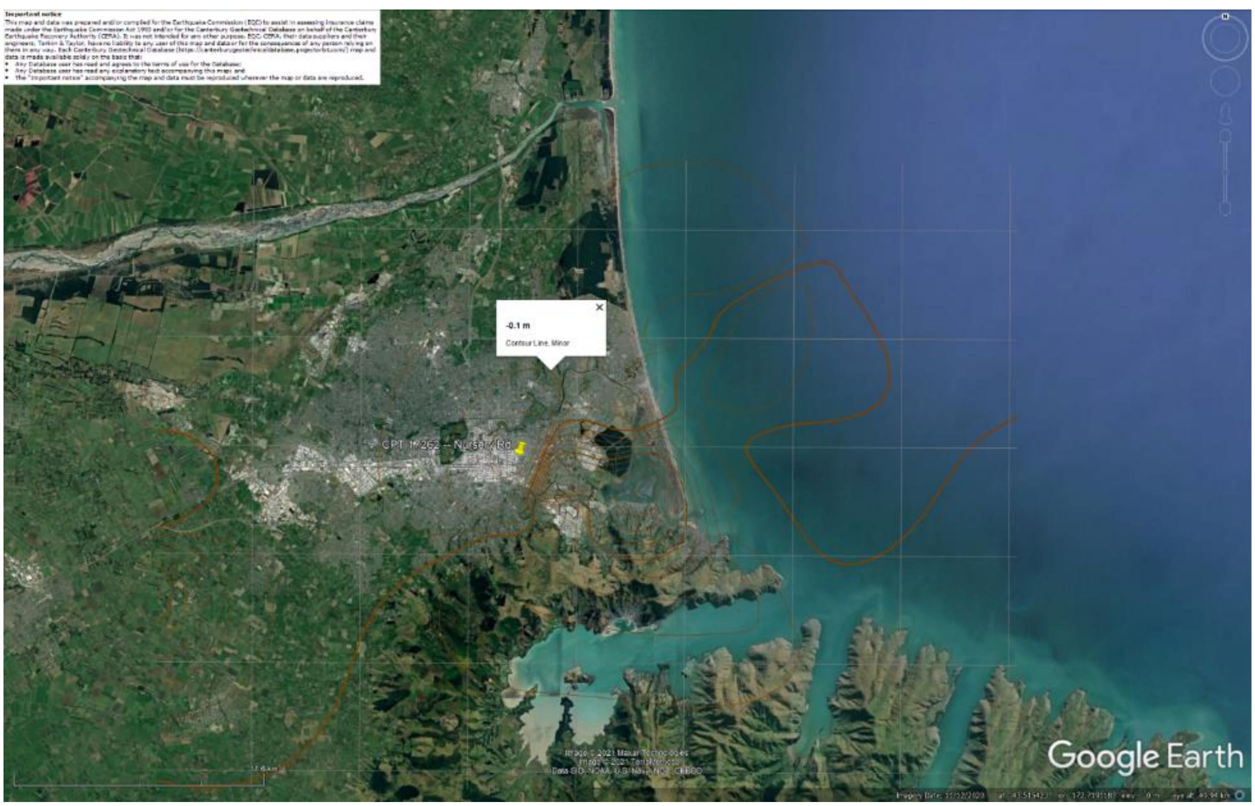

Figure 37: Vertical tectonic movements for Canterbury Earthquake Sequence.

Figure 38: Aerial photograph showing the ejecta outline at the site for Feb-11 EQ.

Figure 39: Aerial photograph acquired on 16 Jun 2011 showing the ejecta outline at the site for Jun-11 EQ.

