BLENHEIM URBAN GROWTH STUDY
GEOTECHNICAL EVALUATION

INTERPRETIVE REPORT
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OPUS

Blenheim Urban Growth Study

Geotechnical Evaluation

Interpretive Report

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Summary

Marlborough District Council is developing a strategy for the urban growth and development of Marlborough. The Council has identified a number of potential urban growth areas for Blenheim that lie on the northern and eastern periphery of the town. An evaluation of the geotechnical hazards of relevance to the proposed urban growth areas has been carried out, the results of which are presented in this report.

The Blenheim area is underlain by Holocene age marine / estuarine silts and sands of the Dillons Point Formation and alluvial gravels and sands of the Rapaura Formation. Both formations have layers of loose material which are susceptible to liquefaction. The Dillons Point Formation soils are highly vulnerable to liquefaction, which investigations show to be thicker than 15 m to the southeast of Blenheim.

Liquefaction could lead to significant ground damage including large subsidence of hundreds of millimetres and severe lateral spreading in areas close to water courses. Lateral spreading is anticipated to be a significant issue in Areas E1 and E2 should liquefaction occur as these sites straddle the Opawa River and tributary streams and are underlain by significant thicknesses of liquefiable material. The risk of lateral spreading is lower in areas Na:Nb and SE, however there is still potential for lateral spreading towards the drainage channels that cross these sites.

Given the loose nature of the soils and the seismicity of the Marlborough area, liquefaction will occur in modest earthquake events, giving earthquake ground shaking with a return period of less than 500 years. Larger events with greater ground shaking will only lead to limited additional liquefaction. Therefore the length of the strategic planning horizon is not important for liquefaction hazards in the area under consideration.

Land susceptible to liquefaction, and particularly lateral spreading is prone to significant risks in earthquake events. In the development areas under consideration in Blenheim, liquefaction of the Dillons Point Formation soils can occur in modest earthquake events which are used for design of normal buildings.

Ground improvement and robust deep foundations to mitigate the risk of liquefaction and lateral spreading are very costly. These measures are generally adopted for important and high value facilities. In our experience these very costly methods are likely to lead to prohibitively high development costs. In this regard we also note the government’s decision not to allow redevelopment of (red zone) residential areas in Christchurch that were subject to liquefaction and lateral spreading, rather than carry out very costly ground improvement to mitigate against future liquefaction.

From a sustainability perspective, it would not be prudent to encourage development on land which will require considerable cost and consume substantially more resources compared to development in land which is more stable in earthquake and other hazards. This is on the basis that it would be more sustainable to develop areas subject to a lower level of hazard, such as the alluvial gravel plains to the west of Blenheim.

The Council should consider the hazard and sustainability issues in zoning the proposed urban growth areas for more intensive development. With a long term view, it may be

prudent for the Council to carefully consider whether to zone these eastern areas prone to liquefaction and lateral spreading for future intensive development, or encourage more development further to the west, where the geology indicates more alluvial gravel soils with a much lower liquefaction hazard. This would be an important consideration for the long term planning of the Blenheim township.

Should the Council decide to zone these areas for development, it would be prudent to ensure that the developments proposed mitigate the effects of liquefaction. The geotechnical assessment needs to be reviewed by a Chartered Professional Engineer, specialising in geotechnical engineering, and with experience in the assessment of earthquake geotechnical hazards. Also the resource consents processes need to ensure that subdivisions developed mitigate risks of liquefaction and associated ground damage hazards. Building consent processes for individual developments need to ensure that the structure and the geotechnical hazards are considered in an integral manner, to ensure that the building can survive without damage in serviceability level earthquake events, and with limited damage which is repairable in ultimate limit state events.

The guidance provided by DBH and the Engineering Advisory Group for reconstruction in Christchurch provides guidance on acceptable solutions. These are expected to be developed further over the next year or so, and based on the Royal Commission report due later this year. It would be prudent to review the acceptance framework as it develops.

1 Introduction

Marlborough District Council is developing a strategy for the urban growth and development of Marlborough. The Council has identified a number of potential urban growth areas for Blenheim that lie on the northern and eastern periphery of the town. The objective is to define a strategic planning horizon and assess geotechnical hazards of relevance to Blenheim, followed by development of parameters that would help the Council to assess the acceptability of geotechnical hazards and conclusions presented in support of any development.

Opus International Consultants Ltd (Opus) has been commissioned by the Council to carry out a geotechnical evaluation of the proposed growth areas. This study has been carried out in three parts, as follows:

(1) *Desk Study (Opus, 2011)*: Preliminary geotechnical appraisal of the ground conditions and geo-hazards, based on a desk study of available information and site reconnaissance inspections.

(2) *Geotechnical Investigations (Opus, 2012)*: Site investigations were carried out in the proposed growth areas in January to February 2012 to provide information to better characterise the ground conditions and assess the geotechnical issues.

(3) *Assessment (this report)*: This report has been prepared as the final part of this study. Here we characterise the ground conditions and geotechnical hazards in the proposed urban growth areas.

2 Site Description

The proposed urban growth areas are located on the outskirts of Blenheim's urban area, to the north (area Na:Nb) and to the east (areas E1, E2 and SE). The following sections describe the location, topography and land use of each area.

2.1 Area Na:Nb

Development area Na:Nb lies on the northern outskirts of Blenheim township. The NZMS 260 Map Grid Reference for the site is P28 885 675.

This site is rectangular in area, approximately 1.5 km long by 0.5 km wide, with the southern and western boundaries formed by Old Renwick Road and Thomsons Ford Road, respectively. The northern boundary lies parallel to Old Renwick Road. The eastern boundary is formed by the recent subdivision at Waipuna Street and Clearwater Place. The Opawa River lies approximately 100 m from the eastern edge of the site and a tributary stream is within 50 m of the northeast corner of the site.

The topography of the site is generally flat. Two open drainage channels run east-west across the land in the southwestern part of the site, and the southern boundary (along Old Renwick Road) lies adjacent to an unnamed tributary stream of Opawa River.

