Proposed 12.5-hectare Residential Subdivision, Grants Road, Papanui

Geotechnical Report

BGL reference: 1409/01

April 2013

Report prepared by:

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1. Introduction

Bell Geoconsulting Ltd was engaged by Richard Peebles to conduct a geotechnical investigation for a proposed residential subdivision of an approximately 12.5-hectare parcel of land in Papanui, Christchurch (hereafter referred to as 'the site'). The site is currently zoned Rural 3 (Styx – Marshland) under the partly operative Christchurch City Council (CCC) City Plan. The site location is shown on Figure A1 (Appendix A).

The proposed subdivision layout currently comprises 23 residential lots of between ~5,000 and 6,000m^2 each. The purpose of this report is to address any geotechnical constraints for residential development on the land, including specific investigation of any potential liquefaction issues. This report was prepared in accordance with Ministry of Building, Innovation and Employment (MBIE) guidelines, dated September 2012.

1.1. Scope of work

The following work was undertaken for the geotechnical investigation:

- A preliminary site walkover and reconnaissance on 5 February 2013;
- Desktop study, which involved a review of:
  - Published geological maps;
  - Existing well records available from the Environment Canterbury (ECan) online geographical information system (GIS);
  - The Canterbury Geotechnical Database (Project Orbit);
- Review of twelve Cone Penetrometer Tests (CPTs) conducted at the site by McMillan Drilling Services Ltd in June 2012;
- Review of seven machine auger boreholes completed by Shearer Consultants in November 2009;
- Drilling of two boreholes in February 2013 to a target depth of 15m below ground level (bgl), including Standard Penetration Tests (SPTs) at 1.5m intervals during borehole advancement;
- Liquefaction susceptibility assessment based on CPT results using current methodology; and
- Review of geotechnical considerations, including an assessment in accordance with Section 106 of the Resource Management Act (RMA), and report compilation.

Detailed design or remedial measures relating to identified geotechnical constraints do not form part of this report, and should be addressed at the design stage of any future consented development at this site. The primary purpose of this report is to establish the land suitability for the proposed residential subdivision in terms of ground stability and liquefaction-induced settlement in a future large-magnitude earthquake.

2. Site Description

The site is located at the eastern end of Grants Road, Christchurch (Figure A1, Appendix A). Grassmere Road bounds part of the western boundary. Neighbouring land use is rural to the north, east and south, with residential properties to the west.

The ~12.5ha area includes eight legal titles, as summarised below:

- Lot 1 DP 7419
- Lot 2 DP 427759
- Part RS 308
- Lot 2 DP 1729
- Part Lot 1 DP 1729
- Part Lot 3 DP 1729
- Part Lot 4 DP 1729
- Part Lot 5 DP 1729

General site photographs are provided in Figures 1 to 4. A confined stream is located on the southern site boundary (Figure 1). Surface water was noted during site walkover inspections in the southern area of the site, which reflects a high water table (Figure 2). The low-lying land is generally flat, and the site is currently used for pastoral farming activities (Figures 3 and 4). There are no residential dwellings presently on site. A number of farm-related sheds are located near the western extent of the site (Figure A2, Appendix A). There was no evidence of surface liquefaction or lateral spreading as a result of the Canterbury earthquake sequence that commenced on 4 September 2010.

Figure 1: Stream, southern site boundary

Figure 2: Localised ponding in southern paddocks

3. Desktop Study

A desktop study was conducted to provide background information relevant to the site in terms of regional geology, groundwater and seismic data. The desktop study involved a review of published geological maps; the Canterbury Geotechnical Database; Environment Canterbury well records; groundwater data; and relevant seismic data from significant earthquakes since 4 September 2010.

3.1. Regional geology

Published geological mapping of the Christchurch urban area (Brown and Weeber, 1992) indicates that the site is underlain by Quaternary peat swamp deposits (now drained). The deposits are part of the Springston Formation, Yaldhurst Member. The wider area is known locally as the Cranford Basin (Figure 5).

