Marlborough District Council

Blenheim Urban Growth Study Stage 2

Geotechnical Evaluation

Interpretive Report

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Geotechnical Evaluation

Interpretive Report

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Contents

1 Introduction

Marlborough District Council is developing a strategy for the urban growth and development of Blenheim. The Council has identified a number of potential urban growth areas that lie on the periphery of the city. Opus International Consultants Ltd (Opus) has been commissioned by the Council to carry out a geotechnical evaluation of the proposed growth areas.

Geotechnical investigations and assessment of proposed growth areas to the north, east and southeast of the city were previously carried out in early 2012 (Opus, 2011; 2012a). The investigations showed the areas to the east and southeast are underlain by significant thicknesses (> 15 m) of loose materials which are susceptible to liquefaction. Consequently, these areas would be prone to damage in earthquakes or alternatively require considerable cost and resources to develop with appropriate mitigation measures.

The geotechnical appraisal of the ground conditions and suitability of the land for development recommended that land which is more stable to earthquake hazards be developed (Opus, 2012b). The Council therefore identified 6 new areas to the northwest, west and southwest of the city for possible urban growth, and engaged Opus to carry out investigations in the new areas to assess the geotechnical issues there, particularly relating to the hazard posed by liquefaction. The site investigations were carried out during September to December 2012 (Opus, 2013).

This report presents a characterisation of the ground conditions and geotechnical hazards in the proposed new urban growth areas, and makes recommendations for land use planning taking into account the earthquake hazards.

2 Site Description

The proposed urban growth areas are located on the outskirts of Blenheim's urban area, to the north (area Na:Nb), northwest (areas 1, 3 to 6) and southwest (area 8). The locations of the growth areas are shown on Figure 1. The sites are situated on predominantly flat to gently undulating alluvial plains, and the land is predominantly under agricultural use with some rural-residential developments. Several streams and drains cross the sites, flowing from west to east.

The NZMS 260 map grid reference of the area under investigation is BR28 775 050.

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 (see Figure 2). Southern Fan Deposits were deposited by the Taylor River to the southwest of Blenheim, contemporaneous with deposition of Rapaura Formation gravels in the Wairau Valley.

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).

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 plate 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. Together, these faults represent earthquake sources that contribute significantly to the seismic hazard in the Marlborough district.

The principal active faults within 15 km of the site are summarised in Table 1 and 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	0.4	Northwest
Vernon Fault	?	3,000 – 4,000	8	Southeast
Awatere Fault	7.5	820 – 950	14	Southeast

Source: Benson et al. (2001); Clark et al. (2011); Geotech Consulting Ltd (2003a, 2003b, 2005); Mason et al. (2006a, 2006b); Zachariasen et al. (2006).

The Wairau Fault is the closest principal active fault to the site, lying approximately 400 m northwest of Area 1. The 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).

Two secondary faults (the Tempello and Fairhall faults) have been inferred from stratigraphic cross-cutting relationships between boreholes in south western Blenheim (Davidson and Wilson, 2011). The activity of these faults is not well defined, as they do not form obvious traces on the ground surface. The Fairhall Fault is indicated to lie within approximately 100 m of the northwestern corner of Area 8 (see Figure 2). This fault appears to displace the base of the Winterholme Formation, which suggests possible activity in the last 75,000 to 130,000 years. The Tempello Fault lies approximately 1.5 km to the south of Area 8. This fault appears to displace the base of Speargrass Formation strata, which suggests possible activity in the last 13,000 years.

As the Tempello and Fairhall faults do not have well defined traces it is likely that they have not ruptured in the last ~9000 years and 75,000 years, respectively (i.e. since the formation of the Dillon's Point and Winterholme formations). These faults are not recorded on GNS' Active Faults Database and given the long duration since the most recent activity the hazard posed by these features is likely to be very low to low. However, no detailed studies of the location, rates and magnitude of displacement of these faults have been carried out, and therefore the hazard posed by these faults cannot be quantified without further investigation.

4 Ground Conditions

4.1 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 scoped and carried out in accordance with the guidelines provided by the former Department of Building and Housing (now the Ministry of Business, Innovation and Employment) for geotechnical investigations of land in Canterbury (MBIE, 2012).

The investigations were carried out between October and December 2012, and comprised the following:

- Twenty seven boreholes, to depths of 10 m to 20 m, with in situ Standard Penetration Tests carried out at 1 m depth intervals.
- Twenty five static Piezo-Cone Penetration Tests (CPTu), to depths of between 1 m and 7.44 m, with further penetration retarded by dense gravels.
- Laboratory testing of samples recovered from the boreholes.

The results of the investigations are provided in the site investigation report (Opus, 2013).

4.2 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 swamp deposits. Information on the ground conditions in the Blenheim area is provided by the 2013 site investigations (Opus, 2013) and factual information available from previous investigations in the wider Blenheim area (Geotech Consulting, 2004; Nelson Consulting Engineers, 2007; CH2M Beca, 2008; Opus, 2012a; MDC borehole database).

These investigations show the surficial soil layers in the local area to consist of interbedded gravels, sands and silts of the Rapaura and shallow Speargrass formations, which interfinger with estuarine silts and sands of the Dillons Point Formation to the east of the study area.

The Rapaura Formation deposits consist of loose sands and soft clayey silts underlain by dense to very dense alluvial gravels, with a sandy matrix and some interbedded sand layers.

Speargrass Formation deposits have been mapped to the southwest of Blenheim, and were encountered in the exploratory holes at Area 8. These strata consist of loose sands and soft silty clays overlying dense to very dense clayey gravels and hard silts and clays.

A summary of the soils encountered is provided below in Table 2.

Table 2 Generalised soil profiles at the growth areas

Areas	Depth Range	Lithology
Na:Nb	0 – 2 m (< 4 m)	Very loose to medium dense sand, silty sand and silt, and firm to hard sandy clay
	2 – 5 m	Medium dense to very dense silty sand and sandy gravel
	5 m +	Medium dense to very dense sandy gravel and gravelly sand with occasional silt and sand layers
1 – 4	0 – 2 m (< 4 m)	Soft to hard silt, clayey silt, and sandy silt
	2 – 4 m (< 6 m)	Loose to very dense silty sand and sandy gravel
	4 m +	Dense to very dense sandy gravel and gravelly sand
5, 6 & 8	0 – 2 m (< 10 m)	Very soft to hard silt, clayey silt and silty clay
	2 – 8 m	Medium dense to very dense sandy silt, silty sand and sandy gravel
	8 m +	Dense to very dense sandy gravel, clayey gravel and gravelly sand

4.3 Groundwater Conditions

The groundwater levels recorded during the site investigations ranged from 1 m to 3 m depth below ground level in Areas 1 to 6 and Na:Nb, and 2 m to 7.1 m depth in Area 8. 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 to 5 m below ground level in the development areas (Davidson and Wilson, 2011).

5 Geotechnical Hazards

5.1 Soft Ground Conditions

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 settlement of the building and consequently damage to the structure. Investigations showed the upper 2 to 4 m of soil in all areas contained clay or silt. In particular, Areas 6 and 8 have significant thicknesses (< 10 m) 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.

5.2 Slope Instability

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 5.5.

5.3 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 300 m to 400 m from Area 1 at its closest point (Geotech Consulting, 2003a; IGNS, 2000). 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 proximity of the fault to Area 1 and the uncertainty of the fault's position suggests fault rupture could pose a hazard to this development area. The land use planning issues from permanent ground damage associated with fault rupture are discussed in Section 6.4.

5.4 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. Taken together, the Wairau and Awatere Faults have a combined recurrence interval of 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 (>M7) earthquakes (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.

5.5 Liquefaction

5.5.1 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.

5.5.2 Analysis

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 and Wride, 1997) and modified Stark and Olsen methods (Stark and 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 design horizontal peak ground acceleration (PGA) has been derived in accordance with the New Zealand Earthquake Loading Standard, NZS 1170.5: 2004 (Standards New Zealand, 2004).

The derivation of the design horizontal PGA is shown as follows.

Design PGA,

$$C_0 g = C_h(T = 0) Z R_u N(T, D) g$$

Where :

C_o	=	design ground acceleration coefficient
g	=	acceleration due to gravity
C_h (T=0)	=	spectral shape factor for Site Class D at period T = 0
	=	1.12
Z	=	hazard factor
	=	0.33
R_u	=	return period factor
	=	1.0 (for a 500 year return period event)
	=	1.3 (for a 1000 year return period event)
	=	1.8 (for a 2500 year return period event)
N (T, D)	=	near-fault factor
	=	1.0

Therefore,

Design horizontal PGA for a 500-year return period event = 0.37g

Design horizontal PGA for a 1000-year return period event = 0.48g

Design horizontal PGA for a 2500-year return period event = 0.67g

The characteristic magnitude used in the liquefaction assessment was assumed to be M_W = 7.5 for all return period events considered, which reflects the magnitude weighting for the calculation of the PGAs and is consistent with the characteristic magnitude of earthquake sources in the region.

5.5.3 Results

The approximate thicknesses of soil layers assessed to liquefy at each area are shown in the cross sections provided in Appendix A. 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.

The liquefaction analyses showed the shallow silt and sand layers 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 underlying Rapaura Formation gravels and sands are typically dense to very dense, and do not exhibit liquefaction potential apart from occasional thin layers of loose sand.