Presently the site consists of open pasture and vineyards, with some residential development. Blenheim substation lies outside the southwestern corner of the site, at the intersection of Old Renwick and Thomsons Ford roads.

2.2 Area E1

Development area E1 lies on Dillons Point Road, on the eastern outskirts of Blenheim. The NZMS 260 Map Grid reference for the site is P28 915 659.

The site is approximately 550 m by 750 m in area, and is bound to the north, west and south by Opawa River. The northeastern boundary is formed by Rowberrys Road. This site is generally flat, apart from alongside Opawa River where the land drops away to the river channel. The land consists predominantly of vineyards, with an open grassed verge alongside Opawa River.

2.3 Area E2

Area E2 lies south of Area E1, to the east and south of Blenheim Township. The NZMS 260 Map grid reference for the site is P28 915 648.

This site is bound by Opawa River to the north, State Highway 1 and Alabama Road to the east and south respectively, and the eastern suburbs of Blenheim to the west. This site consists of six parcels of land, with a combined area of approximately 1.5 km by 0.7 km. State Highway 1 and the South Island Main Trunk railway line both cross the site.

The topography of the land is flat to gently undulating, particularly in the northeast where the land drops to Opawa River. A series of open drainage channels run north-south and east-west across the site; these have been cut approximately 2 to 3 m below the surrounding ground surface.

The site presently consists of open pasture and vineyards, as well as limited commercial and residential development.

2.4 Area SE

Area SE lies on the southeastern outskirts of Blenheim. The NZMS 260 Map grid reference for the site is P28 910 642.

This site is rectangular in area, approximately 450 m by 550 m. The southern boundary of the site is formed by Alabama Road, and the northern boundary formed by Tavera Street. The eastern boundary is formed by the western boundary of Area E2, and the western edge of Area SE is formed by a parcel boundary in rural land.

The topography of the land is generally flat, with open drainage channels running west-east along the northern and southern boundaries. The site consists of open horticultural land.

3 Geological Setting

3.1 Geology

The geology of the Marlborough Area has been mapped at 1:25,000 scale by the New Zealand Geological Survey (NZGS, 1981) and at 1:250,000 scale by the Institute of Geological and Nuclear Sciences (IGNS, 2000).

The mapping shows the Blenheim area to be underlain by Holocene age marine/estuarine silts and sands of the Dillons Point Formation and alluvial gravels and sands of the Rapaura Formation. These strata are underlain by older, clay-bound alluvial gravels of the Speargrass Formation (NZGS, 1981; Landcare Research, 1995; MCRWB, 1987; Davidson and Wilson, 2011).

The characteristics of the Dillons Point Formation and shallow Rapaura Formation strata are described in Section 5.

3.2 Active Faults

The plate boundary between the Pacific and Australian plates passes through Marlborough, and consequently this region is an area of high seismicity. Relative motion between the tectonic plates is accommodated across a zone of active strike-slip faults (the Marlborough fault system), which links the Alpine fault transform plate boundary to the south with the westward-directed Hikurangi subduction margin to the north. The Marlborough fault system comprises four principal strike-slip faults and a number of smaller faults. Those within 15 km of the study area are summarised in Table 1 and are discussed below.

Table 1 Active fault summary table

Fault	Characteristic Event Magnitude	Recurrence Interval (years)	Distance from site (km)	Direction
Wairau Fault	7.1 – 7.6	1,150 – 1,400	1.6	Northwest
Vernon Fault	?	2,000 – 3,500	8	Southeast
Awatere Fault	7.5	820 – 950	14	Southeast

Source: Benson et al. (2001); Geotech Consulting Ltd (2003a, 2003b, 2005); Mason et al. (2006a, 2006b); Zachariasen et al. (2006)

These faults as well as other earthquake sources in the larger region can give rise to earthquakes that could affect the Blenheim area including the identified sites.

The Wairau Fault is the closest active fault to the site, lying approximately 1.6 km to the northwest of area Na:Nb and approximately 4.7 km to the northwest of areas E1, E2 and SE. This fault is capable of rupturing in earthquakes of characteristic magnitude 7.1 to 7.6, and horizontal surface displacements of 5 to 7 m with an average return period of 1150 to 1400 years (Geotech Consulting, 2003a, 2003b, 2005; Zachariasen et al., 2006).

The Awatere Fault is located approximately 14 km southeast of Blenheim. This fault ruptures in earthquakes of characteristic magnitude 7.5 at an average recurrence interval of

820 to 950 years, with surface displacements of between 4 and 7 m. This fault last ruptured in the M_w 7.5 Marlborough earthquake of 1848 (Benson *et al*., 2001; Mason *et al*., 2006a, 2006b).

The Vernon Fault is a secondary fault that splays north off the Awatere Fault at Dumgree, southeast of Blenheim. Little paleoseismic information is available for this fault and its potential surface rupture hazard is therefore not well defined. The slip rate of the fault is estimated to be low (less than 2 mm/year; Benson *et al*., 2001), and it consequently has been assigned a longer return period than the Awatere Fault (GNS Active Faults Database).

4 Site Investigations

Geotechnical site investigations have been carried out across the study area to provide information to better characterise the ground conditions and assess the geotechnical issues, particularly relating to the hazard posed by liquefaction. The investigations were carried out in January and February 2012, and comprised the following:

- Three boreholes, to depths of 12.45 m to 18.45 m, with in situ Standard Penetration Tests carried out at 1 m intervals.
- Twelve static Piezo-Cone Penetration Tests (CPTs), to depths of between 2.72 m and 19.65 m.
- Laboratory testing of samples recovered from the boreholes.

The results of the investigations are provided in the site investigation report (Opus, 2012).

5 Ground Conditions

5.1 Ground Conditions

The area under investigation is located on flat to gently undulating terrace surfaces, which are underlain by young (Holocene and late Pleistocene age) interbedded alluvial and estuarine/swamp deposits. Information on the ground conditions in the Blenheim area is provided by the 2012 site investigations and factual information available from previous investigations in the wider Blenheim area (Geotech Consulting, 2004; Nelson Consulting Engineers, 2007; CH2M Beca, 2008; MDC borehole database).

