DRURY – OPAHEKE STRUCTURE PLAN BACKGROUND INVESTIGATIONS GEOTECHNICAL AND COASTAL EROSION ASSESSMENT

Engineers and Geologists

RILEY CONSULTANTS LTD
New Zealand
Email: riley@riley.co.nz
Email: rileychch@riley.co.nz
Web: www.riley.co.nz

AUCKLAND
4 Fred Thomas Drive, Takapuna, Auckland 0622
PO Box 100253, North Shore, Auckland 0745
Tel: +64 9 489 7872 Fax: +64 9 489 7873

CHRISTCHURCH
22 Moorhouse Avenue, Addington, Christchurch 8011
PO Box 4355, Christchurch 8140
Tel: +64 3 379 4402 Fax: +64 3 379 4403

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Report prepared for: Auckland Council

Report prepared by: James Beaumont, Senior Geotechnical Engineer

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Report reviewed and approved for issue by: Brett Black, Director, CPEng

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Executive Summary

Riley Consultants Ltd (RILEY) has been engaged by Auckland Council (Council) to prepare a geotechnical and coastal erosion assessment for the Drury – Opaheke Structure Plan (DSP) study area. The study area currently has a future urban zoning. The purpose of the assessment is to identify constraints and opportunities to assist with planning for future urban development, and inform Council of identified potential geotechnical and coastal hazards in the study area.

The DSP area is U-shaped and straddles the southern motorway. It extends from near the foot of the Hunua Ranges in the east. The Drury fault is also located at the foot of the Hunua Ranges oriented in a north-south direction. East of the southern motorway, the study area abuts the existing industrial area adjacent to Hunua Road in the north and existing residential housing of Papakura and Drury in the west. To the south it is bounded by the Hingaia Stream. West of the southern motorway, the study area is bounded by Oira Creek to the west, and Pahurehure Inlet and land currently under development to the north. It extends as far south as Cheriton Lane.

The scope of work comprises a desktop review of geotechnical information to hand within and in the immediate vicinity of the DSP. A site walkover of selected parts of the area that are publicly accessible has also been undertaken. This report draws on recommendations from work completed by others and also provides comment regarding the proximity of the Drury Fault to the DSP area.

Previous reporting identified three main geotechnical hazards with the DSP area:

1. slope stability;
2. compressible organic and cohesive soils resulting in long-term consolidation settlement; and
3. liquefaction of fine granular soils during earthquake shaking.

Low development premium areas are considered to have less geotechnical constraints/hazards and are likely to be more economical to develop than medium development premium areas.

Tonkin + Taylor Ltd (T+T) (2013) carried out a broad assessment of most of the DSP area and proposed low, medium, and high development premium (cost) areas. The development premium assessment is a useful approach to assess the relative cost of development for the land across the DSP area as it takes geotechnical hazards (see Section 3.0) into account. It does not mean that development cannot occur in medium or high premium (cost) areas, although these areas will require a higher degree of engineering input for successful development than for areas classified having a low development premium.

The majority of the DSP area has been classified by T+T as being of medium development premium with high development premium areas, typically being identified in areas with steep slopes, adjacent to the lower reaches of the Hingaia Stream and coastal foreshore. Areas to the east of the southern motorway underlain by South Auckland Volcanic Field (SAVF) basalt have been assessed as having a low development premium. Refer to Section 4.6 for development types for differing premium areas.

In general, the development premium areas, as mapped by T+T, are considered appropriate, although we do note that due to changes in the Future Urban Zone (FUZ) as shown in the Auckland Unitary Plan-Operative in part (AUP-Op), there are some parts of the DSP area that were not covered in the T+T assessment and other areas where we have a differing opinion on the hazard potential assessments. Refer to Section 4.5 of the report and Appendix D. In these cases we have updated the geotechnical hazard maps to be consistent with our opinion regarding the hazard potential assessment and extended them to cover the parts of the DSP area not previously covered by the T+T maps.

The identified geotechnical constraints within the study area are not considered to be a fundamental obstacle to development of the identified future urban areas, provided development is undertaken consistent with the guidance provided in this report. Detailed assessment has been recommended to refine the geotechnical hazard potentials with a view to assist with appropriate identification of land into development premium areas.

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DRURY – OPAHEKE STRUCTURE PLAN
BACKGROUND INVESTIGATIONS
GEOTECHNICAL AND COASTAL EROSION ASSESSMENT

1.0 Introduction

Riley Consultants Ltd (RILEY) has been engaged by Auckland Council (Council) to prepare a geotechnical and coastal erosion assessment for the Drury – Opaheke Structure Plan (DSP) area. The study area currently has a future urban zoning. The purpose of the assessment is to identify constraints and opportunities to assist with planning for future urban development, and inform Council of identified geotechnical and coastal hazards in the study area.

RILEY has engaged the services of Davis Coastal Ltd to complete the coastal erosion aspects, while RILEY has addressed the geotechnical components of the assessment.

1.1 Scope and Purpose

The scope of work comprises a desktop review of geotechnical information to hand within, and in, the immediate vicinity of the DSP. A site walkover of selected parts of the area that are publicly accessible has also been undertaken. This report draws on recommendations from work completed by others for the DSP area.

1.2 Related Reports

A key article of previous work is that undertaken by Tonkin + Taylor Ltd (T+T) dated June 2013, which undertook a broad desktop based assessment of potential urban areas in South Auckland and possible geotechnical constraints on development. This included assessment of areas that overlap a substantial proportion (>75%) of the current study area. As such, the T+T 2013 assessment forms a significant basis for the current study. Copies of the T+T geotechnical plans are included within Appendix A.

In preparing this assessment report we have reviewed the following:

Table 1: Summary of related reports

Project/Report Name (Reference)	Prepared By	Reference	Date
Shane Lander – Statement of Evidence (Geotechnical Engineering), 29 Bellfield Road and 117 Opaheke Road, Papakura	Lander Geotechnical Ltd	None provided	3 Nov 2016
Tony Reynolds – Statement of Evidence (Hydrogeology), 29 Bellfield Road and 117 Opaheke Road, Papakura	T+T	None provided	3 Nov 2016
Geotechnical Investigation – Proposed Public Stormwater Line Pararekau Road, Karaka	RILEY	14150-AH	14 Jul 2016
Geotechnical Investigation Report, 29 Bellfield Road and 117 Opaheke Road, Papakura	Lander Geotechnical Ltd	J00213	23 Jun 2016

Project/Report Name (Reference)	Prepared By	Reference	Date
Drury South Project – Geotechnical Addendum Report	Beca	NZ1-7132642 0.5	30 Apr 2016
Geotechnical Investigation Report, Auranga Development, Stage 1 Qualifying Development, Bremner Road Drury	Lander Geotechnical Ltd	J00137	29 Apr 2016
Auranga Coastal Inundation Hazard Assessment	T+T	30935.001.v2	Apr 2016
Preliminary Geotechnical Appraisal Report, Auranga Development, Bremner Road, Drury	Lander Geotechnical Ltd	J00137	19 Jan 2016
Geotechnical Investigation Report – Proposed Industrial Subdivision	RILEY	15215-B	23 Oct 2015
Groundwater Investigation and Modelling – Proposed Karaka North Village (Cnr Dyke and Linwood Roads)	RILEY	13181/1-F	4 Nov 2014
Preliminary Geotechnical Investigation – Proposed Retirement Village Extension, 53 and 59 Pararekau Road, Karaka	RILEY	14150-F	7 Aug 2014
Wesley College: Paerata North SHA - Geotechnical Interpretive Report	Beca	3122921 // NZ1-8773319-41 0.41	4 Jul 2014
Wesley College: Paerata North SHA Preliminary Hydrogeological Assessment: Phase 1	Beca	3122921 // NZ1-8570856-12 1.3	7 May 2014
Geotechnical Investigation Report – Proposed Karaka North Village (Cnr Dyke and Linwood Roads)	RILEY	13181-B	23 Aug 2013
Geotechnical Desk Study – South Auckland Rural Boundary Project	T+T	29129	Jun 2013
Proposed Drury South Private Plan Change (No.12 and 38) – Geotechnical Review	Soil & Rock Consultants Ltd	11430	11 Apr 2013
Landslide Susceptibility for South Auckland Greenfield Areas – Glenbrook, Karaka, Kingseat, Paerata and Pukekohe	GNS	2012/225	Aug 2012
Geotechnical Investigation – 57 Firth Street, Drury	RILEY	11260-E	1 May 2012
Assessment of Activity of the Drury Fault, Papakura District in respect to planning for the proposed Crestview subdivision	GNS	5412-01	13 Dec 2004
Auranga Development, Coastal Hazard Assessment	Eco Nomos Ltd	None provided	26 Feb 2016

Some of the reports relate to land that is outside, but within, the vicinity of the DSP area. They have been considered to be relevant due to the presence of geological conditions consistent with parts of the DSP area. A selection of boreholes obtained from the New Zealand Geotechnical Database (NZGD) to assist with the assessment have also been reviewed.

2.0 Site Description and Geological Setting

2.1 Site Description

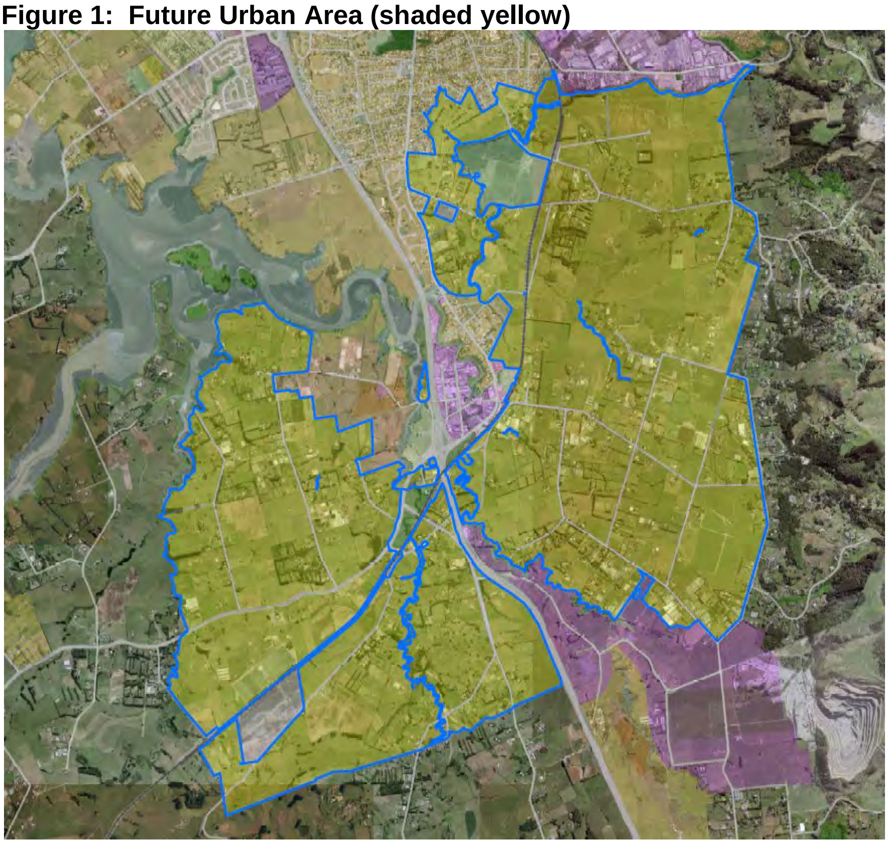
The extent of the DSP area is shown in Figure 1. The DSP is U-shaped and straddles the southern motorway. It extends from near the foot of the Hunua Ranges in the east. The Drury fault is also located at the foot of the Hunua Ranges oriented in a north-south direction. East of the southern motorway, the study area abuts the existing industrial area adjacent to Hunua Road in the north and existing residential housing of Papakura and Drury in the west. To the south it is bounded by the Hingaia Stream.

West of the southern motorway, the study area is bounded by Oira Creek to the west, and Pahurehure Inlet and land currently under development to the north. It extends as far south as Cheriton Lane.

The land is gently undulating with localised steep slopes typically being present adjacent to streams and the Pahurehure Inlet tidal zone. The landform generally falls towards Drury Creek, which is the confluence for a number of the streams that bisect the area. Some parts of the area adjacent to streams are flat, as are parts of the site in the east that are understood to be underlain by Holocene Age alluvial deposits (see Section 2.1 below).

Most of the area is currently used for rural and lifestyle block purposes with corresponding low densities. Structures on these properties range in size but typically comprise single dwellings with ancillary structures associated with rural and lifestyle uses.

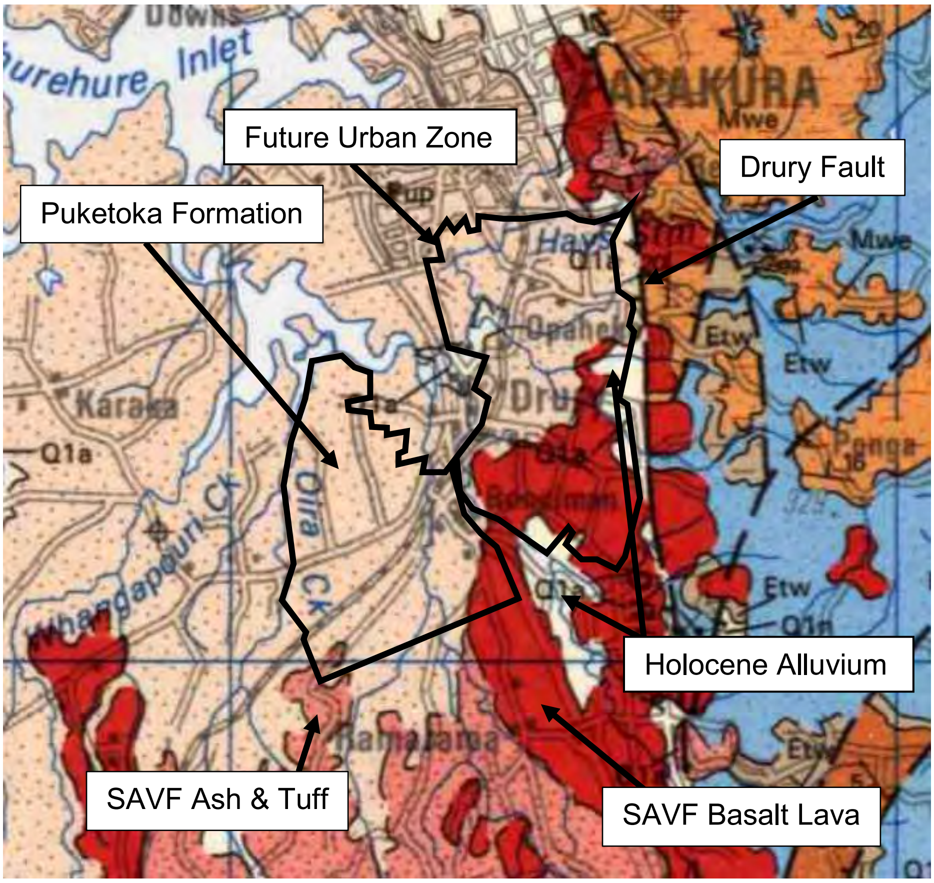
Figure 1: Future Urban Area (shaded yellow)



2.2 Geological Setting

The study area is situated on a mixture of volcanic derived and alluvial materials. Their distribution is shown in Figure 2. The mapped geological distributions are a simplification of the ground conditions.

Figure 2: Extract from Auckland 1:250,000 scale geological map (sheet 3), Edbrooke 2001



2.2.1 Basalt Lava

The basalt lava deposits typically have a weathered surface of between 2m and 10m thick, although this does vary and can be up to 20m, beneath which is fine grained basalt rock.

2.2.2 Ash and Tuff

Ash and tuff is mapped as being present over small area in the south-western part of the DSP. The ash typically comprises orange brown silty clay of moderate to high plasticity and can be up to 10m thick. Site-specific investigations in the vicinity of the DSP encountered a mantle of ash and tuff typically in the order of 2m thick overlying Puketoka Formation deposits.

The tuff is typically concentrated in rings around volcanic centres as proximal airfall deposits often comprising a mixture of volcanic and country rock materials (i.e. the explosion incorporates pre-existing soils and rock into the tuff as it pushes through the overlying material) and thus includes rock fragments of varying sizes. This typically comprises a sandy silt near surface transitioning to weakly welded beds of sand and silt size, but occasionally fine gravel. At depth the tuff beds can be of weak rock strength (1 – 2MPa, although reported as high as 5MPa by various geotechnical professionals).

2.2.3 Puketoka Formation

These are typically alluvial and estuarine deposits comprising sands, silts, clays and occasionally lensoidal peat or organic horizons. Primary rhyolitic ash and/or surge deposits have also been recognised overlying these materials (e.g. Cnr Dyke and Linwood Roads, Pararekau Road). Reworked rhyolitic (pumiceous) deposits are also commonly included.

These materials are highly variable in strength from soft to hard consistency. Generally, these materials are not highly compressible unless weaker materials and organics are subject to significant concentrated heavy loading.

Deposits of the East Coast Bays Formation (ECBF) are known to lie beneath the Puketoka Formation (refer to local geology map 3, Scale 1:250,000). These deposits typically comprise weak to very weak sandstones and siltstones. The geological map indicates that adjacent to the Pahurehure Inlet the rock dips at approximately 2° towards the south-west.

2.2.4 Recent Alluvium

Also termed Holocene alluvium, in reference to its geological age time of deposition, this typically comprises compressible clay, silt and organic material. This is typically found in isolated low-lying areas adjacent to streams and gullies. However, it is also found in localised flat areas where volcanic deposits have dammed a former stream and alluvial soils have been deposited in the lake formed behind. These Holocene deposits also extend towards the south of the study area to the land that was re-zoned as part of Stevensons Ltd business land plan changes (Papakura Plan Change 12 and Franklin Private Plan Change 38) to rezone approximately 223ha of land to the south of the DSP area from rural to industrial land uses.

2.2.5 Groundwater

Groundwater is at variable depth across the study area. Within low-lying land, it is often near-surface in winter, whilst beneath elevated areas it can be at 10m+.

2.3 Aerial Photographs.

A review of aerial photographs available through Council GIS and Google has been undertaken to identify any significant geomorphic features in the study area that may affect urban developing. The terrain map available on Council GIS has also been reviewed for the same purpose.

No large-scale obvious instability features were observed through review of the GIS aerial photographs.

2.4 Site Inspection

We visited the DSP area on 27 June 2017. Selected photographs from the site visits are included within Appendix B. We visited most areas of the site with a particular focus on the areas in the south-west and south-east where changes in geology were present, and where T+T had identified areas with a nominated ‘High Development Premium’ (i.e. the high cost to develop compared to low development premium land).

In general we found, as mentioned above, that the area is dominated by an undulating alluvial-type topography with the landform generally rising up towards the south and west. Down cutting by the numerous streams was visible with some streams being located in wide valleys, particularly the Ngakoroa Stream between Karaka Road and Runciman Road. It is not uncommon for recent alluvium to be present in wide valleys.

In other areas, the stream banks were more incised such as the Oira Creek (western DSP boundary). Localised slope instability was present at some locations adjacent to stream banks. South Auckland Volcanic Field (SAVF) ash soils were visible in the ploughed fields adjacent to Burtt Road and again in the soils exposed at the Bremner Road earthworks sites.

