Appendix A.25:

Kaiwara Reserve – VsVp 57182

Table 1: Site Description for Kaiwara Reserve (VsVp 57182).

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 ~420 m to the west from the Heathcote River and ~570 m to the north from an unnamed stream. The free-face height of the Heathcote River is ~1 m, while that of the unnamed stream is ~0.5-1 m.	NA
Lateral spreading observed during the CES?	No	No	No	Ground cracks were not observed by the mapping team.[1]	NA
Nearby buildings or structures?	No	No	Yes	Building coverage of the 50-m buffer is 7%. The structures are mostly in the N portion of the 50-m buffer.	White Fill + Brown Outline
Sloping land?	No	No	No	Flat land, open + residential 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 5, 27, and 35% of the 10-, 20-, and 50-m buffers, respectively. They are in all quadrants of the 20- and 50-m buffers and the N portion of the 10-m buffer.	White Fill + Green Outline
Anthropogenic changes to the site between the LiDAR surveys?	No	No	Yes	The paddock in the E portion of the 50-m buffer is a subject to ploughing.	NA
Other important factors?	No	Yes	Yes	Two low-motor-vehicle-volume, two-way roadways (Kaiwara St in the NW- SE direction and Blakiston St in the NE-SW direction) occupy 14% of the 50-m buffer and stretch throughout its NW, NE, and SE quadrants. Kaiwara St covers 9% of the 20-m buffer and stretches throughout its E portion. Playground is in the S portion of the 20- and 50-m buffers. The art display wall is in the SW quadrant of the 20- and 50-m buffers.	Road: Gray Fill + Red Outline; Playground: White Fill + Orange Outline; Wall: White Fill + Purple Outline

Note: Buffer is the area within a circle of a specified radius with CPT investigations done at its center (172.608046°, -43.571492°).

[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 free field was selected for settlement assessment as an area free of vegetation and structures. Factors including its proximity to a CPT, a property subjected to addition and/or demolition of a structure, front yard/backyard alterations (e.g., ploughing, rubble, scrap), and aerial distribution of sediment ejecta were all considered in the selection process. The entire portion of the road within the 50-m buffer was also considered for settlement assessment. The LiDAR-based settlement analyses were not conducted for the site.

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	-30
Jun-11	0	38	-15
Dec-11	NA	-65	0
CES	NA	-14	-45
Any LiDAR survey affected by ejecta?			No

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 due to the absence of LiDAR surveys for the site.

Table 3a: LiDAR Measurement Error for Patch A.

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

*Standard deviation; NA = Not available; ND = Not determined.

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

Table 3b: LiDAR Measurement Error for Road.

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	[ND,ND]
	20-m	ND		
	50-m	ND		
Post Dec 2011: Feb 2012 and Oct 2015	10-m	NA	70	[NA,NA]
	20-m	NA		
	50-m	NA		

*Standard deviation; NA = Not available; Not determined.

Table 4a: Ground surface subsidence adjustments due to LiDAR measurement error for Patch A.

Earthquake Event(s)	$\sigma_{\text{pre-EQ LiDAR survey}}$ (mm)	$\sigma_{\text{post-EQ LiDAR survey}}$ (mm)	σ_{total} (mm)	Area Average Adjusted σ (mm) **
Sep-10	158	56	134	ND
Feb-11	56	59	59	ND
Jun-11	59	61	62	ND
Dec-11	61	70	87	ND
CES	158	70	124	ND

**Based on the highest %Reduction in Table 3a.

Table 4b: Ground surface subsidence adjustments due to LiDAR measurement error for Road.

Earthquake Event(s)	$\sigma_{\text{pre-EQ LiDAR survey}}$ (mm)	$\sigma_{\text{post-EQ LiDAR survey}}$ (mm)	σ_{total} (mm)	Area Average Adjusted σ (mm) **
Sep-10	158	56	134	ND
Feb-11	56	59	59	ND
Jun-11	59	61	62	ND
Dec-11	61	70	87	ND
CES	158	70	124	ND

**Based on the highest %Reduction in Table 3b.

Table 5a: 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 5b: Raw liquefaction-related ground surface subsidence using original LiDAR points for Road.

	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	NA	ND	ND
Dec-11	NA	NA	NA
CES	NA	NA	NA

NA = Not available; ND = Not determined.

Table 6a: 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 4a, but rounded to the nearest 25; Positive overall values indicate ground surface subsidence, while negative overall values indicate ground surface uplift.

Table 6b: Corrected liquefaction-related ground surface subsidence using original LiDAR points for Road 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	NA	ND	ND
Dec-11	NA	NA	NA
CES	NA	NA	NA

Notes: Plus/minus values are same as those in Table 4b, but rounded to the nearest 25; Positive overall values indicate ground surface subsidence, while negative overall values indicate ground surface uplift.

Table 7a: 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 7b: Corrected liquefaction-related ground surface subsidence for Road 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	NA	NA	NA	<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	0.25	1.5	NA	118±20	NA
Feb-11	6.2	0.46	1.7	NA	126±50	NA
Jun-11	6.2	0.19	1.5	ND	54±25	ND
Dec-11	6.1	0.13	1.5	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 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	0.25	1.5	NA	124±20	NA
Feb-11	6.2	0.46	1.7	NA	131±50	NA
Jun-11	6.2	0.19	1.5	ND	57±25	ND
Dec-11	6.1	0.13	1.5	NA	5±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	0.25	1.5	NA	124±20	NA
Feb-11	6.2	0.46	1.7	NA	131±50	NA
Jun-11	6.2	0.19	1.5	ND	57±25	ND
Dec-11	6.1	0.13	1.5	NA	5±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 8d: Ejecta-Induced settlement for the top 20 m of the soil profile for Road (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	0.25	1.5	NA	124±20	NA
Feb-11	6.2	0.46	1.7	NA	131±50	NA
Jun-11	6.2	0.19	1.5	ND	57±25	ND
Dec-11	6.1	0.13	1.5	NA	5±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 8e: Ejecta-Induced settlement for the top 20 m of the soil profile for Road (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	0.25	1.5	NA	119±20	NA
Feb-11	6.2	0.46	1.7	NA	129±50	NA
Jun-11	6.2	0.19	1.5	ND	47±25	ND
Dec-11	6.1	0.13	1.5	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.

Earthquake Event	$A_{E,cone}$ (m^2)	$H_{E,cone}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thick}$ (mm)	$A_{E,thin}$ (m^2)	$H_{E,thin}$ (mm)	A_T (m^2)
Sep-10	0	0	0	0	0	0	314
Feb-11	0	0	0	0	0	0	314
Jun-11	0	0	0	0	0	0	314
Dec-11	0	0	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; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta layers; $A_{E,cone}$ = Coverage area of conically shaped ejecta layers.

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

Earthquake Event	$A_{E,cone}$ (m^2)	$H_{E,cone}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thick}$ (mm)	$A_{E,thin}$ (m^2)	$H_{E,thin}$ (mm)	A_T (m^2)
Sep-10	0	0	0	0	0	0	673
Feb-11	14.9	150-250	1.2	20-40	0	0	673
Jun-11	0	0	0	0	0	0	673
Dec-11	0	0	0	0	0	0	673

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; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta layers; $A_{E,cone}$ = Coverage area of conically shaped ejecta layers.

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

Earthquake Event	$A_{E,cone}$ (m^2)	$H_{E,cone}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thick}$ (mm)	$A_{E,thin}$ (m^2)	$H_{E,thin}$ (mm)	A_T (m^2)
Sep-10	0	0	0	0	0	0	866
Feb-11	14.9	150-250	6.5	20-40	0	0	866
Jun-11	0	0	0	0	0	0	866
Dec-11	0	0	0	0	0	0	866

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; $H_{E,cone}$ = Lower-upper estimate of height of conically shaped ejecta layers; $A_{E,cone}$ = Coverage area of conically shaped ejecta layers.

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

EQ Event	$H_{E,thick}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thin1}$ (mm)	$A_{E,thin1}$ (m^2)	$H_{E,thin2}$ (mm)	$A_{E,thin2}$ (m^2)	$H_{E,prism/pyr}$ (mm)	$V_{E,prism+pyr}$ (m^3)	A_T (m^2)
Sep-10	0	0	0	0	0	0	0	0	99.2
Feb-11	0	0	3-6	13.2	0	0	17-57	0.097-0.194	99.2
Jun-11	0	0	0	0	0	0	0	0	99.2
Dec-11	0	0	0	0	0	0	0	0	99.2

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; $H_{E,prism/pyr}$ = Lower-upper estimate of ejecta height near the curb based on 2-4% cross slope of normal crown; $V_{E,prism}$ = Lower-upper estimate of total volume of prismatic-shape ejecta; $V_{E,pyr}$ = Lower-upper estimate of total volume of pyramidal-shape rectangular-base ejecta; A_T= Total assessment area of a buffer being considered.

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

EQ Event	$H_{E,thick}$ (mm)	$A_{E,thick}$ (m^2)	$H_{E,thin1}$ (mm)	$A_{E,thin1}$ (m^2)	$H_{E,thin2}$ (mm)	$A_{E,thin2}$ (m^2)	$H_{E,prism/pyr}$ (mm)	$V_{E,prism+pyr}$ (m^3)	A_T (m^2)
Sep-10	0	0	0	0	0	0	0	0	1114
Feb-11	50-100	21.4	3-6	62.2	2-4	117	16-181	6.80-13.6	1114
Jun-11	0	0	0	0	0	0	0	0	1114
Dec-11	0	0	0	0	0	0	0	0	1114

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; $H_{E,prism/pyr}$ = Lower-upper estimate of ejecta height near the curb based on 2-4% cross slope of normal crown; $V_{E,prism}$ = Lower-upper estimate of total volume of prismatic-shape ejecta; $V_{E,pyr}$ = Lower-upper estimate of total volume of pyramidal-shape rectangular-base ejecta; A_T= Total assessment area of a buffer being considered.

