Appendix A.60:

Tonks St – CPT 128494

Table 1: Site Description for Tonks St (CC NO LIQ 40 – CPT 128494).

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 ~195 m to the W from the Pegasus Bay.	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-m, 20-m, and 50-m buffers is 27%, 32%, and 35%, respectively.	NA
Sloping land?	No	No	Yes	Residential area. Mostly flat land except for the properties in the W portion of the 50-m buffer that typically have sloping driveways.	NA
Step changes in the ground surface?	No	No	Yes	Properties in the W portion of the 50-m buffer are typically ~0.5 m above the road.	NA
Retaining walls?	No	No	Yes	Front lawns of the properties in the W portion of the 50-m buffer are typically retained by ~0.5-m high walls.	NA
Vegetation?	Yes	Yes	Yes	Trees and bushes cover 27% of the 10-m buffer, 17% of the 20-m buffer and 27% 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	Yes	Yes	Low-motor-vehicle-volume road (Tonks St) covers 12% and 14% of the 20-m and 50-m buffers, respectively; it occupies the NW and SW quadrants of the 20-m buffer and the NW and SW 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 (172.724500°, -43.493746°).

[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	-20
Jun-11	0	38	-45
Dec-11	0	-65	0
CES	0	-14	-65
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: 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	0.19	3.3	0±20	1±20	1±20
Feb-11	6.2	0.56	3.3	14±50	20±50	23±50
Jun-11	6.2	0.22	2.5	0±25	1±25	1±25
Dec-11	6.1	0.41	2.3	6±50	11±50	13±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.

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

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	0	0
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 LPI prediction of liquefaction severity for the Sep-10 and Feb-11 EQs by Maurer et al. 2014[3] is not available. No liquefaction ejecta-induced damage was reported for the properties within the 50-m buffer.

Summary:

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

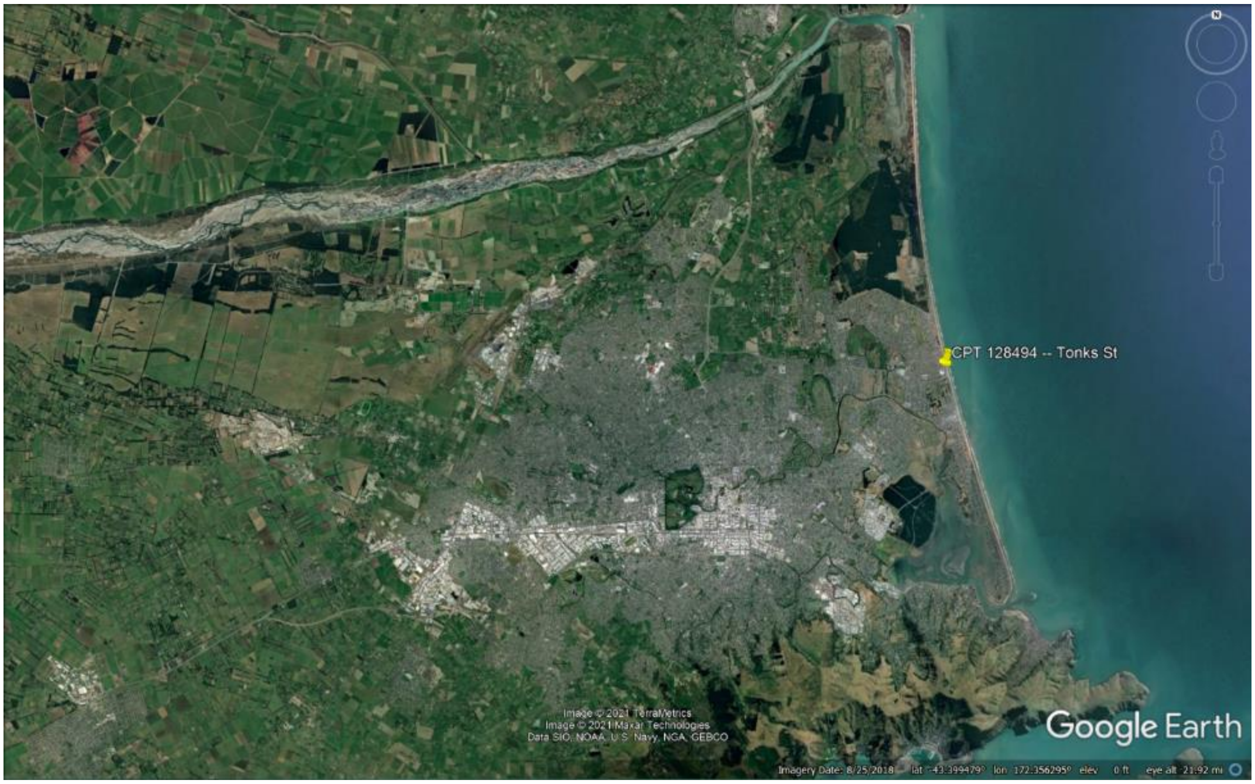

Figure 2: Location of the site.

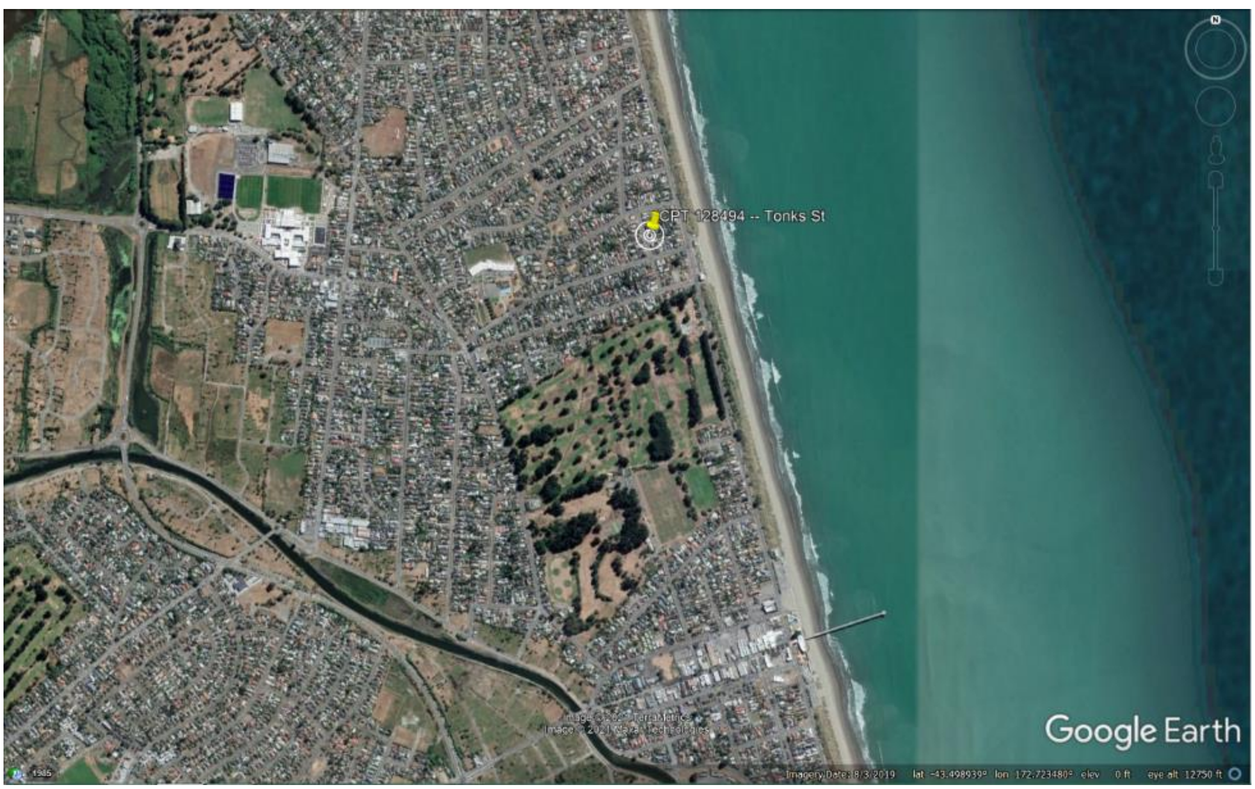

Figure 3: Position of the site relative to nearby buildings, vegetation, and free-face features.

Figure 4: Street view of the flat land.

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

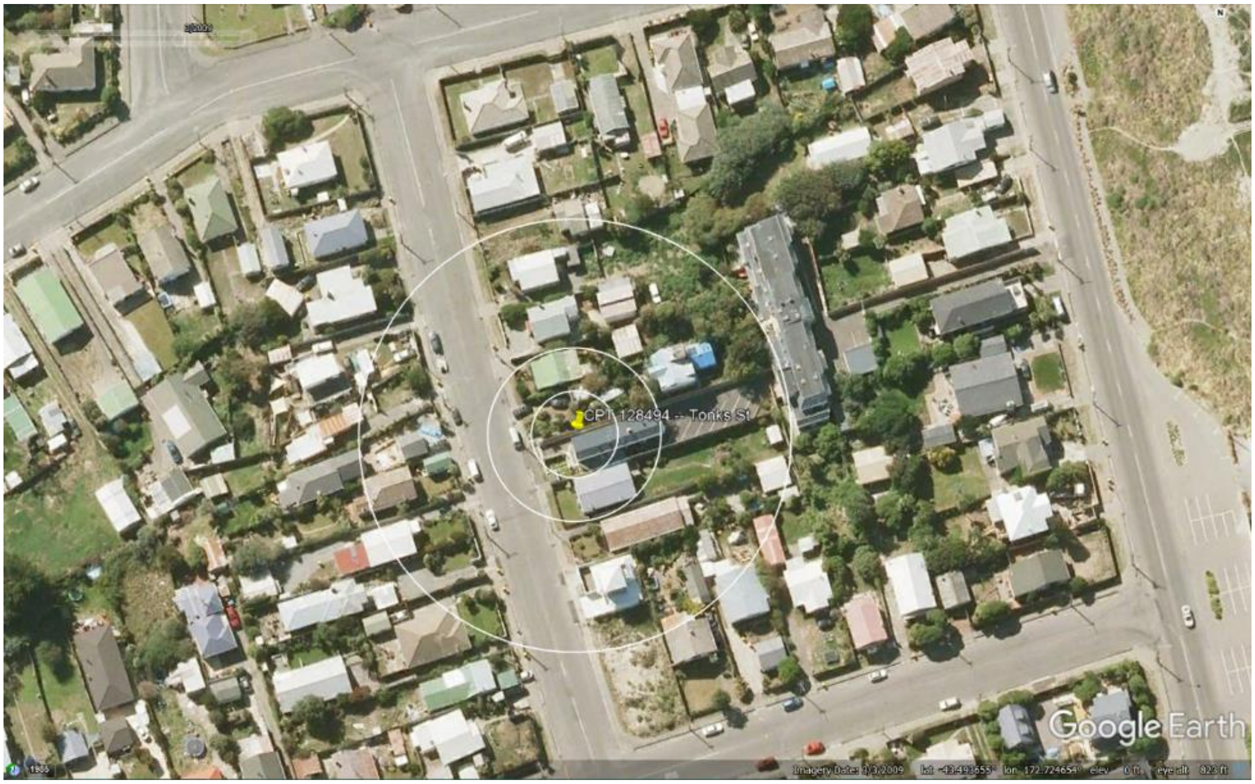

Figure 6: Satellite image of the site taken in Mar 2009.

