Appendix A.4:

Caulfield Ave – VsVp 38175

Table 1: Site Description for Caulfield Ave ($v_s v_p$ 38175).

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	NA	NA
Lateral spreading observed during the CES?	No	No	No	Ground cracks indicating lateral spreading were not observed by the mapping team.[1]	NA
Nearby buildings or structures?	Yes	Yes	Yes	Temporary structures in July 2015.	NA
Sloping land?	No	No	No	NA	NA
Step changes in the ground surface?	Yes	Yes	Yes	Addition of embankment sometime between July 2011 and April 2012.	NA
Retaining walls?	No	No	No	NA	NA
Vegetation?	Yes	Yes	Yes	Removal of green surface sometime between Sep 6, 2010 and Feb 16, 2011 exposing soil. New green surface appears on March 29, 2011 and lasts through July 2011.	NA
Anthropogenic changes to the site between the LiDAR surveys?	Yes	Yes	Yes	Originally farm field, converted to a construction site in its entirety sometime between July 2, 2011 and Apr 27, 2012. Major earthwork was performed.	NA
Other important factors?	Yes	Yes	Yes	Cattle appeared on several satellite images.	NA

Notes: Buffer is the area within a circle of a specified radius with VsVp investigations done at its center (172.548658, -43.579706); Oct 2015 LiDAR survey is excluded from the settlement analysis due to the anthropogenic changes.

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

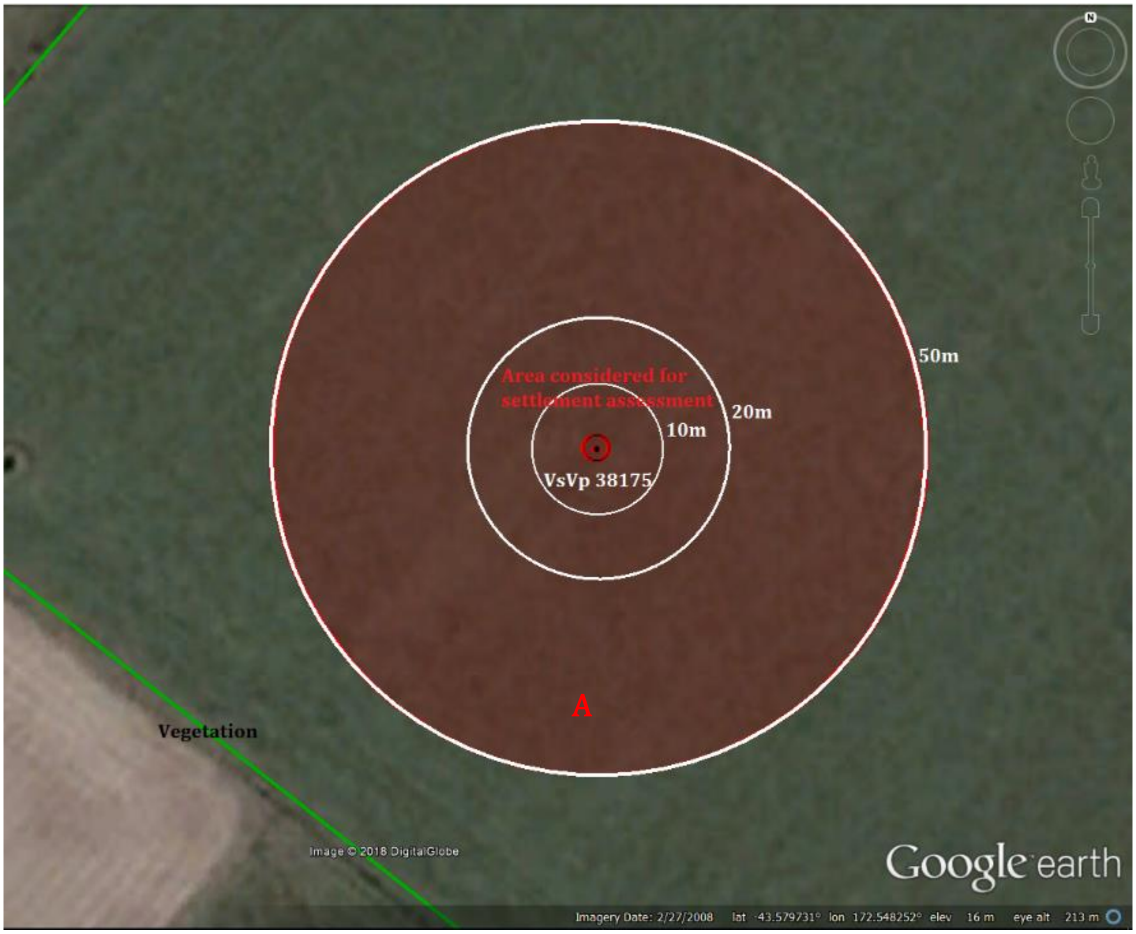

Figure 1: Site plan with areas where LiDAR survey data is considered.

Note 1: The area selected for settlement assessment (Patch A) is free of vegetation, structures, manmade changes, and other important factors that have the potential to influence LiDAR measurements.

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	-30
Feb-11	NA	16	-20
Jun-11	-300	38	0
Dec-11	NA	-65	0
CES	NA	-14	-50
Any LiDAR survey affected by ejecta?*			Yes

*Ground surface subsidence is underestimated for Sep-10 Earthquake and overestimated for Feb-11 Earthquake thus add 20mm of ground surface subsidence to the Sep-10 event and subtract 20mm from the Feb-11 event. The amount is based on judgment and minor quantum of observed ejecta.

Notes: The negative sign indicates the subtraction from the ground surface subsidence, while the positive sign indicates the addition to the ground surface subsidence; NA = Not available.

Table 3: LiDAR Measurement Error.

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

Earthquake Event(s)	$σ_{pre\text{-}EQ\ LiDAR\ survey}$ (mm)	$σ_{post\text{-}EQ\ LiDAR\ survey}$ (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 3.

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

	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	357	351	328
Dec-11	NA	NA	NA
CES	NA	NA	NA

Table 6: Corrected liquefaction-related ground surface subsidence using original LiDAR points 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	95±NA	89±NA	66±NA
Dec-11	NA	NA	NA
CES	NA	NA	NA

Note: Plus/minus values are NA as per Table 4.

Table 7: Corrected liquefaction-related ground surface subsidence 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	NA	NA	NA	NA	NA	NA	NA	NA	NA
Feb-11	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jun-11	50	100	150	50	100	200	<50	50	200
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.

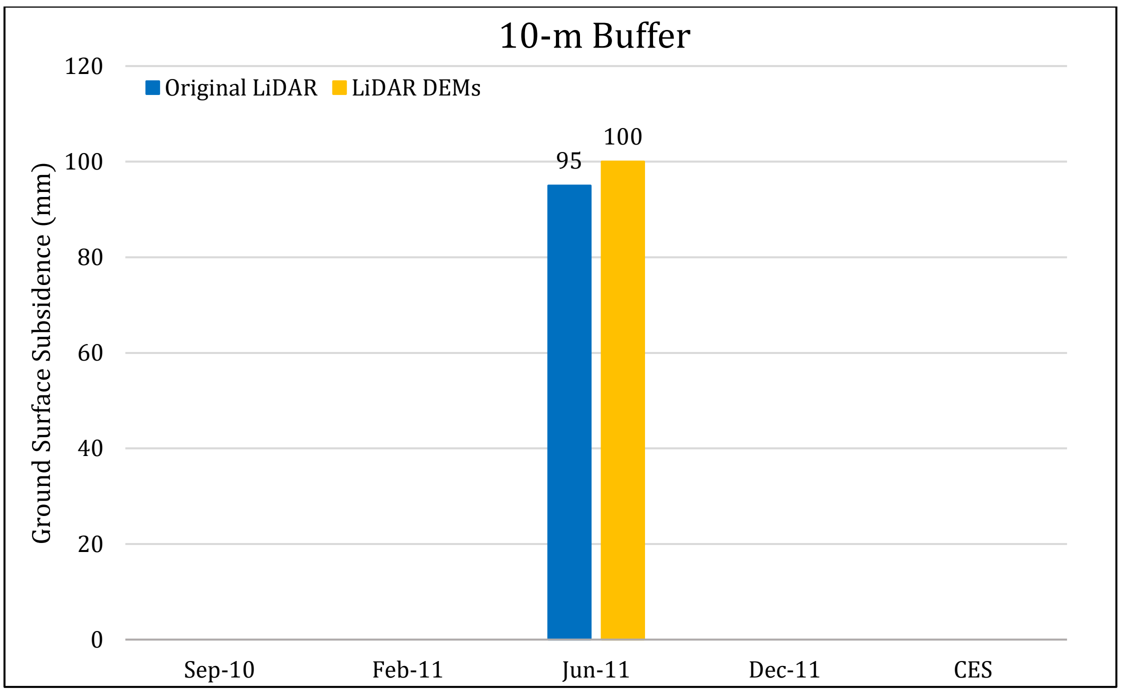

Figure 2: Comparison between ground surface subsidence determined from original LiDAR survey points and ground surface subsidence (50th %ile) estimated using LiDAR DEMs for the 10-m buffer.

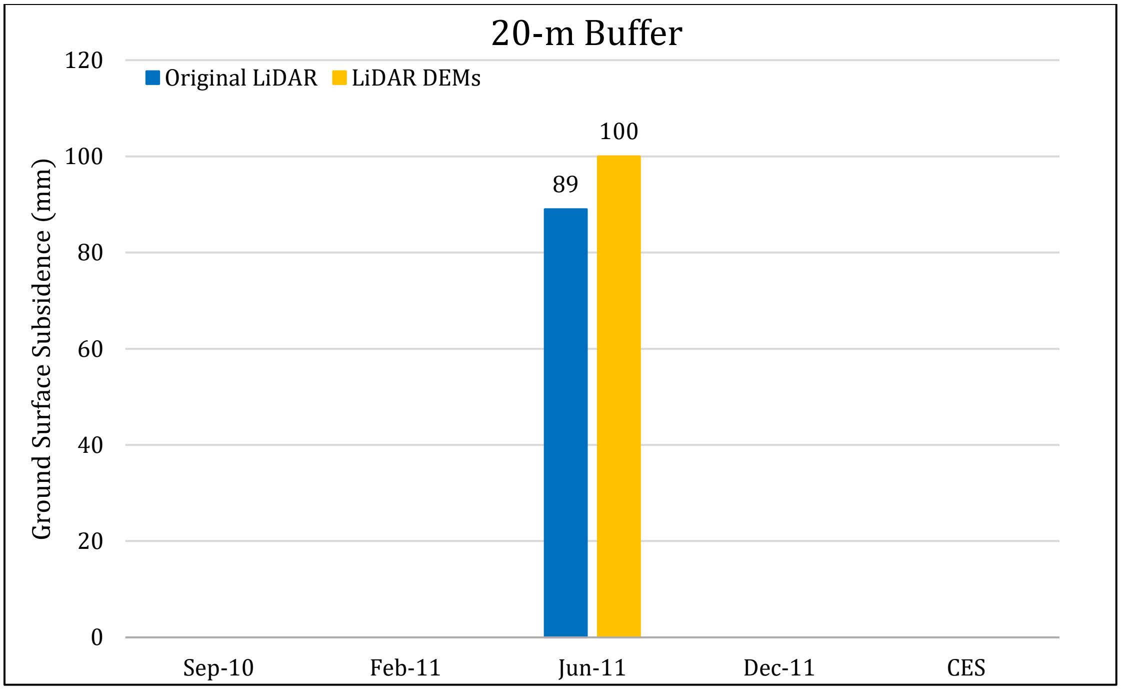

Figure 3: Comparison between ground surface subsidence determined from original LiDAR survey points and ground surface subsidence (50th %ile) estimated using LiDAR DEMs for the 20-m buffer.

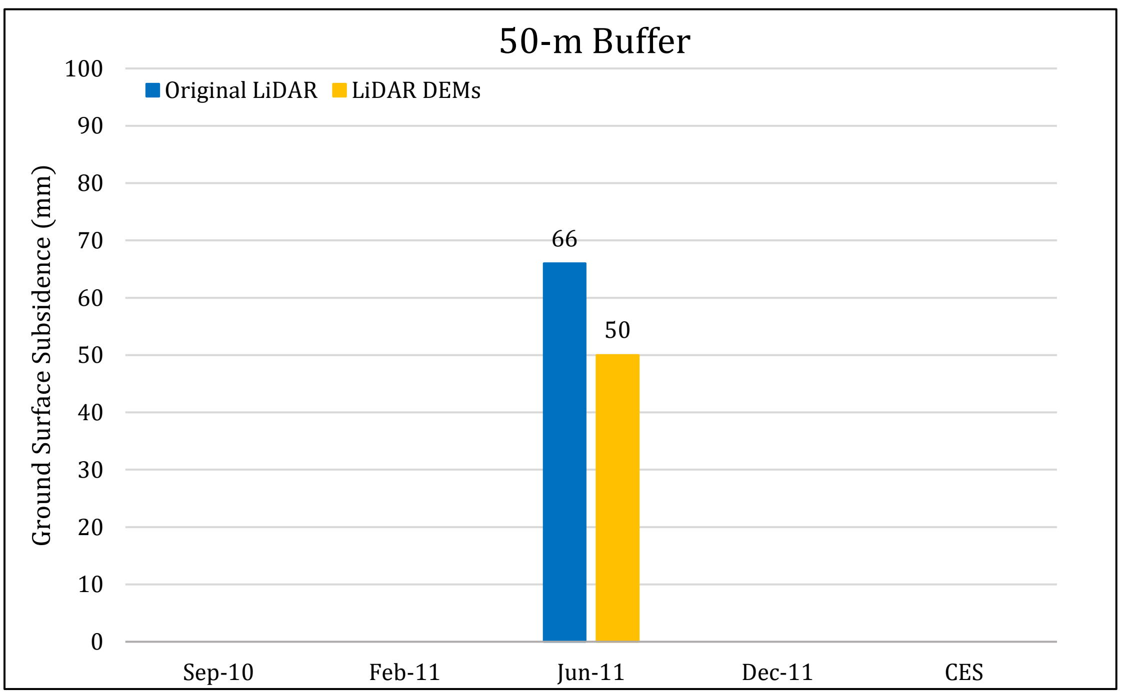

Figure 4: Comparison between ground surface subsidence determined from original LiDAR survey points and ground surface subsidence (50th %ile) estimated using LiDAR DEMs for the 50-m buffer.

Note 2: The ground surface subsidence values determined from original LiDAR survey points are similar to the ground surface subsidence values estimated using LiDAR DEMs for Jun-11 Earthquake.

Table 8a: Ejecta-Induced settlement for the top 20 m of the soil profile for the 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	0.31	0.5	NA	59±20	NA
Feb-11	6.2	0.32	0.5	NA	59±50	NA
Jun-11	6.2	0.13	0.5	95±NA	6±25	89±NA
Dec-11	6.1	0.12	0.5	NA	3±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) and 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}; NA = Not available.

Table 8b: Ejecta-Induced settlement for the top 20 m of the soil profile for the 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	0.31	0.5	NA	45±20	NA
Feb-11	6.2	0.32	0.5	NA	45±50	NA
Jun-11	6.2	0.13	0.5	89±NA	4±25	85±NA
Dec-11	6.1	0.12	0.5	NA	2±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) and 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}; NA = Not available.

Table 8c: Ejecta-Induced settlement for the top 20 m of the soil profile for the 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	0.31	0.5	NA	45±20	NA
Feb-11	6.2	0.32	0.5	NA	45±50	NA
Jun-11	6.2	0.13	0.5	66±NA	4±25	62±NA
Dec-11	6.1	0.12	0.5	NA	2±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) and 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}; NA = Not available.

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 the 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	67	10-30	0	0	314
Feb-11	0	0	0	0	314
Jun-11*	0	0	0	0	314
Dec-11*	0	0	0	0	314

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 uncertainty due to the lack of physical evidence.

Table 9b: Coverage area and height of ejecta estimates for the 20-m buffer using photographs.

Earthquake Event	$A_{E,thick}$ (m²)	$H_{E,thick}$ (mm)	$A_{E,thin}$ (m²)	$H_{E,thin}$ (mm)	A_T (m²)
Sep-10	124	10-30	0	0	1257
Feb-11	0	0	0	0	1257
Jun-11*	0	0	0	0	1257
Dec-11*	0	0	0	0	1257

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 uncertainty due to the lack of physical evidence.

Table 9c: Coverage area and height of ejecta estimates for the 50-m buffer using photographs.

