Appendix A.55:

Keers Rd – CPT 28986

Table 1: Site Description for Keers Rd (CC NO LIQ 43 – CPT 28986).

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	Yes	Yes	The unnamed stream (the free-face height is ~ 0.5-1 m) runs through the E portion of the 20-m buffer and the NW, SW, and SE quadrants of the 50-m buffer. The center of the site is ~770 m to the SE from the Avon River (the free-face height is ~ 2 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?	No	Yes	Yes	Building coverage of the 20-m, and 50-m buffers is 12% and 10%, respectively.	NA
Sloping land?	No	No	No	Flat land, 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 35% of the 20-m buffer and 17% of the 50-m buffer. They are in all quadrants of the buffers.	NA
Anthropogenic changes to the site between the LiDAR surveys?	ND	ND	ND	Not evaluated because LiDAR surveys were not used to estimate the ejecta-induced settlement at the site. Ejecta were evidently absent from the site.	NA
Other important factors?	No	No	Yes	Moderate-motor-vehicle-volume road (Keers Rd) covers 5% of the 50-m buffer; it occupies the NE and SE quadrants of the 50-m buffer.	NA

Note: Buffer is the area within a circle of a specified radius with CPT investigations done at its center (172.680817°, -43.526519°).

[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.

Note 1: The LiDAR surveys were not considered for the ejecta-induced settlement assessment because the site had no ejecta.

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	-50
Dec-11	0	-65	0
CES	0	-14	+50
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.

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

Table 3: Ejecta-Induced settlement for the top 20 m of the soil profile 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_{V1D} (mm)		
				10-m buffer	20-m buffer	50-m buffer
Sep-10	7.1	0.21	0.8	1±20	1±20	2±20
Feb-11	6.2	0.63	1.2	6±50	6±50	21±50
Jun-11	6.2	0.35	1.8	0±25	0±25	1±25
Dec-11	6.1	0.28	3.0	0±50	0±50	0±50

Notes: 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.

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 4: Best final estimates of ejecta-induced settlement for the site.

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	ND	0	0	ND	0	0	ND	0	0
Feb-11	ND	0	0	ND	0	0	ND	0	0
Jun-11	ND	0	0	ND	0	0	ND	<5	<5
Dec-11	ND	0	0	ND	0	0	ND	0	0

Notes: $S_{E,L}$ = Ejecta-induced settlement based on LiDAR data was not determined (ND) due to the evident absence of ejecta at the site; $S_{E,P}$ = Ejecta-induced settlement based on ground and aerial photographs and LDAT property inspection reports; $S_{E,final}$ = Best final estimate of ejecta-induced settlement.

Note 3:

- $S_{E,final}$ for all buffers is based solely on $S_{E,P}$ for all earthquake events due to the evident absence of ejecta.
- The Keers Rd site is in the zone of accurate LPI prediction of liquefaction severity for the Sep-10 EQ and slight to moderate LPI overprediction of liquefaction severity for the Feb-11 EQ

(Maurer et al. 2014[3]). No liquefaction ejecta-induced damage was reported for the properties within the 50-m buffer.

- There were negligible ejecta on the road in the NE quadrant of the 50-m buffer for the Jun-11 EQ.

Summary:

The best estimate of the ejecta-induced free-field ground settlement at the Keers Rd site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 0 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

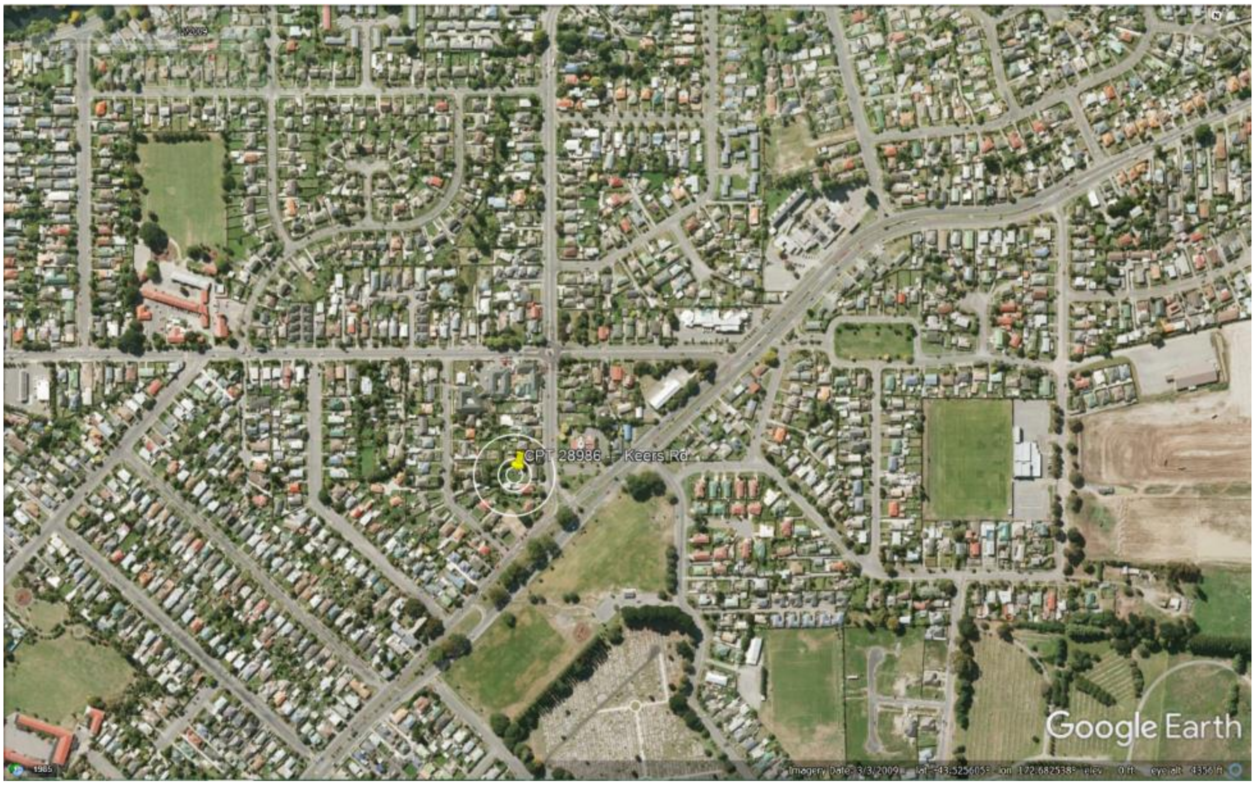

Figure 3: Position of the site relative to nearby buildings, vegetation, and free-face features.

Figure 4: Street view of the flat land.

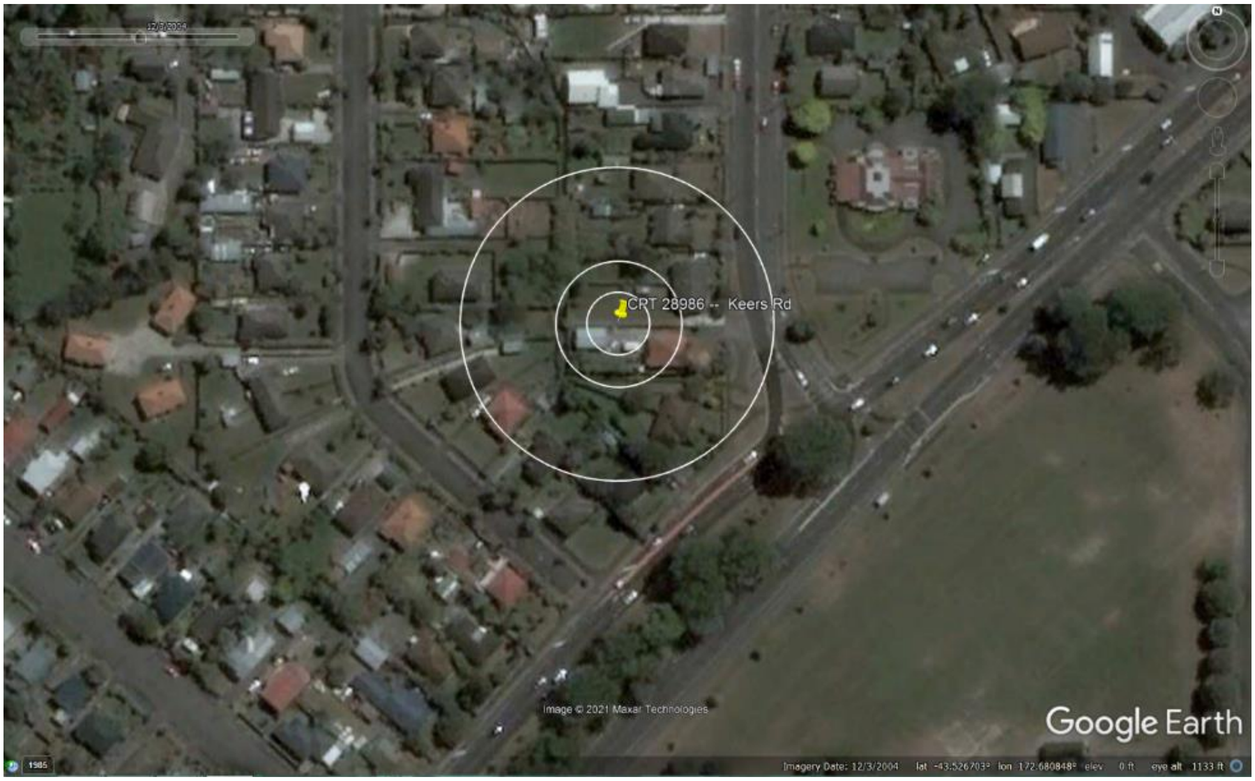

Figure 5: Satellite image of the site taken in Dec 2004.

Figure 6: Satellite image of the site taken in Mar 2009.

Figure 7: Satellite image of the site taken on Sep 3, 2010.

Figure 8: Satellite image of the site taken on Sep 5, 2010.

Figure 9: Satellite image of the site taken on Feb 15, 2011.

Figure 10: Satellite image of the site taken on Feb 26, 2011.