The potential for liquefaction induced ground damage will be strongly influenced by the groundwater table depth. As described above in Section 4.3, 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.

5.5.4 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 from 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	Estimated subsidence (mm) by area						
	Na:Nb	1	3	4	5	6	8
1 / 500	0 – 50	0 – 65	0 – 65	0 – 50	0 – 25	0 – 25	0 – 25
1 / 1,000	0 – 50	0 – 65	0 – 65	0 – 55	0 – 25	0 – 45	0 – 25
1 / 2,500	0 – 50	0 – 65	0 – 65	0 – 60	0 – 25	0 – 65	0 – 25

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 3 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. The effects of lateral spreading are likely to be most significant at the eastern end of this area, where the land is underlain by thicker deposits of liquefiable material and where watercourses run in close proximity to the northeastern and southern boundaries (Opawa River and Caseys Creek, respectively).

Areas 1 to 5

Liquefaction in these areas is not considered likely to cause significant lateral spreading given the thin deposits of liquefiable material and the flat terrain with only minor watercourses (shallow farm drains).

Area 6

Lateral spreading is likely to be a significant issue in Area 6, particularly along the southern boundary where up to 7.5 m of soft silt and clay soils are present adjacent to Old Fairhall Stream. Other watercourses such as Murphys Creek and Camerons Creek cross this area and may also present a lateral spreading risk, however these watercourses are shallower with only thin liquefiable deposits and so the potential ground damage is likely to be less significant.

Area 8

Lateral spreading is not considered to be a significant issue in Area 8, because of the flat ground with no significant watercourses in the vicinity.

6 Land Use Planning for Geotechnical and Earthquake Hazards

6.1 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 life			
	Building life 50 years	Infrastructure Life 100 years	Urban Growth Life 200 years	Urban Growth Life 500 years
1 / 500	10%	-	-	-
1 / 1,000	-	10%	-	-
1 / 2,500	-	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 period 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.

6.2 Poor Foundation Conditions

The thickness of soft and compressible silt and clay deposits present are generally less than 2 m deep, and locally up to 4 m deep. The geotechnical hazards due to poor ground conditions leading to poor foundation conditions and consolidation settlement (referred to in Section 5.1) can be addressed during construction by simple traditional foundation measures. Such measures may include preloading, undercut and replacement or the use of short piles founded below these soft layers.

6.3 Slope Failure

Slope failure is not a significant hazard and does not need special measures other than avoiding building on land very close to the banks of water courses.

6.4 Fault Rupture

As described above, the Wairau Fault has been inferred from available geological evidence to lie approximately 300 m to 400 m from Area 1 at its closest point (Geotech Consulting, 2003a; IGNS, 2000), although the fault trace is intermittent and subdued . Experience of the Greendale Fault rupture during the Darfield Earthquake shows ground damage can be sustained from fault rupture that does not form an obvious fault trace (Villamor *et al.*, 2012), which has important implications for land use planning and resilient infrastructure design.

Ground damage resulting from the rupture of the Greendale Fault comprised discrete shears and localised bulges, but predominantly horizontal dextral flexure. This deformation occurred over a zone up to 300 m wide. About a dozen buildings, mainly single-storey houses and farm sheds, were affected by rupture of the fault, but none collapsed, largely because most of the buildings were relatively flexible and resilient timber-framed structures and also because of the distributed nature of the deformation. Houses with only lightly-reinforced concrete slab foundations suffered moderate to severe structural and non-structural damage, whereas houses with robust concrete slab or shallow pile foundations performed more favourably (Van Dissen *et al.*, 2011).

Recent work by Geotech Consulting (2003a) maps the location of the fault to ±75 m accuracy further up the Wairau Valley, where the fault is located in bedrock terrain and forms an obvious and distinct trace. In the area northeast of Renwick, the fault trace has been buried or obscured by the young alluvial deposits, and as a consequence the fault trace location will have been mapped with less confidence. We recommend further geophysical and paleoseismic investigations be carried out to better constrain the fault's location in the area to the northeast of Renwick, and in particular in the immediate vicinity of the proposed urban growth areas.

Despite the uncertainty surrounding the Wairau Fault's location, the distance of the fault from the study areas suggests fault rupture could pose a ground damage hazard to the northwestern part of Area 1. Potential ground damage in Area 1 will be a function of the magnitude of surface rupture displacement and the width of the zone over which this displacement is accommodated. The nature of surface rupture at the northeastern end of the Wairau Fault is likely to be distributed, given the subdued nature of the fault trace, and therefore ground damage is likely to be relatively minor.

The Ministry for the Environment published guidelines on planning for development of land on, or near, active faults in 2003 (MfE, 2003). In these guidelines, the surface rupture hazard of an active fault is characterised by the location/complexity of surface rupture of the fault, and the activity of the fault, as measured by its average recurrence interval of surface rupture.

The Wairau Fault is a Class I active fault under the MfE guidelines, as it has an average recurrence interval of less than 2000 years (Table 1). Given the proximity of the fault to Area 1, the potential for fault rupture in the northwestern part of that area should be considered as part of any land re-zoning process. We recommend fault avoidance zones be developed for the Wairau Fault, and building control measures be incorporated into the land use policy to ensure any new structures are tolerant to potential ground deformation resulting from fault rupture.

6.5 Ground Shaking

Buildings are designed to withstand earthquake ground shaking, which is derived for each area of New Zealand. Therefore existing design standards cover the design of structures in these areas of Blenheim, and no special measures are considered to be required to be considered as part of land use planning.

6.6 Liquefaction-Induced Ground Damage

6.6.1 Ground Subsidence

There is potential for shallow liquefaction in much of the areas under consideration for urban growth land use re-zoning. Our assessment shows that the ground subsidence from the limited liquefaction is generally expected to be less than 70 mm. Differential subsidence across a building footprint will be smaller, say less than 40 mm.

The amounts of ground subsidence given above are not sufficient to warrant wholesale exclusions on development. One approach could be to exclude areas with an identified liquefaction potential from being zoned for development, however excluding land on this basis would also exclude much of the area in the vicinity of Blenheim.

An alternate pragmatic approach could be to allow development in these areas (except areas that are subject to lateral spreading as discussed below), but put in place planning rules to ensure that the development takes into consideration this low consequential subsidence from liquefaction.

Using the principle of resilience, a suitable approach will be to limit damage and / or build in a manner that any damage can be quickly and economically repaired and the building reinstated. For example, building foundations may be designed to protect the building from damage due to such limited subsidence by using short piles up to 5 m depth, or by use of foundations that are tolerant to limited subsidence and can be easily repaired after any event.

Services should also be designed with the potential for subsidence in mind, such as using flexible connections along pipelines that tolerate some ground deformation.

6.6.2 Lateral Spreading

Land susceptible to liquefaction and lateral spreading is prone to significant risks in earthquake events. Therefore, it would be prudent to not zone for intensive development the areas susceptible to lateral spreading, such as the northeastern part of Area Na:Nb and the southern part of Area 6. 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. Brabhaharan (2013) suggests approaches at three levels that can be considered to avoid lateral spreading hazards depending on the land use and the nature and extent of the hazard.

- Land Use Zoning – extensive hazardous areas can be avoided by zoning the land prone to those hazards for less intensive land use such as rural farming or parks.
- Town planning or Subdivision Planning – District Plan rules can stipulate that smaller extents of severe hazards, perhaps localised liquefaction lateral spreading or slope hazard from nearby hillside, can be mitigated by making use of these areas within a township or sub-division for open areas such as reserves, park lands or car parking with no buildings. A good example is the use of river flood prone areas within the stop banks in the Hutt City for car parking and mobile markets.
- Micro-siting – stipulate and encourage development to avoid areas of high hazard by micro-siting buildings in safer parts of land parcels, with more hazard prone areas used for open space or parking.

Given the limited nature of some of the areas of lateral spreading from liquefaction in the context of the wider area, some of the measures could be to stipulate areas prone to lateral spreading such as near the rivers as areas of high hazard where development is excluded, but the areas can be designated as reserves or used for less intensive land use.

The liquefaction hazard is generally low in the remaining areas (the central and western parts of Area Na:Nb, Areas 1-5, the northern part of Area 6, and Area 8). There is the potential for shallow liquefaction to occur, but this is not considered significant enough to preclude development of these areas. However, we recommend that measures be put in place through planning policy and development controls to ensure foundations for new developments can tolerate deflections imposed by liquefaction-induced ground subsidence.