These investigations show the surficial soil layers in the local area to consist of interbedded silts, clays and sands of the Dillons Point Formation, which interfinger with and are underlain by sands and gravels of the Rapaura Formation. The estuarine deposits of the Dillons Point Formation are observed to vary significantly in their composition and degree of consolidation, both laterally and with depth, from loose sands and soft silts to very dense sands and very stiff clayey silts. The Rapaura Formation deposits consist of loose sands and soft silts to dense to very dense alluvial gravels, with a sandy matrix and some interbedded sand layers.

A summary of the soils encountered in each area is provided below.

Area Na:Nb

0 – 4 m	Very loose to medium dense sand, silty sand and silt, and firm to hard sandy clay
1 – 5 m	Medium dense to very dense silty sand and sandy gravel
5 m +	Medium dense to very dense sandy gravel

Areas E1, E2 and SE

0 – 3 m	Very soft to firm silty clay and clayey silt
0 – 7 m	Firm sandy silt and very loose silty sand
7 m +	Dense to very dense sandy gravel, silty gravel, and firm sandy silt

5.2 Groundwater Conditions

The groundwater levels recorded during the site investigations ranged from 1.3 m to 2.1 m depth below ground level in Area Na:Nb, and 1 m to 4 m depth in Areas E1, E2 and SE. This is consistent with longer term static groundwater levels recorded in the wider Blenheim area, which show that the groundwater table lies approximately 2 m below ground level in the development areas (Davidson and Wilson, 2011).

6 Geotechnical Hazards

The study area is exposed to a number of geotechnical hazards, which are discussed in the following sections.

6.1 Consolidation Settlement

Compressible soft clays and silts can consolidate over time if subjected to loads such as that from a building. Consolidation of founding soils can lead to damage to the structure. Investigations showed the upper 2 to 4 m of soil in all areas contained clay, and some well logs from MDC (e.g. P28w/2168) showed over 20 m of clay.

In particular, Areas E1 and E2 have significant thicknesses (>5m) of potentially compressible soils which could pose a hazard to future development, as special measures may be required such as preloading of the site or deep foundations.

6.2 Slope Failure

The slope failure hazard at the site is very low due to the flat, low-lying topography of the land. Areas in close proximity to river banks will be susceptible to slumping or erosion in flood events or lateral spreading of the banks as a possible consequence of earthquake-induced liquefaction. The issues related to liquefaction hazard at the site are described in Section 6.5.

6.3 Fault Rupture

The closest active fault to the study areas is the Wairau Fault. This fault has a distinct trace over much of its length, except for the lower Wairau Valley where the trace is intermittent and subdued. The fault is inferred from available geological evidence to lie approximately 1.6 km from area Na:Nb and approximately 5 km from the eastern growth areas at its closest point (Geotech Consulting, 2003a). Rupture of this fault is expected to result in 3.4 m to 7 m of lateral displacement of the ground surface at the fault trace (Geotech Consulting Ltd, 2003b, 2005; Zachariasen *et al*., 2006). The distance of the fault from the study areas suggests that the risk from permanent ground damage associated with fault rupture is low.

6.4 Ground Shaking

Blenheim's principal earthquake hazard derives from the close proximity of the active Wairau Fault and Awatere Fault. Geotech Consulting (2003a, 2003b) conclude there is a moderate to high likelihood of a surface rupturing earthquake on the Wairau Fault in the next 50 - 100 years. The average return period of the Wairau and Awatere Faults is between 350 and 950 years (Robertson and Smith, 2004). Other principal active faults in the region include the Clarence, Kekerengu, Elliot, Jordon and Hope faults. All of these faults are capable of producing large magnitude earthquakes, > M7 (Stirling *et al*., 2002), and Robertson and Smith (2004) state that collectively an earthquake on any one of these faults has an average recurrence interval of less than 50 years. Ground shaking is therefore a significant hazard to the Blenheim area.

6.5 Liquefaction

6.5.1 Liquefaction Definition

Liquefaction will occur when saturated loose to medium dense fine grained granular materials and silt are subjected to ground shaking. Liquefaction can cause sand boils, subsidence, lateral spreading and flow slides. Damage from such deformation can include floatation of buried structures, fissuring of the ground, subsidence of large areas, differential subsidence, and foundation failure caused by loss of support as the liquefied soil substantially loses its shear strength.

6.5.2 Geological Context

Mapping of historic river and drainage features in the lower Wairau valley shows the area to the east and southeast of Blenheim (partially covering development areas E1, E2 and SE) consisted of swamps prior to development of the town (MCRWB, 1987), see Figure 1. Soft ground conditions in this area may result in liquefaction and ground damage due to earthquake events.

6.5.3 Liquefaction Assessment

Analysis Methodology

The liquefaction potential of soils was determined using LiquefyPro, version 5.8h (CivilTech Software, 2010). This software uses cyclic liquefaction evaluation methods to determine whether liquefaction is likely in a particular earthquake event and estimate the resulting ground subsidence. The modified Robertson method (Robertson & Wride, 1997) and modified Stark and Olsen methods (Stark & Olsen, 1995) were used to assess liquefaction with CPT and SPT results respectively. The method proposed by Ishihara and Yoshimine (1992) was used to estimate the resulting ground subsidence.

The following return periods and associated peak ground accelerations (PGA) have been considered:

- 1/500 return period event, with a PGA of 0.37g
- 1/1000 return period event, with a PGA of 0.48g
- 1/2500 return period event, with a PGA of 0.67g

The characteristic magnitude used in the liquefaction assessment was assumed to be $M_W = 7.5$ for all return period events considered, consistent with the characteristic magnitude of earthquake sources in the area.

Results

The Dillons Point Formation was assessed to be susceptible to liquefaction in all three return period events. The Rapaura Formation also contains some layers of loose material which exhibit liquefaction potential, principally near the ground surface in Area Na:Nb.

