REPORT

Auckland Council

Geotechnical Desk Study
North and North-West Auckland Rural Urban Boundary Project

Report prepared for:

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1 Introduction

1.1 General

Tonkin & Taylor Ltd (T&T) was engaged by Auckland Council (AC) to undertake a concept level geotechnical desk study assessment for the Rural Urban Boundary (RUB) Project in North and Northwest Auckland. The scope and extent of our engagement is outlined in the T&T proposal dated 3 May 2013[1].

The objective of the desk study assessment was to evaluate the suitability of rural/greenfield land in North and North-West Auckland for future urban development and to identify possible geotechnical constraints that could impact on the viability of development. Specifically the report is intended to provide the following:

i. A summary of the typical subsurface conditions (site stratigraphy) likely to be encountered within each investigation area;

ii. An overview assessment of site stability;

iii. Preliminary recommendations around geotechnical risks/constraints relating to earthworks, foundations and infrastructure within each investigation area;

iv. Preliminary assessment of liquefaction potential (under seismic conditions) for each area; and

v. Concept level advice on the geotechnical suitability of each area for future urban development including an appraisal on the relative viability of development between the different areas.

The conclusions and recommendations presented in this report are a guide only and are based on published geological maps, our past experience on projects in the region and limited historical geotechnical investigations undertaken within each of the proposed investigation areas. Site specific geotechnical investigations comprising machine boreholes, cone penetrometer tests and laboratory testing will be required to refine and confirm the conclusions presented in this report and for detailed planning and consenting purposes.

The investigation area boundaries discussed in this report and presented in associated figures were provided by AC. This study focuses exclusively on the land defined within these boundaries. We understand that the boundaries could change as the RUB is further developed, in which case further assessment of areas not covered in this study would be required.

1.2 Project background

The RUB project has been established to identify suitable rural/greenfield areas for future urban development. It is expected that up to 35,000 new dwellings will be required in the North and Northwest Auckland cluster to accommodate the projected population growth of Auckland City over the next 30 years[2]. The RUB is defined in the Draft Auckland Unitary Plan as "a Rural Urban Boundary that will define the maximum extent of urban development to 2040 in the form of a permanent rural-urban interface".

The challenge identified by AC is to determine a robust RUB that provides the required space for growth whilst upholding other desired outcomes relating to environment, community, heritage etc. It is intended that the final RUB will be incorporated into Auckland Council's Unitary Plan (the

[1] Tonkin & Taylor Ltd Proposal: *Proposal to Provide Geotechnical Consultancy Services: Rural Urban Boundary Project: Northern and Northwest Clusters*, Ref 29129.001, dated 03 May 2013.
[2] Auckland Council. 2013: *Auckland Plan Committee, Auckland Unitary Plan Addendum*, dated 25 February 2013.

plan which determines how Auckland will develop over the next 30 years). Three main regions have been identified for the North and Northwest cluster areas. These are as follows:

i. **Kumeu- Whenuapai** (Northwest cluster): Including areas defined as Kumeu Huapai, Greenfield Investigation Areas, Future Business, Red Hills, Red Hills North, Brigham Creek, Riverhead and Scott Point.

ii. **Warkworth** (North cluster): Including areas defined as Warkworth, Warkworth South, Warkworth North and East, Future Business and Hepburn Creek.

iii. **Silverdale** (North cluster): Including areas defined as Wainui East, Silverdale West Business, Silverdale West, Okura/Weiti and Dairy Flat.

A detailed description of each investigation area is provided in Section 2 and the extents of the investigation areas are presented on Figures 1-3 in Appendix A. The three development scenarios (outlined above) are summarised in Figures A to C.

1.3 Scope

The scope of works for this desk study assessment has included the following in general accordance with our proposal dated 03 May 2013[1]:

- Review of published geological maps for the area;
- Review of T&T's in-house geotechnical database of the areas and generic appraisal of previous geotechnical investigation data;
- Review of any Council supplied geotechnical investigation data;
- Preparation of geological map for the Northern and Northwest 'clusters' showing the extents of various different types of soils/rock;
- Preparation of a series of geotechnical hazard maps illustrating areas that are subject to hazards and will be more costly to develop relative to other areas;
- Preparation of figures illustrating the assessed 'premium' of developing land due to specific geotechnical constraints, qualified as 'low', 'medium' or 'high';
- A preliminary assessment of the liquefaction hazard for the areas based on geological maps and Cone Penetrometer Tests (CPT's) performed on North and North-West Auckland sites with similar soil conditions to those present within the investigation areas; and
- Preparation of this report.

The locations of all relevant geotechnical projects used to prepare this desk study assessment are presented on Figures 1-3 in Appendix A.

2 Site Descriptions

2.1 Kumeu-Whenuapai Investigation Areas

2.1.1 Kumeu Huapai

The Kumeu Huapai investigation area is located predominantly to the south and west of the current Kumeu and Huapai township centres (refer to Figure 1 in Appendix A). The proposed investigation area primarily extends south from the existing Kumeu/Huapai urban areas, beyond the SH16 arterial route, and as far as the present Hanham Road. The investigation area also outspreads west by approximately 2 kilometres from the existing Huapai township. Major transport facilities including SH16 and the North Auckland Rail Line dissect the proposed investigation area.

The Kumeu Huapai development covers an area of approximately 1490 ha. The site topography over the investigation area is variable, with typical elevations ranging between 25 and 35 m RL in the centre to east regions, near low lying floodplains. Along the west and south boundary of the area, however, elevations range from 50 m RL up to 100 m RL where the topography becomes more steeply inclined.

2.1.2 Red Hills and Red Hills North

The Red Hills and Red Hills North investigation areas are located south east of the present Kumeu township and bound by SH16 at the north boundary and the North Auckland Rail Line along the western boundary (see Figure 1 in Appendix A). The area extends from SH16 south encompassing Taupaki, and spreads as far south and west as Massey West. The Kumeu River and Pakinui Stream dissect the western boundary of the investigation area in a north/south direction, while the Takitaki Stream extends through the centre of the investigation area again in a north/south direction. Major transport infrastructure includes SH16 and the North Auckland Rail Line.

The combined Red Hills and Red Hills North area occupies approximately 2200 ha. The typical topographical elevation profile for the western region of the proposed area ranges from 25 m RL to 40 m RL. Where the Takitaki stream dissects the investigation area, the elevations lower to between approximately 10 m RL and 22 m RL. The south region steepens towards the top of the stream catchment, encompassing the highest elevations, between 50 m RL and 100 m RL.

2.1.3 Future Business

The Future Business investigation areas are split, with the greatest proportion of the proposed investigation area in the region of (but not including) the Whenuapai airbase (see Figure 1 in Appendix A). The development extends west, where it is bound by SH16 and also to the south by West Harbour. The east of the region is confined by the Waiarohia Inlet, while the north follows Punga Road, through to Dale road. There is an absence of major waterways within the investigation area, aside from a small tributary associated with Brigham Creek towards the west of the proposed region. Two other smaller regions of Future Business are located adjacent to the current Kumeu town centre and the eastern boundary of the Kumeu Huapai investigation area. Major transport infrastructure to the regions is primarily from SH16, however the Upper Harbour Highway also presents a major arterial route for the Future Business sector.

The combined Future Business proposal areas encompass approximately 1100 ha. The majority of the surface topography is relatively uniform, with elevations ranging between approximately RL 20 m to RL 35 m Around the coastal fringes the typical elevation is between 10 m RL and 20 m RL while the elevation at the south of the investigation area increases to between 40 m RL to 60 m RL.

2.1.4 Scott Point

The Scott Point investigation area is an isolated region on the west flank of the North West RUB options. The area is bound around the south perimeter by the Waitemata Harbour (see Figure 1 in Appendix A). There is an absence of any major watercourses through the investigation area. The topography of the area is relatively uniform and low lying with elevations between approximately 9 m RL and 16 m RL. The south east to south west perimeter is typically gently sloped with the exception of the coastal fringe, where more steeply graded coastal cliffs are often apparent.

The proposed investigation area of Scott Point covers an approximate area of 130 ha. At present the area use is currently split between residential and commercial property and open pasture land.

2.1.5 Greenfield Investigation Areas

The Greenfield Investigation areas comprise several regions including North Kumeu, north, east and west Riverhead, and the north, west and eastern coastal areas of the Brigham Creek investigation area. The investigation area extends to Huapai in the west and to the Waiarohia Inlet Waitemata Harbour to the east. Major transport routes that extend through the area include SH1 which borders the Greenfield Investigation Area and the Kumeu/Huapai, Future Business and Red Hills North investigation areas. This investigation area is relatively large in comparison with others in the North West RUB, with an approximate land area of 2,240 ha.

The site topography over the area is variable, with typical elevations ranging between 20 to 35 m RL in the mid to north of the North Kumeu region. However the northern most region does become more steeply inclined with elevations increasing to 50 to 105 m RL. The areas to the north and west of Riverhead are typically flat to gently sloping with elevations varying between 17 to 30 m RL and lower lying regions near the river valleys. Typically the sites are gently sloping with some regions of higher surface relief north of Kumeu. The present land use in these investigation areas varies between residential, commercial, and horticultural.

2.1.6 Riverhead

The Riverhead investigation area is located primarily south of the current Riverhead Township, while incorporating the township (see Figure 1 in Appendix A). The proposed area is bound to the east by the Rangitopuni Stream, while the west side is bound by the Coatesville-Riverhead Highway, which also provides the main access to the area. The investigation area is the smallest of the North West RUB areas at approximately 125 ha. The area is currently occupied by residential lots and commercial properties.

The surface topography of the investigation area is typically flat lying, with elevations varying between 25 m RL and 30 m RL gently sloping downwards towards the north. Gully features are presented at the eastern end of the study areas, with lower elevations ranging between 10 m RL to 15 m RL.

2.1.7 Brigham Creek

The Brigham Creek area extends over three regions north, north east and north west of the present Whenuapai suburb (see Figure 1 in Appendix A). Brigham Creek West is located immediately south of the Riverhead investigation area, where it is bound by SH16 and Brigham Creek. The investigation area immediately north of Whenuapai borders the coastline between Whenuapai and the Waitemata Harbour. Several creeks and inlets protrude inland from the harbour, where mangroves tend to dominate the area. The east Brigham Creek investigation area encompasses the land between the northern side of the highway and the Waitemata Harbour. The area extends as far west as the inner reach of the Waiarohia inlet.

The collective land coverage of the Brigham Creek investigation area is approximately 550 ha. The site topography is typically level around the north and east Brigham Creek investigation areas and the coastal fringe of the west investigation area, with elevations between approximately 10 m RL and 20 m RL. Towards the western boundary of Brigham Creek west, the elevation rises slightly to between 25 m RL and 40 m RL. As a whole the Brigham Creek area is typically gently graded towards the tidal inlets and the interface with the Waitemata Harbour. The land use in all areas varies between residential lots/lifestyle blocks, commercial properties and horticultural sites.

2.2 Warkworth Investigation Areas

2.2.1 Warkworth North and East

The Warkworth North and East investigation area is positioned immediately north of the present Warkworth township and extends east towards Snells Beach (Figure 2 in Appendix A). The south east portion of the investigation area is bound by the Mahurangi River while the northern extent is bound by Matakana Road. Several small streams and creeks run through the area and discharge into the Mahurangi River. SH1 would provide the primary transport routes into the area.

The land coverage of the investigation area is approximately 3100 ha. The surface topography is typically rolling to moderately sloping, with elevations ranging from RL 35 m to 90 m RL with local lower elevations within gullies and at the coastal fringes.

2.2.2 Warkworth, Warkworth South and Future Business

The Warkworth, Warkworth South and Future Business areas encompass the current Warkworth town centre and an area to the south of the present town (Figure 2 in Appendix A). The northern boundary of the Warkworth investigation area is bound by the Mahurangi River which also dissects the area. The Warkworth South area is bound to the north by the Warkworth and Warkworth North and East investigation areas. The Future Business investigation area is situated between Warkworth North and East and the Warkworth investigation area. SH1 dissects through all investigation areas and provides the major transport infrastructure for the region.

The topography varies between the moderate surface relief in the Warkworth investigation area to more steeply inclined relief in Warkworth South. Surface elevations in the Warkworth area vary between 20 m RL and 80 m RL, while in Warkworth South, elevations typically range between 25 m RL and 90 m RL. The Future Business region has typical elevations between 20 m RL to 30 m RL in the east, rising up to approximately 40 m RL in the west of the area. The three investigation areas have a combined coverage of approximately 1140 ha.

