ANNEXURE 8 **Geotechnical Assessment**

GEOTECHNICAL REPORT FOR PLAN CHANGE AND PROPOSED SUBDIVISION

32571 / LOT 1 & LOT 2 DP 436571, TAI TAPU

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Quality Assurance

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Disclaimer

This geotechnical report has been prepared at the specific instructions of Jonathan Williams and Zane and Sharon Crofts in connection with a plan change and proposed subdivision of Lot 1 and Lot 2 (DP 436571) Tai Tapu. The report provides a geotechnical assessment of the land underlying the site. Davis Ogilvie did not perform a complete assessment of all possible conditions or circumstances that may exist at the site. Conditions may exist which were undetectable given the limited investigation of the site. Variations in conditions may occur between test locations, and there may be conditions onsite which have not been revealed by the investigation, which have not been taken into account in the report.

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Should anyone wish to discuss the content of this report with Davis Ogilvie & Partners Ltd, they are welcome to contact us on (03) 366 1653 or at 11 Deans Avenue, Addington, Christchurch.

Executive Summary

Davis Ogilvie & Partners Ltd has been engaged by Jonathan Williams and Zane and Sharon Crofts to undertake a geotechnical investigation at Lot 1 and Lot 2 DP 436571 Tai Tapu, where a 16 lot residential subdivision is proposed. The site is zoned Inner Plains in the Selwyn District Council Plan and the current land use is pastoral.

The scope of works for the investigation included the following:

- Desktop Study
- Site walkover
- 16 Cone Penetration Tests (CPTs)
- Geotechnical consideration and reporting
- Assessment of suitability of the site for subdivision according to Section 106 of the Resource Management Act (1991)
- Proposed foundation options for future residential development
- Statement of suitability for subdivision

The 8 ha site is adjacent to the Halswell River and is underlain by dominantly river deposits comprising grey river alluvium, beneath plains or low level terraces of the Springston Formation. Sixteen deep Cone Penetration Tests (CPTs) were carried out by Fugro Geotechnical on behalf of Davis Ogilvie as per the recommendations in Section 16.3 of the Ministry of Business Innovation & Employment (MBIE) 2012 Guidance document[1]. Testing revealed the underlying natural soils comprise interbedded clay, silt, sand and gravel extending to approximately 15 m below Existing Ground Level (EGL), where testing terminated in very dense gravel.

During future seismic events liquefaction induced settlements are estimated to be 60 – 120 mm in a Serviceability Limit State (SLS) event and 110 – 160 mm in an Ultimate Limit State (ULS) event, using the MBIE-mandated analysis methodology. Lateral stretch for Lots 1 – 4 given the proximity of the proposed lots to the Halswell River, was estimated at between 75 – 225 mm towards the river.

It is believed that the site is suitable for subdivision under Section 106 of the RMA providing the subsidence and flood hazards are mitigated by ground improvement, appropriate minimum finished floor levels and specific engineering design for foundations. For future development of the site, a site specific geotechnical investigation for each new lot will be required to confirm the underlying geology and provide appropriate design criteria.

[1] Ministry of Business, Innovation and Employment (MBIE), Repairing and rebuilding houses affected by the Canterbury earthquakes. December 2012. Wellington, NZ. Referred to throughout as MBIE 2012.

Table of Contents

1.0 Introduction

Davis Ogilvie & Partners Ltd (Davis Ogilvie) have been engaged by Jonathan Williams and Zane and Sharon Croft to carry out a geotechnical investigation of Lot 1 DP 436571 held under Title 537135, and Lot 2 DP 436571 held under Title 537136. Lots 1 and 2 shall be referred to as “the site” from herein. The 8.0 ha site is located immediately west of Hauschilds Road in the township of Tai Tapu and is proposed to be subdivided into 16 residential lifestyle lots.

The purpose of this report is to describe geotechnical constraints and preliminary design criteria for the subdivision.

The scope of works for the investigation included the following:

- Desktop Study
- Site walkover
- 16 Cone Penetration Tests (CPTs)
- Geotechnical consideration and reporting
- Assessment of suitability of the site for subdivision according to Section 106 of the Resource Management Act (1991)
- Proposed foundation options for future residential development
- Statement of suitability for subdivision

2.0 Site Description

The site is located immediately west of Hauschilds Road in the township of Tai Tapu. The site can be accessed via both Lincoln Tai Tapu Road from the north and via Hauschild Road from the east (refer Figure 1). The site is currently zoned Inner Plains in the Selwyn District Council Plan. The land parcel immediately east of the site is zoned Living 1A.

The Halswell River is located approximately 30 m from the northern end of the site and runs parallel to the boundary, flowing from east to west as it meanders towards Lake Ellesmere approximately 9 km south of Tai Tapu. A small unnamed waterway is located approximately 20 m southwest of the southwestern corner of the site and appears to drain south via man-made drainage ditches.

The existing site is currently used for grazing livestock, is not occupied by any utilities and is generally flat in grade with a gentle slope south, away from the Halswell River. Several ephemeral channels can be observed in aerial photography across the site with water present following periods of heavy rainfall and in winter months[2]. The site is bound to the northeast by residential properties and the southeast of the site is in the process of residential development. The land to the south and west of the site is rural, pastoral land with two storage sheds adjacent the northwestern boundary of the site. Lincoln Tai Tapu Road runs adjacent to the northern site boundary, refer Figure 1. Refer Figure 2 for the Indicative Master Plan for the proposed subdivision.