The approximate thicknesses of soil layers assessed to liquefy at each area are depicted in Figure 3 and Figure 4 which show cross sections of area Na:Nb and areas E1, E2 and SE respectively, Figure 2 shows the cross section locations. These results are tabulated in Table 2. It should be noted that the thicknesses of soil layers that are likely to liquefy vary across each area, and the depths in the table are indicative only. Typically there was only a slight difference in the thicknesses of layers assessed to liquefy in 1/500, 1/1000 and 1/2500 year return period events. This is because most soil layers susceptible to liquefaction have a low density such that they are likely to liquefy in earthquakes with a PGA less than that from a 1/500 year return period level.

Area Na:Nb

Analysis showed the shallow silty sand layer above the gravels as liquefiable for all return period events considered. Site investigations show this layer to be typically 2 m to 4 m thick, and the groundwater to be between 1.3 m to 2.1 m depth. The potential for liquefaction induced ground damage in this area will be strongly influenced by the groundwater table depth. As described above in Section 5.2, the regional groundwater table in the Blenheim area lies approximately 2 m below ground level. If the groundwater table is lower, the thickness of liquefiable material beneath the water table is reduced and the potential ground damage effects will be smaller.

Areas E1, E2 and SE

BH 2, in area E1, identified a sandy gravel layer between 10 m and 13 m depth. This gravel layer was not encountered in the CPTs carried out in this area and is not as susceptible to liquefaction as the soils encountered by the CPTs.

In the southern part of Area E2 (represented by CPT 10 and CPT 12) the groundwater level recorded during investigations was lower, as a result the upper 3.5 m of soil is less susceptible to liquefaction than that in the northern part of Area E2.

Table 2 Indicative depth of soil layers likely to experience liquefaction

Return period event	Soil layers susceptible to liquefaction (m depth)			
	Area Na:Nb	Area E1	*Area E2	Area SE
1/500	2 - 4	3.5 - 5.8 7.7 - 10.0 10.3 - 12.2 12.6 - 14.0 14.4 - 16.7	1.5 – 6.0 6.1 - 11.0 11.0 - 14.0 15.2 - 16.8	1.9 - 5.3 9.6 - 13.2 15.1 - 15.8
1/1000	2 - 4	3.5 - 5.8 7.7 - 16.7	1.5 - 11.0 11.0 - 14.0 15.2 - 16.8	1.9 - 5.3 7.0 - 7.5 9.6 - 13.2 15.1 - 15.8
1/2500	2 - 4	3.5 - 6.1 7.7 - 16.7	1.5 - 11.0 11.0 - 14.0 15.2 - 17.0 17.4 - 18.0	1.6 - 6.2 6.6 - 7.8 8.0 - 8.6 9.6 - 13.2 15.1 - 15.8

**CPT 07 identified a soil layer likely to experience liquefaction from 7.0 m to 16.0 m in Area E2 for a 1/2500 return period event.*

6.5.4 Liquefaction Induced Ground Damage

Liquefaction induced ground damage causes most damage to the built environment including lifelines, and needs to be considered in the assessment of liquefaction hazards (Brabhaharan, 1994 and 2010). Therefore the potential for ground damage form liquefaction has been considered for the urban growth areas under consideration.

Ground Subsidence

Subsidence is the vertical downward displacement of the ground, which happens without any vertical load being applied to the ground. Liquefaction leads to subsidence as a result of the liquefied soil settling to a slightly denser state and ejection of sand with water to the surface.

Widespread ground subsidence can cause areas to become more prone to flooding. Localised differential subsidence can lead to cracking and damage to structures, and affect the functionality of services, particularly gravity sewers and storm water systems.

The magnitude of expected liquefaction induced ground subsidence in each area, excluding the areas that are prone to lateral spreading, is tabulated in Table 3.

Table 3 Estimated ground subsidence due to liquefaction

Return period event	Predicted Subsidence (mm)			
	Area Na:Nb	Area E1	Area E2	Area SE
1/500	25 - 75	150 - 225	100 - 175	100 - 125
1/1000	25 - 75	175 - 250	125 - 200	100 - 150
1/2500	25 - 75	200 - 250	150 - 200	100 - 150

Lateral Spreading

Lateral spreading occurs predominantly in the vicinity of free surfaces such as water courses where the liquefied soil can laterally displace towards the water course, but can also occur when there is slope along which the liquefied ground can displace. This can lead to large displacements of the ground from hundreds of millimetres to a few metres.

Lateral spreading can extend to 200 m or more from water courses but is typically more severe nearer the river. In some situations it has extended 300 m to 500 m due to block sliding. This may be mainly in areas where the land can spread in more than one direction due to bends or loops in the water course. Experience from the 2010 Darfield and 2011 Christchurch earthquakes shows the ground damage due to lateral spreading reduces at a distance greater than 130 m from a river or stream. Figure 5 shows the study areas and the proximity to nearby rivers and streams. The extent of lateral spreading is a function of both the depth of the stream or channel and the depth of the liquefiable soils.

The estimates of ground subsidence given in Table 3 do not take into account the subsidence effects of lateral spreading.

Area Na:Nb

Liquefaction in this area may lead to lateral spreading of the land towards nearby streams and drains although the effects are likely to be limited given the relatively thin deposits of liquefiable material, except close to the southeast boundary with thicker deposits and northeast boundary, close to the river.

Areas E1, E2 and SE

Lateral spreading is anticipated to be a significant issue in Areas E1 and E2 should liquefaction occur as these sites straddle the Opawa River and tributary streams and are underlain by significant thicknesses of liquefiable material.

Due to the lack of streams in Area SE the risk of lateral spreading is less than that for Areas E1 and E2. However there is still potential for lateral spreading towards the drainage channels that cross the site.

7 Discussion

7.1 Strategic Planning Timeframe

The timeframe used for planning and design depends on two factors:

(1) The importance level of the development

(2) The life of the development.

A life of 50 years is traditionally assumed for normal buildings, and 100 years for infrastructure. For normal buildings of Importance Level 2 (NZS 1170.0), a 500 year return period earthquake hazard is used for ultimate state design, which gives about 10% probability of the event occurring over the 50 year life assumed for typical buildings. For higher value infrastructure, a life of 100 years is often assumed, with a 1,000 or 2,500 year return period earthquake is used for ultimate state design, depending on its importance, giving probabilities of 10% and 4% respectively, see Table 4.