2.2.3 Hepburn Creek

The Hepburn Creek investigation area extends south east of the Warkworth area and is bound by the Mahurangi River to the north. The area is serviced by local roads adjoining SH1 and the Warkworth Township. The area is dissected by several small runoff creeks and tributaries of the Mahurangi River.

The surface topography is variable with some steeply inclined hill areas and low lying areas around the coastal fringe. Typical elevations range between 15 m RL at the coast to 60 m RL further inland. The total investigation area occupies approximately 85 ha.

2.3 Silverdale Investigation Areas

2.3.1 Wainui East

The Wainui East investigation area is located to the west of the present Silverdale town centre and extends north to Weranui Road (see Figure 3 in Appendix A). The investigation area is bound to the east by SH1 which also provides the primary arterial transport route to the area. The area is dissected by the Orewa River which exits from the eastern boundary.

The topography of the area is variable between low lying areas adjacent to gullied/creek areas and more steeply inclined regions. Typical elevations range between 25 m RL and 40 m RL for the central to south portions of the region, while to the north elevations range from 40 m RL to 100 m RL. The Wainui East proposed investigation area comprises a total land area of approximately 1000 ha.

2.3.2 Silverdale West and Silverdale West Business

The Silverdale West and West Business areas are adjoined to the south perimeter of the Wainui East development region (Figure 3 in Appendix A). The investigation area extends south incorporating Pine Valley, and spreads to the present Dairy Flat locality. SH1 borders the eastern perimeter of the Silverdale West Business area, which along with the Dairy Flat Highway provides the main transport routes through the proposed areas. The combined land area is approximately 1200 ha and at present is primarily occupied by residential lots.

The surface topography of the region does not vary greatly over large portions of the Silverdale West Business region with typical elevations between 20 m RL and 30 m RL with occasional areas of higher elevation. The Silverdale West region displays greater elevation changes between 30 m RL and 100 m RL, with some moderate to steeply inclined sloping areas.

2.3.3 Dairy Flat

The Dairy Flat region comprises the area south of the Silverdale West Business investigation area through to Coatesville (Figure 3 in Appendix A). The region is bound by SH1 to the east which provides the main arterial route to the Dairy Flat area. The proposed investigation area incorporates approximately 3200 ha. There are no major watercourses that flow through the area.

The surface topography is typically flat lying, with elevations varying subtly between approximately 50 m RL and 65 m RL, with slightly lower elevations near the south of the area. The current land use is typically pastoral land and lifestyle blocks.

2.3.4 Okura/Weiti

The proposed Okura/Weiti investigation area is positioned north of the present Okura urban settlement, throughout the Okura Bush region and incorporates the Stillwater urban development (Figure 3 in Appendix A). The site is bound on the western edge by SH1 and on the north, south and eastern perimeters by the Weiti River/Hauraki Gulf. Primary transport routes within the investigation area include SH1, and the proposed Whangaparaoa Peninsula Link route (Penlink) which is projected to dissect the investigation area when completed.

The surface topography varies across the majority of the region, with typical elevations ranging between 25 m RL and 100 m RL. The area has some high sloping surface relief particularly to the south and south east of the region. The current land use varies between urban development, residential lifestyle blocks, scenic reserve and rural farm land.

3 Geological Overview

3.1 Published geology

The surface geology of the North and North-West Auckland RUB investigation areas are presented as Figures A-C below (detailed descriptions of the different geological units present across the areas are presented in the following sections). The areas labelled 'Q1a' are underlain by Tauranga Group Holocene Age alluvial soils and areas labelled 'Pup' are underlain by Tauranga Group Puketoka Formation soils (Pleistocene Age). The Mahurangi Limestone is labelled 'Omm' and is recognised as a geological formation within the Northland Allochthon. Other materials grouped within the Northern Allochthon in the Silverdale and Warkworth investigation areas include the Puriri Mudstone ('Omp') and Hukerenui Mudstone ('Kkh') and Whangai Formation ('Kkw'). The Waitemata Group (Mwe, Mwy, Mwc) is dominant in many areas and comprises volcaniclastic sandstone and mudstone. A more comprehensive illustration of the geology of North and North-West Auckland is presented on Figures 4-13 in Appendix A.

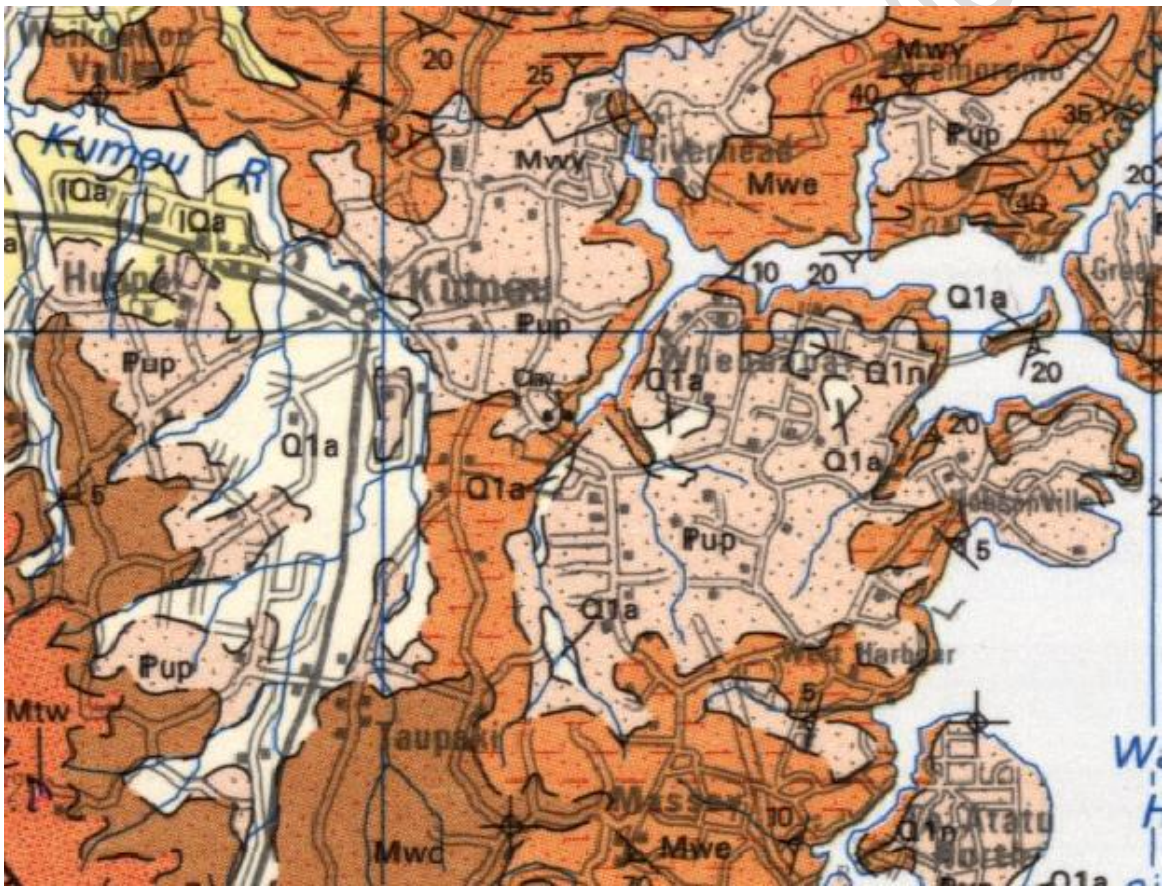

Figure A: Regional Geology Kumeu- Whenuapai investigation areas (Not to Scale)[3]

[3] Edbrooke, S.W (compiler) 2001: Geology of the Auckland Area. Institute of Geological & Nuclear Sciences 1:250,000 geological map3 1 sheet+74p Lower Hutt New Zealand, Institute of Geological & Nuclear Sciences Limited

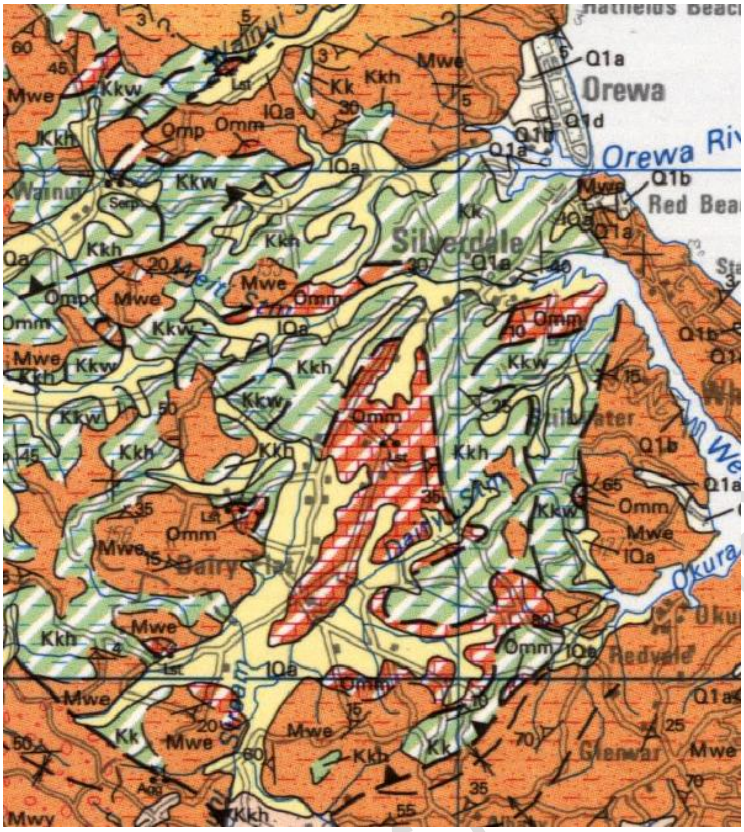

Figure B: Regional Geology of Silverdale investigation areas (Not to Scale)[3]

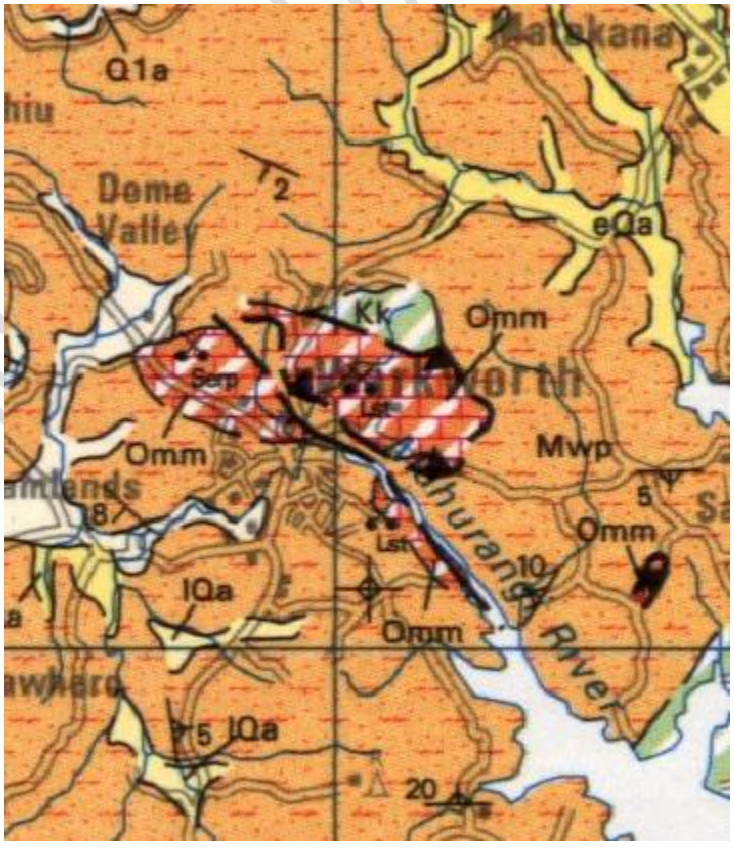

Figure C: Regional Geology of Warkworth investigation areas (Not to Scale)[3]

3.2 Geological units

3.2.1 General

A summary of the various geological units present across the RUB investigation areas, along with a description of their geotechnical behavioural characteristics, is provided below.

3.2.2 Alluvium (Holocene)

Holocene alluvium (Q1a on the geological map – Figures A-C) typically comprises highly compressible, soft to firm organic silts and clays and is found bordering rivers and streams, within gully features, and around low lying coastal areas. The alluvium often includes layers of peat and other low strength/compressible soils which are typically considered unsuitable or difficult to construct over. Where future development extends over existing water courses and low lying coastal areas, and it is permissible to do so, the Holocene Age alluvial soils are typically removed during subdivisional earthworks (e.g. "mucking-out" of stream/gully features and backfilling with engineered fill is a common component of land development). However, we note that it is more likely that environmentally sensitive features such as streans and watercourses will need to be retained and incorporated into future development areas.