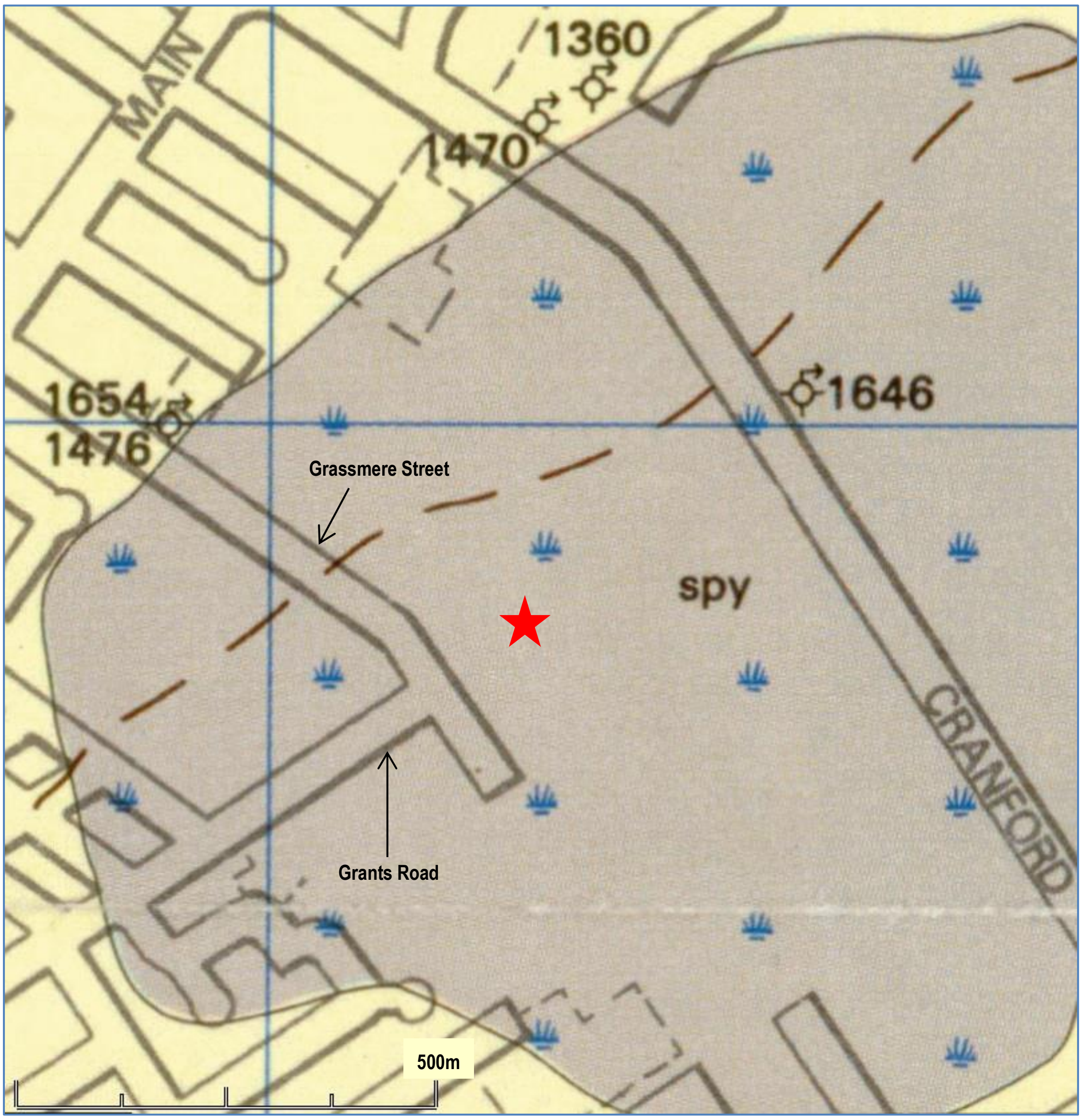

Figure 5: Cranford Basin – site location indicated by star (base map from Brown and Weeber, 1992). Note - The dashed line going through the basin is the 10m above mean sea level topographic contour.

3.2. Environment Canterbury well records

Well records viewed on the ECan GIS are summarised in Table 1 for the geographical area shown on Figure A2 (Appendix A). A total of 32 well logs were reviewed, with all wells located on site, or immediately adjacent to the site highlighted green on Table 2 (eight wells). Only boreholes drilled to a depth of >5m below ground level (bgl) are presented in Table 1. Of the 24 well records viewed for the site and surrounding area, 9 had stratigraphic logs available and these are provided in Appendix B for reference.

Table 1: Environment Canterbury well records

Environment Canterbury well reference	Year drilled	Total well depth (m bgl)	Depth to water (m bgl)	Log available
M35/3023	NR	5.00	*0.40	×
M35/4093	NR	24.30	*0.40	×
M35/4094	NR	24.30	*0.10	×
M35/14017#	1 JAN 1959	6.40	NR	×
M35/14018#	1 JAN 1959	5.79	NR	×
M35/14019#	1 JAN 1959	5.18	NR	×
M35/14020	1 JAN 1959	5.79	NR	✓
M35/15209	NR	7.90	NR	✓
M35/1646	28 FEB 1972	25.40	3.70	✓
M35/3175	NR	21.50	*1.56	×
M35/4089	NR	24.30	*0.10	×
M35/4092	NR	24.30	*0.40	×
M35/4141	NR	26.80	2.36	×
M35/5078	NR	30.00	*0.70	×
M35/6133	NR	26.80	*0.30	×
M35/6134	NR	18.50	*0.20	×
M35/6137	NR	26.80	*0.50	×
M35/12577	NR	6.00	NR	✓
M35/12578	NR	6.00	NR	✓
M35/15016	NR	6.00	4.80	✓
M35/15017	NR	6.00	5.00	✓
M35/15178	NR	6.00	NR	✓
M35/18519	10 FEB 2011	18.00	5.00	✓
M35/18536	NR	35.00	NR	×

NR = not recorded on bore log

* Value represents 'calculated minimum level' – remaining values are noted on the well records as the 'initial water level'

Log available according to ECan bore summary, but not related to correct well reference.

Groundwater levels are typically high (≤0.5m bgl). These levels are expected due to the depositional history for the area (being a low energy environment within a basin), and known artesian pressures.

Stratigraphic information for the two wells adjacent to the site are summarised below (refer Figure A2 for locations):

- **M35/14020 –** located near the western corner of the site: *'peat and clay'* to 3.7m bgl; underlain by *'sand and clay'* to 5.2m bgl and *'gravel'* below this depth to the end of the borehole at 5.8m bgl.
- **M35/15209 –** located on the southern site boundary: *'peat and silt'* to 5.5m bgl; underlain by '*gravel'* to the end of the borehole at 7.9m bgl.