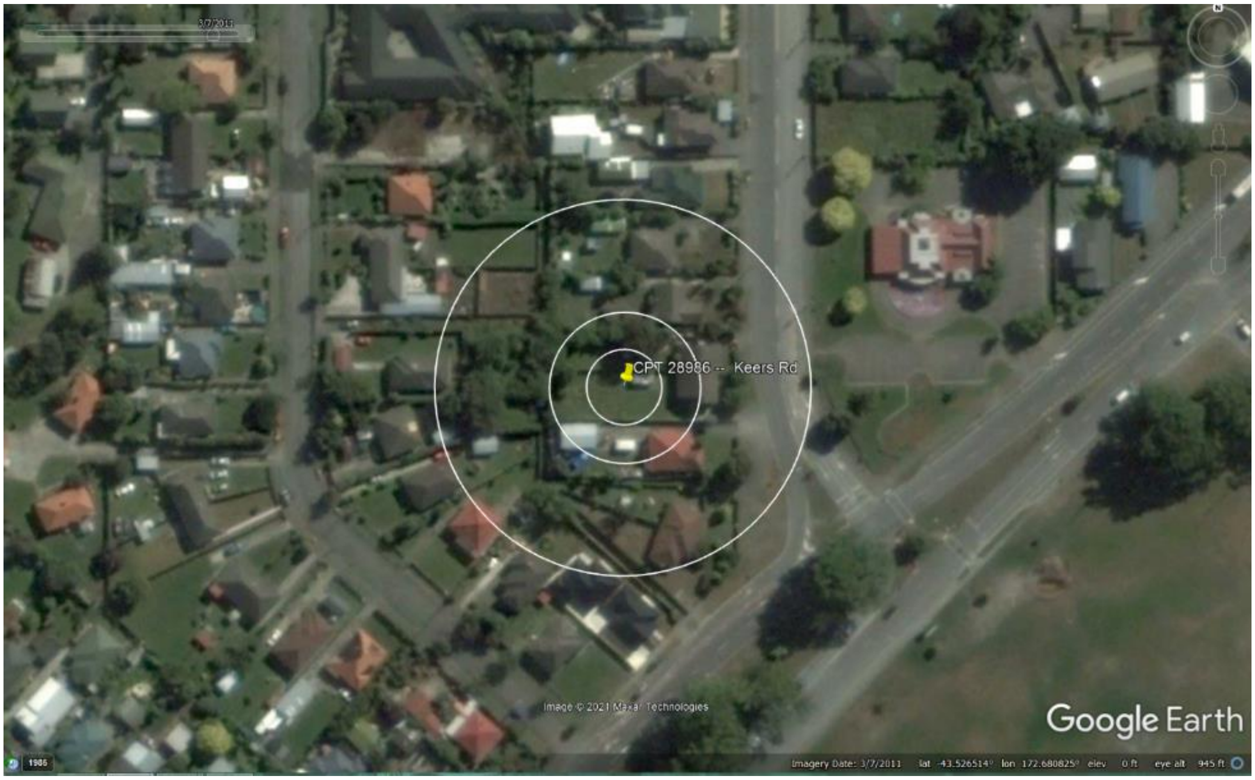

Figure 11: Satellite image of the site taken on Mar 8, 2011.

Figure 12: Satellite image of the site taken in Apr 2012.

Figure 13: Satellite image of the site taken in Nov 2015.

Figure 14: Aerial photograph of the site taken on Sep 4, 2010.

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

Figure 16: Aerial photograph of the site taken on June 14-15, 2011.

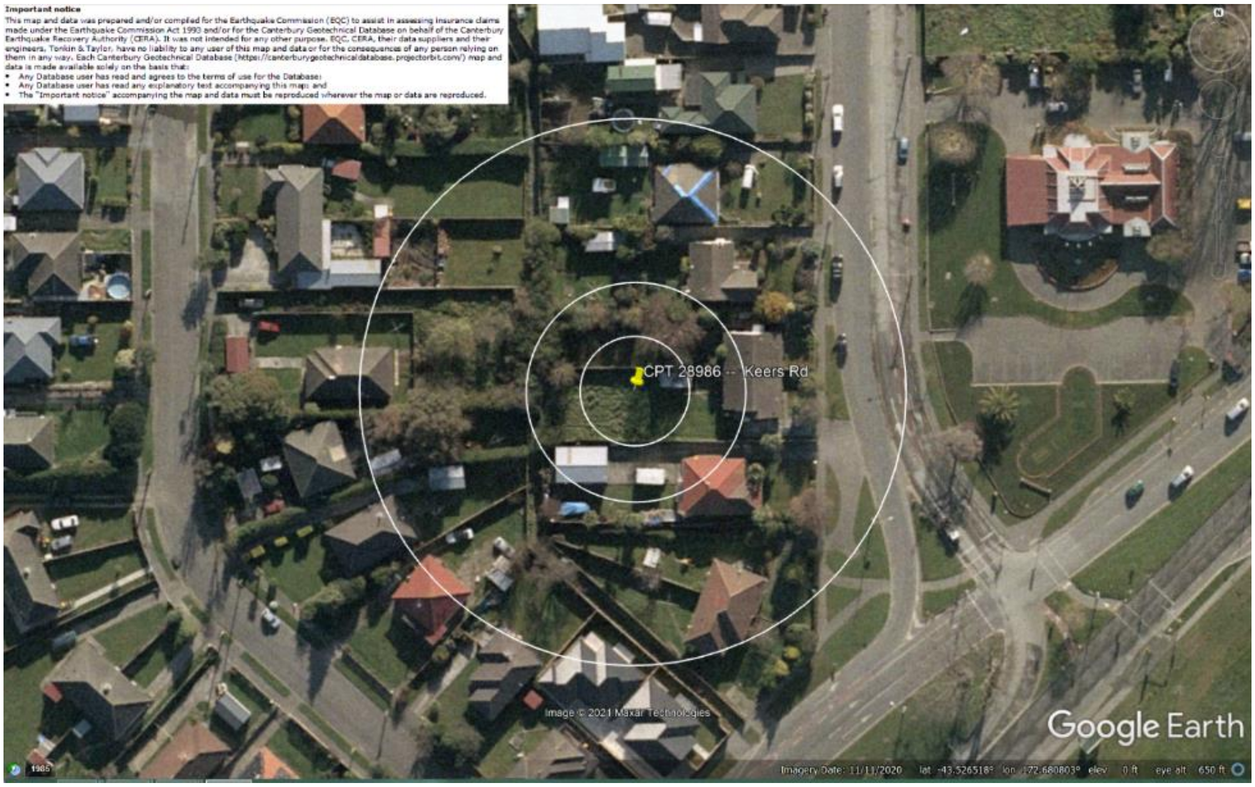

Figure 17: Aerial photograph of the site taken on June 16, 2011.

Figure 18: Aerial photograph of the site taken on Dec 24, 2011.

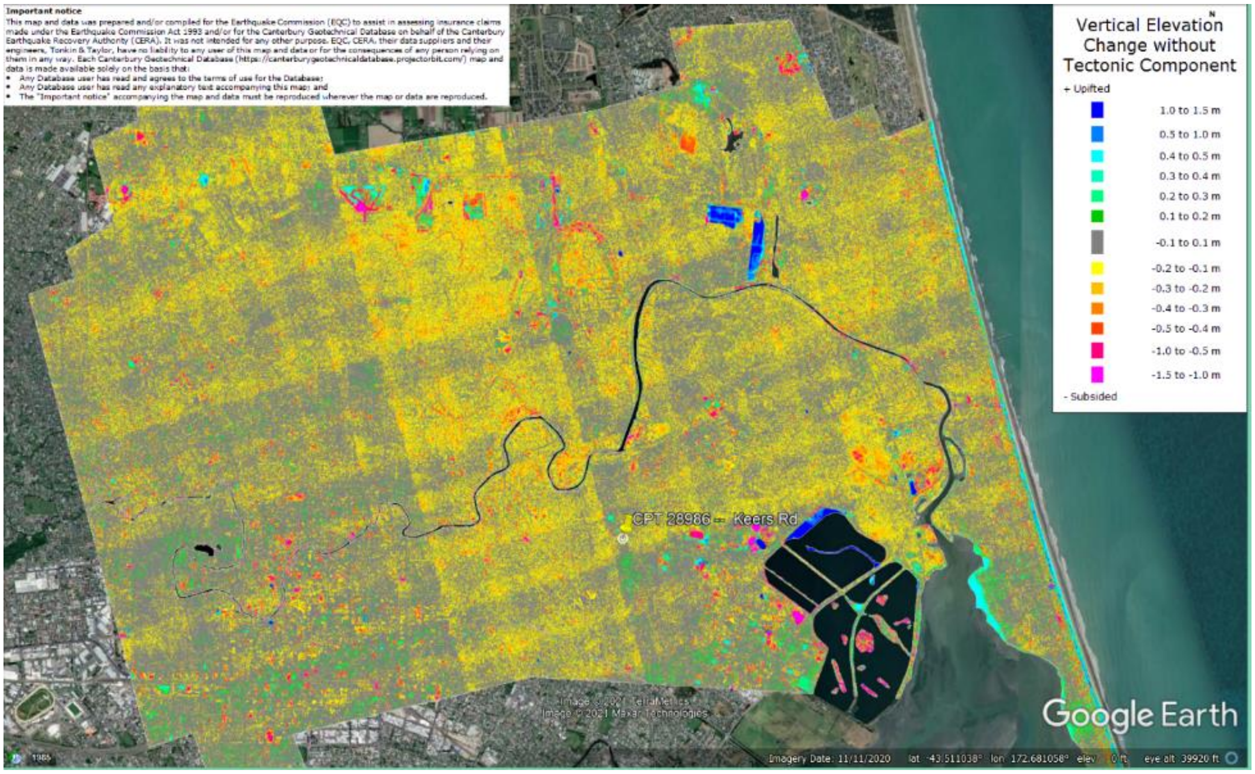

Figure 19: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake – the site is not in the apparent zone of overestimated ground surface subsidence.