Note 4: The values in Table 9 correspond to the coverage area of ejecta outlined in aerial photographs (Figures 8, 9, and 32) 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

$$
\begin{aligned}
S_{E,P} = & \frac{\sum_{i=1}^{a} A_{E,thick,i} * H_{E,thick,i} + \sum_{j=1}^{b} A_{E,thin,j} * H_{E,thin,j}}{A_T} \\
& + \frac{\frac{1}{3}\sum_{m=1}^{e} A_{E,cone,m} * H_{E,cone,m} + \frac{1}{2}\sum_{n=1}^{f} W_{E,prism,n} * H_{E,prism,n} * L_{E,prism,n}}{A_T} \\
& + \frac{\frac{1}{3}\sum_{p=1}^{g} W_{E,pyramid,p} * H_{E,pyramid} * L_{E,pyramid}}{A_T} \\
& = \frac{\sum_{i=1}^{a} V_{E,thick,i} + \sum_{j=1}^{b} V_{E,thin,j}}{A_T} \\
& + \frac{\sum_{m=1}^{e} V_{E,cone,m} + \sum_{n=1}^{f} V_{E,prism,n} + \sum_{p=1}^{g} V_{E,pyramid,p}}{A_T}
\end{aligned}
$$

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;
- $A_{E,cone,m}$ and $H_{E,cone,m}$ are the aerea and the height of a conically shaped ejecta, respectively;
- $W_{E,prism,n}$ and $L_{E,prism,n}$ are the width and the length of the coverage area of a prismatically shaped ejecta layer, respectively, and $H_{E,prism,n}$ is the height of a prism-like ejecta layer;
- $W_{E,pyr,p}$ and $L_{E,pyr,p}$ are the width and the length of the coverage area of a pyramid-like ejecta layer, respectively, and $H_{E,pyr,p}$ is the height of a pyramid-like ejecta layer;
- A_T is the total assessment area for a buffer being considered (Figure 1).

Table 10a: 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	0	0	1	2	1	2
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 the estimates are based on Cubrinovski et al. (2011).

Table 10b: Ejecta-induced settlement estimates for Road based on photographs.

Earthquake Event	Road (20-m buffer)		Road (50-m buffer)	
	$S_{E,P,lower}$ (mm)	$S_{E,P,upper}$ (mm)	$S_{E,P,lower}$ (mm)	$S_{E,P,upper}$ (mm)
Sep-10	0	0	0	0
Feb-11	1	3	7	15
Jun-11*	0	0	0	0
Dec-11	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 the estimates are based on Cubrinovski et al. (2011).

Table 11a: 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	0	0	NA	1.5±0.5	<5	NA	1.5±0.5	<5
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; Final plus/minus values are also rounded to the nearest 5; NA = Not available; ND = Not determined.

Table 11b: Best final estimates of ejecta-induced settlement for Road.

Earthquake Event	Road (20-m buffer)			Road (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)
Sep-10	NA	0	0	NA	0	0
Feb-11	NA	2±1	<5	NA	11±4	10±5
Jun-11*	ND	0	0	ND	0	0
Dec-11	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; NA = Not available; ND = Not determined; * indicates uncertainty due to the lack of physical evidence.

Note 5:

- $S_{E,final}$ for Patch A is based solely on $S_{E,P}$ for all earthquake events due to the evident absence of ejecta for the Sep-10 and Dec-11 EQs and absence of the Sep-10 LiDAR survey that would be used to compute $S_{E,L}$ for the Feb-11 EQ. For the Jun-11 EQ, there are no aerial photographs; however, it is estimated that no ejecta occurred at the site.
- $S_{E,final}$ for Road is equal to $S_{E,P}$ for all earthquake events due to the evident absence of ejecta for the Sep-10 EQ and absence of the Sep-10 and Feb-12 LiDAR surveys that would be used to compute $S_{E,L}$ for the Feb-11 and Dec-11 EQs. For the Jun-11 EQ, there are no aerial photographs; however, it is estimated that no ejecta occurred at the site.
- The site is in the zone of severe to excessive LPI overprediction of liquefaction severity for the Sep-10 EQ and moderate to severe LPI overprediction of liquefaction severity for the Feb-11 EQ (Maurer et al. 2014[3]). There are no ground photographs or property inspection reports for nearby properties.

Summary:

- **The best estimate of the ejecta-induced free-field ground settlement at the Kaiwara Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, <5 mm, 0 mm, and 0 mm, respectively.**
- **The best estimate of the ejecta-induced free-field ground settlement of the road at the Kaiwara Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 10±5 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 streams and rivers.

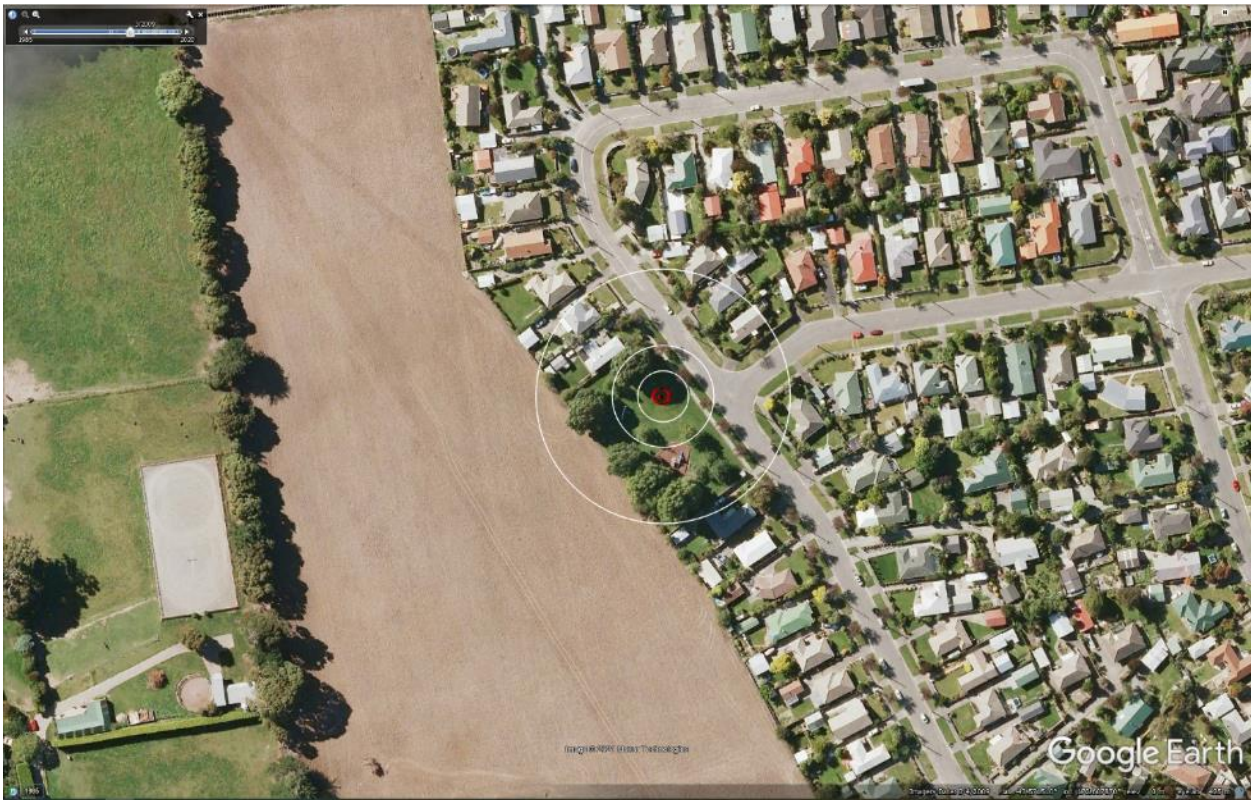

Figure 4: Position of the site relative to nearby buildings, vegetation, and free-face features.

Figure 5: Street view of the flat land.

Figure 6: Satellite image of the site taken in Apr 2004.