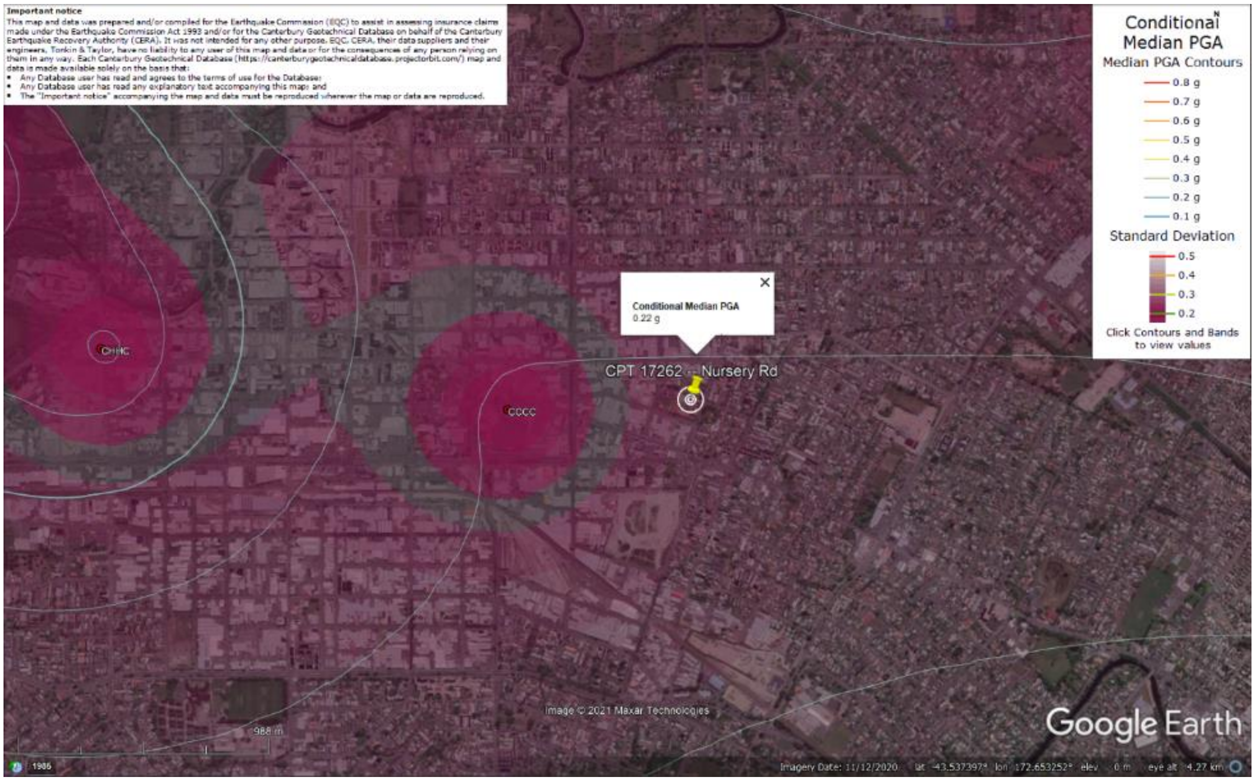

Figure 40: PGA for Sep-10 EQ (st. dev. = 0.275-0.300 ln units).

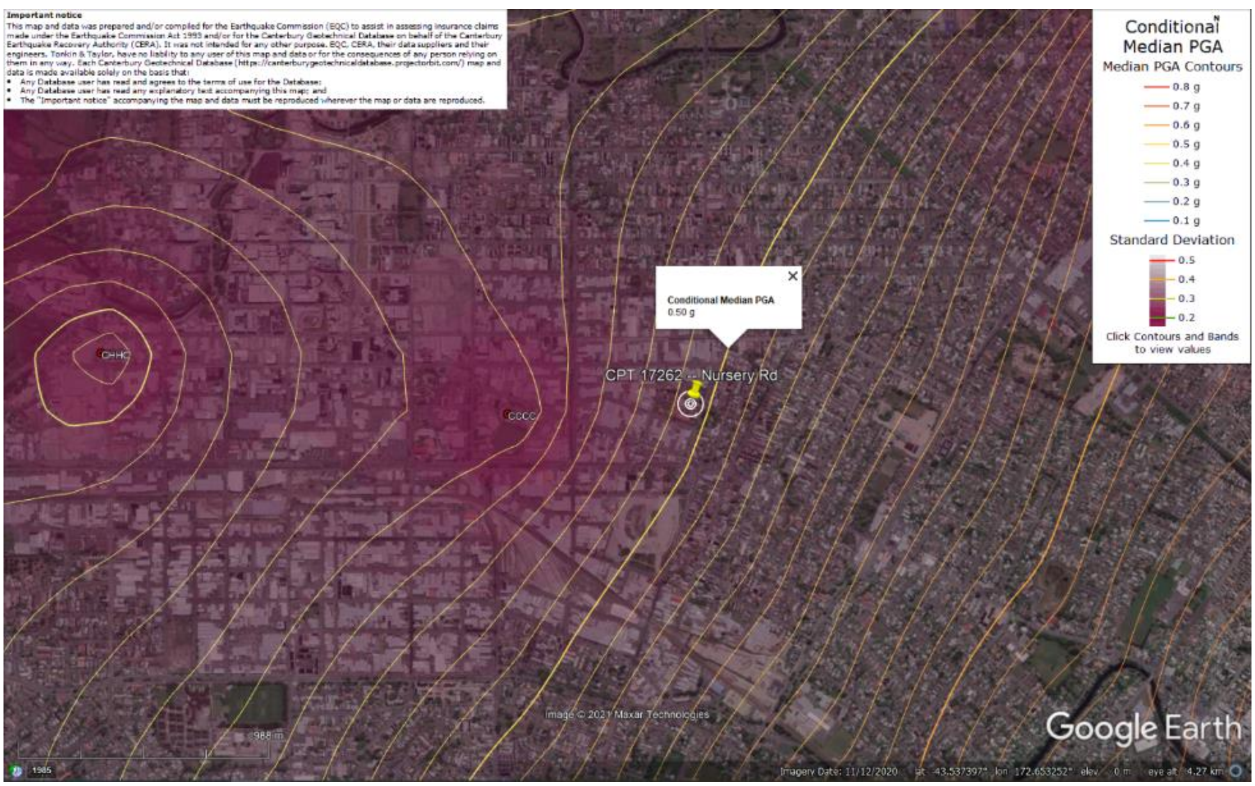

Figure 41: PGA for Feb-11 EQ (st. dev. = 0.275-0.325 ln units).