The stratigraphic log for M35/1646 is shown in Figure 6. This well is located ~250m northeast of the site (Figure A2) and the subsurface profile is considered similar to that expected beneath the subject land. The log indicates Springston Formation peat and gravel to 14.6m bgl; Christchurch Formation sand to 18.3m bgl; and Riccarton Gravel below this depth to the end of the borehole at 25.4m bgl.

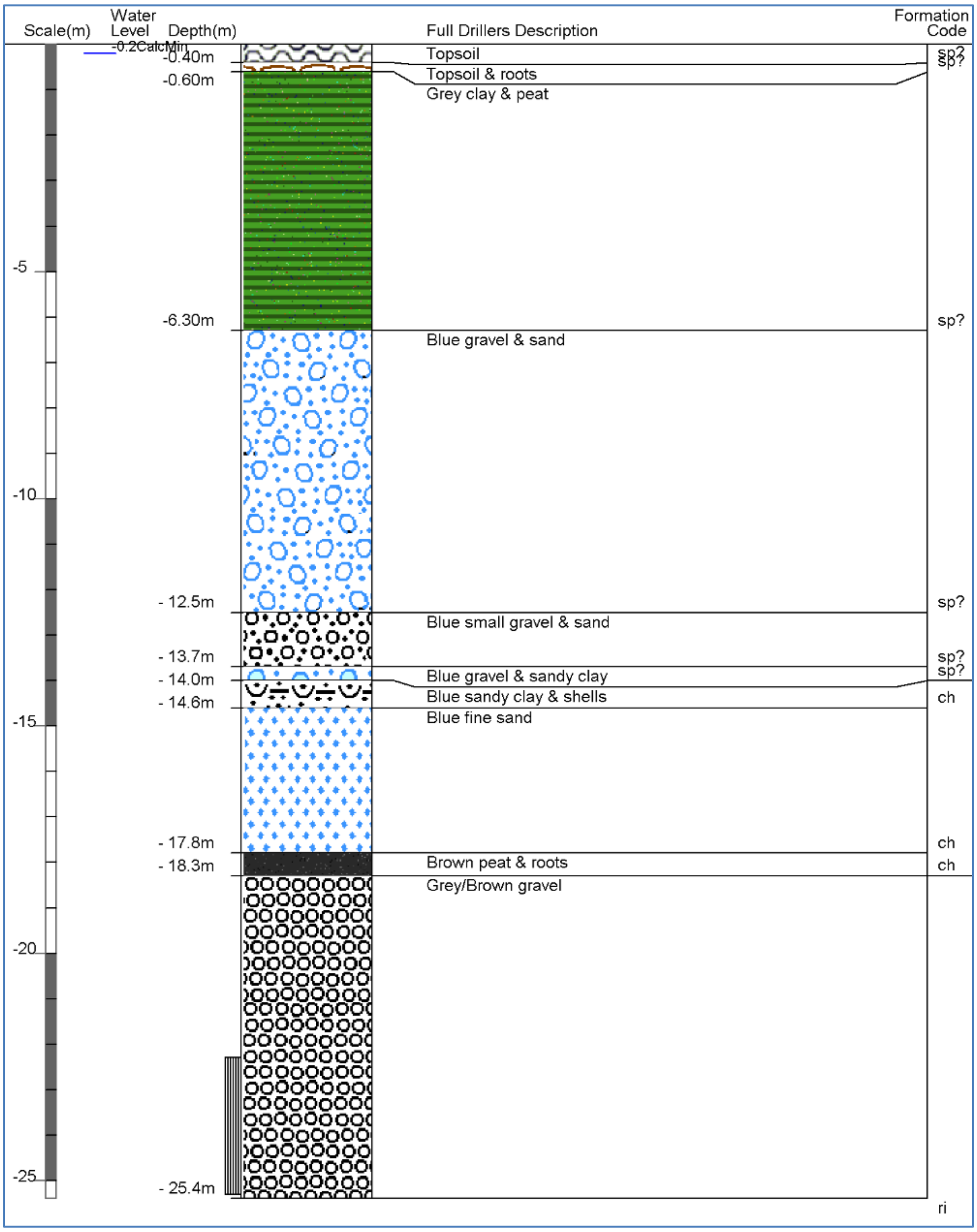

Figure 6: Environment Canterbury well reference M35/1646 – stratigraphic log

3.3. Seismicity

The known active faults nearest to the site are listed below, including approximate distances in relation to the Christchurch Central Business District (CBD):

- Port Hills Fault: located to the southeast of Christchurch, ~7.5km southeast of the site
- Ashley Fault: ~30km north of Christchurch
- Pegasus Bay Fault (off-shore): ~20km northeast of Christchurch
- Greendale Fault: ~10km west of Christchurch

The nearest active faults presently identified in New Zealand Standard NZS:1170 are the Hope and Kakapo faults located in North Canterbury. Seismic design performance requirements are outlined in NZS:1170.5, which includes those for the Ultimate Limit State (ULS) and Serviceability Limit State (SLS). Peak ground accelerations (PGA) for the region have been updated in recently published documentation, including MBIE (2012). These PGA values are outlined in Section 6 of this report, and were adopted for the liquefaction analyses.

