REPORT

Tonkin+Taylor

Liquefaction Desktop Study

T6 and T11 Growth Cell Structure Plan

Prepared for
Boffa Miskell Ltd

Prepared by
Tonkin & Taylor Ltd

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1 Introduction

The Waipa district has been identified as a high growth area in the National Policy Statement on Urban Development Capacity. Te Awamutu and Kihikihi are forecast to grow by 5,400 people by 2050. To provide for this growth, structure plans for the T6 and T11 cells are required, as identified in the Waipa 2050 Growth Strategy (2017) and Waipa District Council (WDC) 2018 – 2028 Long Term Plan.

T6 cell is approximately 165 ha in size, located to the west of State Highway 3 (SH3) between Te Awamutu and Kihikihi and is currently zoned Deferred Large Lot Residential. A Plan Change to the Proposed District Plan will re-zone the land to Large Lot Residential Zone.

T11 cell is approximately 47 ha and is located to the east of central Te Awamutu and is currently zoned Rural. A Plan Change to the Proposed District Plan will re-zone the land to Residential Zone and Deferred Residential Zone.

Tonkin & Taylor Ltd (T+T) have been requested by Boffa Miskell Ltd to investigate and provide a Level A desktop liquefaction assessment for the growth cells. These assessments will support the Structure Plans for each cell and Plan Changes to the District Plan.

1.1 Scope of work

The scope of works comprises a desktop assessment of liquefaction vulnerability of the growth cells in general accordance with a Level A assessment as described in Planning and Engineering Guidance for Potentially Liquefaction-Prone Land (MBIE/MfE/EQC, 2017). A Level A assessment is further described in Section 2.4 and considers basic information about geology, groundwater and seismic hazard to assess the potential for liquefaction to occur.

The scope of this report can be summarised as:

- Collation and review of available data that is relevant to this study including:
  - Geological and geomorphic maps.
  - Ground surface elevation levels for the extent of the study area.
  - Geotechnical investigations and laboratory tests that are currently available on the New Zealand Geotechnical Database (NZGD).
  - Groundwater level information for the study extent.
- Assess the liquefaction vulnerability.
- Provide potential risk treatment options.

It should be noted that the provision of general geotechnical advice relating to the structure plans is outside the scope of the original Request for Proposal.

2 Liquefaction vulnerability assessment

2.1 Liquefaction process

It can be readily observed that dry, loose sands and silts contract in volume if shaken. However, if the loose sand is saturated, the soil's tendency to contract causes the pressure in the water between the sand grains (known as "pore water") to increase. The increase in pore water pressure causes the soil's effective grain-to-grain contact stress (known as "effective stress") to decrease. The soil softens and loses strength as this effective stress is reduced. This process is known as liquefaction.

The elevation in pore water pressure can result in the flow of water in the liquefied soil. This water can collect under a lower permeability soil layer and if this capping layer cracks, can rush to the surface bringing sediment with it. This process causes ground failure and with the removal of water and soil, a reduction in volume and hence subsidence of the ground surface.

The surface manifestation of the liquefaction process is the water, sand and silt ejecta that can be seen flowing up to two hours following an earthquake. The path for the ejecta can be a geological discontinuity or a man-made penetration, such as a fence post, which extends down to the liquefying layer to provide a preferential path for the pressurised water. The sand often forms a cone around the ejecta hole. With the dissipation of the excess pore-water pressure, the liquefied soil regains its pre-earthquake strength and stiffness.

The surface expression of liquefaction, water and sand depends on a number of characteristics of the soil and the geological profile. If there is a thick crust of non-liquefiable soil such as a clay, or sand that is too dense to liquefy during the particular level of shaking of the earthquake, then water fountains and sand ejecta may not be seen on the surface. The amount of ground surface subsidence is generally dependent on the density of the sand layers as well as how close the liquefying layers are to the surface. Ground surface subsidence increases with increasing looseness in the soil packing. The ground rarely subsides uniformly resulting in differential settlement of buildings and foundations. Figure 2.1 summarises the process of liquefaction with a schematic representation.