Figure 42: PGA for Jun-11 EQ (st. dev. = 0.375-0.400 ln units).

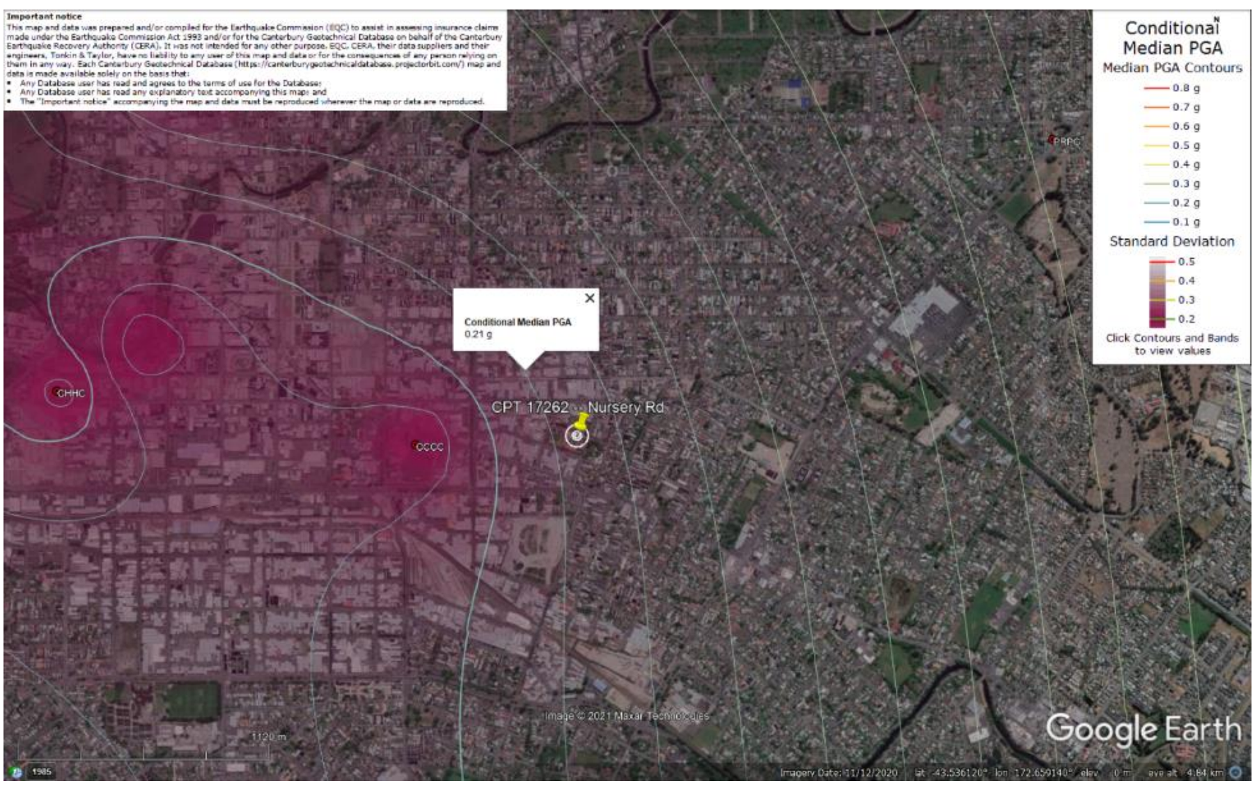

Figure 43: PGA for Dec-11 EQ (st. dev. = 0.300-0.350 ln units).