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 7, 2011.

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

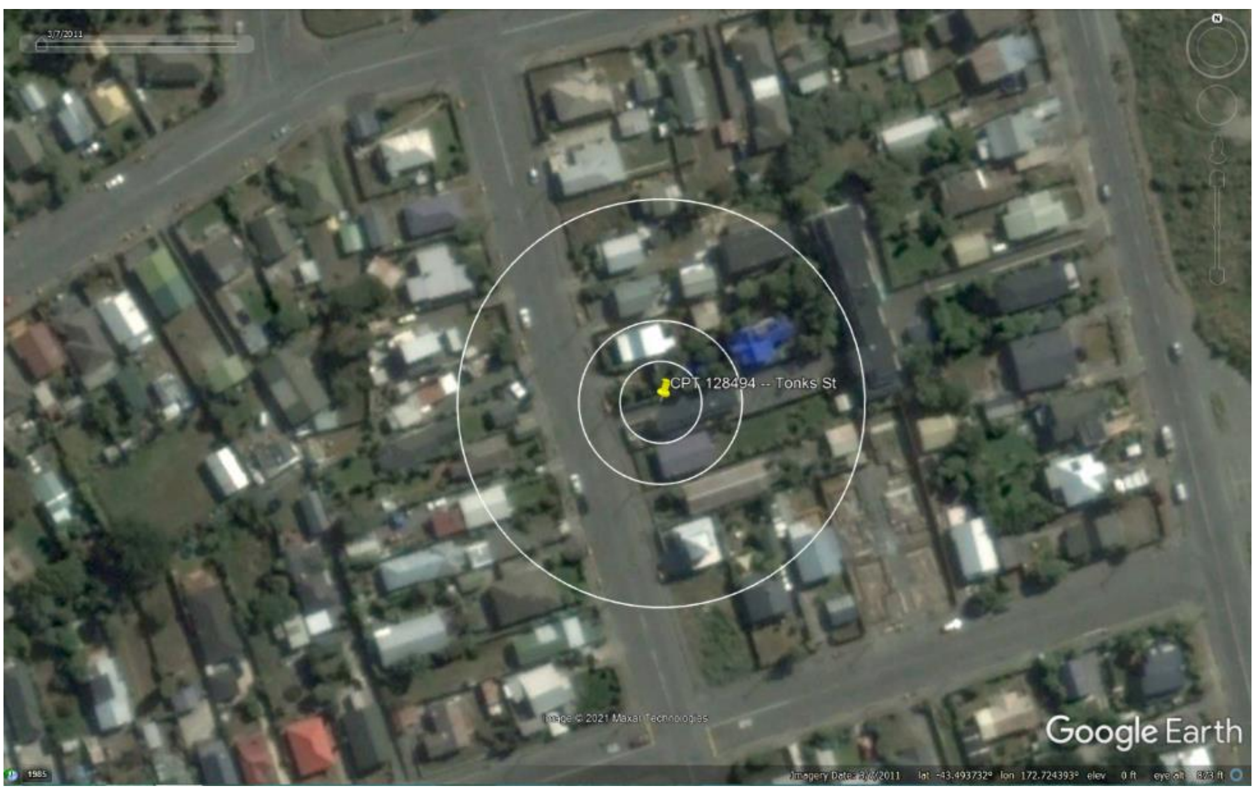

Figure 11: Satellite image of the site taken on Mar 8, 2011.

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.

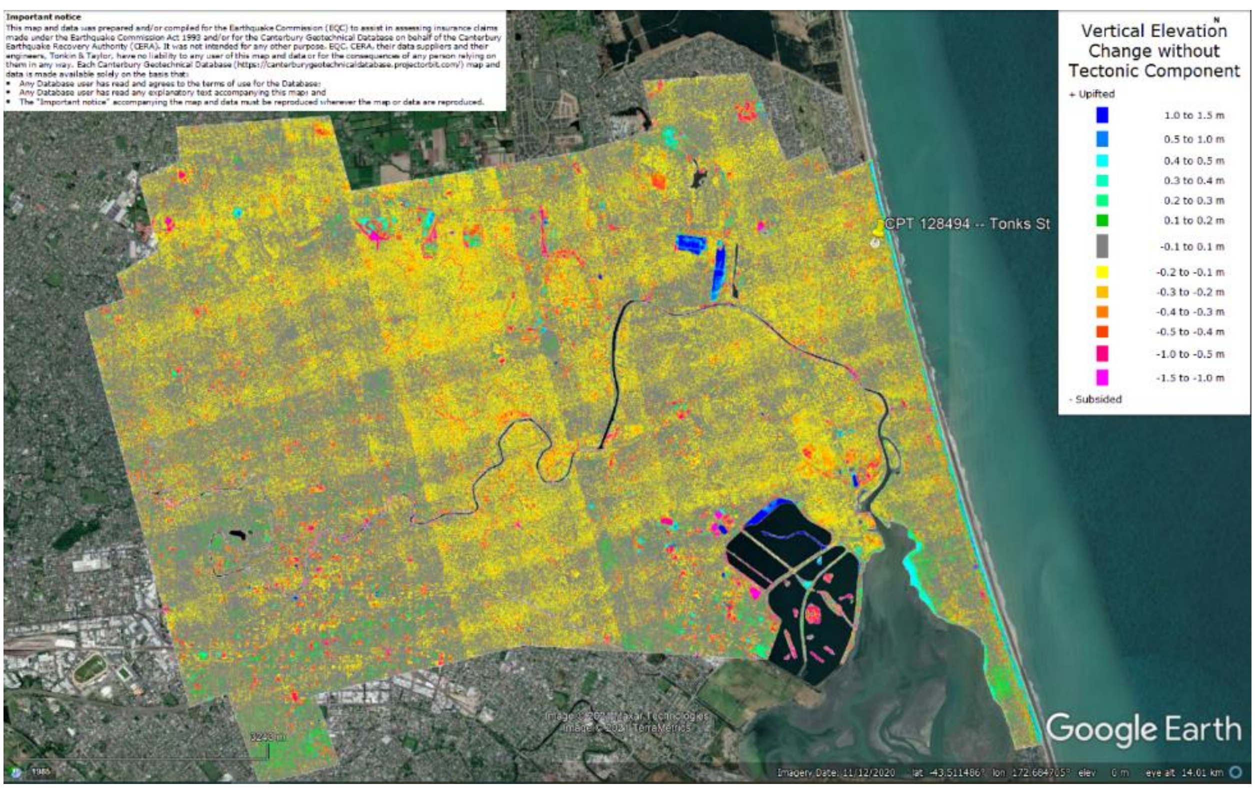

Figure 19: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake – the site is not in the apparent zone of overestimated ground surface subsidence.

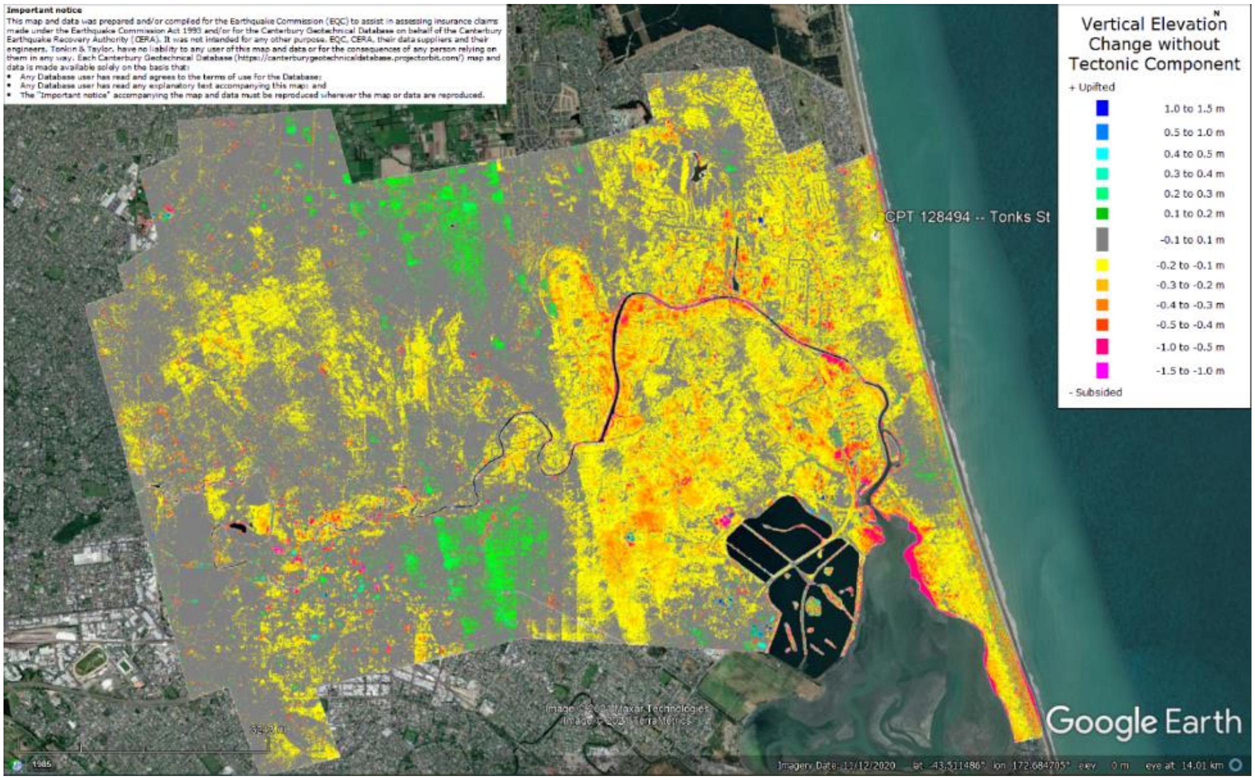

Figure 20: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake – the site is not in the apparent zone of underestimated ground surface subsidence.