Seismological data relating to the four main recent earthquake events are summarised in Table 2, including the inferred peak ground acceleration (PGA). The 22 February 2011 earthquake provided the highest PGA recorded to date of ~0.27g.

Table 2: Seismic data and inferred PGA values*

Seismic event	Magnitude	Conditional Median PGA*
04 September 2010	7.1	0.21g
22 February 2011	6.2	0.27g
13 June 2011	6.0	0.16g
23 December 2011	5.9	0.19g
* Information based on contours available through Project Orbit: *Conditional PGA for Liquefaction Assessment*. Developed for conventional liquefaction assessments by Bradley Seismic Ltd and the University of Canterbury. Canterbury Geotechnical Database (2013) "Conditional PGA for Liquefaction Assessment", Map Layer CGD5110 - 21 Feb 2013, retrieved February 2013 from https://canterburygeotechnicaldatabase.projectorbit.com/		

3.4. Canterbury Geotechnical Database[1]

The Canterbury Land Information Map released by the Canterbury Earthquake Recovery Authority (CERA) in June 2011 indicates that the site is currently zoned: **Green – Technical Category not applicable.** The implication of this zoning is that the site has not been given a technical category due to the 'Urban non-residential' zoning, and normal consenting procedures should therefore apply.

[1] **Important notice:** Information included in this section was obtained/created from maps and/or data extracted from the Canterbury Geotechnical Database (https://canterburygeotechnicaldatabase.projectorbit.com), which were prepared and/or compiled for the Earthquake Commission (EQC) to assist in assessing insurance claims made under the Earthquake Commission Act 1993. The source maps and data were not intended for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability for any use of the maps and data or for the consequences of any person relying on them in any way. This "Important notice" must be reproduced wherever figures or any derivatives are reproduced.

Neighbouring residential areas to the north and west are currently within the Foundation Technical Category TC2, which indicates '*minor to moderate land damage from liquefaction is possible in future large earthquakes*'. Residential sections to the south are zoned TC2 and TC3. The Foundation Technical Category TC3 implies that '*moderate to significant land damage from liquefaction is possible in future large earthquakes*'.

There are no site-specific ground observations of surface liquefaction or lateral spreading at the site. There was no evidence of liquefaction-induced land damage during walkover inspections by BGL, and none is expected given the presence of laterally extensive peat and clay beneath the site.

The 1856 Environmental Ecology 'Black Map' map shown in Figure 7 identifies *'raupo swamp and tussocks'* in the vicinity of the site. This is consistent with bore log information for the area identifying peat and organic-rich sediments, and the presence of drainage features shown on Figure 1.

Figure 7: Project Orbit screenshot of the 1856 Environmental Ecology 'Black Map' (sourced from https://canterburyrecovery.projectorbit.com, Canterbury Geotechnical Database Map CGD5080 – 07 Oct 2012)

4. Geotechnical Site Investigation

The objective of the geotechnical site investigation was to characterise subsoil and groundwater conditions. The investigation was conducted in accordance with the requirements outlined in the MBIE (2012) *'Guidelines for the investigation and assessment of subdivisions'*, which were issued as guidance under Section 175 of the Building Act 2004.

At the subdivision investigation stage, the minimum investigation density recommended in MBIE (2012) for deep investigations is 0.2 to 0.5 per hectare (minimum of 5). A total of twelve CPTs and nine boreholes, including two to 15m bgl, were completed as part of this investigation, and are considered sufficient to characterise the ground conditions. The following sections summarise the findings from the site investigation.

4.1. CPT profiles

In the absence of any liquefaction or lateral spreading observed to date, CPT locations were chosen in June 2012 to determine any lateral variation across the area as shown on Figure A3, Appendix A. Results of the piezocone CPT tests conducted by McMillan Drilling Services Ltd are provided in Appendix C. Table 3 summarises the main findings of the CPTs in terms of soil types. Liquefaction potential is typically limited to soil behaviour types interpreted as silt and/or sand.

Table 3: CPT data summary

CPT reference*	Total depth** (bgl)	Soil Behaviour Type
CPT01	5.6m	Clay and peat to 3.7m bgl; silt and sand to 5.5m bgl.
CPT02	5.3m	Clay and peat to 3.9m bgl; silt and sand to 5.3m bgl.
CPT03	5.3m	Clay and peat to 3.3m bgl; silt and sand to 5.0m bgl.
CPT04	6.2m	Clay and peat to 3.2m bgl; silt and sand to 6.2m bgl.
CPT05	5.0m	Clay and peat to 3.4m bgl; silt and sand to 5.0m bgl.
CPT06	3.8m	Clay and peat to 3.4m bgl; silt and sand to 3.8m bgl.
CPT07	5.3m	Clay and peat to 3.2m bgl; silt and sand to 5.2m bgl.
CPT08	8.1m	Clay and peat to 3.7m bgl; clay, silt, sand to 5.9m bgl; sand/silty sand to 8.1m.
CPT09	4.4m	Clay and peat to 3.3m bgl; silt and sand to 4.4m bgl.
CPT10	4.8m	Clay and peat to 3.6m bgl; silt and sand to 4.8m bgl.
CPT11	6.1m	Clay and peat to 3.2m bgl; silt and sand to 6.1m bgl.
CPT12	6.3m	Clay and peat to 3.9m bgl; silt and sand to 6.3m bgl.