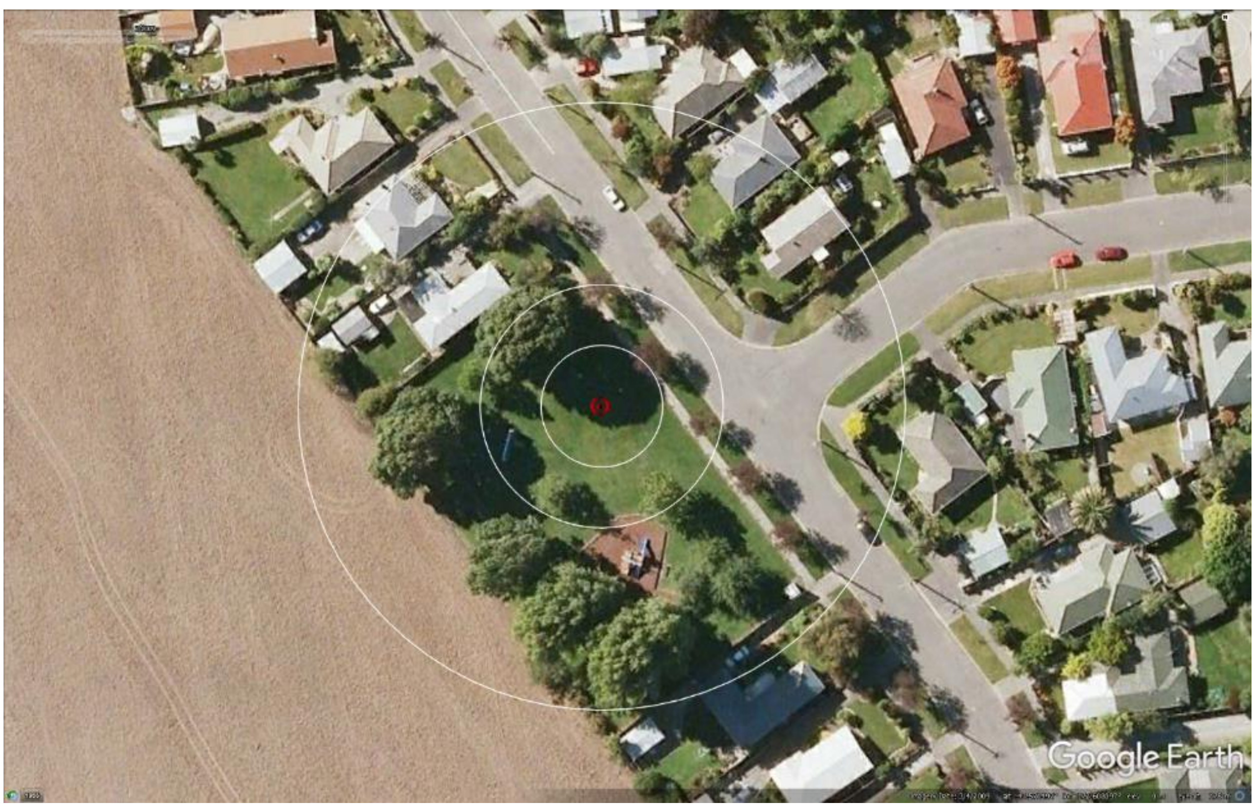

Figure 7: Satellite image of the site taken in Mar 2009.

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.

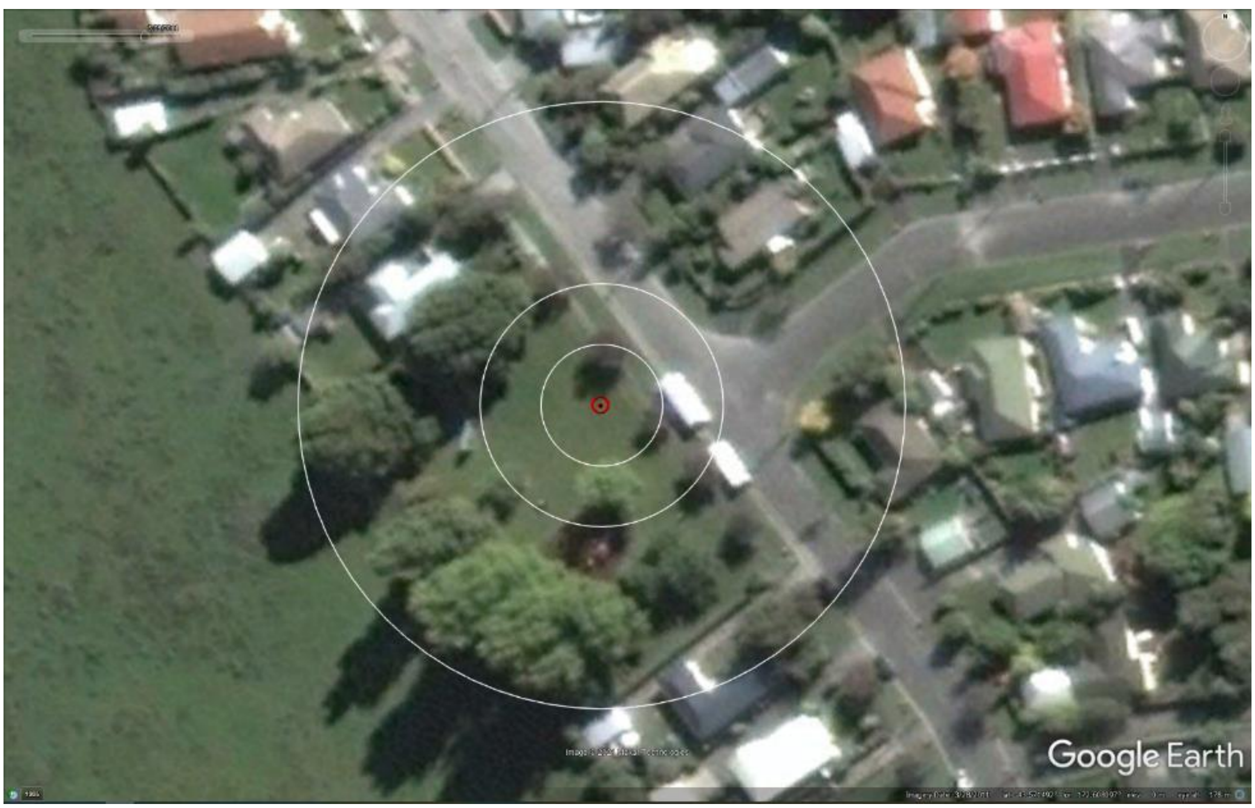

Figure 13: Satellite image of the site taken on Mar 28, 2011.

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

Figure 15: Satellite image of the site taken in Jan 2016.

Figure 16: No aerial photograph of the site from Sep 4, 2010.

Figure 17: Aerial photograph of the site taken on Feb 24, 2011.

Figure 18: No aerial photograph of the site from June 14-15, 2011.

Figure 19: No aerial photograph of the site from June 16, 2011.

Figure 20: Aerial photograph of the site taken on Dec 24, 2011.

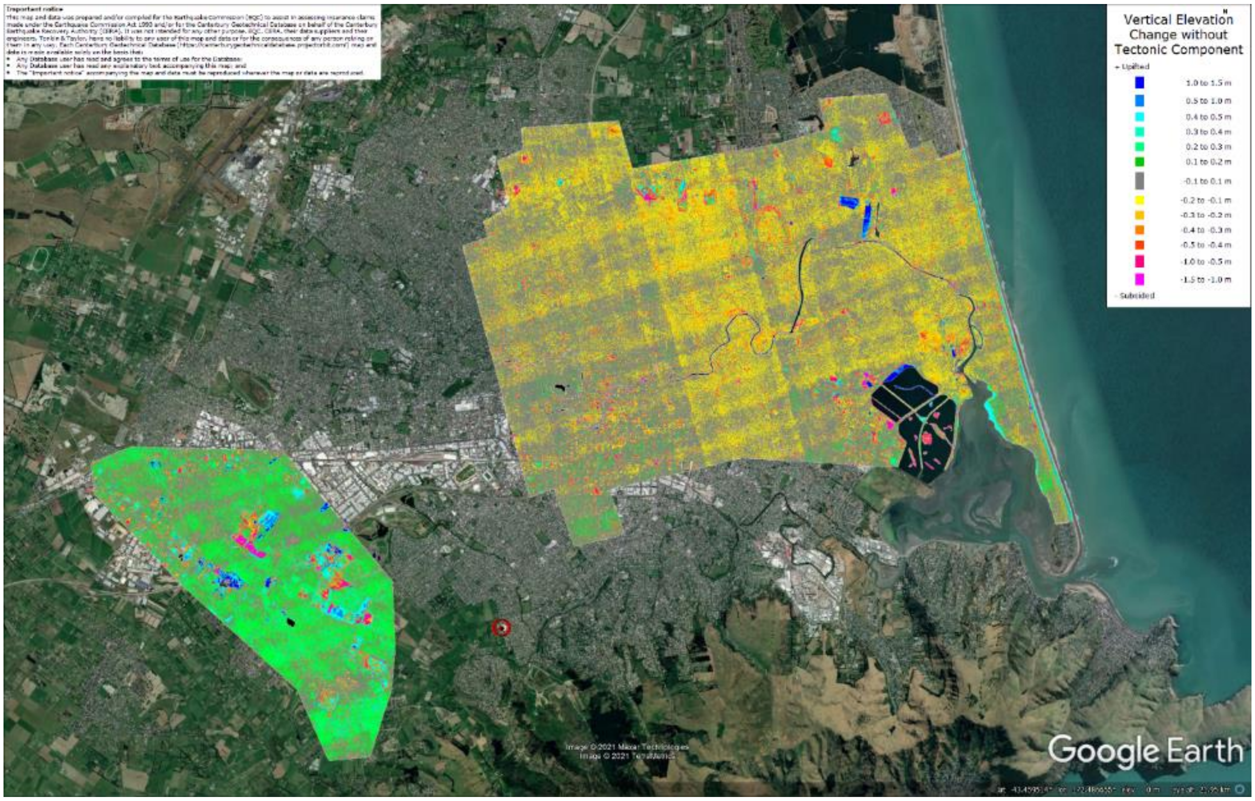

Figure 21: Vertical Ground Movements (Surface – Tectonic) not available for Sep 2010 Earthquake (no Sep 2010 LiDAR survey).