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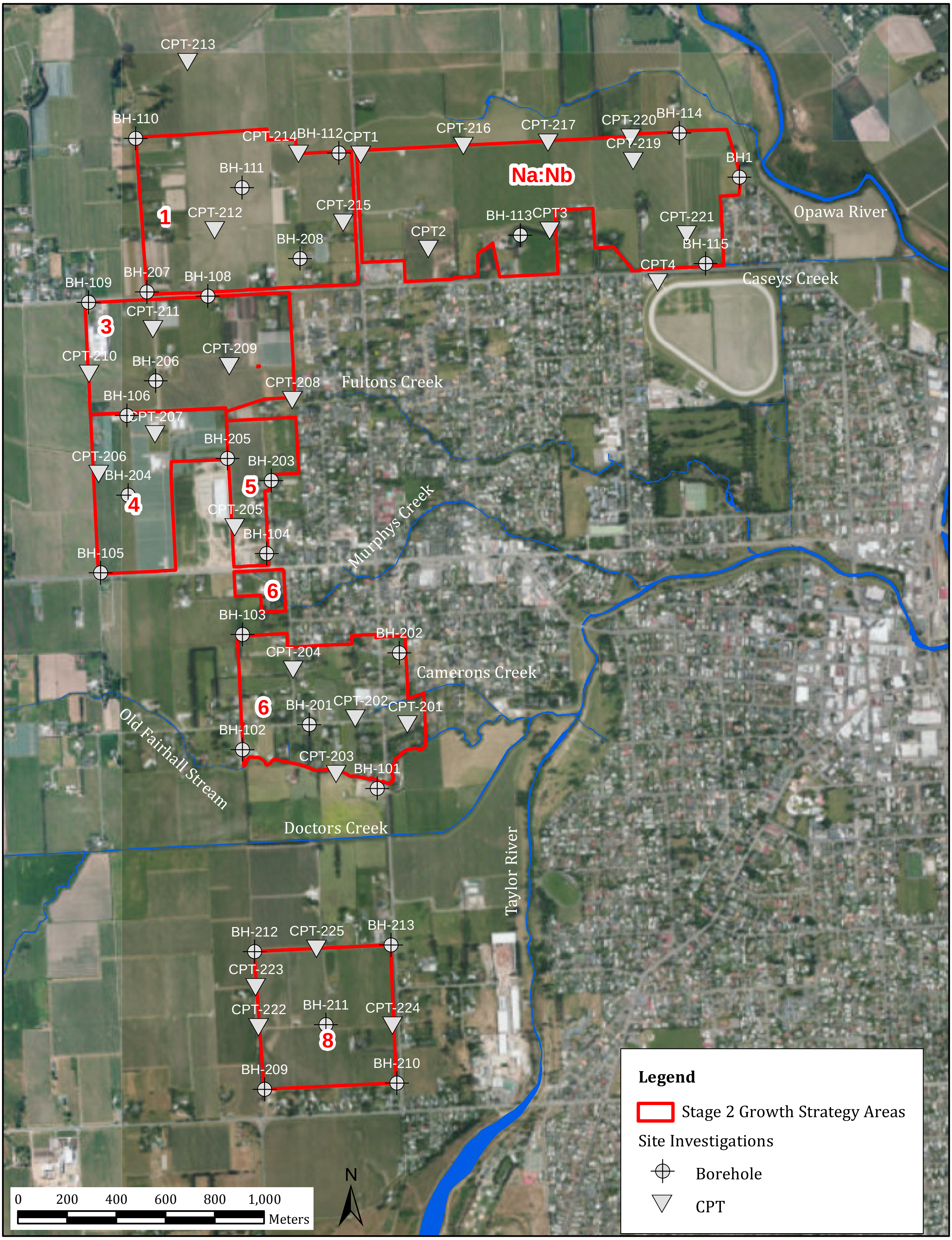
Figures



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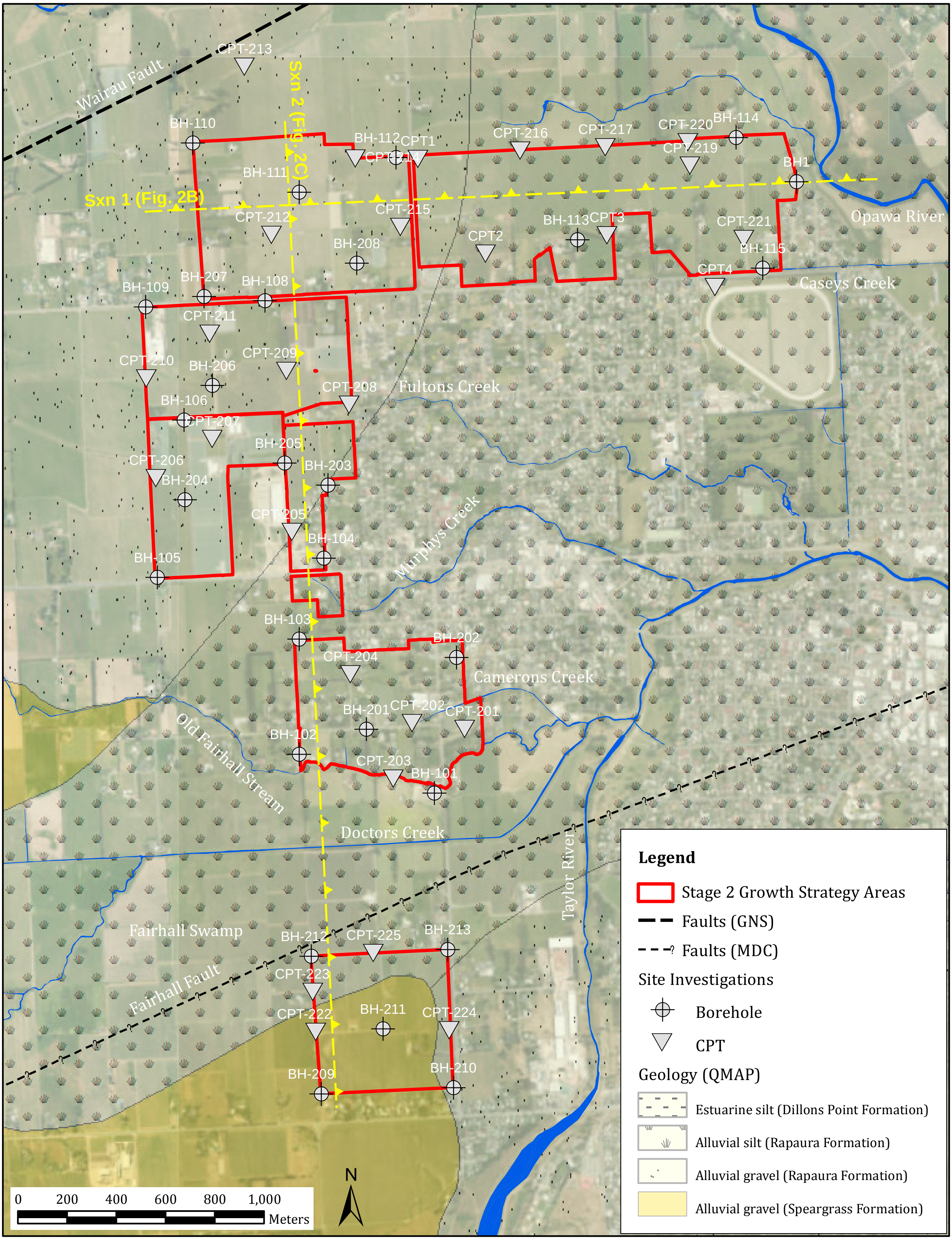
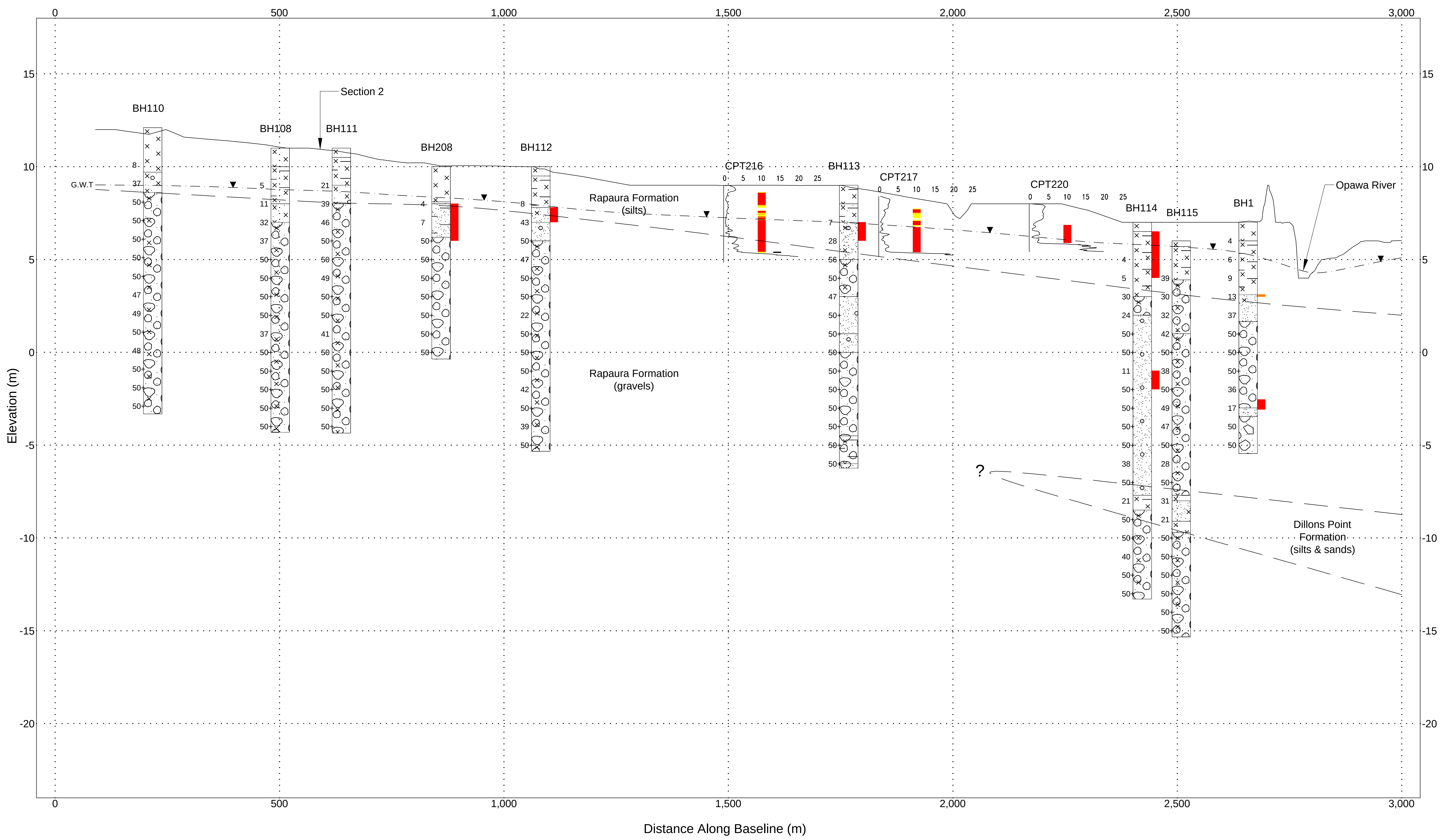
		Scale: 1:20,000	Date: Feb 2013	Project No: 5C2128.01	Figure: 1