The landform undulations to the east of the motorway appeared to be generally more subdued than the land to the west of the motorway and is characterised by wide expanses of flat and gently sloping land. This is likely due to a higher density of streams than the land to the west resulting in more widespread downcutting. This higher stream density is particularly evident in the area between Hunua Road and Appleby Road.

No significant geomorphological features indicating deep-seated instability were observed.

2.4.1 Interpreted Ground Model

In assessing the potential geotechnical constraints on future urban development, we have assumed the following points with respect to the ground model:

- Ground conditions are assumed between known points. It is known the geological map is a simplification, and ground conditions will likely vary in some areas, and we have attempted to take this into consideration where known or suspected.
- Groundwater levels will be near-surface in low-lying ground underlain by recent alluvial deposits.
- Kaawa shell beds and Waitemata Group deposits ECBF are at sufficient depth not to significantly influence the ground model.
- Recent alluvial deposits are inferred to overlie all other units, whilst Puketoka Formation, basalt and ash/tuff are all contemporaneous and as such can overlie and interfinger with each other.
- Besides known fills adjacent to roads and bridges we are not aware of any significant fill deposits.

There is no evidence of geologically active faulting within the study area.

Based on our review of the available geotechnical information and our site visit we consider that the typical ground models for the area can be described as below:

- Volcanic ash of varying thickness but typically in the order of 2m thick, underlain by Puketoka Formation or Basalt. ECBF rock is known to be present at depths in the range of 60m to 70m from water bore drill hole records. Land gradients are generally gently to moderately sloping but steep adjacent to streams.
- In areas of Holocene age alluvium, volcanic ash is considered unlikely to be present at the surface. These materials are likely underlain by basalt at a depth in the order of 20m to 30m.

3.0 Geotechnical Hazards

3.1 General

Previous reporting has identified three main geotechnical hazards with the DSP area:

1. slope stability;
2. compressible organic and cohesive soils resulting in long-term consolidation settlement; and
3. liquefaction of fine granular soils during earthquake shaking.

We have also considered the hazard posed by the proximity of the Drury Fault to the DSP area.

3.2 Slope Stability and Coastal Erosion

3.2.1 Slope Stability

Previous work (T+T, 2013 and GNS Science, 2012) outlined risks of slope failure for various geological units based on slope angles. These are summarised in Table 2 below.

Table 2: Summary and comparison of hazard grading for differing slopes in various geological units

Geological Unit	Report Author	Slope Instability Potential – Slope Profile Limits*		
		Low	Moderate	High
Recent Alluvium	T+T	<10º	10º - 23º	>23º
	GNS	<10º	10º - 15º	>15º
Puketoka Formation	T+T	<10º	10º - 23º	>23º
	GNS	<10º	10º - 15º	>15º
South Auckland Volcanic Field Ash/Tuff	T+T	<18º	18º - 30º	>30º
	GNS	<5º	5º - 15º	>15º
South Auckland Volcanic Field Basalt Lava	GNS	<5º	5º - 15º	>15º

*note each site should be subject to specific review; these values are presented as guidelines only

GNS adopted a uniform range for instability susceptibility values due to the majority of the geological units having a similar range of slopes and, within the study area slope is more important than geology when assessing slope instability potential.

The generally lower slope angle ranges adopted by GNS for the instability potential categories results in more land area being identified as moderate or high susceptibility to instability than that shown by T+T 2013. Following our review of available information, we consider the GNS assessment provides a more appropriate depiction of instability potential, within the DSP area. The slope stability potential hazard map has been updated to reflect this view.

There was no obvious evidence of large-scale slope instability in the DSP area.

In general, the medium to high risk instability areas represent a relatively small proportion of the study area, and they are typically narrow and concentrated in the vicinity of streams throughout the DSP area. Small-scale instability was noted at some locations on moderate to steep slopes typically adjacent to streams and gullies. Such instability risks do not preclude future urban development, however, they will require additional input and assessment, as outlined below:

- Possible additional earthworks to form stable building platforms. For high instability potential areas large scale earthworks may be required to substantially alter landforms to improve 'global' stability.
- Possible installation of groundwater control measures.
- Possible construction of structural support measures, both temporary and permanent. For high potential areas, this may require large retaining structures to provide support to the land, which may comprise timber or reinforced concrete palisade walls or shear keys.
- For high instability potential land, the use of deep foundations where in close proximity to steep slopes for future structures.
- Likely additional engineering assessment, where for high instability potential this may be intensive.

On moderate instability potential areas, where earthworks have been undertaken to address any large-scale instability issues, specific engineering assessment on a lot-by-lot basis is unlikely to be required. For high instability potential land, lot-by lot assessment will likely be required.

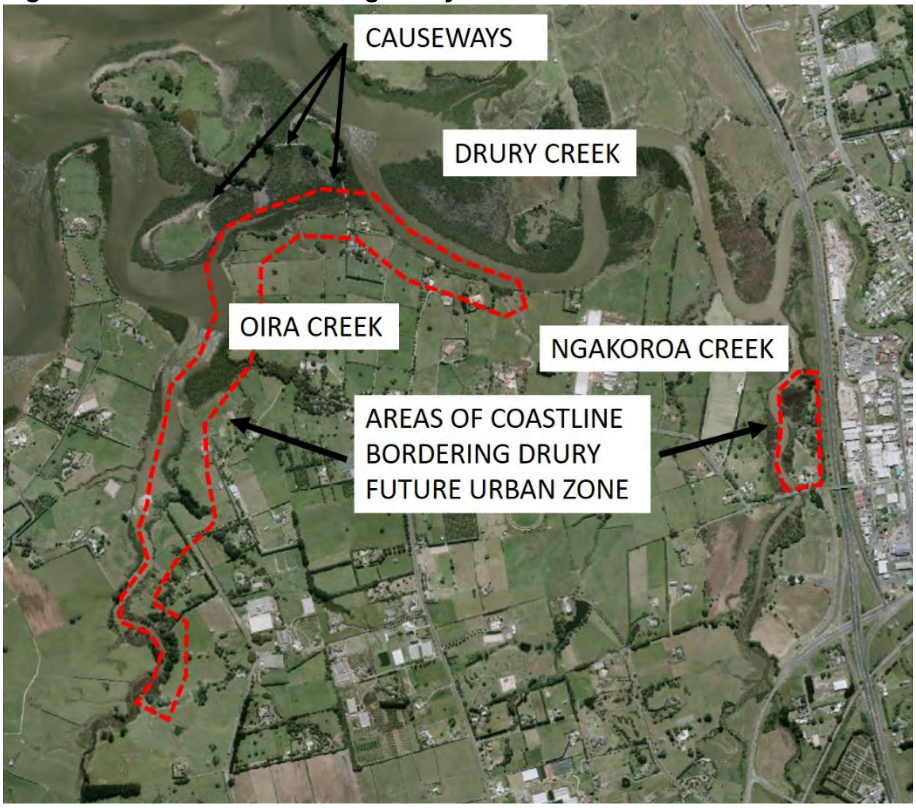
Smaller scale instability noted on moderate to steep slopes is typically adjacent to streams and gullies.

3.2.2 Coastal Erosion

Coastline within the Drury Future Urban Zone

Two small areas, comprising approximately 3.2km of coastline, border the Drury FUZ (Figure 3). These stretches of coastline are tidal areas of the upper Manukau Harbour comprising parts of the Drury, Oira and Ngakaroa Creeks.

Figure 3: Coastline bordering Drury Future Urban Zone



The morphology of the coastline, with a meandering river channel and platform to the base of steep and slumped fringing cliffs, suggests an area subject to progressive retreat. The low tide channel is relatively incised, with intertidal flats comprised primarily of very weathered rock to firm very stiff soils overlain with a veneer of soft estuarine silt. The depth of veneer increases at the outside of bends and embayed areas. The alignment of the shore line cliffs with the channel, and intensification of erosion based on the meander of the river, indicate that the coastline is dominated by fluvial and tidal current processes with deposition tending to occur on the inside of river bends, and erosional processes occurring on the outside. This is consistent with the remoteness from open ocean swells and lack of long fetches to develop wind waves.

Consistency of Hazard Assessment Methodologies

Council prepares multiple Structure Plans, including specialist reports, to inform on the specific geotechnical and coastal hazards of the subject zone.

Consistency across these assessments ensures a coherent and robust assessment of hazards across Council planning documents. Results of the assessments are also more readily recognisable and comparable between studies.

A Regional Assessment of Areas Susceptible to Coastal Erosion (RAASCE) was undertaken by the Auckland Regional Council in 2006. The report utilised a methodology on ‘soft cliffs’ used by the National Research Council in the UK to assess cliff erosion effects of sea level rise (Defra 2002). The same methodology was utilised for the assessment of the coastal erosion hazard for the Whenuapai Structure Plan (Aecom, 2016) and the method and terminology has been largely adopted in this assessment.

The site is more driven by fluvial processes, as opposed to primarily wave driven processes, which dominate the coastal erosion of the comparatively exposed coasts of the Whenuapai Plan and most of the coasts in the RAASCE. There is considerable judgement in adoption of the relevant variables providing opportunity to address the differing drivers. A similar methodology to the earlier reports is therefore considered to provide a suitable framework for the assessment in this location.

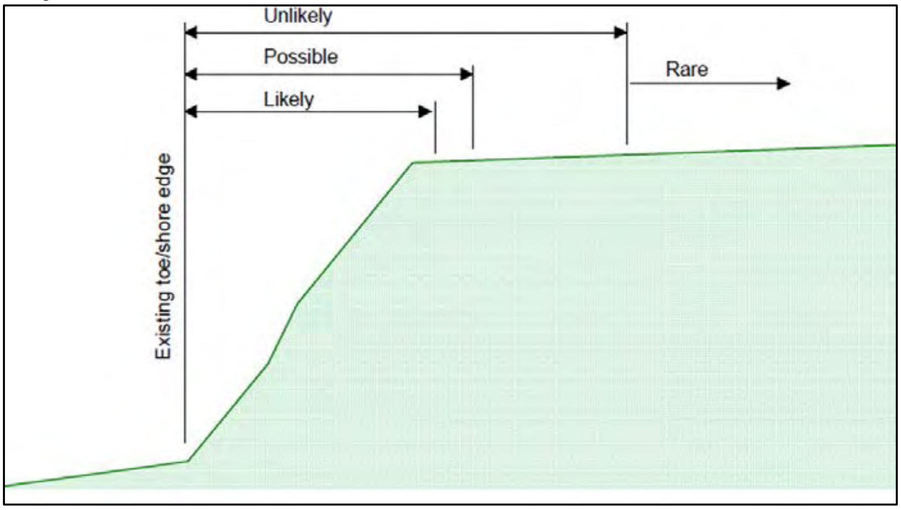
Methodology of Assessment

Providing an assessment of coastal erosion over longer timeframes involves a range of uncertainties. There is scientific debate about the relevant drivers and likely changes in these drivers with future climate change. Typically, limited data is available, especially for large-scale assessments, such as in a Structure Planning exercise and a measure of expert judgement is required. To account for these uncertainties, the Ministy for the Environment has recommended a risk-based approach (2009). The RAASCE adopted the following erosion risk categories:

- **Likely:** Probably will happen during the 100-year timeframe
- **Possible:** Might occur during the 100-year timeframe
- **Unlikely:** Unlikely to occur but possible during the 100-year timeframe

These relative risk areas are shown in the schematic figure below. A 'rare' category, defined as 'highly unlikely, but conceivable' was also included in the RAASCE, however, that has not been included in this report.

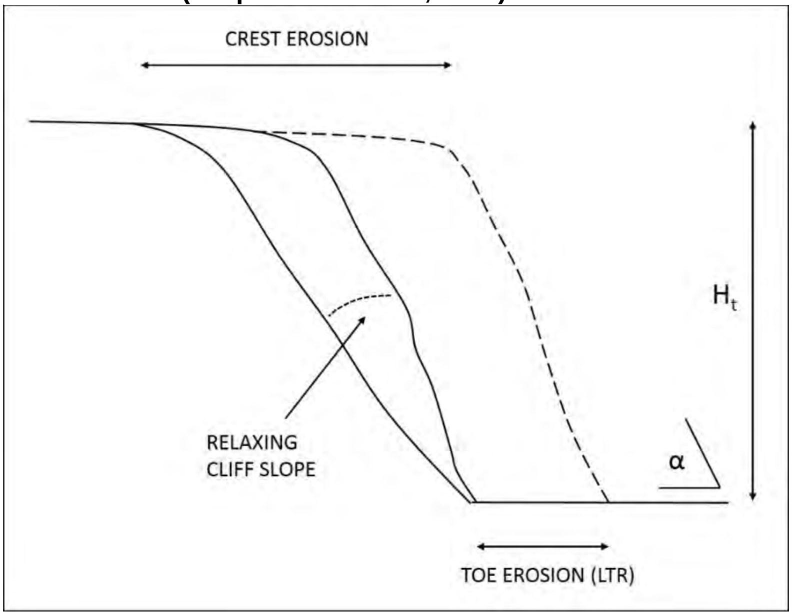
Figure 4: Risk-based approach to area susceptible to erosion over the next 100 years



The distance from the toe of the cliff that is at risk from coastal retreat can be considered as comprised of two parts (Figure 5).

1. **Long-Term Retreat** (LTR) of the toe of the cliff – this is assumed to increase as a result of future accelerated sea level.
2. **Cliff Slope Angle** (α) – relaxation (lessening) of the cliff slope due to weathering and/or geotechnical failure following toe retreat will cause retreat of the crest.

Figure 5: Long-term retreat of cliff assuming uniform lithology and structure (adapted from ARC, 2006)



This gives an area susceptible to erosion for soft cliffs defined by:

$$ASE_{Soft\_Cliffs} = \left[\left((LTR_{2120}) \times T\right) \times F + \left(\frac{H_t}{\tan\alpha}\right)\right]$$

Where:

LTR_{2120}	=	Horizontal coastline retreat (m) by 2120
T	=	Timeframe; 100 years
F	=	Allowance for uncertainty associated with long-term retreat rates
H_t	=	Height (m) of cliff from Council GIS data
α	=	The characteristic slope angle of the cliff surface measured from the horizontal.

The long-term retreat rate is based on measured historic retreat rates and an allowance for an increased rate of erosion due to sea level rise (Section 3.3).

An allowance for uncertainty in historic retreat rates (Section 3.1) of F = 1.25 was included in both the RAASCE and Aecom (2016). Estimate of the rate of retreat allowing for this factor has been adopted in this report.

The height of cliffs was obtained from Council GIS contours. With a relatively short coastline and relatively flat topography, cliff height could be estimated with some precision. Council GIS contours are given above mean sea level and the toe of cliff is generally at or about the high tide mark. Adopted cliff height was taken at 7m being 1m below the maximum top of bank contour indicated on the Council GIS plans.

Rate of Historic Retreat

Aerial surveys from the Council GIS System for 1996, 2001, and 2011 and aerial photography from 1942 and 1960 were used to calculate retreat of the most significantly affected areas of coastline. Recognisable locations on the photographs were used to scale and compare them to aerials.

Distances from man-made structures were measured and compared between aerial surveys, particularly between 2001 and 2011. Although these surveys represented only a 10-year timeframe they were of a higher resolution.

Cadastral survey plans of the coastline from 1918 and 1984 were compared and an assessment against the aerial surveys was attempted. This provided confirmation that retreat rates were of the correct order of magnitude.

Estimation of the long-term average rate of retreat was calibrated geomorphically, on the assumption that the channel has formed subsequent to sea-level rising to, at, or about, its existing elevation 6500 to 7500 years ago (Eco Nomos, 2016). Total channel width was measured on the Council GIS at external eroding bends and average erosion over this period calculated.

The retreat measured by these methods was at the limits of the resolution and accuracy of the surveys used, and the adopted rates were a combination of measured values, published rates for retreat of Auckland coastline, and expert judgement.

We have characterised the coastline into three sections (see Figure 6):

- **Type 1**: The northern extent of the site has been protected by infilling associated with islands and causeway development. This area is the most protected and it is assumed no further retreat will occur.
- **Type 2:** The majority of the site, with a morphology of historic erosion but little sign of recent erosion, and colonisation by mangroves of the intertidal area. A historic rate of retreat of 3m per 100 years (0.03m per annum) was adopted for this area.
- **Type 3:** Two portions of the coastline are on the outside of relatively broad bends and more at risk of rapid retreat. A historic rate of retreat of 6m per 100 years (0.06m per annum) was adopted for the most quickly eroding areas.

Sea Level Rise Allowance

Quantifying the extent of sea level rise is a subject of scientific debate and ongoing revision of the provisions. The most up to date MfE Guidance (2008) is to provide for 500mm and consider the consequences of 800mm between 2000 and 2100 with an allowance after this time of 10mm per annum. Therefore, for a 100-year planning timeframe (2117) an allowance of 980mm could be considered. This number could be decreased to allow for sea level rise that has already occurred between 2000 and 2017.

A more recent study for Council (NIWA 2011) recommended a risk-based approach including the allowance of 1m by 2115 and 2m sea level rise for Greenfield sites. The AUP-Op became operative in 2016 following statutory consideration of the NIWA recommendations. The AUP-Op (E36.3.9) requires *"...*coastal storm inundation areas to be above the 1 per cent annual exceedance probability (AEP) coastal storm inundation event including an additional sea level rise of 1m." In accordance with this we have adopted consideration of 1m sea level rise by 2120, or approximately 10mm per annum, for this report.

Future Retreat Rate including Sea Level Rise Effects

An increased rate in shoreline retreat proportional to the predicted increased rate in sea level rise has been used in previous studies (Defra 2002, ARC 2006).

This is represented in a formula adapted from those studies as:

$$LTR_{2120} = \left(LTR_H \times \left(\frac{SLR_F}{SLR_H}\right)\right)$$

Where:

LTR_{2120} = Horizontal coastline retreat (m) by 2120

LTR_H = Historic long-term retreat (regression rate), m/yr, based on public data sources and judgement.

SLR_H = Historic sea-level rise rate for Auckland (1.3mm/yr, Hannah (2004))

SLR_F = Future sea-level rise rate – 10mm/yr, refer Section 3.2

The approach is loosely based on the Bruun Rule for soft sediment beaches which is a basic empirical tool subject to ongoing scientific debate. However, no more sophisticated assessment or methodology has been recognised for large scale assessment of coastal response to sea level rise.

The site is more driven by fluvial processes, as opposed to primarily wave driven processes, which dominate the coastal erosion of the more exposed coasts of the Whenuapai Plan and most of the coasts in the RAASCE and Defra Report. However, given the similar mechanisms for erosion, toe retreat and changing cliff slope, the approach is considered appropriate.

Future sea level rise of 1m (10mm pa) is 770% greater than historic sea level rise (1.3mm pa) based on 100 years of measurement at the Port of Auckland tide gauge. This factor has the largest influence (over 70% of allowance) on the extent of land potentially affected by coastal erosion. It results in the areas susceptible to future coastal erosion being much greater than areas affected by historic erosion. This is consistent with the uncertainty in both the extent and effect of accelerated sea level rise.

Slope of Bank

The Puketoka Formation soils of the Tauranga Group within the study area are considered to have a regression angle of approximately 30° and this could be the expected cliff angle for much of the coastline.