Earthquake Event	$A_{E,thick}$ (m²)	$H_{E,thick}$ (m)	$A_{E,thin}$ (m²)	$H_{E,thin}$ (m)	A_T (m²)
Sep-10	281	10-30	103	5-10	7854
Feb-11	0	0	0	0	7854
Jun-11*	0	0	0	0	7854
Dec-11*	0	0	0	0	7854

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 uncertainty due to the lack of physical evidence.

Note 4: The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photograph (Figures 53, 55, and 56) and the lower and upper estimates of the ejecta height based on ground photographs taken in neighboring areas (Figure 54). The ejecta-induced settlement using photographs and engineering judgment, $S_{E,P}$, is estimated as

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

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, and A_T is the total assessment area for a buffer being considered (Figure 1). The $A_{E,thick,i}$ and $A_{E,thin,i}$ are contained within the buffer.

Table 10: Ejecta-induced settlement estimates based on aerial photographs.

Earthquake Event	10-m buffer		20-m buffer		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	2	6	1	3	≈0	1
Feb-11	0	0	0	0	0	0
Jun-11*	0	0	0	0	0	0
Dec-11*	0	0	0	0	0	0

Notes: $S_{E,P,lower}$ and $S_{E,P,upper}$ correspond to lower and upper estimates of $S_{E,P}$, respectively; * indicates uncertainty due to the lack of physical evidence.

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

Earthquake 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	NA	4±2	5±5	NA	2±1	<5	NA	0.5±0.5	<5
Feb-11	NA	0	0	NA	0	0	NA	0	0
Jun-11	89±NA	0*	0*	85±NA	0*	0*	63±NA	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; Final plus/minus values are also rounded to the nearest 5; * indicates uncertainty due to the lack of physical evidence.

Note 5: $S_{E,final}$ for the Sep-10 and Feb-11 earthquakes is based solely on $S_{E,P}$ due to the unavailability of $S_{E,L}$. For the Jun-11 earthquake, there is no aerial or ground photograph, only a satellite image acquired a month after the event showing no visible traces of ejecta at the site. (There are several insurance claims ≈500 m NE of the site with reports of ejecta and property damage. However, ejecta was also observed for the Feb-11 earthquake away from the site toward NE but not at the site.) The LiDAR-based results suggest ejecta at the site for the Jun-11 earthquake, but there is large uncertainty associated with May 2011 and Sep 2011 LiDAR measurements due to plowing of the paddock. For the Dec-11 earthquake, Figure 57 shows "liquefaction interpreted from aerial photography" as none for the nearby area, but there is no photograph or LDAT property inspection report at the site to report absence of ejecta with confidence. Also, the Caulfield Ave site is in the zone of moderate LPI overprediction for the Sep-10 earthquake and slight to moderate LPI overprediction for the Feb-11 earthquake (Maurer et al. 2014[3]).

Summary 1: The best estimate of the ejecta-induced free-field ground settlement at the Caulfield Ave site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is <5 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

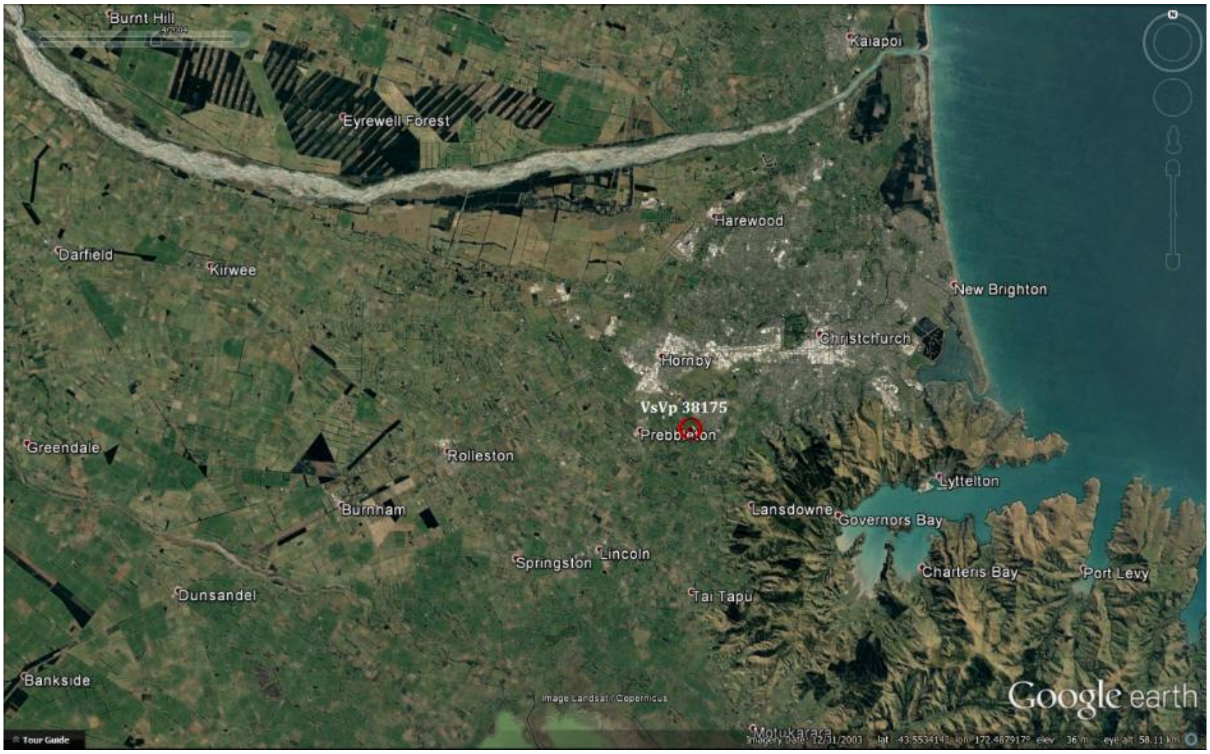

Figure 5: Location of the site.

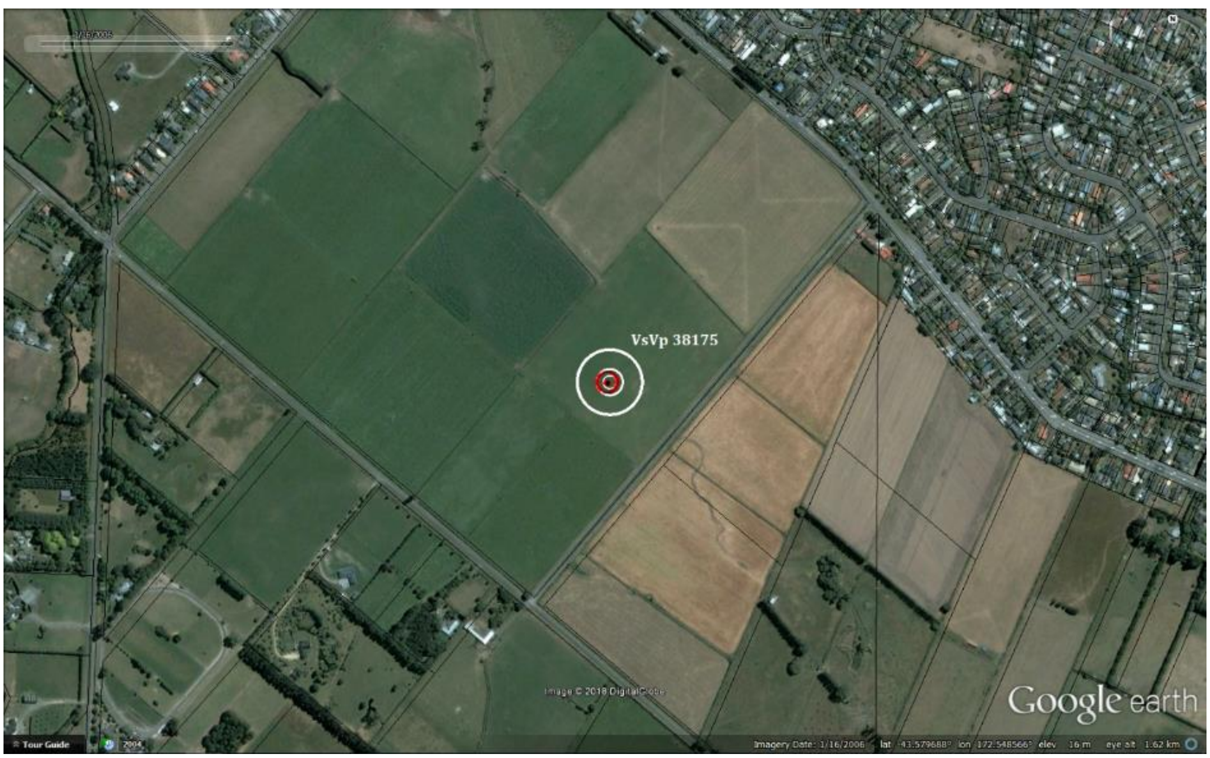

Figure 6: Position of the site relative to nearby buildings, vegetation, and other important features.

Figure 7: Street view of the flat land.

Figure 8: Satellite image of the site taken in Apr 2004 (note the cattle).

Figure 9. Satellite image of the site taken on Sep 6, 2010.

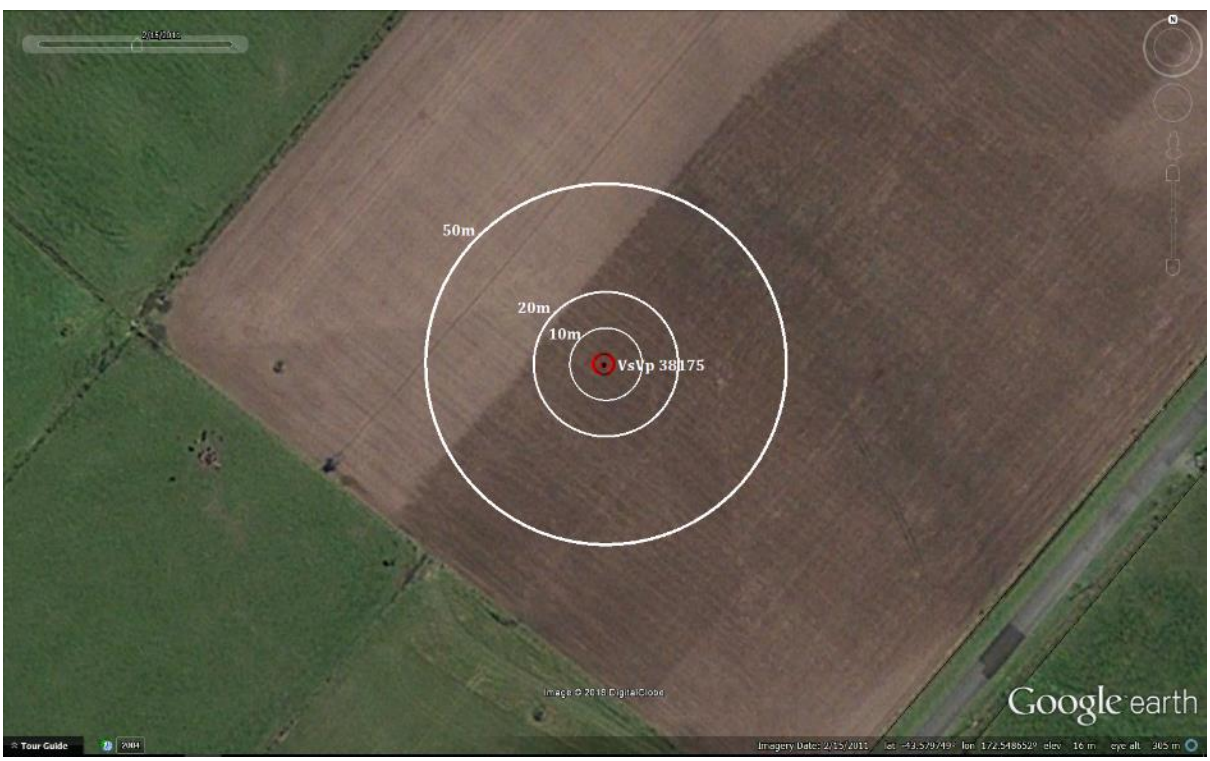

Figure 10. Satellite image of the site taken on Feb 16, 2011.

Figure 11. Satellite image of the site taken on Mar 29, 2011.

Figure 12: Satellite image of the site taken in July 2011.

Figure 13: Satellite image of the site taken in Apr 2012.

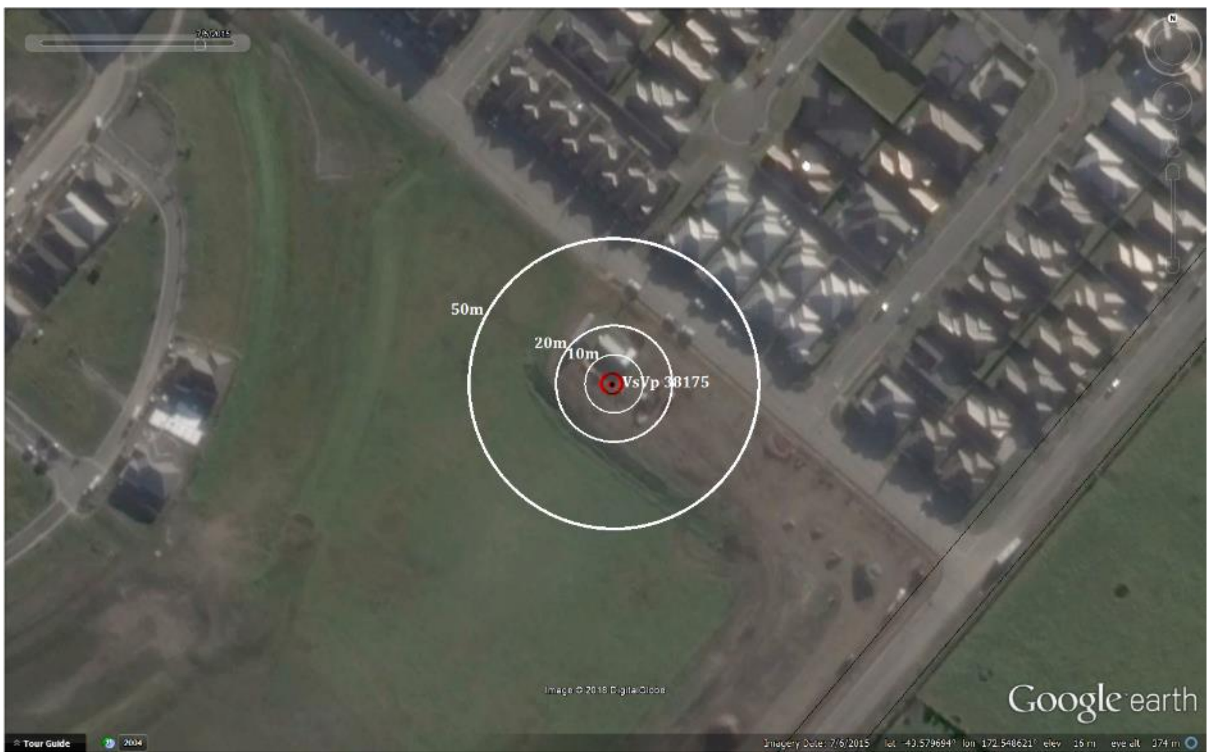

Figure 14. Satellite image of the site taken in July 2015.

Figure 15: Satellite image of the site taken in Nov 2015.

Figure 16: Satellite image of the site taken in March 2010.

Figure 17: Satellite image of the site taken on Sep 4, 2010.