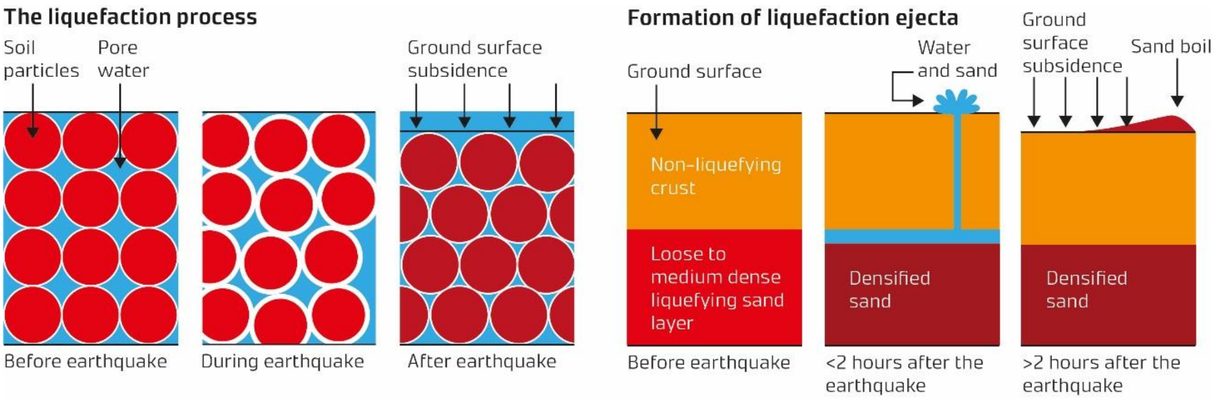

Figure 2.1: Schematic representation of the process of liquefaction and the manifestation of liquefaction ejecta.

2.2 Liquefaction susceptibility and triggering

The conditions often susceptible to liquefaction occur in geologically young sedimentary deposits such as those shown in Figure 2.2. In general terms, loose sands, some silts and in some cases gravels are most susceptible. While clays generally do not liquefy, they may still soften during an earthquake. Soil types which are susceptible to liquefaction include:

- Sands and low plasticity/non-plastic silts. (Bray & et al, 2014).
- Fine grained low to non-plastic soils with a high moisture content. (Bray & Sancio, 2006), (Boulanger & Idriss, 2006).
- Young, typically Holocene-aged (≤12,000 years old) deposits.
- Gravels can liquefy if they have a low permeability or are confined by less permeable layers.

The groundwater level in the soil is an important factor and soils with the groundwater at or near the surface are more susceptible.

Figure 2.2: Some landforms commonly susceptible to liquefaction, (MBIE/MfE/EQC, 2017).

2.3 Liquefaction consequence

Figure 2.3 presents the characteristics of liquefaction related land damage, and a summary of the likely consequences of liquefaction related damage for each category of land damage. This figure has been reproduced from (MBIE/MfE/EQC, 2017). Appendix A of the MBIE Guidance includes photos of liquefaction-induced land damage for each of these categories. These provide a useful reference for understanding the magnitude of land damage that can be expected within each category.

DEGREE OF LIQUEFACTION-INDUCED GROUND DAMAGE (example photographs)	TYPICAL CONSEQUENCES AT THE GROUND SURFACE These are examples of the type of damage that would be expected, they are not intended to be criteria for calculation
None to Minor 	– ***None to Minor*** no signs of ejected liquefied material at the ground surface[1]. – No more than minor differential settlement of the ground surface (eg undulations less than 25 mm in height). – No apparent lateral spreading ground movement (eg only hairline ground cracks). – Liquefaction causes no or only cosmetic damage to buildings and infrastructure (but damage may still occur due to other earthquake effects).
Minor to Moderate 	– ***Minor to Moderate*** quantities of ejected liquefied material at the ground surface (eg less than 25 percent of a typical residential site covered[2]); and/or – Moderate differential settlement of the ground surface (eg undulations 25–100 mm in height). – No significant lateral spreading ground movement (eg ground cracks less than 50 mm wide may be present, but pattern of cracking suggests the cause is primarily ground oscillation or settlement rather than lateral spreading). – Liquefaction causes moderate but typically repairable damage to buildings and infrastructure. Damage may be substantially less where liquefaction was addressed during design (eg enhanced foundations).
Moderate to Severe 	– Large quantities of ejected liquefied material at the ground surface (eg more than 25 percent of a typical residential site covered[2]); and/or – ***Moderate to Severe*** differential settlement of the ground surface (eg undulations more than 100 mm in height); and/or – Significant lateral spreading ground movement (eg ground cracks greater than 50 mm wide, with pattern of cracking suggesting direction of movement downslope or towards a free-face). – Liquefaction causes substantial damage and disruption to buildings and infrastructure, and repair may be difficult or uneconomic in some cases. Damage may be substantially less, and more likely to be repairable, where liquefaction was addressed during design (eg enhanced foundations and robust infrastructure detailing).