The RAASCE (ARC 2006) considered slope angles for various materials and recommended the following figures for Tauranga Group Soils. Within and adjacent to the site, slump features with slope angles of 20° have been measured from the Councils GIS system. The slope angles in Table 3 have been adopted for the soft cliffs at the site.

Table 3: Adopted slope angles

Likely (ex-site investigation)	Possible	Unlikely
30^{θ}	20^{θ}	18^{θ}

An allowance for uncertainty in height was included in the RAASCE. This has not been allowed for in the current investigation, due to the coastline being a relatively short length and comprising even topography.

There is an intrinsic conservatism within the assumed methodology of adding the possible relaxation of slope angle to the possible toe regression rate for soft cliffs. The morphology of steep cliffs can be expected to change under a quickly retreating shoreline regime. The future rates of erosion are over seven times faster than those currently being experienced. We could expect that the face slope of the cliff will be at least as steep as it is presently.

Rate of Retreat Assessment

The coastline has been categorised into three types, based on measured retreat rates, cliff angles, and site morphology. The **calculated** 'likely', 'possible' and 'unlikely' areas susceptible to coastal erosion for each type are shown in Table 4.

Table 4: Calculated areas susceptible to coastal erosion

	Type 1 (Low)	Type 2 (Medium)	Type 3 (High)
Likely (30°)	12m	41m	57m
Possible (20°)	19m	48m	77m
Unlikely (18°)	22m	50m	79m

Because the largest part (over 70%) of the horizontal distance of land susceptible is due to future accelerated sea level rise and relatively low cliff height, the difference between Likely and Unlikely is small. Therefore, we have taken a precautionary approach of adopting the larger value, with rounding to a figure more appropriate to the level of accuracy of estimation. The **adopted** area (Figure 6) susceptible to coastal erosion for each type is shown in Table 5.

Figure 6: Areas susceptible to coastal erosion

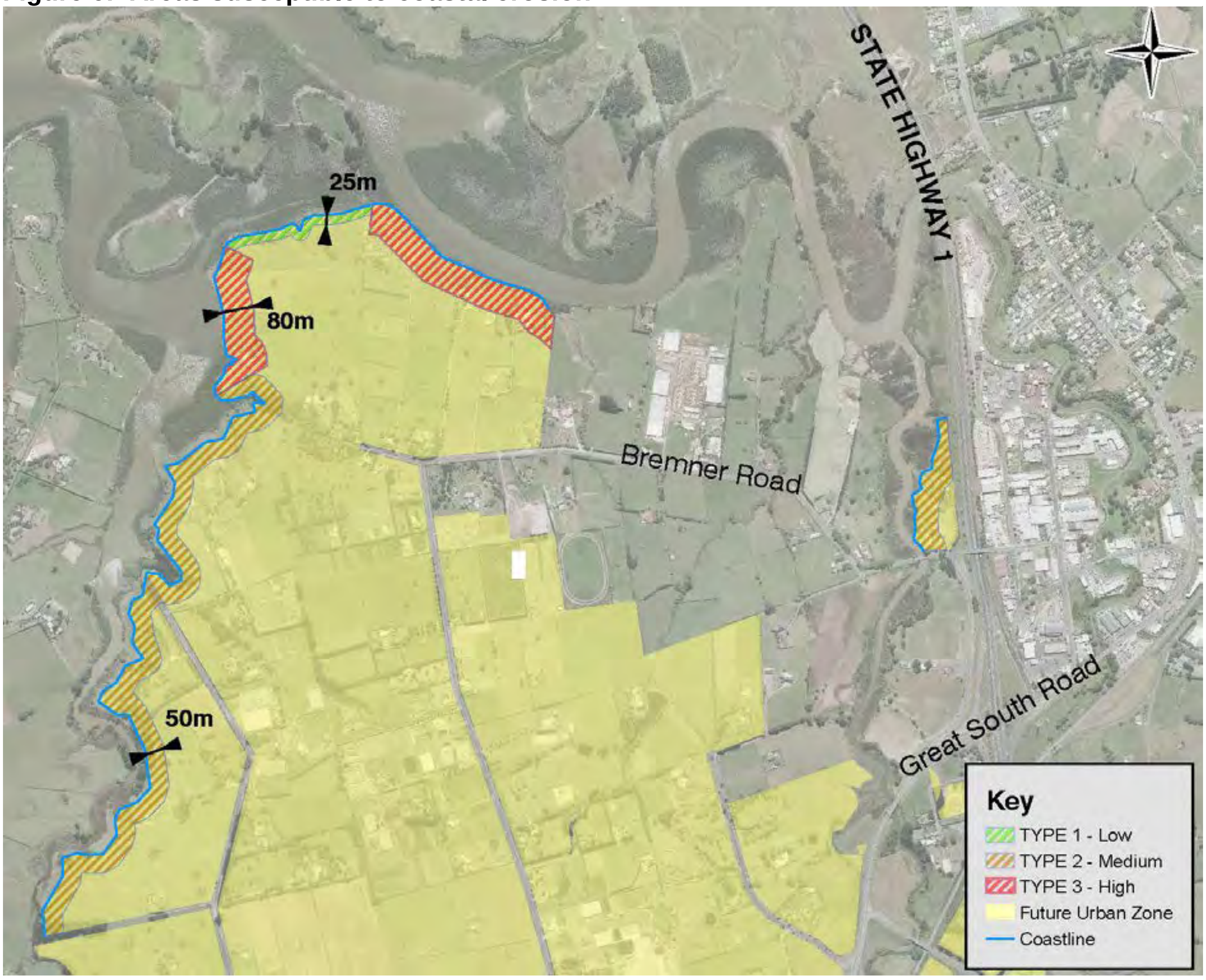


Table 5: Adopted area susceptible to coastal erosion for each type

	Type 1 (Low)	Type 2 (Medium)	Type 3 (High)
Adopted ASE	25m	50m	80m

3.3 Compressible Soils/Consolidation Settlement

The DSP area is underlain by deposits of the varying compressibility. T+T (2013) assessed that the compressibility potential across the area ranges from low to moderate. The Holocene alluvium and Puketoka Formation deposits were assessed as being of moderate compressibility potential, while the SAVF deposits are considered to have a low potential. Beca assessed that settlements within the Holocene alluvium present in the southern parts of the DSP area may be in the range of 50mm to 250mm for fill depths in the order of 2m and could be in the range of 200mm to 1,000mm for fill depths up to 8m. We concur with the Beca assessment and the settlement potential hazard map has been updated to reflect a classification of ‘high’ for the Holocene alluvium.

There are likely to be discrete horizons of organic soils within the Puketoka Formation and may also be more pervasive within the Holocene alluvium. Organic soils typically have a high compressibility and low bearing capacity. Where such soils occur near the ground surface they could be undercut and replaced with engineered fill. Where the thicknesses are more significant, this may not be practical and specific engineering solutions will be required.

Lowering the water table within such compressible soils will result in an increase in the effective stress within the soil with corresponding settlements.

Previous RILEY investigations in the vicinity of the DSP indicate that the surficial crust of the SAVF ash and underlying Puketoka Formation deposits are likely to be sufficiently stiff, such that differential settlements are within limits suitable for one- and two-level dwellings designed in accordance with NZS 3604, and typically supported on shallow strip and pad, or pod raft type foundations. However, structures of three or more levels, concrete framed, large footprint warehouses/factories and structures that are sensitive to settlement would require specific investigation and engineering design. Given the significant depths to rock over the majority of the DSP, preloading, friction piles, and piled rafts are likely engineering solutions for such structures. In areas underlain by SAVF basalt and where the basalt is present within about 30m of the surface (e.g. beneath the Holocene alluvium), bored and concreted, or driven piles may be an economic solution for such structures.

3.4 Liquefaction

3.4.1 General

Liquefaction occurs due to an increase in pore water pressure as a result of an earthquake. Loose silts and sands below the water table are the most susceptible to liquefaction during and immediately following an earthquake. Soils above the water table are not susceptible to liquefaction. Liquefaction results in a loss of strength, which leads to ground deformation, reductions in the available bearing capacity. The presence of sand boils and soil ejecta are indicative of the occurrence of liquefaction where there is insufficient thickness of non-liquefiable soils at the surface. Liquefaction can still occur without the appearance of these features.

The occurrence of liquefaction depends on many factors including the soil particle size and distribution, groundwater level, soil density, and in-situ stresses. Following liquefaction, significant ground deformation may occur as the soil particles are rearranged into a denser state. Such deformations can be damaging to structures located on such soils. There may also be additional building foundation settlement as a result of loss of bearing capacity.

3.4.2 Seismic Parameters

Seismic loading for the DSP has been assessed using NZS 1170.5:2004 (Structural Design Actions, Part 5: Earthquake Actions, New Zealand) with the following inputs:

Foundation Soil Classification:	Class D – Deep soil for the majority of the area. Portions underlain by basalt may be Classes B or C. Further specific assessment would be needed areas underlain by basalt.
Earthquake Magnitude:	7.5
Zone Factor:	0.13 (Auckland)
Structure Importance Level (SIL):	2. Higher SILs are required for structures related to lifelines and those that are required to be functional following a ULS earthquake.
Design Life:	50 years.
Annual Probability of Exceedance:	1/25 (Serviceability) and 1/500 (Ultimate Limit State)

Note: NZS 1170.5 ground acceleration assessments use a magnitude of 7.5. Recent MBIE guidelines indicate that reduced magnitudes may be appropriate for various site locations. For Auckland, a magnitude of 5.8 is recommended for the serviceability and ULS return periods above.

Table 6: Seismic Loads as per NZS 1170.5:2004

Site Soil Category	Peak Ground Acceleration (g)	
	Serviceability Limit State	Ultimate Limit State
B	0.033	0.13
C	0.043	0.17
D	0.036	0.15

3.4.3 Drury Fault

The Drury Fault is present outside the eastern extent of the DSP area (refer to Figure 2). We understand that it has variably been classified as both inactive by Dr Kelvin Berryman in his letter from December 2004 and as active by Beca in their April 2013 Geotechnical Addendum Report. The parties disagree on the activity of the fault and it must be appreciated that due to the passage of time, the Beca view could be considered as the most up-to-date. However, the parties do agree that activity on the Drury Fault is low and does not require specific fault avoidance. Instead, the MfE Guidelines for Planning for Development of Land on or Close to Active Faults (2009) indicates that a buffer zone of 20m should be observed. It should be noted that being more than 20m from an active fault does not preclude damage to structures as a result of a seismic event.

As with most faults there is uncertainty regarding the exact location of the Drury Fault trace and the effect that variations in the fault trace location and lateral width might have on the location/extent of a buffer zone. Data on the width of the Drury Fault is very limited. However, at exposures of similar faults in the South Auckland area, fault widths were 1m to 2m. We consider that in the absence of specific data an approximate fault width of 1m to 2m is reasonable.

To assess the location of the Drury Fault relative to the DSP area we have considered the following:

- Topographical expression
- Local geology
- Various research papers
- NZGD boreholes

The eastern part of the DSP area is relatively flat. However, near the eastern boundary of the DSP area land gradients rise up to the east. The eastern side of the fault is up thrown while the western side is down thrown. The location of the fault is considered to be geomorphically expressed as the boundary between the sloping topography of the up thrown Miocene (ECBF) and Mesozoic (Waipapa Group greywacke) age deposits present to the east and the flat lower strength and younger (Holocene and Pleistocene age) deposits to the west on the down thrown side.

In the immediate vicinity of the study area, the Holocene and Pleistocene age alluvium is confined to the western side of the fault, while Miocene age ECBF, and Mesozoic age Waipapa Group greywacke deposits are confined to the eastern side of the fault.

Quaternary age basalt is present to the east and west of the Drury Fault. Significant portions of the basalt appear to have been bisected by the fault with the result being that basalt is near, or at the surface over parts of the eastern side of the fault, while on the western side at the same longitudinal locations the basalt is buried.

Considering these factors the assessed location of the Drury Fault is shown on RILEY Dwg: 170275-9, appended. However, its exact location is still uncertain. Accordingly, we have also shown the 20m MfE buffer plus an additional 30m buffer to account for the uncertainty in the fault location. The additional buffer could be reduced with either geophysical testing or intrusive field investigations aimed at confirming the location of the western side of the Drury Fault.

3.4.4 Lateral Spread

Lateral spread occurs when liquefied soils spread laterally at a free face such as a slope, river channel or coastal cliff during a seismic event. Beca has identified that lateral spread of up to approximately 100mm could occur adjacent to the Hingaia Stream (located in the centre of the DSP) and that the zone of influence could be up to ten times the height of the free face. This is generally consistent with our view of the likely extent and magnitude of lateral spread adjacent to streams throughout the area, although no specific analysis has been carried out.

3.4.5 Groundwater

The depth of groundwater is likely to vary across the area with higher groundwater levels being present within the more low-lying parts of the DSP and deeper within the more elevated portions. We expect groundwater to be in a typical range of 1m (low-lying areas) to 4m (elevated areas) depth. The groundwater level would be expected to rise by a similar amount to any long-term sea level rise.

3.4.6 Summary of Liquefaction Analysis from Previous Work

Review of the T+T (2013) liquefaction potential maps for the DSP area indicates relatively localised areas of deposits with an assessed moderate liquefaction potential. These typically align with areas of recent alluvial and Puketoka Formation deposits, both those shown on published maps and that encountered in known investigations. The SAVF volcanic deposits (lava/ash/tuff) being mapped as having a low assessed liquefaction potential. Drilling records for historical boreholes within the Holocene alluvium indicate that a significant proportion of this deposit may be highly plastic, possibly implying a reduced liquefaction potential. Further specific investigation would be needed to confirm this.

The blanket classification of all Puketoka Formation as moderate liquefaction potential by T+T (2013) is considered a conservative assessment. Investigation of Puketoka Formation materials north of Paerata (Wesley College) reported by Beca (2014) assessed some localised liquefaction was possible, however, provided a minimum 3m to 4m thick crust of non-liquefiable material is present above the liquefiable soils this would mitigate the effects of liquefaction. Note – while Wesley College is outside the DSP area, the geology is similar to parts of the DSP area. A moderate liquefaction potential for the recent alluvial deposits is considered appropriate.

Extracts provided to us from the draft of the recent liquefaction study by the University of Auckland indicate that liquefaction damage is unlikely in the majority of soils across the DSP area, with the exception of the Holocene Alluvium where liquefaction damage was considered to be possible. We have reservations regarding some of the assumptions outlined in the study extracts provided. As we have only been provided with extracts of the draft study, we have been unable to confirm the appropriateness of the assumptions. Accordingly, we consider that the study should not be relied on in this assessment at this time.

We consider that dwellings constructed on moderate liquefaction potential land will likely require TC2-type (Technical Category 2) foundations (refer MBIE Guidance Repairing and Rebuilding Houses Affected by Canterbury Earthquakes), while land having an assessed low liquefaction potential is considered to require TC1-type foundations. There are a number of TC2-type foundation options, including enhanced foundation slabs and pod raft-type solutions, while typical TC1 solutions involve shallow timber piles or tied concrete slabs designed in accordance with NZS 3604. We consider that these foundation solutions are not particularly onerous or expensive to construct. Specific assessments and engineering designs will be required for other types of structures founded on land requiring TC2-type foundations.

T+T (2013) identifies lateral spread as a risk and proposes minimum setbacks and specific engineering assessments to further quantify the risk. On their assessed Liquefaction Potential drawings none of the coastal foreshore has been mapped as having any liquefaction potential (e.g. lateral spread) but on the Development Premium maps the coastal area is denoted as having a high development premium. We consider that this is consistent with the presence of both lateral spread and coastal erosion hazards. The lateral spread and coastal erosion hazards could be mitigated by ground improvement measures including retaining walls, rip-rap, earthworks and/or drainage.

3.5 Discussion of T+T Assessment (2013)

The T+T (2013) assessment and geotechnical hazard maps form the baseline of the current assessment with the maps covering greater than approximately 75% of the reviewed area (See RILEY Dwg: 170275-7, appended). It should be noted the maps are drawn at regional scale and are not intended for detailed individual site evaluation. RILEY has updated and extended the maps over the DSP area and comment as follows:

3.5.1 Slope Stability

We consider the slope instability risk map (see T+T Figure 8, appended) to adequately capture slopes within the majority of the study area of high potential for instability. The assessment does not cover all of the DSP area. The GNS (2012) assessment addresses the whole DSP area and is considered to be generally in agreement with the T+T assessment. It also highlights areas of moderate and high instability risk in the coastal foreshore area (due to slope gradient and coastal erosion) that is not addressed in the T+T assessment, while also indicating that the slope stability risks in the area of land to the east of the Drury Township (not addressed by T+T) are similar to the remainder of the study area with moderate to high instability risks assessed adjacent to streams and low risk elsewhere.

The presence of moderate to high instability potential areas adjacent to water courses and coastal foreshore does not preclude future urban development in these areas, however, a greater degree of geotechnical assessment will be required at development stage and possible works to improve stability. This is discussed further in Section 4.0 of this report.

3.5.2 Compressibility

The soil compressibility potential risk map (T+T Figure 11) is considered appropriate to known conditions with the exception of the Holocene alluvium, which, based on the Beca work, we consider should be classified as having a high compressibility potential. As previously outlined, the blanket moderate risk potential of all Puketoka Formation deposits including the land to the east of Drury Township, is likely conservative, however, localised areas of potentially compressible soils may be present in the broad valleys and adjacent to watercourses. It is difficult to define such areas accurately without detailed subsurface investigation.

3.5.3 Liquefaction

We consider the liquefaction potential map (T+T Figure 10) adequately captures the likely hazard with the exception of the Holocene alluvium where historical boreholes indicate the presence of highly plastic soils potentially implying a low liquefaction potential. With respect to Puketoka Formation materials a moderate assessment over the whole area is conservative but considered appropriate as localised liquefaction is possible. The T+T assessment does not explicitly assign a lateral spread potential within the coastal foreshore area. We consider the potential for lateral spread as a result of liquefaction to be moderate based on the criteria outlined by T+T and Beca.

3.5.4 Summary Comments on T+T Hazard Potential Mapping

Presented in Table 7 is a summary of RILEY comments on geotechnical hazards assessed by T+T within the study area.

Table 7: Summary of RILEY comments on T+T (2013) zoning in Drury Structure Plan Area

Geotechnical Zoning Aspect	RILEY Comments	Effect on Future Urban Development
Instability Potential	The T+T slope instability risk map adequately captures slopes within the study area of high potential for instability. It is considered slopes, adjacent to the coastal foreshore and area east of Drury Township adjacent to watercourses, should be classified as having a moderate to high instability potential, similar to the GNS 2012 assessment. Elsewhere, a low slope instability risk is considered appropriate. See RILEY Dwg 170275-12	We consider the addition of moderate to high instability risk to isolated areas should not prevent future urban development. Rather, this will require a higher level of geotechnical assessment and possible stability improvement measures where required at development stage.
Compressibility Potential	The soil compressibility potential map (T+T Figure 11) is considered appropriate to known conditions except the Holocene alluvium, which is considered to have a high settlement potential. See RILEY Dwg 170275-10 appended.	Investigation and assessment as per T+T recommendations.
Liquefaction Potential	The liquefaction potential map (T+T Figure 10) is considered to adequately capture the likely hazard based on current information available. The coastal foreshore and adjacent to streams we consider an assessed moderate liquefaction potential is appropriate. See RILEY Dwg 170275-11, appended.	Investigation and assessment as per T+T recommendations. Moderate liquefaction potential is considered likely equivalent to TC1 and TC2-type foundations (MBIE guidelines), which are not envisaged to have a significant effect on development and construction costs, subject to specific assessment as recommended. Building development should not be permitted within the Drury Fault buffer zone without further geotechnical input.