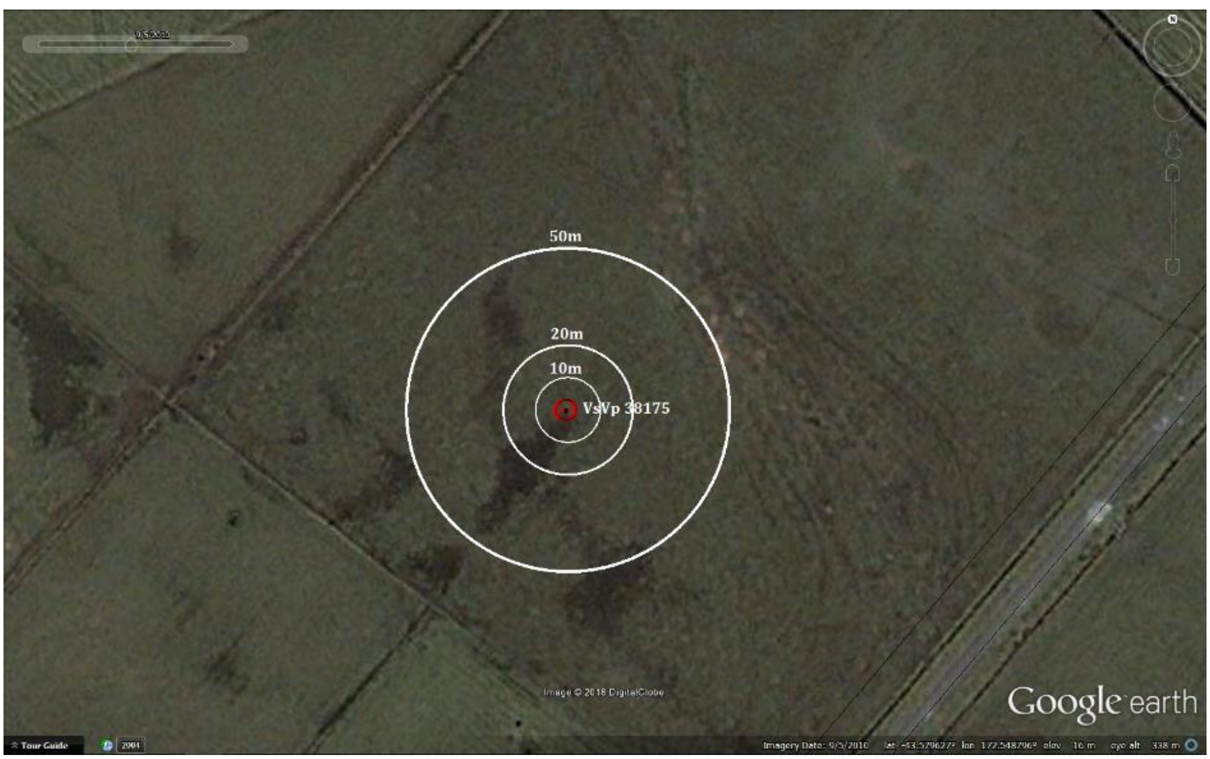

Figure 18: Satellite image of the site taken on Sep 6, 2010.

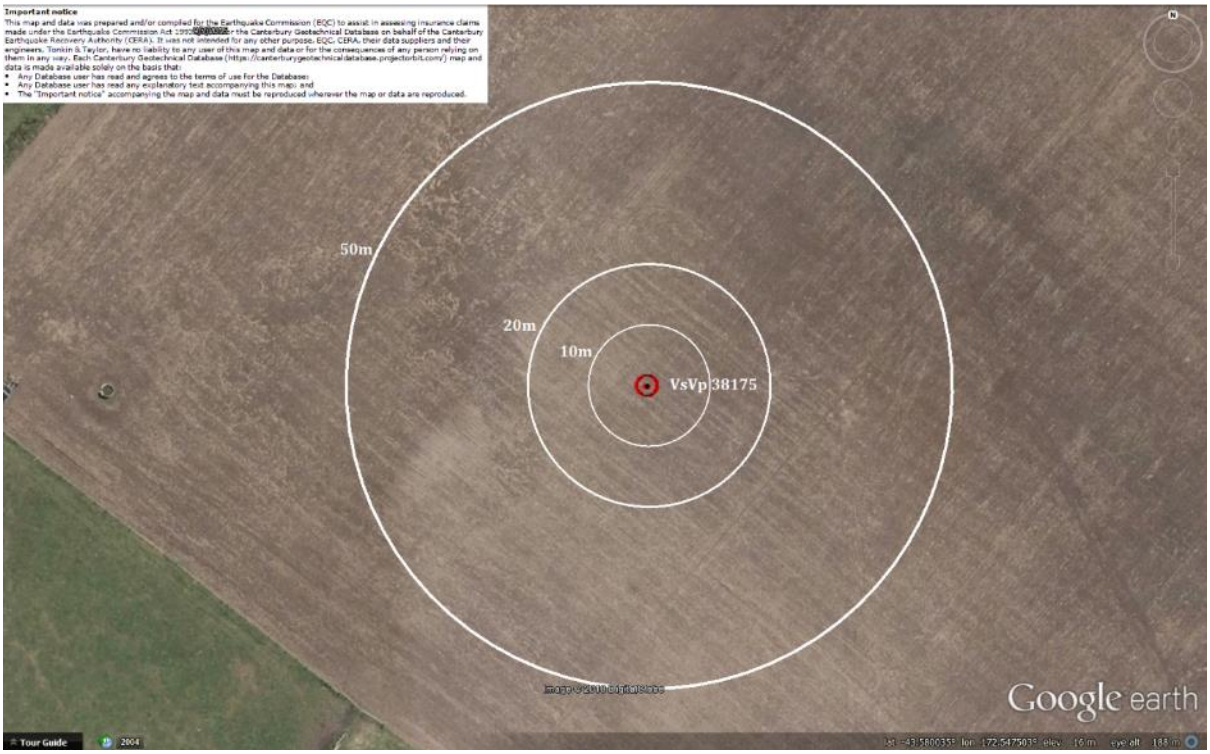

Figure 19: EQC aerial photograph of the site taken on Feb 24, 2011.

Note 6: EQC Aerial Photographs are not available for Sep 2010, Jun 2011, and Dec 2011 earthquake events.

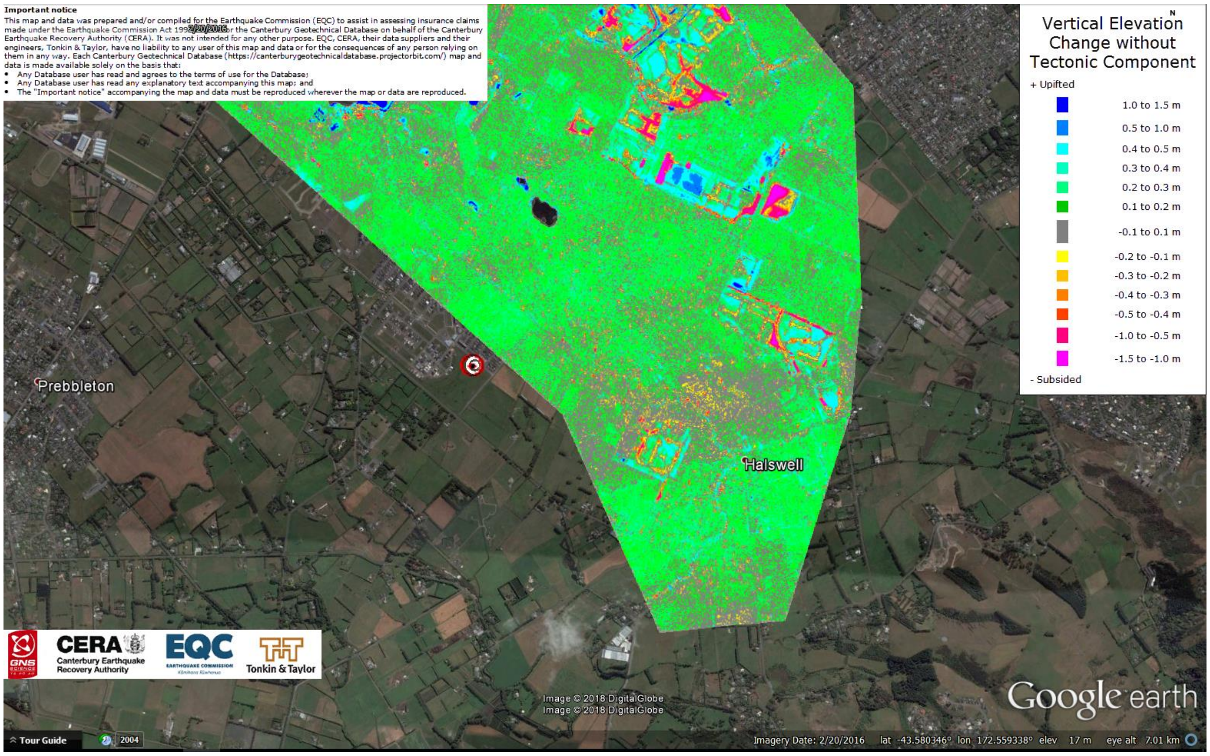

Figure 20: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 Earthquake for the site are not available.

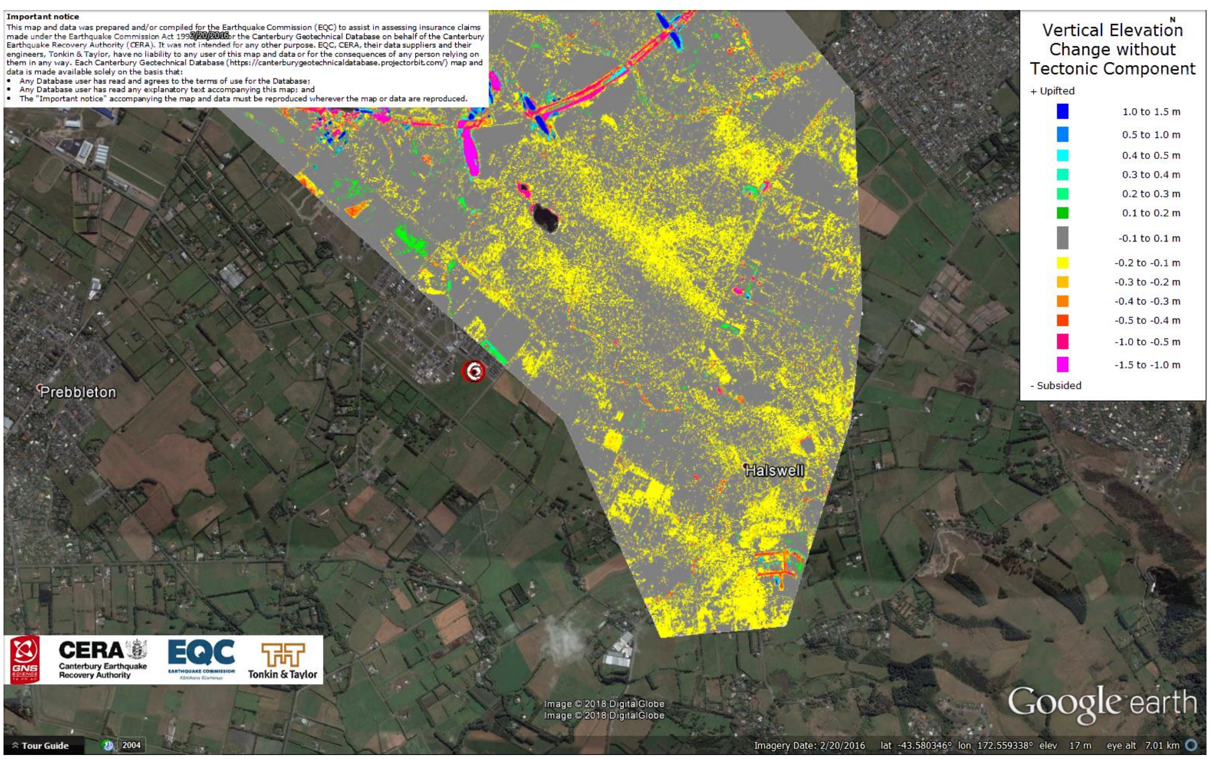

Figure 21: Vertical Ground Movements (Surface – Tectonic) for Feb 2011 Earthquake for the site are not available.

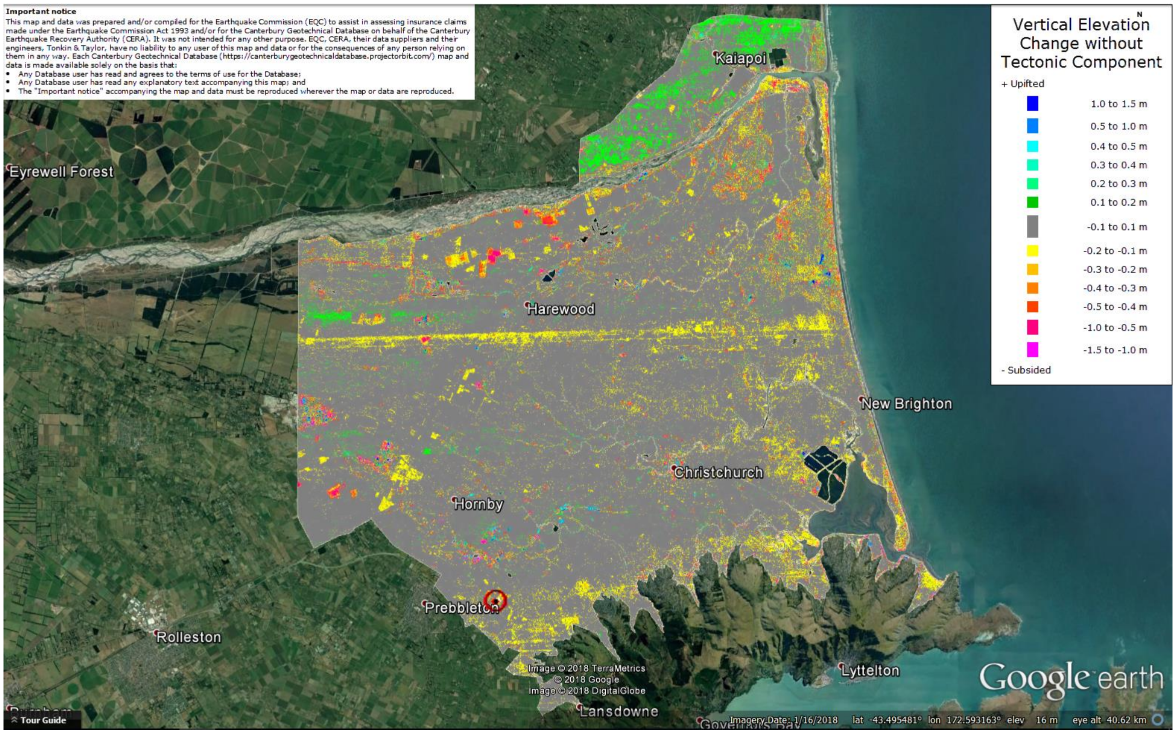

Figure 22: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated or underestimated ground surface subsidence.

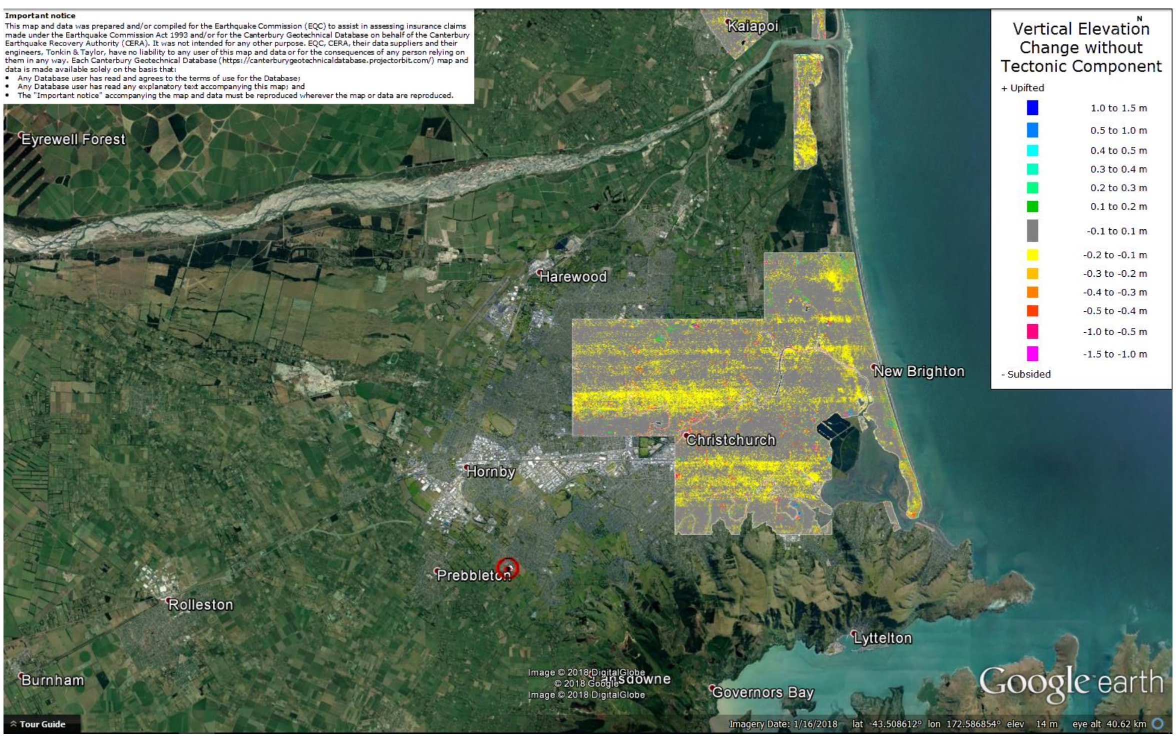

Figure 23: Vertical Ground Movements (Surface – Tectonic) for Dec 2011 Earthquake for the site are not available.