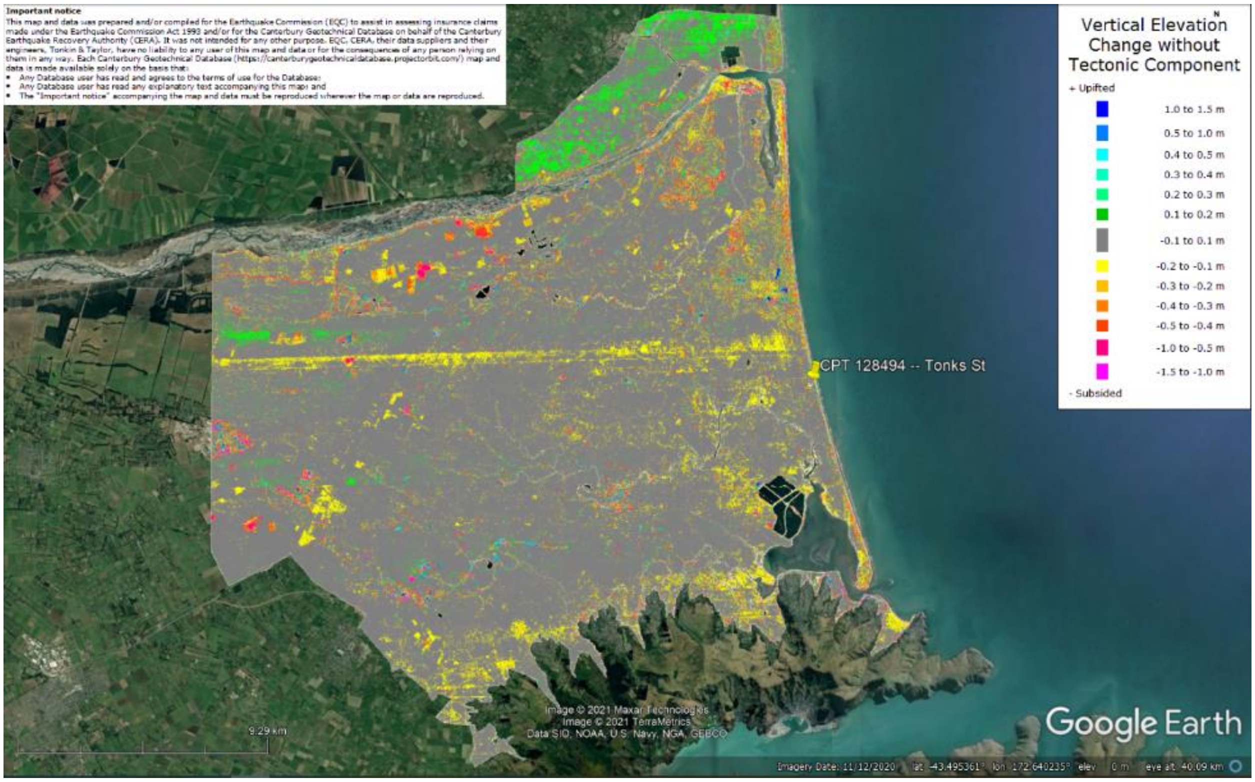

Figure 21: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

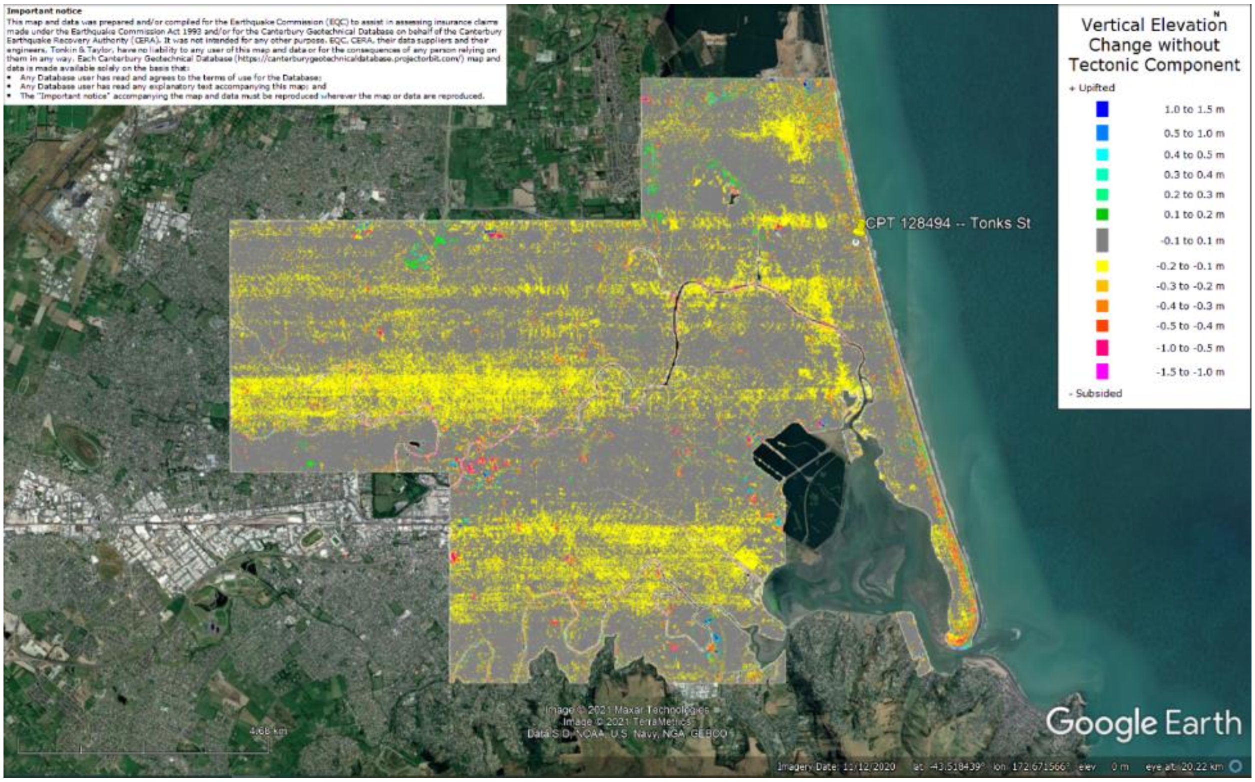

Figure 22: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake – the site is not in the apparent zone of overestimated/underestimated ground surface subsidence.

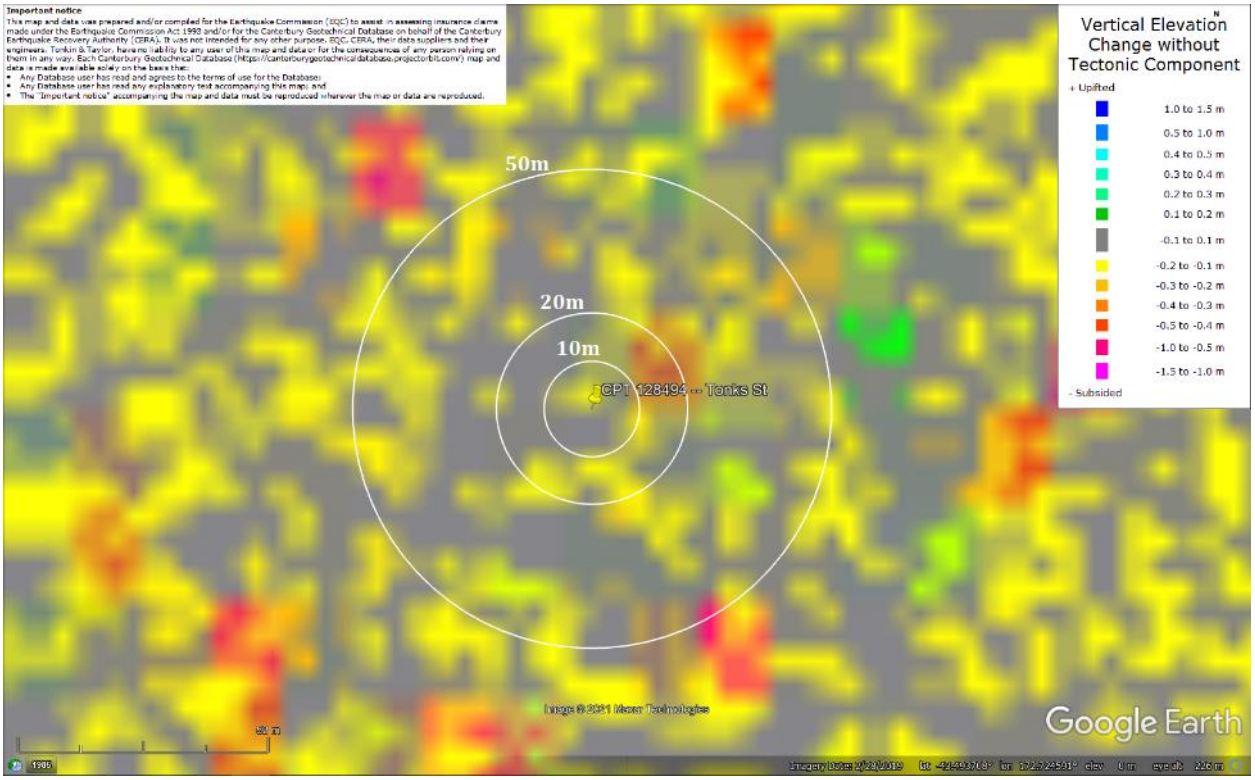

Figure 23: Ground surface subsidence without tectonic component for Sep 2010 Earthquake according to the LiDAR DEM.