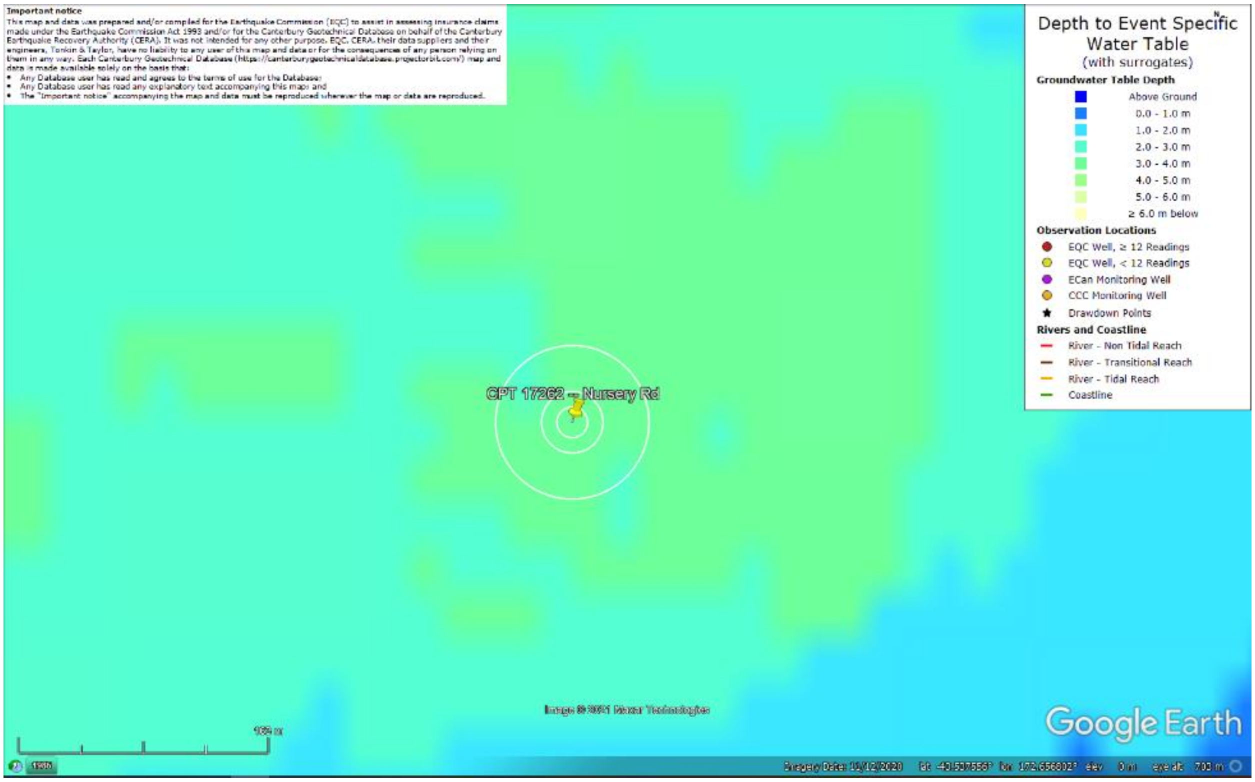

Figure 44: Depth to groundwater table for Sep-10 EQ.

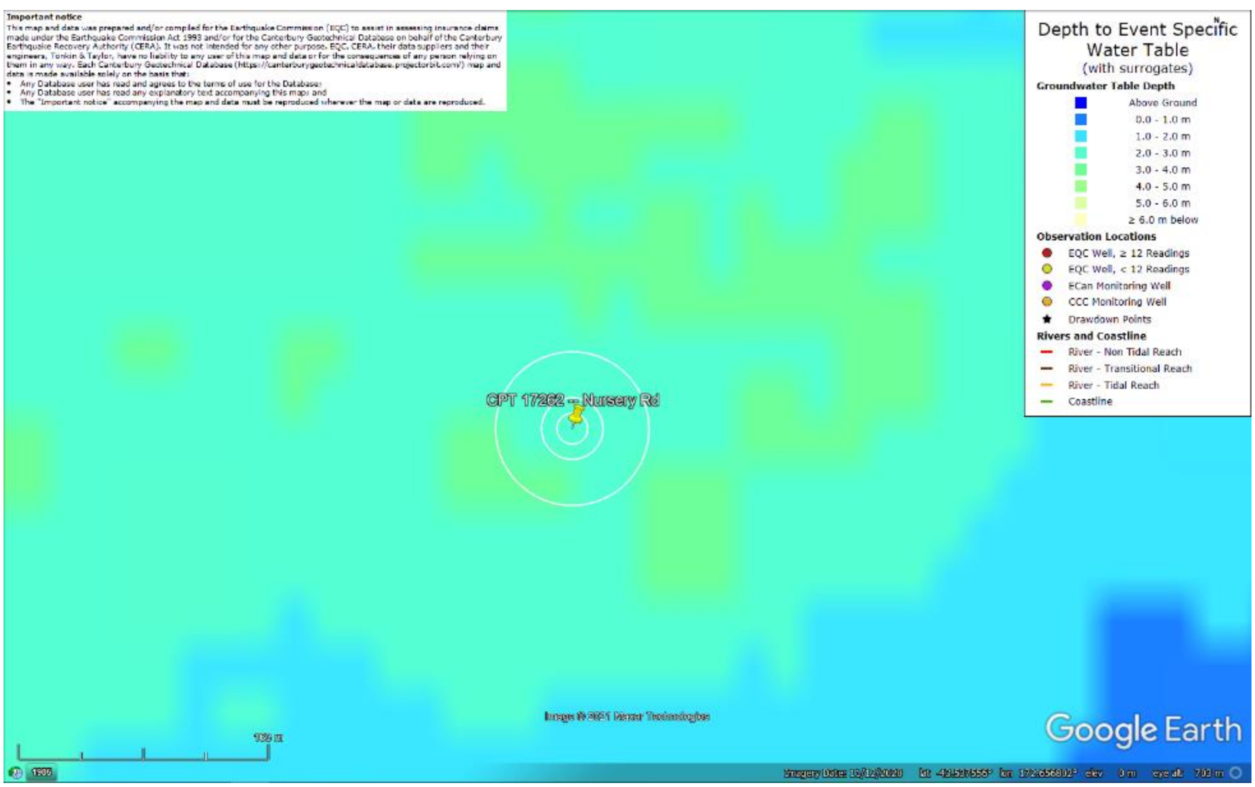

Figure 45: Depth to groundwater table for Feb-11 EQ.