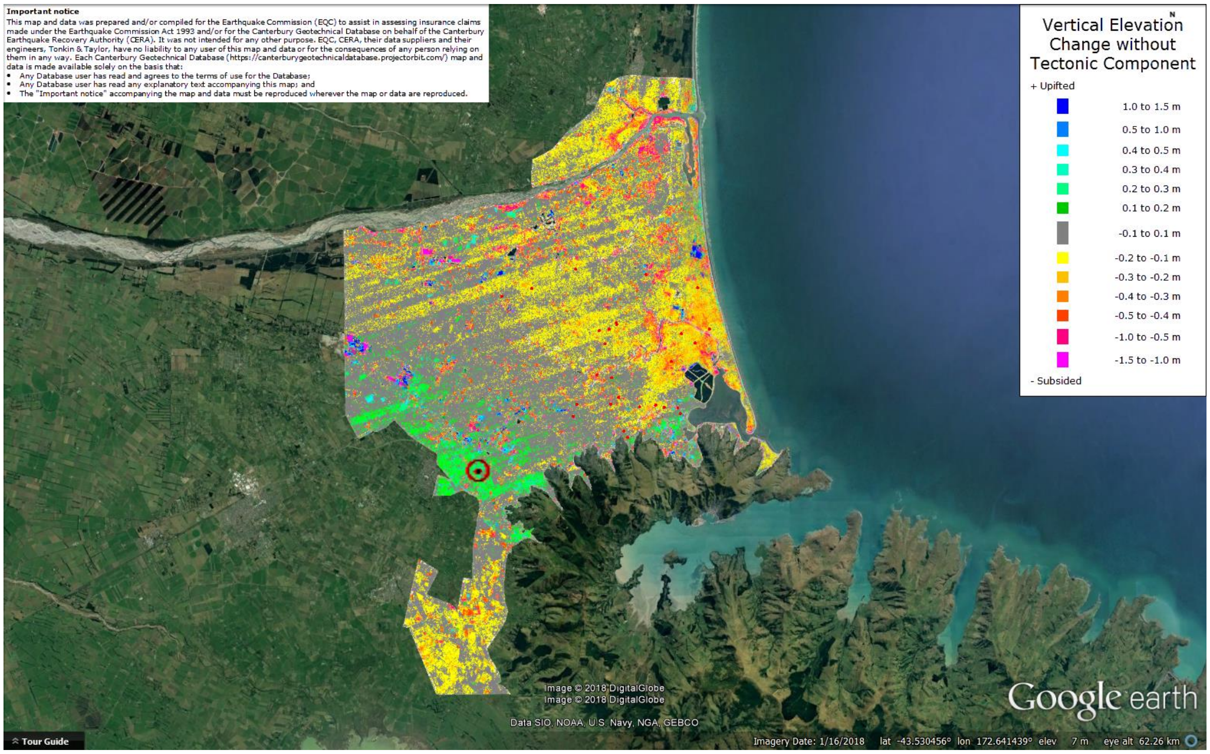

Figure 24: Vertical Ground Movements (Surface – Tectonic) for Sep 2010 and Feb 2011 Earthquakes -- the site is in the apparent zone of ground surface uplift.

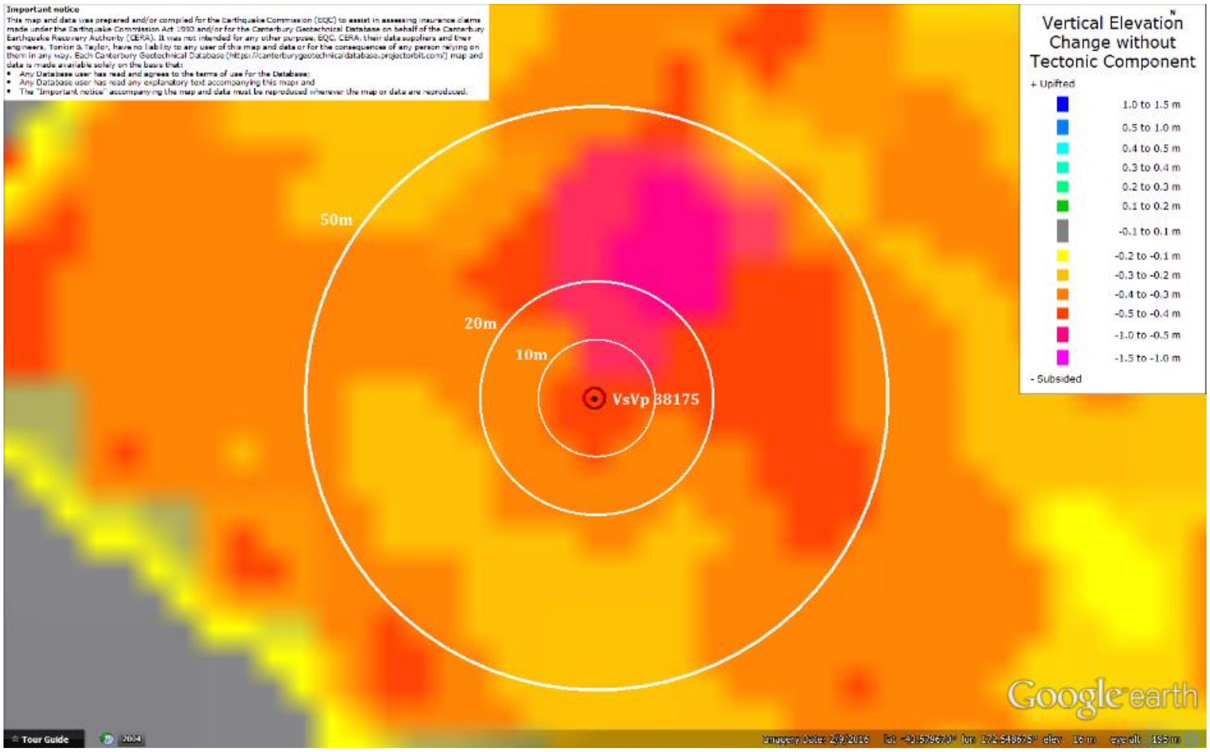

Figure 25: LiDAR DEM-based ground surface subsidence without tectonic component for Jun 2011 Earthquake.

Note 7: LiDAR DEM-based ground surface subsidence without tectonic component is not available for Sep 2010, Feb 2011, and Dec 2011 Earthquakes and Canterbury Earthquake Sequence. The only available LiDAR surveys for this site are dated to Jun 2003, May 2011, and Sep 2011.

Figure 26: Absence of ground cracks indicating no lateral spreading for Canterbury Earthquake Sequence.

Figure 27: Vertical tectonic movements for Sep 2010 Earthquake.

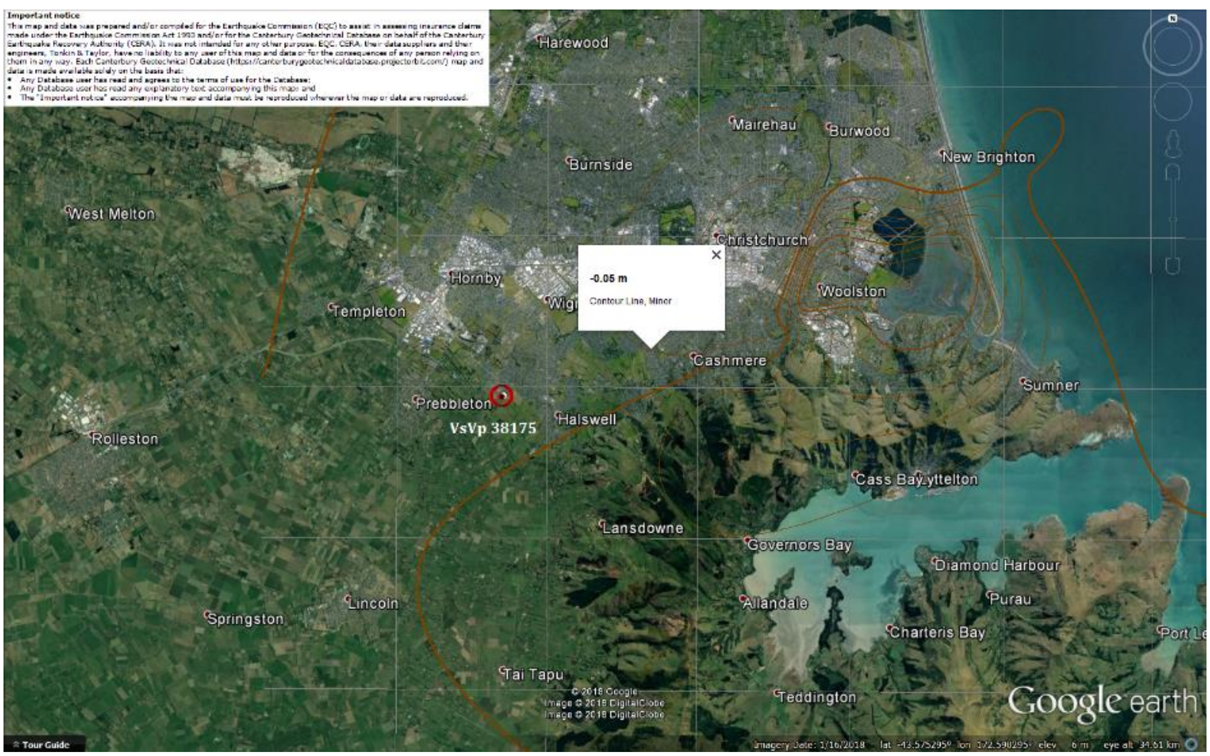

Figure 28: Vertical tectonic movements for Feb 2011 Earthquake.

Figure 29: Vertical tectonic movements for June 2011 Earthquake.

Figure 30: Vertical tectonic movements for Dec 2011 Earthquake.

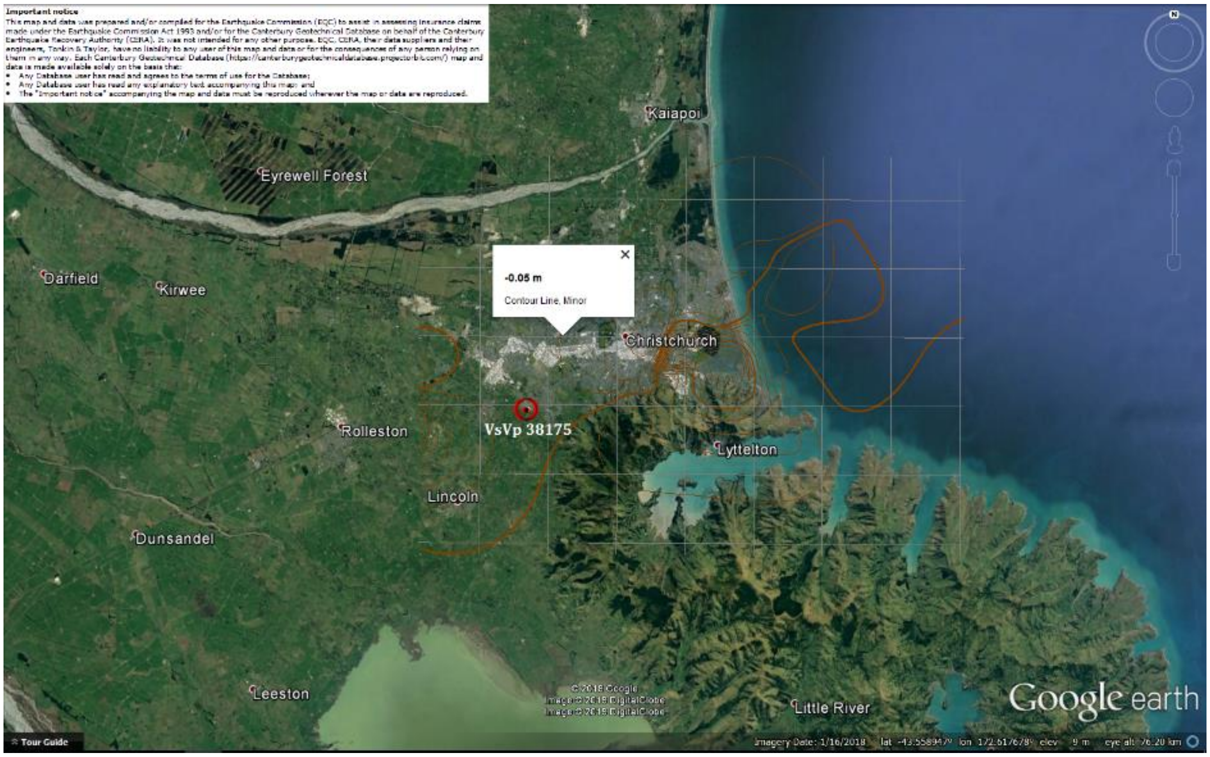

Figure 31: Vertical tectonic movements for Canterbury Earthquake Sequence.

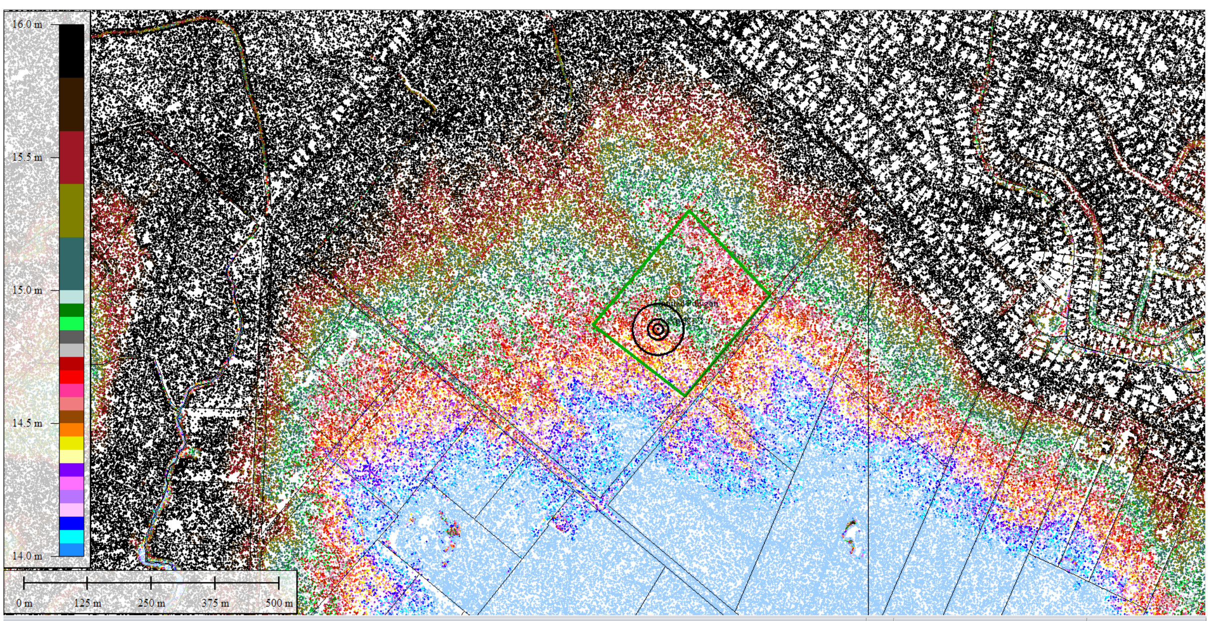

Figure 32: July 2003 LiDAR survey.