As outlined above, there is a difference in classification of instability, liquefaction and settlement potential for portions of the study area between this assessment and that of T+T (2013). RILEY has prepared geotechnical hazard potential maps, based upon the work of T+T, GNS, our own information, and site observations. The maps have been extended to cover the parts of the DSP area not included in the T+T assessment.

Within the T+T (2013) report there is comment on the relative levels of expected geotechnical investigation and assessment for each of the potential areas for stability and liquefaction. We consider these recommendations are appropriate. Further specific assessments should be carried out to assess the lateral spread potential and provide appropriate recommendations for land use zoning.

Within areas of moderate or high compressibility potential, subsurface investigation should be expected to be undertaken to characterise the nature of the underlying soils including their strength and settlement potential. For high compressibility potential areas, a specific compressibility/settlement assessment should be undertaken for individual developments possibly including laboratory testing of soils samples to determine compressibility values for design.

4.0 Development Considerations

4.1 General

The development considerations outlined below are based on the previous investigations and assessments carried out in the DSP area and our experience in similar materials across the wider Auckland region.

4.2 Geotechnical and Seismic Design Criteria

The following specifications, codes, guidelines, and standards are considered to be applicable for future development in the DSP area with respect to geotechnical and seismic design criteria.

- Auckland Council Code of Practice for Land Development and Subdivision – Section 2 Earthworks and Geotechnical Requirements, Version 1.6, 24 September 2013
- NZS 4431:1989 – Code of Practice for Earth Fill for Residential Development
- NZS 4404:2010 – Land Development and Subdivision Infrastructure
- NZS 3604:2011 – Timber Framed Buildings
- B/VM4 Amendment 12 (2014), Department of Building and Housing Compliance Document for New Zealand Building Code Clause B1 Structure, Verification Method 4 – Foundations
- NZTA Bridge Manual 3rd Edition Amendment 1
- NZS 1170.0:2002 – Structural Design Actions, Part 0, General Principles
- NZS 1170.5:2004 – Structural Design Actions, Part 5, Earthquake Actions – New Zealand
- MBIE and NZGS – Earthquake Geotechnical Engineering Modules 1 to 6, 2016 and 2017
- MBIE and NZGS – NZ Ground Investigation Specification, 2017
- MBIE Guidance – Repairing and Rebuilding Houses Affected by the Canterbury Earthquakes, 2012

4.3 Earthworks

The DSP area is generally gently undulating with a mixture of broad and incised valleys associated with stream down cutting. Earthworks will likely be required over significant portions of the area to form relatively dense urban building platforms suitable for future development by creating suitable topography for dense urban development, although the depths of such earthworks are expected to be limited due to the relatively gently sloping nature of the terrain. These earthworks are likely to involve undercutting of unsuitable materials (where depths of unsuitables are not excessive) from gully inverts and placement of engineered clay fill using soils likely won from the more elevated parts of the area.

Filling may also be required in the more low-lying areas to provide adequate freeboard above flood levels for building platforms, or to provide a crust above compressible or potentially liquefiable soils.

Consideration will need to be given to the effect of allophane (mineral associated with soils of volcanic origin) content in the SAVF soils and Puketoka Formation materials containing ash fall, deposits and ignimbrites. Soils with allophane contents over 5% can be problematic for earthworks with respect to moisture contents and irreversible changes once dry. Compacted ash materials often lose volume from their natural condition.

Settlement induced by dewatering should be considered for service trenches and excavations particularly in the low-lying areas of the DSP where groundwater levels are likely to be much closer to the ground surface. This is particularly important in new development in the vicinity of existing urban areas outside the DSP (e.g., existing Drury Township and southern Papakura residential area).

As mentioned earlier, Beca anticipates settlements of up to 1m could be induced within the Holocene alluvium in the Private Plan Change 12 and 38 area due to fill load. Specific engineering design and analyses will be needed for future structures constructed on the Holocene alluvium within the DSP area.

4.4 Civil Infrastructure

Civil infrastructure, including roads, wastewater, water supply, stormwater, power, telecommunications, and gas will need to be installed to support future development. It will be important for stormwater and wastewater services that they are able to be installed at adequate grades. Where such services pass through materials susceptible to the geotechnical hazards outlined in Section 3.0, specific assessments should be carried out. We are not aware of any fundamental geotechnical flaws that would prevent suitable construction of services.

4.5 Development Premium Areas

4.5.1 General

The allocation of development premium areas across the FUZ is based upon an amalgamation of the hazard potential areas for instability, compressibility, and liquefaction. T+T (2013) has carried out a broad assessment of most of the DSP area and has proposed low, medium, and high development premium (cost) areas. RILEY has updated the development premium map and extended it to cover parts of the DSP area not previously addressed by T+T. The RILEY development premium maps broadly agree with the T+T maps for the areas addressed by them. The development premium assessment is a useful tool to establish a relative cost premium for the land across the DSP area as it takes geotechnical hazards (see Section 3.0) into account. It does not mean that development cannot occur in medium or high premium (cost) areas although these areas will require a higher degree of engineering input for successful development than for areas classified as having a low development premium. The allocation of development premium areas across the DSP area is based upon an amalgamation of the hazard potential areas for instability, compressibility, and liquefaction.

The majority of the DSP area has been classified by T+T as being of medium development premium with high development premium areas typically being identified in areas with steep slopes, adjacent to the lower reaches of the Hingaia Stream and coastal foreshore. Areas to the east of the southern motorway underlain by SAVF basalt have been assessed as having a low development premium.

Low development premium (cost) areas are considered to have less geotechnical constraints/hazards and are likely to be more economical to develop than medium development areas. The same applies to between medium and high development areas.

4.5.2 Low Development Premium Areas

T+T has mapped low development premium areas on the eastern side of the southern motorway in areas underlain by SAVF basalt. Ground conditions in this area are considered suitable to a wide range of development types, however, due to the inherent strength of the basalt this area may be more suitable for heavily loaded structures (e.g. structures with high floor loads and/or more than three to four stories) than other geological units within the DSP area. Basement excavations in basalt would likely be more costly than excavations in other geological units.

4.5.3 Medium Development Premium Areas

Areas mapped by T+T as having a medium development premium are underlain by Puketoka Formation deposits and Holocene alluvium at distances more than 100m from the coastal foreshore. Such areas could support a wide range of development types including residential dwellings, apartment blocks, factories, warehousing, office buildings, shopping centres etc. However, owing to the significant depth to rock, specific engineering investigations and designs will likely be required for building foundations for structures over three levels high, having basements, a large footprint, or high floor live loads.

The Holocene alluvium has a high potential for settlement due to applied development loads but could be suitable for varying types of structures on account of the expected limited depth (20m to 30m) to basalt. Such structures are expected to require preloading to be fully supported on piles, or where possible, deleterious materials are undercut. Pre-development groundwater levels will need to be maintained to mitigate the risk of widespread groundwater drawdown induced settlements.

Development on alluvial soils (such as Puketoka or Holocene alluvium) will need to make allowance for soil expansivity through appropriate foundation design in accordance with NZS 3604 and AS 2870 as these materials often exhibit relatively high to extreme soil seasonal shrink-swell behaviour which can be damaging to structures.

Earthworks should be able to be carried out using conventional earthworks machinery and methods. Moisture conditioning is likely to be required to ensure that fill is able to be appropriately compacted. Consideration should also be given to the effect of allophane in carrying out earthworks.

Fill and groundwater drawdown from trenching may induce settlements. These should be able to be managed with appropriate engineering measures

4.5.4 High Development Premium Areas

Areas within the vicinity of the coast adjacent to lower reaches of the Hingaia Stream, or adjacent to steep slopes (e.g. south of Burtt Road and adjacent to Karaka Road at the Oira Road intersection) are considered have a high development premium. These areas have been identified as being at risk of coastal erosion, lateral spreading, and slope instability. It should be appreciated that there may be other unidentified areas adjacent to watercourses that have a high development premium on account of lateral spreading. T+T considers that buildings should be set back at least 25m from unsupported soil faces and that specific assessments should be carried out for structures within 100m of unsupported soil faces. Further investigations should be carried out to specifically assess the lateral spreading potential, extent of the hazard, and likely mitigation measures.

A high development premium does not preclude development in these areas but future development would be expected to require specific investigations, assessments, and designs. Ground improvement measures may be required. These could include retaining walls, rip-rap, earthworks, or drainage. With appropriate mitigation we would expect that the types of structures outlined in Section 4.5.3 above could be successfully constructed.

4.6 Summary Suitable Development Types for Development Premium Areas

Presented below is a summary of assessed most likely suitable development types for the reviewed potential development premium areas from a geotechnical perspective. It should be noted, these do not prevent other types of development occurring within the nominated development premium area; however, it may be associated with a greater development cost.

Table 8: Summary of RILEY assessed suitable development types for reviewed future urban zones

Assessed Development Premium	Suitable development type
Low Development Premium	Suitable for a wide range of residential, commercial and industrial developments. May be more suitable for heavily loaded structures (e.g. structures with high floor loads and/or more than three to four-stories) than other Development Premium Areas. Care will need to be taken with development near the Drury Fault.
Medium Development Premium	Due to the often undulating terrain and localised steeper slopes, residential type development is suitable for much of this area. The flatter areas in the central and eastern parts would potentially be suitable for commercial/industrial structures. Ground treatment may be required and/or specific foundation design. Specific engineering investigations and designs will likely be required for building foundations for structures over three levels high, having basements, a large footprint, or high floor live loads. The Holocene alluvium to the east of the Southern Motorway could be suitable for varying types of structures. Such structures are expected to require preloading, to be fully supported on piles, or where possible, deleterious materials are undercut. Groundwater levels will need to be maintained.
High Development Premium	Future development would be expected to require specific investigations, assessments, and designs. Ground improvement measures may be required. With appropriate mitigation this area should be suitable for the development types outlined above for Moderate Development Premium areas.

Note: The comments in Table 8 above do not consider the presence of the Drury Fault or the required buffer zone.

5.0 Conclusions and Recommendations

5.1 Conclusions

Review of geotechnical constraints for possible future urban development on the margins of Drury has been undertaken, with respect to instability, soil compressibility and liquefaction. This has included a desktop assessment, site inspection, review of previous work by T+T (2013), supported by available geotechnical reports and subsurface information.

We conclude that most of the reviewed area is of medium development premium, i.e. suitable to a wide range of development types with some geotechnical constraints (e.g. low to moderate risk of instability, settlement and/or liquefaction potential). This is generally consistent with the development premium area plans prepared by T+T (2013), included within Appendix A.

Moderate development premium is associated with Puketoka Formation and Holocene alluvium soils away from the coastal foreshore, steep slopes and watercourses (see T+T Development Premium Plan, Figure 12 in Appendix A). There are areas of low development premium underlain by SAVF basalt to the east of the southern motorway while areas of high development premium are present adjacent to the coastal foreshore, steep slopes and Hingaia Stream. There may be other unidentified areas adjacent to water courses that have a high development premium.

In general, the development premium areas, as mapped by T+T, are considered appropriate. However, we note that there are some parts of the DSP area that were not covered in the T+T assessment (see RILEY Dwg: 170275-7, Appendix D). We consider that the above comments are applicable to the parts of the DSP that were not covered by T+T away from the foreshore with respect to the various underlying geological units and have updated and extended the development premium map (see RILEY Dwg: 170275-13). There are also other areas where we have a differing opinion on the hazard potential assessments (refer Section 3.0 of this report and RILEY Dwgs: 170275-10 to -12, appended). The hazard potential assessments have been updated accordingly. These differences are not considered to affect the assessed development premium areas. Comment has also been provided regarding a buffer zone for parts of the DSP in close proximity to the Drury Fault (see RILEY Dwg: 170275-9).

5.2 Recommendations

We recommend the following further work be commissioned as part of the background reporting for the structure planning process:

- A site-specific coastal erosion assessment is carried out along the foreshore area. This should assess the rate of historical coastal retreat and make use of historical stereo photographs, and a study of the rate of erosion in the local environment should be completed to confirm an appropriate coastal erosion setback.
- Given the proximity of the DSP area to the Drury Fault a site-specific seismic hazard assessment should be carried out together with specific liquefaction assessments. Based on previous experience it is our expectation that such an assessment may result in a downgrade of the liquefaction potential across the study area (and potentially reduced the assessed development premium in some areas), particularly if combined with a programme of electronic Cone Penetration Tests (CPTs) and liquefaction analyses at selected locations across the study area. If the assessment were to result in an increase in the hazard potential, this would need to be factored in to considerations for appropriate future land use zones.
- A lateral spread risk assessment should be carried out to assist with the assessment of appropriate land use zones adjacent to areas susceptible to lateral spread as well as refining the areas susceptible to lateral spread. This should involve detailed geological assessments of the coastal foreshore and sections of watercourse considered to be at risk. This should include geotechnical and laboratory testing, such as CPTs, with pore pressure measurement and Atterburg limits. We anticipate this assessment, combined with the site-specific seismic hazard assessment, could result in the areas affected by lateral spread being significantly reduced.

6.0 Limitation

This report has been prepared for the benefit of Auckland Council as our client with respect to the brief. The reliance by other parties on the information or opinions contained in the report shall, without our prior review and agreement in writing, be at such parties' sole risk.

Recommendations and opinions in this report are based on a desktop review and visual appraisal only. The nature and continuity of subsoil conditions are inferred, and it must be appreciated that actual conditions could vary considerably from the assumed model.

APPENDIX A

Maps

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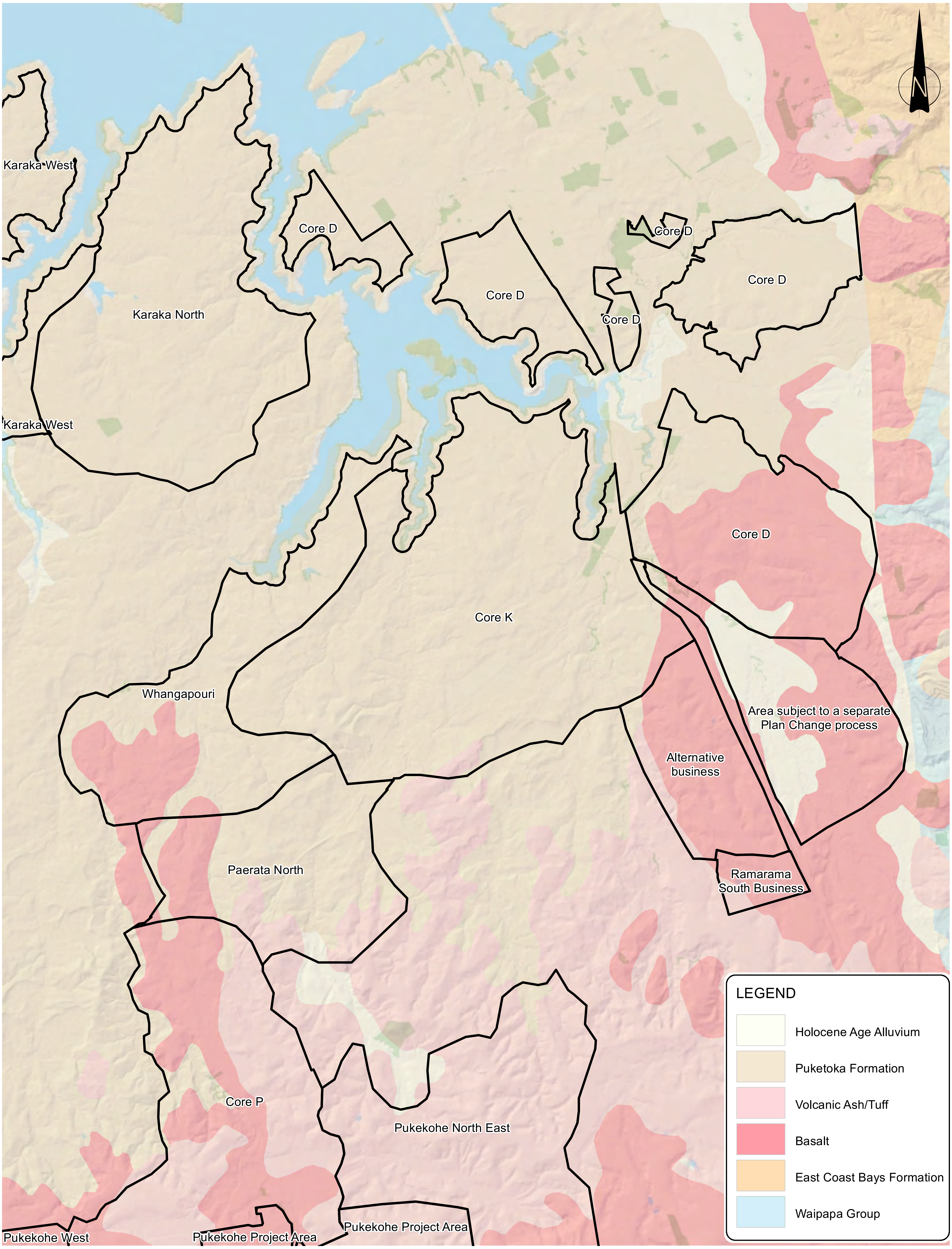

Notes: Basemap - Auckland Council GIS Terrain Model

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Rd, Newmarket, Auckland
www.tonkin.co.nz

DRAWN	JC	Jun.13
CHECKED		
APPROVED		

ARCFILE 29129-F04.mxd

SCALE (AT A3 SIZE) 1:40,000

PROJECT No. 29129

Auckland Council
South Auckland RUB Project
Geological Map:
Drury & Central Areas