Table 4 Probability of event for planning and design

Return period event	Probability of event in the life			
	Buildings Life 50 years	Infrastructure Life 100 years	Urban Growth Life 200 years	Urban Growth Life 500 years
1 / 500	10%	-	-	-
1 / 1000	-	10%	-	-
1 / 2500	-	4%	-	-
1 / 2,000	-	-	10%	-
1 / 5,000	-	-	4%	10%

Areas of urban expansion will have a mix of normal buildings and higher value and importance level infrastructure. Although individual buildings or infrastructure may be renewed from time to time, the areas once developed will remain in use for a long time. An area developed could potentially be in use in perpetuity, unless and until there is some major environmental or social change that leads to abandonment of the area. Therefore, a longer “life” is appropriate for zoning areas for urban growth, a “life” of at least 200 years or 500 years or more may be appropriate.

For considering urban growth, retaining a similar probability of 10%, consideration of events with a return period of 5,000 years may be appropriate for land use planning for hazard events which can have a destructive effect on the built environment. This would limit the probability of such destructive events over a 500 year “life” to 10%.

Such an approach may be appropriate for example when zoning for buildings in an active fault zone. This may also be prudent for land prone to very high landslide hazards or extensive lateral spreading from liquefaction. This is on the basis that these hazards can have a destructive effect on the built environment exposed to the hazard.

For the areas investigated for urban growth in Blenheim, the ground shaking associated with earthquakes with a return periods of less than 500 years is assessed to be sufficient to cause extensive liquefaction (and lateral spreading in vulnerable areas) of the liquefaction susceptible loose soils present. There is only limited additional liquefaction in larger earthquake events with a longer return period. Therefore, in this instance, the length of the strategic planning period for the liquefaction hazards is not significant or important.

7.2 Land Use Zoning

Land susceptible to liquefaction, and particularly lateral spreading is prone to significant risks in earthquake events. In the development areas under consideration in Blenheim, liquefaction of the Dillons Point Formation soils can occur in modest earthquake events which are used for design of normal buildings.

Geotechnical engineering design approaches are available to mitigate the risk of liquefaction and lateral spreading through ground improvement and robust deep foundations. Such costly methods are only generally adopted for important and high value facilities. In our experience these very costly methods are likely to lead to prohibitively high development costs. It should be noted that the government made a decision not to allow redevelopment of residential areas in Christchurch that were subject to liquefaction and lateral spreading (identified as red zone areas) in the Canterbury earthquakes of 2010-2011, rather than carry out very costly mitigation against future liquefaction using ground improvement.

From a sustainability perspective, it would not be prudent to encourage development on land which will require considerable cost and consume substantially more resources compared to development in land which is more stable in earthquake and other hazards. This is on the basis that it would be more sustainable to develop areas subject to a lower level of hazard.

Therefore, it would be prudent to not zone for intensive development, the areas subject to severe lateral spreading, such as in substantial areas of Area E1 and E2 and smaller areas in Na:Nb. These areas subject to liquefaction and lateral spreading can be used for less intensive land uses such as parks and gardens or agriculture. This could be achieved by appropriate zoning of the land through district planning measures.

Area SE has a liquefaction hazard, but a lesser lateral spreading hazard because it is away from main water courses. Localised lateral spreading may occur close to the deep drains, although the overall damage from liquefaction would not be as severe as the areas prone to lateral spreading towards major water courses. However, development in these areas will be more costly because of the high groundwater levels and presence of liquefaction prone soils at shallow depth and the need to mitigate the effects of liquefaction and safeguard against subsidence and foundation failure. Also the Council needs to consider the effect on its services such as stormwater and sewers to service these areas, in deciding whether to zone this area for more intensive development.

Area Na:Nb lies away from the major water courses and appears to have a lesser liquefaction hazard based on the investigations carried out. The thickness of Dillions Point

Formation soils may be thinner in these areas, although localised areas may have thicker deposits, particularly in the southeast part of the area.

The Council should consider the hazard and sustainability issues in zoning these areas for more intensive development. Other parts of the Blenheim township will also be prone to liquefaction and in some cases lateral spreading hazard. With a long term view, it may be prudent for the Council to carefully consider whether to zone these eastern areas prone to liquefaction and lateral spreading for future intensive development, or encourage more development further to the west, where the geology indicates more alluvial gravel soils which are likely to be less at risk from liquefaction. This would be an important consideration for the long term planning of the Blenheim township.

7.3 Experience from Christchurch

In Christchurch, there were areas prone to liquefaction and lateral spreading that experienced severe damage. Some of these areas had been developed early when there was little knowledge or awareness of liquefaction. However, there were also areas that had been developed recently, even when the liquefaction hazard has been known. There was extensive damage to the built environment in these areas, including residential and commercial properties and lifeline services. A number of areas have been now included in the red zone, where re-construction has been precluded at the present time.

There was also extensive damage to services, particularly sewers and stormwater systems, which were damaged by liquefaction induced subsidence and change in levels restricting gravity flow, lateral spreading and damage to pipelines, floatation and damage to pump stations and manholes, and intrusion of liquefied sand and silt into pipelines.

7.4 Acceptability of Geotechnical Assessments for Development

The Dillons Point Formation soils are highly vulnerable to liquefaction and large subsidence of hundreds of millimetres, and also prone to severe lateral spreading in areas close to water courses.

Should the Council decide to zone some of these areas for development, it would be prudent to ensure that the developments proposed mitigate the effects of liquefaction. The geotechnical assessment needs to be reviewed by a Chartered Professional Engineer, specialising in geotechnical engineering, and with experience in the assessment of earthquake geotechnical hazards. Also the building consents need to be considered to ensure that the development has considered the structures and the geotechnical hazards in an integral manner, to ensure that the building can survive without damage in serviceability level earthquake events, and with limited damage which is repairable in ultimate limit state events.