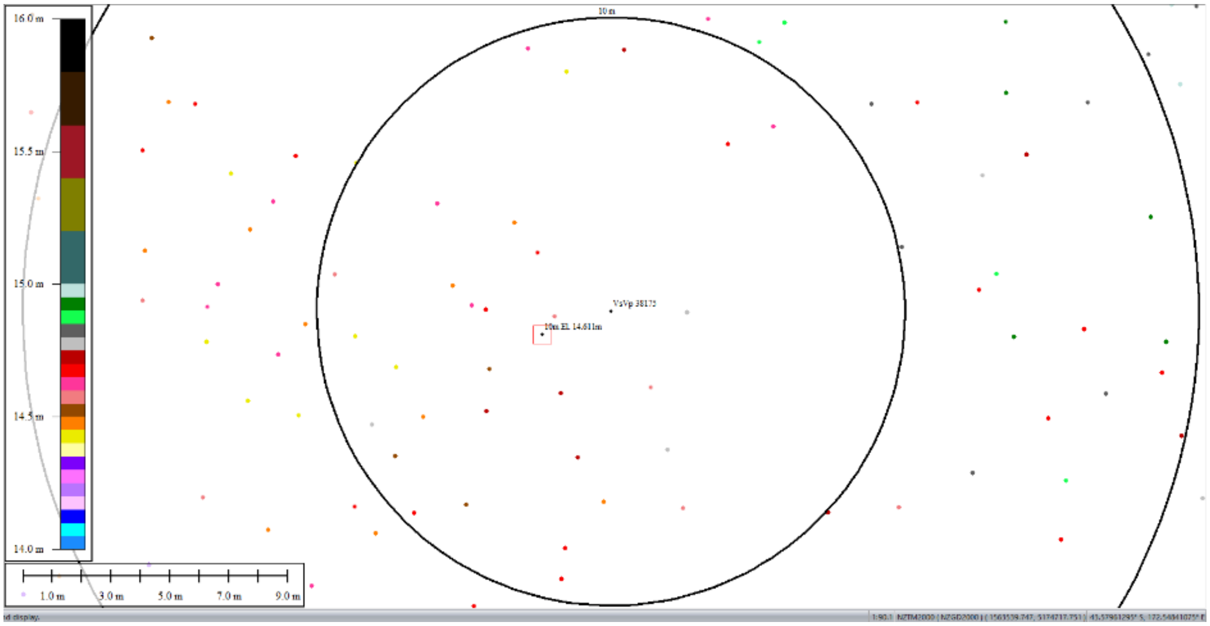

Figure 33: Ground surface elevation averaged over 10-m buffer for July 2003 LiDAR survey.

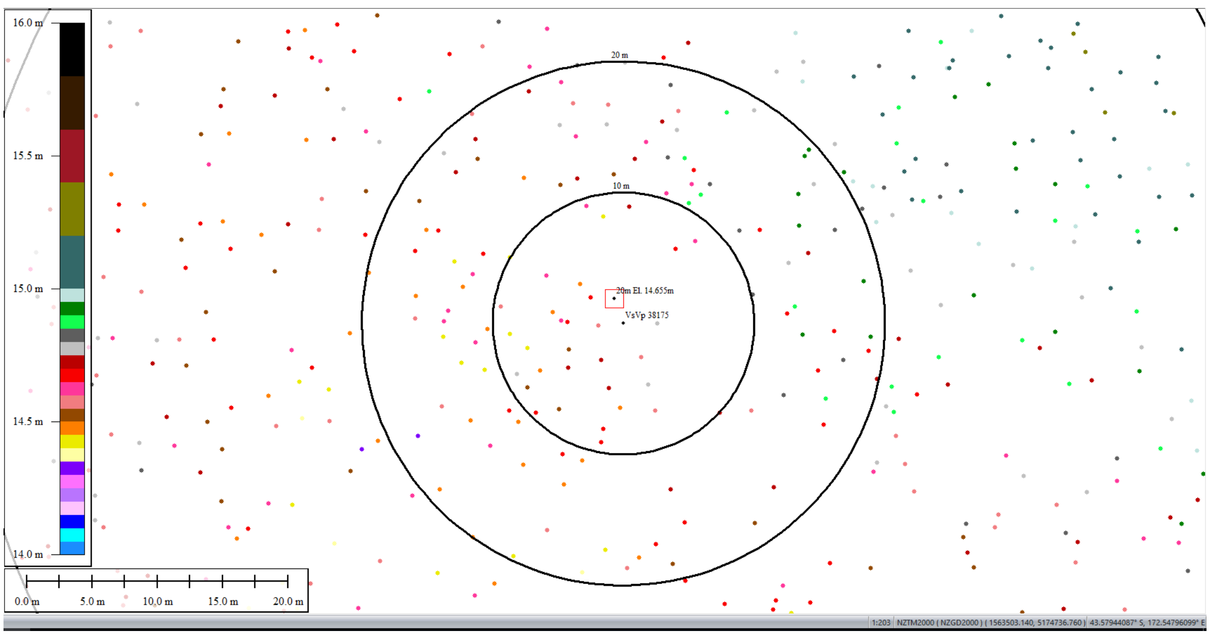

Figure 34: Ground surface elevation averaged over 20-m buffer for July 2003 LiDAR survey.

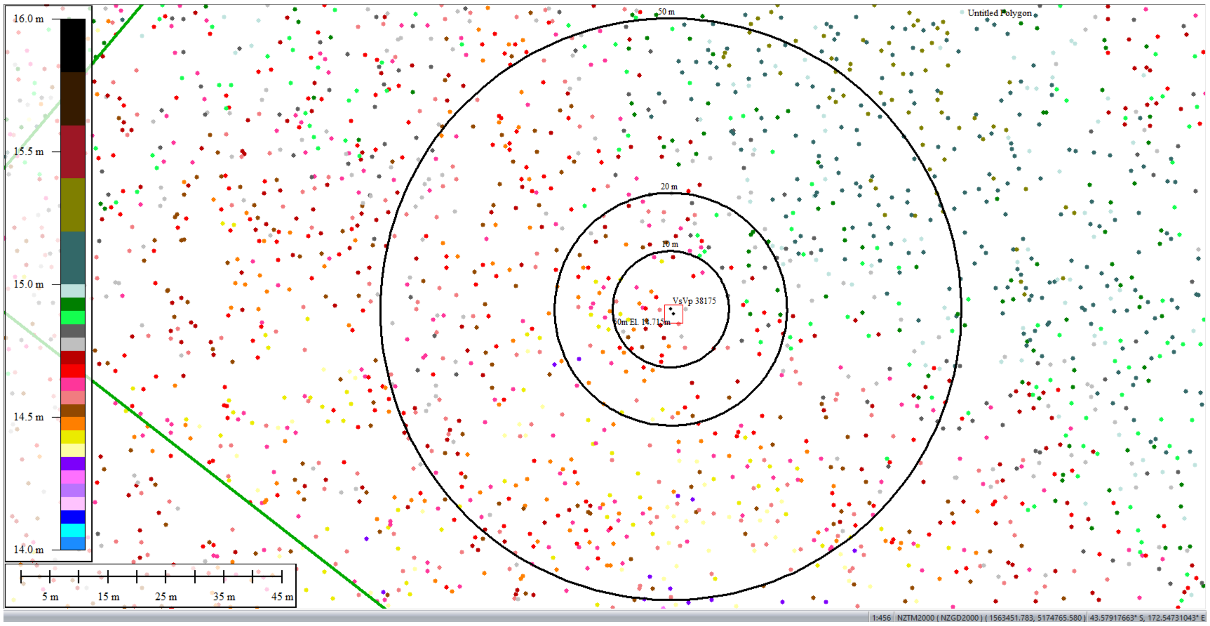

Figure 35: Ground surface elevation averaged over 50-m buffer for July 2003 LiDAR survey.

Note 8: Sep 5, 2010, Mar 2011, Feb 2012, and Oct 2015 LiDAR surveys are not available.

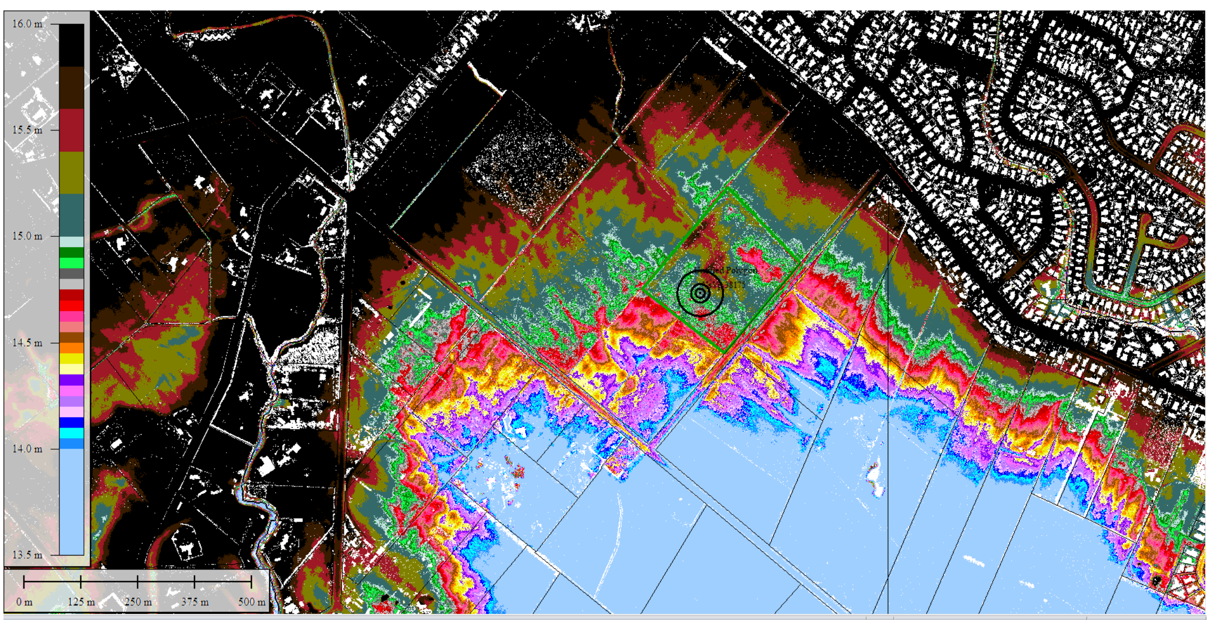

Figure 36: May 2011 LiDAR survey.

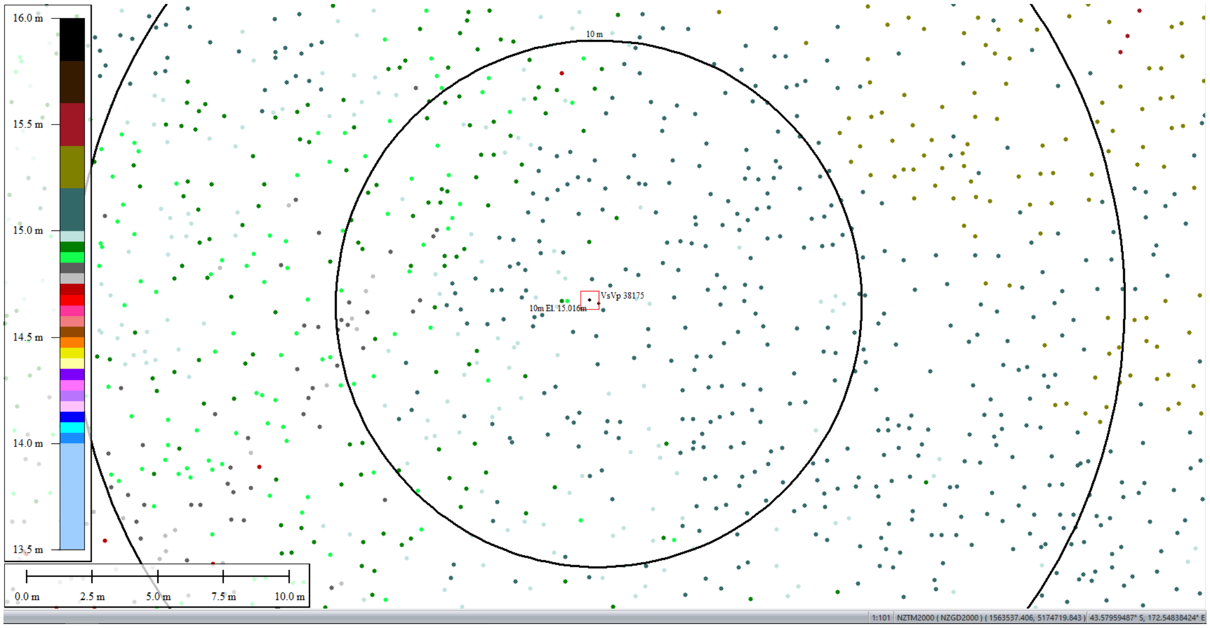

Figure 37: Ground surface elevation averaged over 10-m buffer for May 2011 LiDAR survey.

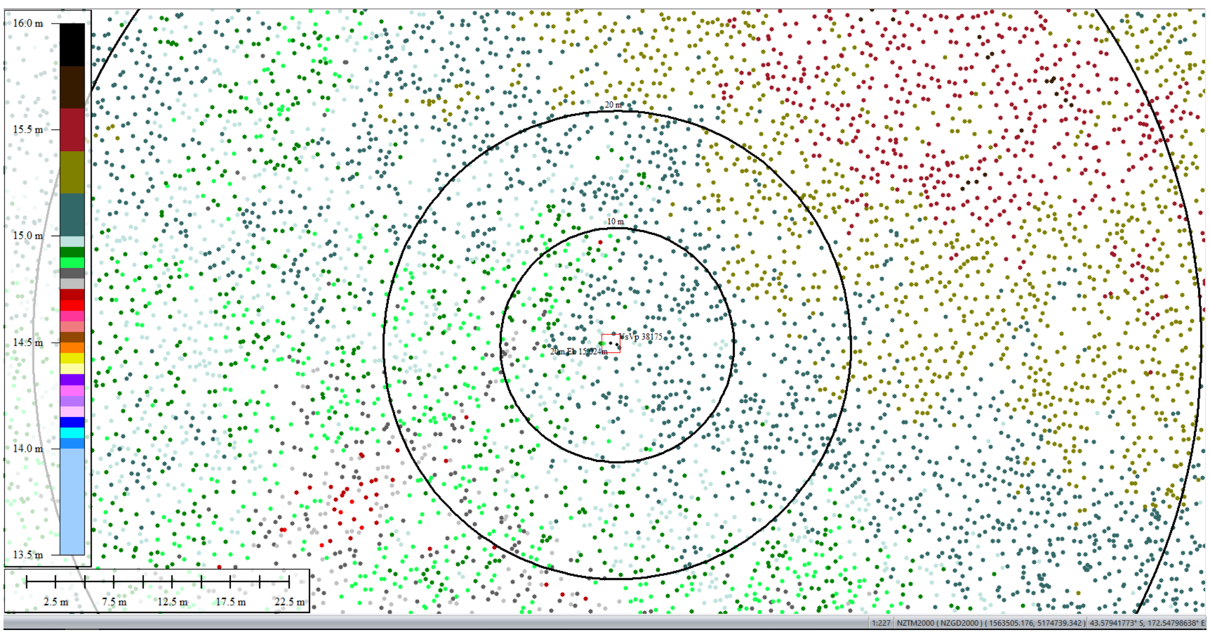

Figure 38: Ground surface elevation averaged over 20-m buffer for May 2011 LiDAR survey.

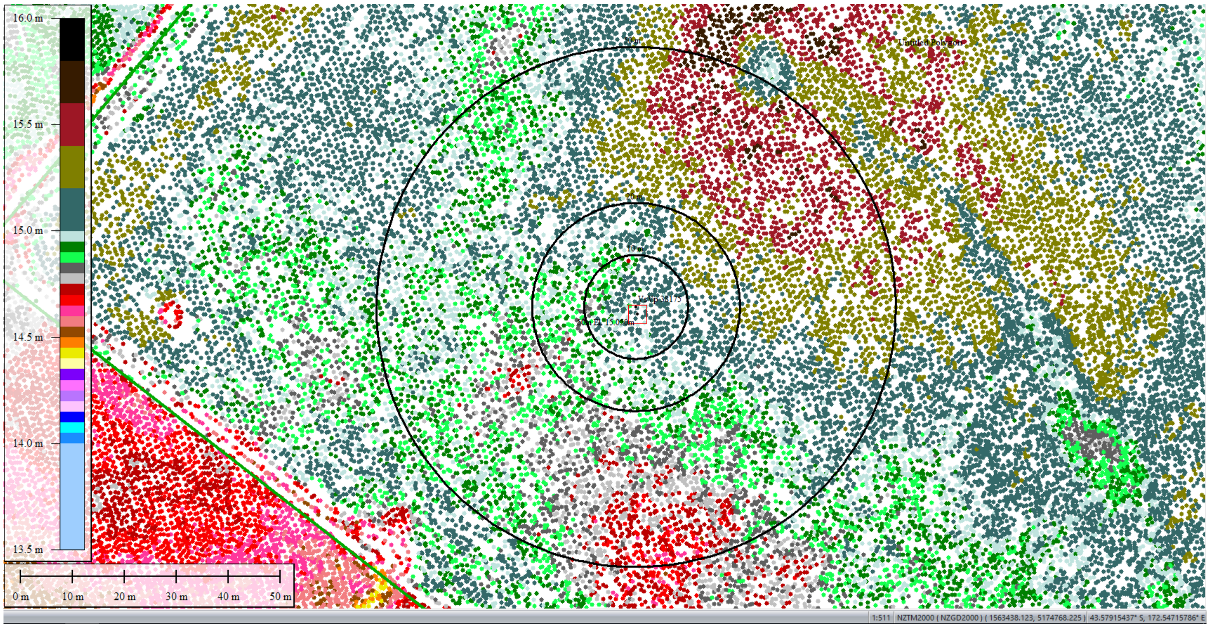

Figure 39: Ground surface elevation averaged over 50-m buffer for May 2011 LiDAR survey.

