Appendix A.33:

Cashmere High School – CPT 33732

Table 1: Site Description for Cashmere High School (CPT 33732).

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 ~120 m away from the unnamed stream located to the SE and ~260 m away from the Heathcote River located to the SE. The heights of the free-face features are ~2 m (the unnamed stream) and ~1.5 m (the Heathcote River).	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	Buildings cover 2, 11, and 15% of the 10-, 20-, and 50-m buffer, respectively. They are in the NE, NW, and SE quadrants of the 50-m buffer, the NE and SE quadrants of the 20-m buffer, and the NE quadrant of the 10-m buffer.	White Fill + Brown Outline
Sloping land?	No	No	No	Flat land, open + school area	NA
Step changes in the ground surface?	No	No	No	NA	NA
Retaining walls?	No	No	No	NA	NA
Vegetation?	Yes	Yes	Yes	Trees and bushes cover 4, 2, and 6% of the 10-, 20-, and 50-m buffer, respectively. They are in the NE quadrant of the 10-m and 20-m buffers and the NW and NE quadrants of the 50-m buffer.	White Fill + Green Outline
Manmade changes to the site between the LiDAR surveys?	No	No	Yes	Minor sidewalk construction in the NE quadrant of the 50-m buffer between Jan 2014 and Mar 2014.	NA
Other important factors?	No	No	No	NA	NA

Note: Buffer is the area within a circle of a specified radius with CPT investigations done at its center (172.623013°, -43.566259°).

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

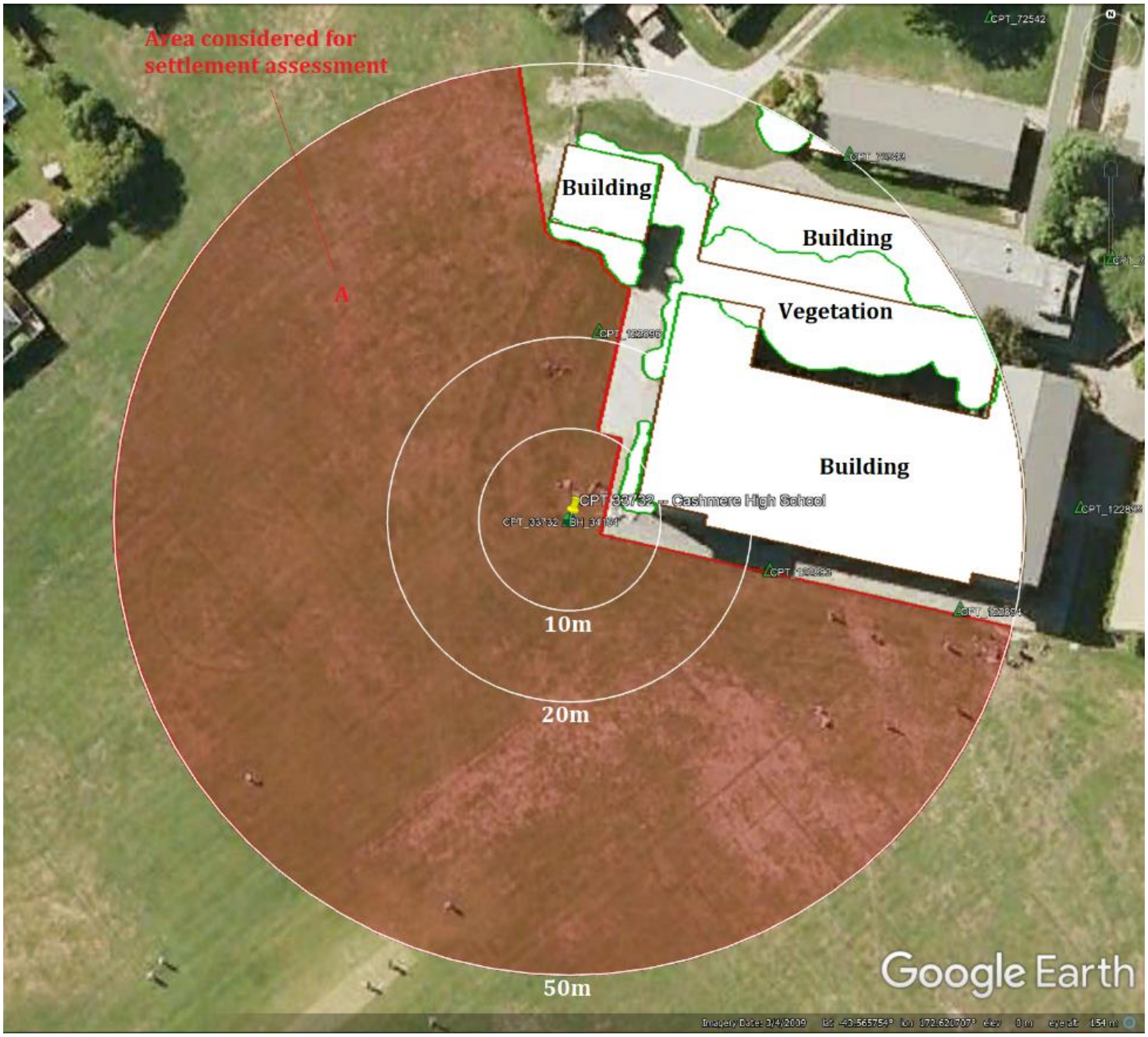

Figure 1: Site plan with areas where ejecta-induced settlement is considered.

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 that were considered in the patch selection were its proximity to a CPT, a property subjected to addition and/or demolition of a structure, and front yard/backyard alterations (e.g., ploughing, rubble, scrap), and aerial distribution of sediment ejecta. The LiDAR-based settlement analyses were not performed for the Sep-10, Jun-11, and Dec-11 earthquakes due to the evident absence of ejecta from the site. The LiDAR-based settlement analysis could not be conducted for the Feb-11 earthquake due to the unavailability of the Sep-10 LiDAR survey.

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	-25
Dec-11	NA	-65	+5
CES	NA	-14	-70
Any 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	NA	59	[NA,NA]
	20-m	NA		
	50-m	NA		
Post Dec 2011: Feb 2012 and Oct 2015	10-m	NA	70	[NA,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 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	±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 3a.

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

NA = Not available; ND = Not determined.

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

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; NA = Not available; 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)	16^{th} %ile	50^{th} %ile	84^{th} %ile	16^{th} %ile	50^{th} %ile	84^{th} %ile	16^{th} %ile	50^{th} %ile	84^{th} %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 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	0.24	3.5	NA	40±20	NA
Feb-11	6.2	0.41	3.5	NA	88±50	NA
Jun-11	6.2	0.19	3.5	ND	6±25	ND
Dec-11	6.1	0.16	3.5	NA	1±50	NA

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	0.24	3.5	NA	47±20	NA
Feb-11	6.2	0.41	3.5	NA	82±50	NA
Jun-11	6.2	0.19	3.5	ND	13±25	ND
Dec-11	6.1	0.16	3.5	NA	4±50	NA

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	0.24	3.5	NA	73±20	NA
Feb-11	6.2	0.41	3.5	NA	110±50	NA
Jun-11	6.2	0.19	3.5	ND	18±25	ND
Dec-11	6.1	0.16	3.5	NA	4±50	NA

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 3: 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	$A_{E,thick1}$ (m²)	$H_{E,thick1}$ (m)	$A_{E,thick2}$ (m²)	$H_{E,thick2}$ (m)	$A_{E,thin1}$ (m²)	$H_{E,thin1}$ (m)	$A_{E,thin2}$ (m²)	$H_{E,thin2}$ (m)	A_T (m²)
Sep-10	0	0	0	0	0	0	0	0	266
Feb-11	5.1	150-250	49.0	100-150	8.4	50-100	168	5-10	266
Jun-11	0	0	0	0	0	0	0	0	266
Dec-11	0	0	0	0	0	0	0	0	266

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.

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

EQ Event	$A_{E,thick1}$ (m²)	$H_{E,thick1}$ (m)	$A_{E,thick2}$ (m²)	$H_{E,thick2}$ (m)	$A_{E,thin1}$ (m²)	$H_{E,thin1}$ (m)	$A_{E,thin2}$ (m²)	$H_{E,thin2}$ (m)	A_T (m²)
Sep-10	0	0	0	0	0	0	0	0	975
Feb-11	114	150-250	82.1	100-200	113	50-100	442	5-10	975
Jun-11	0	0	0	0	0	0	0	0	975
Dec-11	0	0	0	0	0	0	0	0	975

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.

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

EQ Event	$A_{E,thick1}$ (m²)	$H_{E,thick1}$ (m)	$A_{E,thick2}$ (m²)	$H_{E,thick2}$ (m)	$A_{E,thin1}$ (m²)	$H_{E,thin1}$ (m)	$A_{E,thin2}$ (m²)	$H_{E,thin2}$ (m)	A_T (m²)
Sep-10	0	0	0	0	0	0	0	0	5616
Feb-11	977	150-250	650	100-200	961	50-100	1190	5-10	5616
Jun-11	0	0	0	0	0	0	0	0	5616
Dec-11	0	0	0	0	0	0	0	0	5616

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.

Note 3: The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photographs (Figures 8, 9, 23, 24, and 36) 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 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	0	0	0	0	0	0
Feb-11	26	51	34	62	47	86
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.

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	NA	0	0	NA	0	0	NA	0	0
Feb-11	NA	39±12	40±10	NA	48±14	50±15	NA	67±19	65±20
Jun-11	ND	0	0	ND	0	0	ND	0	0
Dec-11	NA	0	0	NA	0	0	NA	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; NA = Not available; ND = Not determined.

Note 4:

- $S_{E,final}$ for Patch A is based solely on $S_{E,P}$ for all earthquake events due to the evidence of absence of ejecta from the site for the Sep-10, Jun-11, and Dec-11 EQs and the absence of the Sep-10 LiDAR survey of the site for the Feb-11 EQ.
- The site is in the zone of severe to excessive LPI overprediction of liquefaction severity for the Sep-10 and Feb-11 EQ (Maurer et al. 2014[3]). The LDAT property inspection reports are available for some nearby properties (outside the 50-m buffer); however, no ground photographs or ejecta measurements were taken.

Summary 1:

The best estimate of the ejecta-induced free-field ground settlement at the Cashmere High School site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 65±20 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 free-face features.