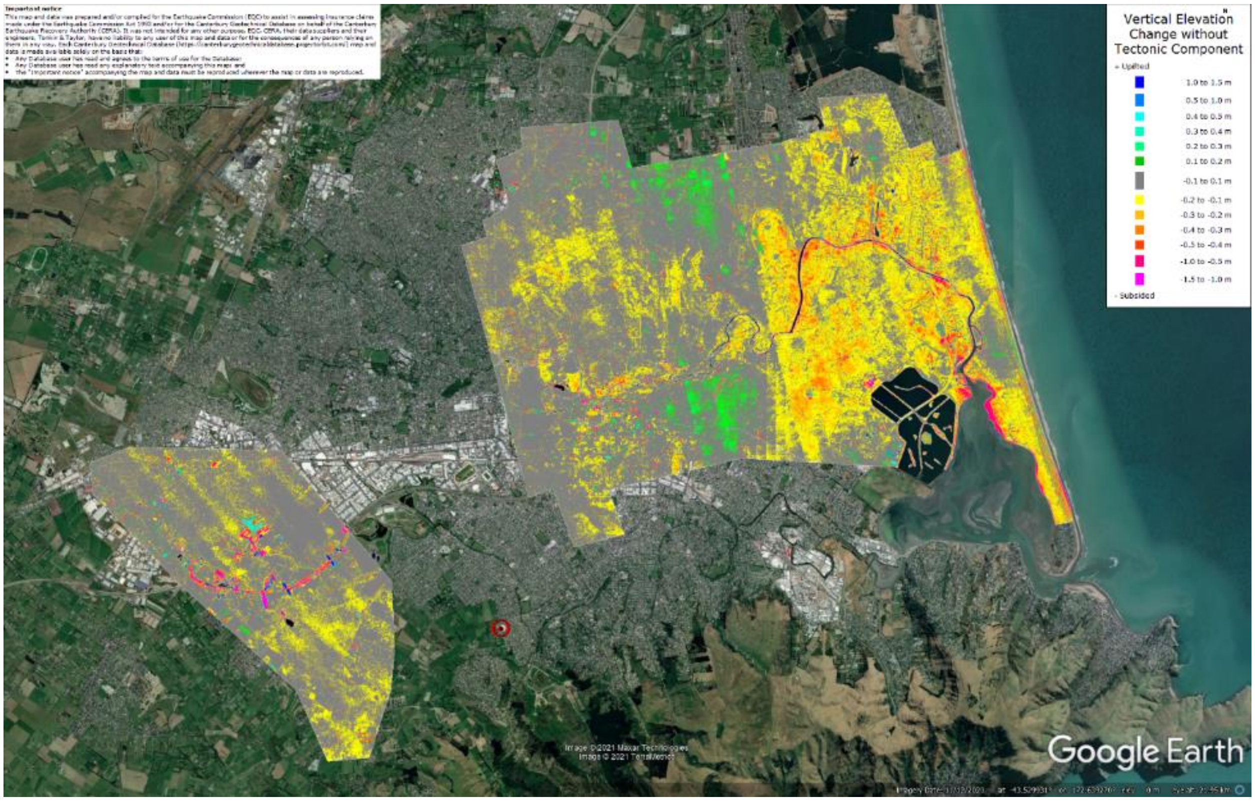

Figure 22: Vertical Ground Movements (Surface – Tectonic) not available for Feb 2011 Earthquake (no Sep 2010 LiDAR survey).

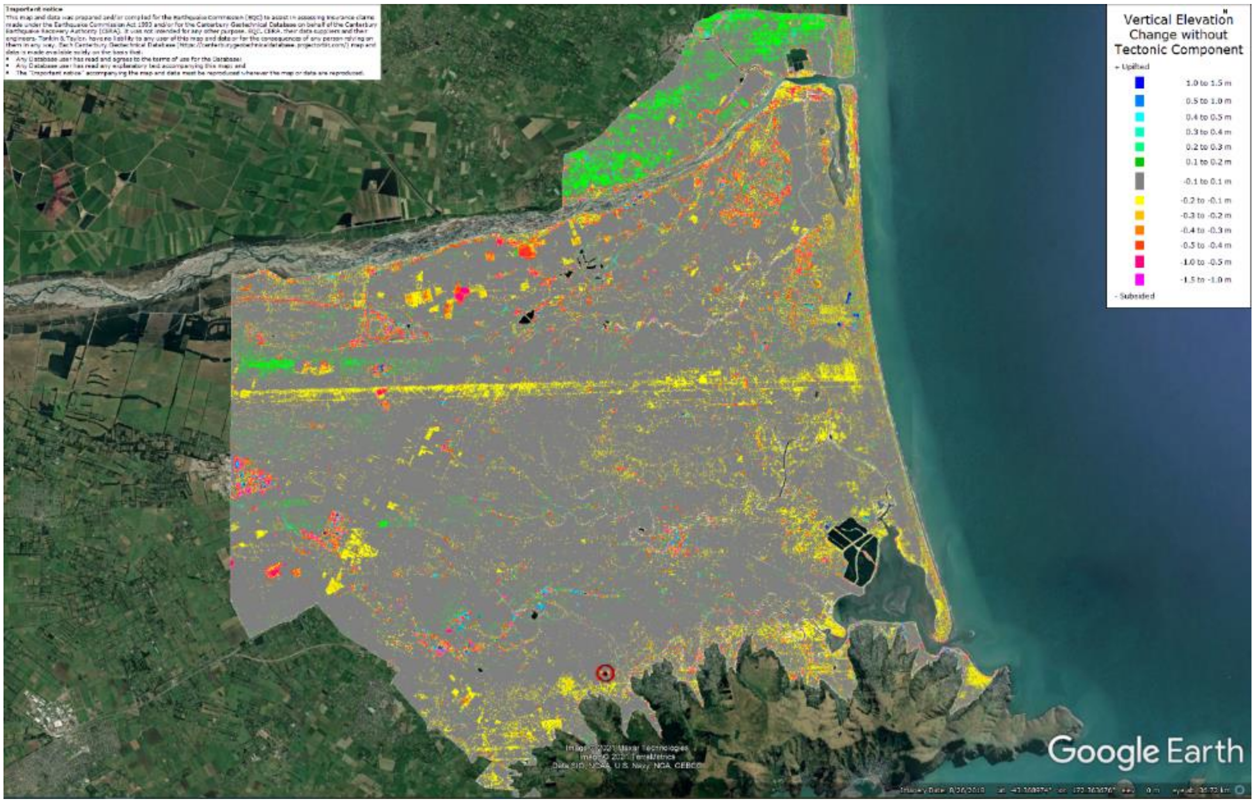

Figure 23: Vertical Ground Movements (Surface – Tectonic) for June 2011 Earthquake – the site is not in the apparent zone of overestimated or underestimated ground surface subsidence.

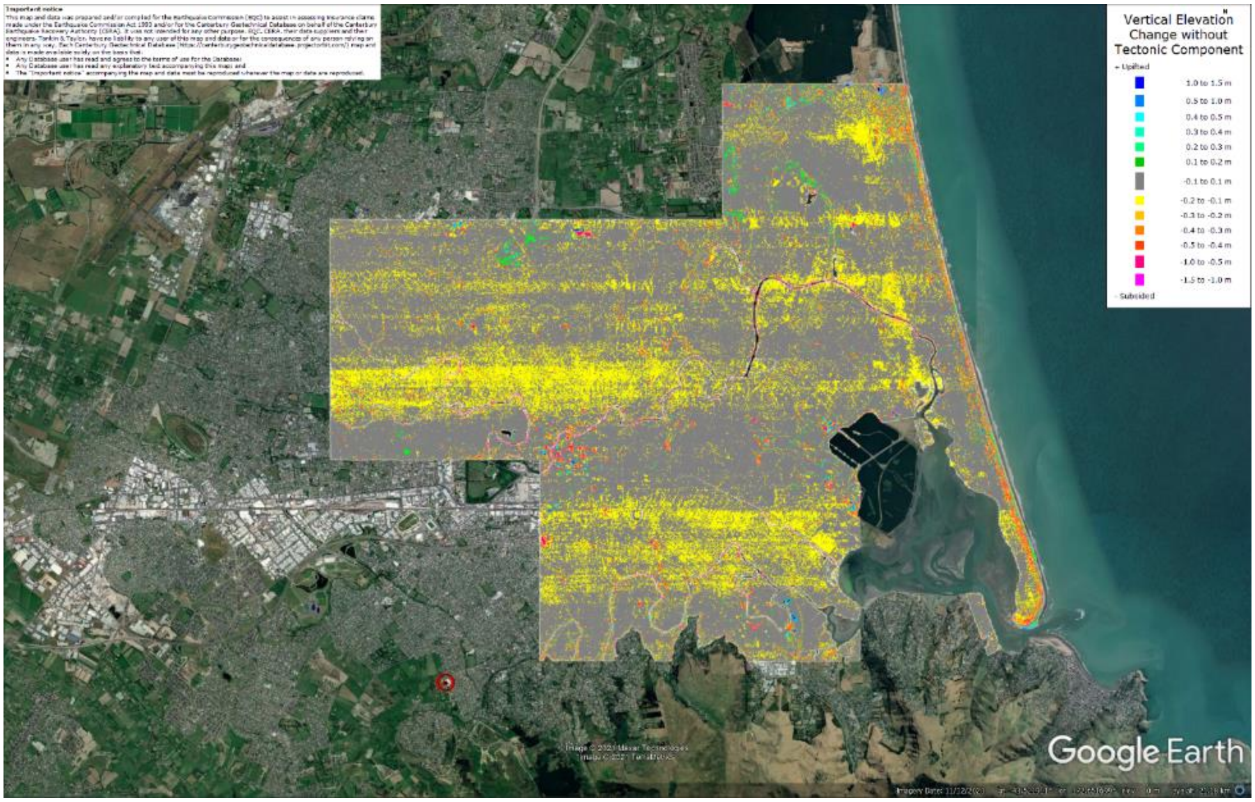

Figure 24: Vertical Ground Movements (Surface – Tectonic) not available for Dec 2011 Earthquake (no Feb 2012 LiDAR survey).