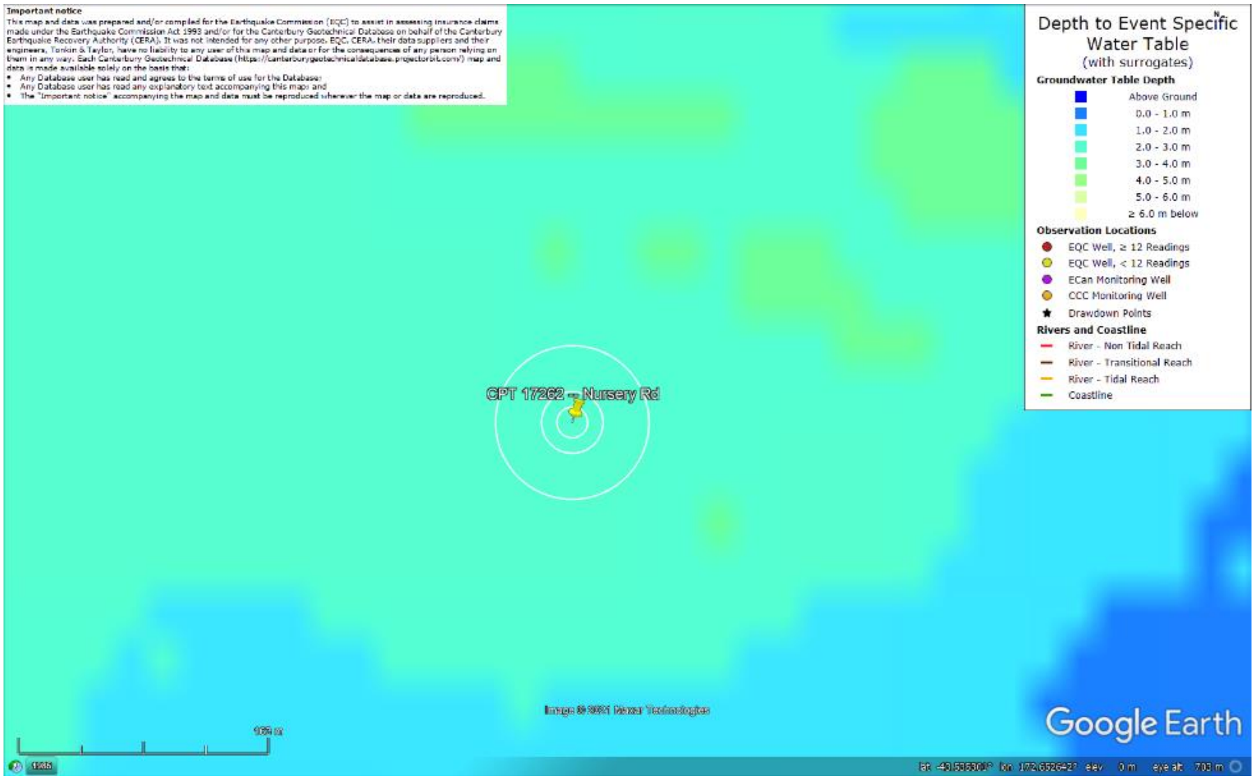

Figure 46: Depth to groundwater table for Jun-11 EQ.