3.2.3 Puketoka Formation and Undifferentiated Tauranga Group Alluvium (Pleistocene)

Published geological maps show that some areas of the development sites are located on land of low relief which are predominately underlain by Puketoka Formation alluvial soils of the Tauranga Group ('Pup' on geological maps – Figures A-C). The Puketoka Formation generally comprises light grey to orange brown pumiceous silt (distal ignimbrite materials), sand and gravel with lenses of muddy black compressible peat and lignite from the Pleistocene Age.

Our experience with Puketoka Formations soils indicates that the peat layers could be up to 3 m thick and are typically present within the upper 10 m. The peat is largely amorphous with minor fibrous content and has usually been subject to a degree of pre-consolidation that limits settlements under moderate loading. However if the pre-consolidation pressure is exceeded then primary consolidation rates of the peat can be high. In addition peat soils can settle over a long period of time due to secondary consolidation (creep) effects. The peat is often lensoidal and is not observed in all excavations or drill holes in Puketoka Formation materials.

The upper Puketoka Formation soils also comprise layers of loose to medium dense, and dense sands which underlie the silty clays. These layers vary considerably in depth, density and thickness. The medium dense to dense Tauranga Group sands are typically present from a depth of approximately 10 to 20 m below ground level but are not necessarily continuous (upper layers typically being limited to 3 to 5 m in thickness). The loose sandy layers of the Puketoka Formation have been identified as being susceptible to liquefaction under seismic conditions.

Undifferentiated Tauranga Group materials include mud, sand, gravels and muddy peat of Pleistocene age, but which are not able to be differentiated in one of the Tauranga Formations (i.e. Puketoka, Whangamarino and Karapiro Formations). On the basis of the strong similarity in characterisation and behaviour between these units it is inferred, for the purposes of this report, that these units will behave in a similar manner to the Puketoka Formation.

3.2.4 Waitemata Group (Miocene)

A primary constituent underlying many areas in both the North and North-Western RUB investigation areas is the Waitemata Group. The Waitemata Group includes East Coast Bays Formation (ECBF) rock (Mwe on the geological map), Albany Conglomerate (Mwy on the

geological map – Figures A-C), Cornwallis Formation (Mwc on the geological map) and the Pakiri Formation (Mwp on the geological map).

The very weak to weak ECBF rock typically consists of interbedded layers of sandstone and mudstone through to coarser grained massive, more volcaniclastic, weak sandstones and conglomerates (Albany Conglomerate, Cornwallis and Pakiri Formations).

Residual soils, derived from the weathering of parent rock material and which overlie unweathered rock, comprise stiff to very stiff, orange brown to grey silts, sandy silts and clays which gradually increase in strength with depth. The weathered (residual) layer thickness can vary between 2 and 10 m. For the purposes of this assessment the residual Waitemata Group soils can be considered to display similar engineering characteristics and this considered as one larger unit.

3.2.5 Undifferentiated Northland Allochthon (Miocene)

The units comprising the Undifferentiated Northland Allochthon are those consisting of Hukerenui Mudstone (Kkh), Puriri Mudstone (Omp) and Mahurangi Limestone (Omm). The Hukerenui Mudstone is characterised as highly sheared, weakly indurated mudstone, while the Puriri Mudstone is a calcareous mudstone with a minor tuff constituent. The Mahurangi Limestone is a common rock type found predominantly through the Warkworth and Silverdale RUB investigation areas. The limestone is described in the published literature as micritic (fine grained), coccolith foraminiferal, muddy limestone. The limestone material is commonly shattered and typically contains localised glauconitic sandstone beds.

Based on our experience with these materials, it is expected that the highly sheared nature of the materials presents significant slope stability and site development issues. Past geotechnical investigations undertaken in locations near the Silverdale investigation area have indicated that even at low slope angles, the material is prone to failure along persistent internal sheared surfaces and on the contact between the fully softened material and the underlying intact rock. This contact is usually slope parallel.

While often less sheared than the mudstone units and thus more resistant to slope instability, the calcareous nature of the Mahurangi Limestone means that it is susceptible to local dissolution by even mildly acidic groundwater flow. This can result in the development of underground streams, hollows, voids and Tomo's (voids collapsed to ground surface). However, the limestone is generally so sheared that dissolution is restricted by a lack of continuous defects.

3.3 Stratigraphy

3.3.1 General

The site stratigraphy presented in the following sections is based on limited geotechnical investigations undertaken for other purposes, within each of the proposed development sites; our experience in the region and based on available published geology. The nature and continuity of the subsoil conditions has been inferred from the available data and it must appreciated that, due to the limited data and large size of the area of interest, actual conditions will locally vary from those presented below. Site specific geotechnical investigations comprising machine boreholes, cone penetrometer tests and laboratory testing will be required to confirm and validate the findings and conclusions presented in this report.

Subsurface conditions of the investigation areas can be categorised into stratigraphic sequences based on their location:

i. Kumeu-Whenuapai: Predominantly Puketoka Formation overlying Waitemata Group East Coast Bays Formation and Cornwallis Formation Rock; and

ii. Warkworth: Residual Waitemata Group soils overlying Pakiri Formation Rock. Waitemata Group is overlain in major stream channel systems by variable thicknesses of Holocene or Pleistocene Tauranga Group Alluvium. Rare areas of Undifferentiated Northland Allochthon.

iii. Silverdale: Tauranga Group Alluvium within low lying valleys and gullies overlying Waitemata Group East Coast Bays Formation rock or Northland Allochthon Rock. Elsewhere residual soils overlie either Northland Allochthon mudstones or Waitemata Group sandstones and siltstones.

In addition to the detailed description of the geological units provided in Section 4.2, the site plan identifying historic investigation sites is provided on Figures 1, 2 and 3 and geology maps are presented in Figures 4-13 in Appendix A.

3.3.2 Kumeu-Whenuapai Investigation Area

The site stratigraphy across the Kumeu-Whenuapai area follows a broadly similar profile. Previous site investigations reveal that typical subsurface stratigraphic sequences include recent (Holocene to Pleistocene) alluvial deposits (within the Tauranga Group). The Pleistocene deposits were predominantly identified as Puketoka Formation soils. The Puketoka Formation soils typically consist of stiff to very stiff pumiceous silt with fine grained sand, and some clay increasing with depth. The Tauranga Group alluvial material typically extends between 1 to 16 m (below ground level). We would expect that recent soft alluvium would be present near infilled inlets, paleo valleys and gullies that extend from the coast.

Underlying the Tauranga Group alluvium, previous geotechnical investigations suggest the presence of completely weathered, residual Waitemata Group rock, which is typically described as stiff to hard clayey silt and fine sandy silt. Beneath the residual material, weathered, alternating sequences of fractured mudstone and fine sandstone are typically present, usually at depths between 6 to 16 m (below ground level).

At a local scale, geotechnical investigations, particularly concentrated around Scott Point and the south boundary of the Brigham Creek investigation area, have indicated the presence of peat at depths between 2 and 8 m below ground level Where such materials are present, the geotechnical constraints associated with development would be significantly increased (see Section 4,5), e.g. piled foundations for new buildings or ground improvement works.

3.3.3 Warkworth Investigation Area

The sequence stratigraphy of the Warkworth area typically consists of Holocene and/or Pleistocene Tauranga Group alluvium overlying Waitemata Group Pakiri Formation rock. Previous geotechnical investigations indicate that around the current Warkworth Township, Tauranga Group alluvium extends to approximately 4.5 m (below ground level) and typically consists of firm to hard clayey silt with some fine sand inclusions.

Away from low lying gullies and the coast, the stratigraphy of the Warkworth investigation area will be dominated by residual soils between 3-10 m in depth, overlying coarse sandstones of the Pakiri Formation (Waitemata Group).

Small parts of the central Warkworth North and East Investigation area are identified on the geological map as being underlain by Northland Allochthon. While limestone in the Allochthon can be expected to exhibit limited residual soil cover (0.5 m to a few metres), deeper residual soils (4-10 m) can be expected in the rarer areas of Allochthon mudstone present near the Warkworth

Golf Course. We have based these descriptions on our experience with these materials in Auckland and Northland as there is limited published geotechnical investigation data in this area. These assumptions will require further verification through future geotechnical works.

3.3.4 Silverdale Investigation Area

The Silverdale investigation area encompasses a highly variable stratigraphy.

For the purposes of this study the site is largely underlain at depth by either Waitemata Group or Northland Allochthon (mudstones and limestone) rock. These units are generally separated by faulting, or shearing due to the mechanism of the emplacement of the Allochthon in this area.

Where Allochthon or Waitemata Group is exposed at ground surface (mainly through areas of Okura-Weiti, Silverdale and Silverdale West) the rock mass has been weathered to clay dominated soils which extend to depths of up to 10 m below ground level.

In low lying areas of Dairy Flat and Okura/Weiti the Waitemata Group and Northland Allochthon is overlain by Tauranga Group alluvium, which infill paleo channels in the underlying rock mass. Geotechnical information sourced from previous geotechnical investigations in these areas indicate that the stratigraphy consists of very stiff clayey silt alluvial/colluvial deposits (Tauranga Group) to a depth of approximately 3 to 8 m below ground level.

Rare beds of peat have been recorded in previous geotechnical investigations, particularly towards the north and south of the Dairy Flat investigation area and typically extend between 1 to 2.5 m below ground level. Softer Holocene Age material is likely to be particularly prominent near the tidal inlets and Weiti River tributary boundaries.

In the north of the investigation area, where investigated around Wainui East, the typical site stratigraphy consists of Holocene (typically soft layers) to Pleistocene (firm to very stiff) Alluvium between 0.1 to 8.5 m (depth below ground level), overlying Northland Allochthon at depth.

3.4 Groundwater

Subsurface groundwater conditions are an important consideration for any development, and may have a major impact on foundations, services (excavations), earthworks, slope stability and liquefaction potential (refer to Sections 5 and 6). While geotechnical investigations have been carried out within the proposed investigation areas, the available specific groundwater data is not considered to be reliable due to changes in groundwater regimes and climate influences. However, based on our experience working with similar areas in the North and North-West Auckland region we expect the following typical groundwater conditions:

- Groundwater levels within coastal areas, including the Riverhead, Brigham Creek, Scott Point, Warkworth, Warkworth North and East, Hepburn Creek and Okura/Weiti investigation areas are likely to be near surface (shallow depth to groundwater). The groundwater within low lying coastal areas is likely to be influenced by tidal effects. Care will need to be taken in the development of land with high groundwater levels to ensure that possible settlement related effects of groundwater drawdown are mitigated and controlled.
- Groundwater levels in investigation areas further inland, including the Kumeu Huapai, Red Hills, Future Business, Warkworth South , Wainui East, Dairy Flat and Silverdale West investigation areas will likely be relatively low (deeper depth to groundwater) with water likely to be present at depths of 3 m or more below ground level.

- Groundwater flow across all investigation areas is typically from elevated areas toward streams and creeks (river re-charge from surrounding environment), with resulting groundwater levels being closer to the surface near streams and creeks and within gullies.
- Groundwater is expected to be perched within residual soils (0.5 to 6 m below ground level) across the investigation areas depending on soil thickness and proximity to the coast. Within the underlying rock units we anticipate a downward flow gradient (several metres of water pressure at any point in the profile) until underlying hydrostatic regional groundwater table is encountered at depth.
- Groundwater aquicludes (interbedded less permeable materials) may exist in some areas allowing the development of perched water tables and zones of seepage where intersected by sloping ground.
- Groundwater in the Allochthon is typically restricted to the softened zone and broken zone near the contact between the soil and rock. Sub-artesian pressures can be encountered in this broken zone.

We recommend groundwater monitoring instruments (piezometers) be installed during future geotechnical investigations to provide design inputs and confirm the assumed groundwater conditions outlined above.

3.5 Seismic Subsoil Class

The New Zealand Standard for Structural Design Actions (NZS 1170: 2004) provides guidance on the levels of ground shaking that should be considered for the design at the site.

Investigation data reviewed for the purposes of this desk study assessment was not sufficient to determine the depth to underlying rock as required to determine the site subsoil class in accordance with NZS 1170. We can therefore only make generalised comments based on our experience across both the North and North-West Auckland RUB area. Detailed geotechnical investigations will be required to confirm the seismic subsoil class at each site.

As a guide, the seismic class for any location may be assessed on the basis of the published geology and experience with soil depths/conditions in each lithology.