[2] Google Earth viewer accessed 11/05/2015

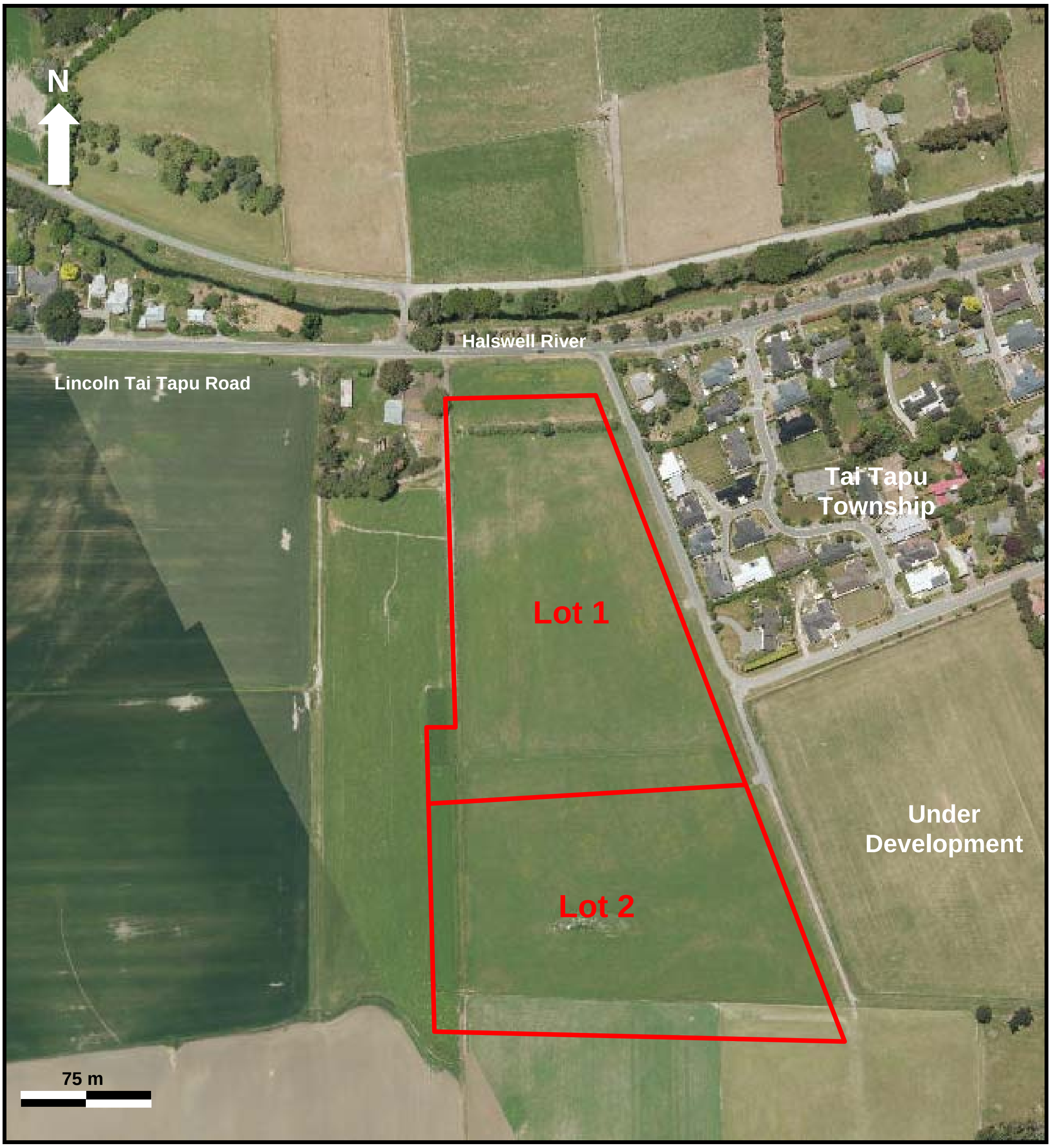

Figure 1: Image shows the two lots where the 16 lot subdivision is proposed. Various features outlined in Section 2.0 are visible in the image.
(Image source: http://canterburymaps.govt.nz/AdvancedViewer/Index.html)

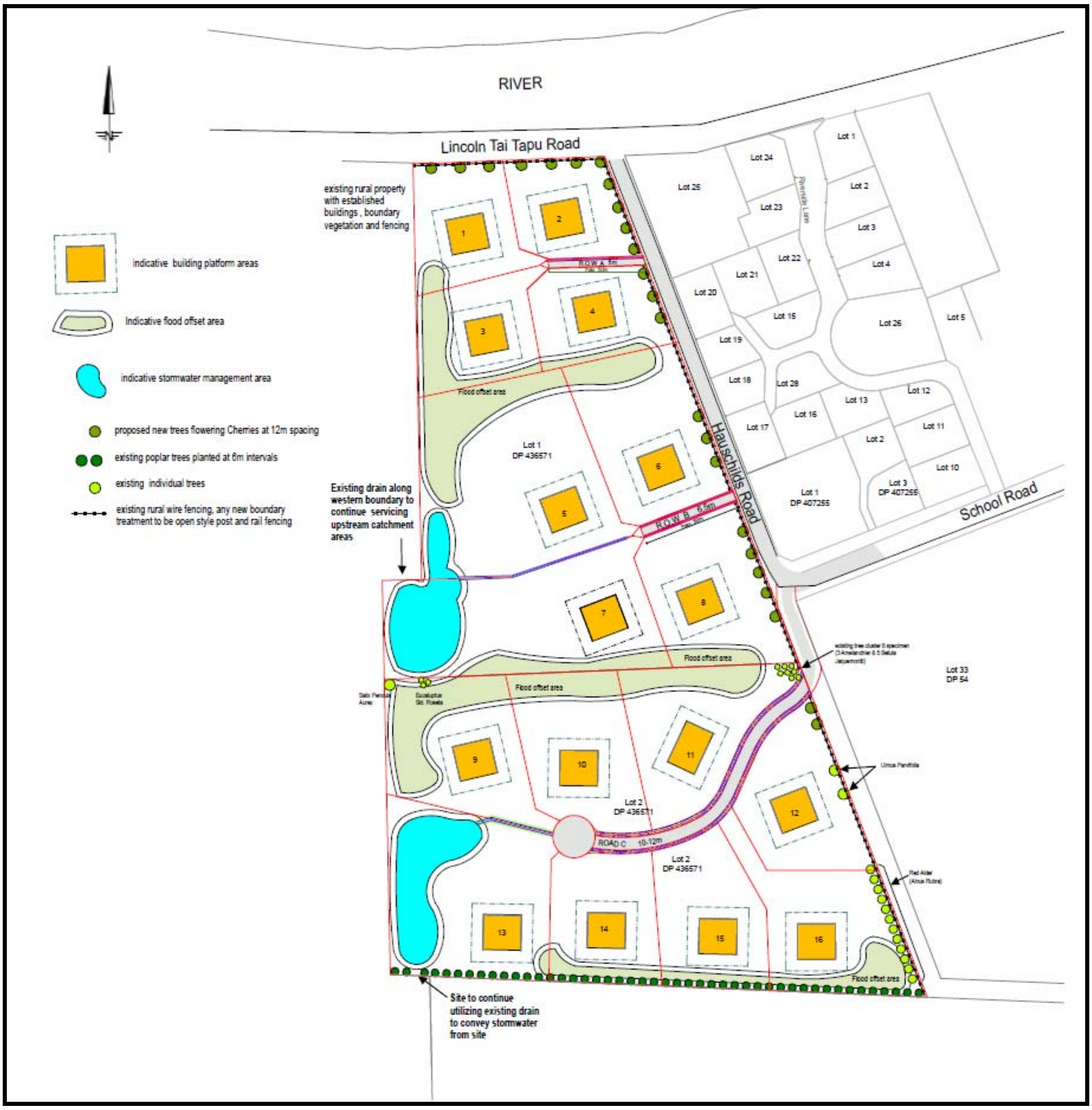

Figure 2: Indicative Master Plan for the proposed 16 lot subdivision of Lot 1 and Lot 2 DP 436571.

3.0 Desktop Study

A desktop study was conducted to provide background information on the site. The desk study included a review of information currently available from the Canterbury Geotechnical Database (CGD/Project Orbit) and the Environment Canterbury (ECan) GIS Maps website.

3.1 Aerial Photography

Aerial photographs[3] cover the site from 1973 and show that the site and adjacent properties are occupied by farmlets and/or pastoral land with the block of land northeast of the site (Tai Tapu Township) being developed from 2004, and the remainder of the properties adjacent the site remaining farmlets and/or pastoral land.

The Tai Tapu township has had a gradual increase in land development since the Canterbury earthquake series with blocks of land within the township being subdivided and land on the periphery of the township also being developed.

3.2 Published Land Damage

Following the Canterbury earthquake series, the majority of the Tai Tapu area has been assigned a MBIE Technical Category of TC2 which indicates minor to moderate land damage from liquefaction is possible in future large earthquake events. Approximately 150 m either side of the Halswell River has been zoned TC3 which identifies that moderate to significant land damage from liquefaction is possible in future large earthquake events, refer Figure 3. This 150 m “buffer zone” either side of the Halswell River was created to identify the risk of moderate to severe liquefaction and lateral spread towards the river in future large earthquake events, and was based on the damage observed following the Canterbury earthquake series.