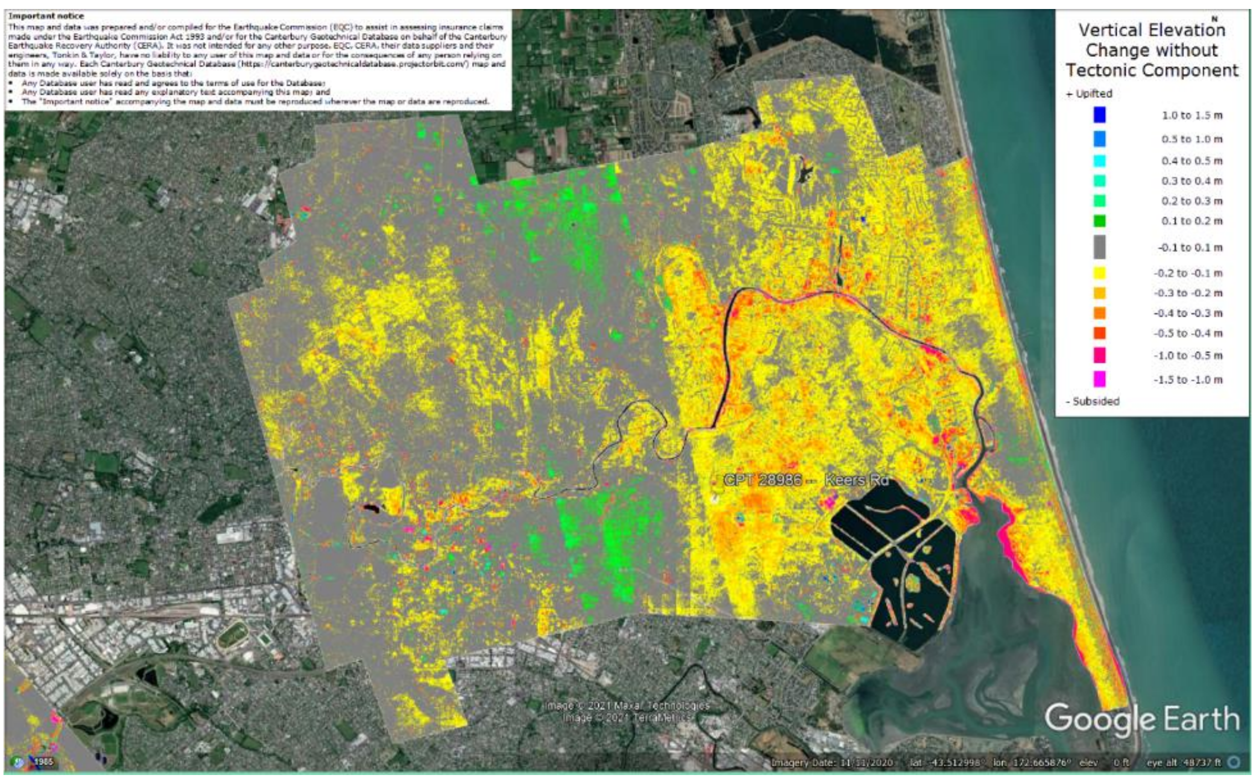

Figure 20: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake – the site is not in the apparent zone of underestimated ground surface subsidence.

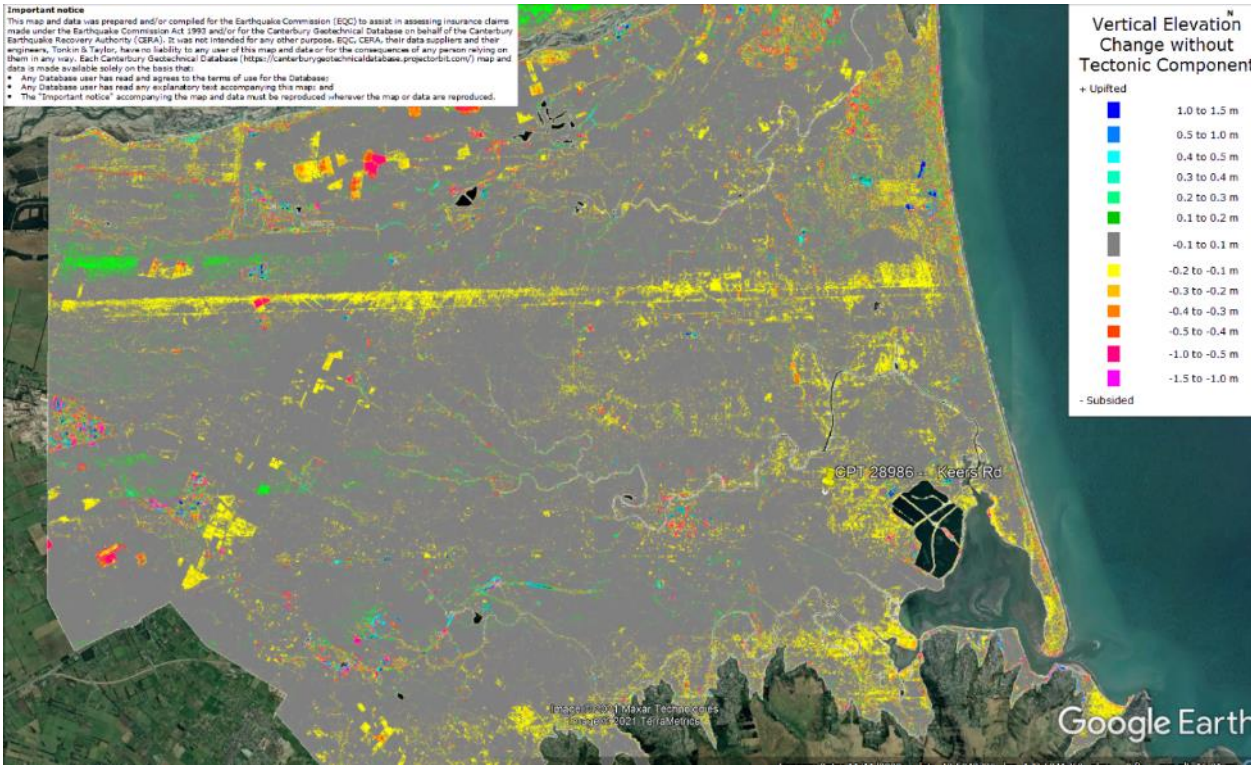

Figure 21: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

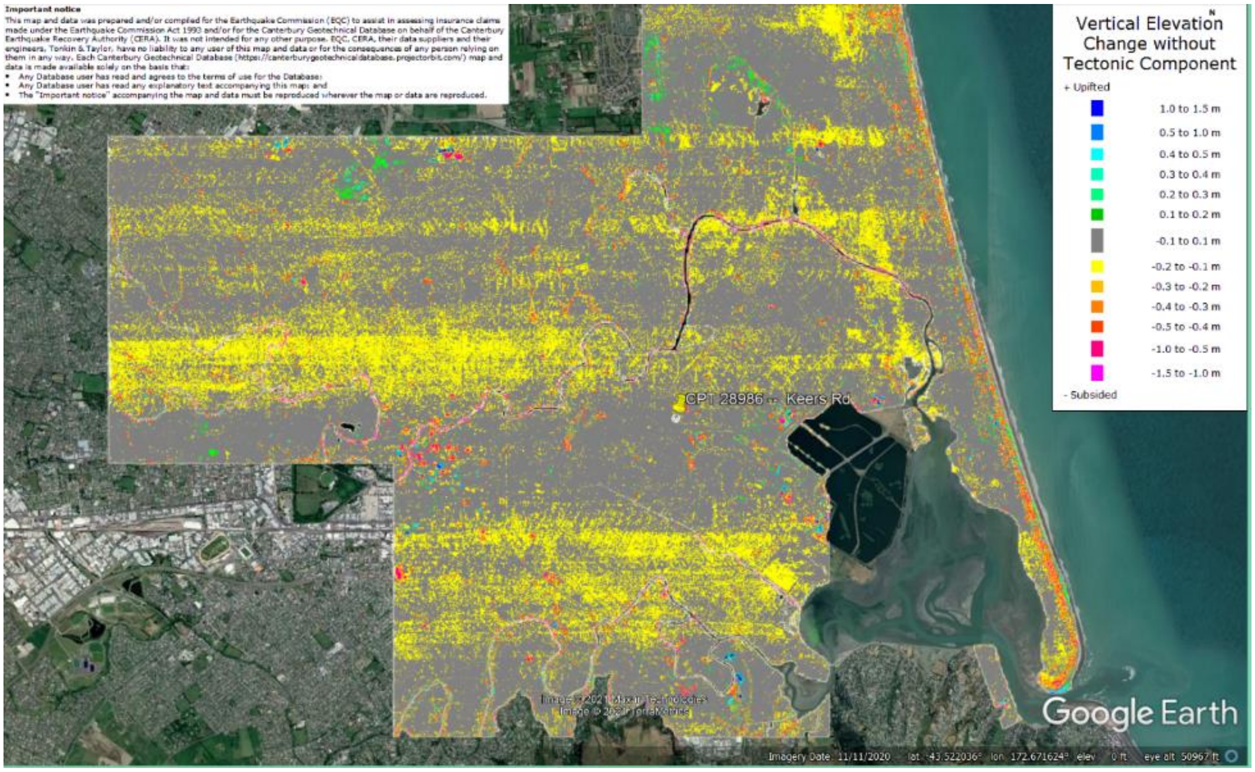

Figure 22: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

Figure 23: Ground surface subsidence without tectonic component for Sep 2010 Earthquake according to the LiDAR DEM.