Prepared For: MARLBOROUGH DISTRICT COUNCIL	*Prepared By:* OPUS	*Title:* Geological map & cross section locations
		Project: Blenheim Urban Growth Study Stage 2

Scale:	*Date:*	*Project No:*	*Figure:*
1:20,000	Feb 2013	5C2128.01	2A



Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

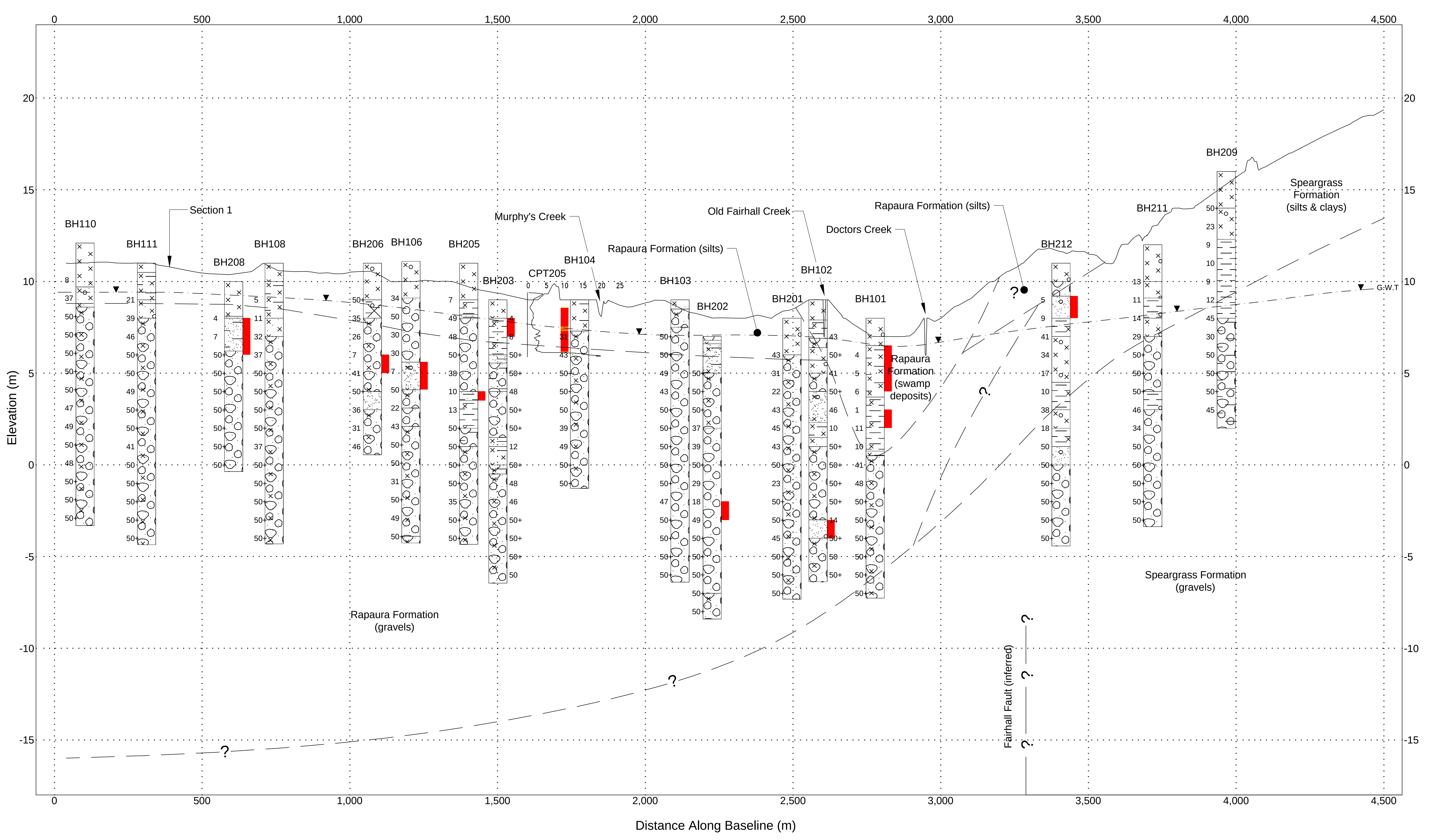
Lithological Graphics

- SILT
- SAND
- Sandy SILT some Gravel rounded/subrounded gravel
- Clayey SILT
- Sandy GRAVEL
- Gravelly sandy SILT angular/subangular
- Silty SAND
- Sandy SILT
- Gravelly SAND
- Sandy GRAVEL
- Sandy Silty GRAVEL
- Silt with some Clay
- Formation Boundary
- Ground Water Table

Return Period Event Liquefaction

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

Title:		
Figure 2B Cross Section 1		
Project: Blenheim Urban Growth Study Stage 2		
Vertical Scale: 1:200 (A3)	Date: 22/02/2013	Project: 5C2128.01



Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

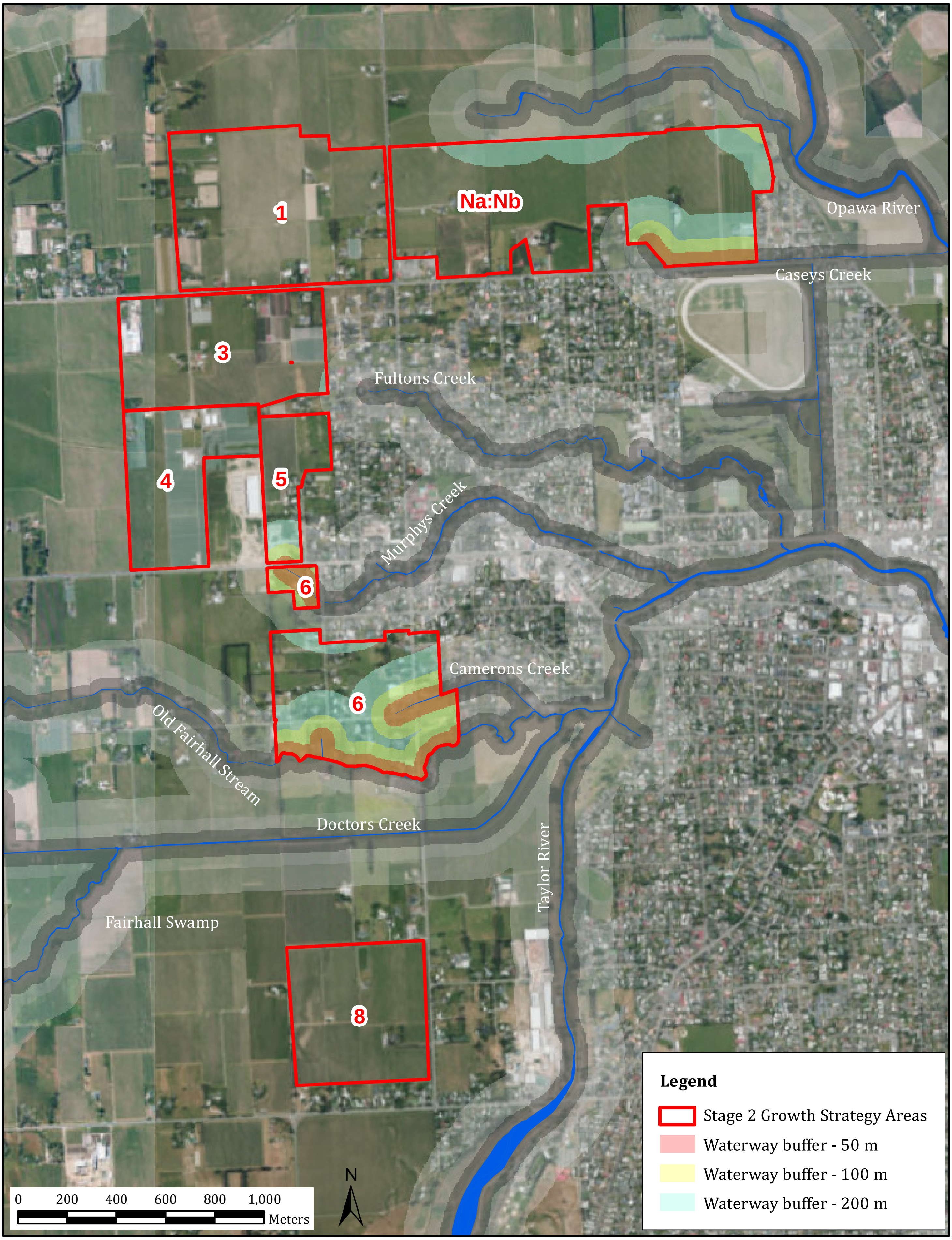
Lithological Graphics

- Silt with some Gravel. Rounded / subrounded gravel
- Sandy Silty GRAVEL
- Silty SAND some gravel rounded/subrounded gravel
- Clayey SILT
- Silt
- Clayey Silt with some sand
- Silty CLAY
- Silty GRAVEL
- SAND with some Gravel. Rounded / subrounded gravel
- Clayey SILT some gravel some sand angular/subangular
- Gravelly sandy SILT angular/subangular
- Silt with some Sand
- Formation Boundary
- Ground Water Table