[3] Aerial photography available from the ECan viewer at http://canterburymaps.govt.nz/AdvancedViewer/

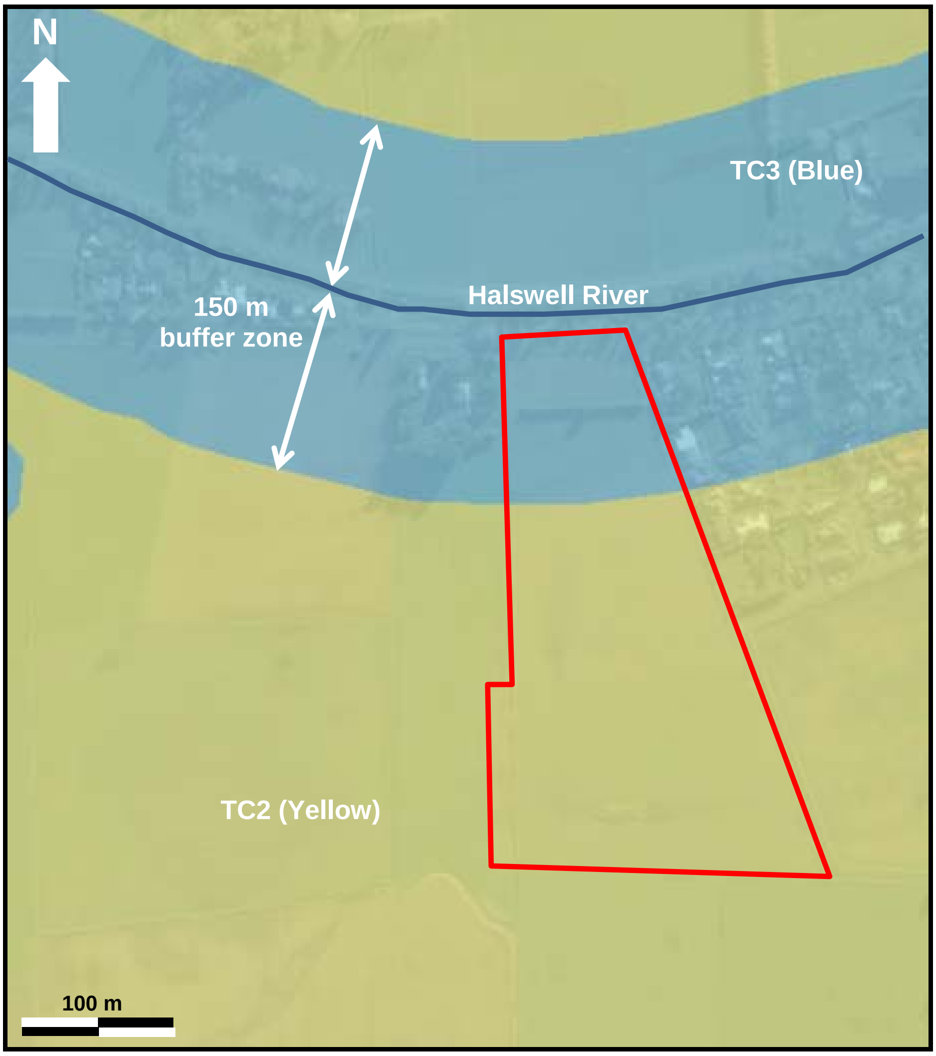

Figure 3: Technical Land Categories in the vicinity of the site (shown in red). TC2 areas are shown in yellow and TC3 areas in blue.

(Image source: Canterbury Geotechnical Database[4])

Moderate surface evidence of liquefaction is evident in Land Information New Zealand (LINZ) aerial photography following the February 2011 earthquake event[5] in the areas north and west of the site, however the imagery does not cover the majority of the site or areas east and south of the site. EQC observed no to moderate liquefaction ejecta on the properties east and northwest of the site following the September 2010 earthquake however there are no EQC recorded observations from the February, June and December 2011 earthquake events[6].

[4] Canterbury Geotechnical Database - Map Layer CGD5020 - 18 Mar 2014
[5] http://maps.cera.govt.nz/advanced-viewer/?Viewer=CERA_PACT.
[6] Canterbury Geotechnical Database (2013) "Liquefaction and Lateral Spreading Observations", Map Layer CGD0300 - 11 Feb 2013, retrieved 08/05/2015 from https://canterburygeotechnicaldatabase.projectorbit.com/

Geotech Consulting Limited produced a report[7] for the Selwyn District Council dated February 2011 stating that following the September 2010 earthquake event *"liquefaction was confined to a strip of land 0.5 to 1.5 km wide that followed the Halswell River".* The map shows an area of liquefaction on the northern section of the site, with observed liquefaction mapped north, west and east of the site following the Halswell River, (refer Figure 4).

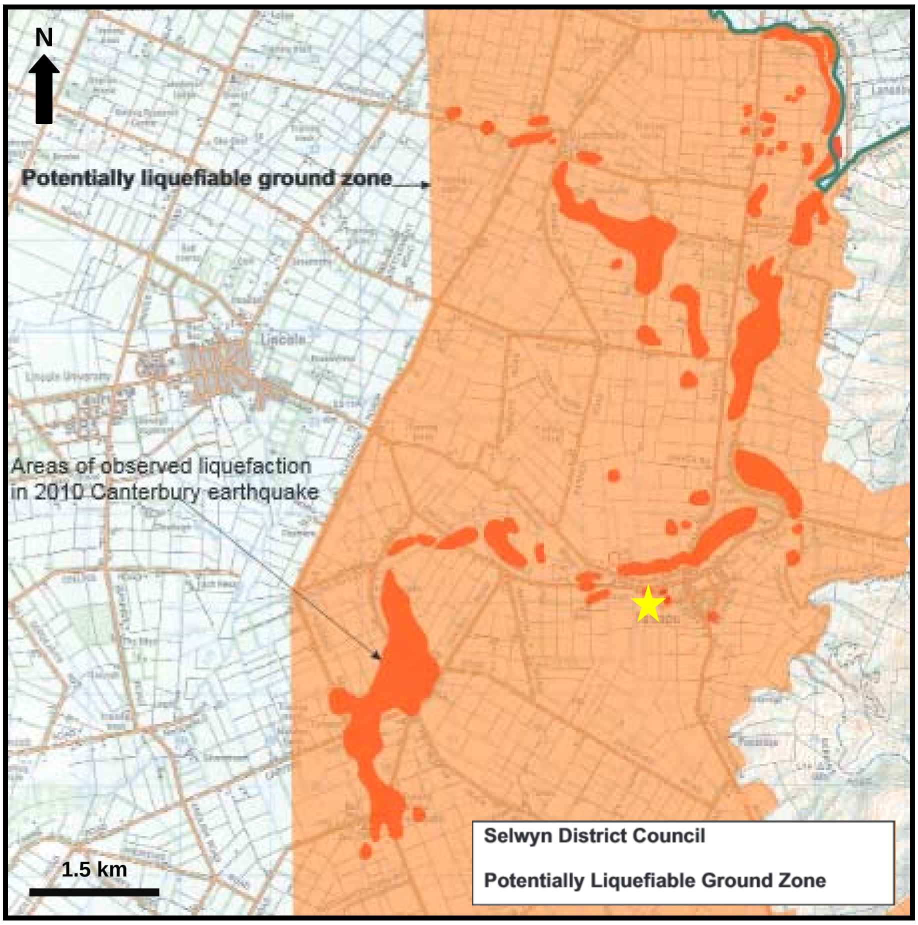

Figure 4: Geotech Consulting Ltd - Liquefaction assessment of the Selwyn District (February 2011). The yellow star indicates the approximate location of the site.