* refer Figure A3, Appendix A for CPT locations

** effective refusal on dense sand and/or gravel at all locations

The target depth of the CPTs was 15m bgl. The presence of medium dense to dense sand and/or gravel within the subsurface prevented CPTs advancing to 15m bgl in all locations. The total depth shown in Table 3 for the remaining CPTs represents effective refusal on dense sand/sandy gravel. The profiles all indicate a similar overlying stratigraphy of very soft (cone resistance q_t values generally <2MPa) fine-grained clayey or organic soils to a depth of 3.2 to 3.9m bgl, and this unit is underlain by medium to very dense sand-dominated units.

4.2. Machine auger boreholes (November 2009)

The depth to refusal of the CPTs is consistent with logging information from seven machine auger boreholes (MA1 to MA7) completed at the site in November 2009. Locations for these boreholes are shown on Figure A3 (Appendix A). Logging information is provided in Appendix D, and was completed independently of BGL. These auger holes show that gravel was encountered between 3.5 and 6.6m bgl. Depth to groundwater was variable, with an artesian head noted at MA7 (near the existing shed, refer Figure A3). The groundwater level varied between 0.1 and 2.3m bgl for the remaining locations.

4.3. Boreholes and SPTs (February 2013)

To confirm the subsurface profile to a depth of 15m bgl, two boreholes (BH01 and BH02) were completed at the site in February 2013 by McMillan Drilling Services Ltd under the supervision of BGL. Borehole locations are shown in Figure A3, Appendix A. SPTs were conducted at 1.5m intervals during borehole advancement. Recovered sample was placed in core boxes, photographed and logged: logs are provided in Appendix E.

As expected, the stratigraphy in the boreholes comprises Springston Formation fine-grained deposits (clay and peat, with some silt/sand interbeds) to a depth of 4.5 – 6.0m bgl, and underlain by gravel to 10.8 – 11.5m bgl. Christchurch Formation sand is present below this depth to at least 15m bgl. SPT N-values (both uncorrected and corrected to $N_{(60)}$) are summarised in Table 4, including the relevant soil type descriptions.

Table 4: SPT and logging summary for BH002 and BH004 (northern end of site)

SPT Depth (m bgl)	Borehole BH1		Borehole BH2	
	SPT-N*	**Soil type**	**SPT-N***	**Soil type**
1.5	3 (4)	Sandy, silty, organic CLAY (Springston Formation)	2 (3)	FILL
3.0	0 (0)		0 (0)	Sandy, silty, organic CLAY (Springston Formation)
4.5	6 (8)		8 (11)	
6.0	14 (19)	Sandy GRAVEL (Springston Formation)	14 (19)	Sandy GRAVEL (Springston Formation)
7.5	22 (30)		19 (26)	
9.0	18 (25)		36 (50)	
10.5	22 (30)		32 (44)	
12.0	9 (12)	SAND (Christchurch Formation)	20 (28)	SAND (Christchurch Formation)
13.5	17 (24)		14 (19)	
15.0	30 (42)		7 (10)	
* Uncorrected SPT (N) values, with corrected $N_{(60)}$ values denoted in brackets.				

The relative density of the subsurface profile within the sandy gravel is 'medium dense' (uncorrected N-values between 10 and 30) from a depth of 4.5m bgl in BH1; and medium dense to dense from 6.0m depth in BH2.

4.4. Summary

The geotechnical site investigation has confirmed the expected subsurface ground profile based on general knowledge of the area and results from the desktop study. A 3 – 4m thickness of soft clay and peat is underlain by silt and sand-dominated units to a depth typically of 4 – 6m bgl. Springston Formation alluvial deposits (sandy gravel) are present beneath the finer-grained deposits, with the minimum thickness of the gravel around 4.5m.

Christchurch Formation sand is present from at least 12m bgl, as evidenced by the presence of shelly sands. Riccarton Gravel was not encountered to the maximum target depth of the boreholes at 15m bgl, and is expected around 18m bgl based on other borehole logs reviewed in the area. Loose fill material was encountered in BH2 beneath the topsoil to a depth of 2.5m bgl, and appears to have been placed sporadically around the site.

5. Assessment of 'Good Ground'

Hand auger and DCP tests were conducted at a number of locations across the site in March 2013 to validate the shallow soil profile (refer Figure A3, Appendix A). Hand auger logs and DCP test results are provided in Appendix F for reference. The soil profile is consistent with the ground conditions inferred from CPT data as presented in Section 4 of this report.

Based on the site investigation data obtained to date, the site is non-compliant with the definition of 'Good Ground' as given in NZS 3604:2011 *Timber Framed Buildings*. 'Good Ground' excludes land where liquefaction and/or lateral spreading could occur, and soils that have a high organic content or uncontrolled fill. The presence of 'Good Ground' was not confirmed on site due to soft soils and high organic content, but not because of liquefaction potential. Accordingly, all foundations will require specific engineering design.

Site Sub-soil Class: The nature of the ground conditions indicates the site should be classified as being a *Class D – Deep or soft soil site*, in accordance with NZS 1170.5:2004.