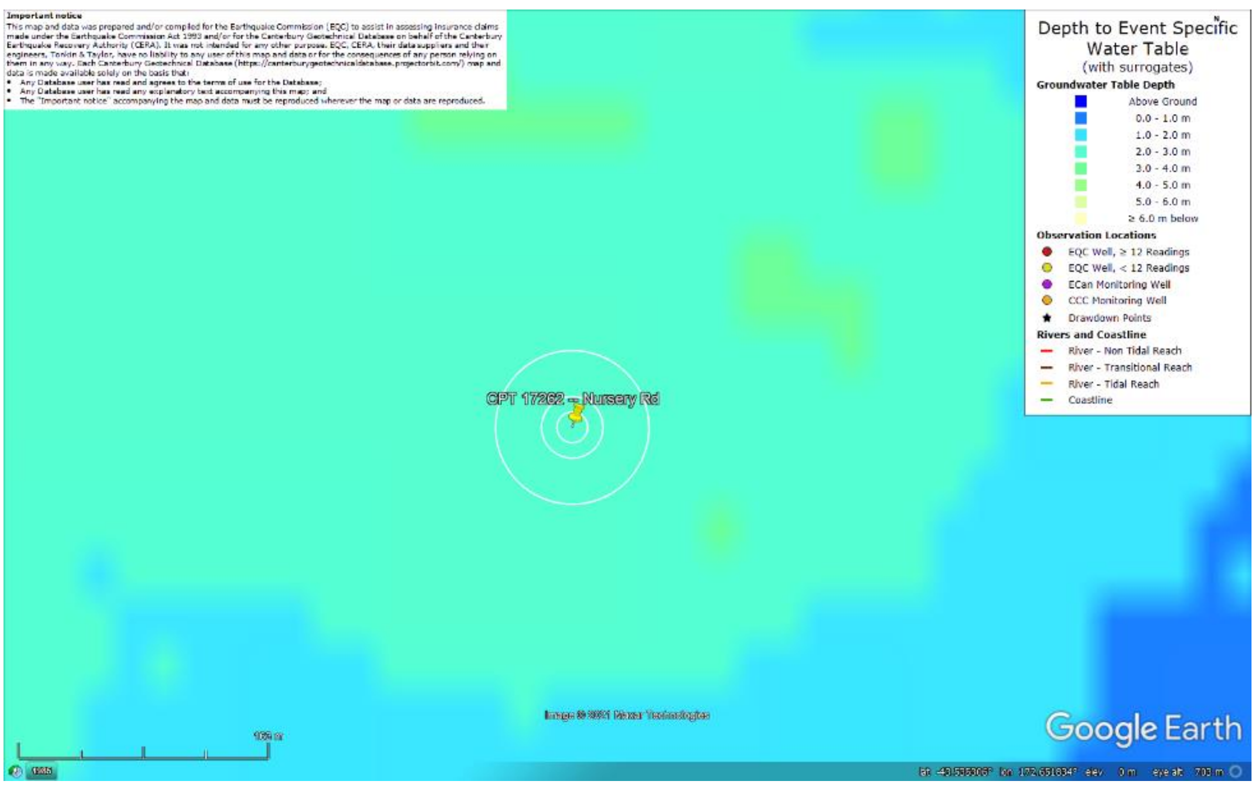

Figure 47: Depth to groundwater table for Dec-11 EQ.

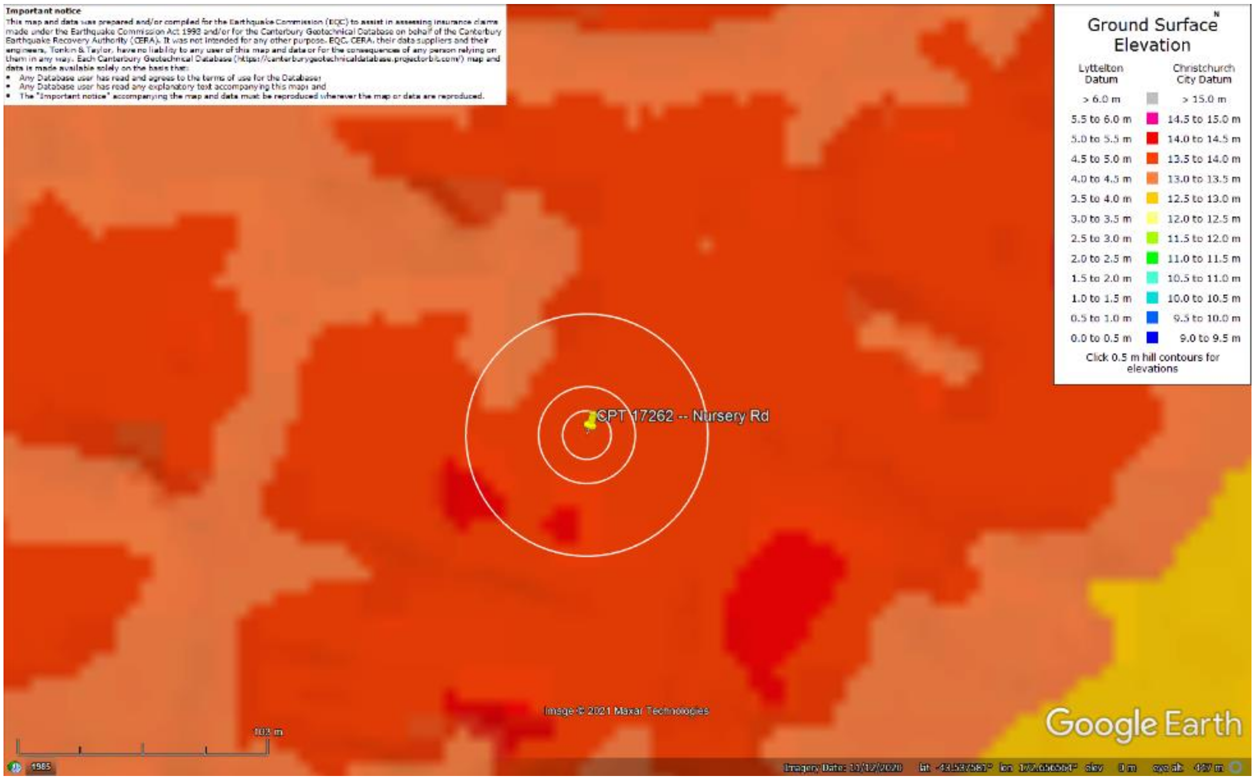

Figure 48: Ground surface elevation according to the Sep-10 LiDAR survey.