FIGURE No. Figure 4

Rev. 1

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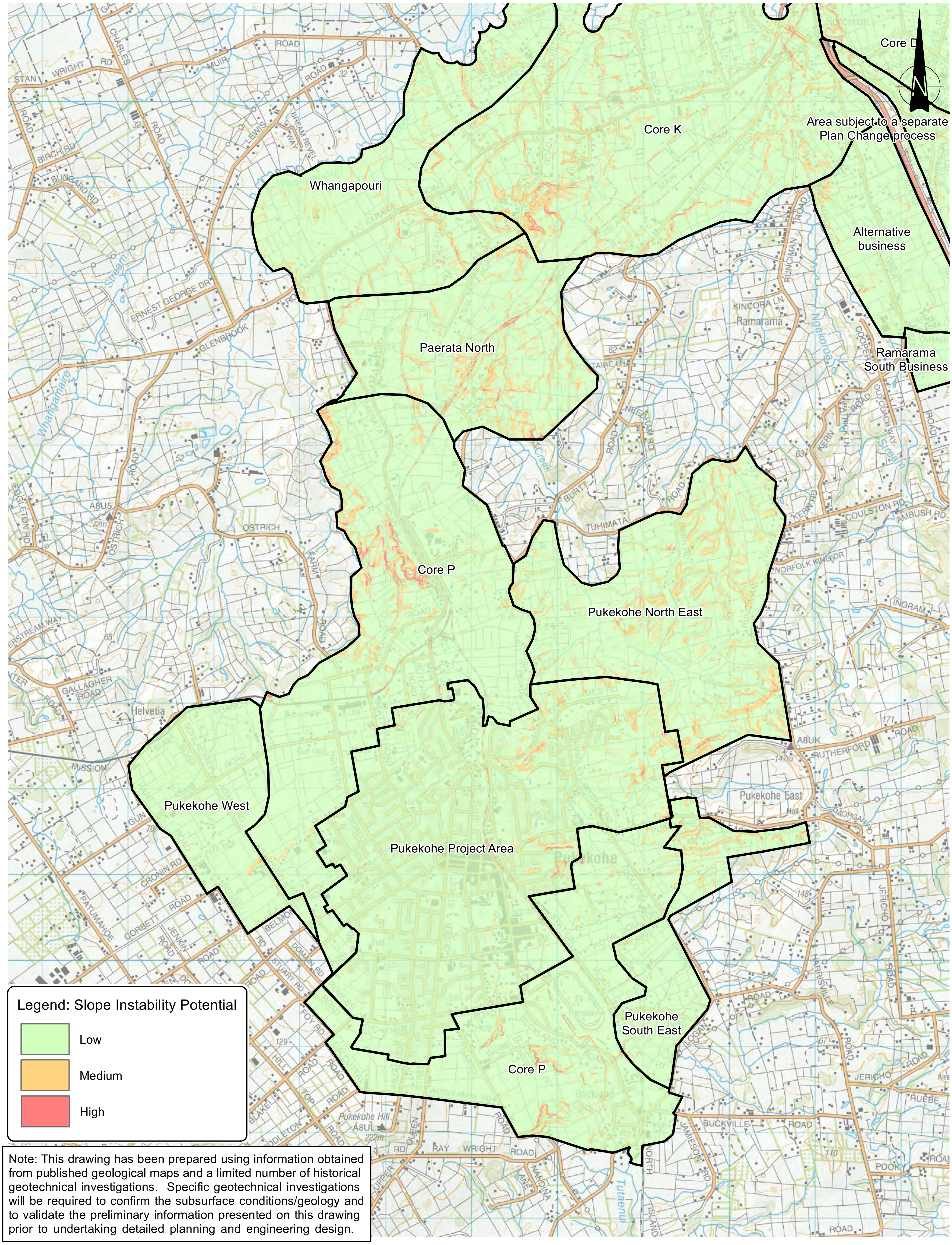

Notes: Basemap LINZ 1:50,000 Topomap

A3 SCALE 1:40,000

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APPROVED		
ARCFILE 29129-F09.mxd		
SCALE (AT A3 SIZE) 1:40,000		
PROJECT No. 29129		

Auckland Council
South Auckland RUB Project
Slope Instability Potential

FIGURE No. Figure 9

Rev. 1

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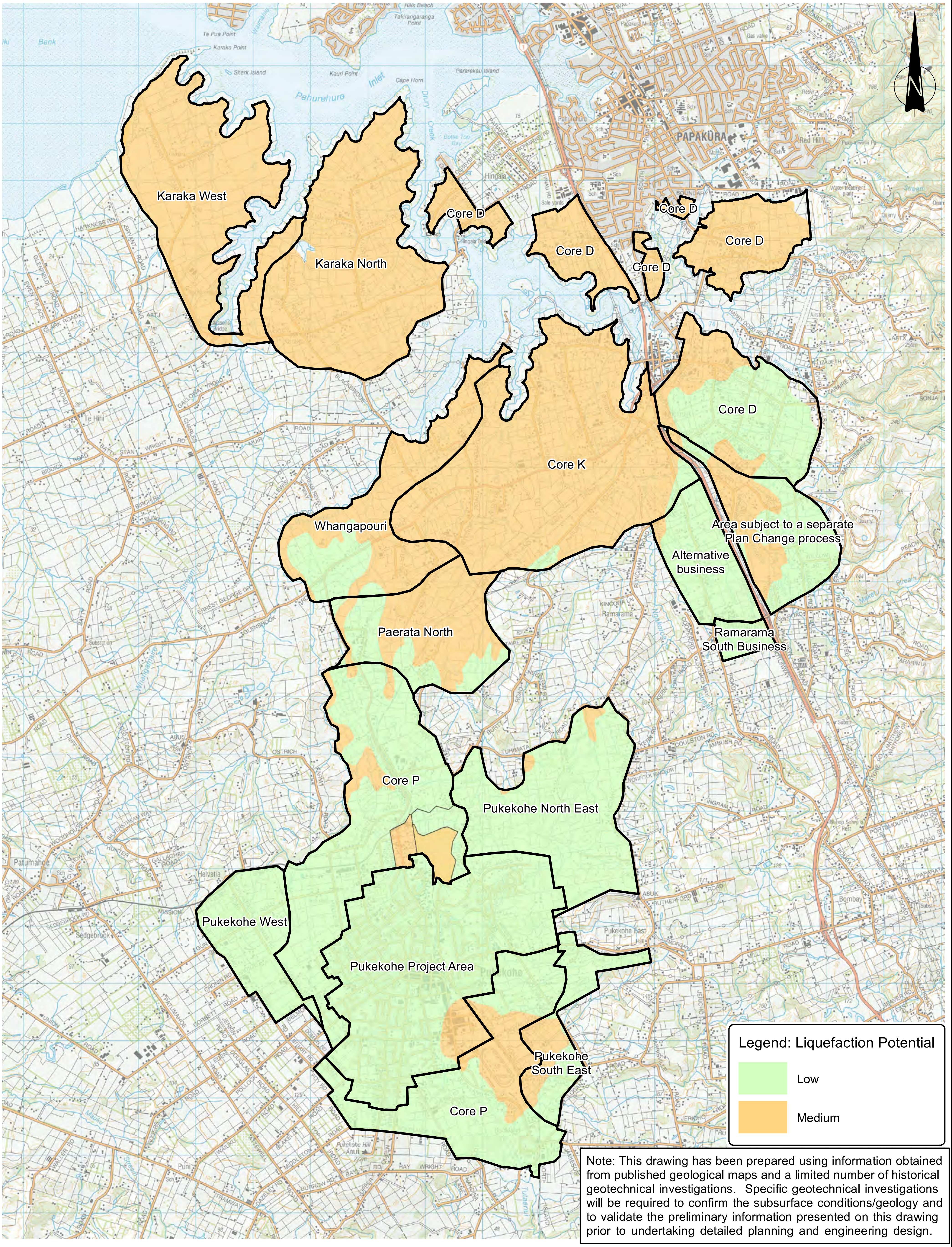

Note: This drawing has been prepared using information obtained from published geological maps and a limited number of historical geotechnical investigations. Specific geotechnical investigations will be required to confirm the subsurface conditions/geology and to validate the preliminary information presented on this drawing prior to undertaking detailed planning and engineering design.

Notes: Basemap LINZ 1:50,000 Topomap

A3 SCALE 1:60,000

0 1 2 3 4 (km)

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ARCFILE 29129-F10.mxd

SCALE (AT A3 SIZE) 1:60,000

PROJECT No. 29129

Auckland Council
South Auckland RUB Project
Liquefaction Potential

FIGURE No. Figure 10

Rev. 0

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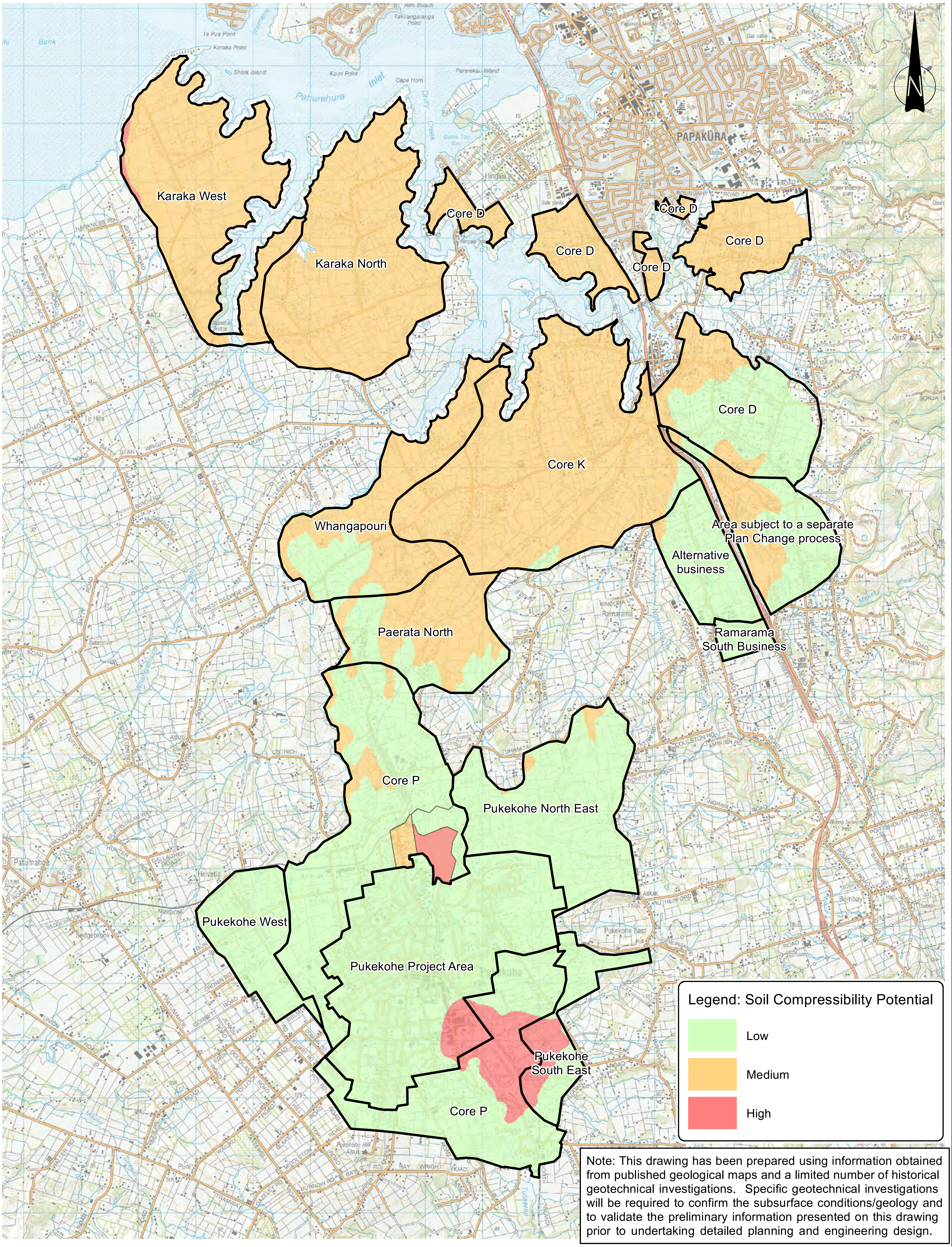

Legend: Soil Compressibility Potential

- Low
- Medium
- High

Note: This drawing has been prepared using information obtained from published geological maps and a limited number of historical geotechnical investigations. Specific geotechnical investigations will be required to confirm the subsurface conditions/geology and to validate the preliminary information presented on this drawing prior to undertaking detailed planning and engineering design.

Notes: Basemap LINZ 1:50,000 Topomap

A3 SCALE 1:60,000

0 1 2 3 4 (km)

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DRAWN	JC	Jun.13
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APPROVED		
ARCFILE 29129-F11.mxd		
SCALE (AT A3 SIZE) 1:60,000		
PROJECT No. 29129		

Auckland Council
South Auckland RUB Project
Soil Compressibility & Building Settlement Potential

FIGURE No. Figure 11

Rev. 0

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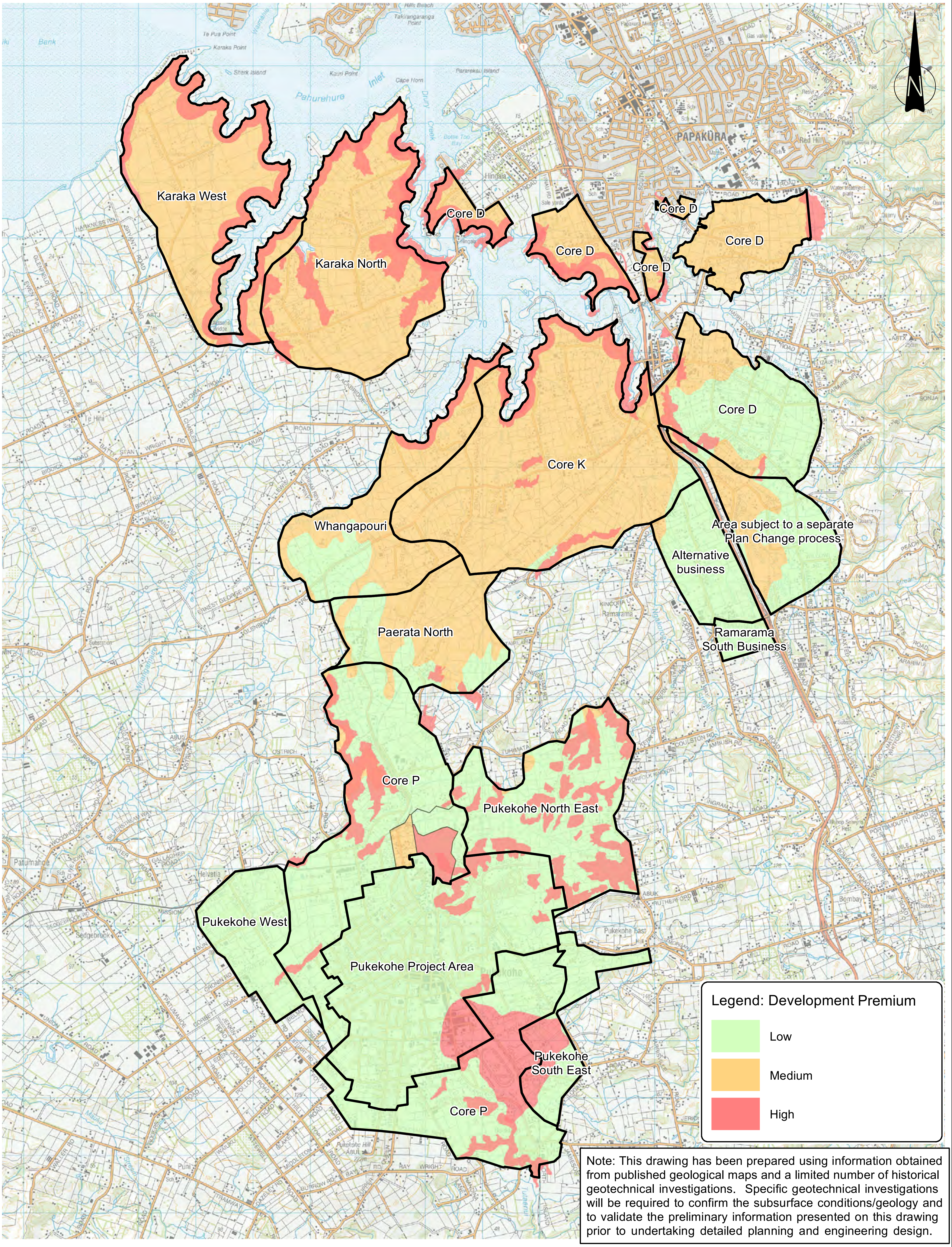
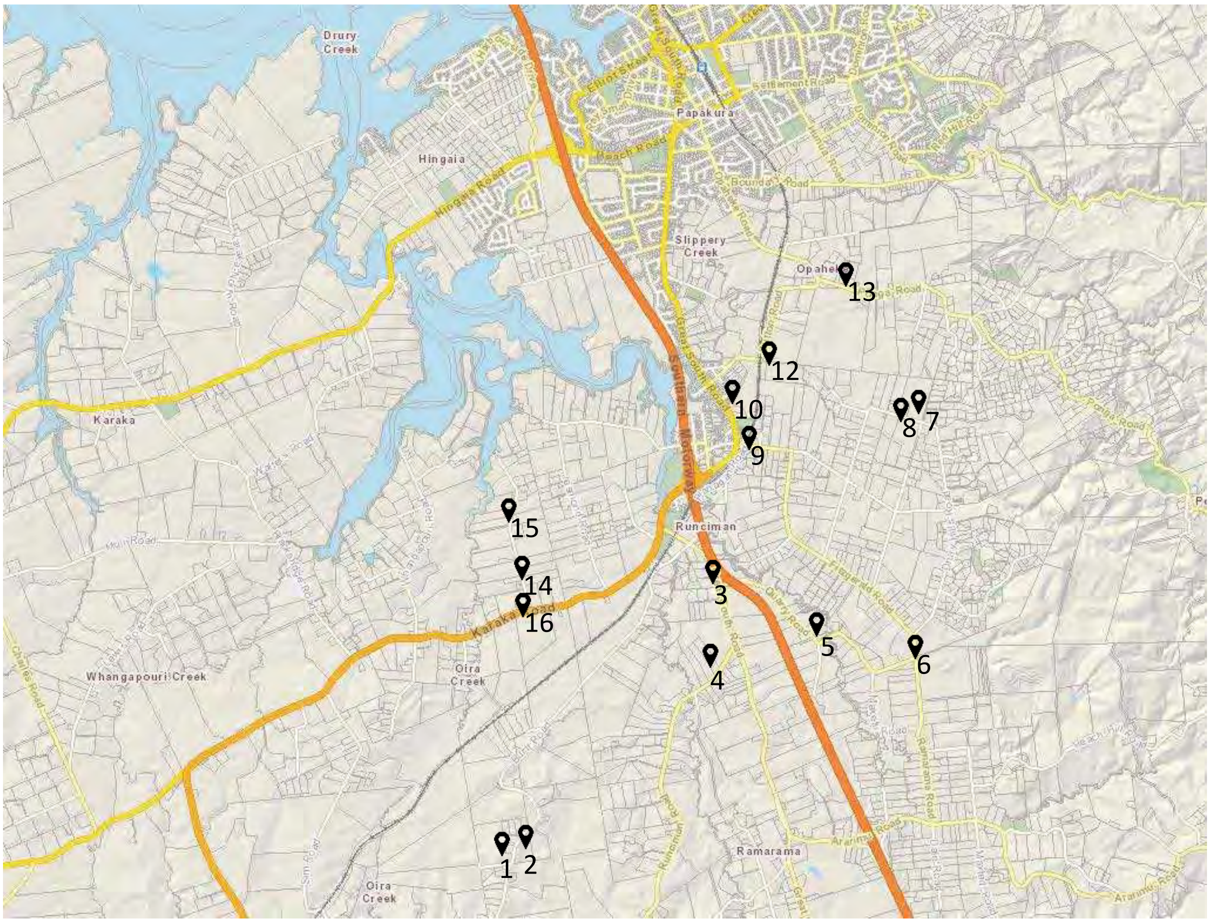


Note: This drawing has been prepared using information obtained from published geological maps and a limited number of historical geotechnical investigations. Specific geotechnical investigations will be required to confirm the subsurface conditions/geology and to validate the preliminary information presented on this drawing prior to undertaking detailed planning and engineering design.