- Sites underlain by Waitemata Group and Northland Allochthon can be considered as Class C (shallow soil). Specific investigations may result in some sites (particularly Allochthon Limestone) being moved to Class B (rock) based on thin or absent soil cover.
- Sites underlain by Holocene Alluvium, Undifferentiated Tauranga Group and Puketoka Formation should be considered to be Class D (deep or soft soil) based on our experience with the behaviour of these materials. Specific investigations may result in many sites being categorised as Class C (shallow soil) sites.

3.5.1 Peak ground accelerations

Approximate peak ground acceleration magnitudes have been assessed under various seismic conditions for preliminary liquefaction analyses. The following has been assumed for calculation of peak ground accelerations in accordance with NZS1170.5 (2004)

- Building importance level: IL 2 (assuming typical residential dwelling or commercial building)
- Building design life: 50 Years

- Return period 500 Years – ULS Event (Table 3.2 NZS 1170.5)
  25 years – SLS event (Table 3.2 NZS 1170.5)
- Near Fault Factor 1.0 (distance to nearest fault > 20km)

Table 1 – Spectral Shape Factors for seismic subsoil class

Site Seismic subsoil Class	**Class B – Rock**	**Class C – Shallow Soil**	**Class D – Deep/soft Soil**
Spectral Shape Factor	1.0	1.33	1.12

Table 2 – Assessed Peak Ground accelerations for varying Site Subsoil Class

Seismic Case	**Class B – Rock**	**Class C – Shallow Soil**	**Class D – Deep/soft Soil**
Serviceability Limit State Event (1 in 25 years)	0.032g	0.042g	0.04g
Ultimate Limit State Event (1 in 500 years)	0.13g	0.17g	0.15g

4 Geotechnical Hazards

4.1 General

Based on the available geotechnical information and our knowledge of the likely subsurface conditions at each investigation area, we have identified the following key geotechnical hazards which will need to be considered for future urban development.

1. Slope instability, including coastal erosion;
2. Liquefaction: loss of strength under earthquake shaking and associated lateral spreading and settlement.
3. Compressible soils, such as peat/organic matter which are prone to degradation and long term consolidation settlement;

The preliminary recommendations and conclusions presented in Sections 6 and 7 are based on our interpretation of published geological information and limited geotechnical investigation data. The recommendations are intended to provide guidance for a feasibility assessment of the proposed investigation areas and should not be used for detailed design or consenting purposes. Appropriately scoped site specific geotechnical investigations will be required to confirm the subsurface conditions across the site and to validate or otherwise the conclusions and recommendations of this report. In particular, it is recommended that investigation be undertaken to assess the liquefaction and lateral spread hazard and risk in areas that have been identified as potentially susceptible to liquefaction under seismic potential, and or when additional data or information indicates additional areas may also be susceptible.

It is understood that flooding, sea level rise and other non-geotechnical hazards have been addressed in other studies. This document therefore excludes reference to these additional hazards, however, we note that sea level rise may increase the susceptibility of some land to liquefaction.

4.2 Hazard Potential

In order to provide Auckland Council with a broad but practicable appraisal of the proposed investigation areas we have adopted a 'hazard potential' categorisation. Each of the areas within the proposed North and North-West Auckland RUB has therefore been defined as having low, medium or high "hazard potential" with regards to slope instability, liquefaction and compressible soils (and the associated settlement potential). The categorisation of each hazard is illustrated on Figures 14 to 31 in Appendix A.

The majority of land within the North and North-West Auckland RUB is considered geotechnically suitable for development, but with various degrees of engineering control required to remedy or mitigate the risk or impact of geotechnical hazards.

4.3 Slope Instability Potential

4.3.1 General

A preliminary assessment of slope instability potential has been undertaken for the proposed North and North-Western Auckland RUB; using published geological maps (for categorisation of soil types), LiDAR surface elevations sourced from AC and our experience with landslips in the Auckland region.

Landforms have been categorised into three slope instability hazard vulnerability classes (low, medium and high) based on the expected geology (per the geological map) and the ground

surface topography (LiDAR data). The category slope profile limits are presented on Table 3 below and discussed in more detail in the following sections. The slope profile limits have been derived based on our previous experience and knowledge of similar soils and topography within the greater Auckland region. In addition, T&T has provided geotechnical advice to the Earthquake Commission in relation to landslip disaster damage on residential properties over the last 30 years and hence, has awareness on the spatial distribution of such events within the Auckland region. We note that our current appreciation of slope instability potential is based on present prevailing weather patterns in NZ. However, it should be recognised that these conditions may be influenced by climate change effects over the longer term.

A plan showing the slope instability hazard categories for the North and North-West Auckland RUB areas is presented as Figures 14-23 in Appendix A.

Typically, the lower lying areas, including flood plains and coastal regions across all three areas (particularly in Kumeu-Whenuapai) have the lowest surface relief and therefore lowest slope instability potential (shown by the green areas in Figures 14-23). Some regions, however, particularly north of the Greenfield Investigation Areas in Kumeu-Whenuapai, north and south east of Warkworth, Okura/Weiti and south to south east Dairy Flat indicated some high risk areas of slope instability – represented by linear orange/red (medium/high) potential classification zones on Figures 14-23. A combination of factors including regions of high surface relief and close proximity to coastal/stream margins underpin the higher assessed hazard potential. Furthermore, from our experience with the sheared nature of the Undifferentiated Northland Allochthon, we believe these materials are more prone to development of slope instability at lower slope angles resulting in a higher proportion of "medium" and "high" slope instability potential compared to other material types.

The more highly susceptible areas would typically be either earthworked (re-profiled to form stable slopes) or alternatively avoided for future development, or retained as reserves. In high value lots it may be possible to design major retention works on a lot by lot basis.

Table 3 - Slope Instability Potential: Slope Profile Limits

Geological unit	Slope Instability Potential - Slope Profile Limits*		
	Low	Medium	High
Holocene Alluvium	0-10 ^{o}	10-23 ^{o}	>23 ^{o}
Puketoka Formation/Undifferentiated Tauranga Group	0-10 ^{o}	10-23 ^{o}	>23 ^{o}
Waitemata Group (includes ECBF, Cornwallis Formation, Albany Conglomerate and Pakiri Formation residual soils).	0-15 ^{o}	15-26 ^{o}	>26 ^{o}
Undifferentiated Northland Allochthon	0-8 ^{o}	8-18 ^{o}	>18 ^{o}

* Indicative only; each site should be subject to specific investigations to evaluate detailed site topography, geology and groundwater conditions.

4.3.2 Low Slope Instability Potential

As outlined on Table 3 and presented on Figures 14 to 23, land typically considered to be flat (those with slope angles less than 8 to 15 ^{o} depending on geology) is likely to have a low slope

instability potential. Some minor slope re-grading works may be required to form the desired finished landform but these works are unlikely to require significant engineering design and/or construction control to address the potential for slope instability. As can be seen from Figures 14 to 23, the many areas within the North and North-West Auckland RUB have 'Low Slope Instability Potential'. When required to form construction platforms, conventional retaining wall structures are likely to be required to support step changes in profiles.

4.3.3 Medium Slope Instability Potential

Land classified as having 'Medium Slope Instability Potential' is typically identified as being moderately sloping with surface relief ranging between 10 to 23 ^{o} (for the lower strength alluvial soils), 15 to 26 ^{o} (for more competent Waitemata Group soil types) and 8-18 ^{o} for sheared Northland Allochthon.

Although these areas are identified as having medium slope instability potential, the hazard does not preclude future development occurring.

Within the 'Medium Slope Instability Hazard' areas, developers will likely need to consider a number of additional factors, not required for development of generally flat (low development premium) land including:

- Additional earthworks to form stable slopes and building platforms;
- Possible low to medium sized retaining structures to support excavations (both temporary and permanent);
- Possible control of groundwater, where deep cuts may be required (required in Northland Allochthon areas);
- Increased design input from engineering professionals.

Specific (lot by lot) engineering design is unlikely to be required for construction on land classified as 'Medium Slope Instability Potential' provided that subdivisional earthworks have been undertaken to address global stability issues and provide stable finished landforms.

4.3.4 High Slope Instability Potential

Land classified as having 'High Slope Instability Potential' is identified as being moderately to steeply sloping with ground profiles exceeding 18 to 26^{o} (depending on the geology and groundwater conditions). However, as with areas that are classified with a Medium Slope Instability Potential; the land is not precluded from future development, although additional factors will need to be considered. These factors may include:

- Global earthworks/re-profiling to achieve stable slope angles and a suitable finished landform to support development;
- Installation of structural retention, e.g. retaining walls, shear keys, stabilised earth slopes, to terrace or support sloping ground. Such works need to consider both local and global stability;
- Possible deep (pile) foundations for dwellings/buildings positioned close to steep slopes;
- Control of groundwater (e.g. installation of subsoil drainage – horizontal drains, buttress drains etc.).
- Possible specific engineering design and construction control to address stability issues on a 'lot by lot' basis;

- Intensive engineering design and construction control by consulting engineers and Council.

Land which falls within the 'High Slope Instability Potential' category is most effectively and economically made available for development by using a global earthworks approach to provide stable landforms over wide areas.

4.4 Liquefaction Potential

4.4.1 General

Liquefaction occurs when excess groundwater pressures are generated within loose, saturated and generally cohesionless soils (typically sands and silty sands) during earthquake shaking. The resulting high groundwater pressures can cause the soils to undergo a partial to complete loss of strength which can result in settlement and/or horizontal movement (lateral spread) of the soil mass. The occurrence of liquefaction is dependent on several factors including:

- the intensity and duration of ground shaking;
- soil density;
- particle size and distribution; and
- the groundwater elevation.

Liquefaction could affect the future development in the following ways:

- Deformation and rupture of road pavements;
- Flotation of manhole risers and sagging/hogging of services;
- Differential settlement of services resulting in rupture or reversal of grade;
- Total and differential settlement of building floor slabs (on grade) which could also result in structural failure and where severe, increased post-seismic flooding hazard;
- Differential settlement of building foundations resulting in deformation or possible structural failure;
- Lateral spreading of ground within 100 to 200m[4] of unsupported faces (e.g. streams, harbour); and
- Ejection of sand/silt on to the ground surface.

The extent by which liquefaction can effect urban development can be coarsely assessed with knowledge of the "crust thickness" overlying a liquefiable soil, i.e. the thickness of the surface soils (non-liquefiable cohesive soils and/or above groundwater level) which 'raft' over the liquefied soils. Based on experience gained from the Christchurch sequence of earthquakes through 2010 and 2011 and published empirically based information (Ishihara, 1985) it is anticipated that where the "crust thickness" exceeds a minimum of 3 m, the effects of liquefaction can generally be mitigated to avoid significant damage to residential and light commercial structures at ground surface. This assumes that the "crust" is of sufficient capacity/strength to 'raft' over the liquefiable layers, though this does not preclude global settlement and deep-seated lateral spreading.

The liquefaction potential over the North and North-West Auckland RUB areas has been categorised as low, medium or high based on our present knowledge of the geology and anticipated groundwater levels. The assessed liquefaction 'trigger' hazard (i.e. the hazard of

[4] Youd,T.L, Hansen, C.M, Bartlett, S.F. (2002) *Revised Multilinear Regression Equations for prediction of lateral Spread Displacement*, Journal of Geotechnical and Geoenvironmental Engineering, December 2002

liquefaction occurring under given seismic design conditions) for each area is presented on Figures 24 to 26 in Appendix A and is summarised further below. It should be noted that the information presented on Figures 24-26 do not provide quantitative assessment/categorisation of the potential effects of liquefaction (as outlined in the bullet points above).

4.4.2 Preliminary Liquefaction Analysis

Preliminary liquefaction analyses have been undertaken to evaluate the potential of typical North and North-West Auckland soils to liquefy under seismic conditions. The analyses have been undertaken using geotechnical data sourced from limited geotechnical investigations undertaken in the Kumeu-Whenuapai investigation area.

The CPT trace adopted for preliminary analysis was sourced from an investigation completed near Whenuapai. This site was underlain by Puketoka Formation soils overlying Waitemata Group residual soils and rock. Based on the published geological map, we consider the ground conditions at this site to be comparable to other areas shown to be underlain by Puketoka Formation geology. Therefore, the analysis provides an indication of the liquefaction potential for regions with a similar geology but is to be used for guidance purposes only. Detailed geotechnical investigations will be required to establish the liquefaction potential of the various investigation areas.

Analyses were undertaken for both serviceability limit state (SLS) and ultimate limit state (ULS) seismic events with peak ground accelerations as outlined in Table 2 in Section 5.5.1.

The Cone Penetrometer Tests (CPT's) results from local investigations yielded the following ground profile

- Approximately 5 to 6 m of stiff to very stiff silty clay to clayey silt soils of Puketoka Formation overlying;
- 2 to 3 m of silty sand and silty clay to organic peat soils overlying;
- Approximately 2 m of loose silty sands and firm sandy silts above;
- 4 to 5 m of silty clay to sandy silt of ECBF residual soil.
- Groundwater at depths of between 2 to 3 m below ground level.