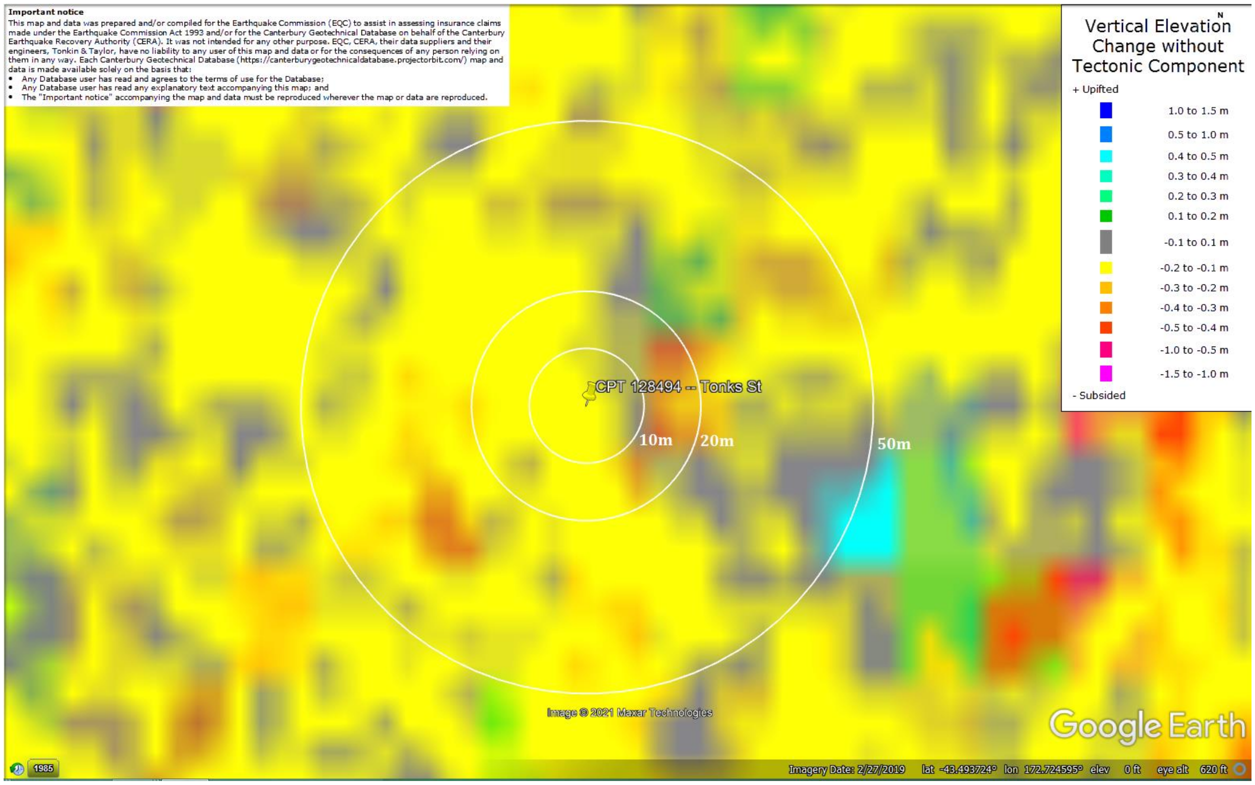

Figure 24: Ground surface subsidence without tectonic component for Feb 2011 Earthquake according to the LiDAR DEM.

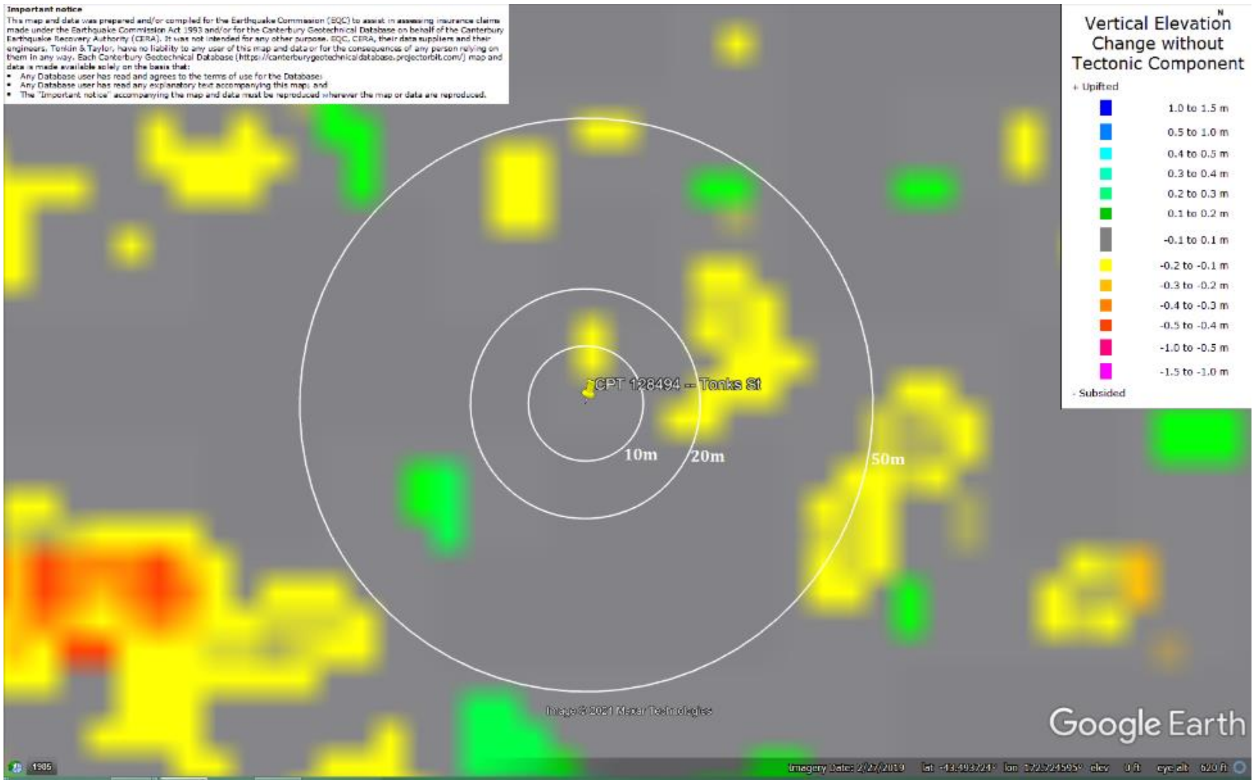

Figure 25: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

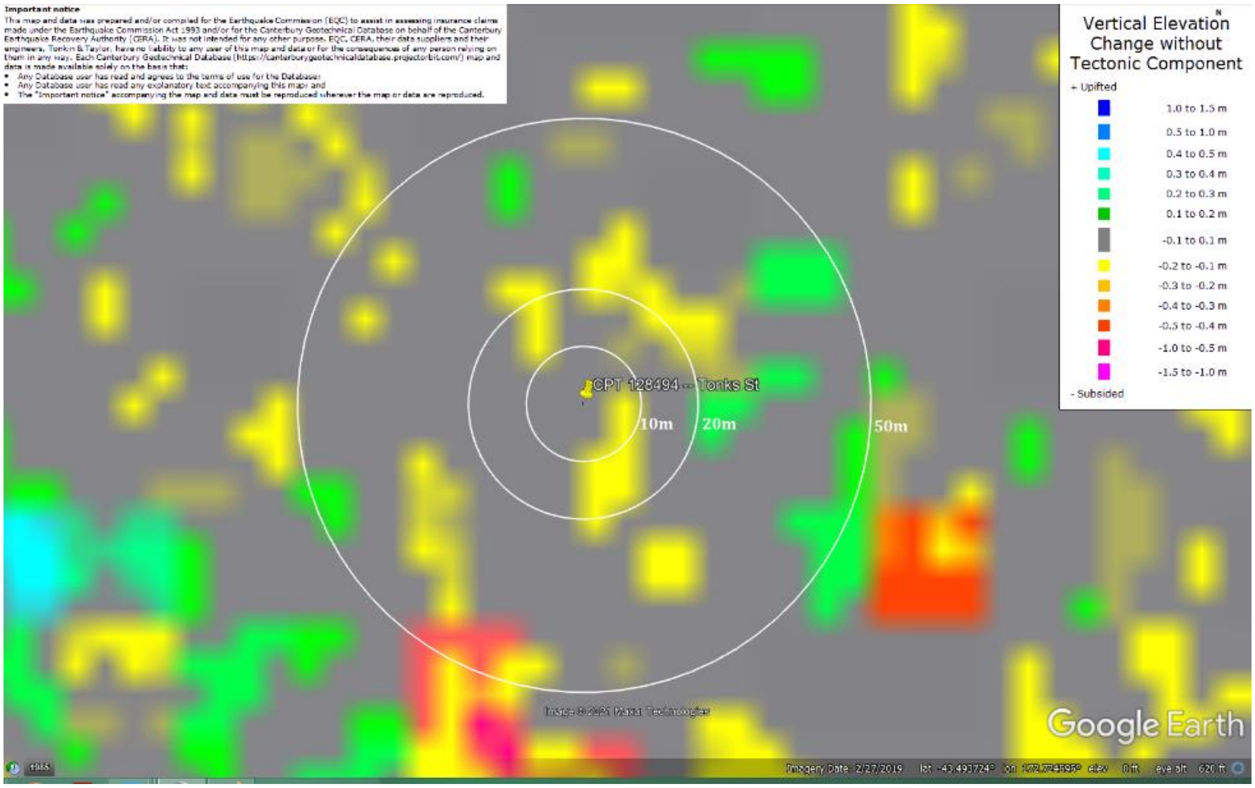

Figure 26: Ground surface subsidence without tectonic component for Dec 2011 Earthquake according to the LiDAR DEM.

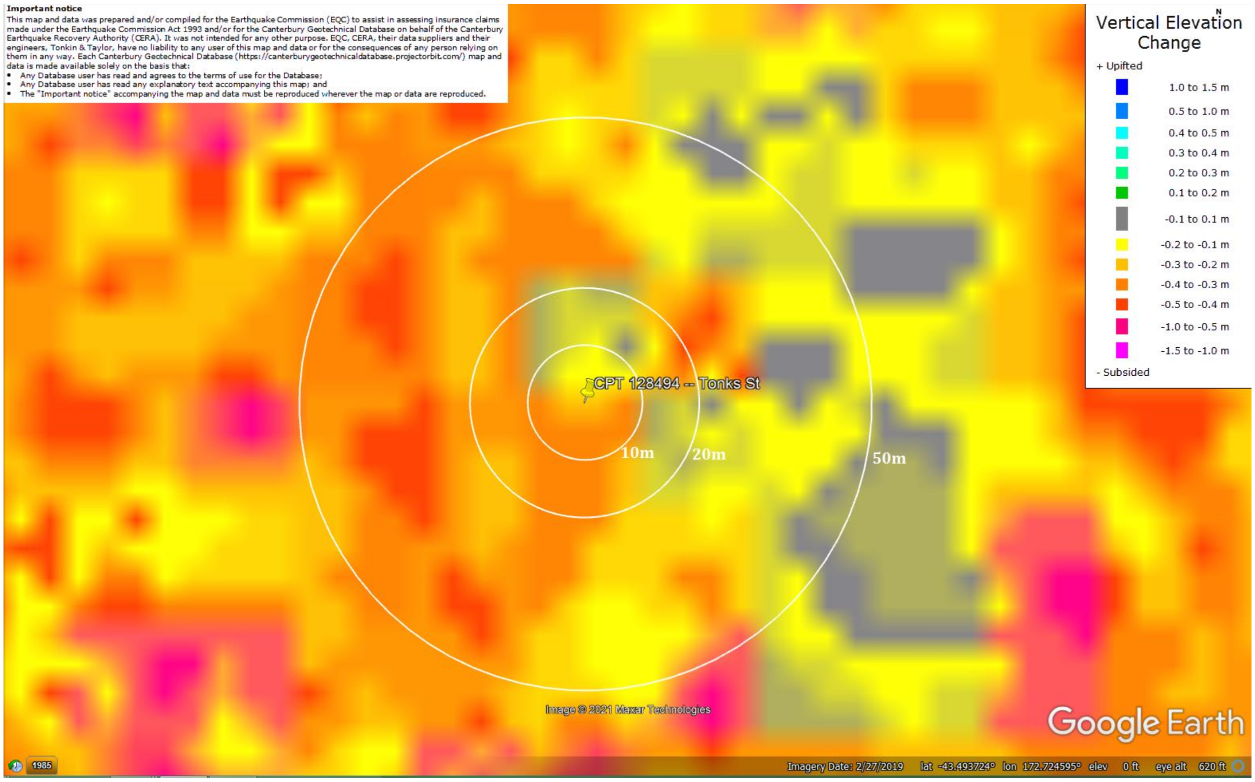

Figure 27: Ground surface subsidence without tectonic component for Canterbury Earthquake Sequence according to the LiDAR DEM.