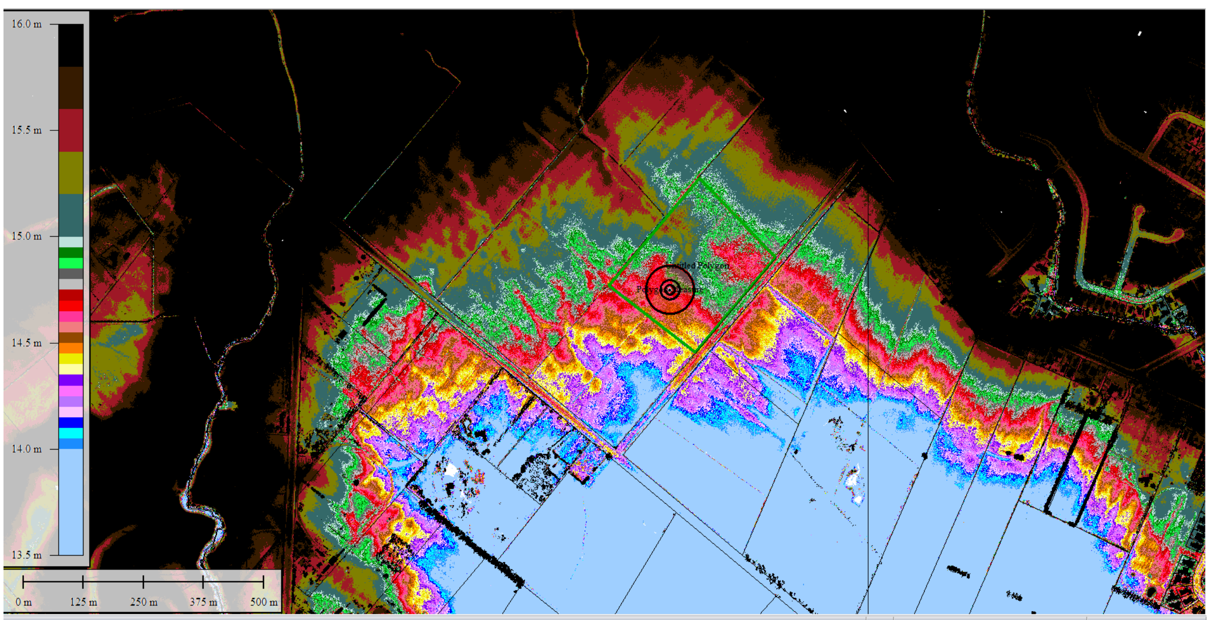

Figure 40: Sep 2011 LiDAR survey.

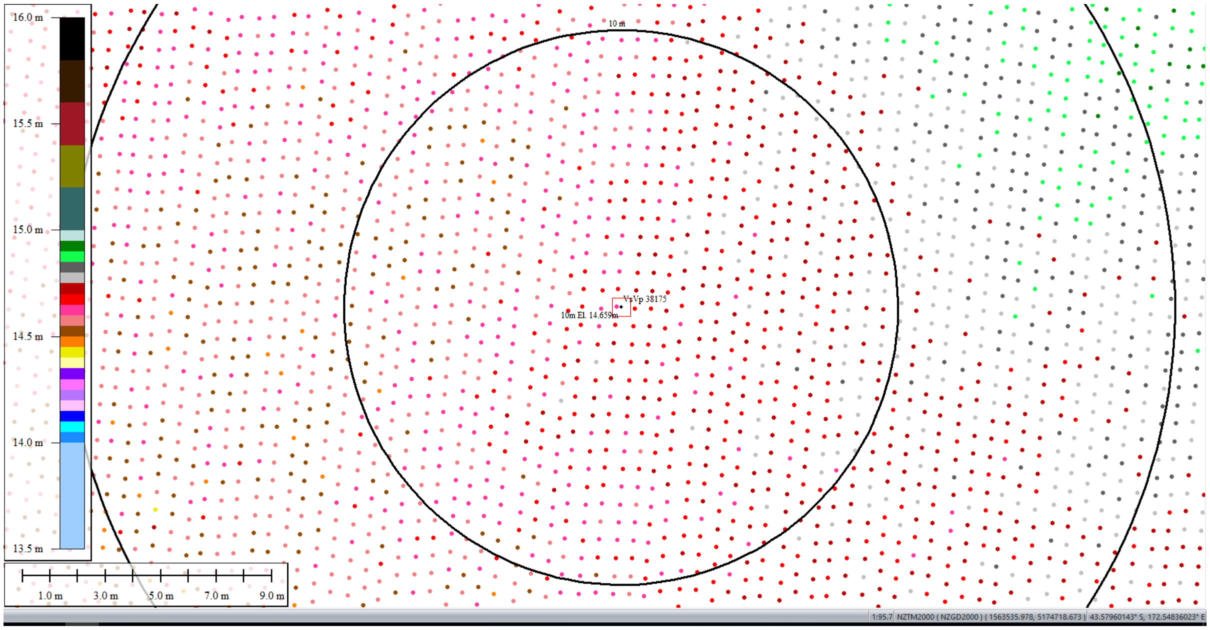

Figure 41: Ground surface elevation averaged over 10-m buffer for Sep 2011 LiDAR survey.

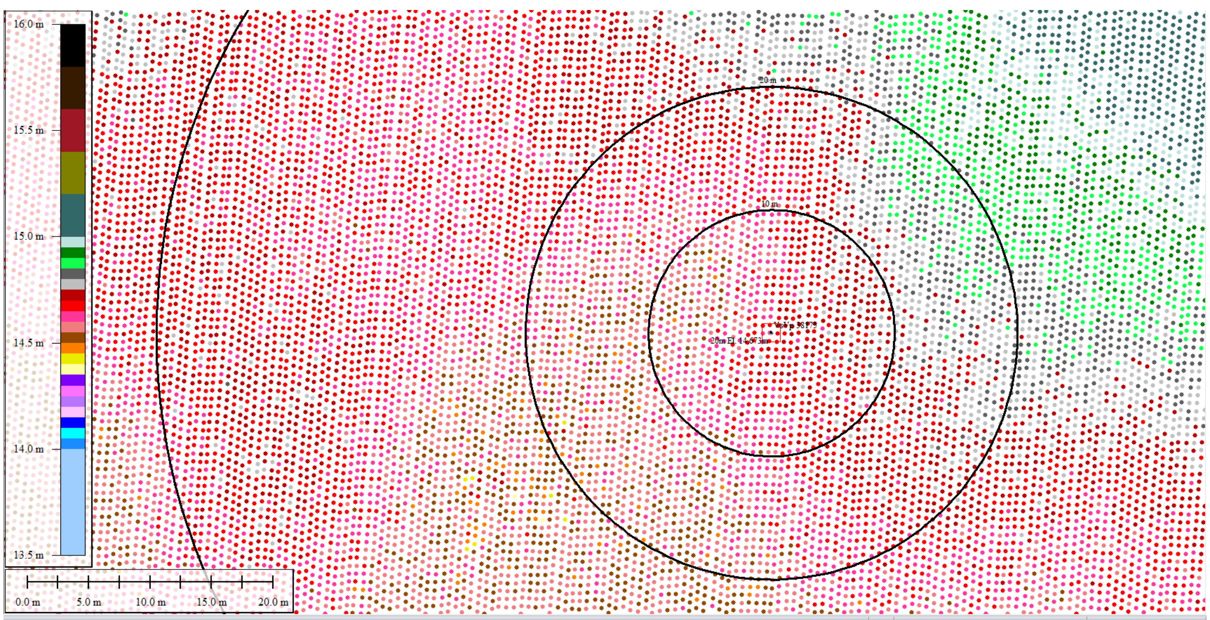

Figure 42: Ground surface elevation averaged over 20-m buffer for Sep 2011 LiDAR survey.

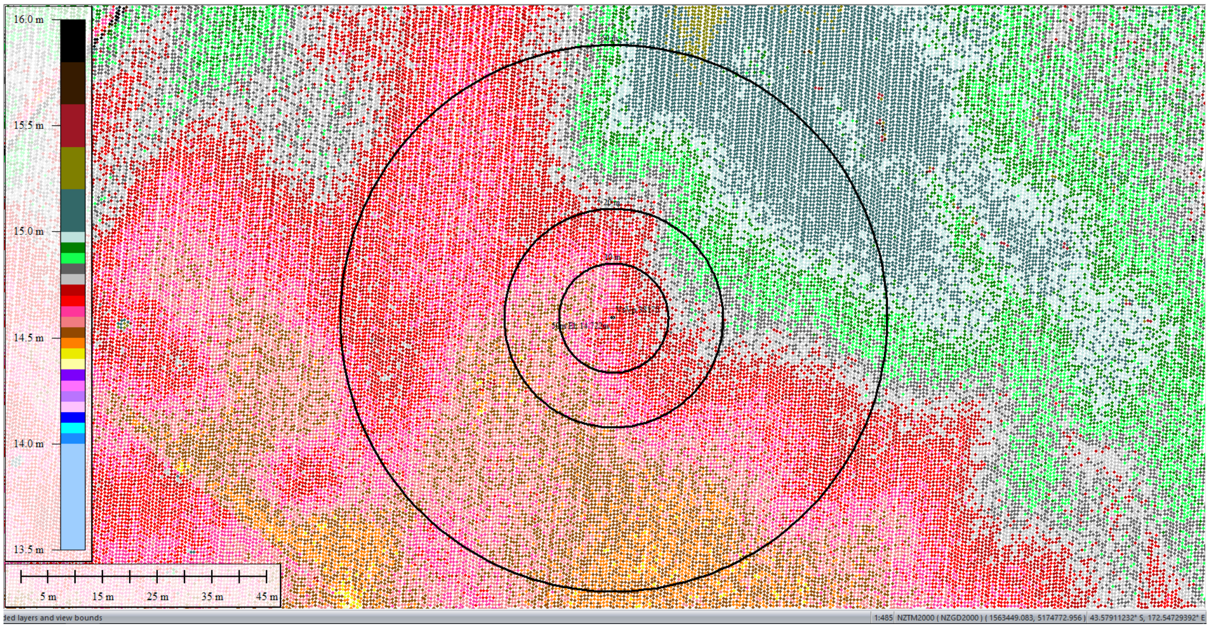

Figure 43: Ground surface elevation averaged over 50-m buffer for Sep 2011 LiDAR survey.

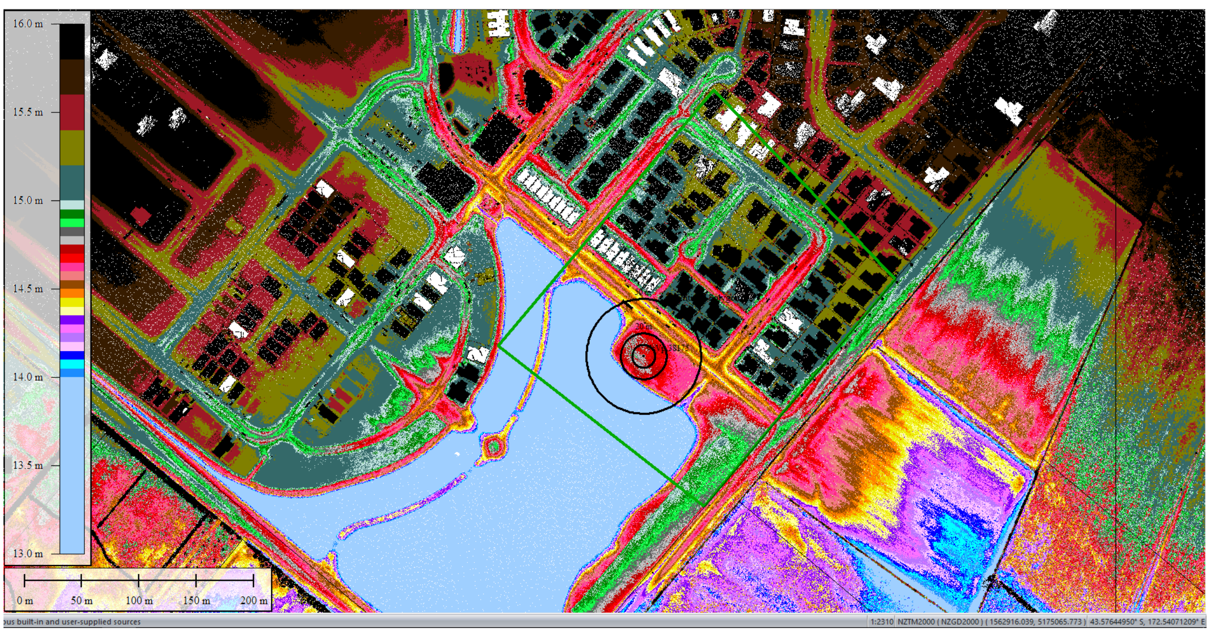

Figure 44: Oct 2015 LiDAR survey (note the change in ground surface elevation due to construction).

Contents of this figure cannot be shared as doing so is restricted by a Non-Disclosure Agreement.

Figure 45: EQC liquefaction and lateral spreading observations for Sep 2010 Earthquake to determine ejecta quantum.

Contents of this figure cannot be shared as doing so is restricted by a Non-Disclosure Agreement.

Figure 46: EQC Level 2 Damage Index map for Sep 2010 Earthquake to determine ejecta quantum.

Figure 47: EQC liquefaction and lateral spreading observations for Dec 2011 Earthquake to determine ejecta quantum.

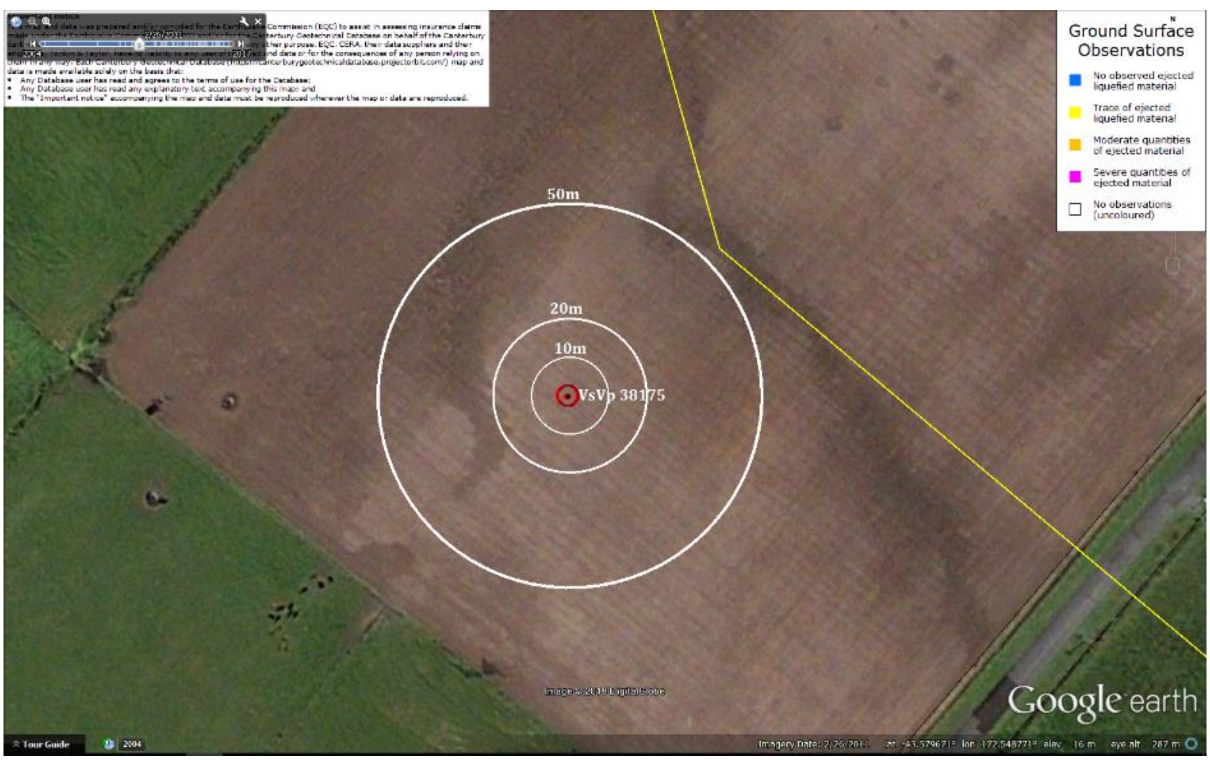

Figure 48: Aerial photograph of the site taken on Feb 26, 2011, showing traces of ejecta.