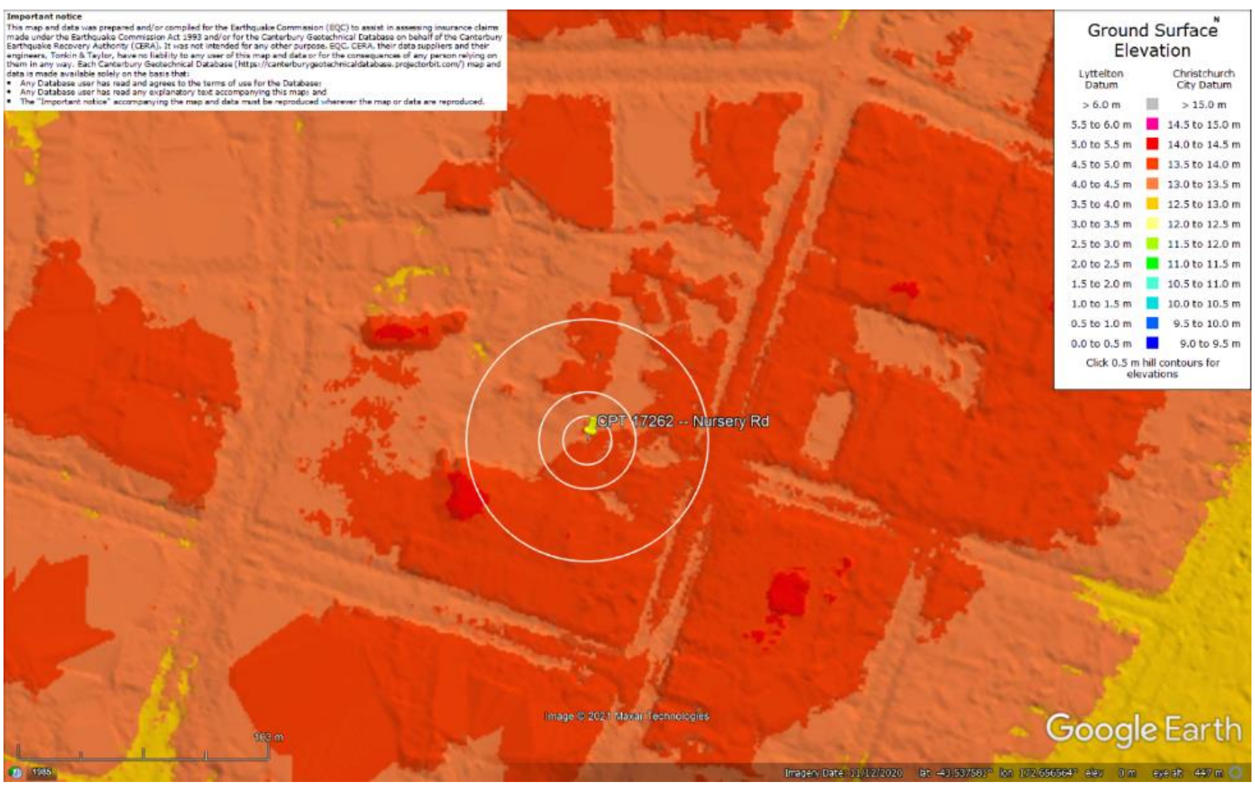

Figure 49: Ground surface elevation according to the Sep-11 LiDAR survey.