(Image source: Geotech Consulting Limited Liquefaction Report)

Following the September 2010 event GNS Science[8] undertook detailed mapping of Canterbury as part of a review of areas affected by the September 2010 Darfield earthquake. GNS identified the presence of surface water in an old channel, flooding by water, and sand boils in some areas of the site, (refer Figure 5).

[7] McCahon. I. Traylen. N. & Yetton. M. 2011. 2010 Canterbury Earthquake. Liquefaction Report. Reference 3680. Version 05.6.
[8] Review of liquefaction hazard information in eastern Canterbury, including Christchurch City and parts of Selwyn, Waimakariri and Hurunui Districts. Environment Canterbury Report R12/83. December 2012. Accessed 19 April 2015 fromhttp://ecan.govt.nz/advice/emergencies-and-hazard/earthquakes/Pages/liquefaction-information.aspx#review

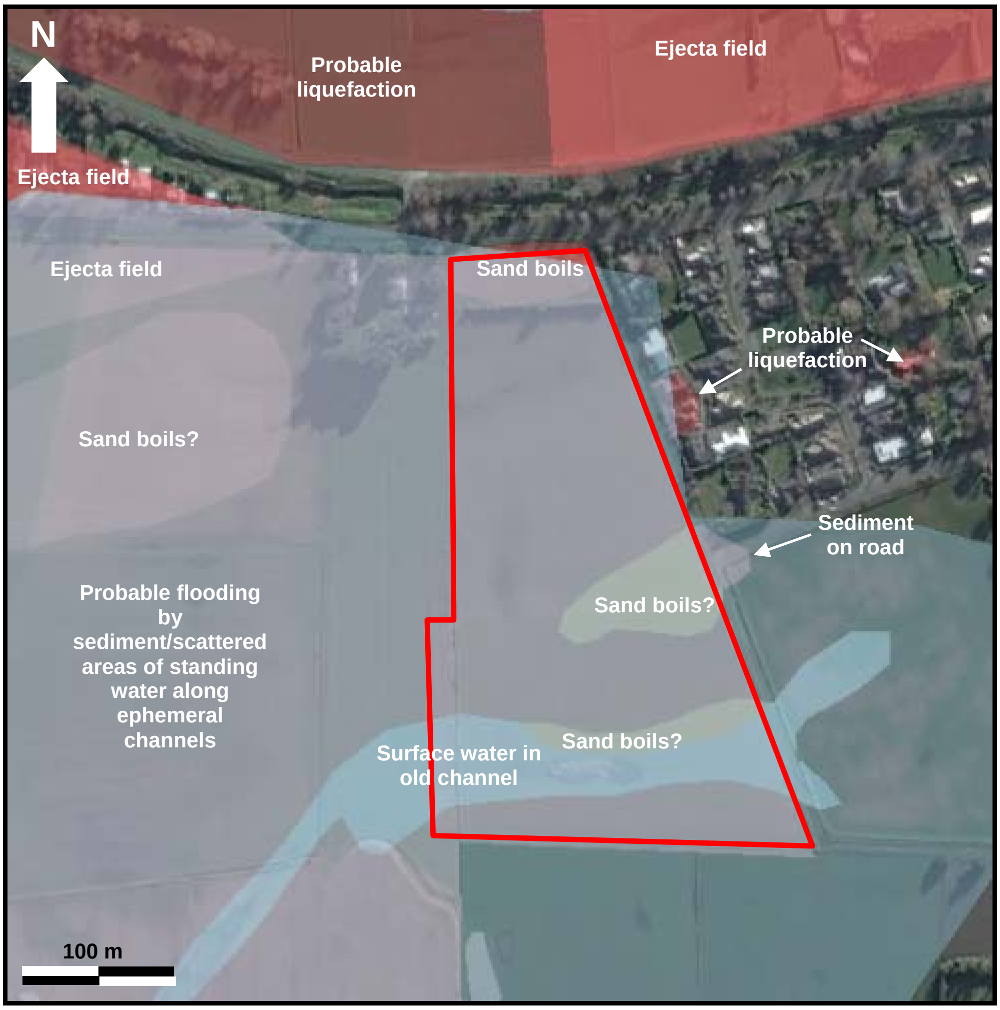

Figure 5: GNS Science Liquefaction observations following the September 2010 M_w 7.1 Darfield earthquake. The site is shown in red.

(Image source: Project Orbit)

3.3 Geology

The published geological map which covers the area (Geology of the Christchurch Area, Institute of Geological and Nuclear Sciences, 1:250,000 Geological Map 16, 2008)[9] indicates that the site is underlain by dominantly river deposits of the Springston Formation comprising grey river alluvium beneath plains or low level terraces (Q1a).

The site lies within an area known as the *"Canterbury Plains"* which comprises a series of coalesced floodplains which have created a succession of abandoned braided river channels that were active during the last glacial maximum approximately 12,000 years ago[9]. Although many river channels are abandoned and inactive, historically during peak flows the Waimakariri River flowed through Christchurch and south of the present day city, where the river discharged into Lake Ellesmere.

[9] Forsyth, P.J., Barrell, D.J.A., Jongens, R. (2008) (compilers), Geology of the Christchurch Area, Institute of Geological and Nuclear Sciences 1:250 000 geological map 16. 1 sheet. Lower Hutt, New Zealand. GNS Science. ISBN 987-0-478-19649-8

3.4 Ground Water

An ECan well, M36/0945, located approximately 100 m west of the northern section of the site records an initial water level of 0.9 m below EGL with fluctuations in static readings from 1.1 – 1.3 m below Existing Ground Level (EGL). Groundwater levels are expected to fluctuate seasonally and spatially.

3.5 Seismicity

The nearest known active faults identified in AS/NZS1170.5:2004[10] are the Alpine, Kakapo, Kelly and Hope Faults. The Port Hills and Greendale Faults and a number of smaller faults were identified from the GNS fault database[11]. Approximate distances from the nearest known faults are presented in Table 1.

Table 1: AS/NZS 1170.5 Active Fault Distances

Fault Name	Fault Sense	Approximate distance from fault (km)
Greendale	Dextral	10 (W)
Port Hills	Oblique Reverse	10 (NE)
Kakapo	Dextral	100 (NW)
Hope	Dextral	100 (NW)
Alpine	Dextral	125 (NW)

Table 2 presents an approximate record of the Peak Ground Accelerations (PGAs) experienced in Tai Tapu based on ground motion maps of recorded motions for the earthquakes in the Canterbury earthquake series[12].

The approximate PGAs experienced onsite indicate the site has experienced ground motions near ULS design levels during the September 2010 earthquake event and ground motions in excess of SLS design levels during the September 2010, February and June 2011 events.