Notes:

1 An absence of ejecta at the ground surface does not necessarily mean that liquefaction has not occurred. Liquefaction may still occur at depth, potentially causing ground settlement.

2 The coverage of the site with ejected liquefied material does not in itself represent ground damage in an engineering sense, however there is a strong correlation between the volume of ejecta and the severity of differential ground settlement and foundation/infrastructure damage.

Figure 2.3: Degrees of liquefaction-induced land damage (MBIE/MfE/EQC, 2017)

The main potential consequences of liquefaction are discussed in MBIE Planning and Engineering Guidance for Potentially Liquefaction-Prone Land. Table 2.1 from these guidelines is reproduced in Table 2.1 of this report.

Table 2.1: Consequences of liquefaction, as published in Planning and engineering guidance for potentially liquefaction-prone land

Land	• Sand boils, where pressurised liquefied material is ejected to the surface (ejecta). • Ground settlement and undulation, due to consolidation and ejection of liquefied soil. • Ground cracking from lateral spreading, where the ground moves downslope or towards an unsupported face (e.g. a river channel or terrace edge).
Environment	• Discharge of sediment into waterways, impacting water quality and habitat. • Fine airborne dust from dried ejecta, impacting air quality. • Potential contamination issues from ejected soil. • Potential alteration of groundwater flow paths and formation of new springs.
Buildings	• Distortion of the structure due to differential settlement of the underlying ground, impacting the amenity and weathertightness of the building. • Loss of foundation-bearing capacity, resulting in settlement of the structure. In some cases this can result in tilting or overturning of multi-level buildings. • Stretch of the foundation due to lateral spreading, pulling the structure apart. In some cases this can result in collapse or near-collapse of buildings. • Damage to piles due to lateral ground movements, and settlement of piles due to down drag from ground settlement. • Damage to service connections due to ground and building deformations.
Infrastructure	• Damage to road, rail and port infrastructure (settlement, cracking, sinkholes, ejecta). • Damage to underground services due to ground deformation (e.g. 'three waters', power and gas networks). • Ongoing issues with sediment blocking pipes and chambers. • Uplift of buoyant buried structures (e.g. pipes, pump stations, manholes and tanks). • Damage to port facilities. • Sedimentation and 'squeezing' of waterway channels, reducing drainage capacity. • Deformation of embankments and bridge abutments (causing damage to bridge foundations and superstructure). • Settlement and cracking of flood stop banks, resulting in leakage and loss of freeboard. • Disruption of stormwater drainage and increased flooding due to ground settlement.
Economic	• Lost productivity due to damage to commercial facilities, and disruption to the utilities, transport networks and other businesses that are relied upon. • Absence of staff who are displaced due to damage to their homes or unable to travel due to transport disruption. • Cost of repairing damage.
Social	• Community disruption and displacement – initially due to damage to buildings and infrastructure, then the complex and lengthy process of repairing and rebuilding. • Potential ongoing health issues (e.g. respiratory and psychological health issues).

While the immediate effects of liquefaction relate primarily to land, building and infrastructure damage, liquefaction can also have a significant social, economic and environmental impact, refer to Section 2.4 of Planning and engineering guidance for potentially liquefaction-prone land (MBIE/MfE/EQC, 2017).

2.4 Assessment methodology

This liquefaction vulnerability assessment has been undertaken general accordance with a Level A assessment as described in Planning and engineering guidance for potentially liquefaction-prone land (MBIE/MfE/EQC, 2017). In that document a Level A assessment is described as a *Basic Desktop Assessment* which equates to an assessment of regional-scale information supported by a site walkover. For the purposes of this study, each growth cell has been classified in terms of its geomorphic zone. These zones are then assigned a liquefaction vulnerability classification as described below.