The CPT data from the above tests were run through a liquefaction calculator which assesses the probability of liquefaction occurring based on the Idriss & Boulanger (2008)[5] liquefaction trigging method with an assumed near-surface groundwater elevation. The analyses indicate that the 'typical soil profile' is unlikely to liquefy under a serviceability limit state event (PGA = 0.042g for an assumed 25 year return period) seismic event. However, under a ULS earthquake event (PGA = 0.15g for a 500 year return period) the preliminary analyses indicate that liquefaction of the saturated loose silty sand and sandy silt layers could theoretically occur. The theoretically liquefiable soils typically lie at a depth of between 6 and 10 m below ground level and the thickness of the liquefiable soils is between 0.5 and 2 m. Such an event could result in ground surface settlements of between approximately 50 and 200 mm.

4.4.3 Low Liquefaction Potential

As noted above, two of the principal factors which can result in liquefaction occurring under seismic conditions is the presence of sands/sandy silts and groundwater. Typically areas defined by the published geological literature as Waitemata Group series, or Northland Allochthon

[5] Idriss, I.M. & Boulanger, R.W. (2008). *Soil liquefaction during earthquakes*, MNO–12, Earthquake Engineering Research Institute, 242p

materials are considered to have low liquefaction potential on the basis of their fine grained and/or dense composition. These materials are typically cohesive or cemented and therefore are considered to have a low liquefaction potential. Areas of this category are typically west Kumeu Huapai, north of the Greenfield Investigation Areas, central Red Hills North, and southern Red Hills in the Kumeu-Whenuapai investigation areas. In Warkworth the majority of the investigation area has a low liquefaction potential excluding localised pockets towards the north and west of Warkworth North and East, Warkworth and Warkworth South. The Silverdale investigation area also displays a large majority of low liquefaction potential areas, however with some localised bands that typically extend through Wainui East, Dairy Flat and Okura/Weiti are again classified in the medium range (as described below).

4.4.4 Medium Liquefaction Potential

Areas which have been identified as having a medium potential of liquefaction are those areas which, based on our understanding of the subsurface conditions (soils and groundwater levels) have the potential to liquefy under an ULS seismic event (as defined by NZS1170.5 – refer to Section 4.5). Preliminary analyses have been undertaken to validate this using the results of historical geotechnical tests (CPTs) completed in areas with comparable geology (Whenuapai, North-West Auckland). These preliminary analyses are discussed above in Section 6.4.2.

The medium liquefaction potential areas are those which are known to be underlain by alluvial soils (both Puketoka Formation and Holocene Age alluvium) which include layers of loose sand or sandy silts present below groundwater levels. These areas include the majority of Kumeu Huapai, the Greenfield Investigation Areas, Brigham Creek, Riverhead, Scott Point, Red Hills North and the Future Business investigation area in Kumeu-Whenuapai, while isolated bands in the Silverdale and Warkworth areas are also rated as having a medium liquefaction hazard. These areas are considered likely to experience some form of liquefaction under peak ground accelerations consistent with a 1 in 500 year return period seismic event.

Medium potential liquefaction areas may not necessarily require specific engineering design for residential type construction (excluding multi-storey buildings). However, the following will likely be required for urban development extending into these areas:

- Site specific geotechnical investigations including; CPT and machine boreholes to determine whether loose sands/silts are present with in the upper materials, groundwater levels and the “crust thickness”. These investigations should be undertaken as part of the subdivision stage of development
- Site specific lateral spread assessment. As a general guide a minimum ‘set-back’ distance (e.g. 25 m) of all building platforms from unsupported soil faces (i.e. slopes, embankments, creeks, streams, harbours) to minimise the risk of being affected by ‘lateral spreading’. Buildings located within 100 m of unsupported soil faces may also be subject to specific analyses and design. For ‘life-line’ and important structures, lateral spreading effects may need to be considered at greater distances from unsupported faces.
- Design of commercial retail and multi storey residential tower building foundations to tolerate large magnitude total and differential settlements, and lateral kinematic loadings under ULS seismic conditions.
- Possible earthwork controls to ensure that the “crust thickness” over investigation areas is maintained to at least 3 m in thickness to mitigate the surface effects of below ground liquefaction (as listed in the bullet points in Section 5.4.1).
- Detailing of services to maintain falls and resist flotation.

4.4.5 High Liquefaction Potential

Areas identified as having a high risk of liquefaction are defined in this report as sites having the potential for liquefaction to occur under SLS (1 in 25 year return period) seismic conditions. Considering the proximity of some of the investigation areas to the coast, and our knowledge and experience of the materials, it is expected that, Holocene aged materials adjacent to the coast pose a high risk of liquefaction potential. These areas were limited to small areas of east Okura/Weiti, primarily where riverine systems extended inland from the coast, where recent sediment has been deposited.

While not all areas neighbouring creeks and streams have been represented as having a high liquefaction risk in Figures 24 - 26, these areas could still potentially liquefy under SLS seismic conditions if underlain by very loose sand/silts and with high groundwater levels.

For future construction within these areas the following options may need to be considered in addition to those outlines in Section 6.4.4 (medium):

- Add fill material across the construction site to increase the "crust thickness". Fill material would need to be cohesive to prevent silt ejection and be compacted to an engineered standard. The effect of fill placement would need to be assessed in relation to the risk of consolidation settlement (refer to Section 6.3 - Earthworks), and aggravation of lateral spread risk.
- Piled foundations to support building structures. Negative skin friction effects would need to be considered for pile foundations extending above and through the liquefiable soil layers and lateral loads applied by any lateral spreading.

Table 4 summarises the predominant liquefaction potential within each investigation area.

Table 4 – Summary of Predominant Liquefaction Potential Hazard

Kumeu - Whenuapai (Refer to Figure 24 in Appendix A for details).

Area	Kumeu Huapai	Future Business	Brigham Creek	Red Hills North	Red Hills	Scott Point	Riverhead	Greenfield Investigation Areas
Low				X	X			X
Medium	X	X	X	X	X	X	X	X
High								

Warkworth (Refer to Figure 25 in Appendix A for details).

Area	Warkworth North and East	Warkworth	Warkworth South	Hepburn Creek	Future Business
Low	X	X	X	X	X
Medium					
High					

Silverdale (Refer to Figure 26 in Appendix A for details).

Area	Wainui East	Silverdale West Business	Silverdale West	Dairy Flat	Okura/Weiti
Low	X	X	X	X	X
Medium	X	X	X	X	
High					

4.4.6 Liquefaction Potential Investigations

It is recommended that detailed geotechnical investigations, comprising site specific Cone Penetrometer Tests, be undertaken in the areas identified as having significant areas of 'Medium' Liquefaction potential (noting that we have not identified any areas of high liquefaction potential in this desk study assessment).

Using the results of the Cone Penetrometer Tests, an assessment of the liquefaction trigger potential of each area can be undertaken to confirm and validate the preliminary information presented on Figures 24-26. In addition, analysis of CPT data would enable assessment/qualification of possible liquefaction effects (e.g. ground settlement, ejection of sand/silt or lateral spreading). T&T have recently completed a similar study in Christchurch utilising the results of thousands of CPTs to map liquefaction hazard zones. Using this data, T&T have developed an engineering tool, the Liquefaction Severity Number (LSN)[6] which can be used to evaluate the potential effects of liquefaction and risk of damage to structures at the ground surface, i.e. to measure what effects liquefaction would have at a site, and consequently the level of design and construction effort required to develop robust foundation solutions. It is recommended that a preliminary study, focused on the most at-risk areas, be undertaken for the North and North-West Auckland RUB project.

[6] Tonkin and Taylor (2013) *Liquefaction vulnerability study*, Tonkin and Taylor Report 52020.0200/v1.0. February 2013. 52 pages and 14 appendices.

4.5 Soil Compressibility and Building Settlements

4.5.1 General

Foundations for future dwellings and buildings will vary across the North and North-West Auckland RUB areas. The following main factors will need to be considered in relation to foundation design and construction for future development in the North and North-West Auckland RUB.

In general, foundation design and construction will be principally governed by the geology/subsurface conditions and the size of the buildings proposed. Slope stability hazards are discussed in Section 5.3 and liquefaction issues are presented in Section 5.4.

The hazard potential associated with constructing new buildings on land which may be underlain by moderately to highly compressible soils has been assessed in comparison to a theoretical baseline site underlain by very stiff/dense, low-compressibility soils overlying rock at a relatively shallow depth. Development of land which is underlain by moderately to highly compressible soils would have high settlement potential in comparison with the baseline site. Figure 27 to 29 in Appendix A illustrate the assessed hazard potential associated with soil compressibility and building settlements within the North and North-West RUB.

4.5.2 Low Settlement Potential

Primary geological units considered to have low soil compressibility potential include the Waitemata Group materials, along with the Northland Allochthon, which are typically compact, with moderate to high shear strengths and low compressibility. These units are therefore considered to have relatively good bearing capacities (for shallow foundations) and a low risk of consolidation settlement. The areas underlain by Waitemata Group and Northland Allochthon include the southwest of Kumeu Huapai, north of the Greenfield Investigation Areas and central Red Hills/Red Hills North in the Kumeu-Whenuapai investigation area. In Warkworth the majority of all investigation areas are included in the low settlement and soil compressibility potential category, while in Silverdale the south of Dairy Flat, majority of Okura/Weiti and north of Wainui East are also considered low potential.

These areas outlined above are expected to be suitable for construction of one to four storey buildings (dwellings and commercial structures) supported on shallow foundations. Pile foundations may be required for structures four or more storeys high or for highly loaded structures and/or where isolated areas of peat and alluvial soils are present (e.g. Dairy Flat and Okura/Weiti in the Silverdale investigation area).

4.5.3 Medium Settlement Potential

Large parts of the Kumeu-Whenuapai and Silverdale investigation areas are underlain by Undifferentiated Tauranga Group or Puketoka Formation soils which are considered to be of firm to stiff shear strength and of moderate compressibility (refer to Section 5.3/ Figures 4-13 in Appendix A). From our previous experience with the Puketoka Formation soils layers of highly compressible soils, such as peat and organic clays/silts (see Section 5.2), are present. These soils, however, are typically in discrete layers of limited thickness and are unlikely to preclude future urban development.

Based on our experience with similar conditions in the Auckland region, it is likely that land underlain by Puketoka Formation soils will be suitable for construction of one to two storey light weight framed residential dwellings and light commercial buildings (retail, supermarkets etc) founded on shallow footings. Larger buildings, e.g. residential towers or commercial buildings of three storeys or more in height are likely to require pile foundations for support. Alternatively,

areas with near surface, less competent/moderately compressible soils could be either excavated and replaced with engineered fill, pre-loaded/surcharged or excluded from future investigation areas. Raft type foundations can also provide an economic option to mitigate risk of soil variability and settlement. Where infilled gullies and soft ground are encountered, these zones can be locally excavated and replaced during subdivisional earthworks.

Commercial and light industrial buildings with low and evenly distributed floor slab loads (10-20 kPa) are likely to be suitable for construction in the 'Medium Settlement Potential' areas. However building floor slabs with loads greater than 20 kPa will have higher potential settlement issues and will require specific geotechnical design input.

4.5.4 High Settlement Potential

The areas considered to be of high settlement potential are typically underlain by highly compressible soils (Holocene Age alluvium, coastal sediments or soils with a peat constituent in the profile). The high settlement potential of these materials means that future building development is constrained by the risk of consolidation settlement (total and differential) occurring under foundations and floor slabs. These soils are likely to be present around the coastal fringes of all three investigation areas, within gullies and around watercourses.

The areas recognised as having high settlement potential are largely within the Kumeu-Whenuapai investigation area, particularly in the proposed western investigation areas. Isolated areas, towards the west of the Warkworth investigation area and south and east of the Silverdale investigation area are also considered to have high settlement potential. Construction of most new buildings within areas underlain by Holocene Alluvium will likely necessitate either the removal of 'unsuitable' soils during the subdivisional earthworks (see Section 6.3 above) or installation of deep, piled foundations extending through the alluvium to a hard bearing stratum for support. Raft foundations could also be considered as an alternative foundation option. Raft foundations would enable the distribution of structural loads over a larger bearing area and therefore limit settlement effects.

Floor slab loads associated with large commercial and light industrial buildings would generally need to be limited to 10 kPa in high settlement potential areas to mitigate settlement related issues.

A summary of the 'Soil Compressibility and Building Settlement Potential' categorisation of each of the investigation areas is provided in Table 5.