6. Liquefaction Assessment and Implications

There is no evidence on site for surface liquefaction or lateral spreading since the magnitude 7.1 Darfield Earthquake on 4 September 2010. A review of CPT logs provided by McMillan Drilling Services Ltd (Appendix C) supports this finding, with limited liquefaction susceptibility indicated in the subsurface profile. The presence of predominantly fine-grained soil, including a high organic content, limits the liquefaction potential and also acts as a 'cap' across the site for any deeper liquefaction of sandier soils.

In accordance with MBIE (2012) guidelines, analysis of CPT data has been undertaken to estimate the potential for earthquake-induced liquefaction and associated settlement to occur on-site. PGA values adopted for the assessment are based on a magnitude 7.5 earthquake, as summarised in Table 5. For reference, deformation limits provided in MBIE (2012) are outlined in Table 6 for land classifications TC1, TC2 and TC3 respectively.

Table 5: Design earthquake peak ground acceleration – MBIE (2012)

Seismic Event	Seismic Return Period (years)	PGA (g)
Ultimate Limit State (ULS)	1 in 500	0.35
Serviceability Limit State (SLS)	1 in 25	0.13

Table 6: Liquefaction deformation limits (MBIE, 2012)

Technical Category	Vertical settlement	
	SLS	ULS
TC1	15 mm	25 mm
TC2	50 mm	100 mm
TC3	>50 mm	>100 mm

CPT data analysis has been undertaken using GeoLogismiki CLiq v1.7.1.6 (CLiq), based on the method of Idriss and Boulanger (2008), and on the National Centre for Earthquake Engineering Research (NCEER) method as outlined by Youd et al (2001). The Idriss and Boulanger (2008) methodology consistently reports higher predicted vertical settlements, with both methodologies used being regarded as inherently conservative.

A depth to groundwater of 0.5m was used in all calculations. Results are not sensitive to groundwater depth as the shallow fine-grained soil types, including variable thicknesses of peat, are not liquefiable. No lateral spreading calculations were made due to the flat topography and absence of free edges in the general area. The stream on the southern site boundary is not considered a free edge due to the shallow depth (≤1.5m), retained stream edges, absence of any lateral spreading to date, and non-liquefiable surficial soil.

6.1. NCEER method (Youd et al, 2001)

Results of the analysis based on the NCEER method are presented in Table 7 for vertical settlement estimates under SLS and ULS design events. Copies of the full CLiq summary reports are available upon request due to the large amount of data involved (150+ pages).

Table 7: NCEER (Youd et al, 2001) methodology – vertical settlement estimates

CPT Reference	Total depth (m bgl)	Vertical settlement (mm)		Depth interval for potential liquefaction to occur (ULS design event only)
		SLS (0.13g)	ULS (0.35g)	
CPT01	5.6m	25	35	3.8 – 5.4m bgl
CPT02	5.3m	10	20	4.0 – 4.9m bgl
CPT03	5.3m	25	30	3.6 – 4.6m bgl
CPT04	6.2m	10	15	2.3 – 3.8m bgl
CPT05	5.0m	10	15	3.3 – 4.0m bgl
CPT06	3.8m	<5	<5	3.6 – 3.7m bgl
CPT07	5.3m	40	50	3.4 – 5.0m bgl
CPT08	8.1m	80	100	3.8 – 7.0m bgl
CPT09	4.4m	50	45	3.1 – 4.3m bgl
CPT10	4.8m	20	20	3.6 – 4.3m bgl
CPT11	6.1m	10	20	3.3 – 4.0m bgl
CPT12	6.3m	35	45	4.1 – 5.8m bgl
Notes: - Refer Figure A3, Appendix A for CPT locations - Vertical settlement estimates presented to nearest 5mm				

Results in Table 7 indicate a range of estimated vertical settlement from <5 to 80mm under SLS conditions, with 11 of the 12 profiles showing less than ≤50mm. Under ULS the range was <5 to 100mm. Results using the NCEER methodology indicate that a TC2 foundation technical category is appropriate for the site.

6.2. Idriss and Boulanger (2008) method

Results of the analysis based on the method of Idriss and Boulanger (2008) are presented in Table 8 for vertical settlement estimates under SLS and ULS design events. Copies of the full CLiq summary reports are available upon request due to the large amount of data involved (150+ pages).

Table 8: Idriss and Boulanger (2008) methodology – vertical settlement estimates

CPT Reference	Total depth (m bgl)	Vertical settlement (mm)		Depth interval for potential liquefaction to occur (ULS design event only)
		SLS (0.13g)	ULS (0.35g)	
CPT01	5.6m	45	50	3.8 – 5.4m bgl
CPT02	5.3m	25	30	4.0 – 4.9m bgl
CPT03	5.3m	35	40	3.6 – 4.6m bgl
CPT04	6.2m	40	45	2.3 – 2.5m bgl (25mm) 3.2 – 3.8m bgl (20mm)
CPT05	5.0m	10	20	3.3 – 4.0m bgl
CPT06	3.8m	30	30	2.0 – 2.1m bgl (25mm) 3.6 – 3.7m bgl (5mm)
CPT07	5.3m	70	70	3.4 – 5.0m bgl
CPT08	8.1m	140	150	3.8 – 7.0m bgl
CPT09	4.4m	60	65	3.1 – 4.3m bgl
CPT10	4.8m	30	30	3.6 – 4.3m bgl
CPT11	6.1m	20	30	3.3 – 4.0m bgl
CPT12	6.3m	60	60	4.1 – 5.8m bgl
Notes: - Refer Figure A3, Appendix A for CPT locations - Vertical settlement estimates presented to the nearest 5mm				

Higher vertical settlements are estimated using the Idriss and Boulanger (2008) methodology in comparison to NCEER. SLS and ULS design event estimates are very similar in most cases, with values ranging from 10 to 140mm (SLS) and 20 to 150mm (ULS). Of the 12 CPT profiles, four exceeded 50mm under SLS and one was >100mm under ULS (CPT08; Figure A3). A TC2 classification is again considered appropriate.