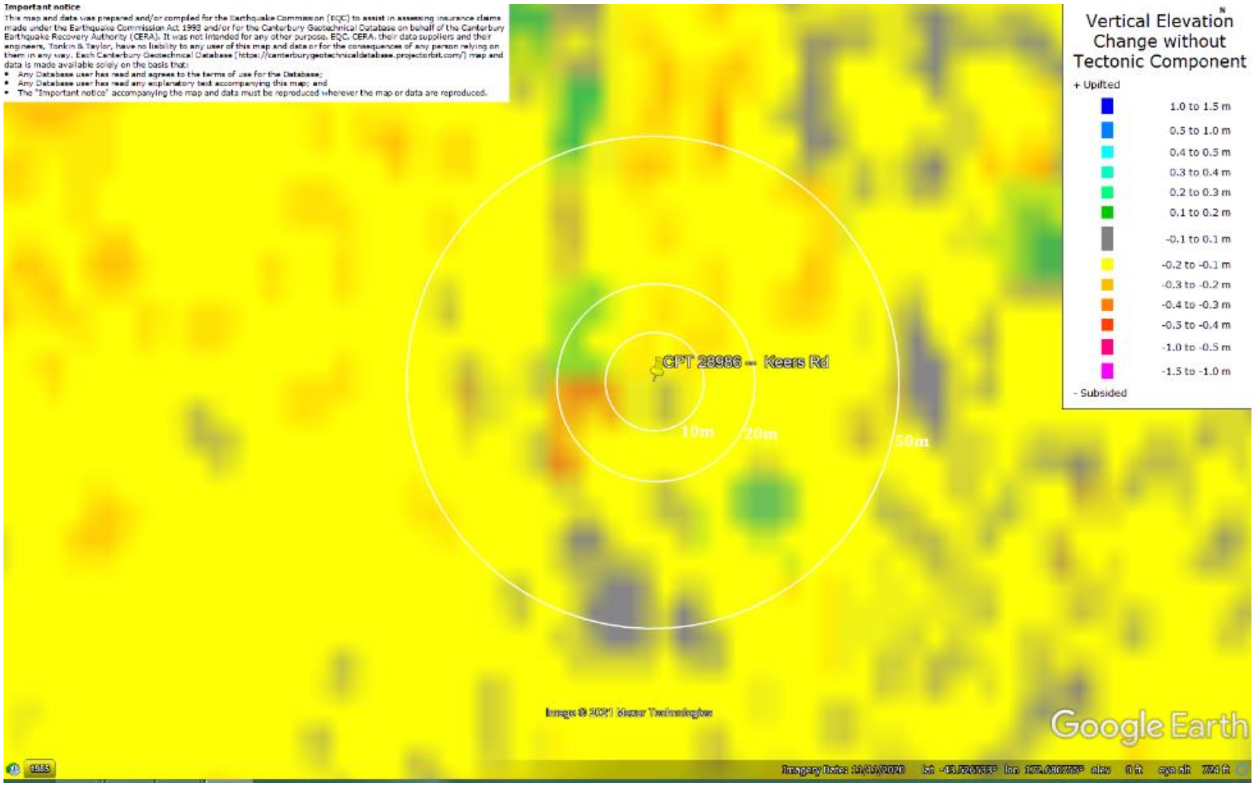

Figure 24: Ground surface subsidence without tectonic component for Feb 2011 Earthquake according to the LiDAR DEM.

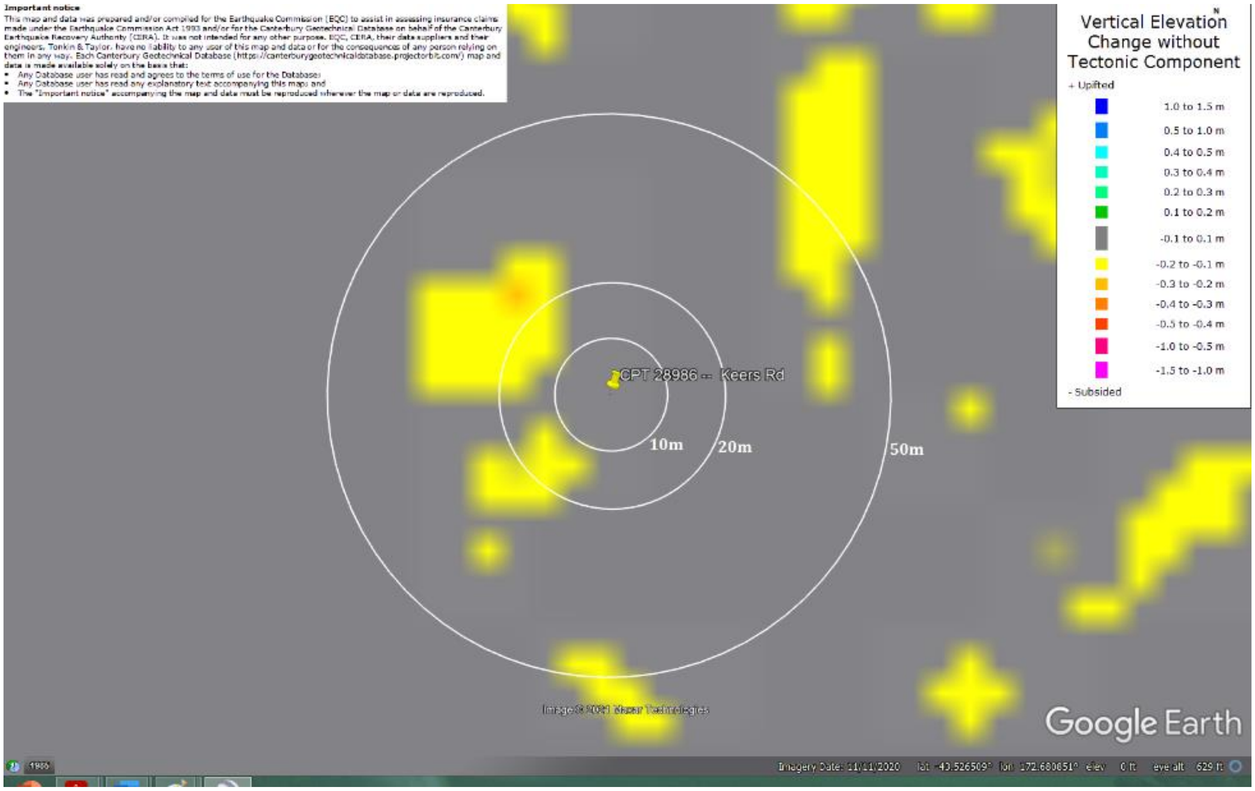

Figure 25: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

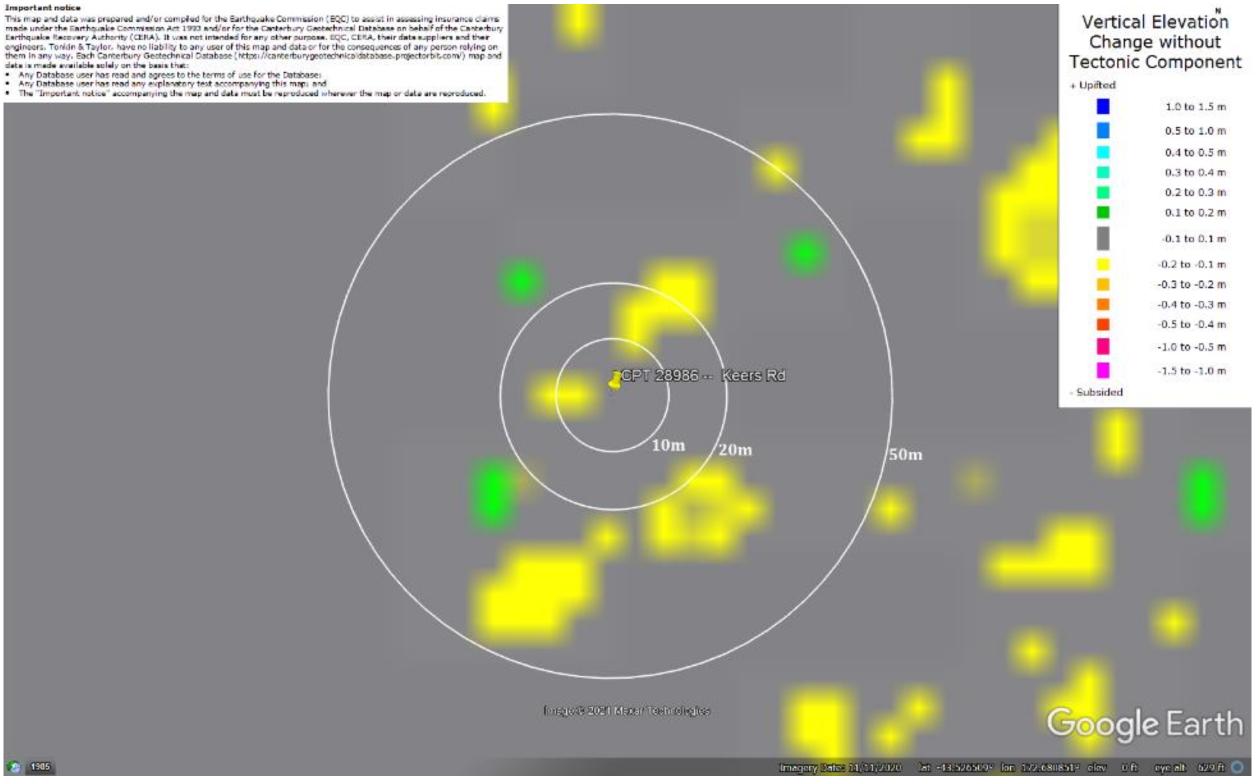

Figure 26: Ground surface subsidence without tectonic component for Dec 2011 Earthquake according to the LiDAR DEM.