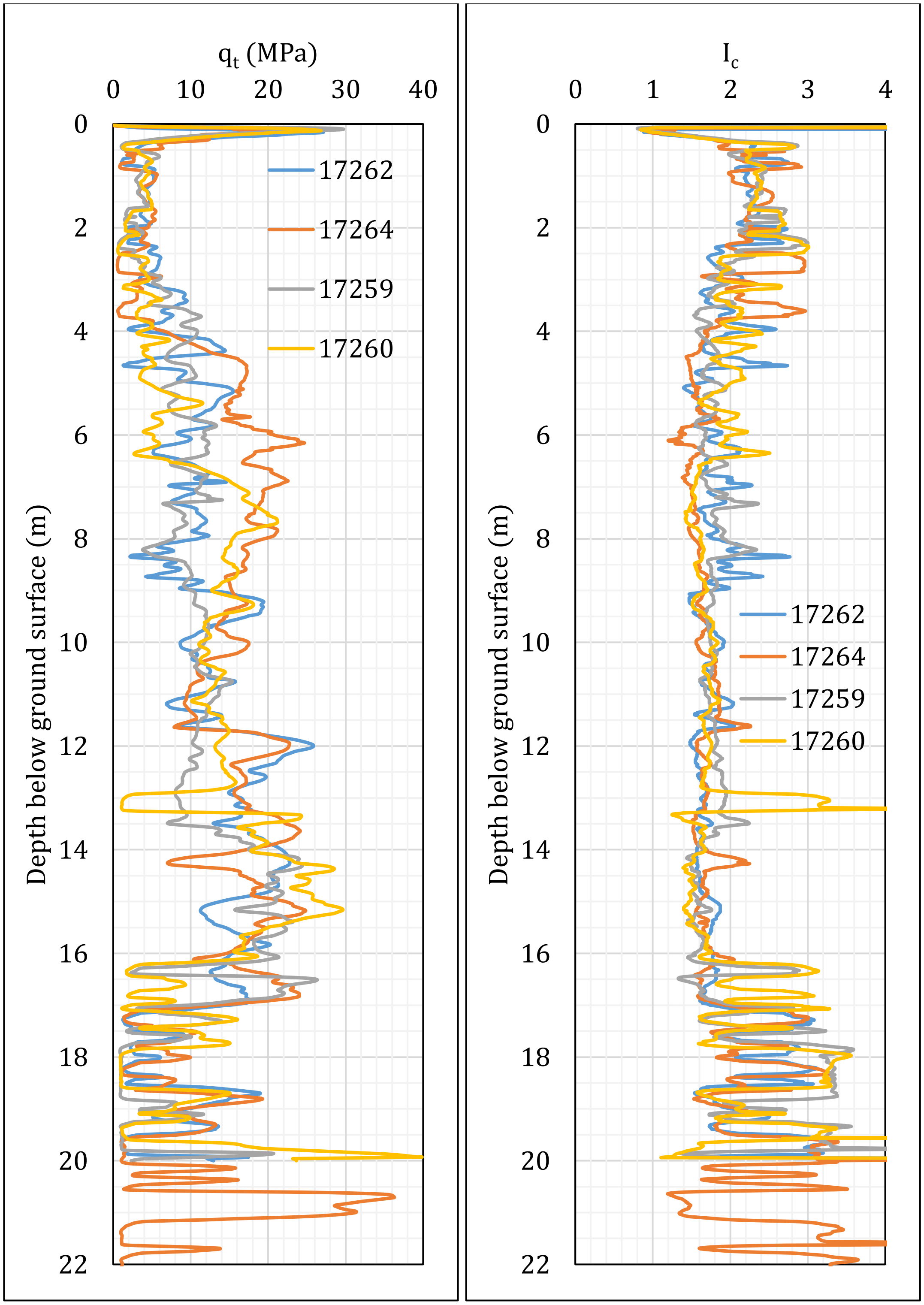

Figure 50: q_t and I_c profiles.

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.	Patch A (10-m buffer)	Patch A (20-m buffer)	Patch A (50-m buffer)
17262	✓	✓	✓
17264		✓	✓
17259			✓
17260			✓
1054			

Table 13: CPT-based results.

		CPT ID			
EQ Event	Parameter	17262	17264	17259	17260
Sep-10	S_{V1D} (mm)	37	24	45	42
	LSN	4	2	4	5
	LPI	0	0	0	0
	LPI_{ish}	0	0	0	0
	$D_{FS<1}$ (m)	17.49	17.82	8.15	16.45
Feb-11	S_{V1D} (mm)	195	122	225	199
	LSN	25	15	30	29
	LPI	16	8	21	19
	LPI_{ish}	11	7	0	14
	$D_{FS<1}$ (m)	2.71	2.87	2.71	2.71
Jun-11	S_{V1D} (mm)	67	46	83	89
	LSN	9	7	10	14
	LPI	1	1	2	3
	LPI_{ish}	0	0	0	0
	$D_{FS<1}$ (m)	4.68	3.03	8.04	3.54
Dec-11	S_{V1D} (mm)	15	12	17	24
	LSN	2	2	2	4
	LPI	0	0	0	0
	LPI_{ish}	0	0	0	0
	$D_{FS<1}$ (m)	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.

Note 6: Based on the borehole log (BH 1778, ~70 m to the NE from the center of the site, shown in Figure 1), the soil profile below the 0.65-m thick silty, ML, topsoil layer consists of (1) silt, ML, the Yaldhurst member of the Springston formation, to a depth of 2.5 m, (2) fine to medium sand, SW, the Yaldhurst member of the Springston formation, to a depth of 7.1 m, (3) sandy fine to coarse gravel, GW, the Yaldhurst member of the Springston formation, to a depth of 7.6 m, (4) fine to coarse sand, SW, the Yaldhurst member of the Springston formation, to a depth of 9.5 m, (5) fine to coarse sand, SW, of the Christchurch formation, to a depth of 18.2 m, (6) sandy silt, ML, of the Christchurch formation, to a depth of 18.5 m, and (7) fine to medium sand, SW, of the Christchurch formation, to a depth of 20 m. According to the 5-year piezometer readings (INST 1778, Figure 1), the average groundwater table is at a 2.9-m depth.

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 (m²)	A_E (m²)	V_E (m³)	S_{E,P_areal} (mm)	$S_{E,P\_localized}$ (mm)
Sep-10	252	0	0	0	0
Feb-11	252	245	11.6-18.3	60±15	60±15
Jun-11	235	106	1.1-4.2	10±5	25±15
Dec-11	252	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.

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	804	0	0	0	0
Feb-11	804	290	21.4-36.0	35±10	100±25
Jun-11	496	131	1.3-5.2	5±5	25±15
Dec-11	804	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.

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	1912	0	0	0	0
Feb-11	1912	1704	57.6-100	40±10	45±10
Jun-11	1351	635	11.4-30.4	15±5	35±15
Dec-11	1912	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.

Summary 2:

The best estimate of the localized ejecta-induced free-field ground settlement at the Nursery Rd site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 60±15 mm, 25±15 mm, and 0 mm, respectively.