Table 5 - Summary of Predominant Soil Compressibility and Building Settlement Potential Hazard

Kumeu-Whenuapai (Refer to Figure 27 in Appendix A for details).

Area	Kumeu Huapai	Future Business	Brigham Creek	Red Hills North	Red Hills	Scott Point	Riverhead	Greenfield Investigation Areas
Low				X	X			X
Medium	X	X	X	X	X	X	X	X
High	X	X		X		X		

Warkworth (Refer to Figure 28 in Appendix A for details).

Area	Warkworth North and East	Warkworth	Warkworth South	Hepburn Creek	Future Business
Low	X	X	X	X	X
Medium					
High					

Silverdale (Refer to Figure 29 in Appendix A for details).

Area	Wainui East	Silverdale West Business	Silverdale West	Dairy Flat	Okura/Weiti
Low	X	X	X	X	X
Medium	X	X	X	X	
High					

5 Development Constraints

5.1 General

In addition to the specific geotechnical hazards identified in Section 4, there are other development considerations and issues which can constrain development of land for urban use. These include:

1. Earthworks, i.e. modification of land forms to achieve global development solutions;
2. Civil infrastructure, (installation of services, construction of new roads etc)
3. Individual property development (specific engineering design)

In general, we note that the majority of the land identified within the proposed North and North-West Auckland RUB areas is likely to be geotechnically suitable for future urban development, assuming appropriate engineering control and design is undertaken. However, some areas are likely to be more easily developed, having few, if any constraints, whilst other areas may be more difficult to develop because of multiple constraints. We have categorised land as having one or more of these constraints as land that may be suitable for urban use, but at an associated 'Development Premium'.

5.2 Earthworks

For future development of greenfields/rural land, we would expect some form of earthworks to provide geometrically suitable and stable building platforms for construction of new dwellings and buildings.

The extent and type of earthworks required will be largely dependent on the natural profile of the land (topography and relief), the inherent stability of the soil types (geology), the volume of unsuitable soils present (peat/organics/stream alluvium), groundwater levels, and the engineering characteristics of the soils (i.e. how readily they can be earthworked, their susceptibility to consolidation settlement after placement of new fill etc.). Other factors which could impact on the extent/nature of earthworks required include; the type of development proposed, the presence of rock at near surface levels and the economic re-use of natural resources (e.g. aggregates).

Specific earthworks programs are beyond the scope of this assessment so the following commentary addresses the issues around earthworks that we anticipate based on topography, geology and material characteristics. We would expect that in some regions, even moderately sloped sites may need to be earthworked with the likely insertion of shear keys to support gulley fills and cutting upper slopes to produce an idealised gently graded site topography suitable for development.

In general, the Waitemata Group is expected to have stiff to very stiff soils and very weak to extremely weak rock mass. Key earthworks considerations in these materials include the exposure of the soil/rock contact in cut slopes and providing adequate support to gully fills and drainage, both of which can fail if not adequately investigated and designed. The same issues hold true for Northland Allochthon materials, except the Allochthon materials are heavily sheared and more susceptible to slope instability due to changes in slope profile at a lower range of slope angles. Based on this, the 'high' slope stability hazard with regard to earthworks is reduced to 12^{o}, and in general earthworks in these materials need to be approached with caution.

Within the North and North-West Auckland RUB, we have identified all areas as containing some degree of low, medium or high development premium in regards to earthworks. These inferences are based on underlying geology, slope angle, liquefaction hazard and soil compressibility potential.

A summary of the typical development premium associated with Earthworks within each investigation area is provided in Table 6.

5.3 Civil Infrastructure

As part of the future development of the identified greenfield sites, new civil infrastructure comprising roads and the installation of stormwater, wastewater and water supply services will be required.

The development of civil infrastructure and earthworks (discussed in Section 5.2) are closely linked. Therefore the areas identified as low development premium areas with respect to earthworks are typically those areas which will also have a low civil infrastructure development premium. Geotechnical risks, such as compressible soils and slope instability areas (as identified in Section 5), will also influence the ease with which civil infrastructure can be developed.

Through many areas of the North and North-West RUB investigation areas it is expected that there are may be some areas where roads pass through materials of relatively low strength (Tauranga Group Alluvium). Such conditions may necessitate some form of limited ground improvement, additional earthworks, subsoil drainage (for control of groundwater), robust pavement construction and differential settlement considerations relating to gravity fed services. Likewise, areas of moderate to steep topography may restrict road infrastructure construction in areas and may result in additional earthworks, ground retention, alternative road and service alignments and increased road and service network distances. This is particularly true of areas of Undifferentiated Northland Allochthon, where small changes to site topography (i.e. cut/fills associated with road development) may result in slope instability.

Groundwater is expected to be a factor in the development of civil infrastructure particularly in coastal areas where the groundwater level is near surface. Groundwater inflows and induced settlements related to groundwater drawdown may need to be considered when undertaking excavation and trenching for buried services. Although not precluding development, high groundwater levels may result in an increased development premium. Sea level rise should also been taken into account, estimated by government agencies to be 1m higher by the year 2115.

In general areas underlain by Waitemata Group and Northland Allochthon materials are considered to have ‘low’ civil infrastructure development premium due to the high strength soils and low groundwater level. Coastal locations and areas underlain by less competent alluvial deposits were typically considered to have a ‘medium’ to ‘high’ premium development.

5.4 Individual Property Development

Based on our experience with subdivision development projects, we expect that shrink/swell effects, excavation stability and groundwater levels will influence the development of building foundations.

Clay soils typically exhibit shrink/swell characteristics during extended wet and dry periods, e.g. over prolonged periods of summer the soils dry out and shrink, likewise over prolonged wet periods, soils can swell with excess water. Shrink/swell can result in cracking at the ground surface and cause cracking and distortion of adjacent structures (windows/ doors no longer open/ close) and induce settlements. We expect that soils particularly prone to shrink/swell behaviour are those associated with the Undifferentiated Northland Allochthon, however this does not preclude the potential for shrink/swell effects in clay rich soils of other formations. Shrink/swell effects can be mitigated by ensuring earthworks fill material (refer to Section 5.3) are placed at the optimum moisture content and building footings are set a minimum 600mm below ground level. In some cases 900mm or even 1200mm embedment may be required.

The ease at which excavations are carried out to allow for the construction and installation of foundations is influenced by the stability of the subsurface materials. Typically the presence of lower strength, less stable soils will reduce the allowable height of un-retained excavations, result in larger excavations to ensure stability and can result in increased construction timeframes.

Our experience suggests that the presence of groundwater above founding levels will affect the construction of building foundations. Water can lower the strength of soils and compromise the stability of excavations. Water inflows into foundation excavations will require pumping out and could induce groundwater drawdown. Service installation may require sheet piling or well pointing.

5.5 Development Premium

5.5.1 General

In order to provide Auckland Council with a broad scale but useable appraisal of the various North and North-West Auckland RUB areas we have adopted a land development premium categorisation.

To mitigate one or more of the above mentioned development constraints or geotechnical hazards, there would be an associated 'premium' for developing the land by comparison with land which is not constrained by the same issue. For example, development over land which is underlain by soft, low strength soils may require a higher degree of engineering (e.g. ground improvements, deep pile foundations) and would therefore be developed at a 'high premium' compared to land which is underlain by stiff high strength soils ('low premium').

We have adopted a qualitative assessment of low, medium and high "development premium" categories to contrast the geotechnical suitability of the various areas.

The development premium assessment has been entirely based on interpretation of the published geological maps and our appreciation of the types of soils present within the various geological units. The presently available geotechnical investigation data within the investigation areas is limited and not sufficiently detailed to be used for developing subsurface models and inferring the continuity of ground conditions.

5.5.2 Basis for category selection

The premium for development in relation to earthworks, civil infrastructure and individual lot development has been assessed relative to a baseline 'flat' or gently sloping site, requiring only limited re-profiling to support development, with 'stable' soils of high strength that can be readily earthworked and with a low groundwater level. This baseline site would be considered to have a low development premium.

The basis for selection of sites as having either low, medium or high development premium is based on the hazards and development constraints outlined above and is summarised in Table 6 below.

Table 6: Basis for development premium category selection

Low Development Premium	Medium Development Premium	High Development Premium
Gently graded/not subject to historical slope instability, ***and***	Earthworks or Civil Infrastructure in Tauranga Group (incl. Puketoka Formation) or Holocene Alluvium, ***or***	Known areas of historical slope instability, ***or***
Low compressibility/high strength soils or rock, ***and***	Development on slopes between 15-26° in Waitemata Group soils, ***or***	Earthworks in areas of (undifferentiated) Northland Allochthon exceeding 12° slope angles, ***or***
Easy to earthwork, ***and***	Development on slopes between 8-23° in Undifferentiated Northland Allochthon, Holocene Alluvium or Pleistocene Tauranga Group soils, ***or***	Slopes exceeding 26° in Waitemata Group, ***or***
Easy to develop civil Infrastructure, ***and***	Individual lot development in Holocene Alluvium or Tauranga Group (incl Puketoka Formation)	Slopes exceeding 23° in Tauranga, Group (incl. Puketoka Formation) and Holocene Alluvium, ***or***
Easy to develop individual lots, ***and***	Groundwater close to excavation levels.	Development of individual lots in Holocene Alluvium (settlement, groundwater issues), ***or***,
Low groundwater levels		Development of individual lots in Tauranga Group (incl Puketoka Formation) within 200m of the coast (lateral spread risk in the design earthquake).

These assessed development premiums for individual areas are summarised on Figures 30-32, and a summary of the category of development premium associated with each development constraint is presented in Tables 7 and 8, with additional detail provided in Tables 9 to 11 below.

It is important to note that the broad scale nature of the assessment means that the highest geotechnical hazard or development constraint rating defines the development premium shown in the plans. There is no differentiation at this time between sites that have multiple "high" ratings and sites that have a single high rating. Development of a risk matrix to allow for this should be considered for future, more detailed, assessment programs.

5.5.3 Low 'Development Premium' Areas

For the purposes of earthworks and civil infrastructure areas of low development premium are typically those underlain by competent Waitemata Group derived soils, or Undifferentiated Northland Allochthon materials (where slopes are below 12 ^{o}) and typically situated away from any major watercourses or coastlines.

Earthworks and civil infrastructure in low development premium areas are not expected to present significant difficulty, however if excavations extend into hard Waitemata Group rock, these would be both more time consuming and expensive. Planning constraints on both noise and vibration levels would also need to be considered. Geotechnical investigations are recommended to determine the depth to the top of the rock layers for significant earthworks or civil infrastructure projects.

For individual property development it is expected that areas considered to exhibit a low development premium are those again underlain by Waitemata Group materials. While these materials may exhibit some shrink/swell potential, this can be mitigated relatively easily through the embedment of foundations to a minimum 600 mm depth.

Overall, low development premium areas generally include gently rolling hill country in the southwest of Kumeu Huapai, north of the Greenfield Investigation Areas and through the centre of Red Hills and Red Hills North as well small parts of Silverdale West Business and Dairy Flat. The majority of Warkworth can be considered low premium, with the exception of steep gully side slopes and infilled low lying channels. As noted in Section 5.5.1, this assessment is based entirely on interpretation of the published geological maps and our understanding of the various soil types present within each of geological unit. It is important to realise that there may be isolated areas of unfavourable ground conditions with study areas that have been identified as having a low or medium development premium. Geotechnical investigations would be required to accurately delineate these zones.

5.5.4 Medium 'Development Premium' Areas

Our experience with earthworks and civil infrastructure projects around the Auckland region indicates that areas dominated by alluvial soils (both Holocene alluvium and Puketoka Formation deposits) are likely to have a medium development premium for future urban development. These types of materials are typically moderately to highly compressible and may require either a high level of conditioning or excavation and removal from future building platforms. Furthermore, the placement of new fill over compressible soils (peat and soft alluvium) may initiate consolidation settlement that will require periods of 12 months or more to occur before construction can commence on site. Other works such as wick drains and pre-loading may also need to be carried out to accelerate such settlement. The time period required to allow for settlements prior to the construction of dwellings and infrastructure would depend on the thickness of fill placed, depth of alluvial soils present and the presence of peat. This would all need to be confirmed during geotechnical investigation and design of individual sites.

Ignimbritic silts are present within Puketoka Formation deposits and these materials are both highly sensitive and difficult to work, owing to their narrow optimum moisture content range, i.e. the soils can be difficult to handle/earthwork when they are either too dry or too wet. Appropriate conditioning and management of the soils is therefore required for earthworking of these materials.

Although not identified on all locations on Figures 4 to 13 in Appendix A, localised areas of alluvium and peat are likely to be present along the margins of bodies of water (streams, creeks and coastal fringes).