The guidance provided by DBH and the Engineering Advisory Group for reconstruction in Christchurch provides guidance on acceptable solutions. These are expected to be developed further over the next year or so, and based on the Royal Commission report due later this year. It would be prudent to review the acceptance framework as it develops.

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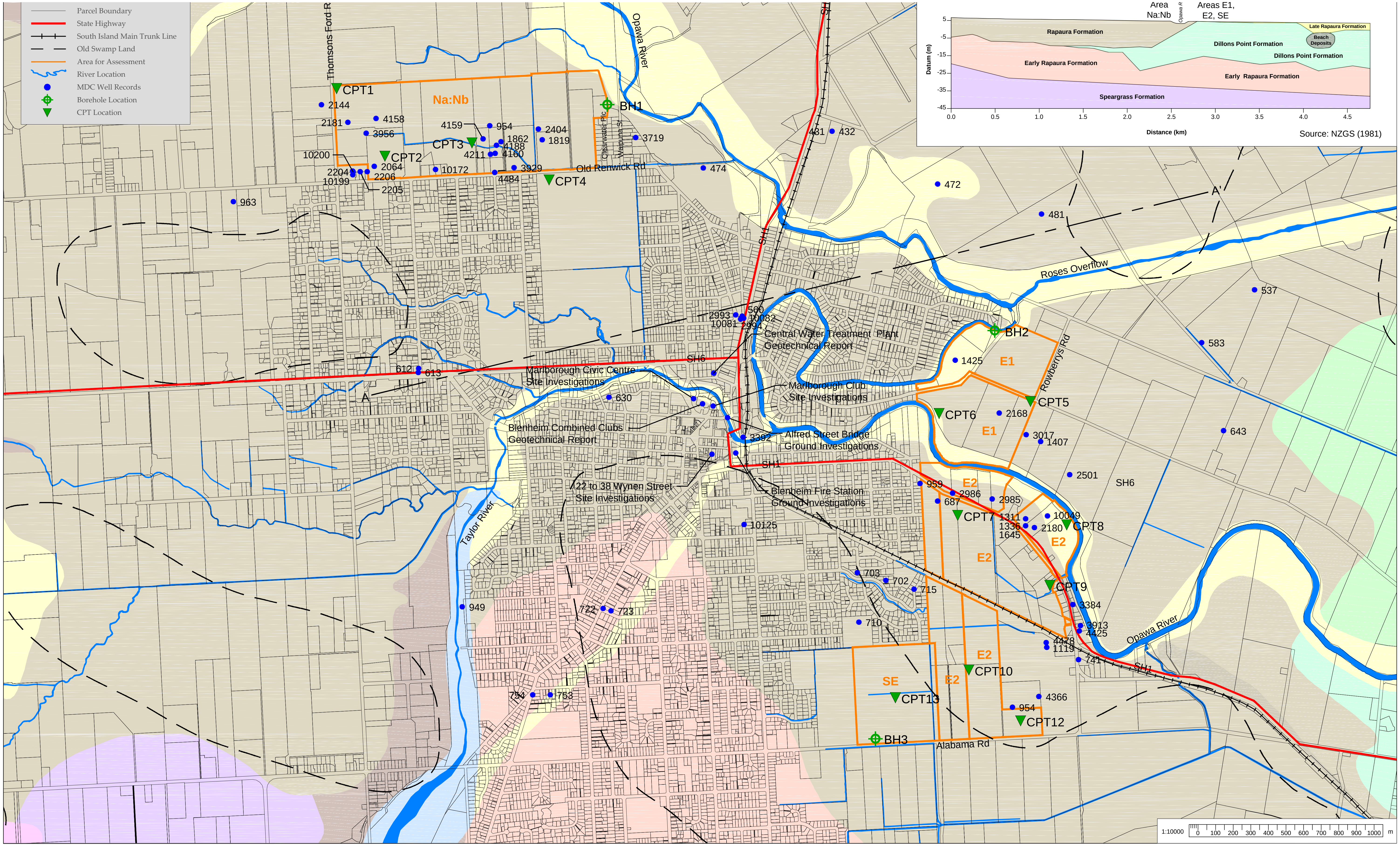
FIGURES



Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Surficial Geology (after NZGS, 1981)

Rapaura Formation	fa	Unstabilised river silt, sand, and gravel in present river beds.
	rg	Gravel, sand, and silt in river flood channels occupied during historic flooding, or in modern time prior to river flood protection constructions.
	ra_2	Alluvial silt adjacent to present or historic river flood or man made diversion channels and reclaimed or drained swamps.
	ra_1	Alluvial gravel, sand, and silt.
	ra	Alluvial gravel, sand, and silt at higher level and well drained
Dillons Point Formation	dl_1	Sand, silt, and mud lagoon deposits
	dl	Sand, silt, and mud lagoon deposits better drained and less saline.
	dd	Sand dunes
Speargrass Formation	sp	Fluvial (glacial outwash) brown and blue gravel, sand, and silt.
Tophouse Formation	to	Glacial outwash of weathered to slightyweathered brown gravel, sand, andsilt; covered by a layer of loess up to i m thick