Notes: Basemap LINZ 1:50,000 Topomap A3 SCALE 1:60,000 0 1 2 3 4 (km)	Tonkin & Taylor Environmental and Engineering Consultants 105 Carlton Gore Rd, Newmarket, Auckland www.tonkin.co.nz	DRAWN JC Jun.13 CHECKED APPROVED ARCFILE 29129-F12.mxd SCALE (AT A3 SIZE) 1:60,000 PROJECT No. 29129	Auckland Council South Auckland RUB Project Geotechnical Constraints: Development Premium FIGURE No. Figure 12 Rev. 0

APPENDIX B

Site Photographs



Locations Map

Photo 1: Looking north near the intersection of Cheriton Road and Burtt Road. Mapped as being underlain by SAVF ash with Puketoka Formation in the lower lying and undulating areas in the distance.

Photo 2: Looking east near the intersection of Cheriton Road and Burtt Road. The slope in the foreground is mapped as being underlain by SAVF ash (note the steep contour) and has an assessed high slope instability potential. The flat land in the distance is mapped as being Puketoka Formation but is low lying and may have portions of Holocene Alluvium.

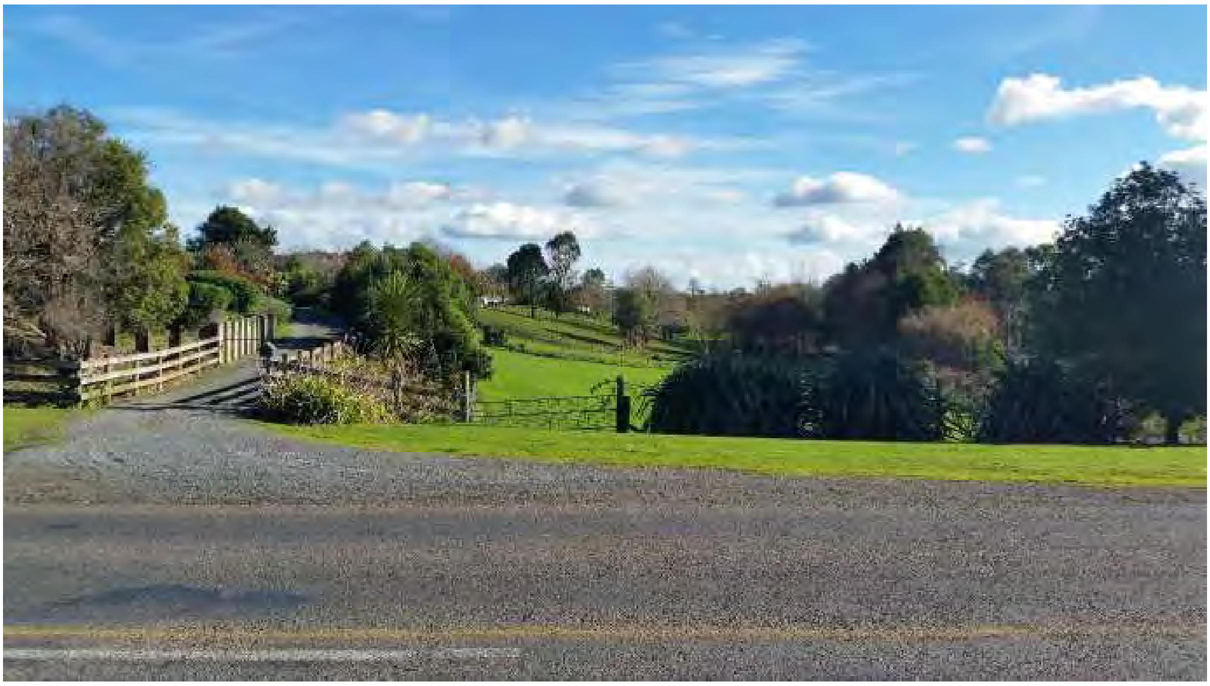


Photo 3: Looking west from Great South Road near the intersection with Quarry Road. The locality is underlain by Puketoka Formation deposits. Note moderate to steep gradients in the distance.

Photo 4: Looking north from Runciman Road. Low-lying land mapped as Puketoka Formation. Holocene Alluvium may also be present.

Photo 5: Looking north from Quarry Road near the intersection with Harrison Road. Area is underlain by Holocene Alluvium. It has a subdued contour with a creek in the middle ground.

Photo 6: Looking north at the intersection of Quarry Road and Fitzgerald Road. The land in the foreground is underlain by Holocene Alluvium, while the rising ground in the distance is underlain by SAVF ash and basalt.

Photo 7: Looking north from Appleby Road. Has a flat contour similar to the Holocene Alluvium but is mapped as being underlain by Puketoka Formation.

Photo 8: Looking South from Appleby Road. Has a flat contour similar to the Holocene Alluvium but is mapped as being underlain by Puketoka Formation.

Photo 9: Looking south west down Flanagan Road. The land falls gently to the south west and is underlain by Puketoka Formation.

Photo 10: Looking east from Young Crescent. Note the subdued contour.

Photo 11: Looking north towards Slippery Creek from Sutton Road. Mapped as being underlain by Puketoka Formation. The land has a flat contour with steep slopes adjacent to the creek.

Photo 12: Looking east from Sutton Road near the railway crossing. The land has a flat contour and is mapped as being underlain by Puketoka Formation.

Photo 13: Looking north from Ponga Road. The land is gently sloping down to the north.

Photo 14: Looking to the north-west on Oira Road near the Karaka Road intersection. The land is undulating with low-lying pockets.

Photo 15: Looking west from Oira Road to Oira Creek. Flat land visible in the foreground rolling down to Oira Creek. Note the local instability features in the western creek bank outside the study area.

Photo 16: Looking south at intersection of Oira Road and Karaka Road. The land is mapped as being underlain by Puketoka Formation and is undulating.

Photo 17: Looking east from Jesmond Road near the Karaka Road intersection. Note the undulating contour of the land. Mapped as being underlain by Puketoka Formation.

APPENDIX C

Davis Coastal Report

Drury Future Urban Zone

for

Auckland Council

Coastal Hazard Investigation

P.O. Box 185
Orewa
P: 09 428 0040
M:021 627 193
E:coastal@daviscoastal.co.nz

July 2017

Job Ref: 1712

COASTAL MANAGEMENT AND ENGINEERING

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2.0 Consistency of Hazard Assessment Methodologies 5

3.0 Site Description 6

4.0 Site Investigation 7

5.0 Site Observations 8

6.0 Methodology of Assessment 9

7.0 Rate of Retreat Assessment 15

Appendix A – Mapped Areas Susceptible to Coastal Erosion

1.0 Introduction

The Auckland Council is preparing to undertake a structure planning exercise on the Drury Future Urban Zone (FUZ) Area, as part of the wider Future Urban Land Supply Strategy (FULSS). The Council have commissioned background reporting on the existing geotechnical and coastal hazards, to inform on potential constraints to the FUZ.

Davis Coastal Consultants have been engaged as a sub-consultant to Riley Consultants Ltd (Riley), to undertake a report on land within the Drury FUZ susceptible to coastal erosion hazards. An assessment of coastal inundation hazards was not part of the project brief.

This report is to be submitted in conjunction with a report by Riley. It is assumed that a generalised description of the wider site is to be included in that report, and therefore has not been included here.

The scope of work comprised a desktop exercise to review available literature, historical cadastral and photographic information, regional erosion assessments and tidal water level and inundation studies. A single site visit was undertaken to inspect geomorphological features, vegetation and other physical aspects of the relevant coastline and backshore.

2.0 Consistency of Hazard Assessment Methodologies

Auckland Council prepares multiple Structure Plans, including specialist reports, to inform on the specific geotechnical and coastal hazards of the subject zone.

Consistency across these assessments ensures a coherent and robust assessment of hazards across Council planning documents. Results of the assessments are also more readily recognisable and comparable between studies.

A Regional Assessment of Areas Susceptible to Coastal Erosion (RAASCE) was undertaken by the Auckland Regional Council in 2006. The report utilised a methodology on 'soft cliffs' used by the National Research Council in the UK to assess cliff erosion including effects of sea level rise (Defra 2002). The same methodology was utilised for the assessment of the coastal erosion hazard for the Whenuapai Structure Plan (Aecom, 2016) and the method and terminology has been largely adopted in this assessment.

The subject site is more driven by fluvial processes, as opposed to primarily wave driven processes which dominate the coastal erosion of the comparatively exposed coasts of the Whenuapai Plan and most of the coasts in the RAASCE. There is considerable judgement in adoption of the relevant variables providing opportunity to address the differing drivers. A similar methodology to the earlier reports is therefore considered to provide a suitable framework for the assessment in this location.

3.0 Site Description

The subject site is located in the upper reaches of the Manukau Harbour, and consists of two small areas comprising approximately 3.2km of coastline bordering the Drury FUZ (Figure 3.0a). It includes approximately 500m of shoreline on the western bank of the Ngakoroa Stream immediately downstream from the Bremner Road Bridge, and 2.7km of shoreline at the confluence of the Drury and Oira Creeks.

The water courses meander through the site and are characterised by small low tide channel widths in the order of 10 – 40m, increasing to 50 – 100m at high tide with wide mangrove covered flats outside this in places.

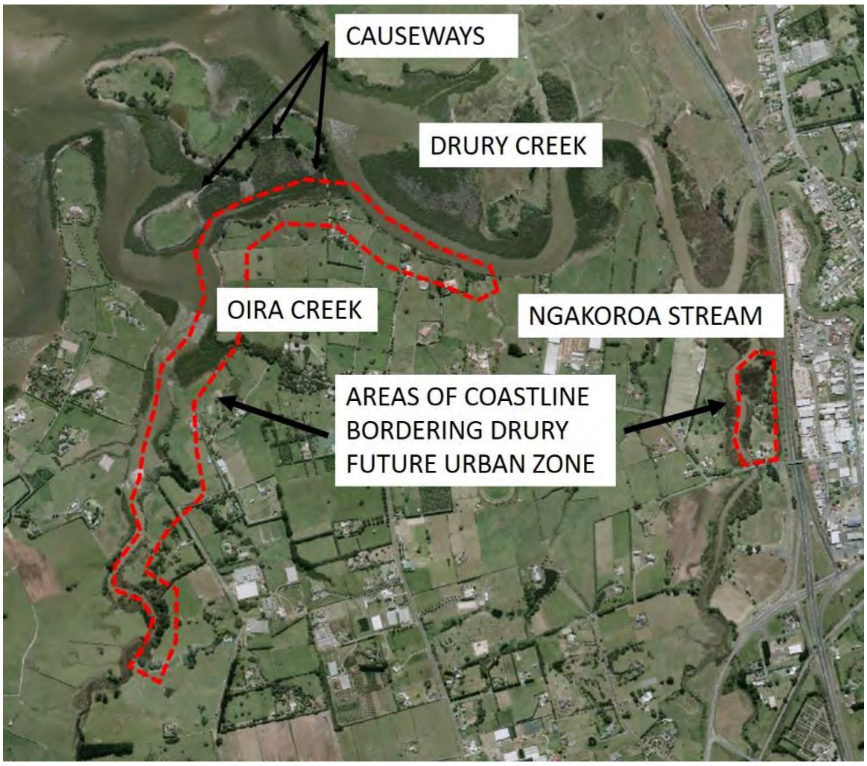


Figure 3.0a: Areas of coastline bordering Drury FUZ

The coastal margin is comprised of soft cliffs in the order of 4 – 7m high, comprised of a depth of 0.5 – 2m of highly weathered volcanic ash overlying firmer underlying material. The underlying geology is defined in the 1:50,000 Geological Map 'Geology of the Auckland Urban Area' published by GNS as belonging to the Puketoka Formation, a non-marine substrate containing pumiceous mud, sand and gravel with tephra and alluvia (Figure 3.0b). The area landward of the cliffs is relatively flat, rising to a height of RL 10 approximately 500m from the cliffs.

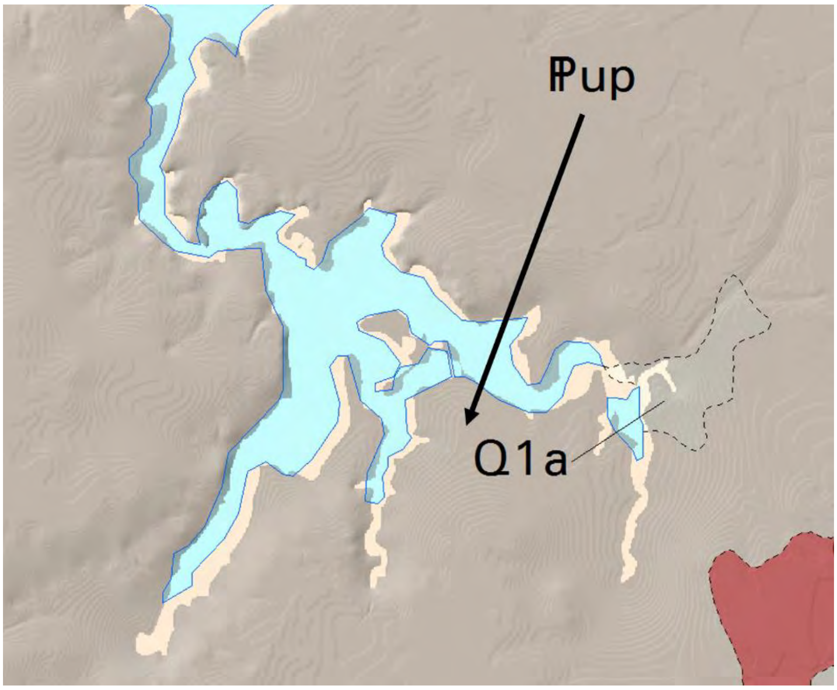


Figure 3.0b: Excerpt from Geology of the Auckland Urban Area showing subject site

4.0 Site Investigation

A single site visit was undertaken by Davis Coastal Consultants on 19/06/2017, where the subject areas of coastline were observed from the water by kayak, with subsequent closer inspection on foot to confirm initial observations. The visit covered site conditions over a predicted spring low tide, and comprised observations only, with no measurements or testing undertaken.

5.0 Site Observations

The morphology of the subject coastline, with a meandering river channel and platform to the base of steep and slumped fringing cliffs, suggests an area subject to progressive retreat. The low tide channel is relatively incised, with intertidal flats comprised primarily of very weathered rock to firm very stiff soils overlain with a veneer of soft estuarine silt. The depth of veneer increases at the outside of bends and embayed areas. The alignment of the shoreline cliffs with the channel, and intensification of erosion based on the meander of the river, indicate that the subject coastline is dominated by fluvial and tidal current processes with deposition tending to occur on the inside of river bends, and erosional processes occurring on the outside. This is consistent with the remoteness from open ocean swells and lack of long fetches to develop wind waves.

The proposed Drury FUZ is adjacent to the Ngakoroa Stream, Oira Creek and the Drury Creek. Both smaller waterways are tributaries to the Drury Creek. All waterways are tidal with elevated sections of stream bed at the downstream confluence providing a controlling weir over low tide but water levels are dominated by tidal height over the majority of the tide.

The area can be characterised as three sections. The northern extent of the site (Type 1) is at the junction of the Oira and Drury Creeks. A number of islands exist immediately north of the area and these have been connected by causeways between 1960 and 1996. Infilling between the islands and the mainland has effectively excluded stream flow through this area affording protection from future toe erosion. Ground elevation is limited to 4-6m in height with much of it at relatively shallow grades. This area has been nominated as having low susceptibility to coastal erosion (Type 1).

The majority of the rest of the site was characterised by steep cliffs 4-7m high, vegetated by larger colonising plant species (eg. gorse pampas mahoe etc) fronted by an intertidal platform being rapidly colonised by mangroves.

As is typical of many upriver estuarine environments the system is subject to siltation, infill and mangrove colonisation, with larger deposits and greater width of vegetated areas tending to be concentrated on the inside of the river bends where flows are slowest.

In most areas, despite the cliff morphology suggesting a pattern of historic erosion, the rate of erosion along the majority of the subject coastline has clearly slowed. A very low energy environment is indicated by mangrove colonisation and yet minimal talus material is present at the base of cliffs. This is indicates material eroded from the cliffs is transported away from the base over time. Once this material is removed slow erosion recommences. The slowing of the erosion rate is likely to be associated with mangrove growth and changes to the harbour by infilling and siltation slowing overall current flows.

A headland control point on Oira Creek present in photographs from 1942 is armoured and plays an important part in controlling downstream erosion rates. The islands, elevated levels of soft rock and associated sand banks at the confluence of the Oira and Drury Creeks currently affect the low tide flow regime. As this material erodes over time the waterway meander and associated erosion patterns may change.

The historic erosion evidenced by the steep morphology and likelihood of significantly increased erosion associated with rising sea levels result in this area likely to be subject to further cliff top retreat over time. The majority of the coastline (Type 2) within the Study Area has been classed as having a medium risk of coastal retreat.

Two portions of the coastline (Type 3) are on the outside of relatively broad bends and more at risk of rapid retreat. The northern end of Oira Creek is subject to obvious significant erosion. Slump features including bare earth, fallen and leaning trees and talus material were evident.

6.0 Methodology of Assessment

Providing an assessment of coastal erosion over longer timeframes involves a range of uncertainties. There is scientific debate about the relevant drivers and likely changes in these drivers with future climate change. Typically, limited data is available, especially for large scale assessments such as in a Structure Planning exercise and a measure of expert judgement is required. To account for these uncertainties, the MfE has recommended a risk-based approach (2009). The RAASCE adopted the following erosion risk categories:

- **Likely:** Probably will happen during the 100 year timeframe
- **Possible:** Might occur during the 100 year timeframe
- **Unlikely:** Unlikely to occur but possible during the 100 year timeframe

These relative risk areas are shown in the schematic below (Figure 6.0a). A ‘rare’ category, defined as ‘highly unlikely, but conceivable’ was also included in the RAASCE, however that has not been included in this report.

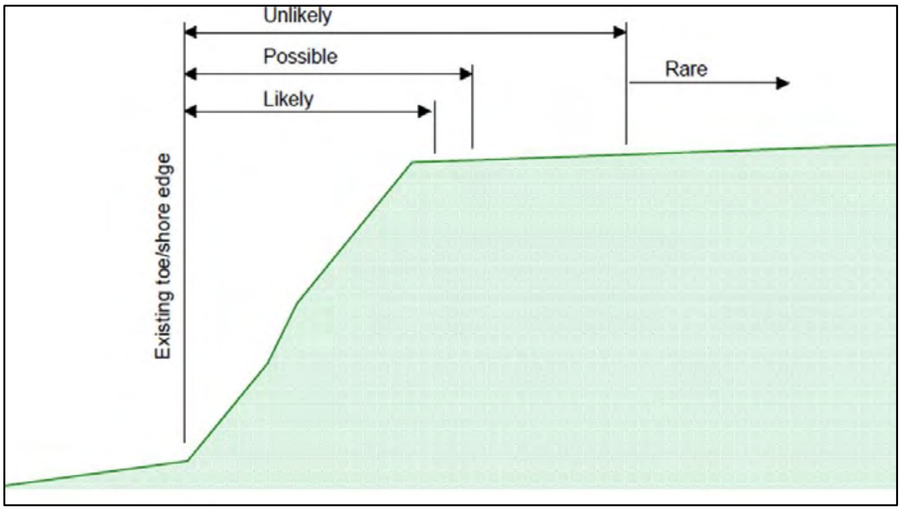


Figure 6.0a: Risk-based approach to area susceptible to erosion over the next 100 years

The distance from the toe of the cliff that is at risk from Coastal Retreat can be considered as comprised of two parts (Figure 6.0b)

1. Long Term Retreat (LTR) of the toe of the cliff – this is assumed to increase in as a result of future accelerated sea level
2. Cliff Slope Angle (α) - relaxation (lessening) of the cliff slope due to weathering and/or geotechnical failure following toe retreat will cause retreat of the crest .