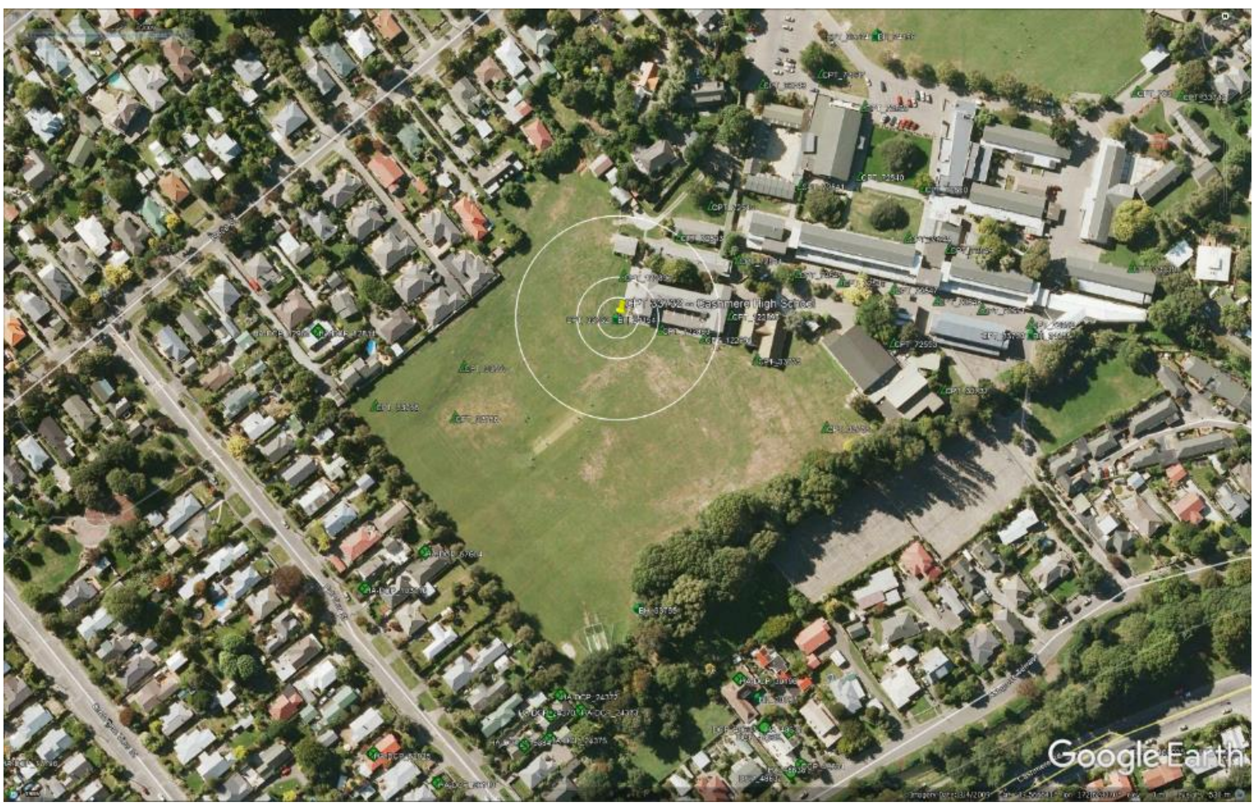

Figure 4: Position of the site relative to nearby buildings, vegetation, and CPTs.

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

Figure 6: Satellite image of the site taken in Feb 2008.

Figure 7: Satellite image of the site taken in Mar 2009.

Figure 8: Satellite image of the site taken on Sep 3, 2010.

Figure 9: Satellite image of the site taken on Sep 5, 2010.

Figure 10: Satellite image of the site taken on Feb 15, 2011.

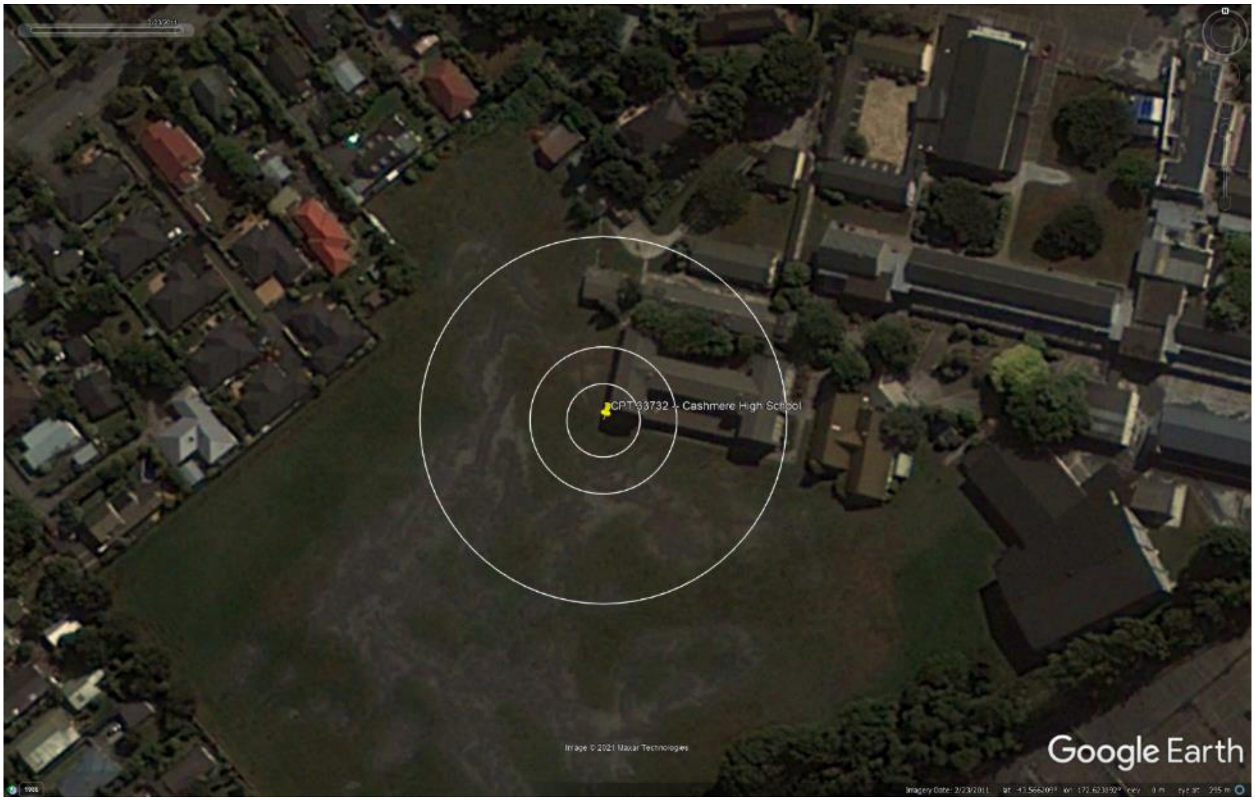

Figure 11: Satellite image of the site taken on Feb 23, 2011.

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 Jan 2014.

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

Figure 17: Satellite image of the site taken in Sep 2014.

Figure 18: Satellite image of the site taken in Jan 2015.

Figure 19: Satellite image of the site taken in Nov 2015.

Figure 20: Aerial photograph of the site taken on Sep 4, 2010.

Figure 21: Aerial photograph of the site taken on Feb 24, 2011.

Figure 22: Aerial photograph of the site taken on June 14-15, 2011.

Figure 23: Aerial photograph of the site taken on June 16, 2011.

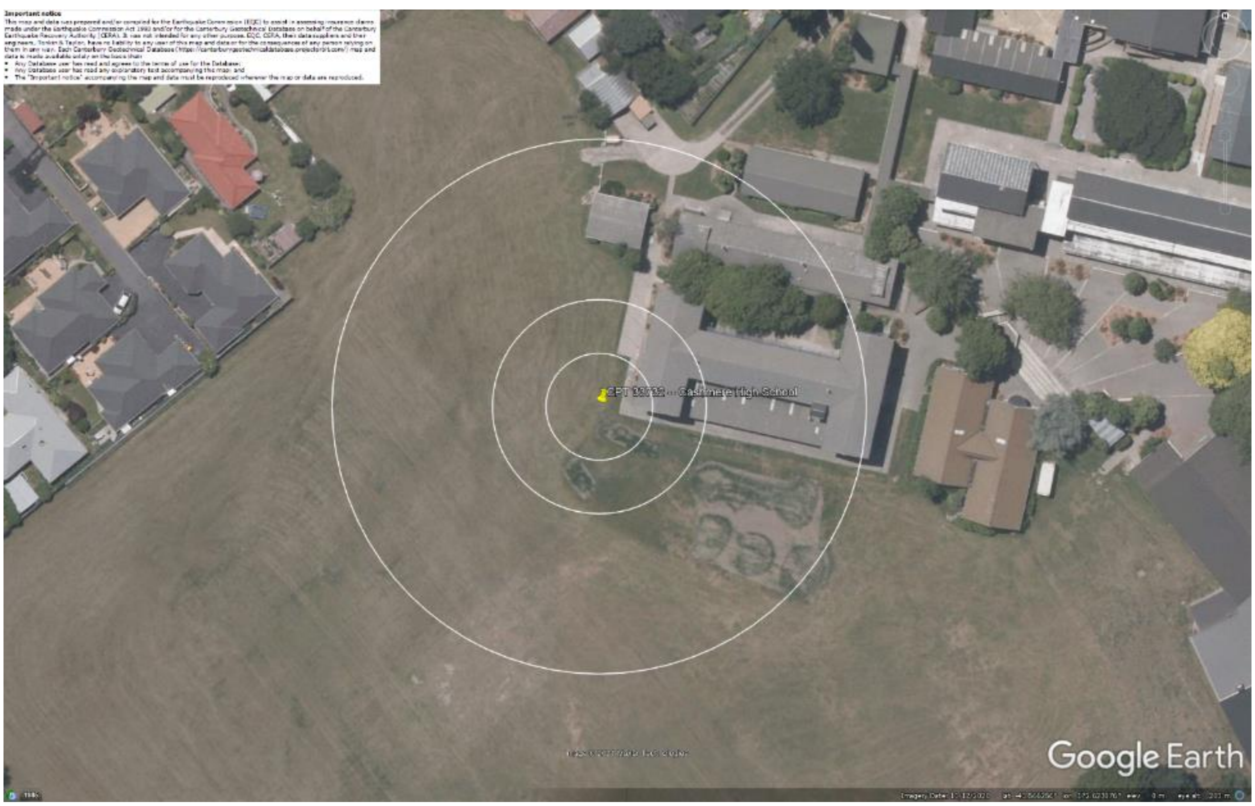

Figure 24: Aerial photograph of the site taken on Dec 24, 2011.