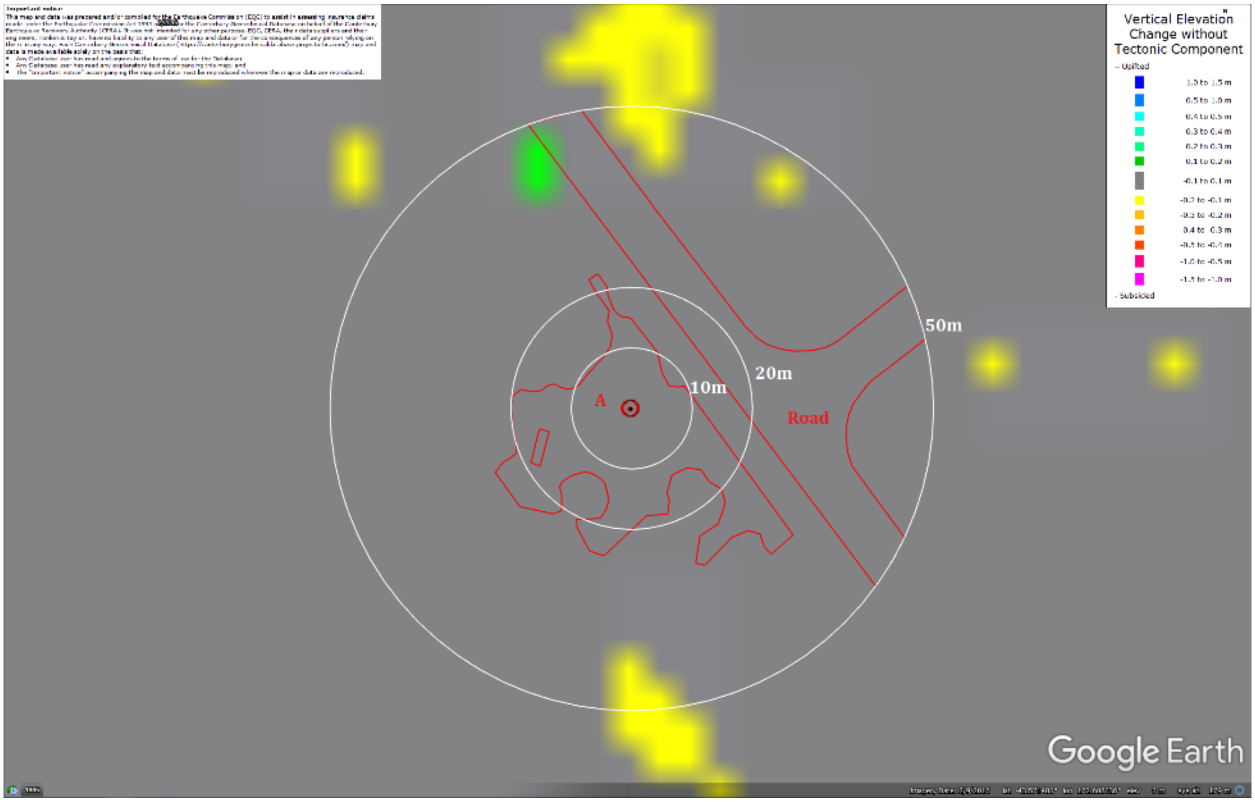

Figure 25: Ground surface subsidence without tectonic component for June 2011 Earthquake according to the LiDAR DEM.

Figure 26: Absence of 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.

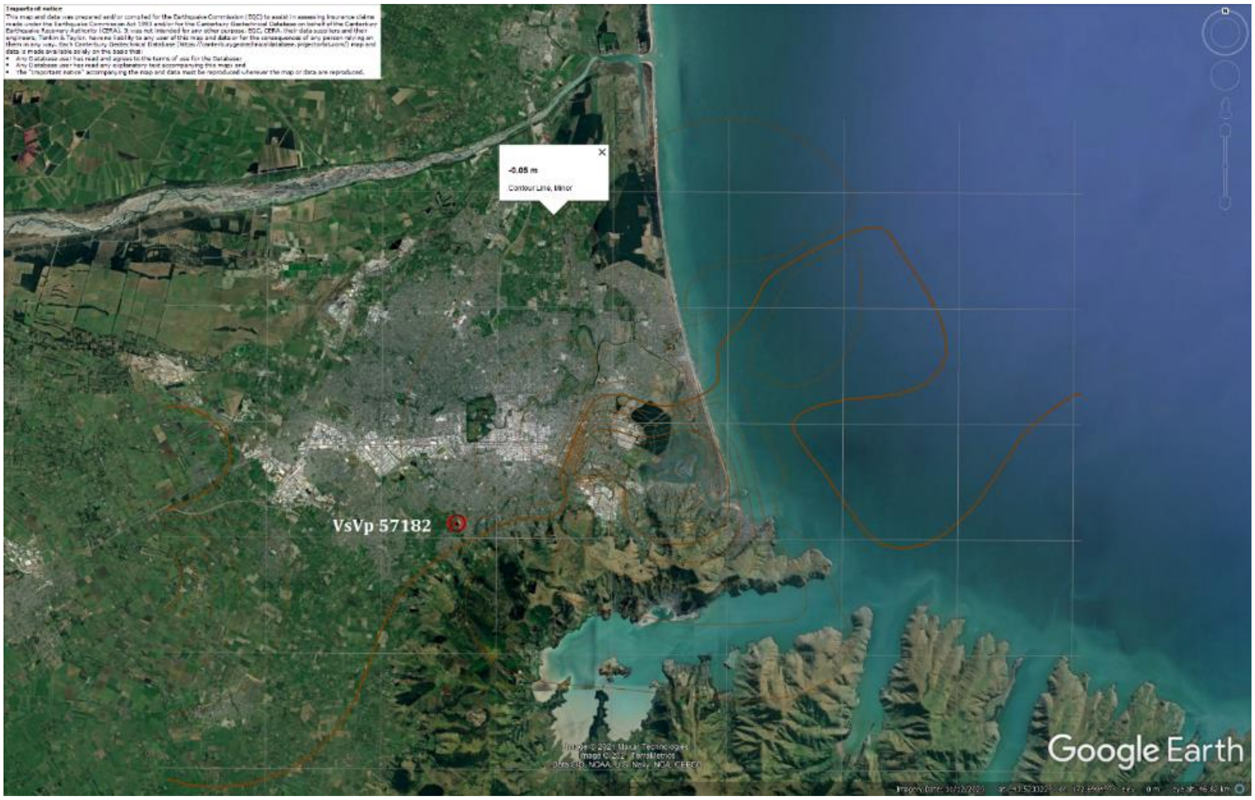

Figure 31: Vertical tectonic movements for Canterbury Earthquake Sequence.

Figure 32: Aerial photograph showing the ejecta outline at the site for Feb-11 EQ.

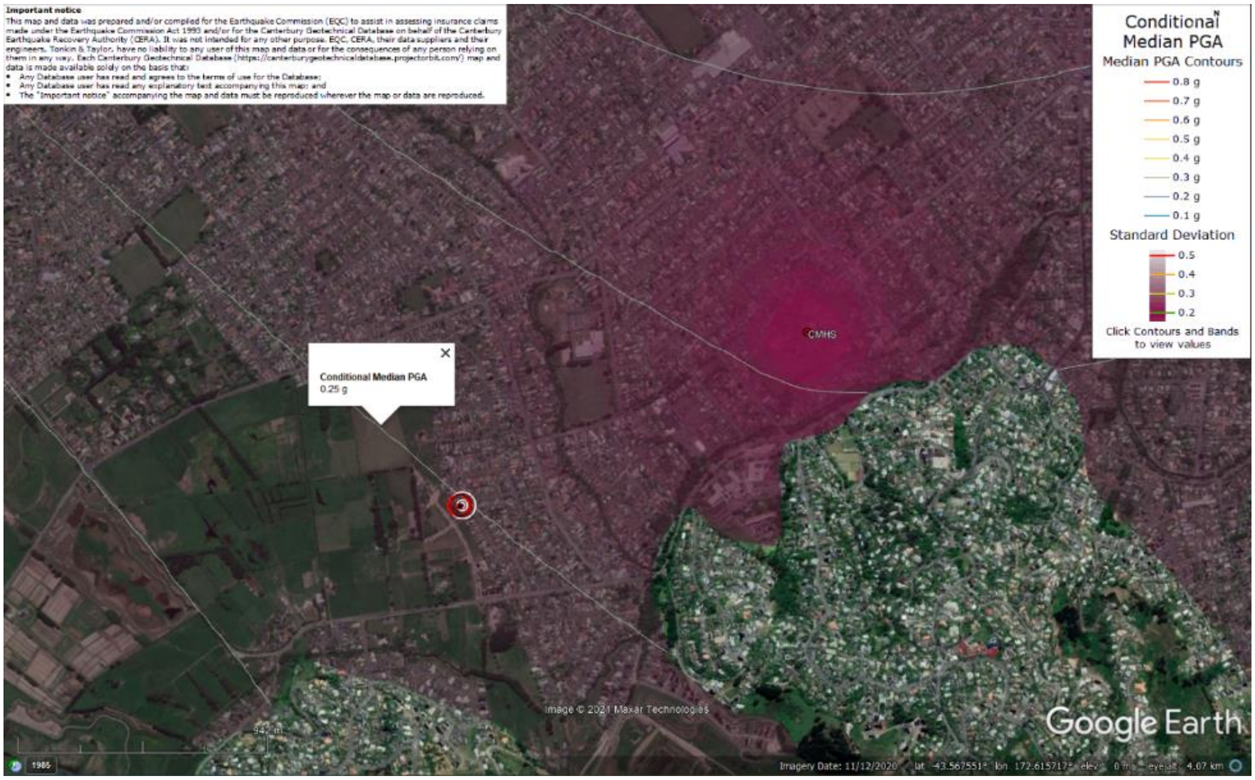

Figure 33: PGA for Sep-10 EQ (st. dev. = 0.325-0.350 ln units).