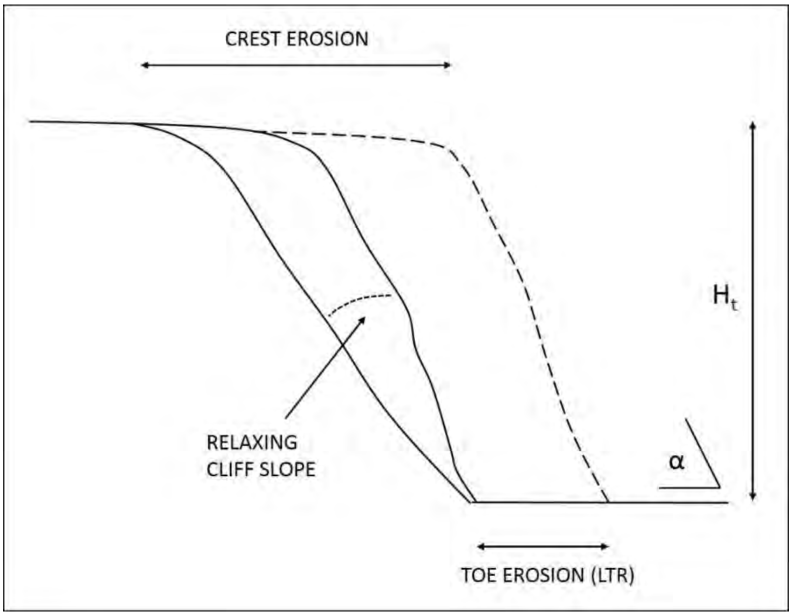


Figure 6.0b: Long term retreat of cliff assuming uniform lithology and structure (adapted from ARC, 2006)

This gives an area susceptible to erosion for soft cliffs defined by:

$$ASE_{Soft\_Cliffs} = \left[\left((LTR_{2120}) \times T\right) \times F + \left(\frac{H_t}{\tan \alpha}\right)\right]$$

Where:

LTR_{2120}	=	Horizontal coastline retreat (m) by 2120
T	=	Timeframe; 100 years
F	=	Allowance for uncertainty associated with long-term retreat rates
H_t	=	Height (m) of cliff from Auckland Council GIS data
α	=	The characteristic slope angle of the cliff surface measured from the horizontal.

The long term retreat rate is based on measure historic retreat rates and allowance for an increased rate of erosion due to sea level rise (Section 6.2).

An allowance for uncertainty in historic retreat rates (Section 6.1) of F = 1.25 was included in both the RAASCE and Aecom (2016). Estimate of the rate of retreat allowing for this factor has been adopted in this report.

The height of cliffs was obtained from Council GIS contours. With a relatively short coastline and relatively flat topography, cliff height could be estimated with some precision. Council GIS contours are given above mean sea level and the toe of cliff is generally at or about the high tide mark. Adopted cliff height was taken at 7m being 1m below the maximum top of bank contour indicated on the Council GIS plans.

6.1 Rate of Historic Retreat

The rate of future cliff retreat is proportional to the historic rate of retreat, multiplied by the ratio of the rate of future sea-level rise to the rate of historic sea-level rise. Given a 7-800% increase in predicted Sea Level Rise the calculation of this figure is a key determinant for the hazard set back.

As is typical for this type of assessment there is neither the quantity nor quality of data that theoretical techniques to quantify risk require. Therefore, estimates must be made based on a limited number of observations, and extrapolations of the available data.

Four sources of data are typically available in this regard:

- **Aerial surveys / photography** – Aerial surveys from the Council GIS system for 1996, 2001 and 2011, and Aerial photography from 1942 and 1960 were used to calculate retreat of the most significantly affected areas of coastline. Recognisable locations on the photographs were used to scale and compare them to aerials. Distances from man-made structures were measured and compared between aerial surveys particularly the 2001 and 2011. Although these surveys represented only a 10 year timeframe they were of higher resolution.

- **Cadastral surveys** – a Survey Plan deposited in 1984 was obtained, for a subdivision fringing the Oira Creek. This included provision for an Esplanade Reserve, which the survey notes had a boundary as 'Mean High Water Spring Tides'. A 1918 Deposited Plan was also obtained of the worst affected areas, however comparison between these two plans was made difficult due to poor resolution of the 1918 image.

- It was hoped that overlaying the Cadastral Plans with the aerial photography provided on the Council GIS would allow a comparison of erosion rate over the 27 or 99 years, respectively, since the seaward boundary (approximately the base of the cliff) was surveyed. Without ortho-rectification of the Aerial image and better resolution the apparent error was such that obtaining a likely rate of erosion from this method was not practicable. They did however, confirm the order of magnitude of historic erosion.

- **Man-made structures** – Fence lines adjacent to the coast were utilised in conjunction with the aerial photographs to help plot proposed erosion rates.

- **Geological/geomorphic markers** – on open coastlines shore platform width can be used as an indicator of long-term erosion rates, assuming that sub-surface rock erosion is negligible in the horizontal direction. Given the upper harbour location there are no relevant geological markers available on the subject coastline.

- Estimation of the long term average rate of retreat was calibrated geomorphically, on the assumption that the channel has formed subsequent to sea-level rising to about its existing elevation 6500 – 7500 years ago (Eco Nomos, 2016). Total channel width was measured on the Council GIS at external eroding bends and average erosion over this period calculated.

The retreat measured by these methods was at the limits of the resolution and accuracy of the surveys used, and the adopted rates were a combination of measured values, published rates for retreat of Auckland coastline and expert judgement.

For the three sections of coastline, the following rates of retreat have been adopted:

- **Type 1** - This area is the most protected and it is assumed no further toe retreat will occur.
- **Type 2** - The majority of the site, with a morphology of historic erosion but little sign of recent erosion, and colonisation by mangroves of the intertidal area. A historic rate of retreat of 3m per 100 years (0.03m per annum) was adopted for this area.
- **Type 3** - Two portions of the coastline are on the outside of relatively broad bends and more at risk of rapid retreat. A historic rate of retreat of 6m per 100 years (0.06m per annum) was adopted for these most quickly eroding areas.

6.2 Sea Level Rise Allowance

Quantifying the extent of sea level rise is a subject of scientific debate and ongoing revision of the provisions. The most up to date MfE guidance (2008) is to provide for 500mm and consider the consequences of 800mm between 2000 - 2100 with an allowance after this time of 10mm per annum. Therefore for a 100 year planning timeframe (2117) an allowance of 980mm could be considered. This number could be decreased to allow for sea level rise that has already occurred between 2000 and 2017.

A more recent study for Auckland Council (NIWA 2011) recommended a risk-based approach including the allowance of 1m by 2115 and 2m sea level rise for Greenfield sites. The Auckland Unitary Plan Operative in part (AUPOIP) became operative in 2016 following statutory consideration of the NIWA recommendations. The AUPOIP (E36.3.9) requires *"... coastal storm inundation areas to be above the 1 per cent annual exceedance probability (AEP) coastal storm inundation event including an additional sea level rise of 1m*." In accordance with this we have adopted consideration of 1m sea level rise by 2120, or approximately 10mm per annum, for this report.

6.3 Future Retreat Rate including Sea Level Rise Effects

An increased rate of shoreline retreat proportional to the predicted increased rate in sea level rise has been used in previous studies (Defra 2002, ARC 2006).

This is represented in a formula adapted from those studies as:

$$LTR_{2120} = \left(LTR_H \times \left(\frac{SLR_F}{SLR_H}\right)\right)$$

Where:

LTR_{2120} = Horizontal coastline retreat (m) by 2120

LTR_H = Historic long-term retreat (regression rate), m/yr, based on public data sources and judgement.

SLR_H = Historic sea-level rise rate for Auckland (1.3mm/yr, Hannah (2004))

SLR_F = Future sea-level rise rate – 10mm/yr, refer Section 6.2

The approach is loosely based on the Bruun Rule for soft sediment beaches which is a basic empirical tool subject to ongoing scientific debate. However, no more sophisticated assessment or methodology has been recognised for large scale assessment of coastal response to sea level rise.

The subject site is more driven by fluvial processes, as opposed to primarily wave driven processes which dominate the coastal erosion of the more exposed coasts of the Whenuapai Plan and most of the coasts in the RAASCE and Defra Report. However, given the similar mechanisms for erosion, toe retreat and changing cliff slope, the approach is considered appropriate.

Future sea level rise of 1m (10mm pa) is 770% greater than historic sea level rise (1.3mm pa) based on 100 years of measurement at the Port of Auckland tide gauge. This factor has the largest influence (over 70% of allowance) on the extent of land potentially affected by coastal erosion. It results in the areas susceptible to future coastal erosion being much greater than areas affected by historic erosion. This is consistent with the uncertainty in both the extent and effect of accelerated sea level rise.

6.4 Slope of Bank

In calculating the total retreat at the crest of the banks a regression angle for the slope is defined. The angle will depend on the material, its lithology and water content. The likelihood of retreat can be associated with a decreasing angle of regression for the material. The Puketoka formation soils of the Tauranga Group within the study area are considered to have a regression angle of approximately 30 degrees and this could be the expected cliff angle for much of the coastline if the toe position remains constant.

The RAASCE (ARC2006) considered slope angles for various materials and recommended the following figures for Tauranga Group Soils. These figures were calibrated on cliffs within and adjacent to the site, where slump features with slope angles of 20^0 have been measured from the Councils GIS system. The following slope angles have been adopted for the soft cliffs at the site (Table 6.4).

Likely (ex site investigation)	Possible	Unlikely
30^θ	20^θ	18^θ

Table 6.4: Adopted slope angles

An allowance for uncertainty in height was included in the RAASCE. This has not been allowed for in the current investigation, due to the coastline being a relatively short length and comprising even topography.

There is an intrinsic conservatism within the assumed methodology of adding the possible relaxation of slope angle to the possible toe regression rate for soft cliffs. The morphology of steep cliffs can be expected under a quickly retreating shoreline regime. The future rates of erosion are over seven times faster than those currently being experienced. We could expect that the face slope of the cliff will be at least as steep as it is presently.

7.0 Rate of Retreat Assessment

The subject coastline has been categorised into three Types, based on measured retreat rates, cliff angles and site morphology. The **calculated** 'likely', 'possible' and 'unlikely' areas susceptible to coastal erosion for each Type are shown below (Table 7.0a).

	Type 1 (Low)	Type 2 (Medium)	Type 3 (High)
Likely (30°)	12m	41m	57m
Possible (20°)	19m	48m	77m
Unlikely (18°)	22m	50m	79m

Table 7.0a: Calculated areas susceptible to coastal erosion

Because the largest part (over 70%) of the horizontal distance of land susceptible is due to future accelerated sea level rise and relatively low cliff height the difference between Likely and Unlikely is small. Therefore we have taken a precautionary approach of adopting the larger value, with rounding to a figure more appropriate to the level of accuracy of estimation.

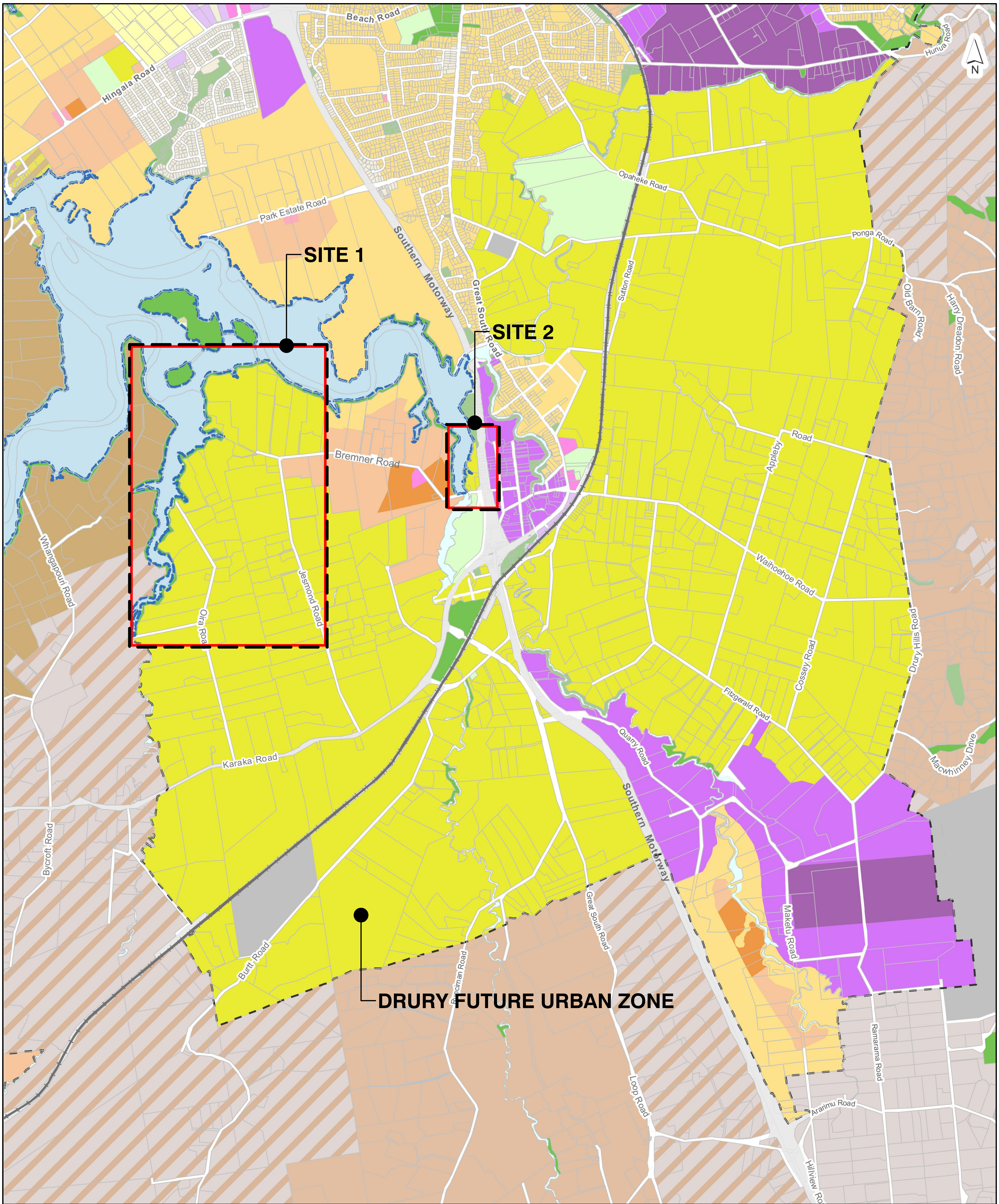
The **adopted** area susceptible to coastal erosion for each Type is shown in Table 7.0b, and appended as Appendix A.

	Type 1 (Low)	Type 2 (Medium)	Type 3 (High)
Adopted ASE	25m	50m	80m

Table 7.0b: Adopted area susceptible to coastal erosion for each Type

Appendix A

Mapped Areas Susceptible To Coastal Erosion



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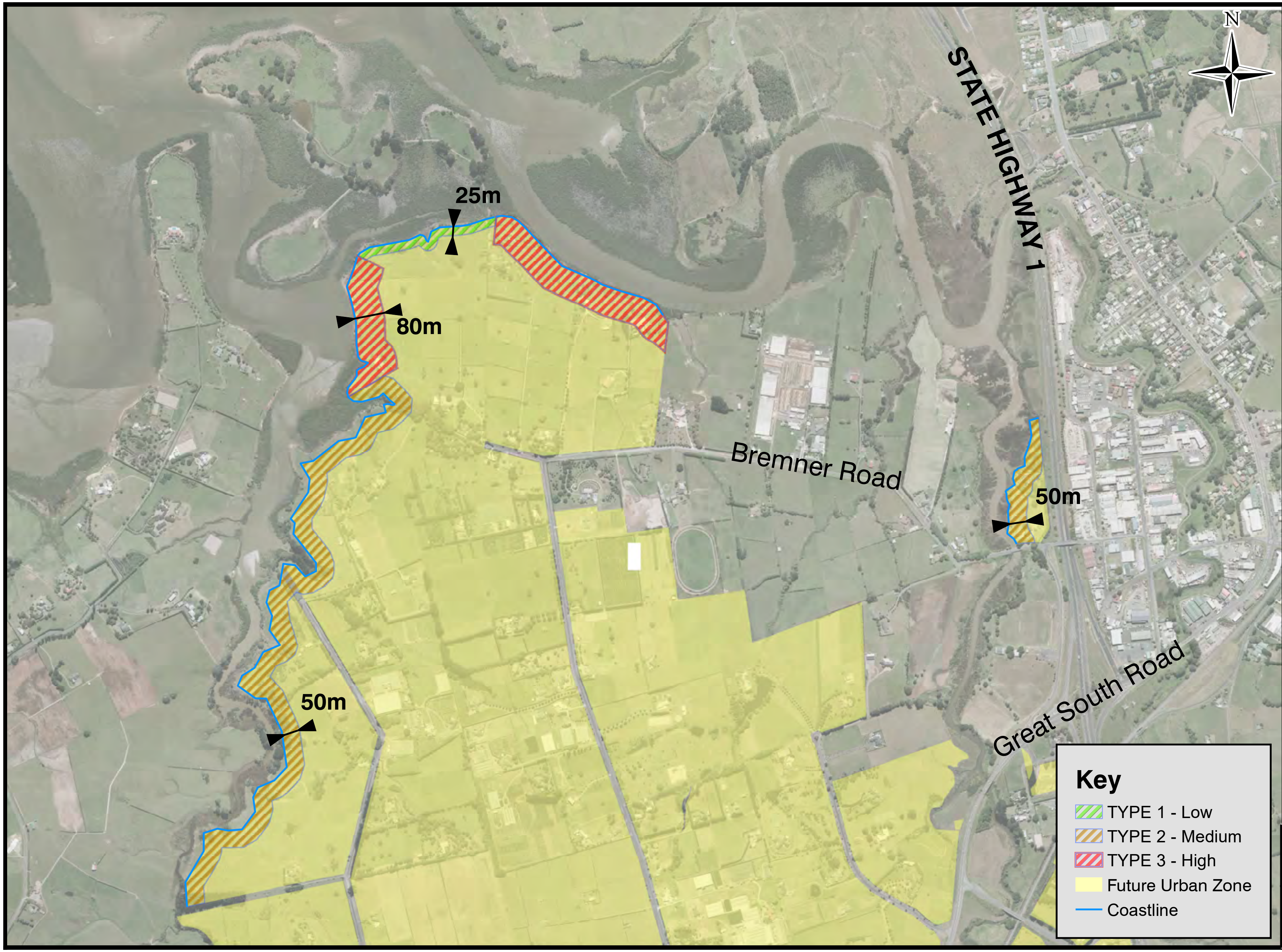
Date	30/06/2017