[10] Standards New Zealand (2002) AS/NZS 1170.5:2004 Structural Design Actions – Part 5: Earthquake Actions, New Zealand Standards Council, Wellington.
[11] Geological and Nuclear Sciences (2014). New Zealand Active Fault Database GIS Viewer [Online Query]. Retrieved from http://data.gns.cri.nz/af/
[12] Buxton, R., McVerry, G., Goded, T. (Geological and Nuclear Sciences) (2014). Ground motion maps based on recorded motions for the earthquakes in the Canterbury earthquake sequence.

Table 2: Approximate Peak Ground Accelerations Experienced Onsite			
Event	**Magnitude (M_w)**	**PGA**	**Magnitude (Mw) 7.5 Equivalent**
September 2010	7.1	0.30 g	0.27 g
February 2011	6.2	0.30 g	0.21 g
June 2011	6.0	0.20 g	0.13 g
December 2011	5.9	0.14 g	0.09 g

3.6 NZS 1170.5 Site Soil Class

According to NZS1170.5 a site soil class of D (deep or soft soils) is recommended for the site due to the significant depth to bedrock in the area.

3.7 Nearby Geotechnical Testing

The surrounding Cone Penetration Tests (CPTs), (CPT_36572 – CPT_36592, CPT_836, CPT_837, and CPT_17225) located within 5 to 270 m of the site have been undertaken to between 13 – 14 m below EGL where testing terminated in dense gravel. Interbedded soft to hard clay and silt, and very loose to medium dense sand is present from the surface to between 6.5 – 7.7 m below EGL, and is underlain by medium dense to dense sand and gravel to between 7.9 – 9.5 m below EGL. Stiff to hard silt and very loose to medium dense sand was encountered to between 12.5 – 14.0 m below EGL underlain by dense to very dense gravel to between 13 – 14 m below EGL.

3.8 Flood Management Area

Environment Canterbury undertook an assessment of the flood risk for Lot 2 in 2012. The results and recommendations of this preliminary assessment are assumed to apply equally to and therefore be applicable for Lot 1.

Historic photographs taken following heavy and prolonged rainfall events in 1986, 1992 and 1994 reveal the site is outside areas of major ponding within the Halswell River catchment. Larger flood events are noted to have occurred, however the site was not visible in the photographs. The rainfall events previously mentioned range in return periods from 2 – 5 years up to 20 years.

Following peak flood levels recorded in 1977 from stations both upstream and downstream of the site, an estimated peak level of approximately 6.7 m above mean sea level was recorded in the Halswell River. Selwyn District Council LiDAR information indicates the ground level across the property ranges from 6.3 – 7.1 m above mean sea level.

ECan undertook flood modelling based on 50 year and 200 year return period flood events for the site. Modelled scenarios indicate flood levels of approximately 6.7 – 6.9 m above mean sea level.

The site has also been mapped as being on the Waimakariri River floodplain because of the possibility of Waimakariri River overflows reaching the Halswell River catchment. Given the low probability of this occurring ECan has not specified a minimum finished floor level to mitigate such an event.

It was therefore recommended by Selwyn District Council that any dwelling built onsite should have a minimum finished floor level that is 0.3 m above the modelled floodwater levels (minimum RL of 7.4 m) or at least 0.4 m above the existing ground level, whichever is highest. Prior to the construction of any dwelling onsite, the minimum finished floor level will need to be confirmed by Selwyn District Council or ECan.

3.9 Listed Land Use Register

A review of the ECan Listed Land Use Register (LLUR) website indicates that the regional council does not have any information regarding a Hazardous Activity or Industry (as defined on the HAIL list) on this land parcel.

Please note that this does not confirm that the site is not contaminated, however it does show there are no known historical listed land uses that may have caused elevated levels of potentially harmful contaminants.

4.0 Geotechnical Investigation and Results

Section 16 in Part D of the MBIE 2012 Guidance document provides recommendations for the geotechnical investigation and assessment of subdivisions in the Canterbury region. It is recommended that appropriate geotechnical investigations be carried out to enable the characterisation of the ground-forming materials to at least 15 m depth onsite. Because the size of the lots to be subdivided are greater than 1 ha and the land is currently zoned rural, 1 CPT per proposed site, i.e. 16 CPTs, was considered adequate for characterisation of the ground underlying the site for subdivision purposes.

The CPTs were carried out by Fugro Geotechnical NZ Limited on 8 April 2015. Test locations are shown in Figure 5 and are also shown on the appended geotechnical site plan (DWG 600A). Test locations were selected based on the most recent concept plans Davis Ogilvie were provided with at the time of testing.

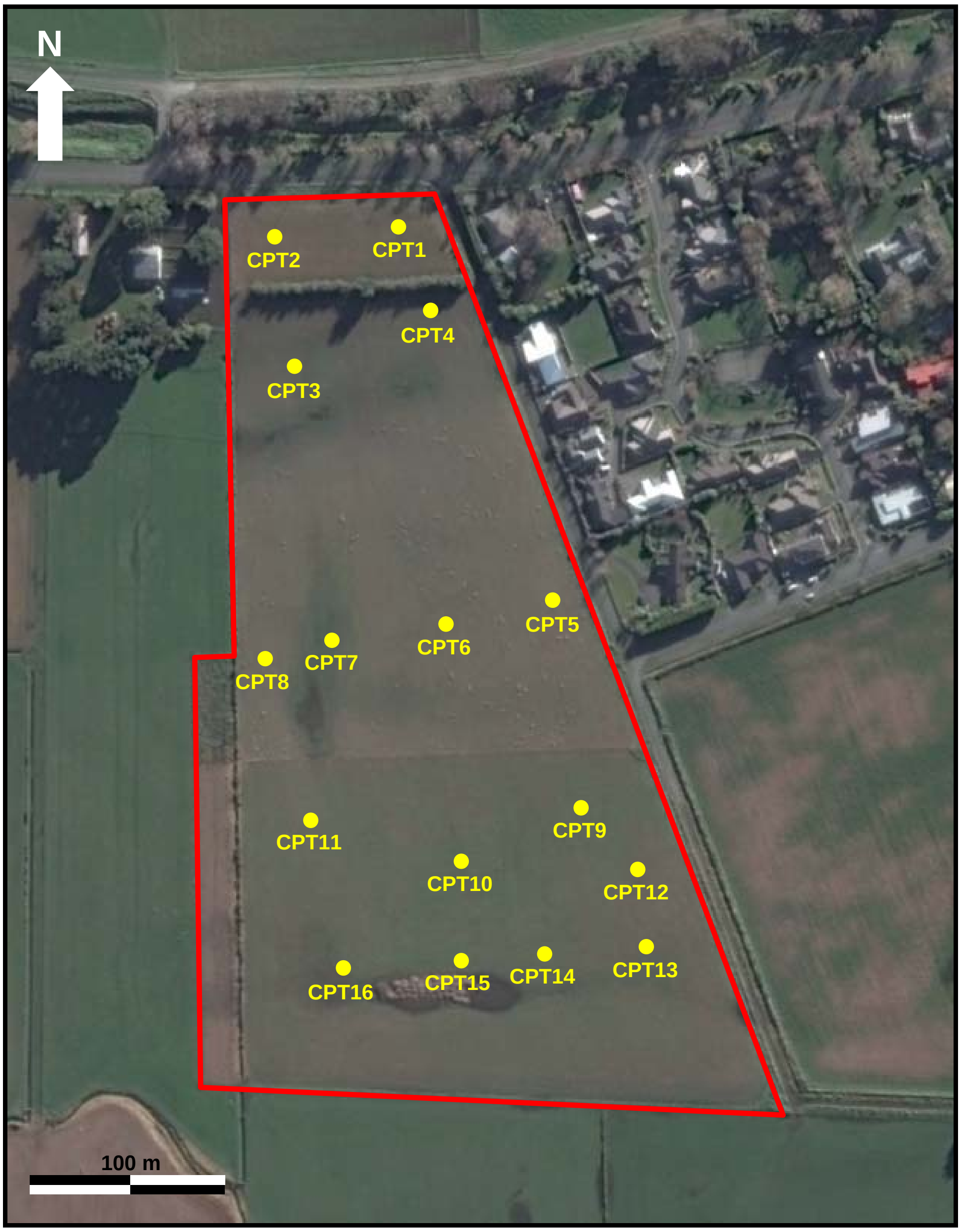

Figure 6: Geotechnical test locations undertaken onsite.