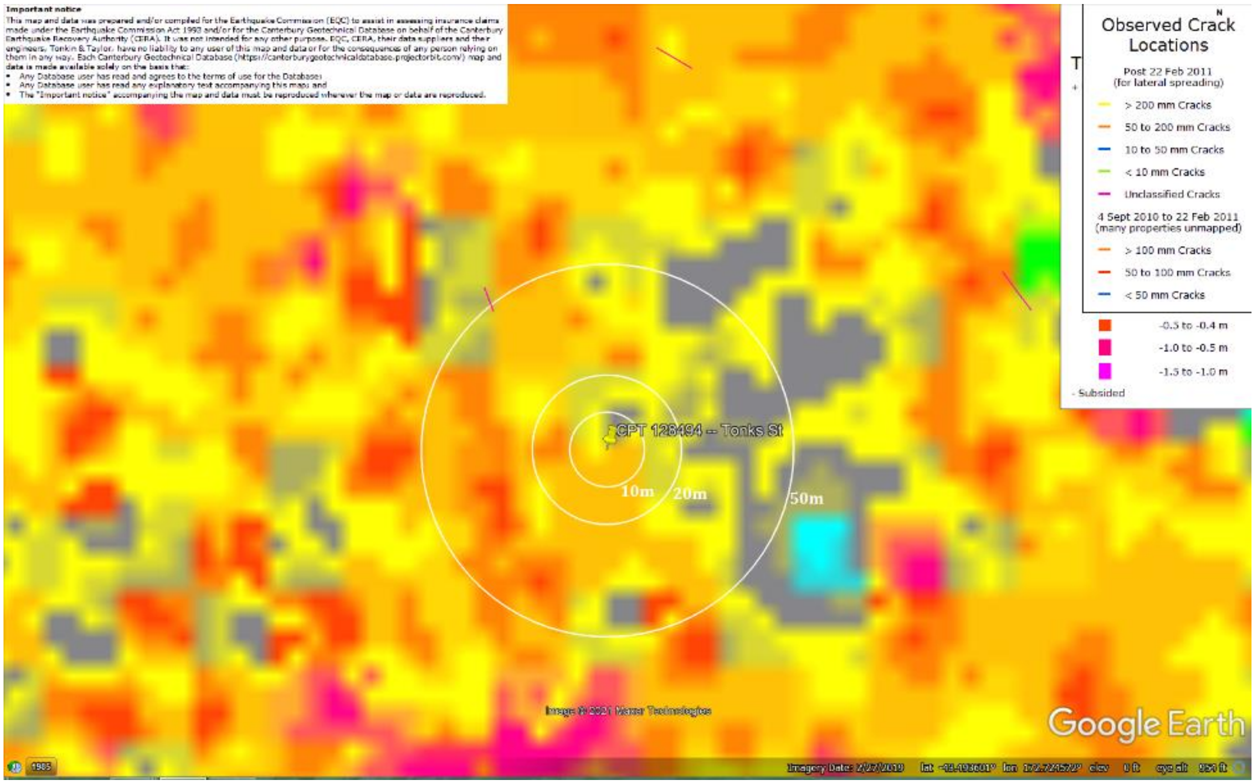

Figure 28: No lateral spreading for Canterbury Earthquake Sequence.

Figure 29: Vertical tectonic movements for Sep 2010 Earthquake.

Figure 30: Vertical tectonic movements for Feb 2011 Earthquake.

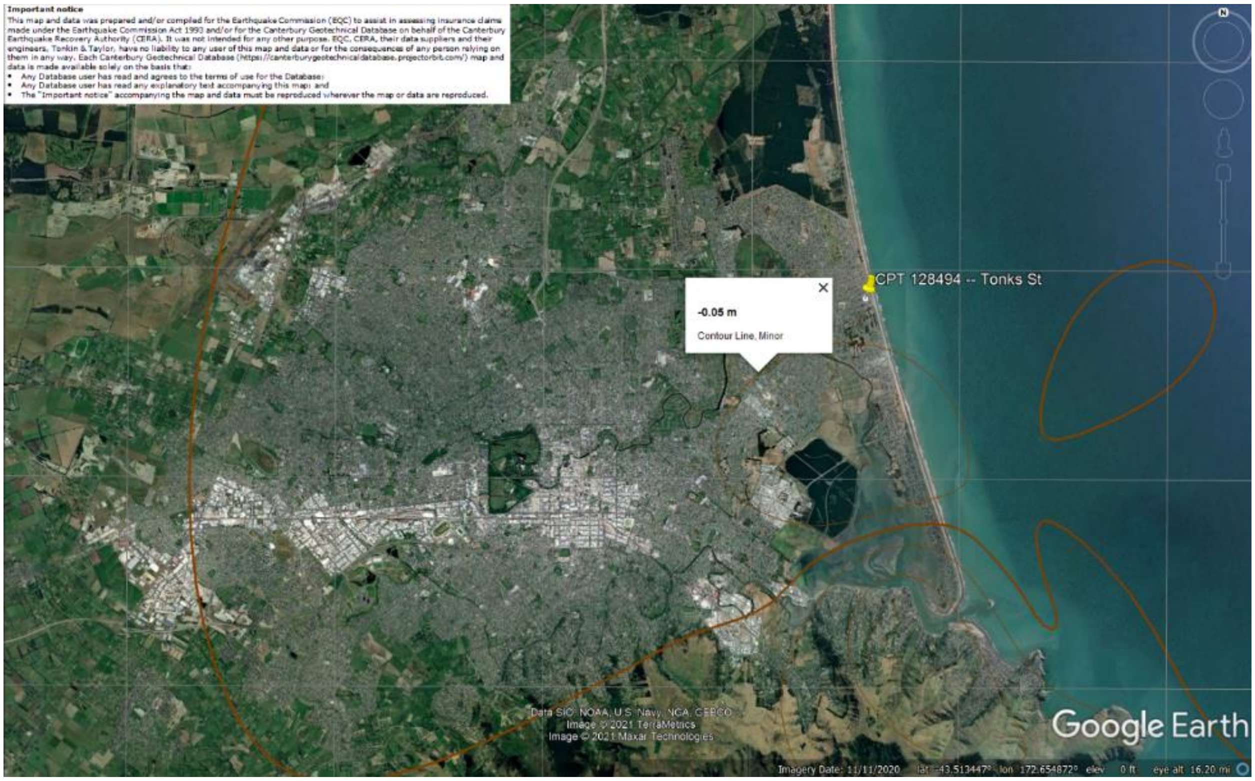

Figure 31: Vertical tectonic movements for June 2011 Earthquake.

Figure 32: Vertical tectonic movements for Dec 2011 Earthquake.

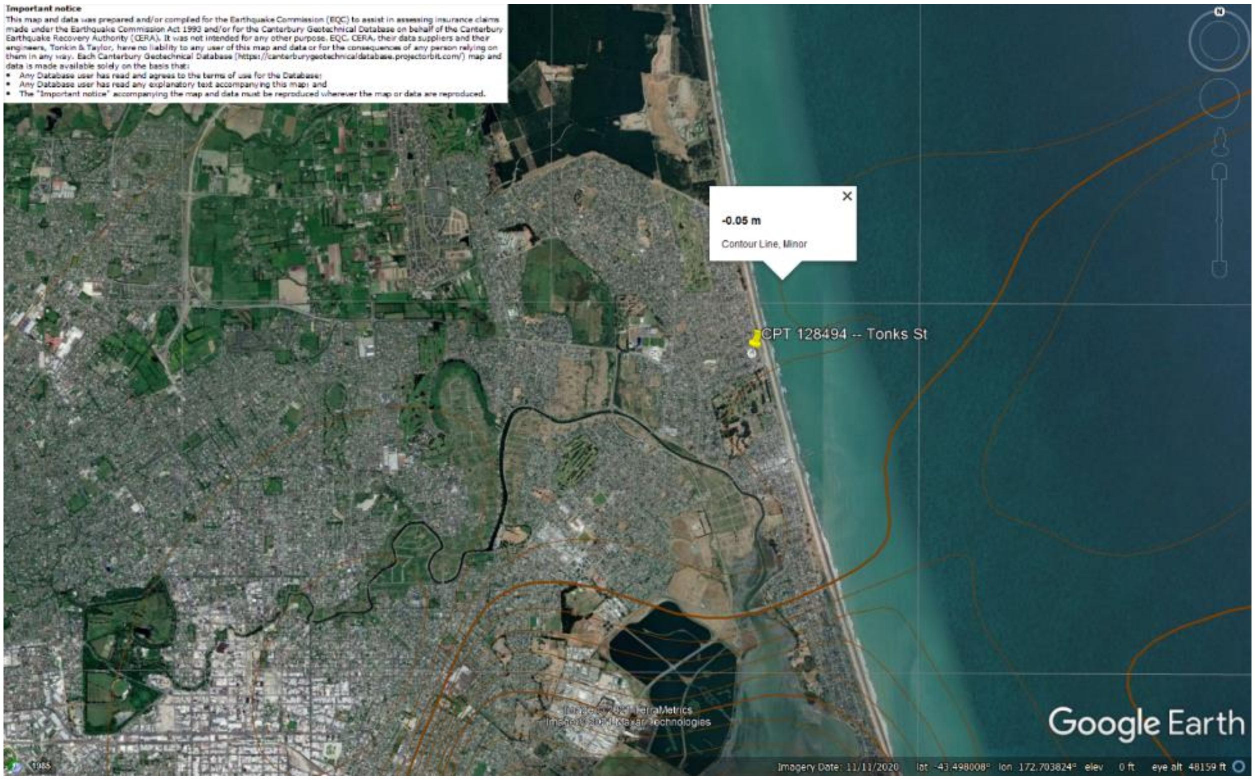

Figure 33: Vertical tectonic movements for Canterbury Earthquake Sequence.