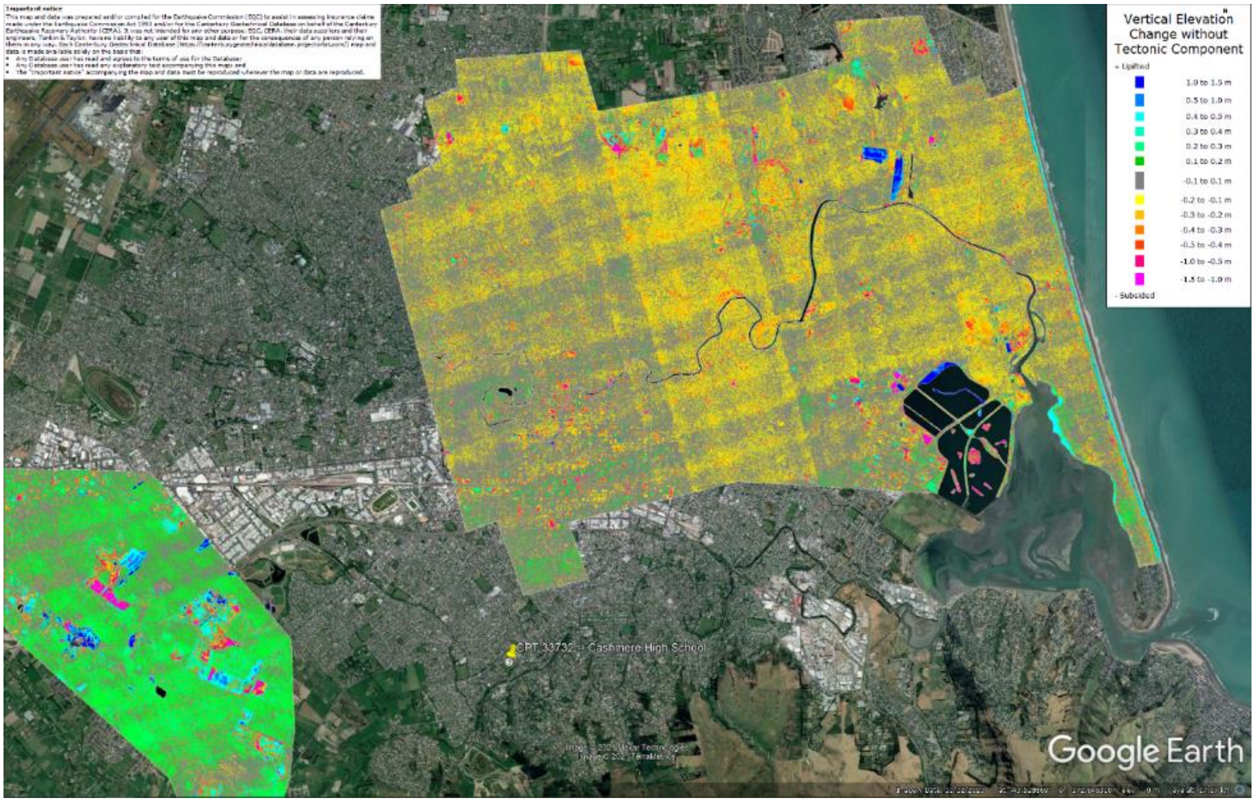

Figure 25: Vertical Ground Movements (Surface – Tectonic) are not available for Sep 2010 Earthquake.

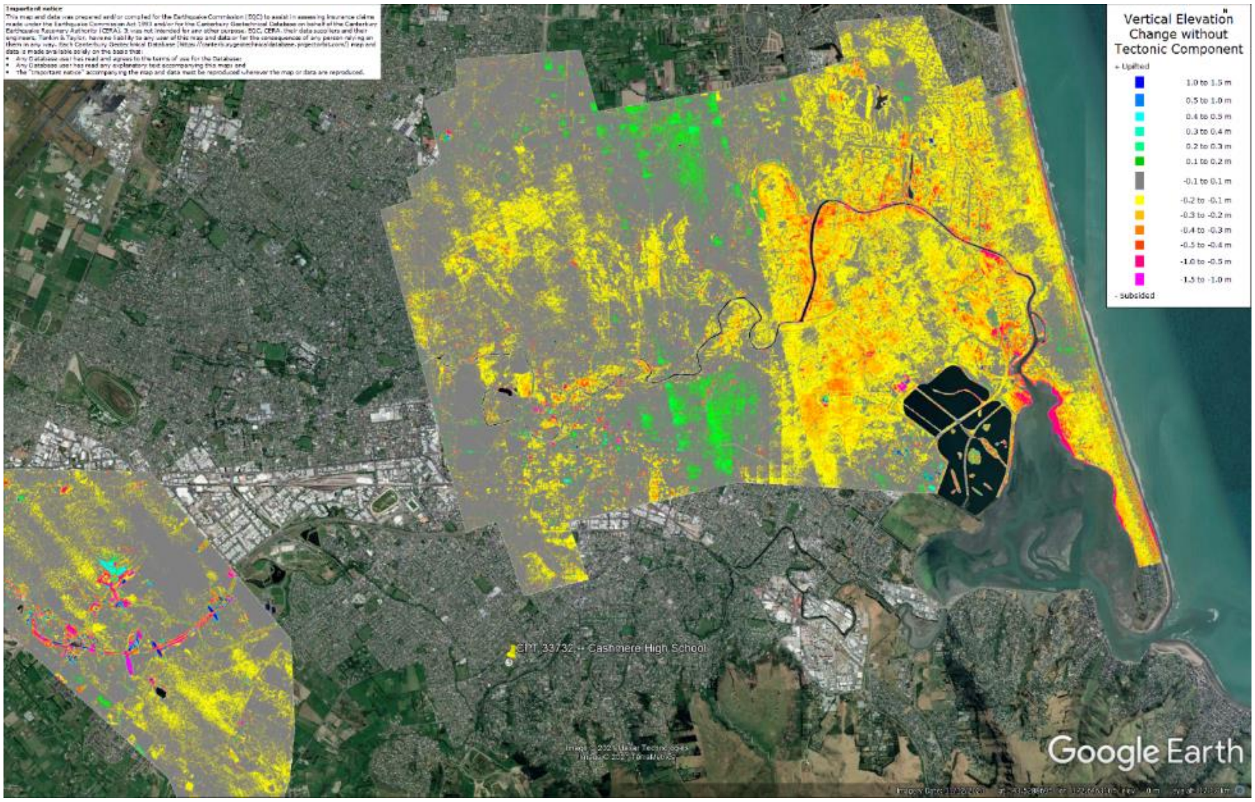

Figure 26: Vertical Ground Movements (Surface – Tectonic) are not available for Feb 2011 Earthquake.

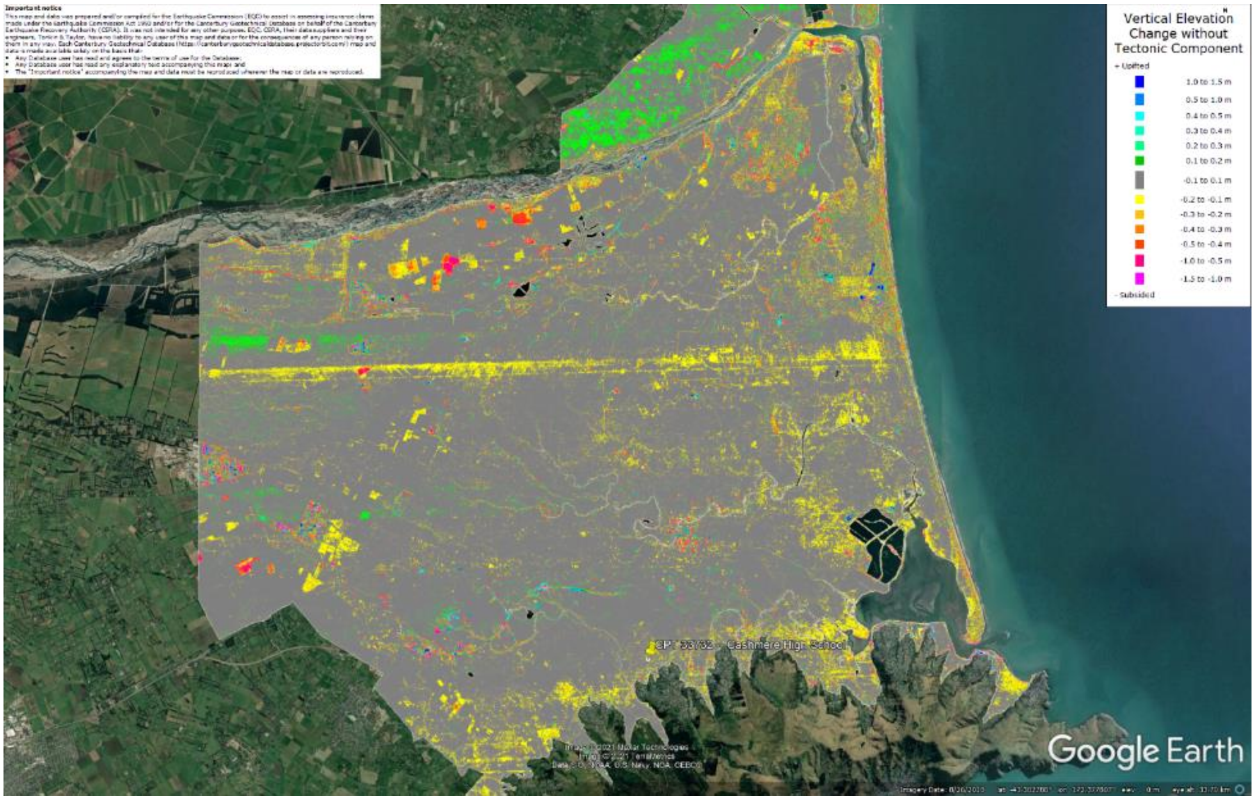

Figure 27: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

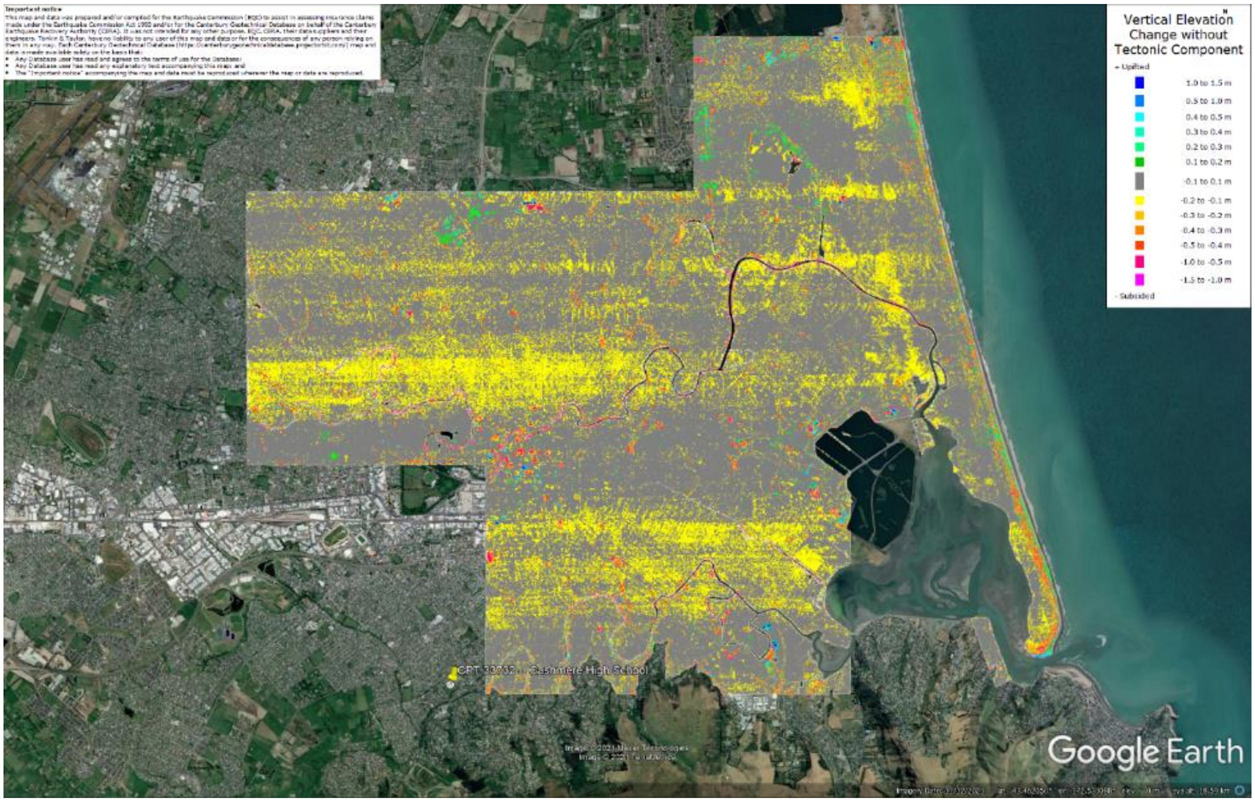

Figure 28: Vertical Ground Movements (Surface – Tectonic) are not available for Dec 2011 Earthquake.