The less stable alluvial soils which are present within these investigation areas typically have lower strength than soils derived from Waitemata Group or Northland Allochthon materials and therefore may fail under moderate loading. The result is less favourable bearing stratum in terms of road infrastructure. Ground improvement comprising lime stabilisation or sub-excavation and replacement of soft soil with hardfill may be required to improve ground conditions.

Differential settlement rates of alluvial soils; particularly where peat and other organics are present will need to be considered for both road construction and service infrastructure. Differing settlement rates along lengths of pipes can affect the grade and performance of pipes while differential settlement in roads can cause ponding and water infiltration into pavement layers, compromising the overall performance of the road.

Due to the relatively high groundwater levels present in coastal and low lying areas, groundwater inflow and drawdown should be considered when undertaking excavations for services

installation. Lowering local groundwater levels can result in consolidation settlements in neighbouring structures and infrastructure. There is potential for groundwater to be present within foundation excavations which will influence construction by lowering stability and requiring dewatering which could induce drawdown and result in settlements. Deeper foundations particularly cast *in-situ* concrete piles may also require casing through the upper saturated soils.

With respect to individual lot investigation areas underlain by Tauranga Group (including Puketoka Formation) and Undifferentiated Northland Allochthon are likely to have a medium development premium based on their shrink/swell properties and potential for building settlements respectively.

Medium development premium areas include low lying areas of Dairy Flat, Silverdale, Wainui East in the Silverdale investigation area, while in the Kumeu-Whenuapai area, the eastern Future Business region, Brigham Creek and Kumeu Huapai where Tauranga Group materials are the underlying geology. Other areas are present through Silverdale, Okura and Wainui East where Allochthon mudstones are present. These areas are illustrated on Figures 30-32 and summarised in Table 9 below.

5.5.5 High 'Development Premium' Areas

The areas of high development premium associated with earthworks and civil infrastructure are typically in locations of known instability. These areas have been isolated by visual identification from aerial photography and our previous knowledge and experience within the potential investigation areas.

The primary geological unit considered significantly prone to instability due to earthworking is the Undifferentiated Northland Allochthon, where the instability risk is considered high for even modest earthworks on slopes as gentle as 12 °. Our past experience has informed this judgement, where earthworked slopes with increased surcharge load or where over-steepened by cut can induce slope instability at low slope angles, especially when influenced by high groundwater.

For individual lot development a high development premium has been placed on areas of known instability and highly compressible soils associated with Holocene Alluvium. Tauranga Group (including Puketoka Formation) material within 200m of the coast is also considered to have a high development premium due to the potential for lateral spreading associated with liquefaction during the design earthquake.

Coastal areas are considered to be at risk of cliff face retreat/erosion as well as seismic instability. It is generally accepted that Waitemata Group cliff faces retreat at a rate of approximately 5 to 10 m horizontally per 100 years. These areas include the coastal fringe of the Riverhead, Brigham Creek and Riverhead north and east sections of the Greenfield Investigation Areas.

High development premium areas include many identified instability around Okura-Weiti, Dairy Flat, the southern extents of Red Hills and Kumeu-Huapai as well as the fringe surrounding Warkworth. Other high premium areas include the coastal fringe around Whenuapai and Brigham Creek and Holocene infill in channels through Red Hills North, Kumeu-Huapai, Warkworth and Wainui East. These areas are illustrated on Figures 30-32 and summarised in Tables 7 and 8 below.

Table 7 - Development Premium for Earthworks & Civil Infrastructure in Investigation Areas

Kumeu-Whenuapai (Refer to Figure 30 in Appendix A for details).

Area	Kumeu Huapai	Future Business	Brigham Creek	Red Hills North	Red Hills	Scott Point	Riverhead	Greenfield Investigation Areas
Low				X	X			X
Medium	X	X	X	X	X	X	X	X
High								

Warkworth (Refer to Figure 31 in Appendix A for details).

Area	Warkworth North and East	Warkworth	Warkworth South	Hepburn Creek	Future Business
Low	X	X	X	X	X
Medium					
High					

Silverdale (Refer to Figure 32 in Appendix A for details).

Area	Wainui East	Silverdale West Business	Silverdale West	Dairy Flat	Okura/Weiti
Low		X			
Medium	X	X	X	X	
High	X			X	X

Table 8 - Development Premium for Individual Lots in Investigation Areas

Kumeu-Whenuapai (Refer to Figure 30 in Appendix A for details).

Area	Kumeu Huapai	Future Business	Brigham Creek	Red Hills North	Red Hills	Scott Point	Riverhead	Greenfield Investigation Areas
Low				X	X			X
Medium	X	X	X	X	X	X	X	X
High						X		

Warkworth (Refer to Figure 31 in Appendix A for details).

Area	Warkworth North and East	Warkworth	Warkworth South	Hepburn Creek	Future Business
Low	X	X	X	X	X
Medium					
High					

Silverdale (Refer to Figure 32 in Appendix A for details).

Area	Wainui East	Silverdale West Business	Silverdale West	Dairy Flat	Okura/Weiti
Low		X		X	X
Medium	X	X	X		
High	X			X	X

6 Summary

Figures 30-32 in Appendix A present a combined summary of our assessed premium for developing land with the various geotechnical hazards and constraints outlined in Sections 5 and 6. Overall with regard to the hazards assessed, the North and North-West Auckland RUB areas have been categorised primarily as either Low or Medium Development Premium with some concentrated zones of High Development Premium. In the areas of High Development Premium, we consider that the areas are susceptible to one or more geotechnical hazards and/or development constraints, e.g. slope instability, lateral spreading and /or settlements from liquefaction, seasonal shrink/ swell, coastal erosion or consolidation settlement.

It is important to note that the land classified as high development premium is not necessarily geotechnically unsuitable for development but it is likely to require greater engineering oversight to support typical urban development, e.g. major earthworks, ground improvements, deep foundations, retaining structures and groundwater control. Land categorised as having a high development premium could therefore be expected to be developable at a cost premium and with some residual risk of future geotechnical issues. Also, given the high level approach of this report, isolated areas considered to have a high development premium may have the characteristics of those low development premium options.

Moreover, regions of low and medium development premium are expected to incur lower development constraints, however this does not preclude localised areas of unsuitable geotechnical conditions or varied subsurface conditions from those inferred in this report. Further geotechnical investigation would, therefore, still be required.

A summary of the information outlined in the above sections is presented on Figures 4 to 29 and on Tables 9 -11 below. It is noted that this information is provided for high level planning purposes and should not be used for detailed planning, consenting or engineering design. Geotechnical investigations are recommended as part of any future planning assessment to confirm and validate the preliminary conclusions and recommendations presented in this document and in associated appendices.

If, during development of areas covered within this report, ground conditions are identified as being different to those documented, the conclusions, findings and hazard maps contained should be reviewed and refined where appropriate.

Table 9: Summary of Predominant Geotechnical Hazards and Considerations for Future Urban Development in Kumeu-Whenuapai (Refer to Figure 30 for details)

Geotechnical Consideration/Issue	Assessed Hazard Potential/Development Premium for Urban Land Development								
	Hazard Categories	**Kumeu Huapai**	**Red Hills**	**Red Hills North**	**Future Business**	**Scott Point**	**Riverhead**	**Brigham Creek**	**Greenfield Investigation Areas**
Slope Instability Potential	Low to moderate surface relief	✓	✓	✓	✓	✓	✓	✓	✓
	Medium slope stability hazard around watercourse and gullies.	✓	✓	✓	✓	✓	✓	✓	✓
	Earthworks may be required to form stable slopes and building platforms.	✓	✓	✓	✓	✓	✓	✓	✓
	Risk of erosion/foreshore retreat around coastal fringe	✗	✗	✗	✗	✓	✓	✓	✓
Liquefaction Potential	Low regional groundwater levels.	✓	✓	✗	✗	✗	✗	✗	✗
	Low to moderate regional groundwater levels.	✗	✗	✓	✓	✗	✗	✗	✓
	Moderately high regional groundwater levels.	✗	✗	✗	✗	✓	✓	✓	✗
	Presence of some loose sand/silt lenses.	✓	✗	✗	✓	✓	✓	✓	✓
	Predominantly cohesive (clayey) soils– negligible liquefaction hazard.	✗	✓	✗	✗	✗	✗	✗	✗
	Lateral spread risk around open faces (e.g. coastline/foreshore) and slopes.	✗	✗	✗	✓	✓	✓	✓	✓
	Detailed investigations recommended to qualify/quantify possible liquefaction effects.	✓	✗	✓	✓	✓	✓	✓	✓
Soil Compressibility and Building Settlement Potential	Presence of stiff Undifferentiated Tauranga Group material, suitable for construction of most buildings on shallow foundations.	✓	✓	✓	✓	✓	✓	✓	✓
	Presence of stiff to very stiff Waitemata Group residual material, suitable for construction of most buildings on shallow foundations.	✗	✓	✓	✗	✗	✗	✗	✓
	Localised areas/zones of highly compressible soils which may necessitate either ground improvement or deep foundations.	✓	✓	✓	✓	✗	✓	✓	✓
	Areas of highly compressible soils (peat) that may necessitate either ground improvement or deep foundations.	✗	✗	✗	✗	✓	✗	✗	✗
Earthworks Development Premium	Moderately compressible soils (settlement under new fill) with possible drainage requirements.	✓	✗	✓	✓	✓	✓	✓	✓
	Low soil compressibility potential.	✗	✓	✗	✗	✗	✗	✗	✗
	Predominantly comprised of Waitemata Group residual material	✗	✓	✗	✗	✗	✗	✗	✗
	Ignimbritic silts present in Undifferentiated Tauranga Group material which may be difficult to earthwork/handle	✓	✗	✓	✓	✓	✓	✓	✓
	Possible 'unsuitable' soils (peat/organic clays) may require removal from site.	✗	✓	✓	✓	✓	✓	✓	✓
	Areas of high hazard potential are present in regions of high relief and areas of known instability.	✓	✓	✓	✓	✓	✓	✓	✓

Table 9: Summary of Predominant Geotechnical Hazards and Considerations for Future Urban Development in Kumeu-Whenuapai (continued)

Geotechnical Consideration/Issue	Assessed Hazard Potential/Development Premium for Urban Land Development								
	Hazard Categories	**Kumeu Huapai**	**Red Hills**	**Red Hills North**	**Future Business**	**Scott Point**	**Riverhead**	**Brigham Creek**	
Civil Infrastructure Development Premium	Possible drainage requirements in localised areas with moderate to high groundwater levels	✓	✓	✓	✓	✓	✓	✓	✓
	Predominantly low soil compressibility	✗	✓	✗	✗	✗	✗	✗	✗
	Possible requirement for road subgrade stabilisation/ground improvements particularly in localised regions of high relief/known instability.	✓	✓	✓	✓	✓	✓	✓	✓
Individual Property Foundations Development Premium	Stiff to very stiff Tauranga Group soils.	✓	✓	✓	✓	✓	✓	✓	✓
	Stiff to very stiff Waitemata Group residual soils	✓	✓	✓	✓	✗	✗	✗	✓
	Minor presence of highly compressible material promoting settlement potential risk.	✗	✓	✗	✗	✗	✗	✗	✗
	Some highly compressible material promoting settlement potential risk.	✓	✗	✓	✓	✗	✗	✗	✓
	Highly compressible material promoting settlement potential risk.	✗	✗	✗	✗	✓	✗	✗	✗
	Some regions of high hazard potential are present in regions of high relief and areas of known instability.	✓	✓	✓	✓	✓	✓	✓	✓
	Lateral spread potential near the coastal margin.	✗	✗	✗	✗	✓	✓	✗	✓
Overall Assessed Development Premium (Figure 30)		Medium to High	Low to Medium	Low to Medium	Medium	Medium to High	Medium	Medium	Low to Medium
Suitable Urban Development Type		**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.