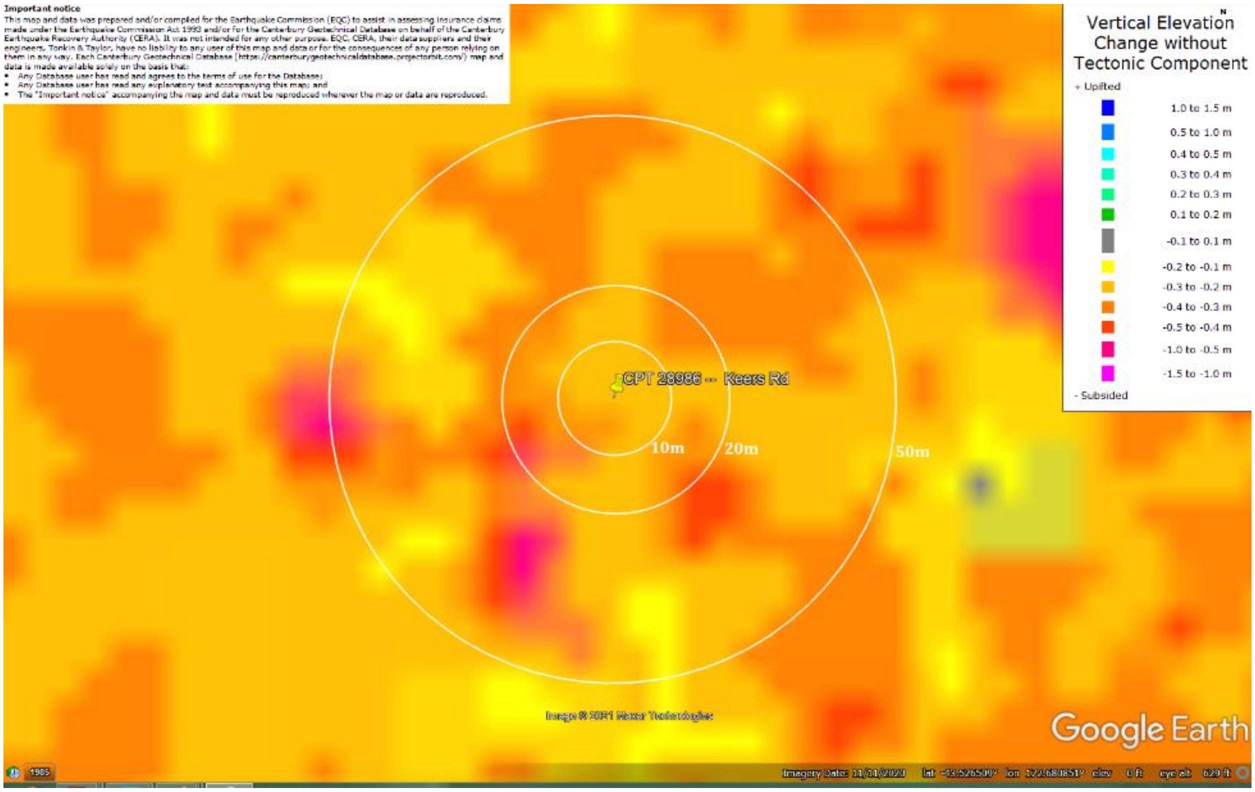

Figure 27: Ground surface subsidence without tectonic component for Canterbury Earthquake Sequence according to the LiDAR DEM.

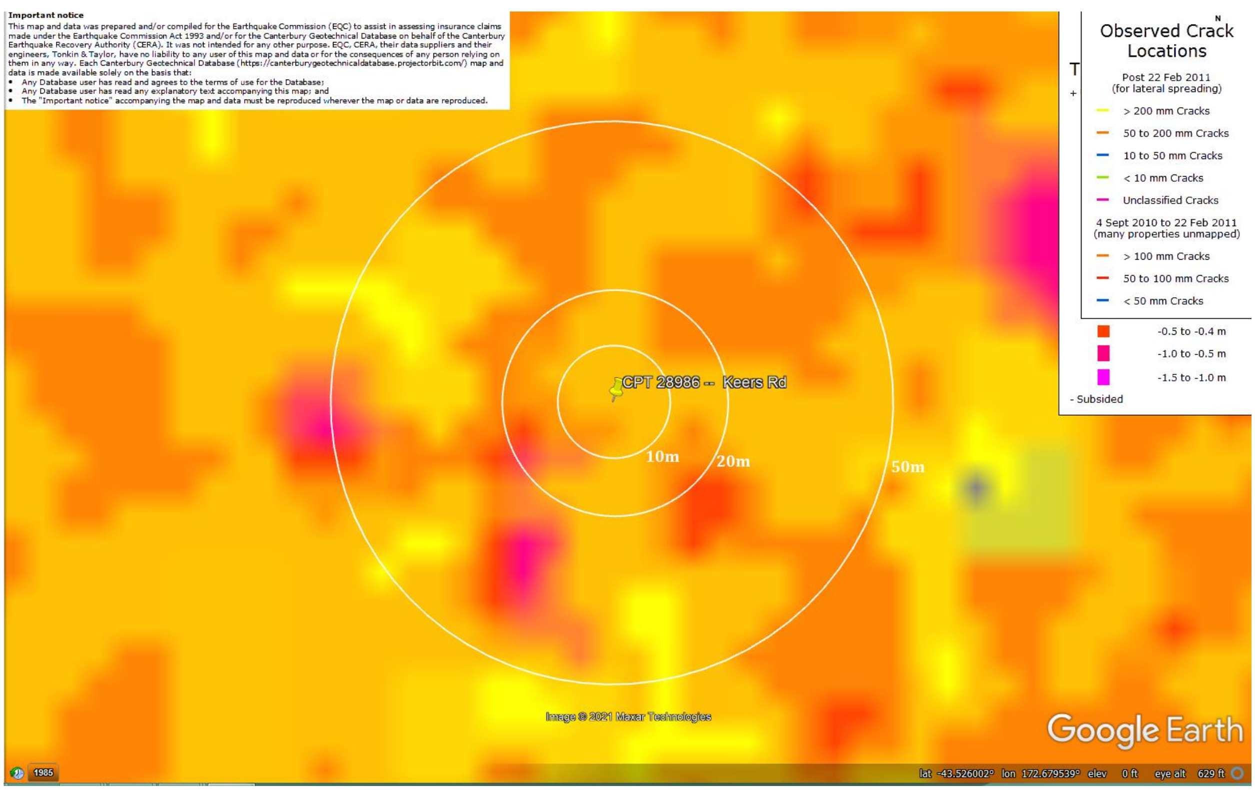

Figure 28: No lateral spreading for Canterbury Earthquake Sequence.

Figure 29: Vertical tectonic movements for Sep 2010 Earthquake.

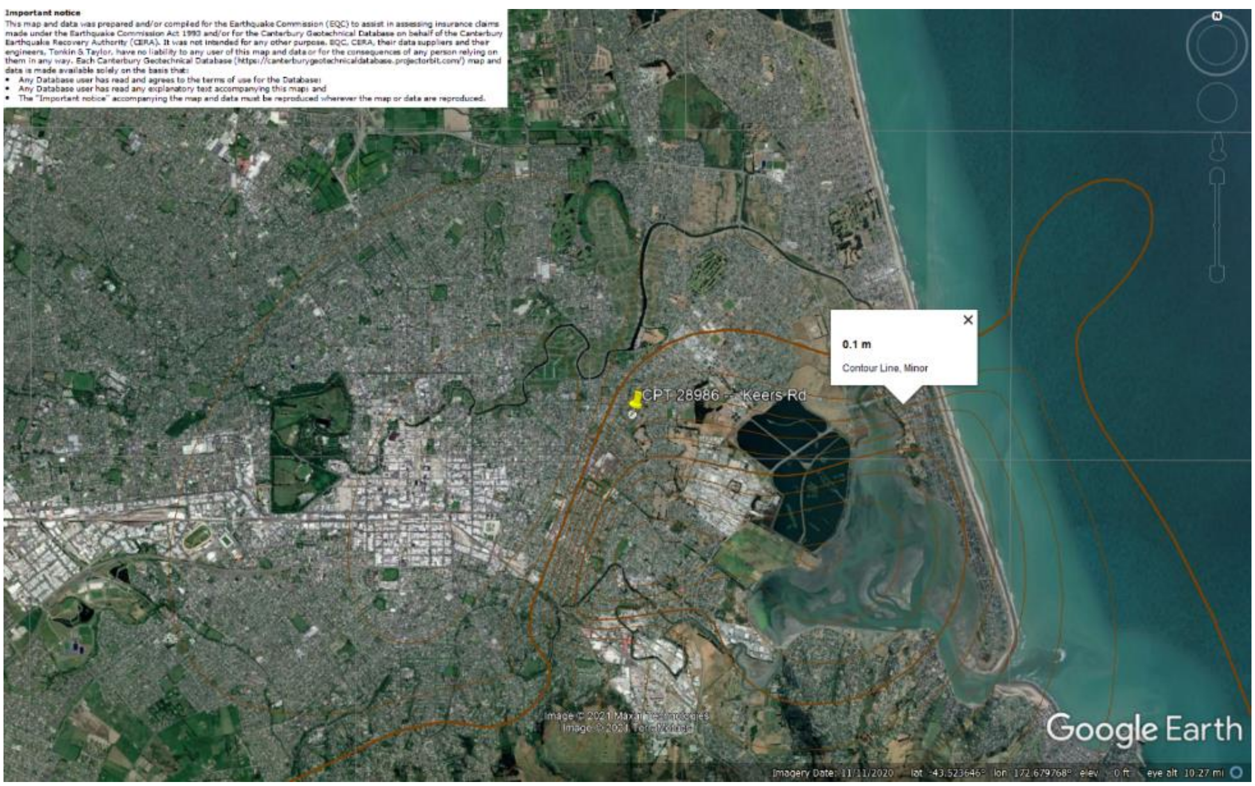

Figure 30: Vertical tectonic movements for Feb 2011 Earthquake.

Figure 31: Vertical tectonic movements for June 2011 Earthquake.

Figure 32: Vertical tectonic movements for Dec 2011 Earthquake.