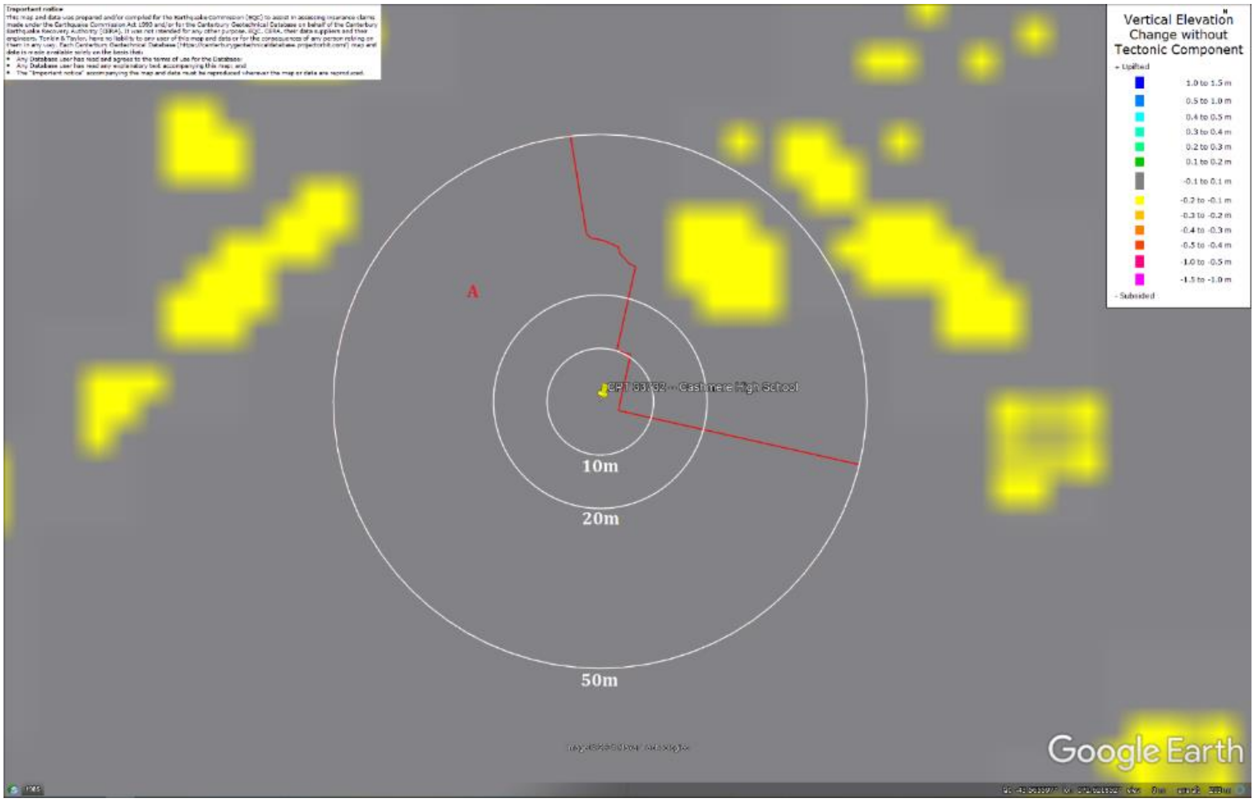

Figure 29: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

Figure 30: No lateral spreading for Canterbury Earthquake Sequence.

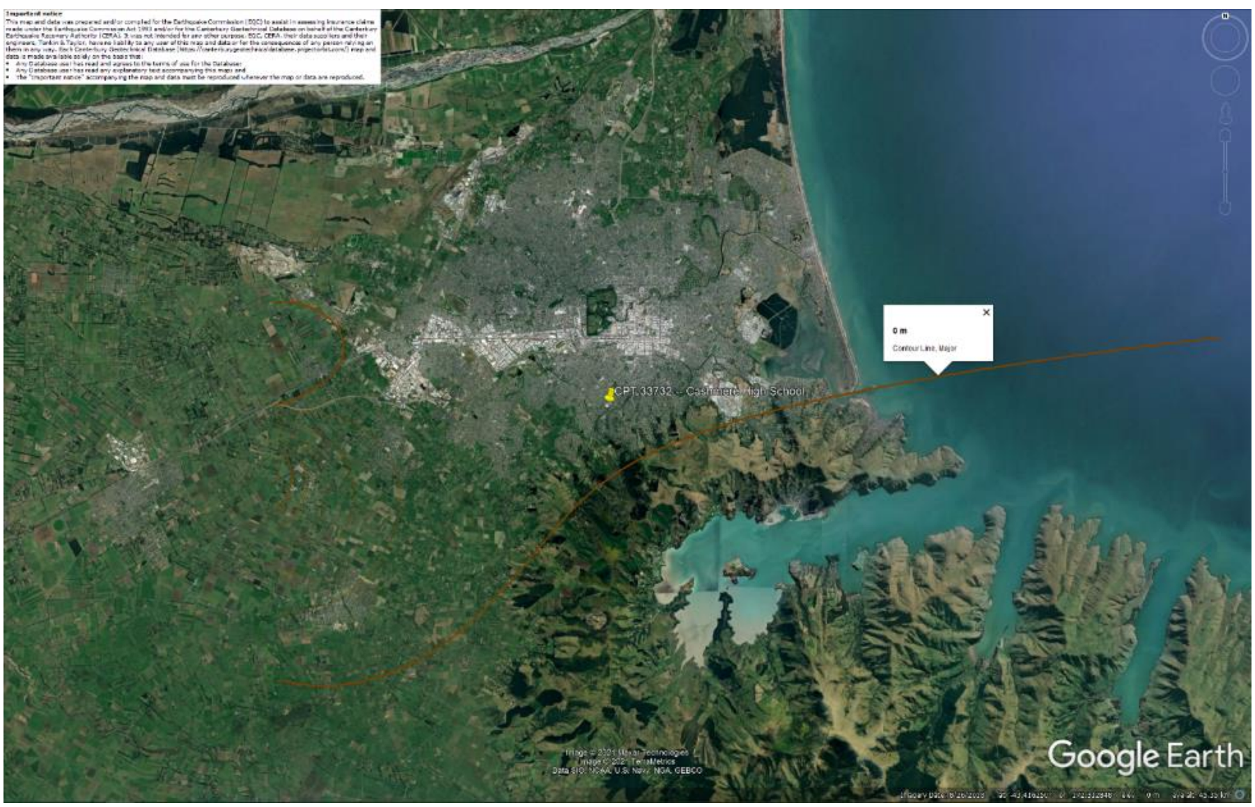

Figure 31: Vertical tectonic movements for Sep 2010 Earthquake.

Figure 32: Vertical tectonic movements for Feb 2011 Earthquake.

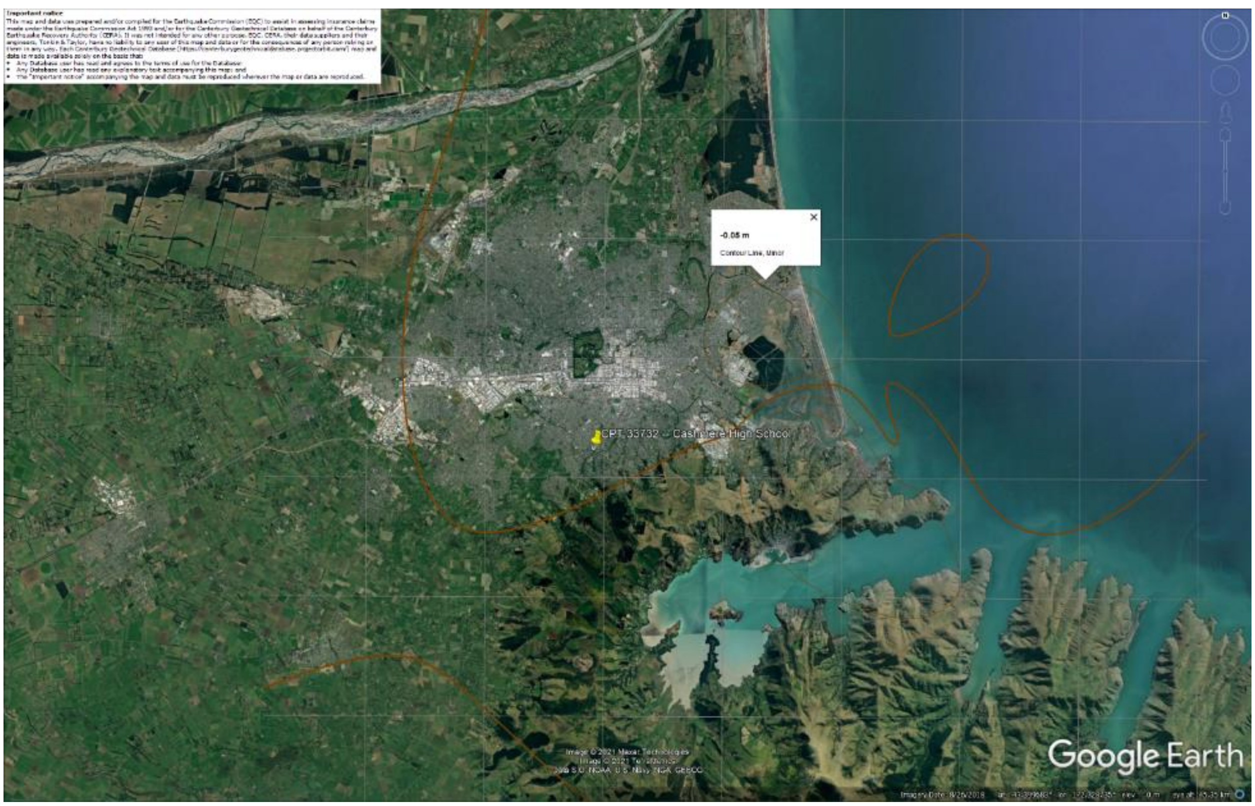

Figure 33: Vertical tectonic movements for June 2011 Earthquake.