N

Title: Regional Geology

Project: Blenheim Urban Growth Study

Scale:	*Date:*	*Project No:*	*Figure:*
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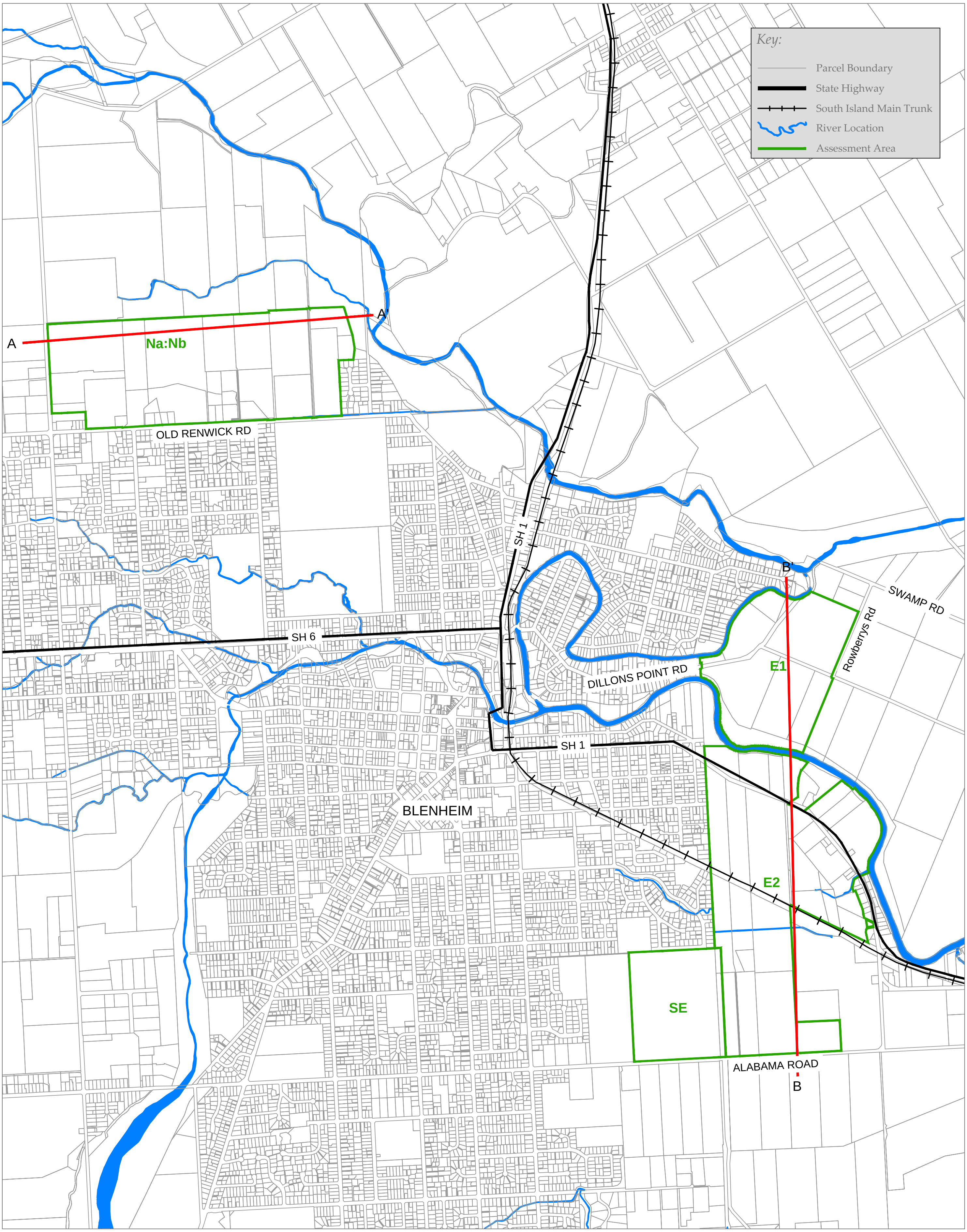

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Title: Cross Section Location Plan

Project: Blenheim Urban Growth Study

Scale:	Date:	Project No:	Figure:
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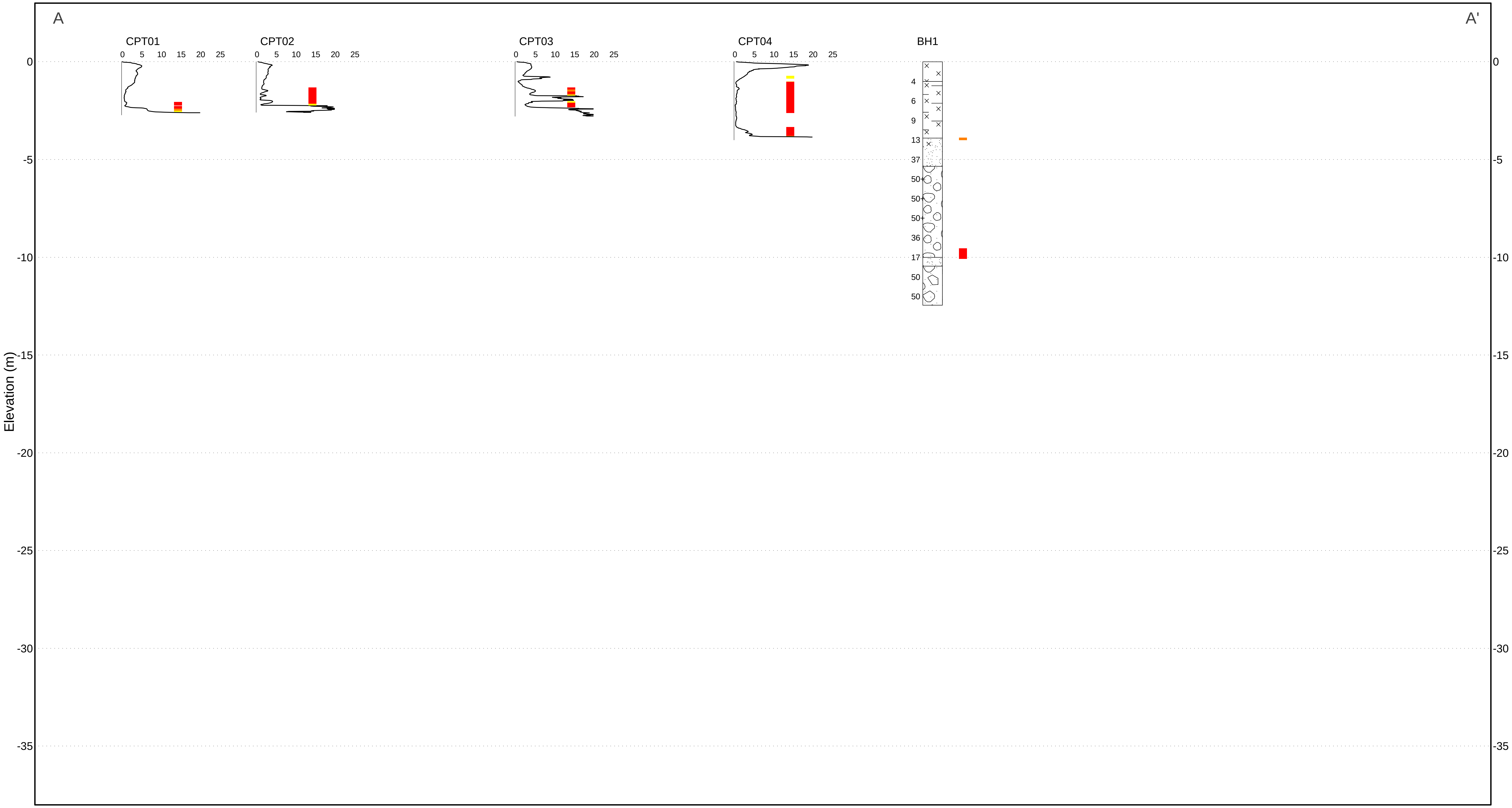