6.3. Foundation implications

The site has experienced PGAs up to the SLS design event (Table 2, Section 3.3). It is recognised that liquefaction modelling is not an exact process, and while we consider that the vertical settlements estimates are conservative they do provide a useful basis for foundation design, subject to further ground testing at the building consent stage. The soft nature of the materials, including the high organic content, will require appropriate design measures. The shallow and variable water table is also a constraint, and will need to be addressed by design.

BGL consider that the ~12.5ha area is suited to one or two-storey residential dwellings with appropriate shallow ground improvement for the soft soils and organic material extending beyond the immediate building footprint. Excavation and replacement of the upper soft layers (e.g. to a 2m maximum depth) of soil with compacted, well-graded gravels and construction of a reinforced NZS 3604:2011 slab foundation or a TC2-type rib-raft is one approach. Light-weight wall cladding and roofing materials are recommended to reduce loading on foundations. Groundwater levels vary across the site and artesian pressures may need to be considered. Dewatering may be required at some sites prior to or during gravel raft construction, and Geogrid reinforcement could be appropriate.

Piling to the shallow Springston Formation gravel deposits, present from depths ranging between ~3.5m and 6.5m bgl, could be considered depending on the type of dwelling and anticipated ground loadings. This report does not provide design methodology but identifies ground conditions that will influence foundation requirements. We are of the opinion that either piling or reinforced gravel raft construction methods are appropriate for the shallow "soft" soils that have been identified over this site, with minimum floor level provision for inundation.

In terms of flood management, the site is outside of the Flood Management Area (FMA) defined on the Christchurch City Council (CCC) City Plan (Planning Maps 25A and 32A). The Building Act requirements indicate finished floor levels for new structures will be no less than the level established for a 2% annual exceedance probability (AEP) inundation event, plus 400mm freeboard. The presence of surface water and shallow (at times flowing artesian) groundwater is a matter for consideration during construction, and the installation of piezometers to establish seasonal and storm fluctuations is advised as part of any development.

6.4. Roading and buried infrastructure

We understand that it is proposed to develop a total of 23 residential lots, each having a plan area of ~5,000 to 6,000m^2, with access provision by means of three laneways off Grassmere Street. Road construction will require the excavation of soft near-surface sediments to an approximate depth of 2m, with provision for engineered filling to a depth consistent with drainage requirements. The use of AP65 or equivalent is advised for basecourse, with the use of 'river run' sub-rounded sandy coarse to fine gravel as possible subgrade and sub-base materials. Fill placement is to be monitored for settlement during earthworks, for example using surface marker plates embedded in the compacted materials, and cessation of ground movement is to be confirmed post-construction.

Buried services will be placed within the road corridor to service individual building lots, and additional access will need to be constructed to dwellings and associated buildings. Although on-site development is a matter for individual owners, the establishment of the buried service network (sewerage; water supply; telecommunications; electricity) will require appropriate engineering design to address consolidation-induced settlement within the road corridors. Because of the presence of 'soft ground' over most of the site, careful design of services and monitoring of compacted gravel fill will be essential to ensure that gradients are maintained where required. The presence of an engineered trunk sewer along Grassmere Street provides assurance that geotechnical issues can be addressed by appropriate design and construction measures.

6.5. Residential development

BGL is satisfied that the high water table within the 12.5ha parcel of land does not preclude its use for residential development. Underlying soils are soft in the first few metres, but gravels are present below a depth of ~5m bgl and medium dense to dense Christchurch Formation marine sands are logged from 11 – 12m bgl. A TC2 land classification is considered appropriate for the site; the land is not prone to significant liquefaction-induced settlement, and can be developed by appropriate engineering of infrastructure and individual building sites.

7. RMA Section 106 Assessment

Section 106 of the RMA (1991) states that territorial authorities *'....may refuse subdivision consent in certain circumstances:*

(1) A consent authority may refuse to grant a subdivision consent, or may grant a subdivision consent subject to conditions, if it considers that—

(a) the land in respect of which a consent is sought, or any structure on the land, is or is likely to be subject to material damage by erosion, falling debris, subsidence, slippage, or inundation from any source; or

(b) any subsequent use that is likely to be made of the land is likely to accelerate, worsen, or result in material damage to the land, other land, or structure by erosion, falling debris, subsidence, slippage, or inundation from any source....'

The investigation conducted shows that there are no rockfall sources because of the flat nature of the land, and the site is not subject to slippage or erosion. Subsidence in terms of liquefaction-induced land damage has been considered in this report, and results presented in Section 6 show that under ULS conditions the estimated settlement is less than 100mm, with a maximum of 150mm at one site only that could be remediated. This maximum estimate is considered conservatively high, with the majority of results being ≤45mm (vertical settlement) under ULS conditions when adopting NCEER calculation methodology. Thicknesses of potentially liquefiable sediments are low (<2m), with a clay and organic-rich 'cap' typically 3m+ in thickness in the top part of the profile. Given appropriate foundation design, liquefaction-induced subsidence is not considered to pose any significant geotechnical constraints for future residential development at the site.