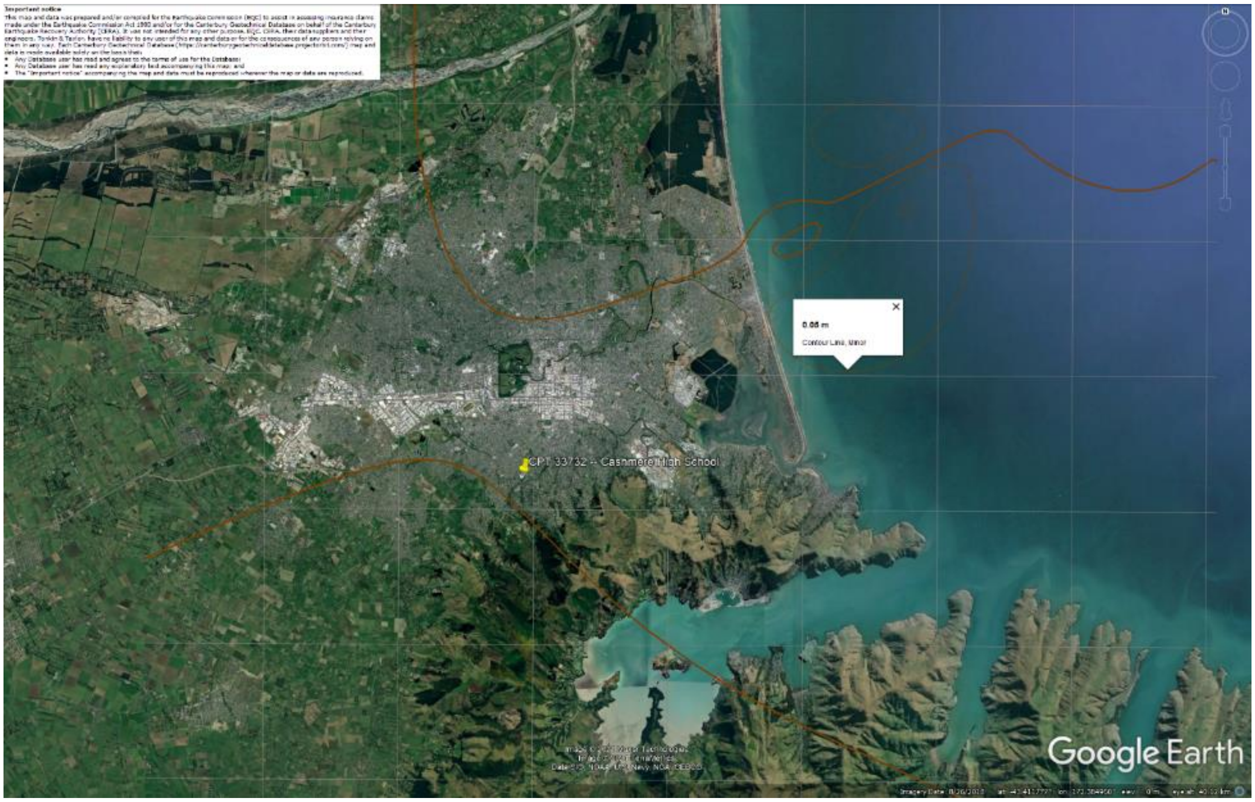

Figure 34: Vertical tectonic movements for Dec 2011 Earthquake.

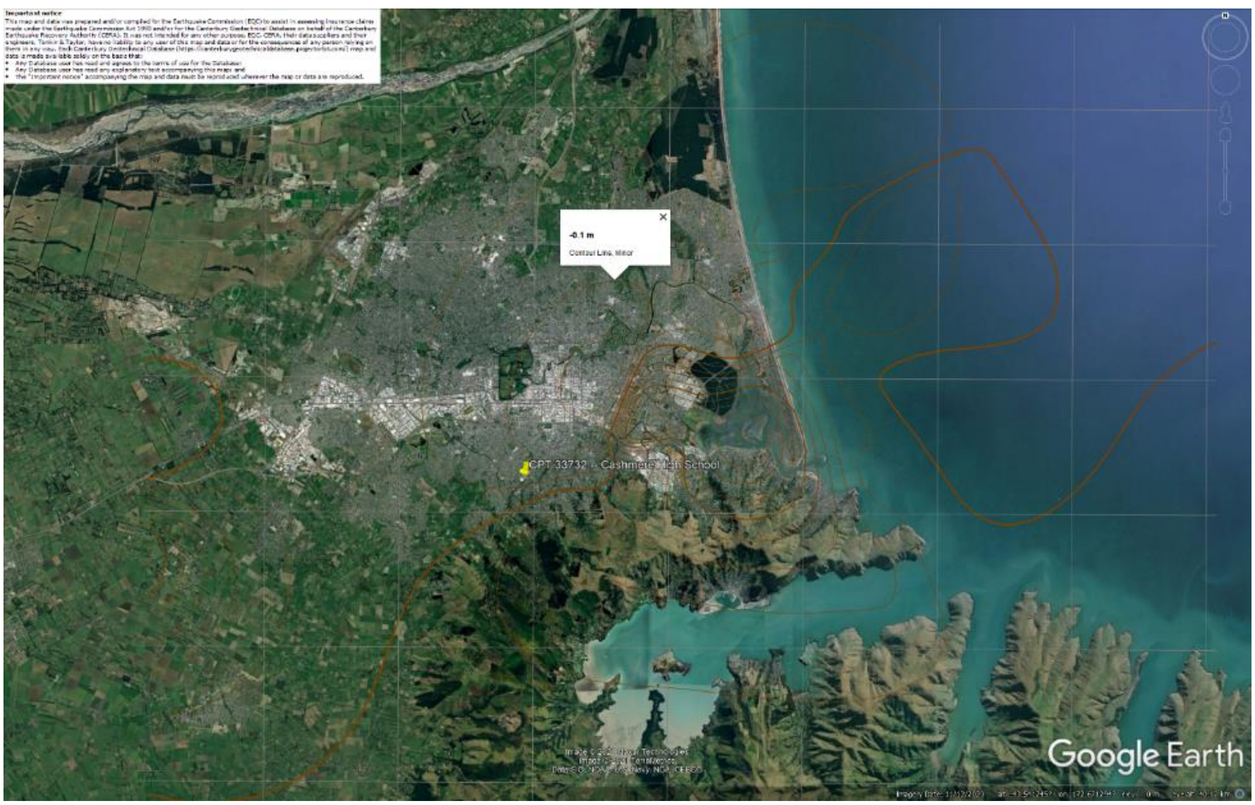

Figure 35: Vertical tectonic movements for Canterbury Earthquake Sequence.

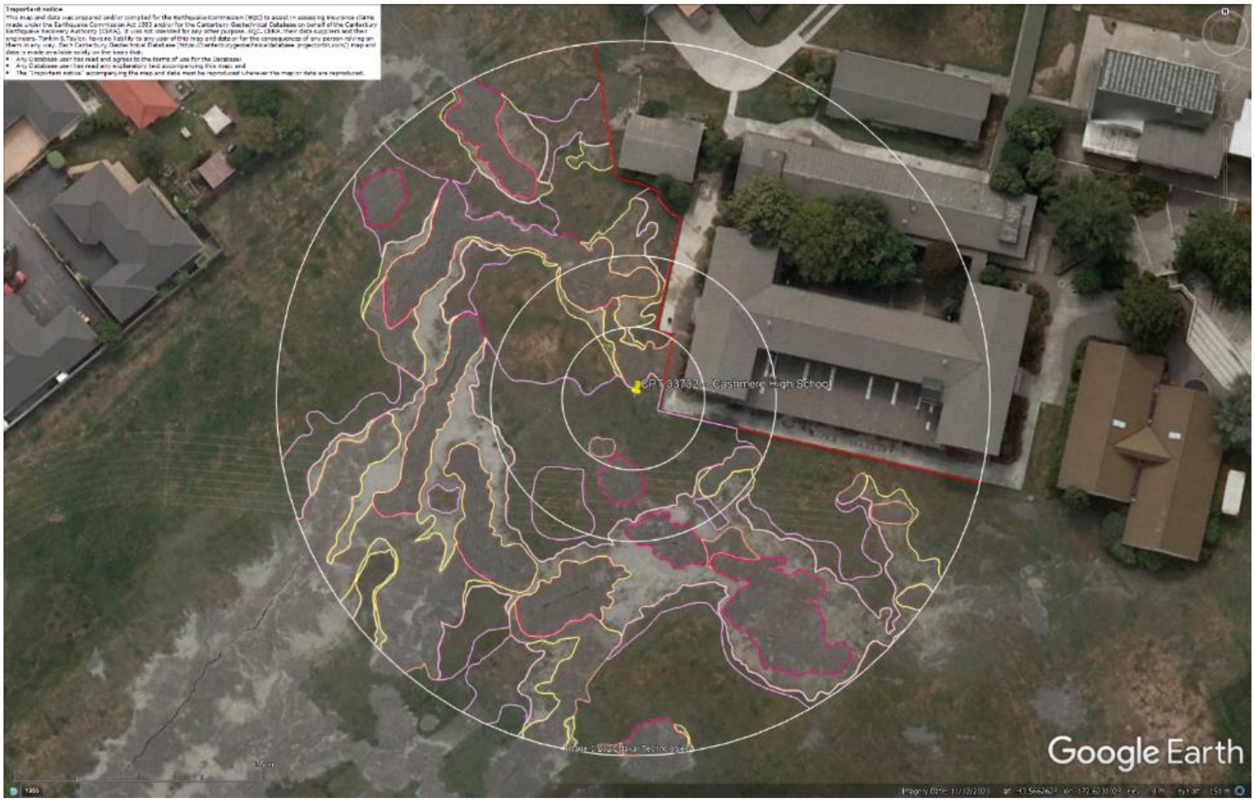

Figure 36: Aerial photograph showing the ejecta outline at the site for Feb-11 EQ.

Figure 37: PGA for Sep-10 EQ (st. dev. <0.175 ln units).