The methodology described in the Planning and engineering guidance for potentially liquefaction-prone land (MBIE/MfE/EQC, 2017) recommends categorisation of the liquefaction vulnerability of the land based on the performance criteria described in Figure 2.4 below.

<table>
<tr><td colspan="4">LIQUEFACTION CATEGORY IS UNDETERMINED
A liquefaction vulnerability category has not been assigned at this stage, either because a liquefaction assessment has not been undertaken for this area, or there is not enough information to determine the appropriate category with the required level of confidence.</td></tr>
<tr><td colspan="2">LIQUEFACTION DAMAGE IS UNLIKELY
There is a probability of more than 85 percent that liquefaction-induced ground damage will be None to Minor for 500-year shaking.
At this stage there is not enough information to distinguish between Very Low and Low. More detailed assessment would be required to assign a more specific liquefaction category.</td><td colspan="2">LIQUEFACTION DAMAGE IS POSSIBLE
There is a probability of more than 15 percent that liquefaction-induced ground damage will be Minor to Moderate (or more) for 500-year shaking.
At this stage there is not enough information to distinguish between Medium and High. More detailed assessment would be required to assign a more specific liquefaction category.</td></tr>
<tr><td>Very Low
Liquefaction Vulnerability
There is a probability of more than 99 percent that liquefaction-induced ground damage will be None to Minor for 500-year shaking.</td><td>Low
Liquefaction Vulnerability
There is a probability of more than 85 percent that liquefaction-induced ground damage will be None to Minor for 500-year shaking.</td><td>Medium
Liquefaction Vulnerability
There is a probability of more than 50 percent that liquefaction-induced ground damage will be:
Minor to Moderate (or less) for 500-year shaking; and
None to Minor for 100-year shaking.</td><td>High
Liquefaction Vulnerability
There is a probability of more than 50 percent that liquefaction-induced ground damage will be:
Moderate to Severe for 500-year shaking; and/or
Minor to Moderate (or more) for 100-year shaking.</td></tr>
</table>

Figure 2.4: Performance criteria for determining the liquefaction vulnerability category - reproduced from Table 4.4 of MBIE/MfE/EQC (2017)

The performance criteria listed in Figure 2.4 relate the liquefaction vulnerability category to the expected liquefaction-induced land damage at a given ARI level of earthquake shaking. The assessment requires the assessor to consider the probability that a particular level of liquefaction-induced land damage will occur for a given level of shaking. In undertaking this assessment it is important to understand the following note attached to the table in the guidance document:

"The probabilities listed in this table are intended to provide a general indication of the level of confidence required to assign a particular category, rather than to be a specific numerical criteria for calculation. Conceptually, these probabilities relate to the total effect of all uncertainties in the assessment…"

That is, the guidance recommends the assessor consider the combined effect of all the uncertainties associated with the available information in the determination of the land damage category.

The general methodology applied to determine the liquefaction vulnerability category for the study area is as follows:

1 Evaluate the uncertainties associated with the mapping. This includes consideration of the resolution of mapping and the variability of soil conditions.
2 Evaluate the uncertainties associated with the groundwater level. Due to the limited amount of information about groundwater within the study area this is primarily dependent on field experience and engineering judgement and is one of the most significant sources of uncertainty in this assessment.
3 Evaluate the uncertainties associated with the determination of the seismic hazard for the study extent. Whilst current scientific understanding suggests that the Hamilton and Waipa Basin area is expected to have a relatively low level of seismic hazard compared to other regions across New Zealand, there remains considerable uncertainty regarding the likelihood and intensity of earthquake shaking that could occur. This uncertainty is especially relevant where liquefaction-susceptible soils are present but estimated design shaking intensities (e.g. PGA for 100 year ARI design event) are unlikely to be strong enough to trigger liquefaction. This means that if earthquake shaking intensity is slightly greater than assumed for design (or if design PGA values increase in future due to improved understanding of the hazard), then a step-change worsening in performance could occur. For this reason, where liquefaction-susceptible soils are present it is generally not preferable to rely exclusively on low design PGA values to assign a liquefaction vulnerability category of *Liquefaction Damage Is Unlikely, Very Low* or *Low*.
4 Based on the consideration of all of these uncertainties, assign one of the liquefaction vulnerability categories defined in Figure 2.4 to the land within the project extent.