Table 10: Summary of Predominant Geotechnical Hazards and Considerations for Future Urban Development for Warkworth (Continued)

Geotechnical Consideration/Issue	Assessed Hazard Potential/Development Premium for Urban Land Development					
	Hazard Categories	**Warkworth North and East**	**Warkworth**	**Warkworth South**	**Future Business**	**Hepburn Creek**
Slope Instability Potential	Low to moderate surface relief.	✓	✓	✓	✓	✓
	Risk of erosion/foreshore retreat around coastal fringe.	✓	✓	✗	✗	✓
	Medium slope stability hazard around watercourse and gullies.	✗	✓	✓	✓	✓
	Medium to high slope stability hazard around watercourse and gullies.	✓	✗	✗	✗	✗
	Additional earthworks may be required to form stable slopes and building platforms.	✓	✓	✓	✓	✓
Liquefaction Potential	Expected low regional groundwater levels.	✗	✗	✓	✓	✗
	Expected moderate to high regional groundwater levels.	✓	✓	✗	✗	✓
	Predominantly cohesive (clayey) soils overlying Waitemata Group rock - negligible liquefaction hazard.	✗	✓	✗	✗	✓
	Predominantly cohesive (clayey) soils overlying Waitemata Group or Northland Allochthon rock - negligible liquefaction hazard.	✓	✗	✓	✓	✗
	May be some localised areas of medium liquefaction hazard towards the western boundary where Holocene Age Alluvium is present.	✓	✓	✓	✗	✗
	Lateral spread risk around open faces (e.g. coastline/foreshore) and slopes.	✗	✓	✗	✗	✓
	Detailed investigations recommended to qualify/quantify possible liquefaction effects.	✗	✓	✗	✗	✓
Soil Compressibility and Building Settlement Potential	Presence of stiff to very stiff Undifferentiated Tauranga Group soils suitable for construction of most buildings on shallow foundations.	✓	✗	✓	✗	✗
	Presence of stiff to very stiff Waitemata Group residual soils suitable for construction of most buildings on shallow foundations.	✓	✓	✓	✓	✓
	Presence of stiff to very stiff Northland Allochthon residual soils suitable for construction of most buildings on shallow foundations.	✓	✓	✗	✓	✗
	Some localised areas of highly compressible soils are present towards the western boundary which may necessitate either ground improvement or deep foundations.	✓	✓	✓	✗	✗
Earthworks Development Premium	Typically low soil compressibility potential.	✓	✓	✓	✓	✓
	Low soil compressibility potential, with some highly compressible materials	✓	✗	✗	✗	✗
	Largely comprised of Waitemata Group/Northland Allochthon residual material.	✓	✓	✓	✓	✓
	Some potentially difficult to earthwork ignimbritic silts within the Undifferentiated Tauranga Group.	✓	✗	✓	✗	✗
	Possible 'unsuitable' soils (peat/organic clays) may require removal from site.	✓	✗	✓	✗	✗
	Areas of high hazard potential are present in regions of high relief and areas of known instability.	✓	✓	✓	✓	✓

ivil Infrastructure Development Premium	Typically low soil compressibility potential.	✓	✓	✓	✓	✓
	Possible drainage requirements in localised areas of high groundwater positions.	✓	✓	✗	✗	✓
	Possible requirement for road subgrade stabilisation/ground improvements particularly in localised regions of high relief/known instability.	✓	✓	✓	✓	✓
Individual Property Foundations Development Premium	Stiff to very stiff Tauranga Group soils.	✓	✓	✓	✗	✗
	Stiff to very stiff Waitemata Group residual soils	✓	✓	✓	✓	✓
	Stiff to very stiff Northland Allochthon residual soils	✓	✓	✗	✓	✗
	Minor presence of highly compressible material promoting settlement potential risk.	✓	✓	✓	✗	✗
	Northland Allochthon material susceptible to shrink/swell issues.	✓	✗	✗	✓	✗
	Some regions of high hazard potential are present in regions of high relief and areas of known instability.	✓	✓	✓	✓	✓
Overall, Predominant Assessed Development Premium (Figure 31)		**Low**	**Low**	**Low**	**Low**	**Low**
Suitable Urban Development Type		**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group/Northland Allochthon** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group/Northland Allochthon** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.

Table 11: Summary of Predominant Geotechnical Hazards and Considerations for Future Urban Development for Silverdale (Refer to Figure 32 for details)

Geotechnical Consideration/Issue	Assessed Hazard Potential/Development Premium for Urban Land Development					
	Hazard Categories	**Wainui East**	**Silverdale West**	**Silverdale West Business**	**Dairy Flat**	**Okura/Weiti**
Slope Instability Potential	Low to high surface relief.	✗	✗	✗	✗	✓
	Typically low surface relief, with localised areas of high slope instability potential where Northland Allochthon material is present and steep surface relief.	✓	✓	✓	✓	✗
	Typically low regional ground groundwater levels.	✓	✓	✓	✓	✗
	Medium to high slope stability hazard around watercourses and gullies. Additional earthworks may be required to form stable slopes and building platforms.	✓	✓	✓	✓	✓
	Risk of erosion/foreshore retreat around coastal fringe	✗	✗	✗	✗	✓
Liquefaction Potential	Low regional groundwater levels.	✓	✓	✓	✓	✓
	Predominantly cohesive (clayey) soils– negligible liquefaction hazard.	✓	✓	✓	✓	✓
	Some localised areas of medium liquefaction hazard where loose silt/sand lenses are present and localised areas of high groundwater tables.	✓	✓	✓	✓	✓
	Lateral spread risk around open faces (e.g. coastline/foreshore) and slopes.	✗	✗	✗	✗	✓
	Detailed investigations recommended to qualify/quantify possible liquefaction effects.	✗	✗	✗	✗	✓
Soil Compressibility and Building Settlement Potential	Presence of stiff to very stiff Undifferentiated Tauranga Group soils suitable for construction of most buildings on shallow foundations.	✓	✓	✓	✓	✓
	Presence of stiff to very stiff Waitemata Group residual material suitable for construction of most buildings on shallow foundations.	✓	✓	✗	✓	✓
	Presence of stiff to very stiff Northland Allochthon residual material suitable for construction of most buildings on shallow foundations.	✓	✓	✓	✓	✓
	Some localised areas of highly compressible soils are present towards the southern boundary which may necessitate either ground improvement or deep foundations.	✗	✗	✗	✗	✓
Earthworks Development Premium	Low to moderate compressible soils (settlement under new fill) with possible drainage requirements.	✗	✓	✗	✗	✗
	Moderately compressible soils (settlement under new fill) with possible drainage requirements.	✓	✗	✓	✓	✓
	Ignimbritic silts present – may be difficult to earthwork/handle	✓	✓	✓	✓	✗
	Possible 'unsuitable' soils (peat/organic clays) may require removal from site.	✗	✗	✗	✗	✓
	Some areas of high hazard potential are present in regions of high relief and areas of known instability.	✓	✓	✓	✓	✗
	Multitudes of high hazard potential areas are present in regions of high relief and areas of known instability.	✗	✗	✗	✗	✓

Table 11: Summary of Predominant Geotechnical Hazards and Considerations for Future Urban Development for Silverdale (Continued)

Geotechnical Consideration/Issue	Assessed Hazard Potential/Development Premium for Urban Land Development					
	Hazard Categories	**Wainui East**	**Silverdale West**	**Silverdale West Business**	**Dairy Flat**	**Okura/Weiti**
Civil Infrastructure Development Premium	Possible drainage requirements in localised areas of high groundwater positions.	✓	✓	✓	✓	✓
	Possible requirement for road subgrade stabilisation/ground improvements particularly in localised regions of high relief/known instability.	✓	✓	✓	✓	✓
Individual Property Foundations Development Premium	Stiff to very stiff Tauranga Group soils	✓	✓	✓	✓	✓
	Stiff to very stiff Waitemata Group residual soils	✓	✗	✗	✓	✓
	Stiff to very stiff Northland Allochthon residual soils	✓	✓	✓	✓	✓
	Minor presence of highly compressible material promoting settlement potential risk	✗	✗	✗	✓	✓
	Northland Allochthon material also susceptible to shrink/swell issues.	✓	✓	✓	✓	✓
	Regions of high hazard potential are present in areas of high relief and areas of known instability.	✓	✓	✓	✗	✓
Overall Assessed Development Premium (Figure 32)		**Medium to High**	**Medium to High**	**Medium**	**Medium**	**High**
Suitable Urban Development Type		Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 2 storeys) Retail/Commercial buildings (> 2 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.	**Areas Underlain by Holocene Alluvium** Residential dwellings (single storey only) All other buildings on pile foundations **Areas Underlain by Waitemata Group/Undifferentiated Tauranga Group** Residential dwellings (1 to 3 storeys) Retail & commercial buildings (1 to 3 storeys) Retail/Commercial buildings (> 3 storeys) and residential towers supported on pile foundations.

7 Conclusions

The RUB project has been set up to define the rural-urban of Auckland through to 2040 and to provide sufficient land for development to meet the expected growth of Auckland over the next 30 years. Auckland Council has identified land packages around Silverdale, Warkworth and Whenuapai to Kumeu (refer to Figures 1-3, Appendix A) for possible future urban development. Specific areas within these land packages have been proposed for development. The purpose of this report is to assess the suitability for development of these areas with respect to geotechnical conditions. The conclusions of this assessment are provided below.

The proposed investigation areas are generally underlain by one of three distinct geological units. The geological units, when combined with groundwater conditions and topographical profiles, help define the geotechnical suitability and constraints for future development in these areas.

- The Warkworth investigation areas are typically underlain by stiff residual soils weathered from the underlying Waitemata Group rock mass. Northland Allochthon is also present, rarely, in Warkworth North & East and local low lying stream channels have a variety of Holocene Age (recent alluvium) and Pleistocene Age (Tauranga Group) alluvial soils.
- The Silverdale investigation areas are typically underlain by residual soils weathered from Waitemata Group or Northland Allochthon rock masses, which are typically tectonically deformed in this area. Large areas of low lying paleo channels have been infilled with Tauranga Group and Holocene Alluvium, which overlie the Waitemata Group or Northland Allochthon.
- The Kumeu – Whenuapai investigation areas are largely dominated by Puketoka Formation and Holocene Alluvium, overlying Waitemata Group at depth. Residual soils weathered from the Waitemata Group form the rolling hill country through the centre of Red Hills North, Red Hills and western Kumeu-Huapai.

The typical geological conditions are presented on Figures 4 to 13 (Appendix A). Localised areas where geology differs to the conditions outlined are expected across these areas, particularly in proximity to identified geological boundaries. These areas would need to be identified by specific investigations.

Groundwater is expected to be present between 0 and 3 m below ground level within low lying and coastal areas, while groundwater is likely to be encountered below 3m depth in inland areas, depending on the thickness of residual soil cover.

As part of our desk study assessment we have identified the following key geotechnical hazards and potential constraints for urban development which will affect the development of each land package to some extent.

Geotechnical Hazards:

- Slope Instability
- Liquefaction
- Soil Compressibility

Development Constraints:

- Earthworks
- Civil infrastructure
- Individual property development

In general none of the geotechnical hazards or development constraints outlined above would prevent future urban development; however each hazard and/or development constraint will

have an associated premium for development of the land. Tables 9 to 11 (Section 7) identify the key hazards and constraints for each investigation area and outline how susceptible each area is to the specific hazard and/or development constraint. Conceptual development types within each area are also identified with respect to the various geotechnical conditions (these concepts do not limit or preclude other options).

In conclusion, the areas where the lowest geotechnical development premium can be expected include large parts of Red Hills North, Red Hills, parts of Silverdale West Business and Dairy Flat and much of the various Warkworth investigation areas.

We note that this assessment is only based on geotechnical issues and construction constraints and other development issues (for example environmental impact) may be as significant or more significant in the overall assessment, particularly when comparing the merits of "low" and "medium" development premium areas.

Areas which we consider to have a high premium associated with future development are presented on Figures 30 to 32 (Appendix A). These areas have been identified as being susceptible to one or more significant geotechnical hazards and/or development constraints. Geotechnical investigations would be required to more accurately delineate these zones.

In summary these areas are:

- The coastal fringes of **Brigham Creek**, **Whenuapai Future Business**, and **Warkworth North & East** (adjacent to Matakana Stream);
- Low lying areas underlain by Holocene Alluvium in **Red Hills North**, **Kumeu-Huapai**, **Wainui East**, **Warkworth** and **Warkworth North & East**;
- Large parts of hill country in **Okura-Weiti**, **Dairy Flat**, **Wainui East** and **Silverdale** investigation areas;
- Isolated gully heads in hill country in the south and west of **Red Hills**, **Red Hills North** and **Kumeu-Huapai** investigation areas and to the north and south of **Warkworth North & East** and **Warkworth South**.

While these areas of "high" development premium are present across many of the investigation areas, these do not necessarily preclude development; however the premium associated with development may be substantial. The plans provided should be used as a guide to highlight areas where a higher level of geotechnical investigation, design and construction monitoring will be required and to ensure that development in these areas is appropriately controlled. The boundaries between areas are based on a broad analysis of existing data and can be refined at individual locations following completion of site specific geotechnical investigations. Such investigations would also enable the delineation of local geotechnically unsuitable zones within the wider study areas that could be specifically excluded from the RUB.

8 Applicability

This report has been prepared for the benefit of Auckland Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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Appendix A: Figures