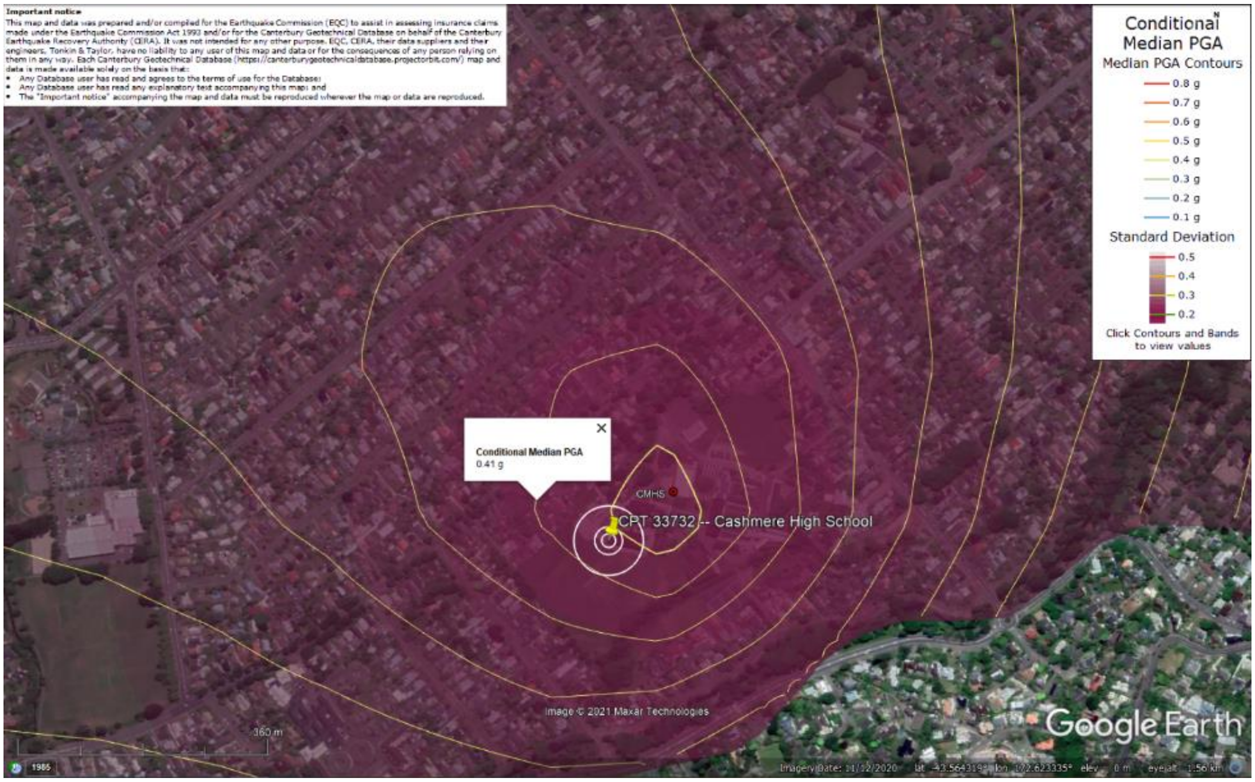

Figure 38: PGA for Feb-11 EQ (st. dev. = 0.200-0.225 ln units).

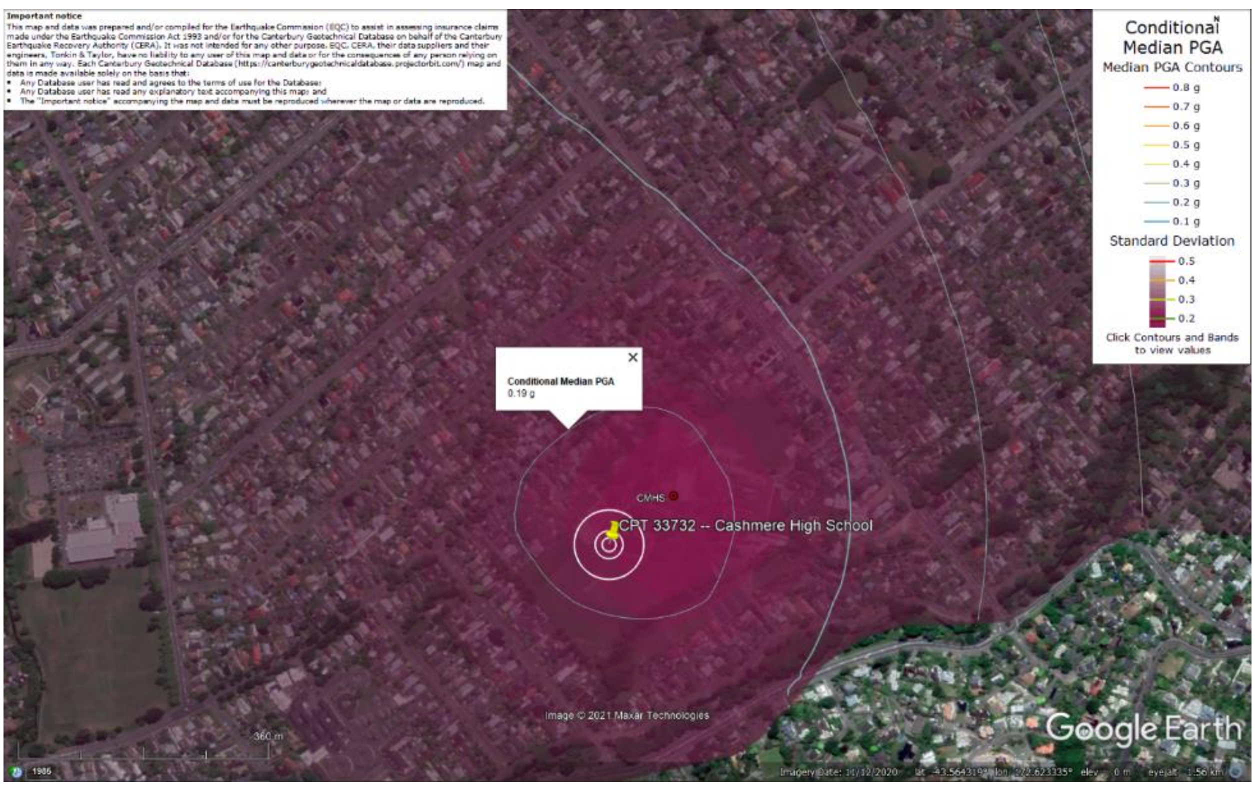

Figure 39: PGA for Jun-11 EQ (st. dev. <0.175-0.200 ln units).

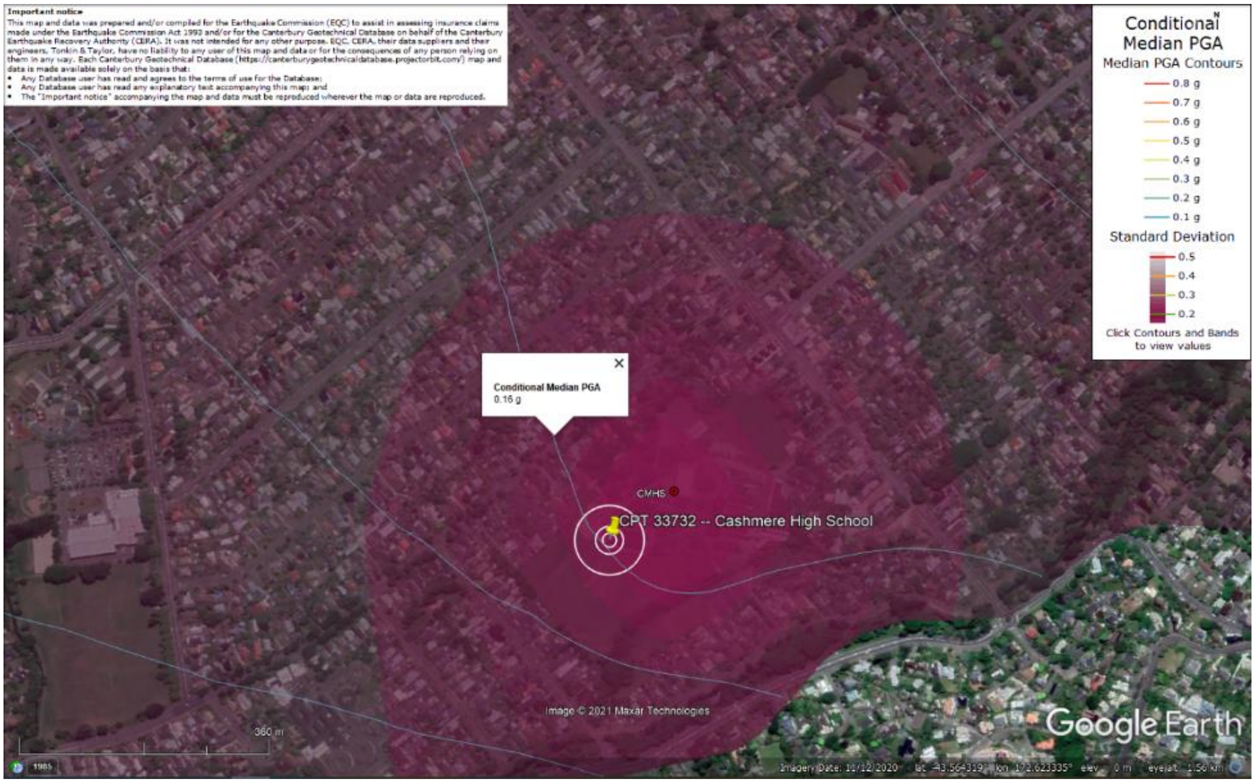

Figure 40: PGA for Dec-11 EQ (st. dev. <0.175-0.200 ln units).