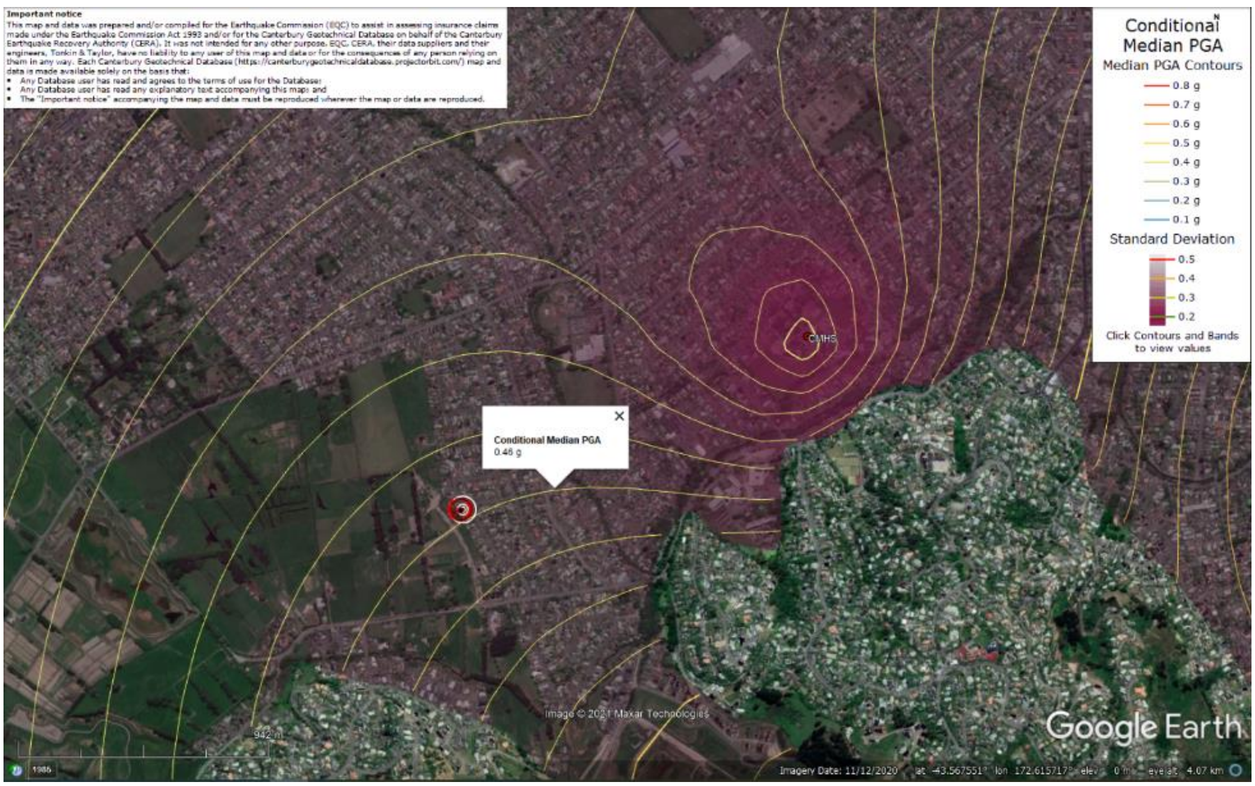

Figure 34: PGA for Feb-11 EQ (st. dev. = 0.350-0.375 ln units).

Figure 35: PGA for Jun-11 EQ (st. dev. = 0.375-0.400 ln units).

Figure 36: PGA for Dec-11 EQ (st. dev. = 0.350-0.375 ln units).

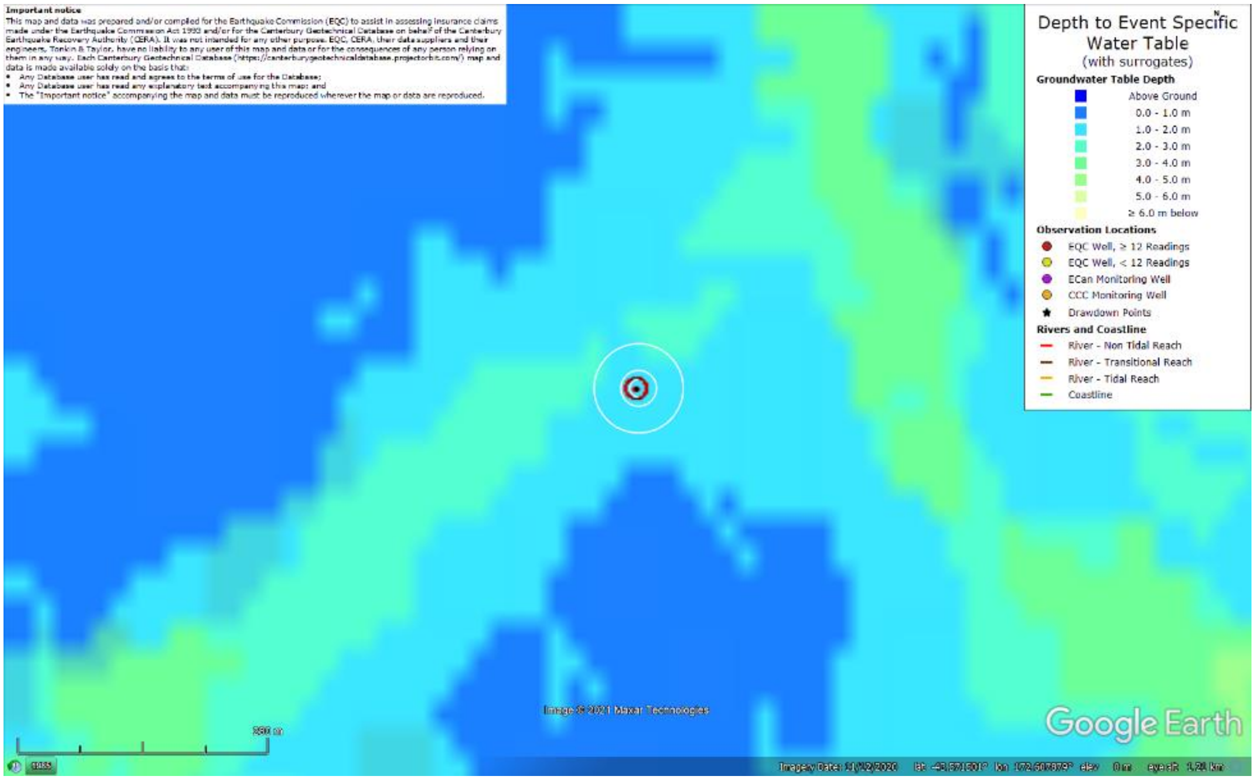

Figure 37: Depth to groundwater table for Sep-10 EQ.