(Image source: Google Earth accessed 11/5/15).

4.1 Deep Geotechnical Site Investigation

The 16 CPTs were undertaken from the surface to depths ranging from 13.5 – 15.0 m where testing terminated in very dense gravel.

A summary of the geological profiles derived from the CPT results is presented in Table 3 and cone resistance plots with geological interpretations are presented in Figure 7 (yellow units indicate where potential liquefaction can occur). The full CPT logs are included in Appendix B of this report.

Table 3: Summary of Soil Profiles from Deep Investigations				
Test (Depth)	**Description**	**Depth (m) below EGL***	**Cone Tip Resistance (qc, MPa)**	**Relative Density**
CPT 1 – 16	Interbedded Silt and Sand	0.0 – 4.0 m	0.9 – 7.0	Stiff – hard/very loose to medium dense
	Interbedded Clay and Silt	4.0 – 6.5 m	<0.2 – 2	Very soft – stiff
	Interbedded Silt and Sand	6.5 – 9.0 m	0.4 – 10	Firm – hard/very loose – medium dense
	Interbedded Clay and Silt	9.0 – 12.5 m	0.2 – 2.0	Soft – stiff
	Interbedded Sand and Gravel**	12.5 – 15.0 m	2.5 – >20	Loose – very dense

* Note the depths referred to in the table are approximate and averaged for the 16 CPTs

** Note there are some lenses of silt within the interbedded sand and gravel unit

The soil stratigraphy represented in the CPT data is consistent with the surrounding testing obtained from CGD and the geological map of the Christchurch area described in Section 3.3 of this report.

Upon retrieval of the CPT probe the hole was “dipped” by the CPT operator to give an indication of natural groundwater, this was undertaken for CPT 6 only and the groundwater was found at 2.0 m below EGL. The groundwater level can be derived by interpretation of pore pressure readings (taken during testing), this was undertaken for CPTs 2, 6, 7 and 15 which revealed groundwater levels ranging between 1.9 m – 2.6 m.

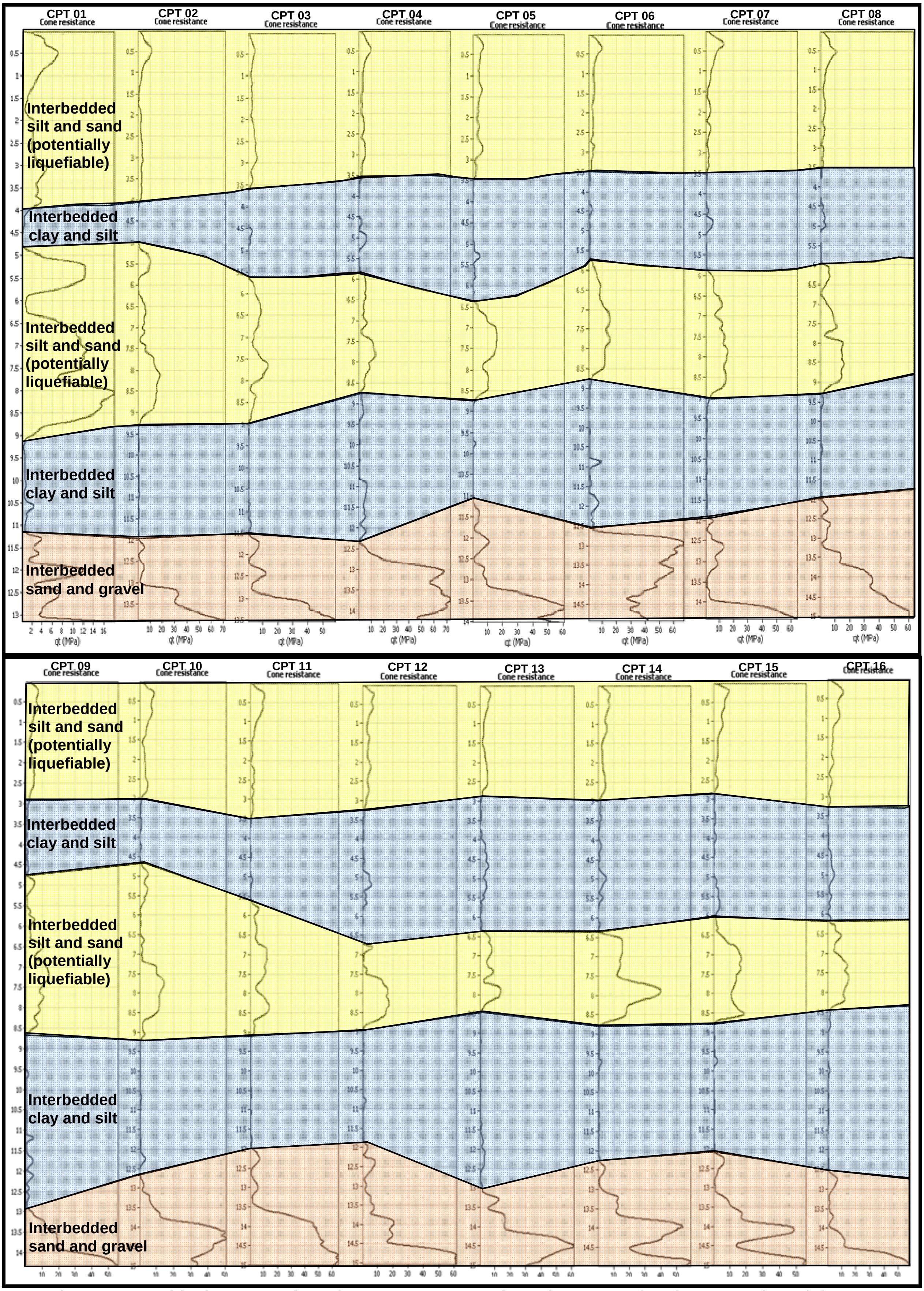

Figure 6: Graphical presentation of CPTs 1 – 16 cone tip resistance and an interpretation of the underlying geology. Liquefaction is predicted from the silt and sand units indicated in yellow.

5.0 Liquefaction Hazard

For the purposes of assessing ground performance during future seismic events, the CPT data has been analysed under the following seismic loads: Serviceability Limit State (SLS) events with, M_w 7.5 and PGA_{SLS1} = 0.13 g and M_w 6.0 and PGA_{SLS2} = 0.19 g; Ultimate Limit State (ULS) events with M_w 7.5 and PGA_{ULS} = 0.35 g. A conservative groundwater level of 0.9 m below EGL is assumed based on ECan well M36/0945 located approximately 100 m west of the northern section of the site.