Contents of this figure cannot be shared as doing so is restricted by a Non-Disclosure Agreement.

Figure 49: EQC Level 2 Damage Index map for Feb 2011 Earthquake to determine ejecta quantum.

Contents of this figure cannot be shared as doing so is restricted by a Non-Disclosure Agreement.

Figure 50: EQC Level 2 Damage Index map for Jun 2011 Earthquake to determine ejecta quantum.

Figure 51: EQC liquefaction and lateral spreading observations for Jun 2011 Earthquake to determine ejecta quantum.

Contents of this figure cannot be shared as doing so is restricted by a Non-Disclosure Agreement.

Figure 52: EQC Level 2 Damage Index map for Dec 2011 Earthquake to determine ejecta quantum.

Fig. 53. Ejecta outline for Sep-10 EQ.

Fig. 54. Ejecta 800 m away from the center of the site for Sep-10 EQ (taken on 18 Feb 2011).

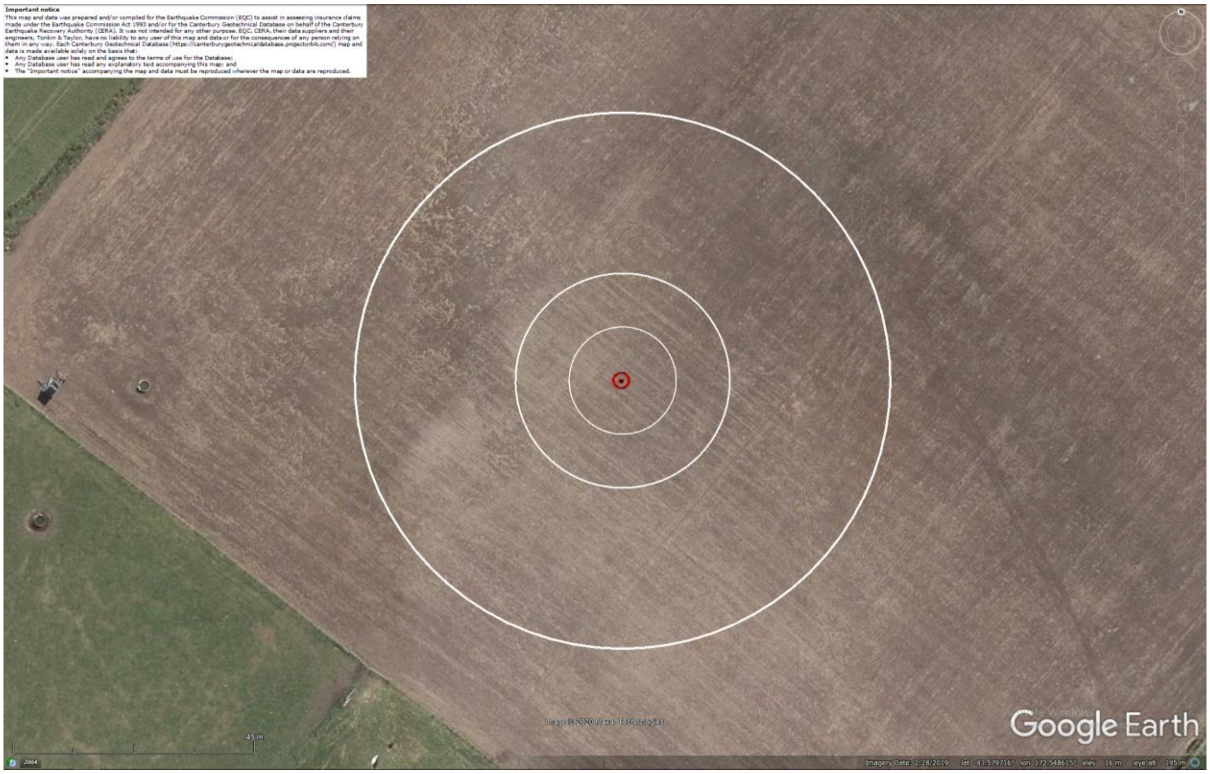

Fig. 55. Absence of ejecta for Feb-11 EQ.

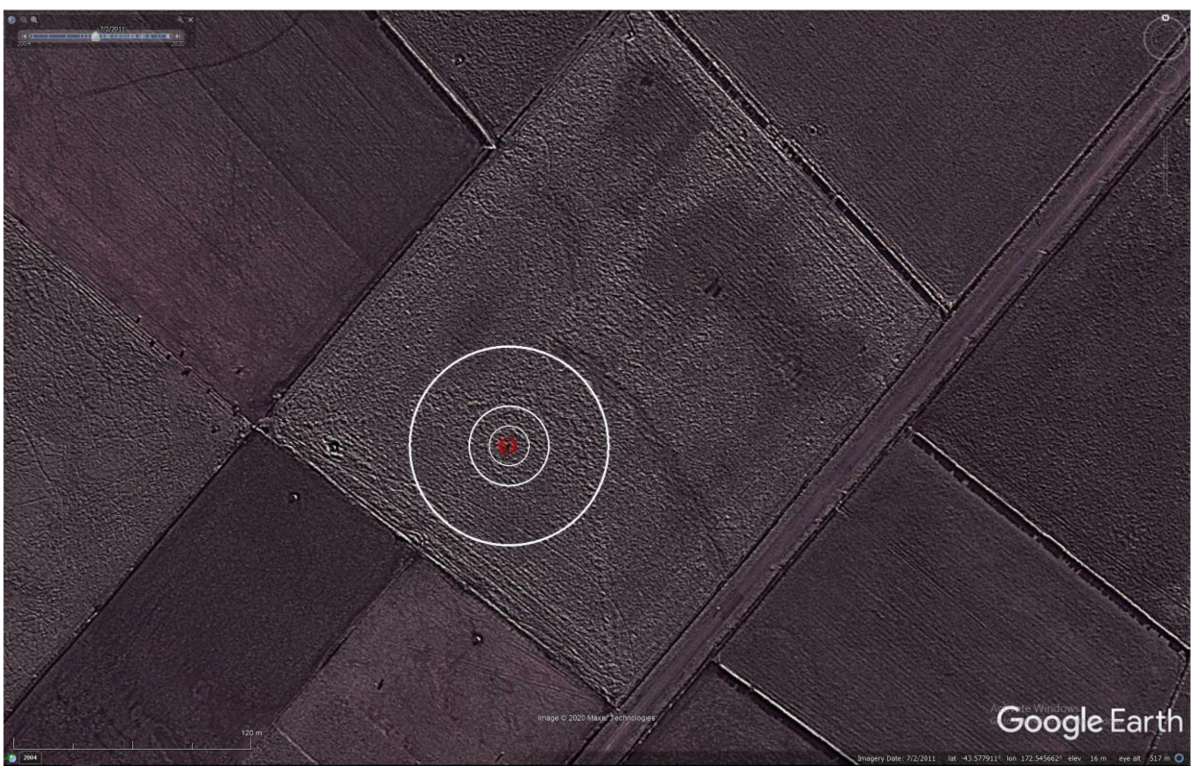

Fig. 56. Absence of ejecta for Jun-11 EQ (the photograph was acquired a month after the event).

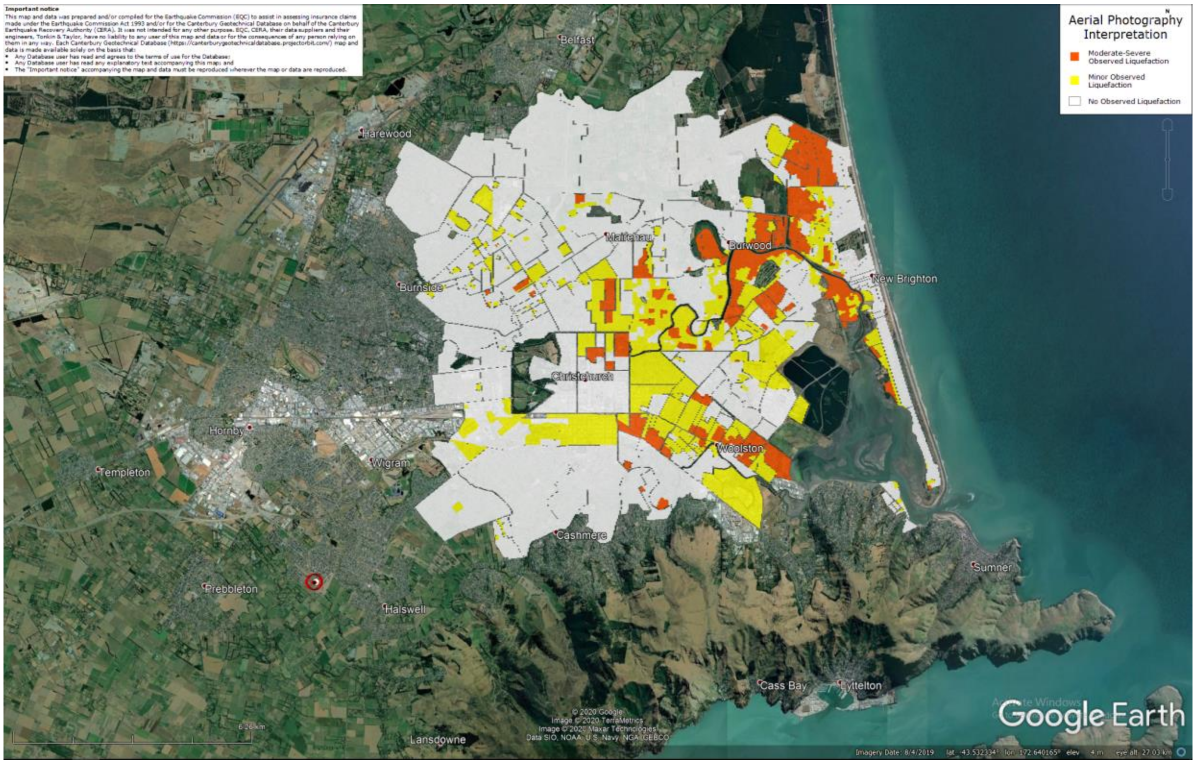

Fig. 57. Liquefaction interpreted from aerial photography for Dec-2011 EQ (low confidence in ejecta estimate due to extrapolation of the interpretation for the site).

Figure 58: CPT locations.

Figure 59: PGA for Sep-10 EQ (st. dev. = 0.375-0.400 ln units).

Figure 60: PGA for Feb-11 EQ (st. dev. = 0.425-0.450 ln units).

Figure 61: PGA for Jun-11 EQ (st. dev. = 0.450-0.475 ln units).

Figure 62: PGA for Dec-11 EQ (st. dev. = 0.425-0.450 ln units).

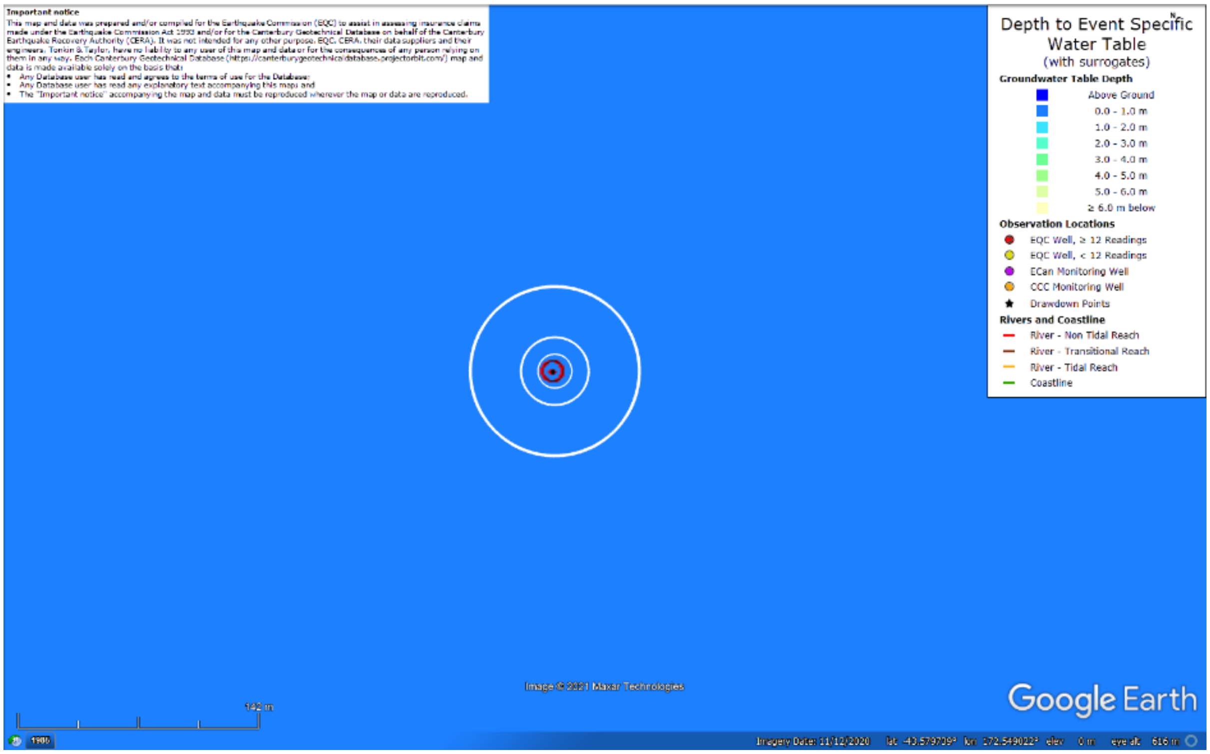

Figure 63: Depth to groundwater table PGA for Sep-10 EQ.

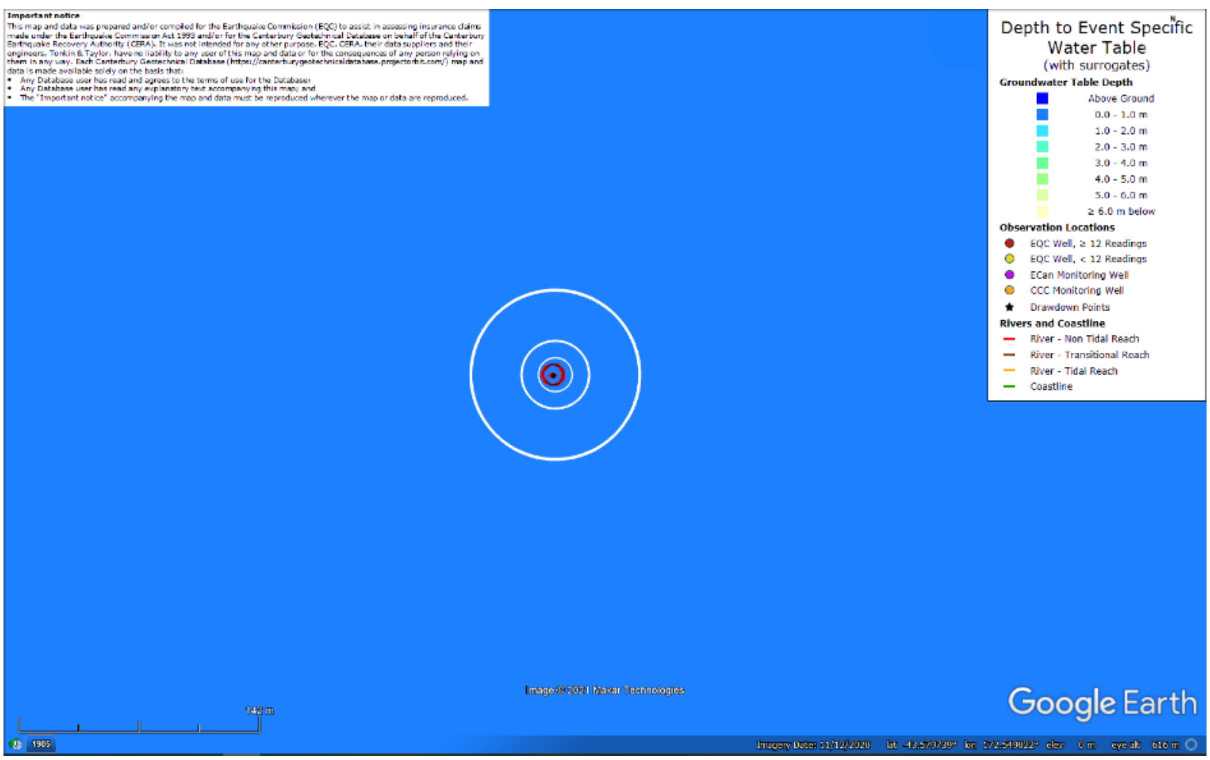

Figure 64: Depth to groundwater table PGA for Feb-11 EQ.