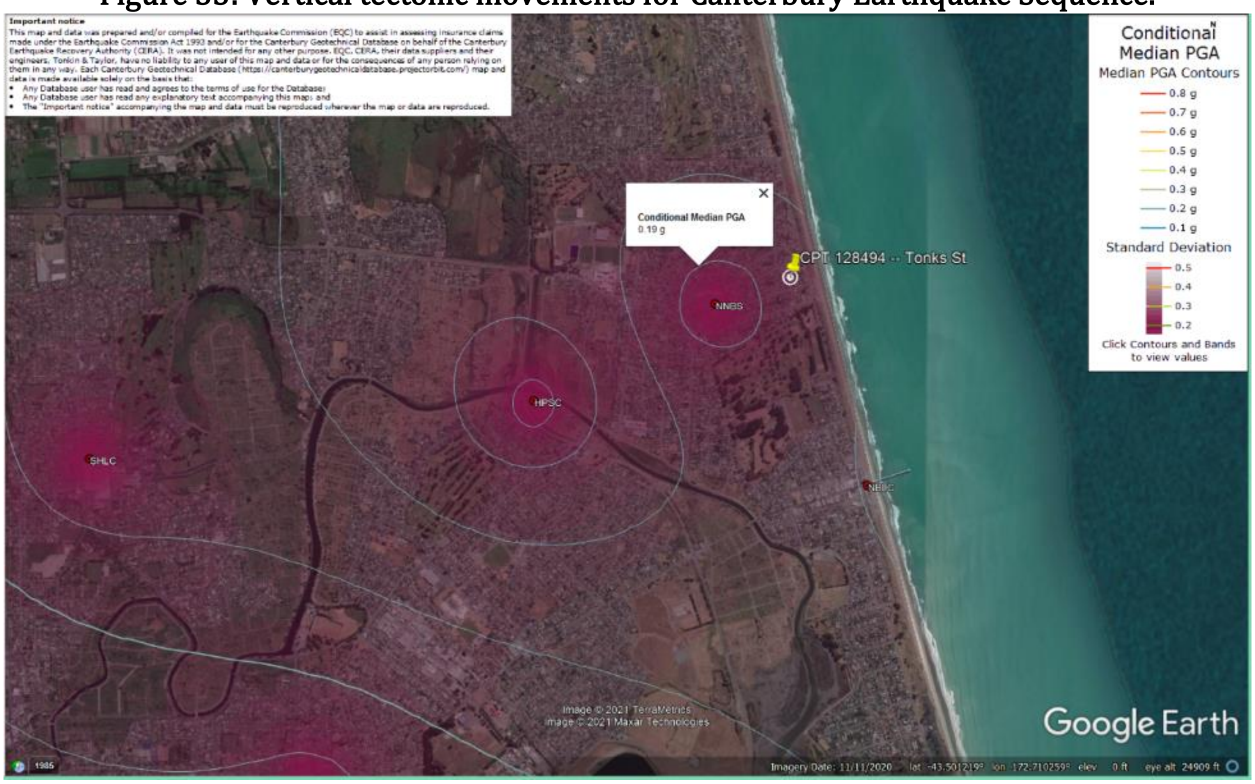

Figure 34: PGA for Sep-10 EQ (st. dev. = 0.250-0.300 ln units).

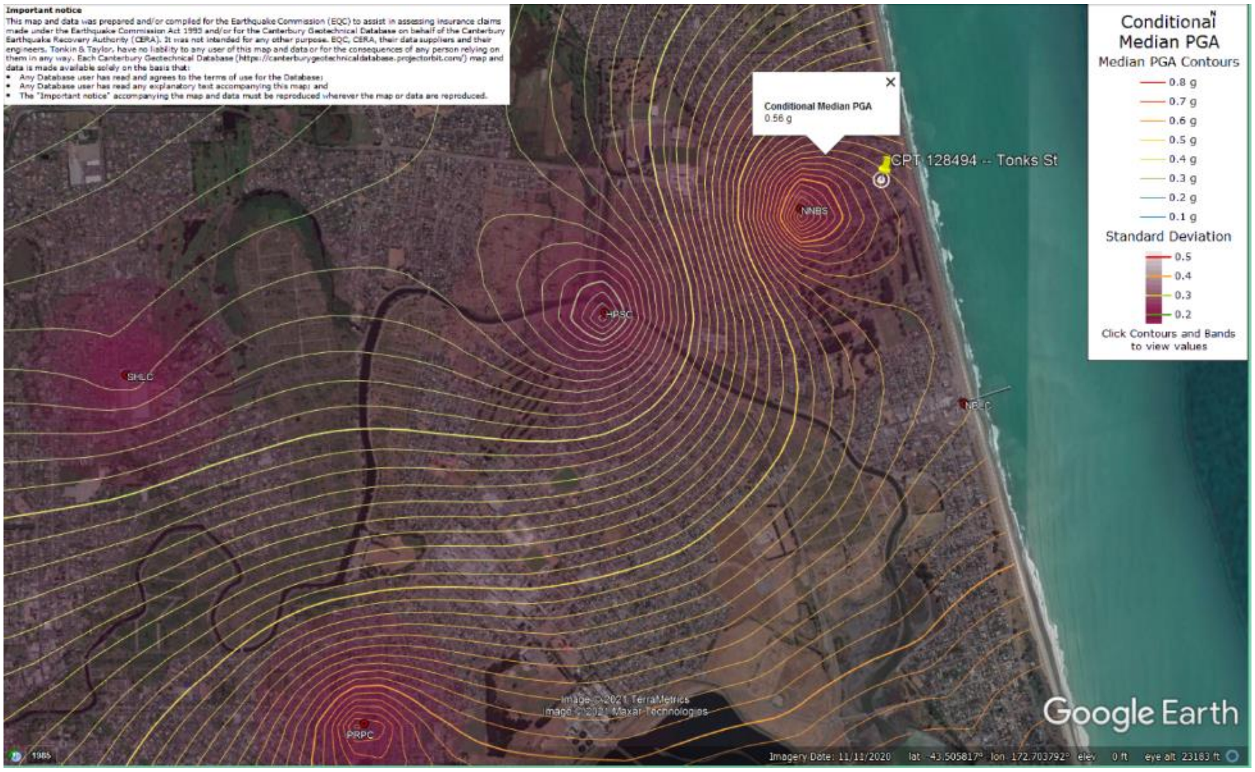

Figure 35: PGA for Feb-11 EQ (st. dev. = 0.275-0.300 ln units).

Figure 36: PGA for Jun-11 EQ (st. dev. = 0.275-0.300 ln units).

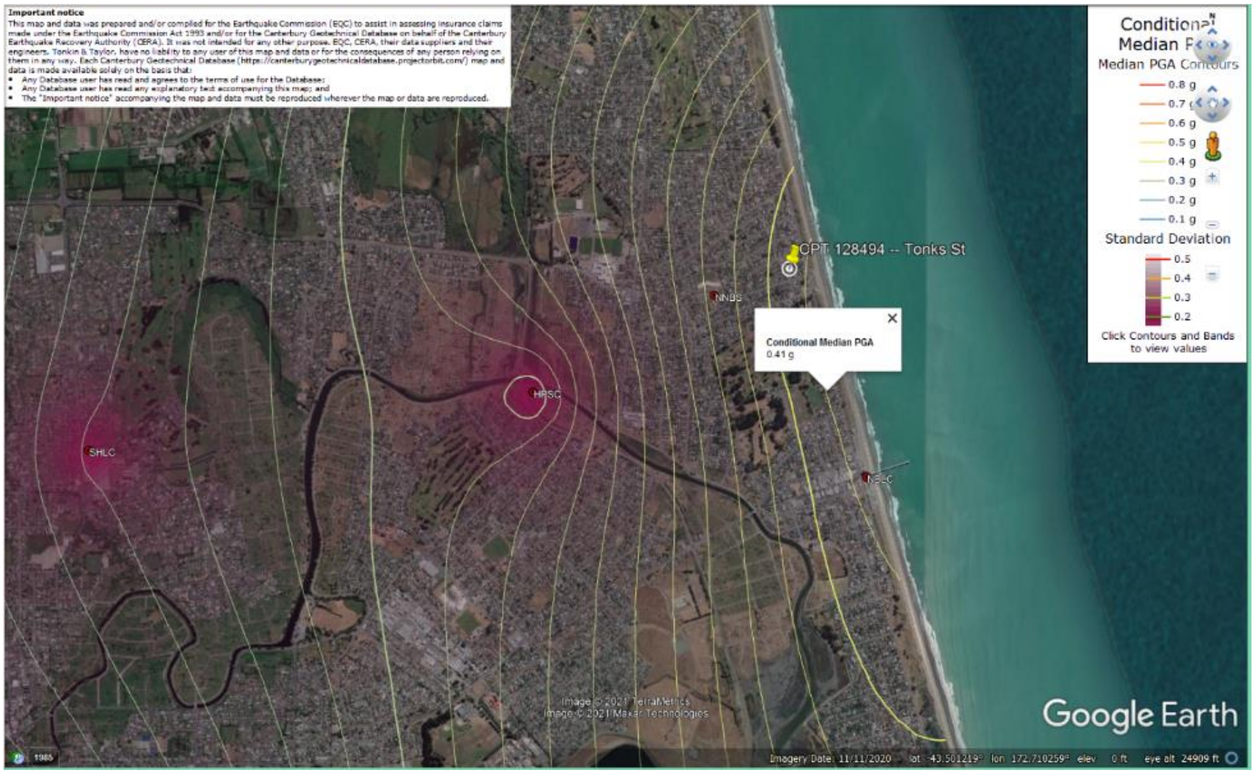

Figure 37: PGA for Dec-11 EQ (st. dev. = 0.400-0.425 ln units).