5.1 Liquefaction-induced ground settlements and lateral movements

Liquefaction-induced vertical settlements were estimated from CPT data using the process described in MBIE (2012) Section 13.5 (Boulanger and Idriss (2014), with settlements calculated according to the method of Zhang et al, 2002[13]). Summarised results are presented in Table 4.

Lateral displacements were modelled for CPTs 1 – 4 which are in close proximity to the Halswell River. CPTs 5 – 16 were not analysed for lateral displacements due to the absence of a free edge within 200 m of the proposed lots.

Comparison of the 10 m index values with Table 3.1 of the MBIE Guidelines indicates that in both an SLS event and a ULS event, TC3 land performance is predicted.

The CPT analysis suggests that for the purposes of subdivision for future development the site, the site can be considered as having the potential for moderate to major land damage from liquefaction in future large earthquake events. The results of the analysis are broadly consistent with the GNS Science mapping undertaken following the September 2010 earthquake event and the land damage described in Section 3.2 of this report.

[13] Idriss, I.M. and Boulanger, R.W., 2008. Soil Liquefaction During Earthquakes. Monograph series, No. MNO-12, Earthquake Engineering Research Institute.
Zhang, G., Robertson, P.K., and Brachman, R.W.I., 2002. Estimating liquefaction-induced ground settlements from CPT for level ground. Canadian Geotechnical Journal 39: 1168-1180.

Table 4: Liquefaction Induced Vertical Settlements and Lateral Displacements				
CPT (Depth)	**SLS** Mw 7.5 PGA: 0.13 g	**SLS** Mw 6.0 PGA: 0.19 g	**ULS** Mw 7.5 PGA: 0.35 g	**Lateral Displacements at ULS**** Mw 7.5 PGA: 0.35 g
CPT 1* (13.14 m)	45 mm	80 mm	125 mm	225 mm
CPT 2* (13.88 m)	55 mm	80 mm	130 mm	185 mm
CPT 3* (13.54 m)	70 mm	100 mm	150 mm	75 mm
CPT 4* (14.22 m)	80 mm	110 mm	160 mm	90 mm
CPT 5* (14.02 m)	45 mm	60 mm	115 mm	N/A
CPT 6 (14.92 m)	50 mm	70 mm	125 mm	N/A
CPT 7* (14.42 m)	60 mm	90 mm	130 mm	N/A
CPT 8 (15.06 m)	85 mm	120 mm	150 mm	N/A
CPT 9* (14.32 m)	80 mm	110 mm	155 mm	N/A
CPT 10 (15.00 m)	70 mm	95 mm	140 mm	N/A
CPT 11 (15.00 m)	70 mm	105 mm	140 mm	N/A
CPT 12 (15.04 m)	55 mm	75 mm	115 mm	N/A
CPT 13 (15.02 m)	85 mm	120 mm	150 mm	N/A
CPT 14 (14.98 m)	50 mm	70 mm	110 mm	N/A
CPT 15 (15.00 m)	70 mm	95 mm	130 mm	N/A
CPT 16 (14.96 m)	90 mm	120 mm	155 mm	N/A

Note – all estimated settlements are recorded to the nearest 5mm.
Note – all analysis assumed a conservative groundwater level of 0.9 m below EGL
Key – Yellow denotes settlements in the TC2 range (<50 mm SLS); Blue denotes settlements in the TC3 range (>50 mm SLS)
* Denotes either early termination in very dense gravels or penetration into soils that are predicted to not liquefy, excess thrust, excess cone inclination, rod flex or a combination
** Lateral stretch estimated across a 20 m building foot print. For Lot 1 & Lot 2 have assumed a setback from the free face of 40 m
Lots 5 – 16 were not assessed for lateral stretch given the distance from the free face (Halswell River).

MBIE (2012) Part D provides a note that "It is strongly recommended that residential lots in new subdivisions meet the performance criteria specified for TC1 and TC2". Selwyn District Council also requires new residential subdivisions to have a minimum land performance of TC1 or TC2 criteria. Given TC3 land performance may be expected in future large earthquake events, consideration of ground improvements to decrease the liquefaction susceptibility is recommended to align with TC2 land performance or better in future large earthquake events.

6.0 Development Recommendations

Given the identified risk of future liquefaction-induced settlement, potential lateral stretch (Lots 1 – 4) and flood risk to the proposed subdivision, each proposed future building on the site will require the following:

- Ground improvement to meet a minimum TC2 performance criteria (see below)
- A raised fill platform to mitigate flood hazard
- Specific engineering design of foundations

6.1 Ground Improvement

Consideration should be given to ground improvement options[14] to improve the land to TC1 or TC2 performance criteria. The following options for ground improvement are provided:

Option 1: Shallow Densified Crust - Reinforced Crushed Gravel Raft (G1d)

The shallow gravel raft should be placed to a minimum depth of 1.2 m below EGL and placed in accordance with New Zealand Standard (NZS) 4431:1989, extending approximately 1.0 m beyond the building footprint (refer to Version 3a of Part C, Appendix C4 for further information of this ground improvement method)[15].

- Suitable for lots 1 – 16, however lots 1 – 4 will require geogrid reinforcement to mitigate the lateral stretch hazard;
- Given the shallow depth to groundwater it is recommended gravel rafts are constructed in the summer months to reduce the cost of dewatering;
- Gravel rafts should be raised above the existing ground level to a level suitable to mitigate against the flood hazard;
- The gravel raft to a minimum depth of 1.2 m below EGL will reduce the liquefaction hazard by creating a stiffened building platform. TC2 foundation systems should then be appropriate for buildings on the gravel rafts.

Option 2: Shallow Cement Stabilised Crust - Stabilised Crust (in-situ mixing (G2b))

The shallow stabilised crust involves excavation of the soils below the building footprint to a minimum depth of 2.0 m below EGL and mixing with the correct amount of cement before placing back into the excavation. Specified compaction shall also be undertaken to ensure

[14] Ministry of Business, Innovation and Employment, December 2012. Repairing and rebuilding houses affected by the Canterbury earthquakes, supplementary guidance, Version 3a Part C, 15.3.5: Improvement types and options.
[15] Ministry of Business, Innovation and Employment, December 2012. Repairing and rebuilding houses affected by the Canterbury earthquakes, supplementary guidance, Version 3a Part C, Appendix C4: Method Statements for Site Ground Improvement

adequate bearing is achieved (refer to Version 3a of Part C, Appendix C4 for further information of this ground improvement method)[16].

- Suitable for lots 1 – 16, however lots 1 – 4 will require specific engineering design to mitigate the lateral stretch hazard;
- A gravel fill platform above the stiffened crust will need to be constructed to mitigate against the flood hazard;
- A minimum treatment depth of 2.0 m below EGL is required to provide a sufficient reduction in liquefaction hazard by creating a stiffened crust and building platform. TC2 (or TC3 for lots 1 – 4) foundation systems will be appropriate for building on the stabilised crust.

Option 3: Crust Reinforced with Inclusions - Driven Timber Piles (G5a or G5b)

The driven timber pile option is intended to create a densified soil raft at least 2.0 m thick below the building footprint, extending at least 2.0 m beyond the building footprint (refer to Version 3a of Part C, Appendix C4 for further information of this ground improvement method)[17].