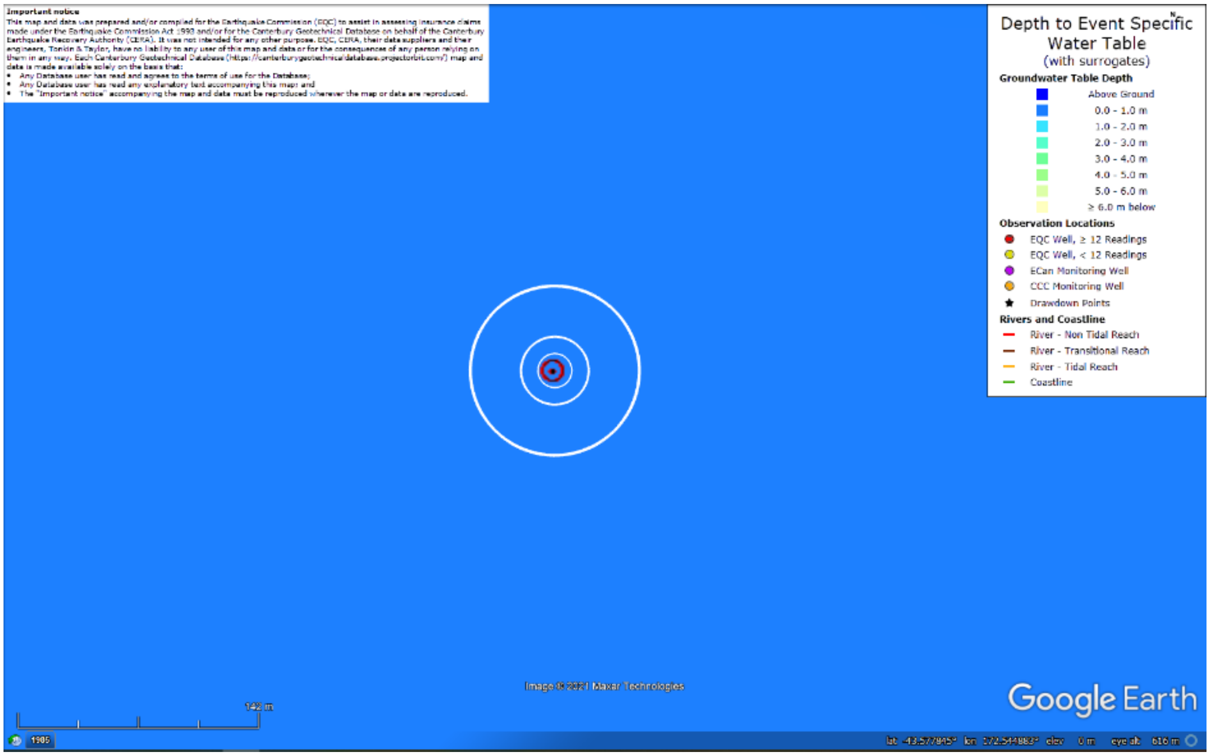

Figure 65: Depth to groundwater table PGA for Jun-11 EQ.

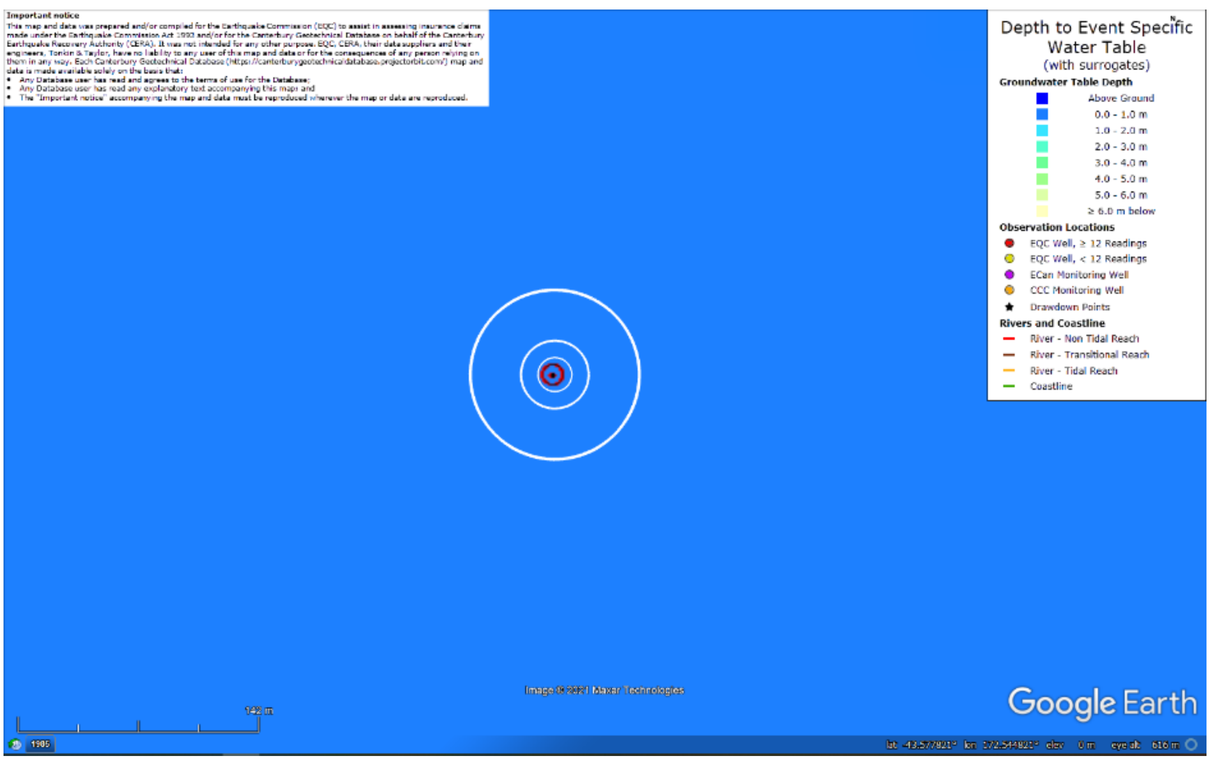

Figure 66: Depth to groundwater table PGA for Dec-11 EQ.

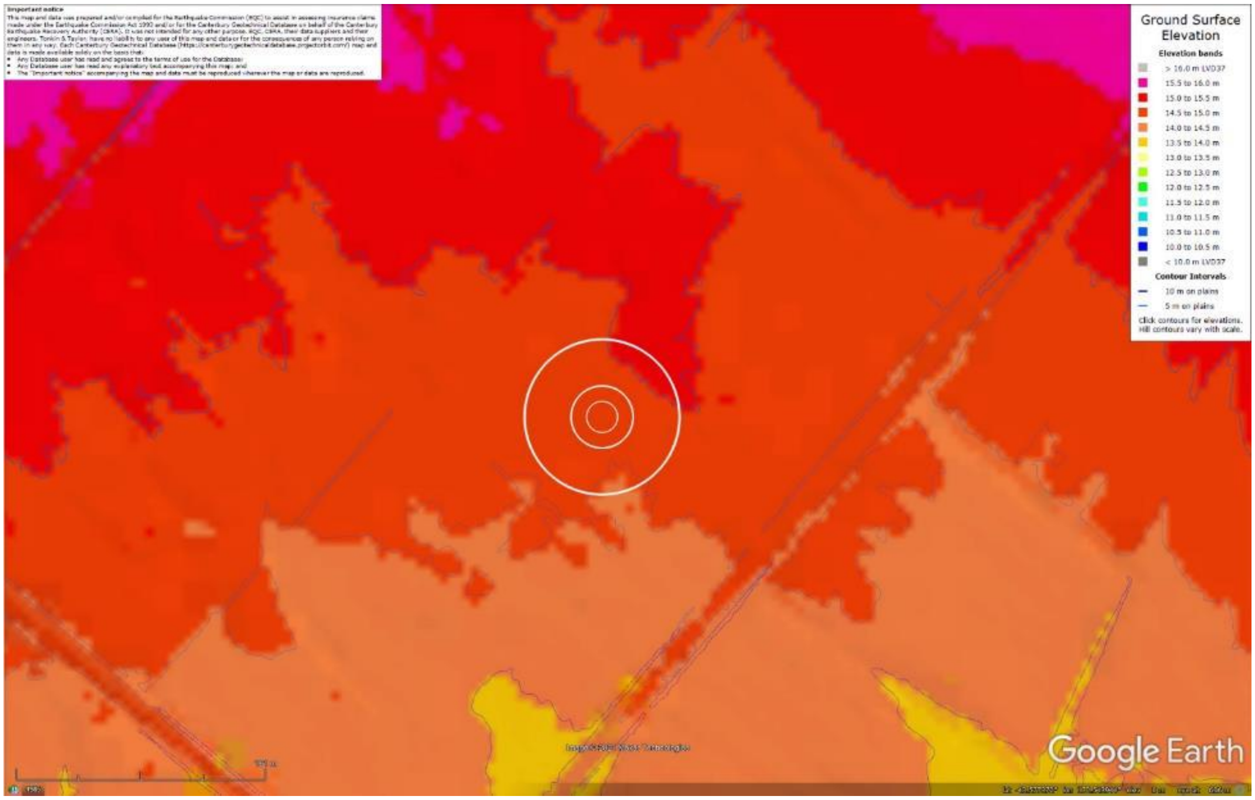

Figure 67: Ground surface elevation according to the Sep-11 LiDAR survey.

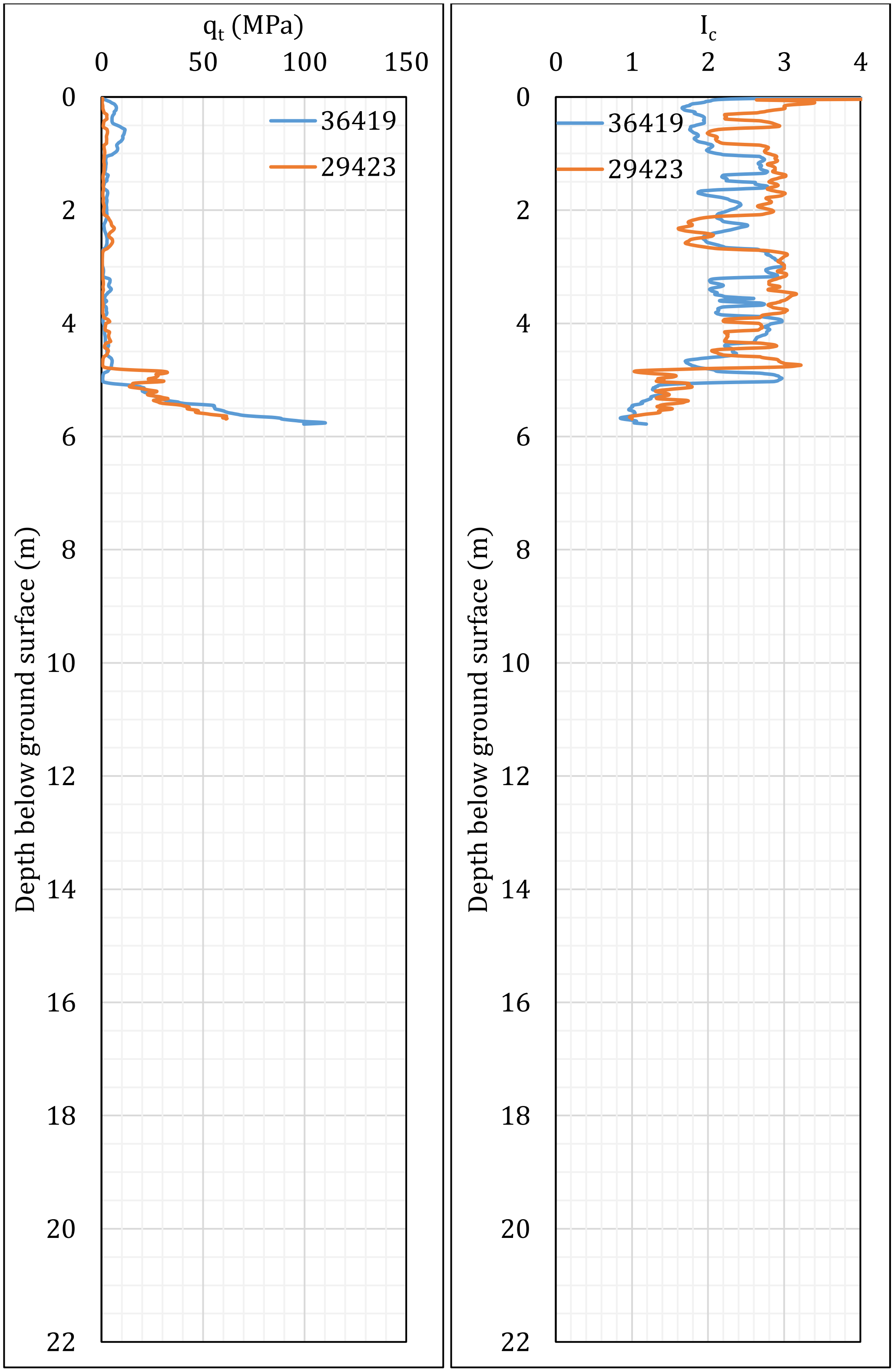

Figure 68: q_t and I_c profiles.

Note 9: 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
36419 (38495)	✓	✓	✓
20433*			
29423		✓	✓
20434*			

Note: * indicates a CPT without dynamic pore water pressure measurements; all nearby CPTs had shallow refusal depths due to the gravel layer that extends to a depth of 20 m so the volumetric settlement is assumed to be negligible below the 6-m depth.

Table 13: CPT-based results.

		CPT ID	
EQ Event	Parameter	36419	29423
Sep-10	S_{V1D} (mm)	59	31
	LSN	22	18
	LPI	10	5
	LPI_{ish}	10	4
	$D_{FS<1}$ (m)	1.62	0.55
Feb-11	S_{V1D} (mm)	59	30
	LSN	22	17
	LPI	9	4
	LPI_{ish}	10	4
	$D_{FS<1}$ (m)	1.62	0.55
Jun-11	S_{V1D} (mm)	6	1
	LSN	2	0
	LPI	0	0
	LPI_{ish}	0	0
	$D_{FS<1}$ (m)	undet.	undet.
Dec-11	S_{V1D} (mm)	3	0
	LSN	1	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 10: Based on the borehole log (BH 38194, Figure 58), the groundwater table is at a depth of 0.95 m below the ground surface. The soil profile consists of (1) topsoil to a depth of 0.25 m, (2) interchanging layers of silty fine sand, SM, and non-plastic to low-plasticity silt, ML, to a depth of 5.3 m, and (3) fine to coarse gravel, GW, to a depth of 10.0 m (the end of the borehole). The SM, ML, and GW are the Yaldhurst members of the Springston formation. Based on the nearby borehole logs and CPT interpretations, it is inferred that gravel extends to a depth of 20 m.

Note 11: 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	314	67.0	0.7-2.0	5±5	20±10
Feb-11	314	0	0	0	0
Jun-11	314	0	0	0	0
Dec-11	314	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; NA = Not available.

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	1257	124	1.2-3.7	<5	20±10
Feb-11	1257	0	0	0	0
Jun-11	1257	0	0	0	0
Dec-11	1257	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; NA = Not available.

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	7854	384	3.3-9.5	<5	15±10
Feb-11	7854	0	0	0	0
Jun-11	7854	0	0	0	0
Dec-11	7854	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; NA = Not available.

Summary 2:

The best estimate of the localized ejecta-induced free-field ground settlement at the Caulfield Ave site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 20±10 mm, 0 mm, 0 mm, and 0 mm, respectively.