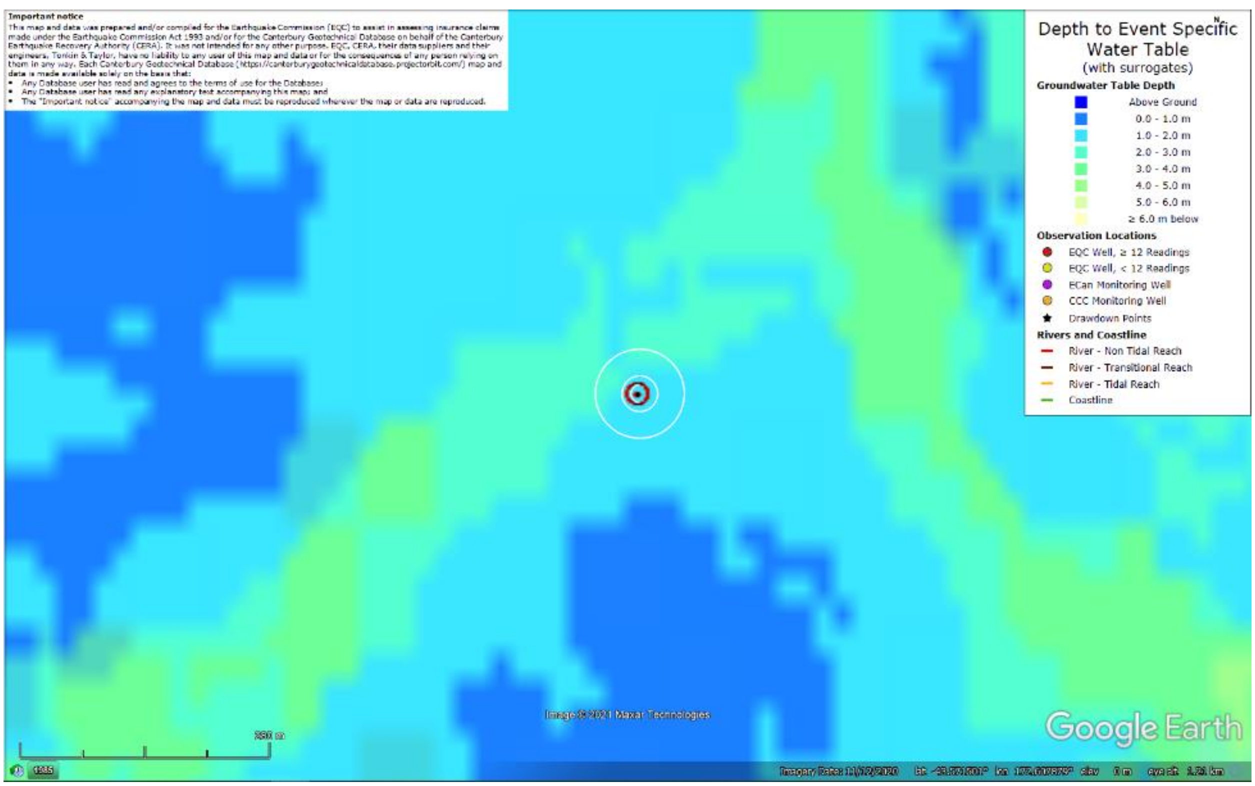

Figure 38: Depth to groundwater table for Feb-11 EQ.

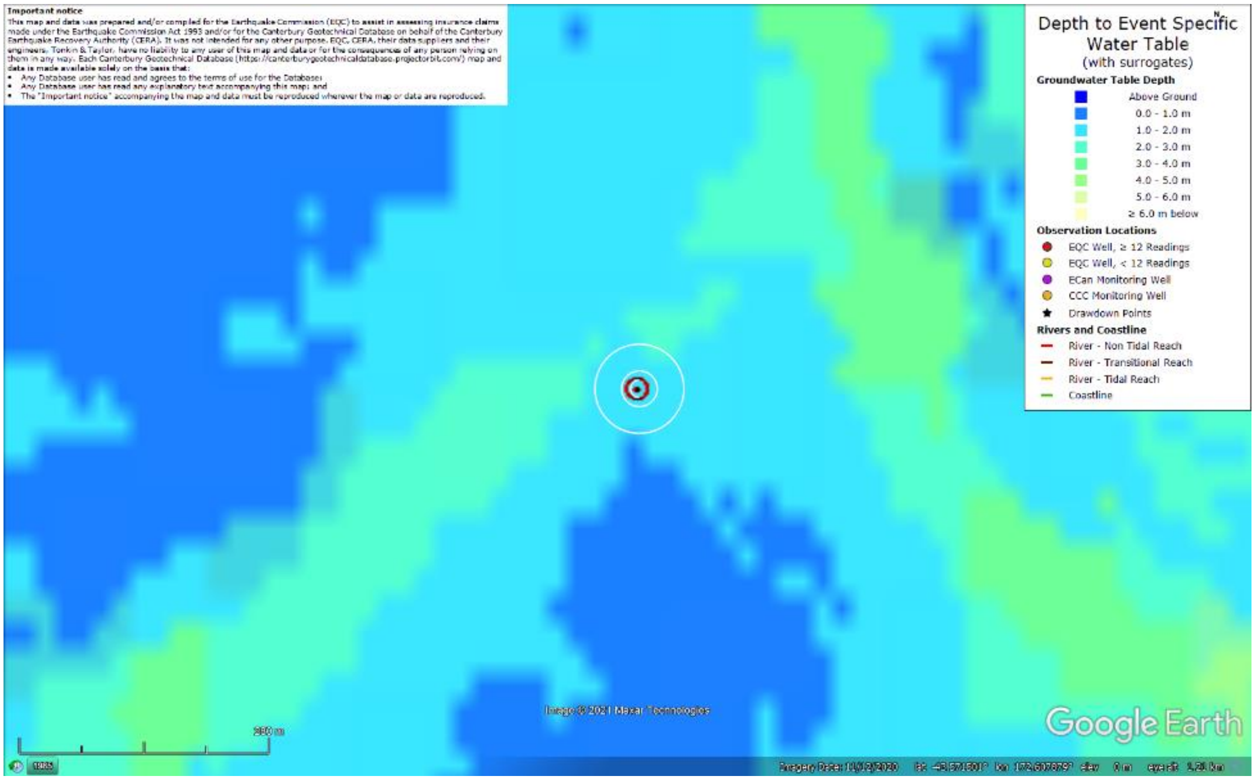

Figure 39: Depth to groundwater table for Jun-11 EQ.

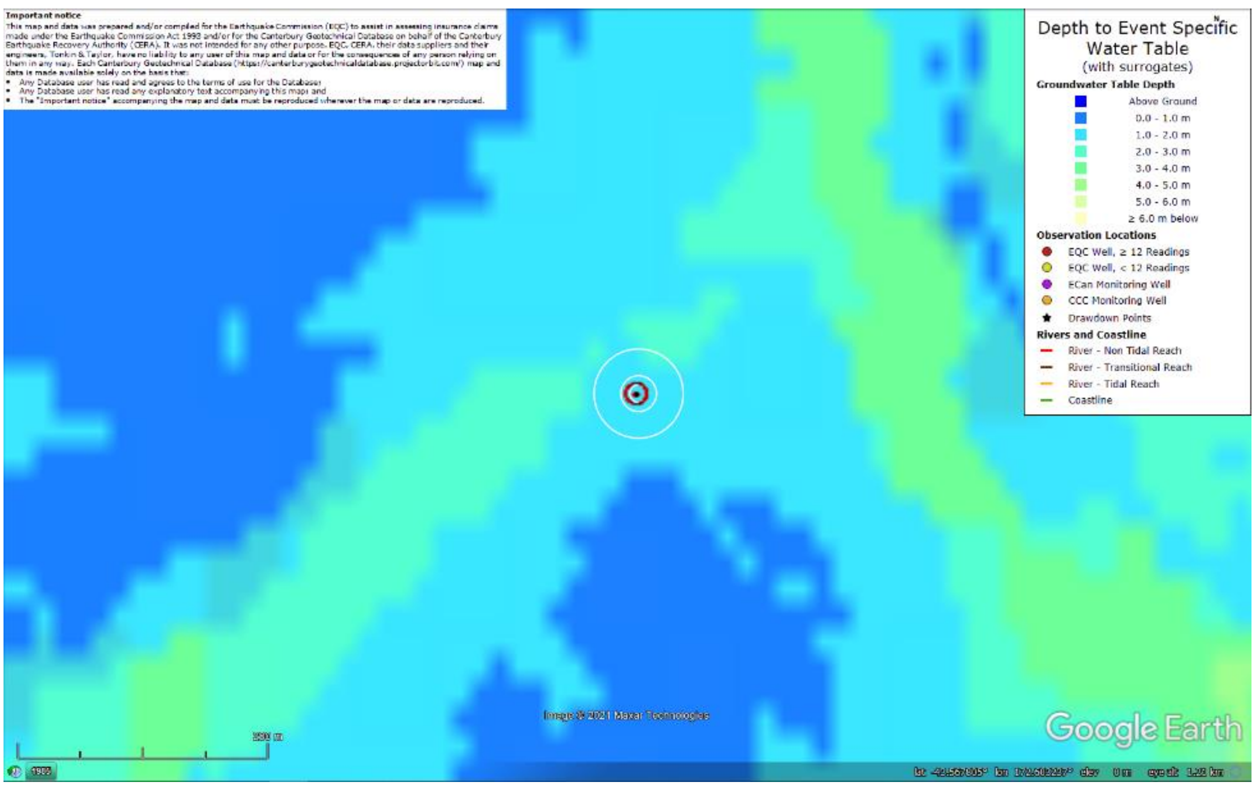

Figure 40: Depth to groundwater table for Dec-11 EQ.