Prepared for: MARLBOROUGH DISTRICT COUNCIL

Prepared by: OPUS INTERNATIONAL CONSULTANTS

Legend:

Return Period Event

- 1/500
- 1/1000
- 1/2500

Lithological Graphics

- SILT
- Clayey SILT
- Silty SAND
- Sandy GRAVEL
- SAND
- Sandy GRAVEL

Title:	Cross Section of Area Na:Nb		
Project:	Blenheim Urban Growth Study		
Vertical Scale:	*Date:*	*Project No:*	*Figure:*
1: 200	4/05/2012	5C2128.00	3

Prepared for: MARLBOROUGH DISTRICT COUNCIL

Prepared by: OPUS

Legend:

Return Period Event

- 1/500
- 1/1000
- 1/2500

Lithological Graphics

- Sandy SILT
- Silty SAND
- Sandy GRAVEL
- Clayey SILT
- Sandy Silty GRAVEL
- Silty GRAVEL

Title: **Cross Section of Areas E1, E2 and SE**

Project: **Blenheim Urban Growth Strategy**

Vertical Scale:	*Date:*	*Project:No:*	*Figure:*
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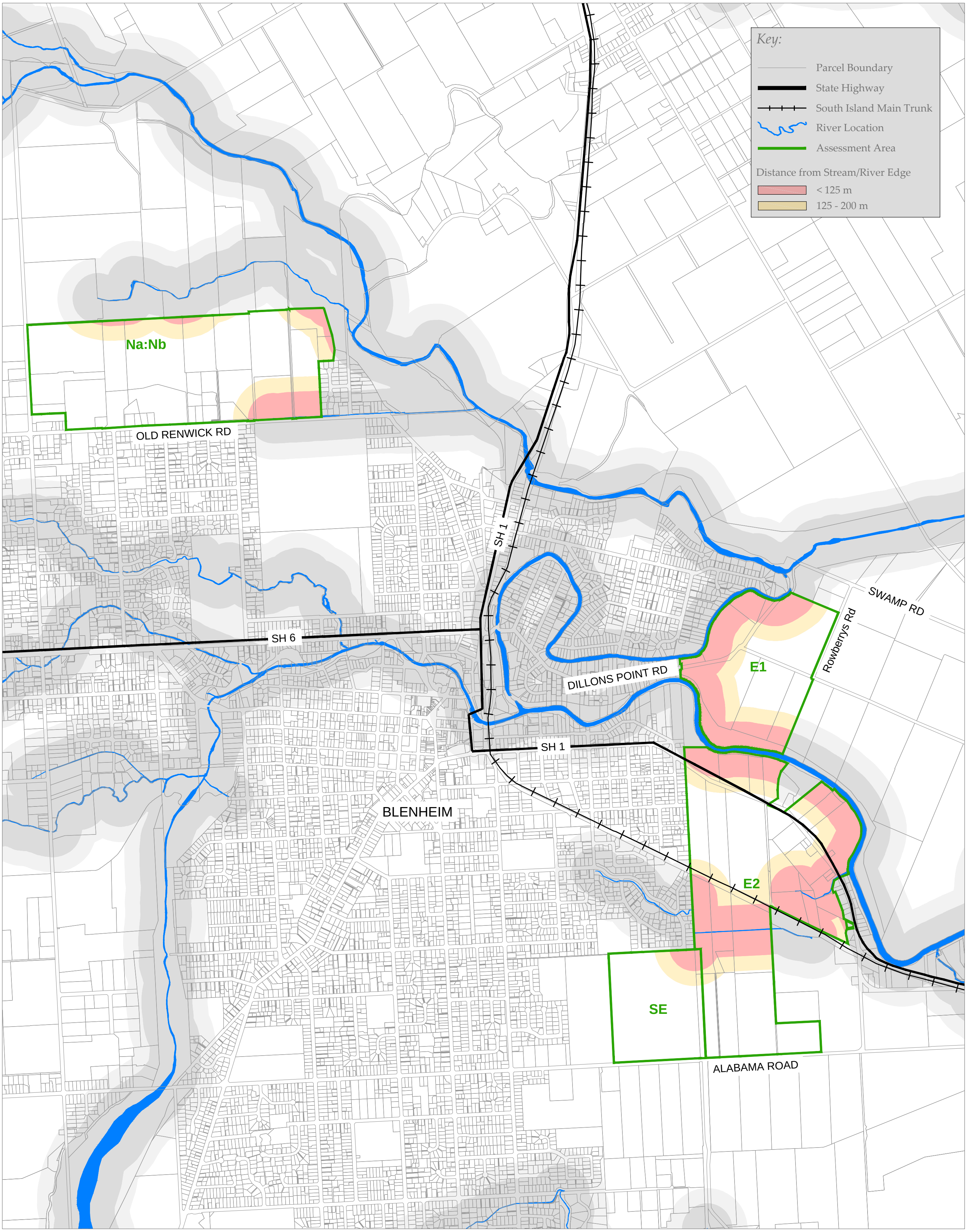

Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

N

Title:
Proximity to Edge of Waterways

Project:
Blenheim Urban Growth Study

Scale:	Date:	Project No:	Figure:
1:25,000 (A4)	May 2012	5C2128.00	5