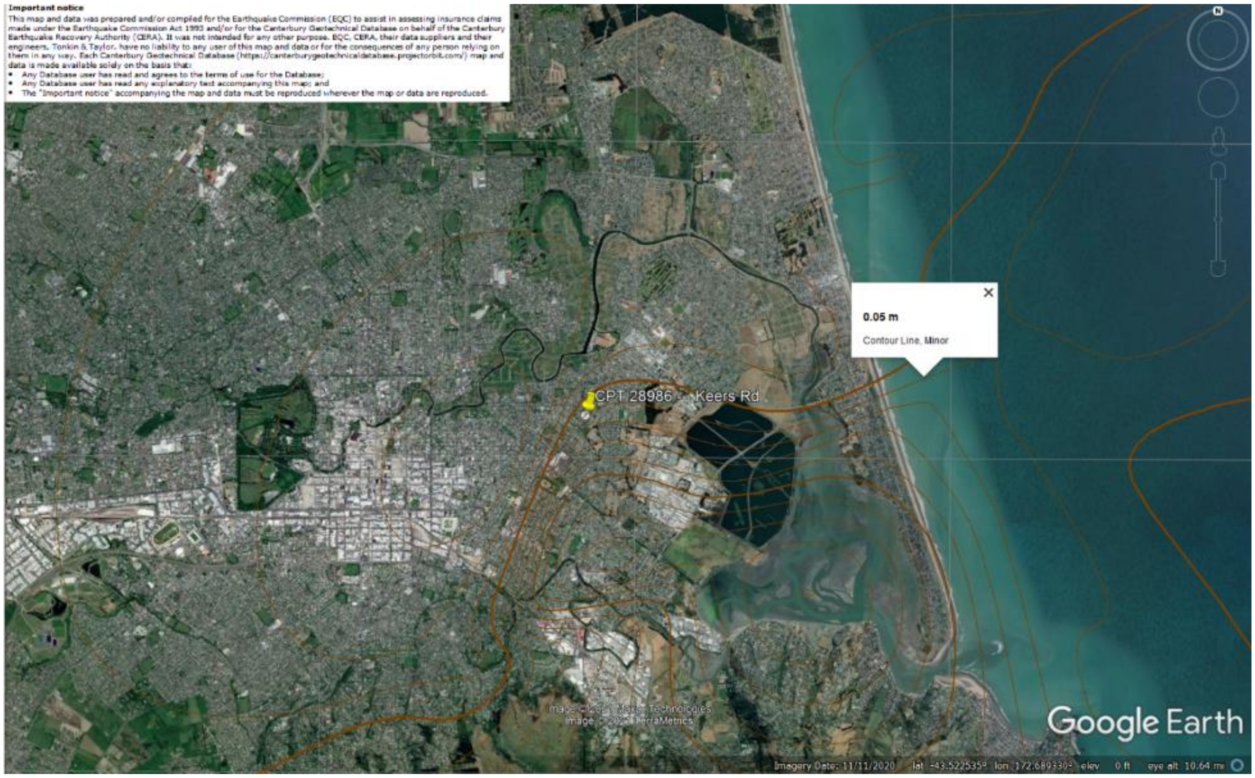

Figure 33: Vertical tectonic movements for Canterbury Earthquake Sequence.

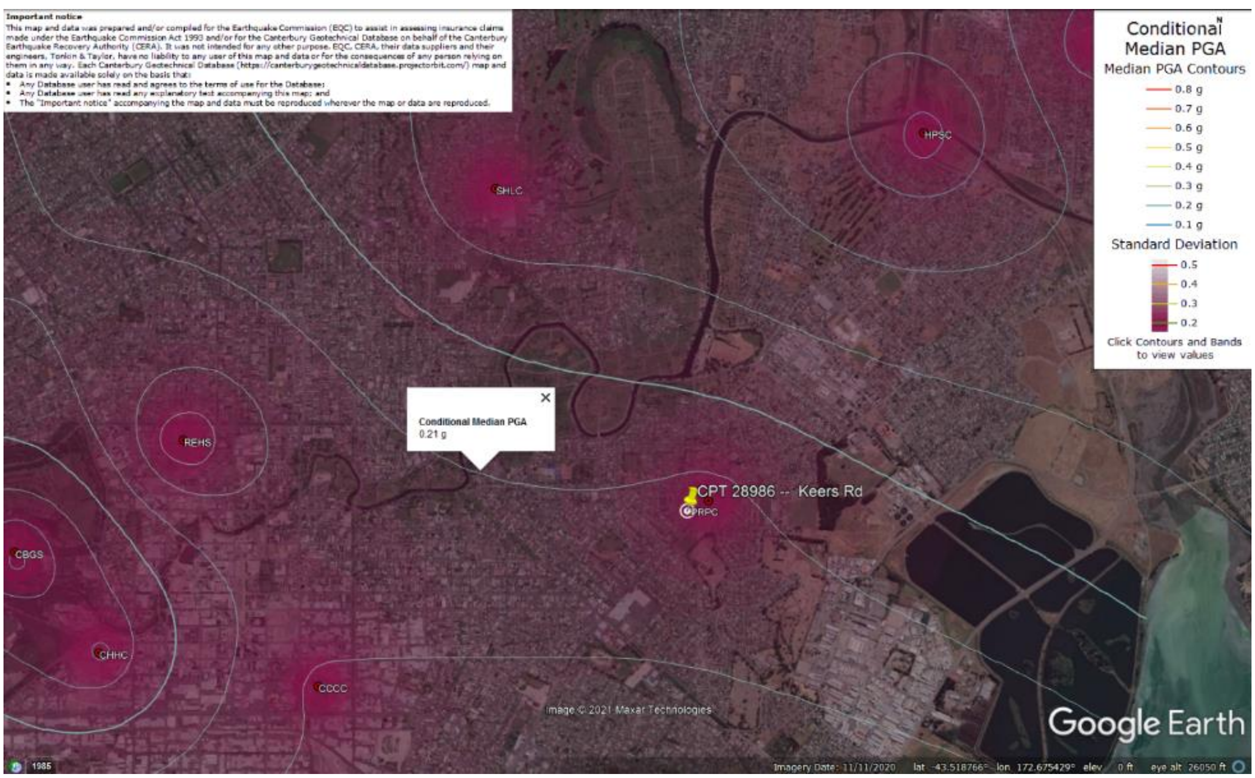

Figure 34: PGA for Sep-10 EQ (st. dev. <0.175 to 0.200 ln units).

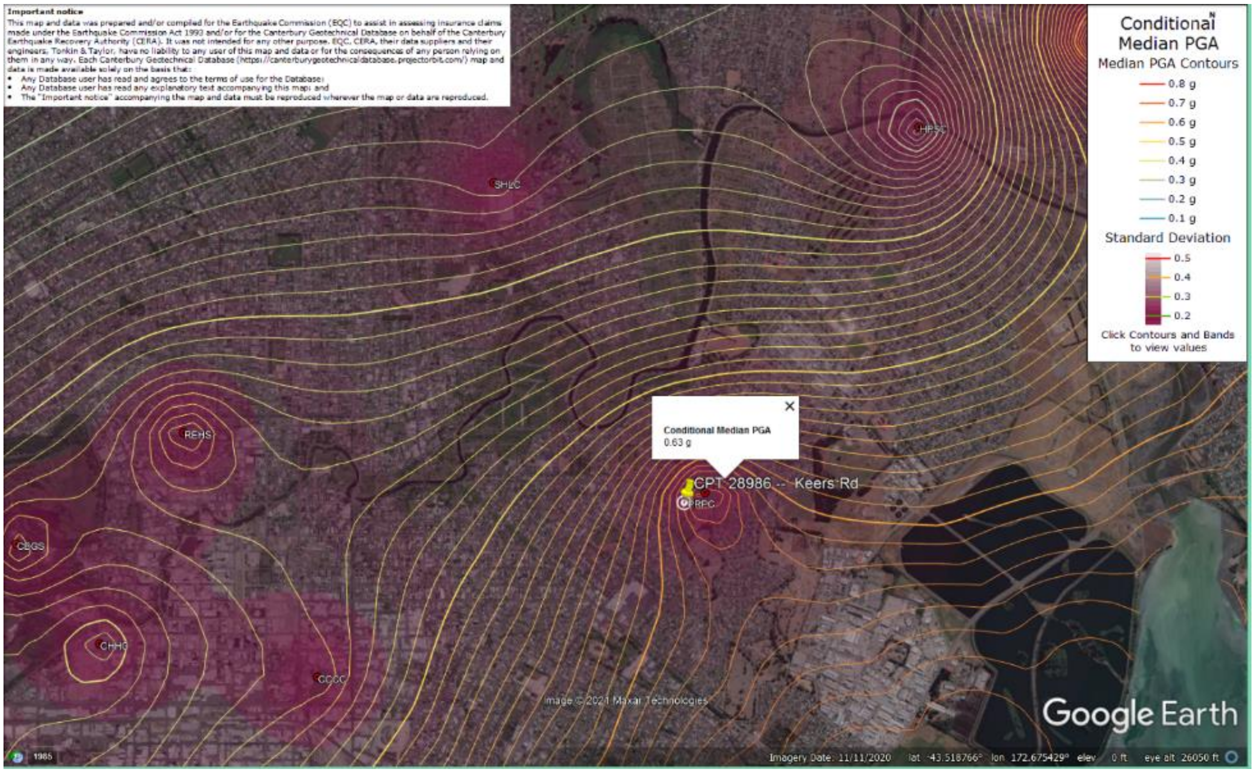

Figure 35: PGA for Feb-11 EQ (st. dev. = 0.225 to 0.250 ln units).

Figure 36: PGA for Jun-11 EQ (st. dev. <0.175 to 0.225 ln units).

Figure 37: PGA for Dec-11 EQ (st. dev. = 0.400 to 0.425 ln units).