Return Period Event Liquefaction

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

Title:		Figure 2C Cross Section 2
Project:		Blenheim Urban Growth Study Stage 2
Vertical Scale: 1:200 (A3)	Date: 22/02/2013	Project: 5C2128.01



Prepared For:	Prepared By:	Title: Site areas and proximity of waterways
MARLBOROUGH DISTRICT COUNCIL	OPUS	Project: Blenheim Urban Growth Study Stage 2

Scale:	Date:	Project No:	Figure:
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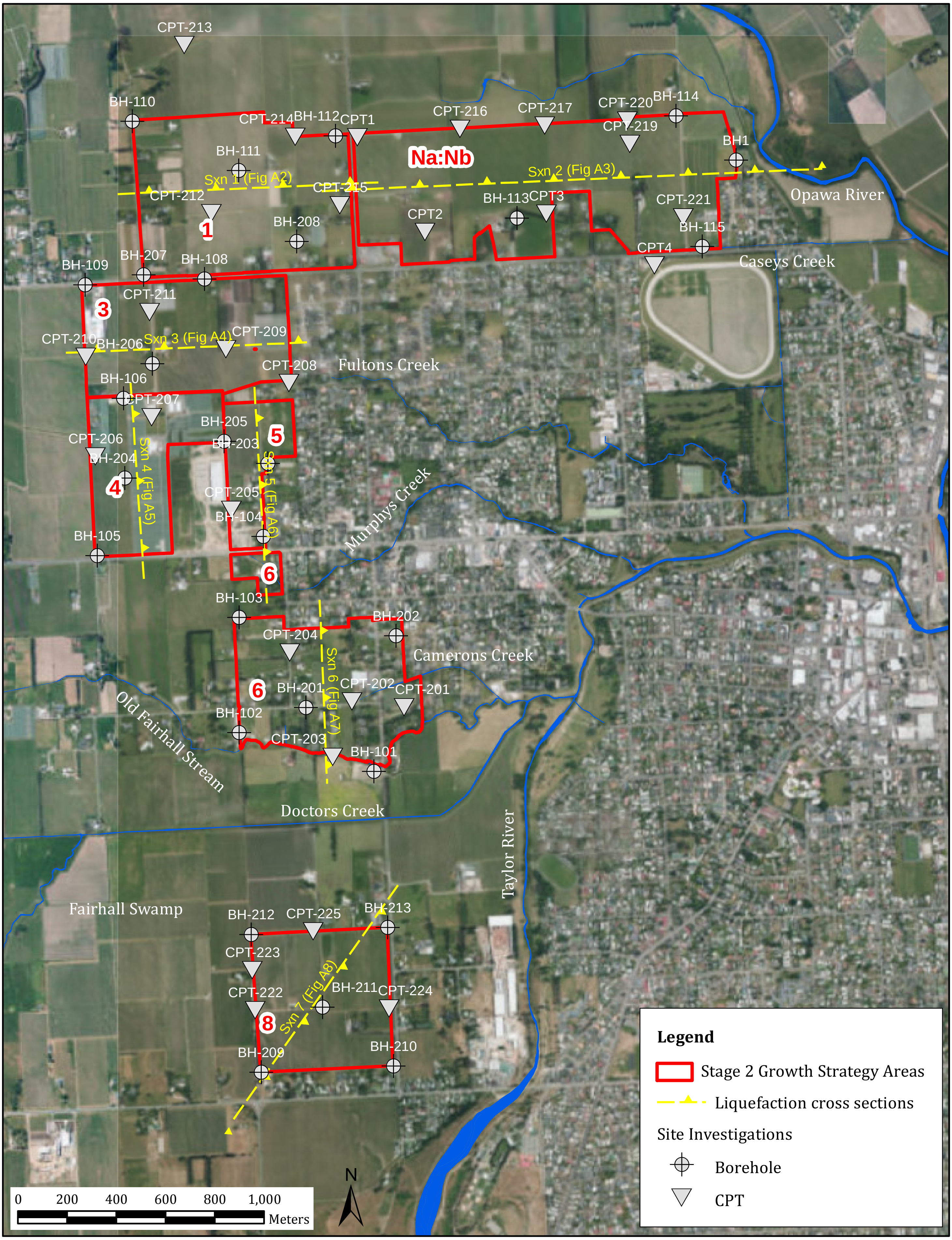
Appendix A

Liquefaction susceptibility cross sections



Prepared For:	Prepared By:	Title: Liquefaction cross section locations			
MARLBOROUGH DISTRICT COUNCIL	OPUS	Project: Blenheim Urban Growth Study Stage 2			
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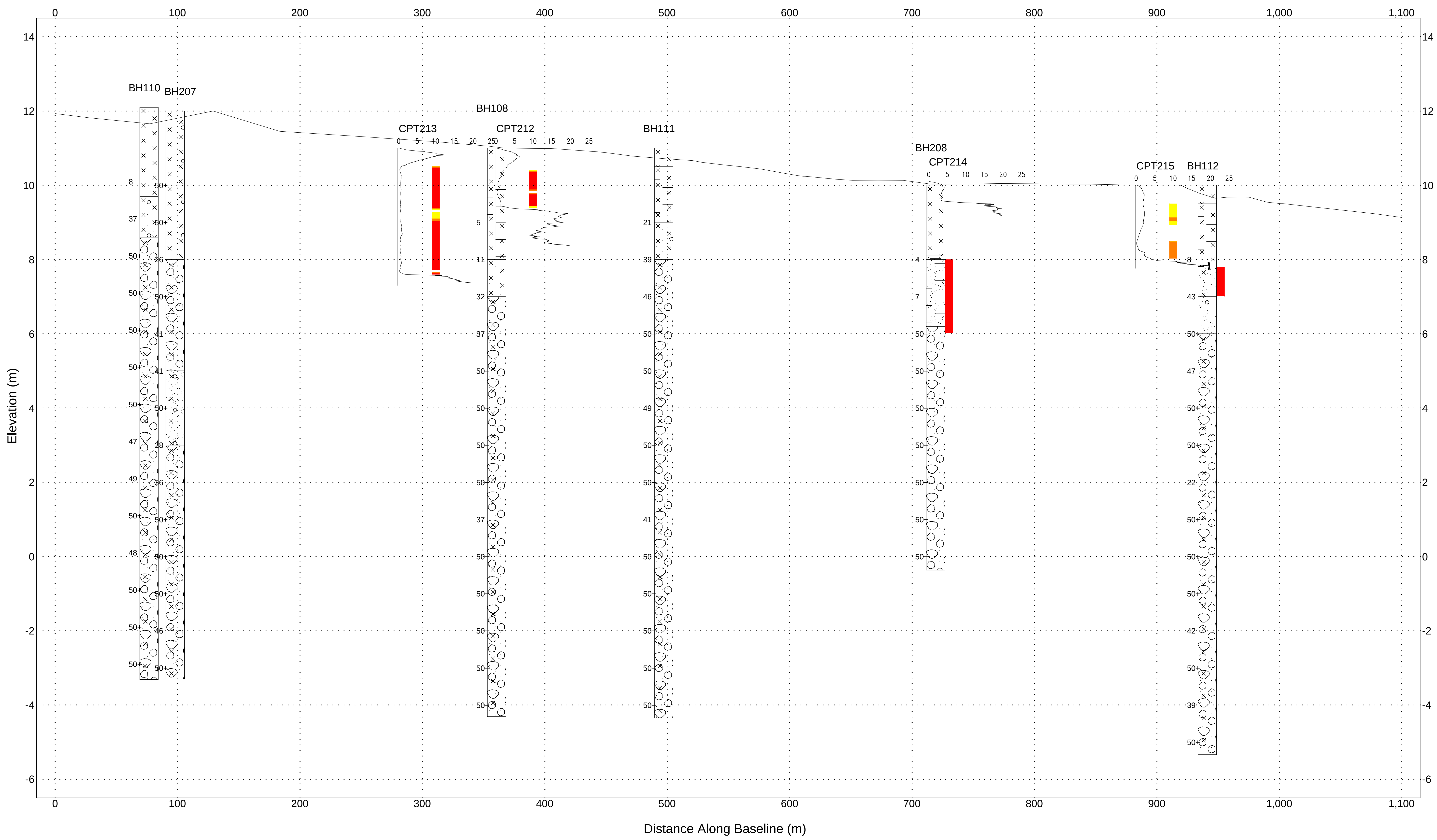


Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

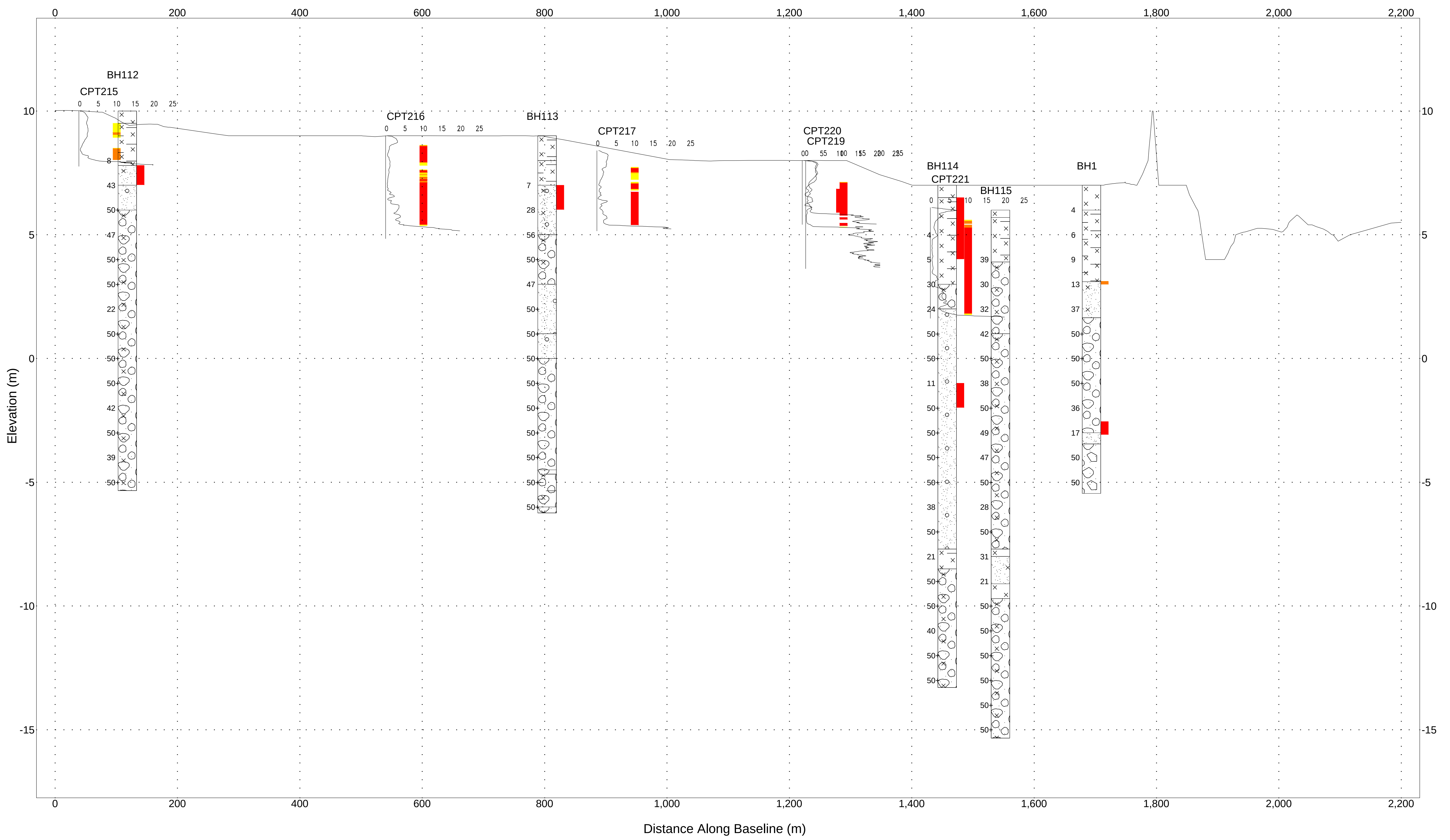
Lithological Graphics

- SILT
- Clayey SILT
- Sandy SILT
- Sandy Silty GRAVEL
- Sandy SILT some Gravel rounded/subrounded gravel
- Gravelly sandy SILT angular/subangular
- Silty SAND
- Gravelly SAND
- Silt with some Gravel. Rounded / subrounded gravel
- Gravelly SAND. Rounded / subrounded gravel
- Sandy CLAY
- Clayey SAND

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 1			
Project: Blenheim Urban Growth Study Stage 2			
Vertical Scale: 1:100	Date: 24/02/2013	Project: 5C2128.01	Figure: A2



Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

Lithological Graphics

SILT	Clayey SILT	Silty SAND	Sandy GRAVEL
SAND	Sandy GRAVEL	Gravelly SAND	Sandy Silty GRAVEL
Silt with some Clay	Clayey sandy Silt	Silty SAND some gravel rounded / subrounded gravel	SAND with some Gravel. Rounded / subrounded gravel

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 2

Project: Blenheim Urban Growth Study Stage 2

Vertical Scale:	Date:	Project:	Figure:
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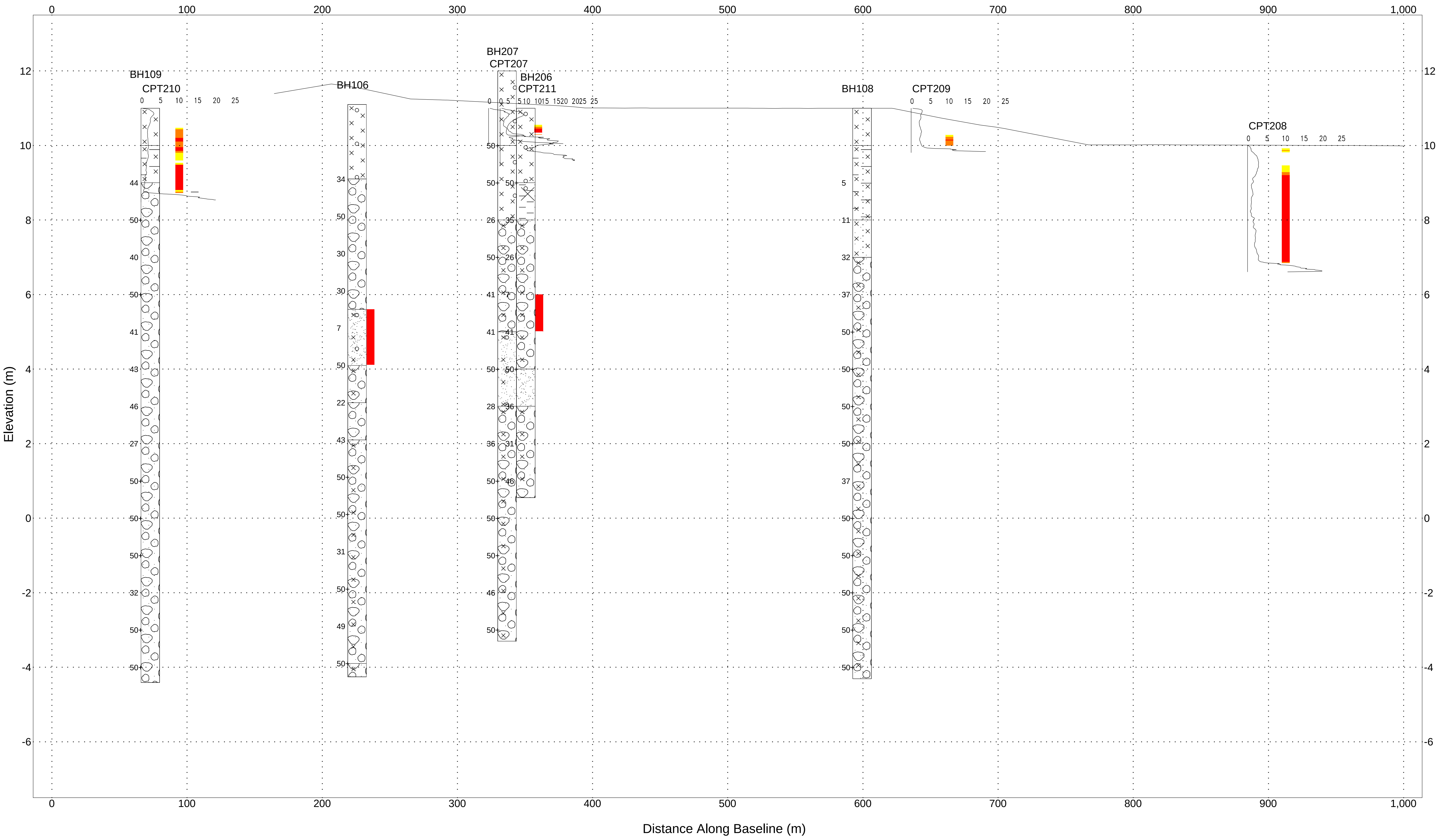


Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

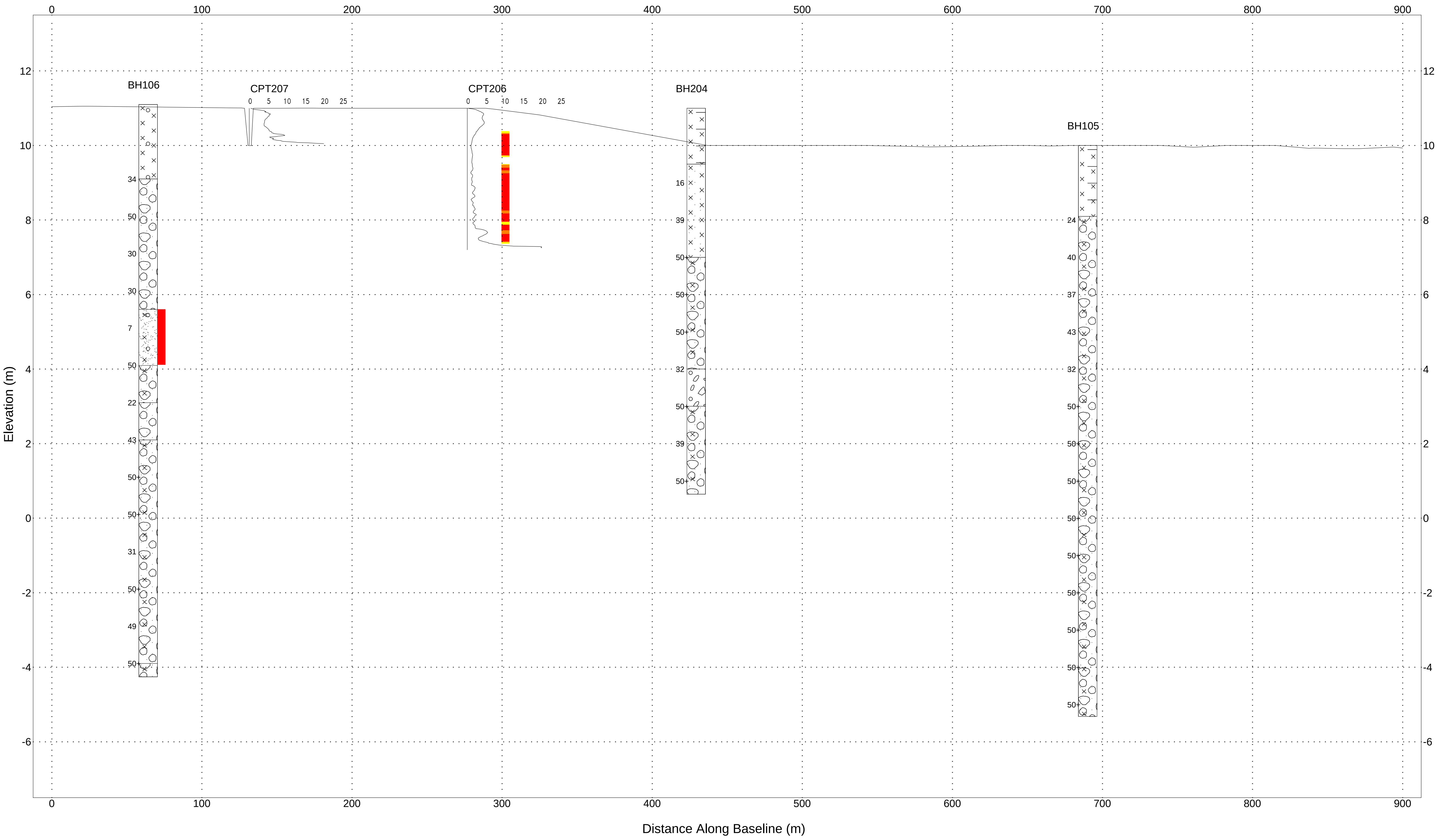
Lithological Graphics

- Gravelly SILT
- SILT
- Clayey Gravelly Silt. Rounded / subrounded gravel
- Sandy GRAVEL
- Clayey SILT
- SAND
- Silty SAND some gravel rounded/subrounded gravel
- Sandy SILT
- Silt with some Gravel. Rounded / subrounded gravel
- Sandy Silty GRAVEL
- Gravelly Silt
- Gravelly SAND. Rounded / subrounded gravel

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 3			
Project: Blenheim Urban Growth Study Stage 2			
Vertical Scale: 1:100	Date: 24/02/2013	Project: 5C2128.01	Figure: A4



Prepared for:

MARLBOROUGH DISTRICT COUNCIL

Prepared by:

OPUS

Legend:

Lithological Graphics

- Silt with some Clay
- Silty SAND some gravel rounded / subrounded gravel
- Sandy Silty GRAVEL
- Sandy SILT
- Gravelly SILT
- Gravel
- Sandy GRAVEL

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 4

Project: Blenheim Urban Growth Study Stage 2

Vertical Scale:	Date:	Project:	Figure:
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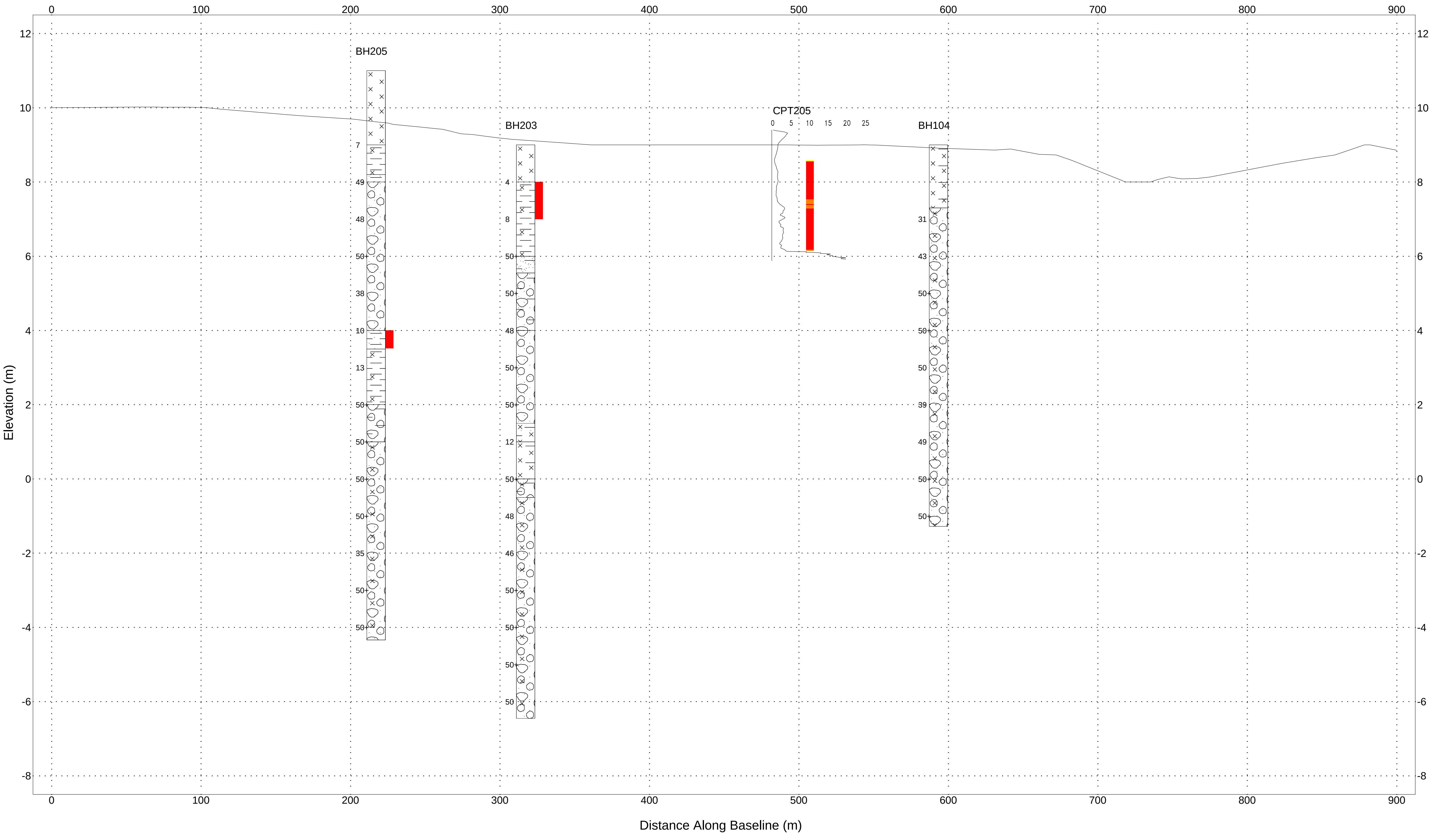

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Legend:

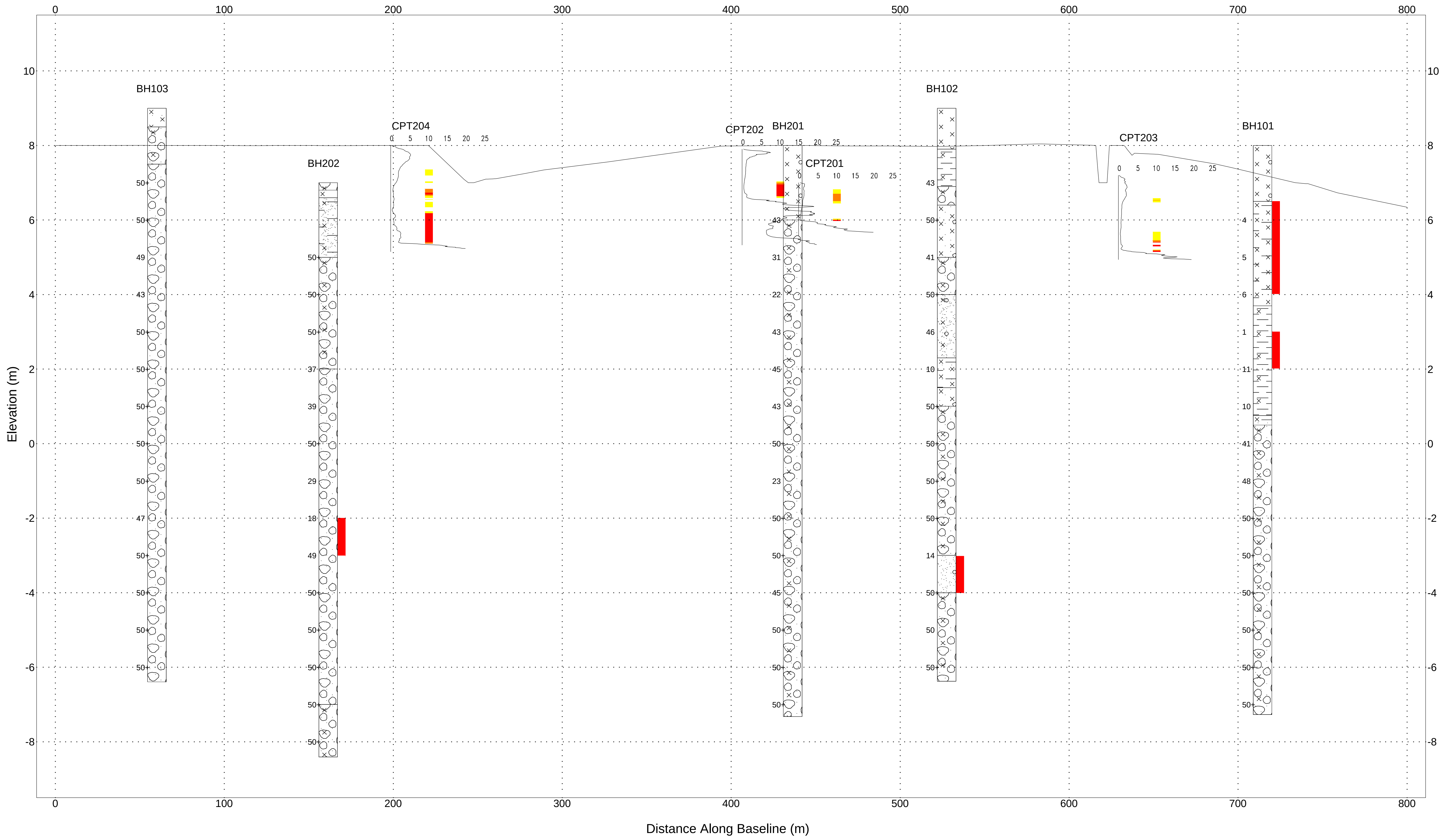
Lithological Graphics

- Silt with some Clay
- Clayey SAND
- Silty Clayey GRAVEL. Rounded / subrounded gravel
- Sandy Silty GRAVEL
- Clayey Sandy GRAVEL. Rounded / subrounded gravel
- Sandy CLAY
- SILT
- Sandy GRAVEL
- Clayey GRAVEL
- Silty CLAY
- Clayey Silt with some sand

Return Period Event Liquefaction

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

Title:			
Liquefaction Susceptibility Cross Section 5			
Project: Blenheim Urban Growth Study Stage 2			
Vertical Scale: 1:100	Date: 24/02/2013	Project: 5C2128.01	Figure: A6



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Legend:

Lithological Graphics

Silt with some Gravel. Rounded / subrounded gravel	Clayey SILT	Silty CLAY	Clayey SILT some gravel some sand angular/subangular
Sandy Silty GRAVEL	Silt	Silty GRAVEL	Gravelly sandy SILT angular/subangular
Silty SAND some gravel rounded / subrounded gravel	Clayey Silt with some sand	SAND with some Gravel. Rounded / subrounded gravel	Silt with some Sand

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 6

Project: Blenheim Urban Growth Study Stage 2

Vertical Scale:	Date:	Project:	Figure:
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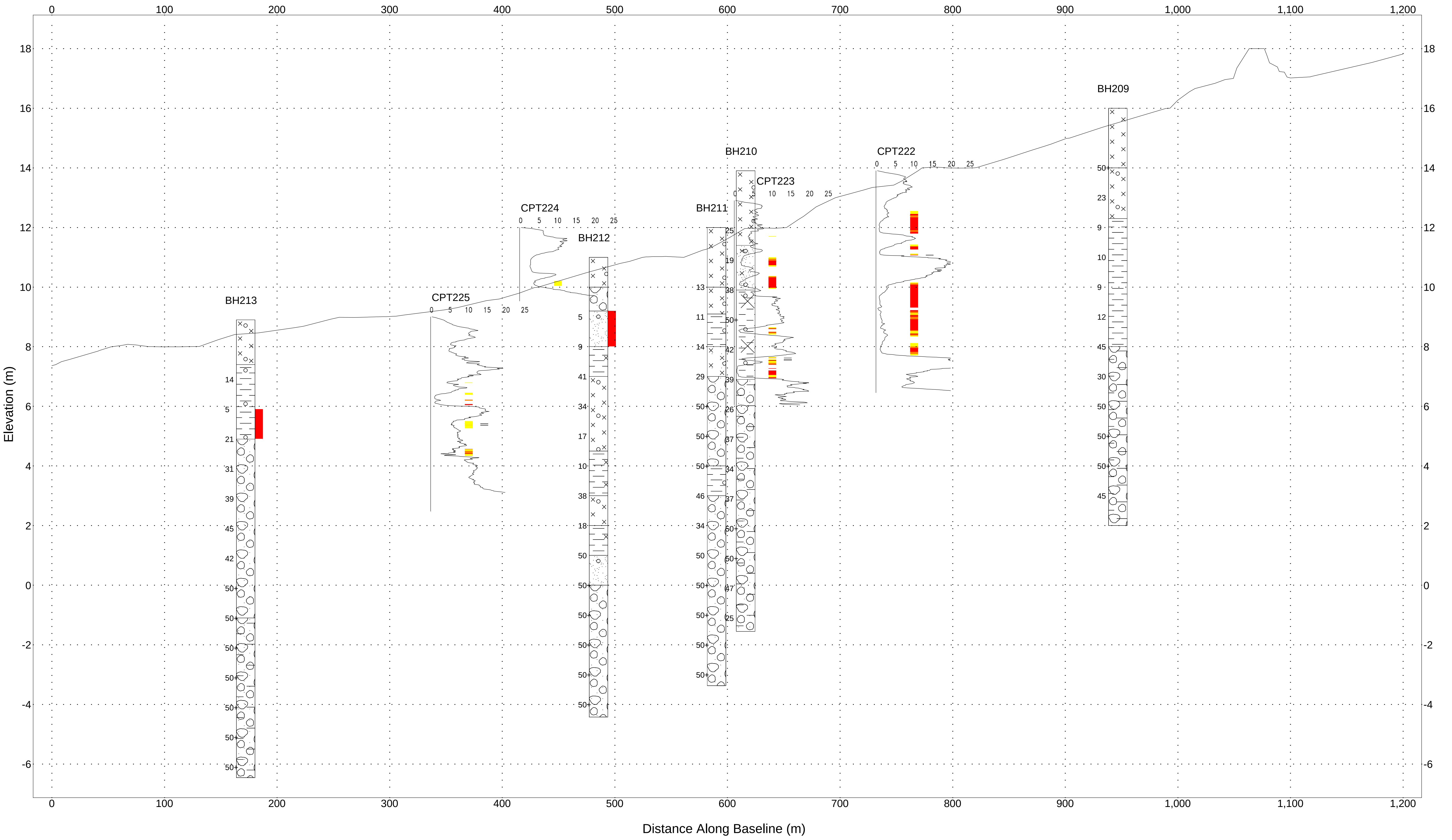

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Prepared by:

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Legend:

Lithological Graphics

SILT	Gravelly SILT	CLAY	Clayey GRAVEL
Silt with some Gravel. Rounded / subrounded gravel	Gravelly Silty SAND. (Angular / subangular gravel)	Clayey Gravelly Silt. Rounded / subrounded gravel	Clayey Sandy GRAVEL. Rounded / subrounded gravel
Clay with some Gravel. Rounded / subrounded gravel	SILT some gravel some sand angular / subangular	Sandy GRAVEL	Gravelly SAND

Return Period Event Liquefaction

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

Title: Liquefaction Susceptibility Cross Section 7

Project: Blenheim Urban Growth Study Stage 2

Vertical Scale:	Date:	Project:	Figure:
1:125	24/02/2013	5C2128.01	A8

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