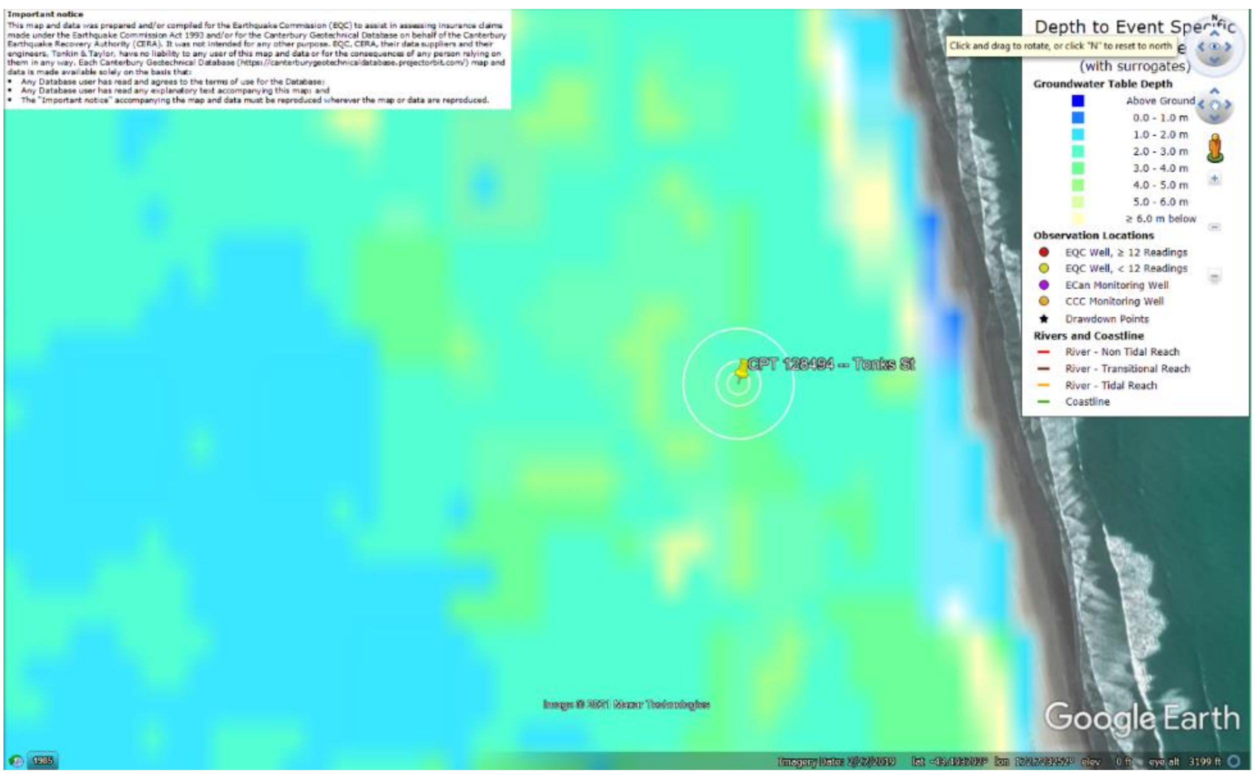

Figure 38: Depth to groundwater table for Sep-10 EQ.

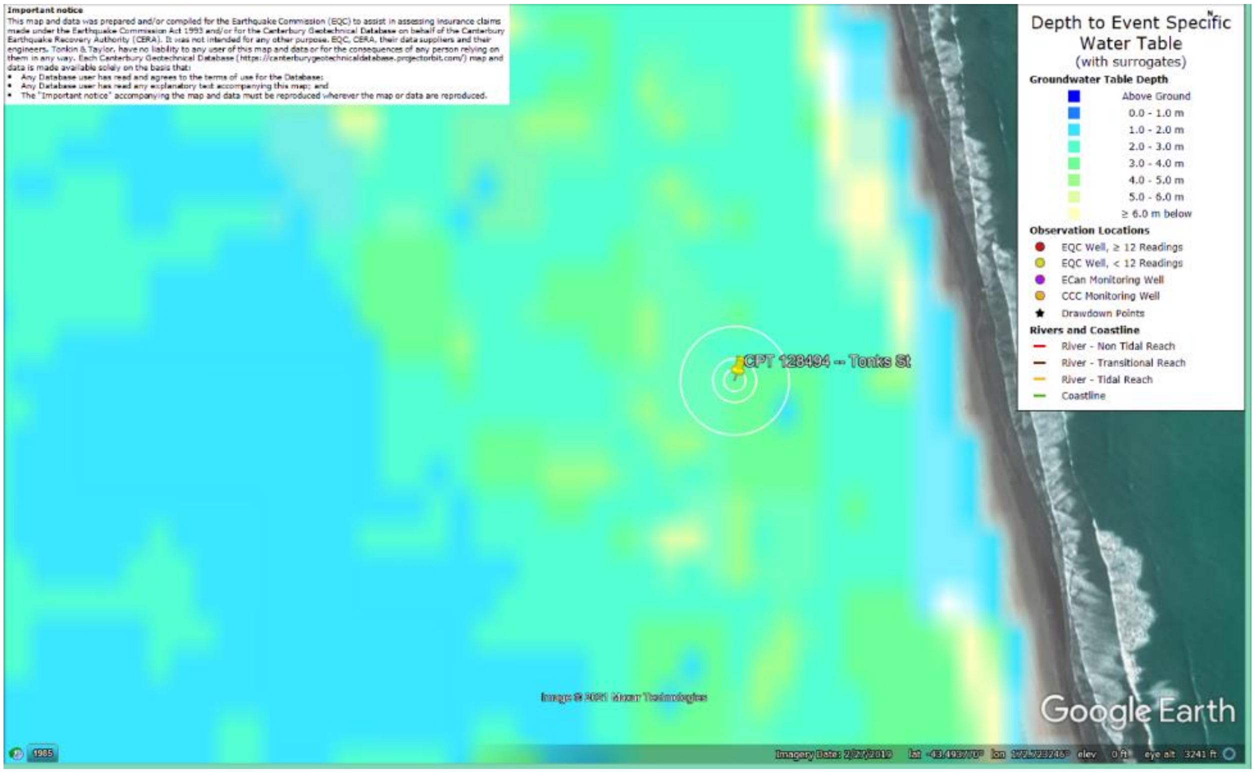

Figure 39: Depth to groundwater table for Feb-11 EQ.

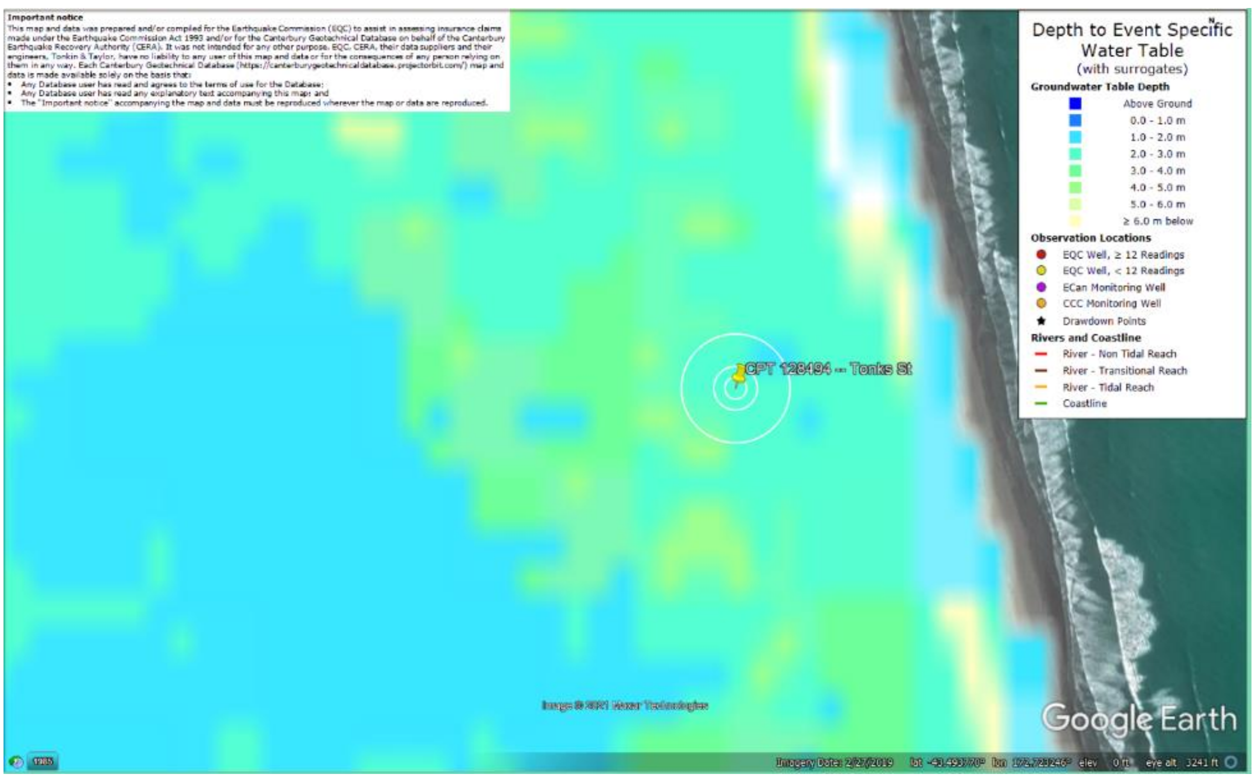

Figure 40: Depth to groundwater table for Jun-11 EQ.