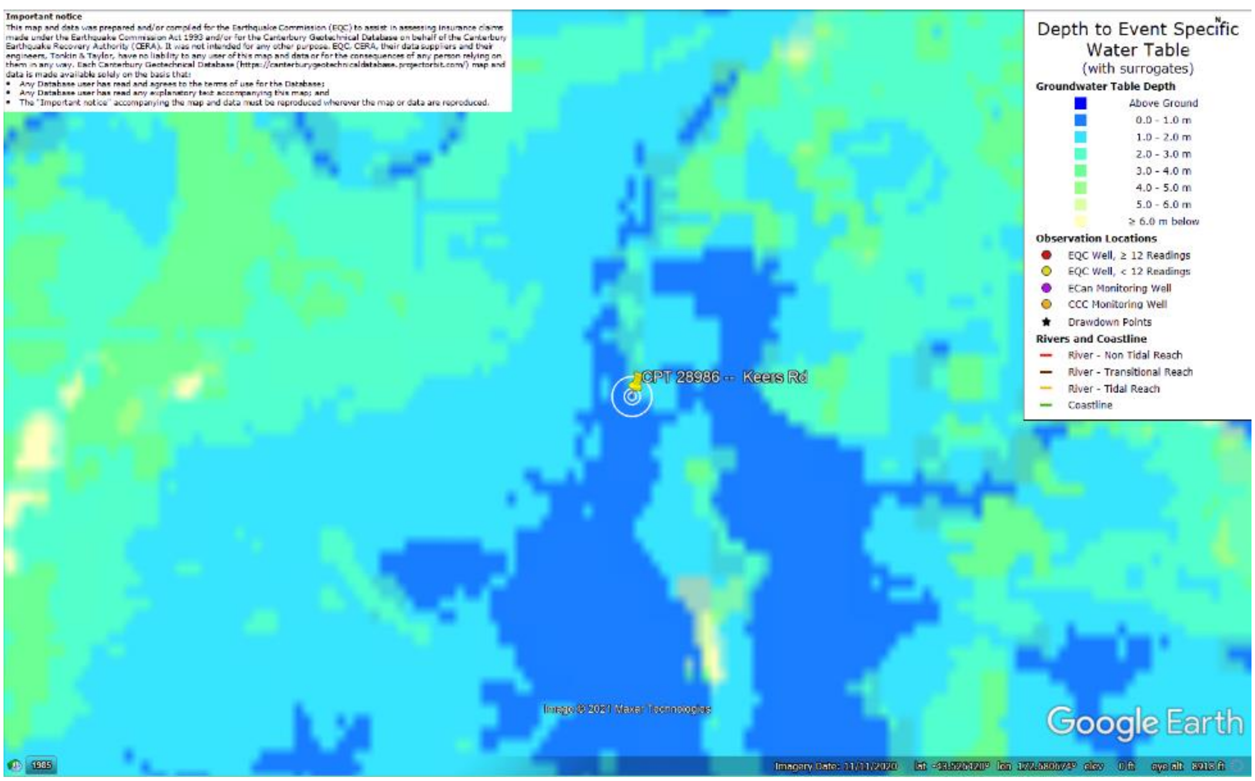

Figure 38: Depth to groundwater table for Sep-10 EQ.

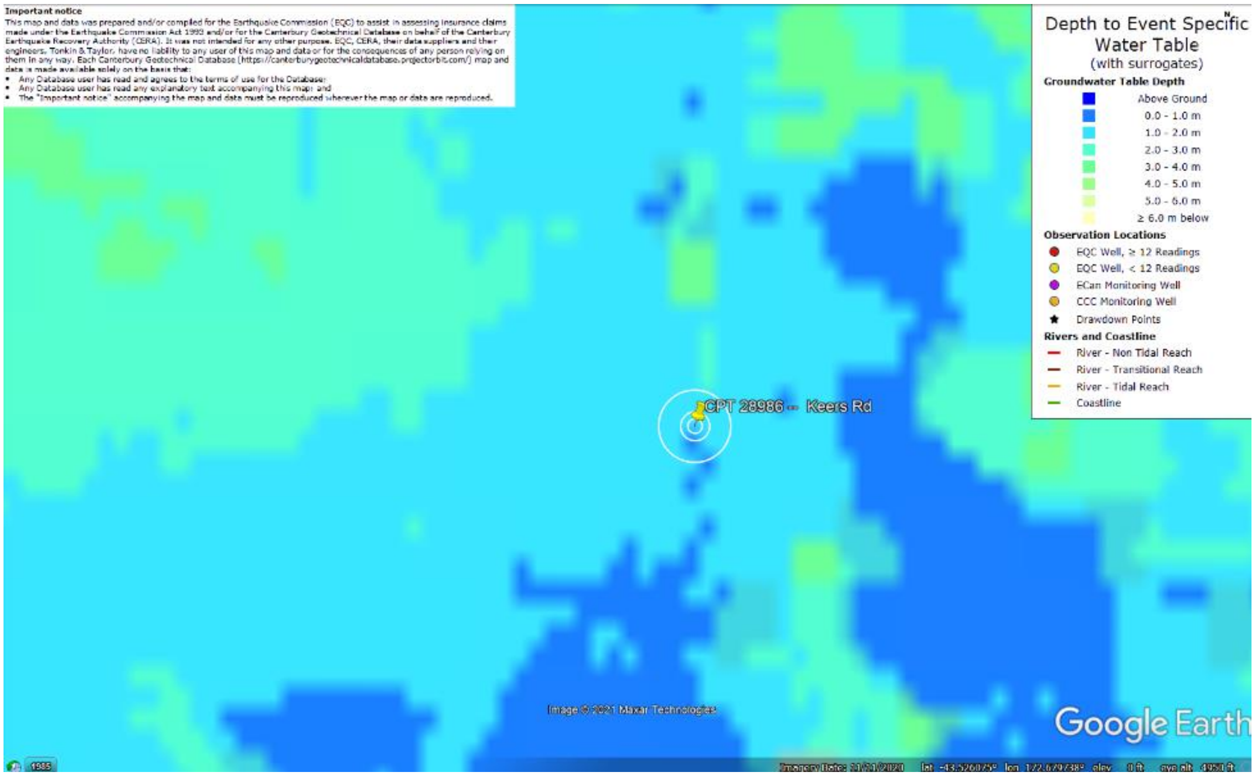

Figure 39: Depth to groundwater table for Feb-11 EQ.

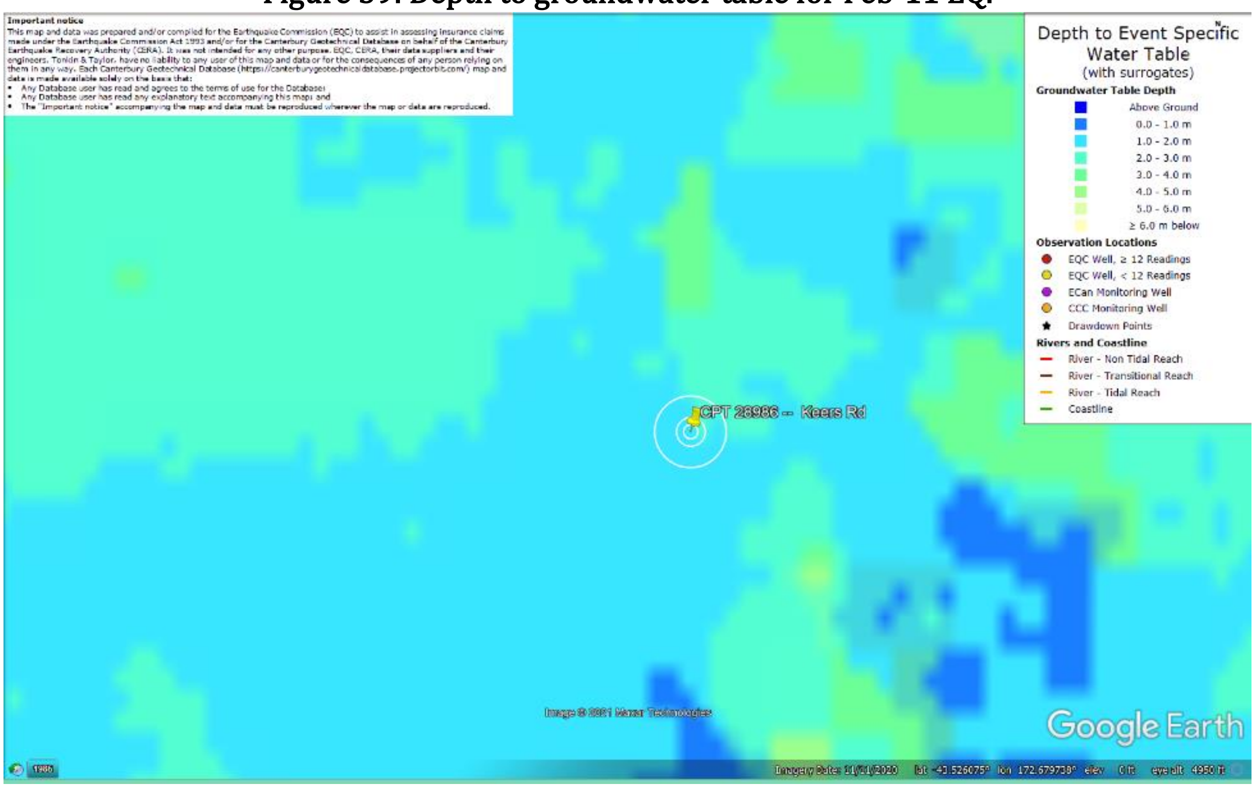

Figure 40: Depth to groundwater table for Jun-11 EQ.

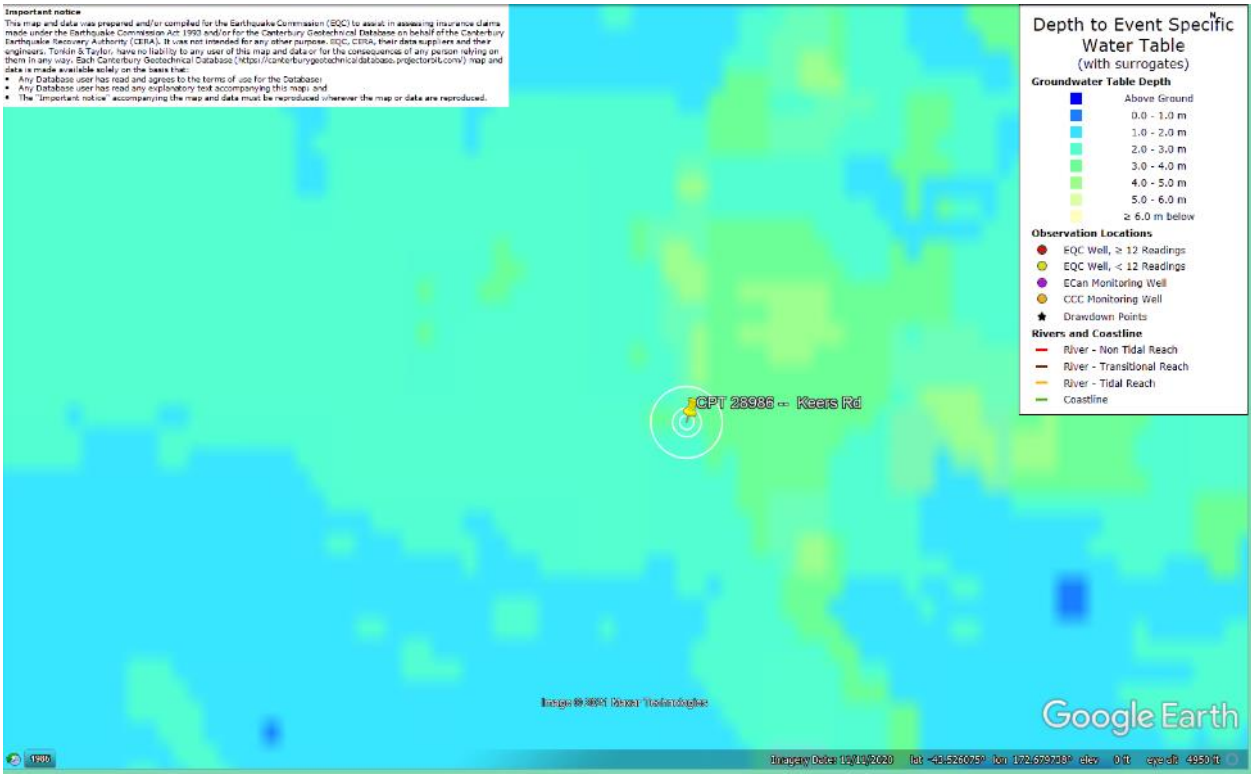

Figure 41: Depth to groundwater table for Dec-11 EQ.