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APPENDIX D

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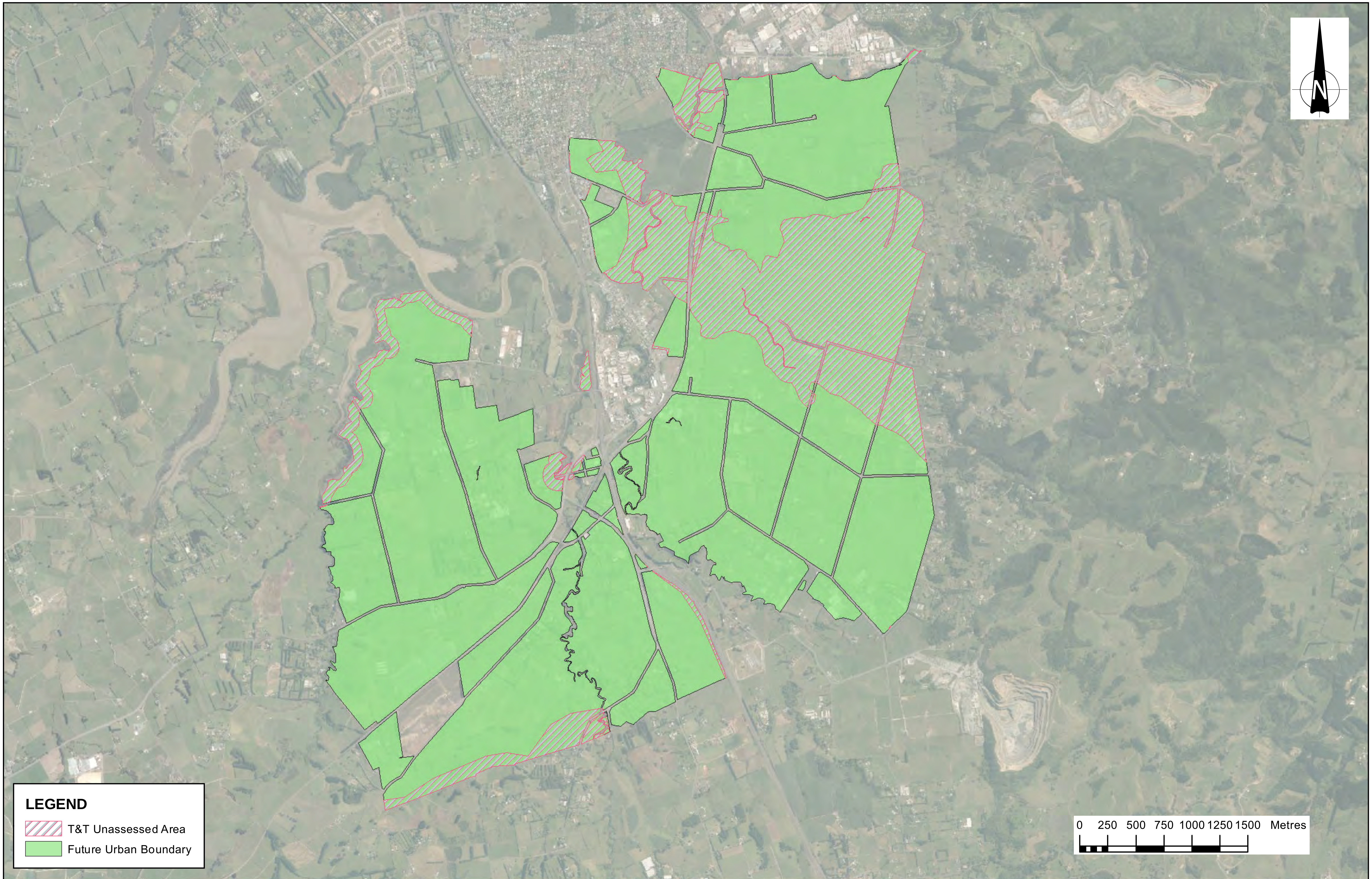

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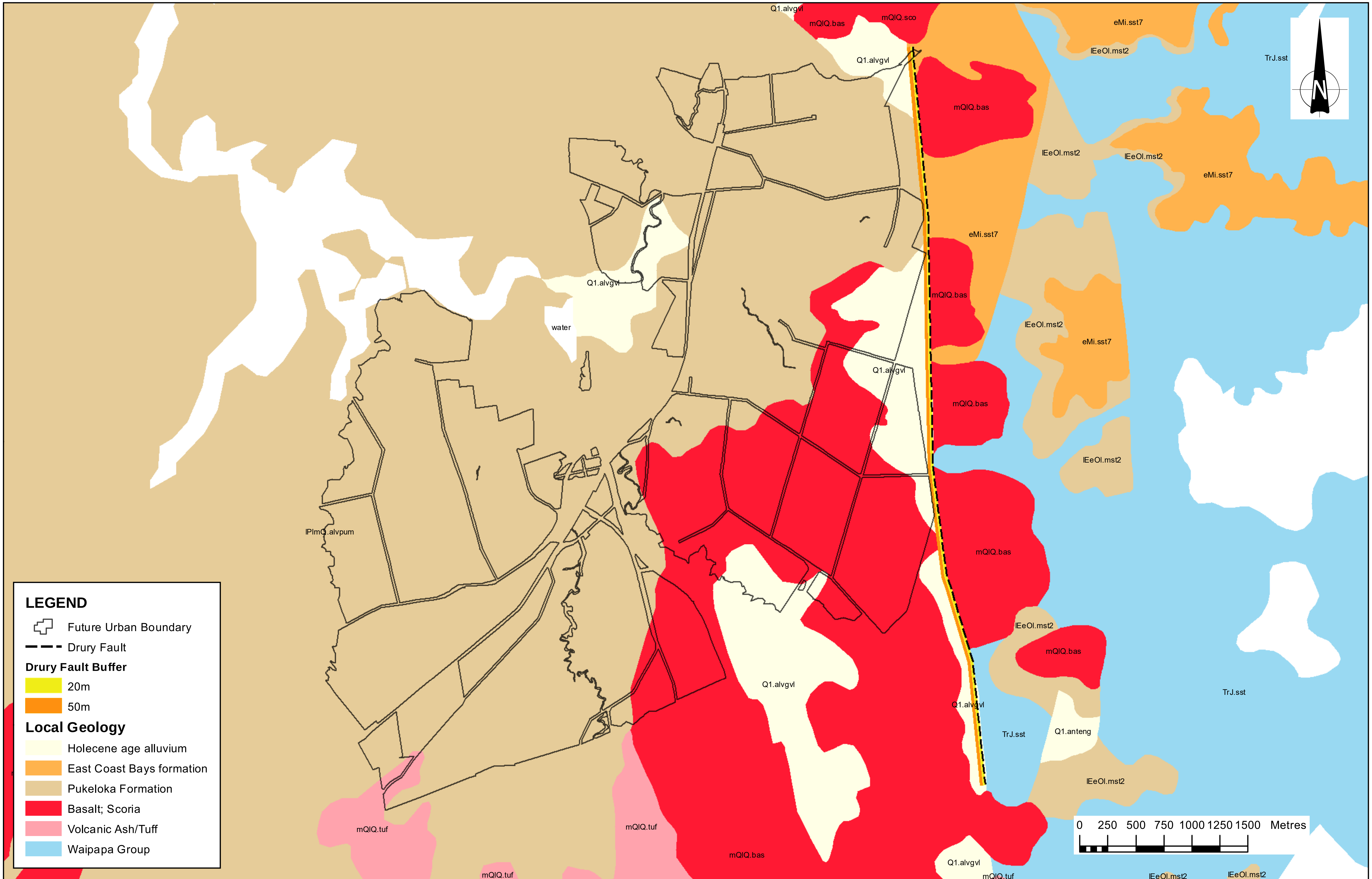

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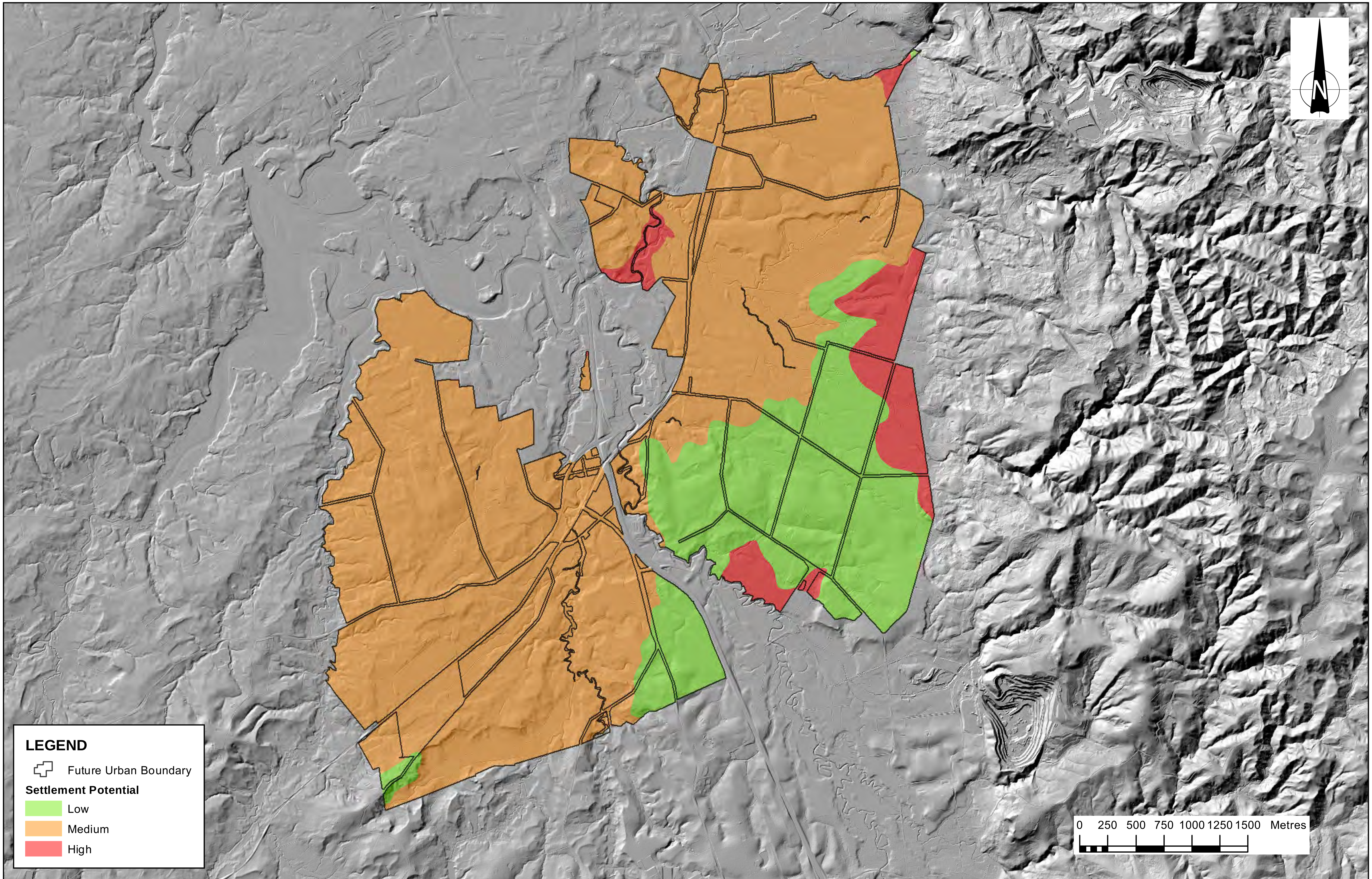

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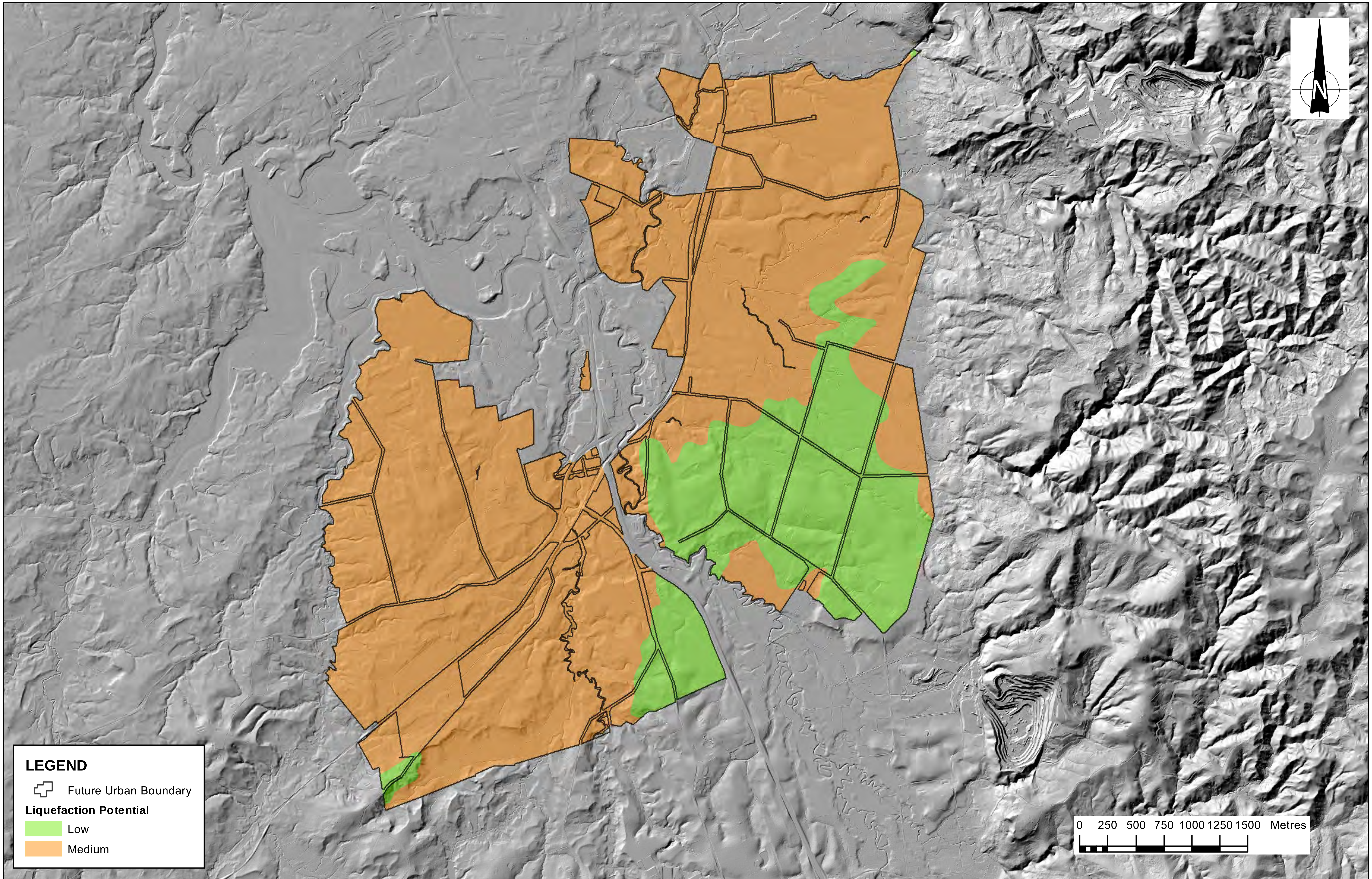

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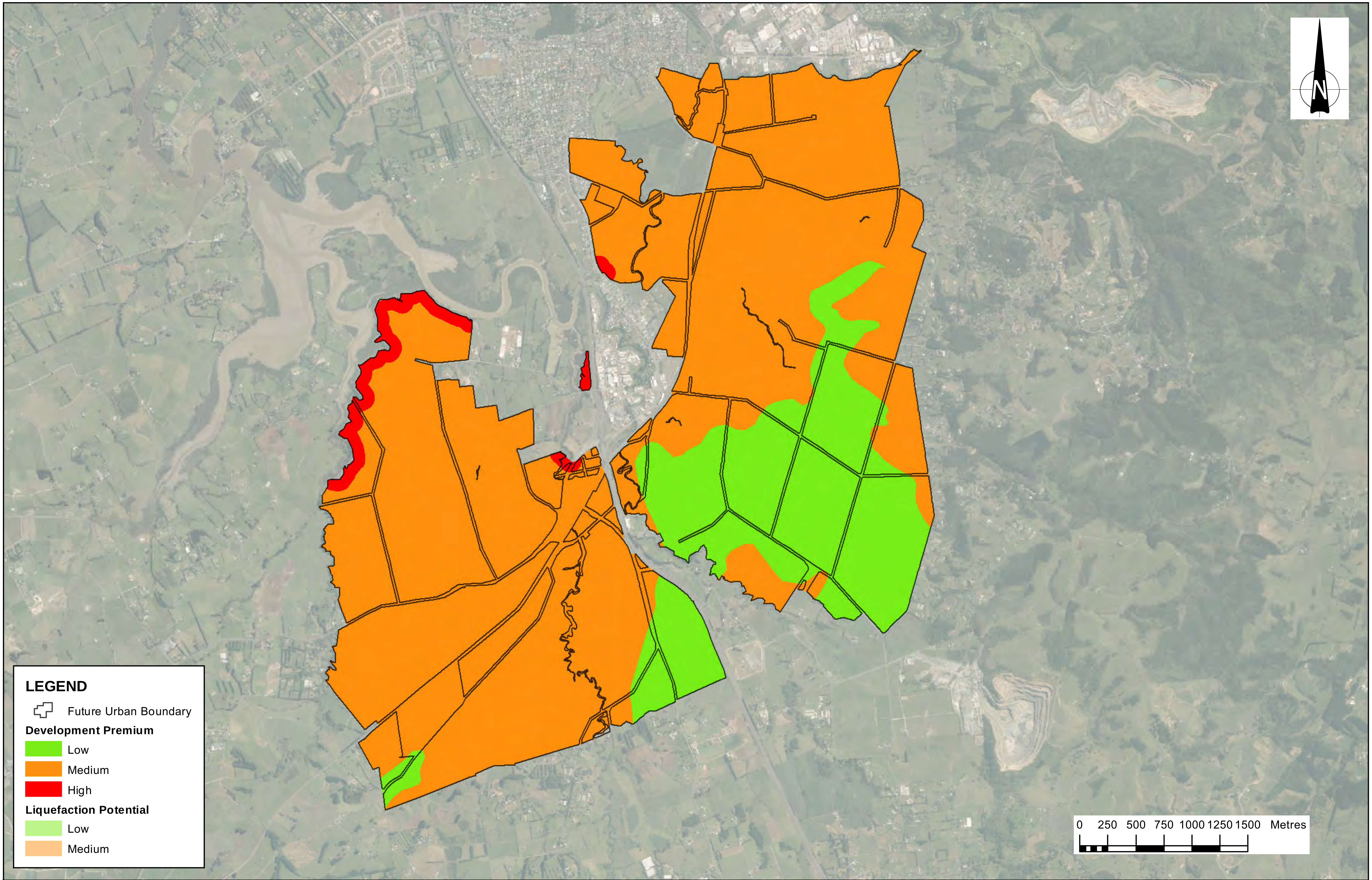

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