Inundation of areas of low-lying land is a matter for further consideration as part of the engineered development of this land. While the land is not currently zoned within the FMA according to the CCC City Plan, future development will need to consider minimum floor levels for residential dwellings in regard to possible inundation and drainage requirements.

Further discussion with relevant authorities will be necessary to facilitate planning, but the measures proposed for the 23 residential lots and associated infrastructure are considered appropriate. With engineering design of facilities and services, including settlement monitoring of 'soft ground' remediation to ensure long-term stability of the ground, we are satisfied that this land is not likely to be subject to subsidence or inundation: erosion, falling debris and slippage are not issues.

8. Conclusions

BGL have completed a geotechnical investigation for the 12.5ha site proposed for a residential subdivision within the western extent of Cranford Basin. The main findings from the investigations are as follows:

- No surface liquefaction or lateral spreading has been identified at the site since commencement of seismic activity in the Canterbury region on 4 September 2010. No paleo-liquefaction features have been identified.
- The geotechnical investigation has shown that the site is characterised by 'soft ground', including a high organic content, to depths between 3.3m and 3.9m bgl. This interpretation is based on data obtained from twelve CPTs and numerous boreholes and hand augers completed across the site by various parties.

- Loose to medium dense sand is present beneath the organic-clay and peat "cap", and is underlain by medium dense to dense sandy gravel (Springston Formation) from 4.5 – 6.0m to 10.8 – 11.5m bgl.
- Christchurch Formation sand and silt is present beneath the Springston Formation gravel to the maximum extent of the boreholes completed on site (15m bgl). Riccarton Gravel is expected around 18m bgl in this area of Christchurch, based on known borehole data from the surrounding area.
- The shallow soils do not meet the definition of 'Good Ground' specified in NZS 3604:2011 due to the soft nature and presence of peat, and resulting in subsidence due to loading. Liquefaction susceptibility is low.
- Vertical settlements are estimated up to a maximum of 150mm in a ULS design event using the Idriss and Boulanger (2008) calculation method, but 11 of the 12 CPT profiles show less than 100mm. A TC2 land classification is considered appropriate based on our analysis of the liquefaction evaluation data.
- An assessment against RMA (1991) Section 106 requirements identified that the site is not subject to falling debris, erosion or slippage because of the flat nature of the land. This is consistent with observations that the land has not been subject to ejection of liquefaction materials or inundation as a result of earthquakes.
- Liquefaction-induced subsidence is not considered to pose a geotechnical constraint for future development at the site given appropriate foundation design. Compressive loading of the organic-rich soils in the top ~3m of the profile may, however, result in consolidation and potentially non-uniform settlement.
- In our opinion design of individual building lots to minimise long-term settlement and inundation potential is a priority, and roading must be engineered so as to eliminate differential ground movements. Design and placement of buried infrastructure must also address acceptable tolerances in terms of settlement.
- While the land is not currently zoned within the FMA, future development will need to consider minimum floor levels for residential and any commercial buildings. Any potential for inundation affecting residential land, and associated landscaping and drainage issues, must be prioritised in design and construction.
- BGL consider that the ~12.5ha area is suited to one or two-storey residential dwellings with appropriate shallow ground improvement for the soft soils and organic material. Site-specific foundation design and related structural engineering considerations are critical to successful subdivision of this site.

9. References

Brown, L.J., and Weeber, J.H. 1992. *Geology of the Christchurch Urban Area*. Scale 1:25 000 Institute of Geological and Nuclear Sciences geological map 1.

Idriss, I.M. and Boulanger, R.W. 2008. *Soil liquefaction during earthquakes – Earthquake Engineering Research Institute Monograph MNO12*.

Ministry of Business, Innovation and Employment, September 2012. *Guidelines for the investigation and assessment of subdivisions on the flat in Canterbury* (Appendix B2 to the November 2011 guidance document)

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NZS 3604:2011 – Timber Framed Buildings.

Youd, T.L., and Idriss, I.M. 2001. Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 127(10), 817-833.

10. Limitations

This report has been prepared for the benefit of Richard Peebles with respect to the particular brief provided to Bell Geoconsulting Ltd and it may not be relied upon in other contexts or for any other purposes without prior review and agreement by Bell Geoconsulting Ltd.

The engineering geological model developed is based on desktop data interpretation, and geotechnical testing across the site as presented in this report. While subsurface ground conditions are inferred between test locations it must be appreciated that variability may occur.

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Appendix A: Figures A1 to A3

- Figure A1: Site location plan
- Figure A2: Environment Canterbury well locations
- Figure A3: Geotechnical testing locations

Appendix B: Environment Canterbury well records

- M35/14020
- M35/15209
- M35/1646
- M35/12577
- M35/12578
- M35/15016
- M35/15017
- M35/15018
- M35/15178
- M35/18519

Appendix C: CPT reports from McMillan Drilling Services Ltd

Appendix D: Machine auger borehole records

Appendix E: Borehole logs (BH1 and BH2)

- Logging completed by McMillan Drilling Services Ltd
- All borehole logs checked and reviewed by Bell Geoconsulting Ltd

Appendix F: Hand auger and DCP test results