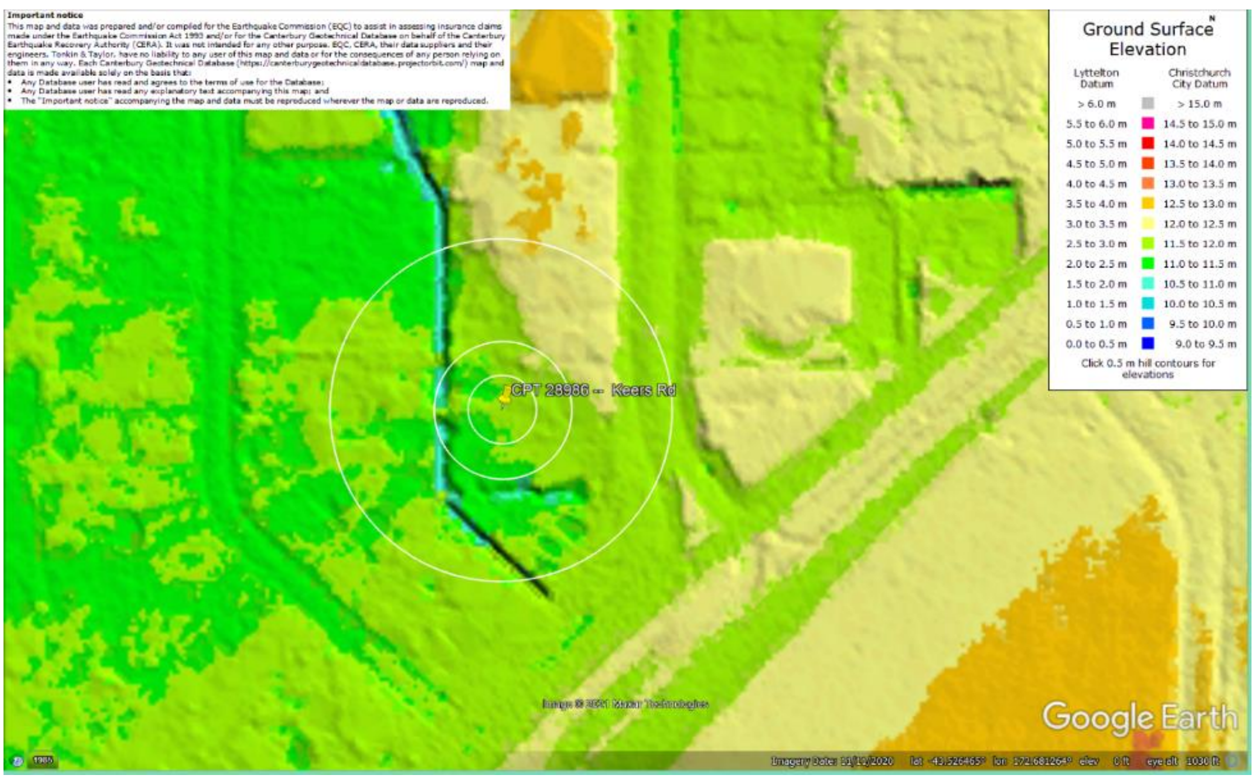

Figure 42: Ground surface elevation according to the Sep-11 LiDAR survey.

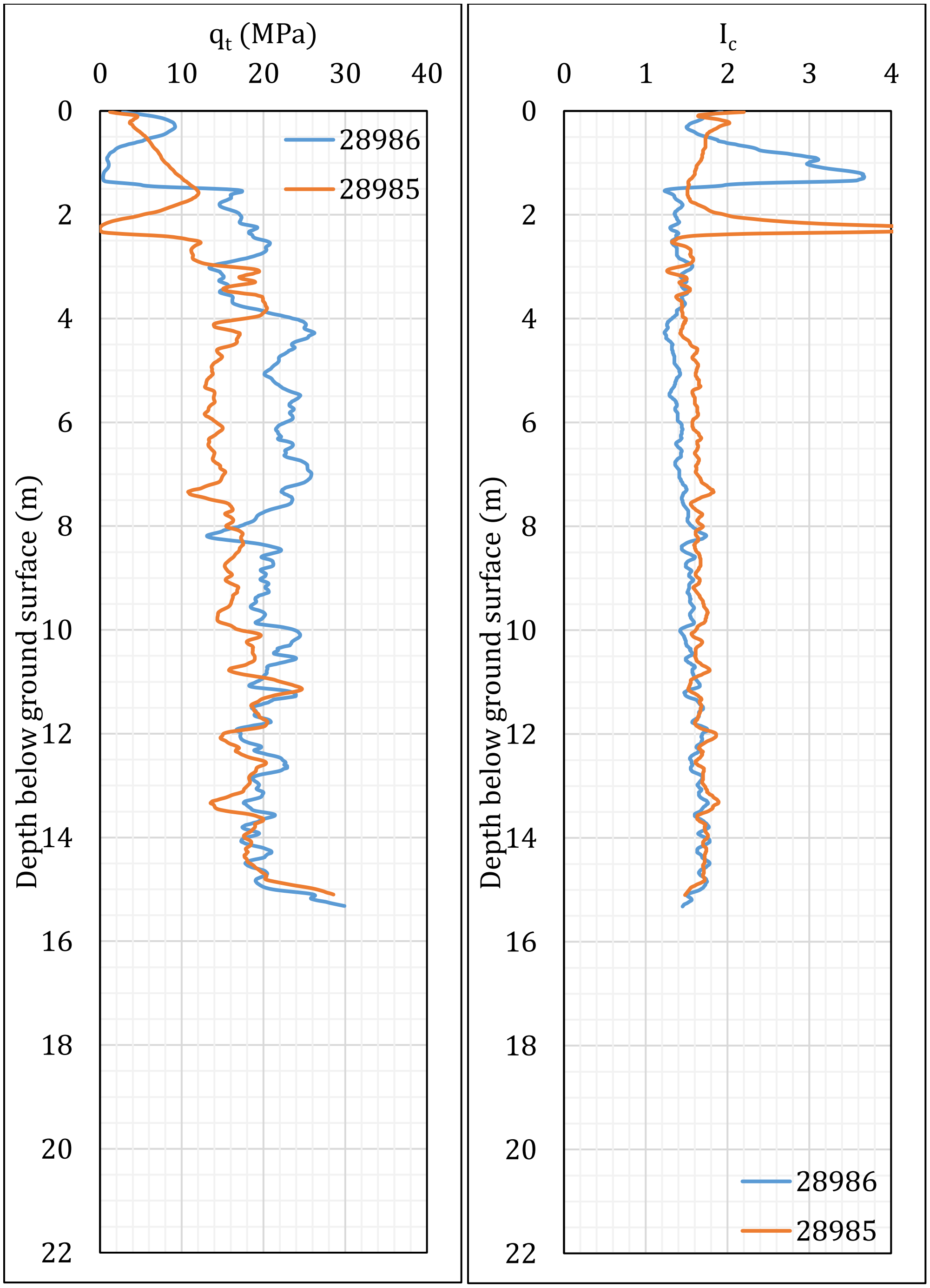

Figure 43: q_t and I_c profiles.

Note 4: The selection of CPTs for the area considered for settlement assessment (Figure 1) is based on the proximity of the CPTs to the considered area. 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 3.)

Table 5: 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
28986 (17042)	✓	✓	✓
28985 (17040)			✓

Note: It is assumed that the volumetric settlement below the 15-m depth is negligible.

Table 6: CPT-based results.

EQ Event	Parameter	CPT ID 28986	CPT ID 28985
Sep-10	S_{V1D} (mm)	1	2
	LSN	0	1
	LPI	0	0
	LPI_{ish}	0	0
	$D_{FS<1}$ (m)	undet.	undet.
Feb-11	S_{V1D} (mm)	6	36
	LSN	2	7
	LPI	1	3
	LPI_{ish}	1	2
	$D_{FS<1}$ (m)	8.06	1.82
Jun-11	S_{V1D} (mm)	0	2
	LSN	0	1
	LPI	0	0
	LPI_{ish}	0	0
	$D_{FS<1}$ (m)	undet.	undet.
Dec-11	S_{V1D} (mm)	0	0
	LSN	0	0
	LPI	0	0
	LPI_{ish}	0	0
	$D_{FS<1}$ (m)	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 5: Based on the nearest borehole log (BH 23529, ~120 m to the NE from the center of the site, Figure 1) and CPT 28986, the soil profile below the topsoil consists of (1) silt, ML, to a depth of 1.6 m and (2) fine to coarse sand, SW, to a depth of 15.5 m. All soil layers are of the Christchurch formation. The groundwater table is ~2 m below the ground surface.