3 Ground conditions

3.1 Geology

Te Awamutu and Kihikihi are situated on the border of the Waipa and Hamilton basins (Figure 3.1), a graben that has been progressively infilled with a complex sequence of volcanogenic alluvium and various ignimbrites and tephra since c. 2 million years ago (McCraw, 2011).

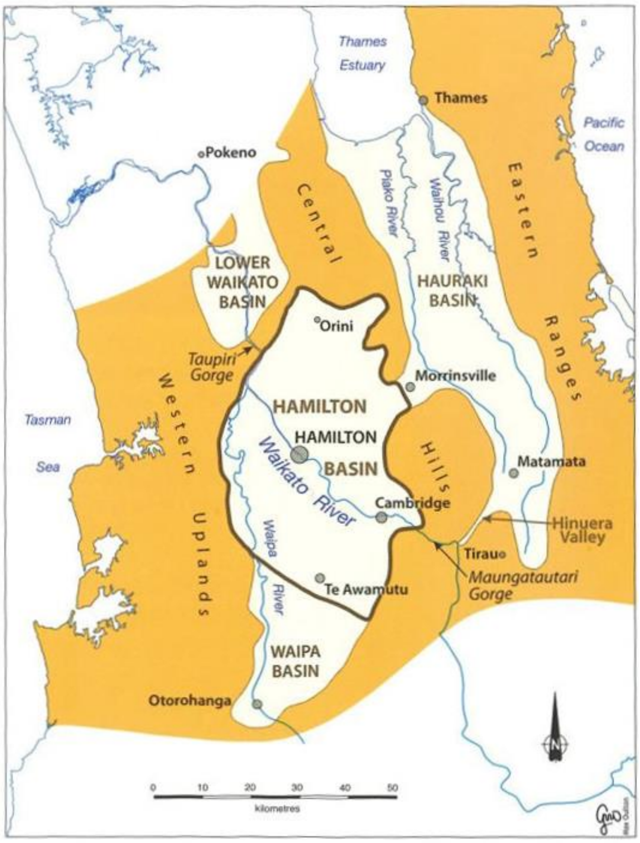

Figure 3.1: The Hamilton lowlands or Basin in the upper central North Island is bounded to the west and east by ranges and bisected by the Waikato River (McCraw, 2011).

Two distinct periods of deposition can be characterised in the Hamilton lowlands and are observed in the present day landscape as older materials (Walton Subgroup) forming the broad hills and younger materials (Primarily the Hinuera Formation of the Piako Subgroup) forming extensive plains. The Walton Subgroup and Piako Subgroup are part of the Tauranga Group. Younger Holocene sediments are also present in the Hamilton and Waipa Basin within gullies, peat bogs and along river terraces. The relationship between the geological materials is shown in Figure 3.2.