- Suitable for lots 5 – 16;
- Following ground improvements the crust will require further testing to confirm adequate ground improvement has been achieved;
- A gravel fill platform above the improved ground will need to be constructed to mitigate against the flood hazard;
- A minimum treatment depth of 4.0 m below EGL is required to provide a sufficient reduction in liquefaction hazard by improving the subsurface soils and creating a stiffened building platform. Following pile densification TC2 foundation systems will be appropriate for building on the reinforced crust.
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6.2 Foundations

The type of overlying foundation[18] is dependent on the level of ground improvement undertaken and the associated susceptibility to the liquefaction hazard. Refer below for the types of foundation appropriate for the options provided above:

Shallow Densified or Cement Stabilised Crust (MBIE Type G1 & G2)

Where predicted SLS index settlements are ≤100 mm (refer Table 4):

- TC2 concrete slab Option 2 or 4 (MBIE Guidance Section 5.3);

[16] Ministry of Business, Innovation and Employment, December 2012. Repairing and rebuilding houses affected by the Canterbury earthquakes, supplementary guidance, Version 3a Part C, Appendix C4: Method Statements for Site Ground Improvement
[17] Ministry of Business, Innovation and Employment, December 2012. Repairing and rebuilding houses affected by the Canterbury earthquakes, supplementary guidance, Version 3a Part C, Appendix C4: Method Statements for Site Ground Improvement
[18] Ministry of Business, Innovation and Employment, December 2012. Repairing and rebuilding houses affected by the Canterbury earthquakes, supplementary guidance, Version 3a Part C, 15.3.8.2; 15.3.8.3: Shallow surface crust treatment options; Deep treatment options.

- TC2 Type B (ring foundation) with suspended timber floor

Where predicted SLS index settlements exceed 100 mm (refer Table 3), treatment should extend 2 m outside the building footprint and geogrid installed at a depth of 0.5 m then:

- TC3 Type 1 & 2 (suspended floor) surface structure;
- TC3 relevelable concrete surface structure.

Crust Reinforced with Inclusions (MBIE Type G5)

This method is only suitable for sites what have predicted index SLS settlements less than 100 mm (refer Table 3):

- TC2 concrete slab Option 2 or 4 (MBIE Guidance Section 5.3);
- TC3 Type 2 (suspended floor) surface structure;
-

Any future development will require site specific geotechnical testing likely involving DCP and hand auger and/or test pitting across the planned building location to confirm ground conditions and foundation requirements at the building consent stage. It is recommended that ground improvement is undertaken at subdivision consent stage to provide a technical category of TC2.

7.0 Section 106 Resource Management Act (1991)

Section 106 of the Resource Management Act (RMA) requires that the site of a subdivision be assessed for potential material damage from erosion, falling debris, subsidence, slippage, or inundation of the proposed lots. These aspects are addressed in the following section.

7.1 Erosion

Due to the flat topography of the site and the no significant record of flooding it is our opinion that the site is not susceptible to significant erosion.

7.2 Falling Debris and Slippage

Lots 1 – 16 are located on flat ground with no areas of elevated land on or near the site, no mechanism exists for falling debris, rockfall or landsliding and therefore are not affected by falling debris.

Lots 1 – 4 are within 150 m of the Halswell River and the lateral stretch estimates from the CPT data reveal potential lateral movements in the order of 75 – 225 mm north, towards the river edge. Lots 5 – 16 are considered to have a low risk of lateral movement.

The lateral stretch risk identified for lots 1 – 4 can be mitigated by the use of ground improvement and/or specific design of foundation systems. Further site specific geotechnical testing is recommended at building consent stage to provide further information for foundation design on these lots.

7.3 Subsidence

Liquefaction-induced subsidence index estimates calculated in accordance with the MBIE guidelines for subdivision are 60 to 120 mm for SLS, and 110 to 160 mm for ULS design earthquake events. These values are within MBIE (2012) Guidance values for TC3 land. Therefore the land is susceptible to moderate to major liquefaction-induced ground settlements. These ground settlements can be mitigated by the use of ground improvement and specific design of foundations for any building constructed on the site.

MBIE (2012) Part D provides a note that “It is strongly recommended that residential lots in new subdivisions meet the performance criteria specified for TC1 and TC2”. Selwyn District Council also require new residential subdivisions to have a minimum land performance of TC1 or TC2 criteria. It is therefore recommended that the proposed subdivision should include ground improvements to better the land performance to a minimum TC2 level. Further recommendations are provided in Section 6.0 of this report.

7.4 Inundation

The proposed lots are located in an area of the Selwyn District where ECan has recommended a minimum finished floor level to mitigate the hazard posed by flooding and ponding in ephemeral channels across the site. It is recommended that any dwelling built on the property should have a minimum finished floor level at least 300 mm above the modelled floodwater levels, i.e. in the order of 7.1 – 7.2 m above mean sea level or 400 mm above the existing ground level (whichever is highest). If a dwelling is to be constructed at the property, a floor level recommendation for the specific dwelling location must be obtained from ECan during building consent.

Inundation is considered to be a minor hazard associated with the proposed subdivision, however various options are available to raise the finished floor level of future buildings on the site and mitigate against the potential flood hazard.
Given the need for ground improvement and a requirement for a raised platform the inundation hazard can be easily mitigated by careful design. The site is at a similar risk to surrounding residential land.

7.5 Section 106 General Discussion

It is believed the site is suitable for subdivision under Section 106 of the RMA. However liquefaction-induced settlements and flood hazards have been identified as risks that require mitigation. Ground improvements including a requirement for a raised gravel platform in conjunction with specific engineering design of foundations are considered appropriate mitigation options for these hazards.

Any building planned for the proposed lots in the future will require a site specific geotechnical investigations to confirm the underlying geology and appropriate design criteria.

A statement of professional opinion on the suitability of land for subdivision is presented in Appendix D.

8.0 Conclusions

It is the professional opinion of Davis Ogilvie & Partners Ltd (not to be construed as a guarantee) that the site is suitable for plan change and residential subdivision subject to the recommendations regarding ground improvement and flood hazard mitigation are followed.

Liquefaction ejecta and surface flooding was mapped across the site by GNS Science following the September 2010 Darfield earthquake. Minor to severe quantities of liquefaction ejecta and/or lateral spread is observed in the areas surrounding the site.

Deep testing consisting of 16 CPTs indicated that the proposed subdivision is underlain predominantly by interbedded alluvial deposits of clay, silt, sand and gravel to at least 15.0 m below EGL, which confirms the published geology. Liquefaction-induced vertical settlements are expected to be within 60 – 120 mm during an SLS design event and 110 – 160 mm in a ULS design event. Lateral stretch assessed for lots 1 – 4 indicate potential displacements between 75 – 225 mm north, towards the Halswell River.

Subsidence and flood hazards have been identified for the site, however the proposed remediation strategies shall sufficiently mitigate against the identified hazards. Ground improvement by crushed gravel raft, in-situ soil mixing or driven timber piles will create a stiffened crust which will reduce the liquefaction hazard and create an adequate surface for a flood mitigation platform to be constructed and engineered foundation to found upon.

Future development will require lot specific geotechnical testing likely involving DCP and hand auger and/or test pitting across the planned building location before ground improvement to confirm the underlying geology and establish appropriate design criteria for ground improvement and any building.