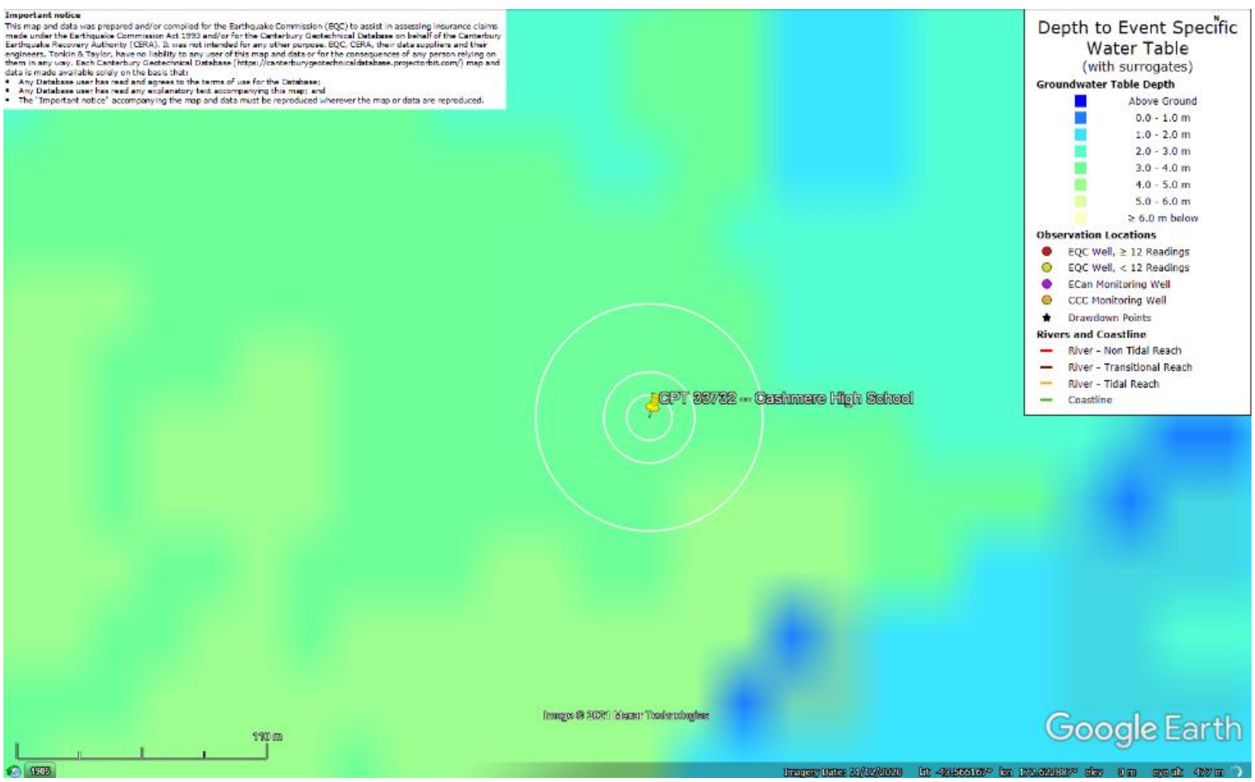

Figure 41: Depth to groundwater table for Sep-10 EQ.

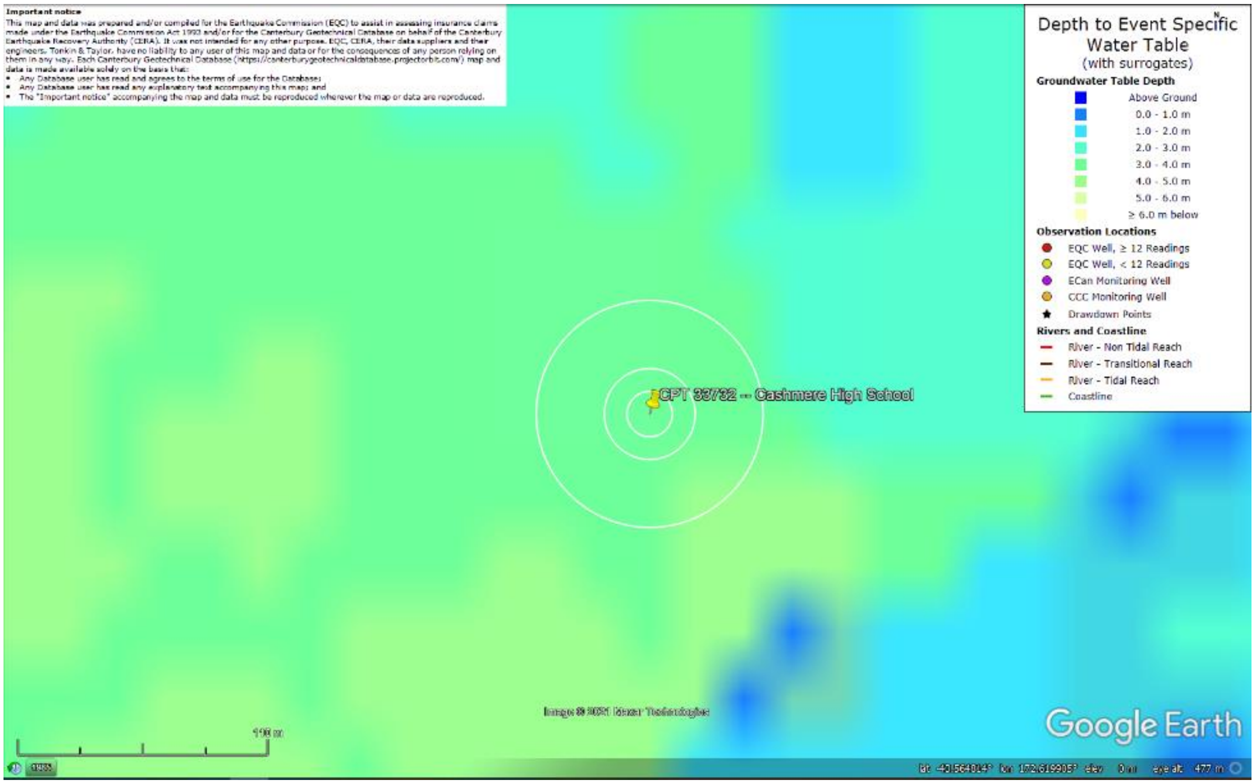

Figure 42: Depth to groundwater table for Feb-11 EQ.

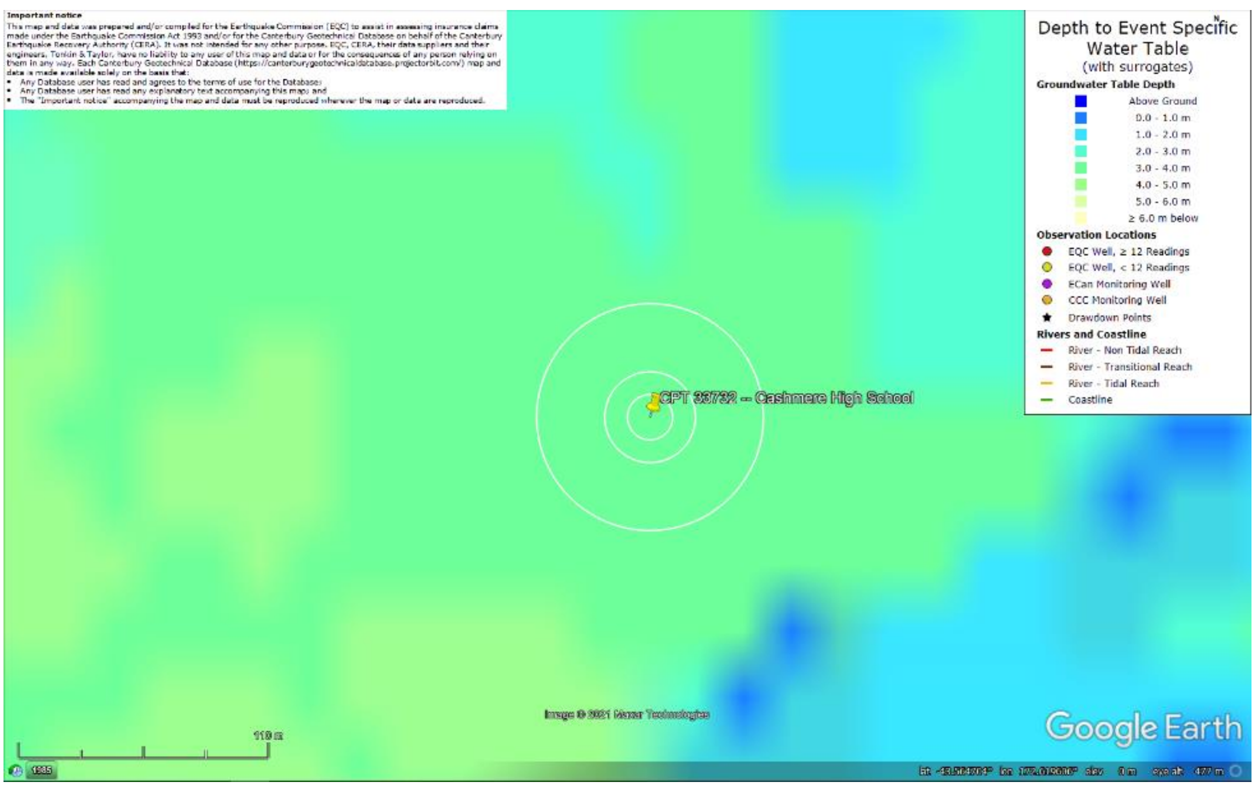

Figure 43: Depth to groundwater table for Jun-11 EQ.

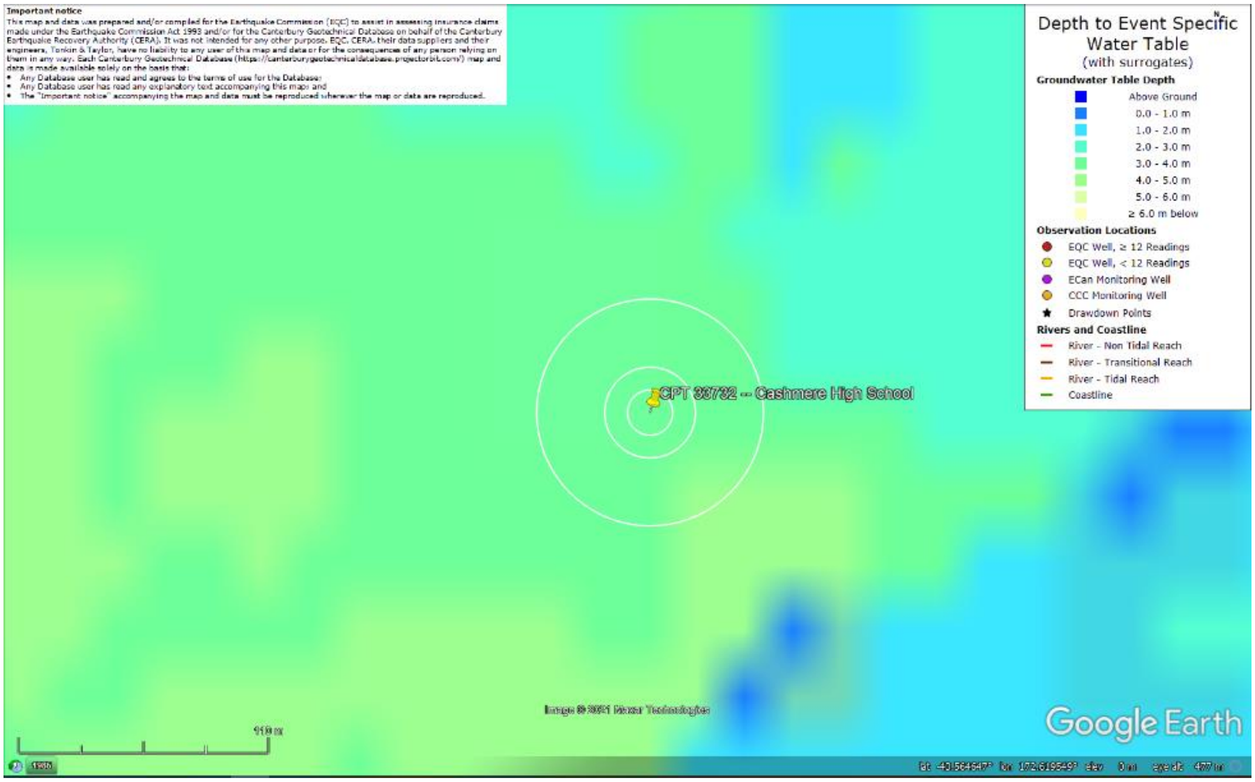

Figure 44: Depth to groundwater table for Dec-11 EQ.