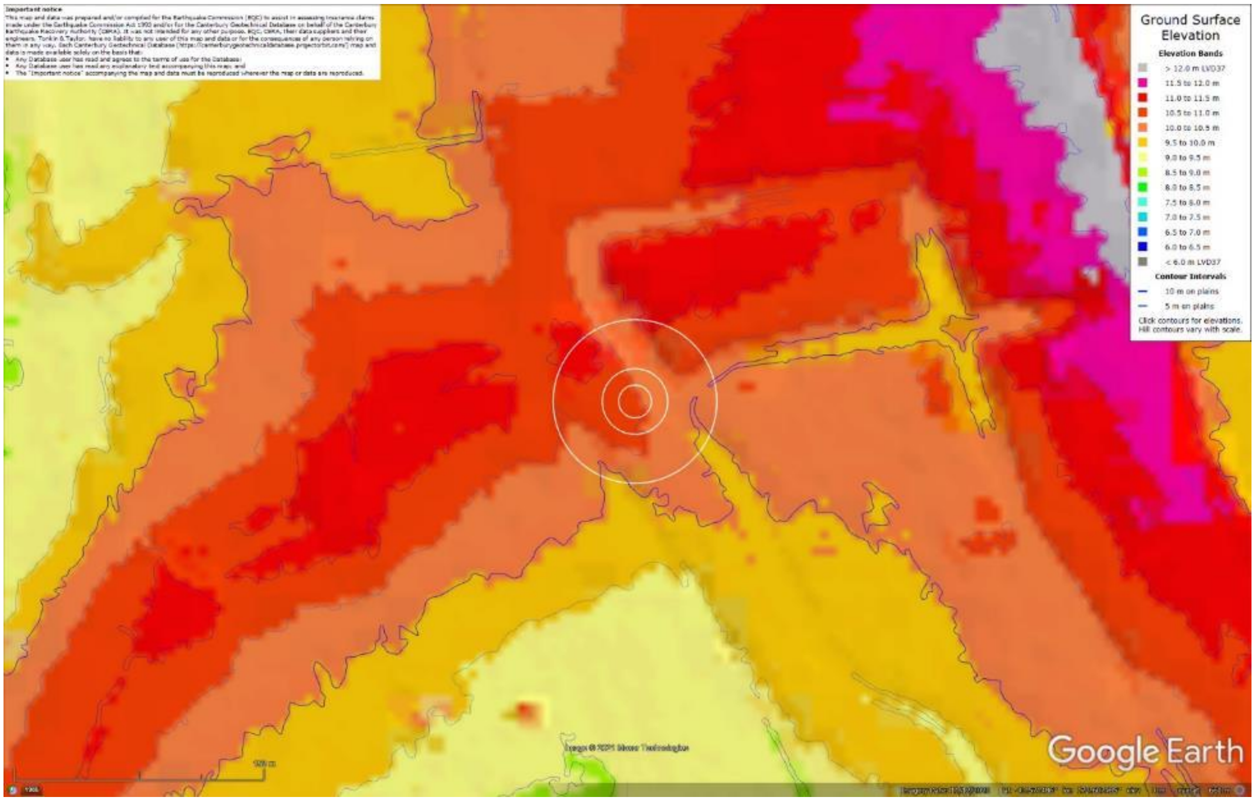

Figure 41: Ground surface elevation according to the Sep-11 LiDAR survey.

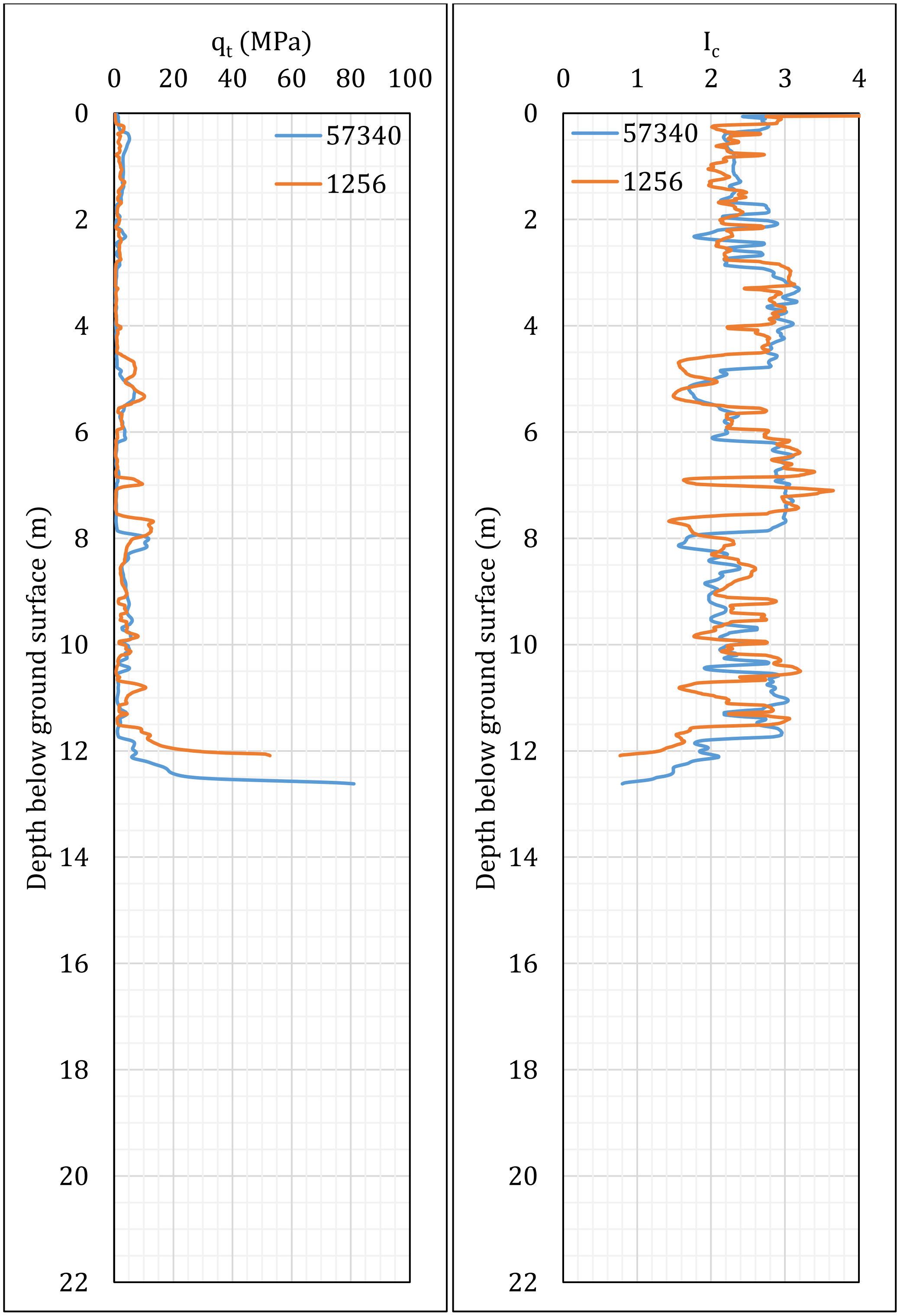

Figure 42: q_t and I_c profiles.

Note 6: 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)	Road (50-m buffer)
57340	✓	✓	✓	✓
1256		✓	✓	✓

Table 13: CPT-based results.

		CPT ID	
EQ Event	Parameter	57340	1256
Sep-10	S_{V1D} (mm)	118	130
	LSN	21	28
	LPI	9	11
	LPI_{ish}	5	6
	$D_{FS<1}$ (m)	2.16	1.71
Feb-11	S_{V1D} (mm)	126	136
	LSN	22	28
	LPI	18	20
	LPI_{ish}	8	12
	$D_{FS<1}$ (m)	2.16	1.71
Jun-11	S_{V1D} (mm)	54	60
	LSN	8	10
	LPI	1	2
	LPI_{ish}	0	0
	$D_{FS<1}$ (m)	4.80	5.64
Dec-11	S_{V1D} (mm)	4	5
	LSN	1	1
	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; S_{V1D} is assumed to be negligible for a depth range from ~12.5 m (tip refusal due to gravel) to 20 m.

Note 7: Based on the borehole log (BH 57225, Figure 1), the groundwater table is at a depth of 0.6 m below the ground surface. The soil profile consists of (1) topsoil (organic silt, OL) to a depth of 0.3 m, (2) silt, ML, to a depth of 1.0 m, (3) silty fine sand, SM, to a depth of 1.2 m, (4) silt, ML, to a depth of 4.85m, (5) fine to medium sand, SP, to a depth of 5.25 m, (6) silt, ML, to a depth of 6.55 m, (7) peat, Pt, to a depth of 6.65 m, (8) silt, ML, to a depth of 7.85 m, (9), fine sand, SP, to a depth of 9.9 m, (10) silt, ML, to a depth of 12.15m, (11) silty fine to medium sand, SM, to a depth of 12.45 m, (12) sandy fine to coarse gravel, GW, to a depth of 13.75 m, (13) gravelly fine to coarse sand, SP, to a depth of 14.35 m, and (14) sandy fine to coarse gravel, GW, to a depth of 15.65 m (the end of the borehole). All soil layers (except the topsoil) are the Yaldhurst members of the Springston formation. Trace organics are present throughout most of the soil profile.

Note 8: 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 (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	673	0	0	0	0
Feb-11	673	16.1	0.8-1.3	<5	65±15
Jun-11	673	0	0	0	0
Dec-11	673	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 (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	866	0	0	0	0
Feb-11	866	21.4	0.9-1.5	<5	55±15
Jun-11	866	0	0	0	0
Dec-11	866	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 Road (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	99.2	0	0	0	0
Feb-11	99.2	21.1	0.1-0.3	<5	10±5
Jun-11	99.2	0	0	0	0
Dec-11	99.2	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 14d: Areal and localized ejecta-induced settlement estimates for Road (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	1114	0	0	0	0
Feb-11	1114	395	8.3-16.6	10±5	30±10
Jun-11	1114	0	0	0	0
Dec-11	1114	0	0	0	0

Notes: S_{E,P_areal} = $S_{E,P}$ reported in Table 11 = areal ejecta-induced settlement; $S_{E,P\_localized}$ = localized ejecta-induced settlement; A_T = total settlement assessment area; V_E = total volume of ejecta within A_T; A_E = total area of ejecta within A_T; The estimates of both areal and localized ejecta-induced settlement are rounded to the nearest 5; Final plus/minus values are also rounded to the nearest 5.

Summary 2:

- **The best estimate of the localized ejecta-induced free-field ground settlement at the Kaiwara Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 55±15 mm, 0 mm, and 0 mm, respectively.**

- **The best estimate of the localized ejecta-induced settlement of the road at the Kaiwara Reserve site for the SEP 2010, FEB 2011, JUN 2011, and DEC 2011 earthquake is 0 mm, 30±10 mm, 0 mm, and 0 mm, respectively.**