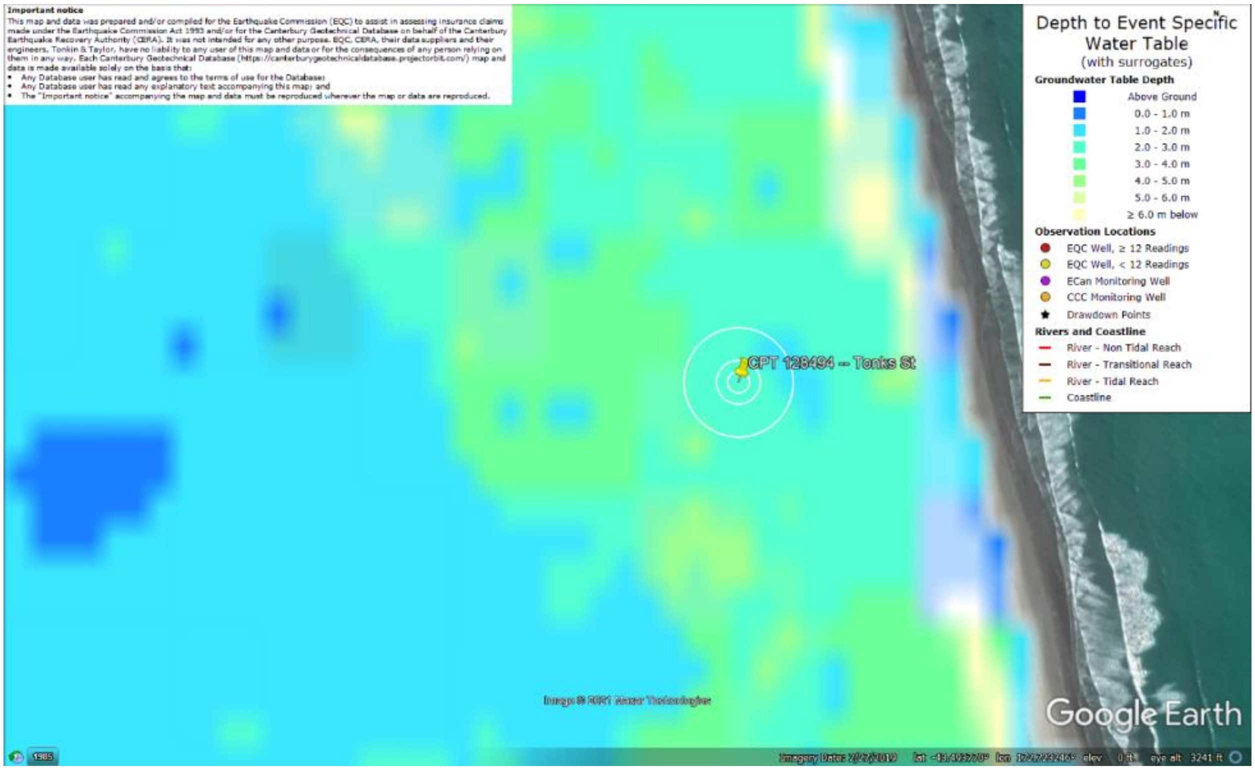

Figure 41: Depth to groundwater table for Dec-11 EQ.

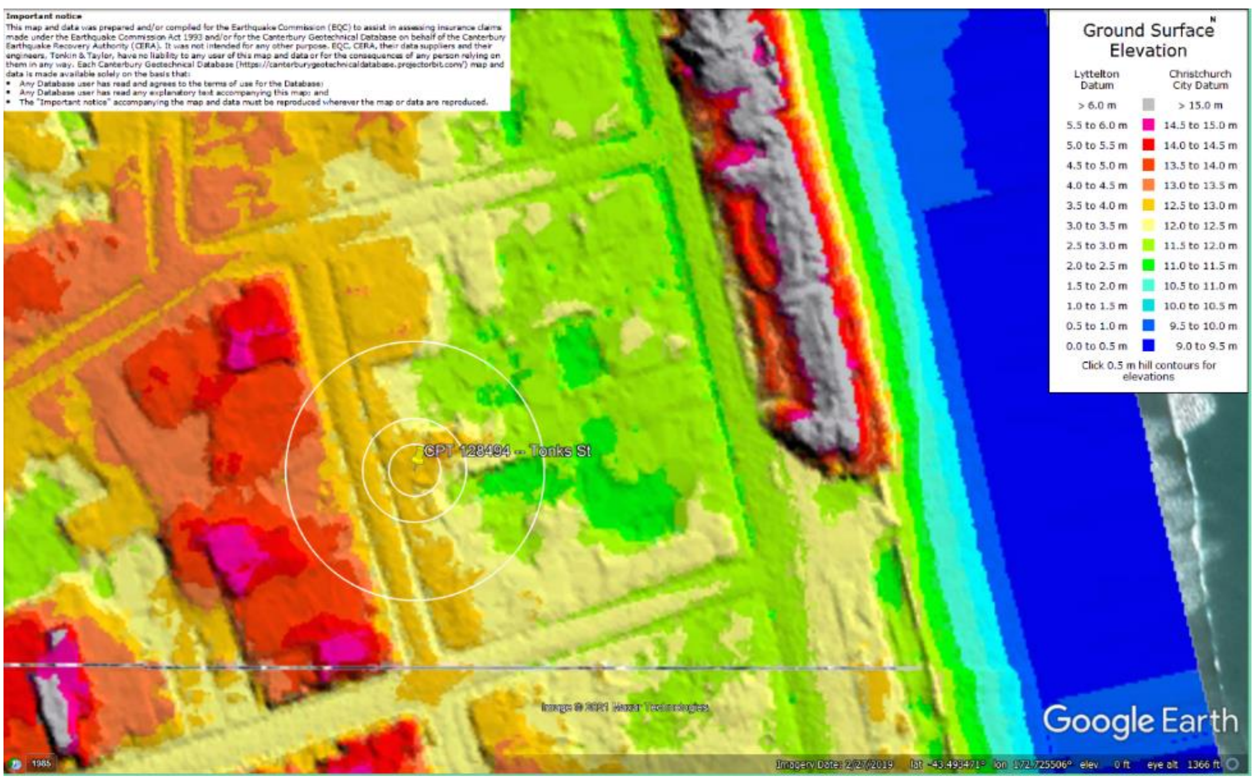

Figure 42: Ground surface elevation according to the Sep-11 LiDAR survey.

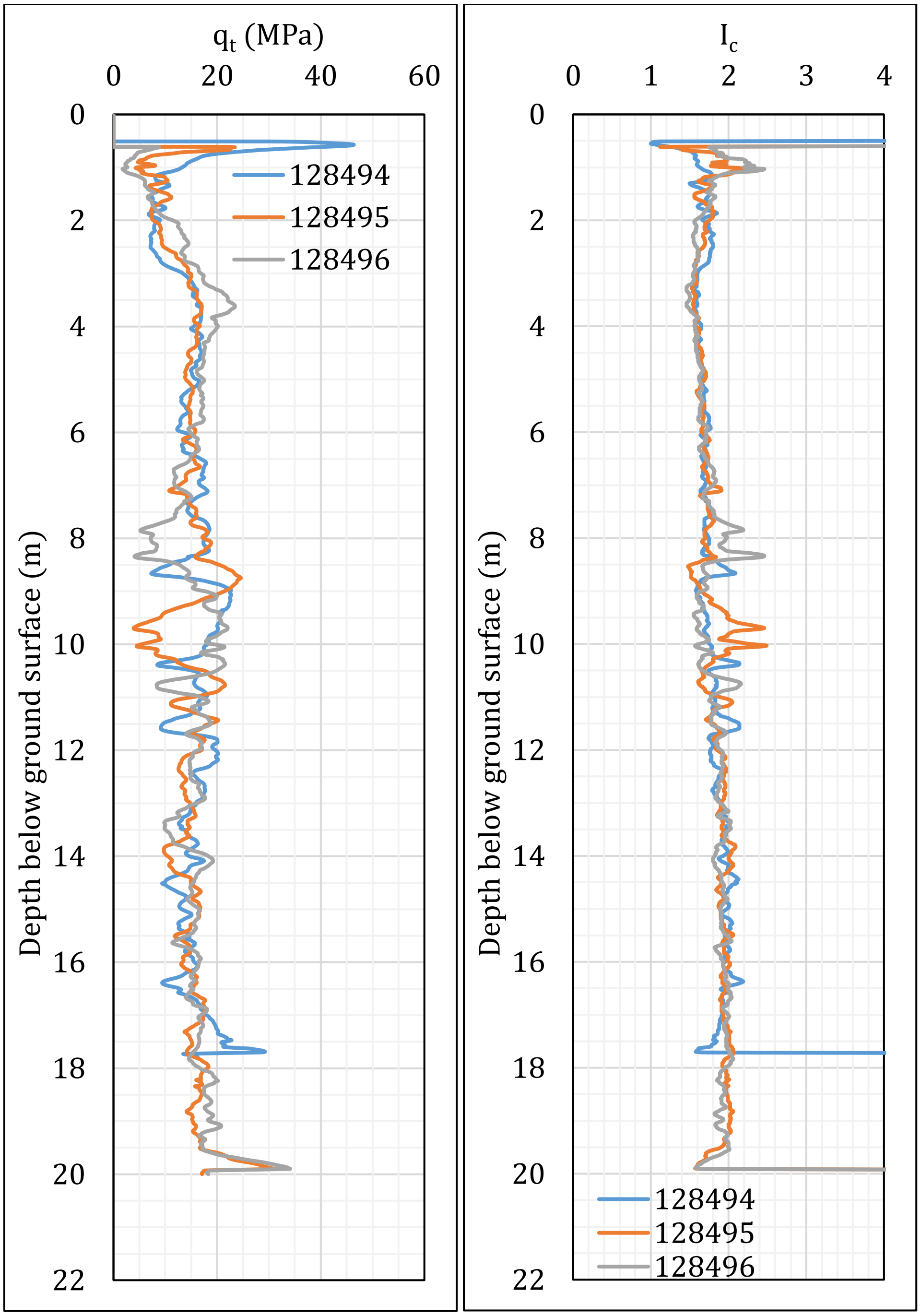

Figure 43: q_t and I_c profiles.

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 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 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
128494 (140497)	✓	✓	✓
128495 (140498)		✓	✓
128496 (140499)			✓

Note: The CPTs do not have pore water pressure measurements; It is assumed for CPT 128494 that the volumetric settlement below a 17.6-m depth is negligible.

Table 6: CPT-based results.

		CPT ID		
EQ Event	Parameter	128494	128495	128496
Sep-10	S_{V1D} (mm)	0	2	1
	LSN	0	0	0
	LPI	0	0	0
	LPI_{ish}	0	0	0
	$D_{FS<1}$ (m)	undet.	undet.	undet.
Feb-11	S_{V1D} (mm)	14	25	31
	LSN	1	2	3
	LPI	1	2	3
	LPI_{ish}	0	1	1
	$D_{FS<1}$ (m)	8.52	9.4	7.7
Jun-11	S_{V1D} (mm)	0	2	1
	LSN	0	0	0
	LPI	0	0	0
	LPI_{ish}	0	0	0
	$D_{FS<1}$ (m)	undet.	undet.	undet.
Dec-11	S_{V1D} (mm)	6	16	17
	LSN	1	2	2
	LPI	0	1	1
	LPI_{ish}	0	1	1
	$D_{FS<1}$ (m)	undet.	9.50	7.75

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 CPT 128494 (and nearby borehole logs), the soil profile below the topsoil consists of (1) fine to medium sand, SP, to a depth of 1 m, (2) silty sand, SM, to a depth of 3 m, and (3) fine to medium sand, SP, to a depth of 20 m. According to the hand auger scala report (HA DCP 37240, ~100 m to the SE from the center of the site), the groundwater table is at a depth of ~2.5 m below the ground surface. The nearest borehole log (BH 125677, ~430 m to the NW from the center of the site) suggests that all soil layers are of the Christchurch formation.