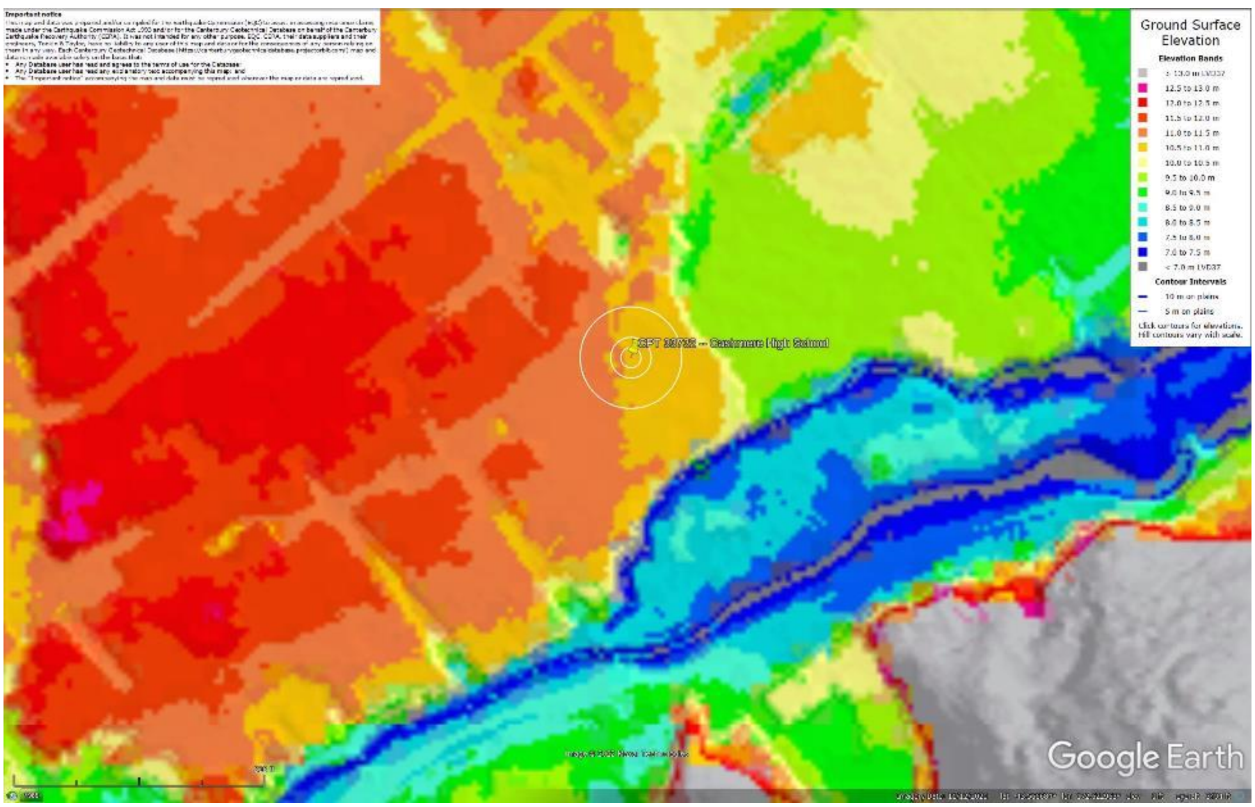

Figure 45: Ground surface elevation (Sep-11 LiDAR survey).

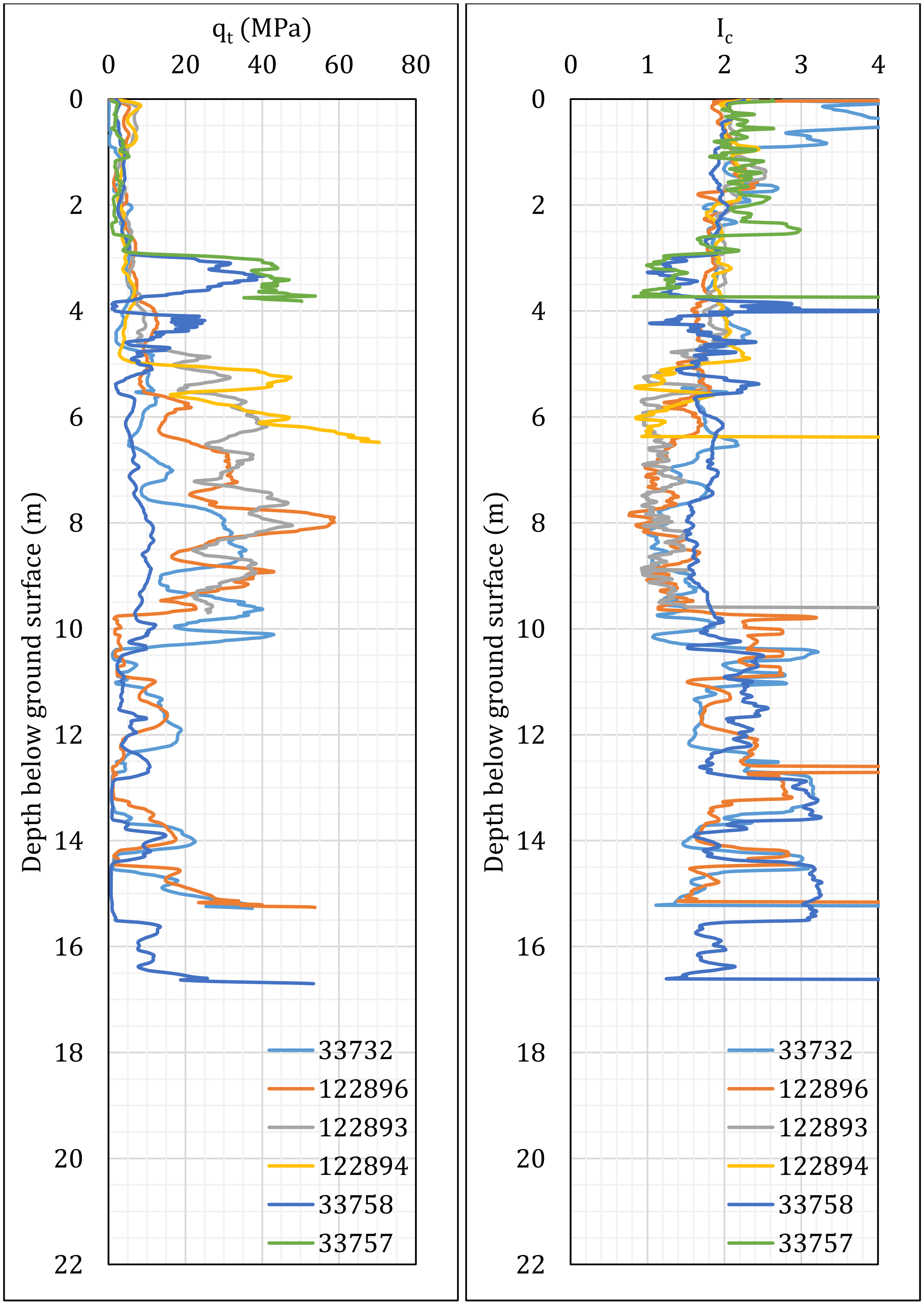

Figure 46: q_t and I_c profiles.

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)
33732	✓	✓	✓
122896 (133010)		✓	✓
122893 (133007)			✓
122894 (133008)			
33758			✓
33757			

Notes: Only CPT 33732 has pore water pressure measurements; The borehole log indicates that a thick layer of gravel is present below the ~15-m depth.

Table 13: CPT-based results.

EQ Event	Parameter	CPT ID 33732	122896	122893	33758	$\Delta_{9.7m-15.3m}$
Sep-10	S_{V1D} (mm)	40	53	0	150	50
	LSN	5	5	0	17	4
	LPI	1	2	0	6	2
	LPI_{ish}	0	0	0	0	--
	$D_{FS<1}$ (m)	4.34	10.11	undet.	5.32	--
Feb-11	S_{V1D} (mm)	88	76	2	215	59
	LSN	13	9	1	25	5
	LPI	6	5	0	19	4
	LPI_{ish}	2	0	0	5	--
	$D_{FS<1}$ (m)	3.51	5.04	undet.	4.82	--
Jun-11	S_{V1D} (mm)	6	19	0	29	17
	LSN	1	2	0	3	2
	LPI	0	0	0	0	0
	LPI_{ish}	0	0	0	0	--
	$D_{FS<1}$ (m)	undet.	undet.	undet.	undet.	--
Dec-11	S_{V1D} (mm)	1	6	0	7	1
	LSN	0	1	0	1	1
	LPI	0	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; $\Delta_{9.7m-15.3m}$ indicates the S_{V1D}, LSN, and LPI values added to CPT 122893 based on CPT 122896; The volumetric settlement below ~15-16 m is assumed to be negligible due to the layer of gravel with a high cone tip resistance.

Note 6: Based on the borehole log (BH 34154, Figure 1), the groundwater table is at a depth of 2.8 m below the ground surface. The soil profile consists of (1) silt, ML, to a depth of 0.55 m, (2) silty sand, SM, to a depth of 1.5 m, (3) sandy silt, ML, to a depth of 3.0 m, (4) fine to medium sand, SP, to a depth of 3.45 m, (5) sandy silt, ML, to a depth of 4.5 m, (6) silty fine to medium sand, SM, to a depth of 5.75 m, (7) fine to coarse sand, SP, to a depth of 9.0 m, (8) sandy fine to coarse gravel, GW, to a depth of 10.5 m, (9) sandy silt, ML, to a depth of 10.65 m, (10), silty fine to coarse sand, SP, to a depth of 13.1 m, (11) silt, ML, to a depth of 13.5, (12) silty fine to coarse sand, SM, to a depth of 14.2 m, (13) sandy silt, ML, to a depth of 14.4 m, (14) silty fine sand, SM, to a depth of 15.15 m, (15) sandy fine to medium gravel, GW, to a depth of 19.65 m. All soil layers are the Yaldhurst members of the Springston formation.

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	266	0	0	0	0
Feb-11	266	231	6.9-13.6	40±10	45±15
Jun-11	266	0	0	0	0
Dec-11	266	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	975	0	0	0	0
Feb-11	975	750	33.1-60.5	50±15	65±20
Jun-11	975	0	0	0	0
Dec-11	975	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	5616	0	0	0	0
Feb-11	5616	3778	266-482	65±20	100±30
Jun-11	5616	0	0	0	0
Dec-11	5616	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.

<u>Summary 2:</u>

The best estimate of the <u>localized</u> ejecta-induced free-field ground settlement at the Cashmere High School site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 100±30 mm, 0 mm, and 0 mm, respectively.