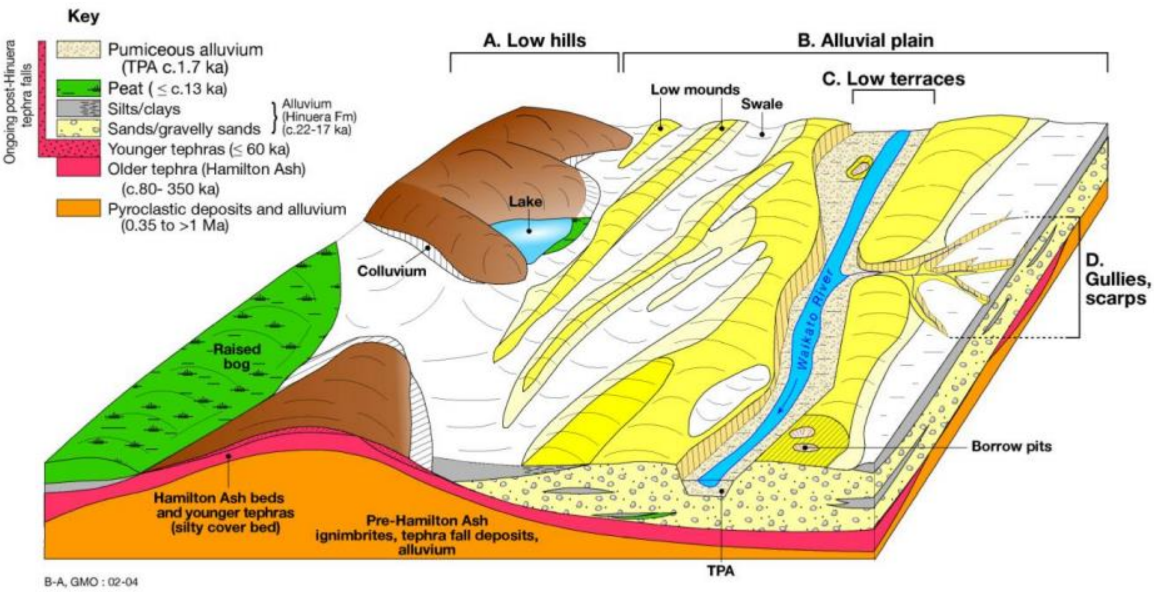

Figure 3.2: Main landscape units and geological materials, Hamilton and Waipa Basin (Lowe, 2010).

<u>Walton Subgroup</u>

The Walton Subgroup, forming the present day broad hills, comprises a sequence of ignimbrites and tephra from several sources and fine grained volcanoclastic alluvium (Edbrooke, 2005). The deposition of the Walton Subgroup beds occurred between 2 million years ago to 27,000 years ago in the Pleistocene Epoch. During later stages these materials eroded forming hills and valleys. The Walton Subgroup deposition ended upon the Oruanui Eruption (27,000 years ago).

<u>The Piako Subgroup</u>

Following the Oruanui eruption, the existing topography was infilled by the Piako Subgroup, which formed the extensive plains observed in Hamilton lowlands. The Piako Subgroup comprises interbedded coarse alluvium, pumice gravels, peat and silts deposited by braided river systems of the ancestral Waikato and Waipa Rivers. These rivers continued to deposit vast amounts of sediment into the Hamilton lowlands until climatic conditions changed c. 17,000 and the river systems entrenched into present day positions (Molloy, 1998).

Due to the nature of the depositional environment, the Piako Subgroup is highly variable both laterally and vertically. Loose sands and gravels are found in the higher energy environments and levees and finer grained sediments such as silt represent the low energy environments such as embayed channels and on the inside of river bends.

<u>Recent Holocene Sediments</u>

Subsequent to the deposition of the Hinuera Formation to form the "Hinuera Surface", a network of gullies have formed within the Hamilton and Waipa Basin. The floors of these narrow gullies are filled with young Holocene (<12,000 years old) colluvium and alluvium deposits consisting of reworked sands, silts and gravels of the Hinuera Formation and Walton Subgroup.

3.2 Faulting

The GNS New Zealand Active Fault Database identifies the Kerepehi fault as the closest active fault to the site at approximately 42km to the east. Other faults affecting the Hamilton and Waipa Basin include the inferred non-active Waipa fault and the Taupiri fault to the north proposed by (Kirk, 1991).

3.3 Site geomorphology

For the purposes of this study, the site has been divided into three geomorphic zones. These zones are presented in Figure A1 and Figure A2 in Appendix A and described in Table 3.1. The basis of the zones are the geological mapping (Edbrooke, 2005), a Digital Elevation Model (DEM) derived from LiDAR data and a site walkover undertaken in January 2019.

Table 3.1: Description of geomorphic zones adopted for the study areas

Geomorphic zone	Typical geology	Description
Low hills	Walton Subgroup	The relatively higher ground of the basin consists of low rounded hills representing the remnants of a previous ground surface. A typical sequence through this zone may consist of: Post Hamilton Ash Tephra – silt Hamilton Ash weather tephra – clay Karapiro Formation – Alluvial gravelly clay Puketoka Formation – ignimbrites
Alluvial plains	Piako Subgroup	Highly variable both vertically and laterally as the ancestral Waipa and Waikato Rivers deposited material eroded from the volcanic catchments of the central North Island. The deposits filled the low lying ground and channels and depressions within the eroded surface of the Walton Subgroup. The “Hinuera Surface” today consists of a series of low ridges, swales and flat plains sloping gently to the north. Soils comprise cross-bedded silts, sands, gravels with peat lenses also common. Sequences may exhibit a general fining upwards sequence, (McKay, Lowe, & Moon, 2017).
Gullies	Recent Holocene Deposits	Gullies are formed in the Hinuera Surface forming moderately steep slopes and terraces. Material within the gullies is recent alluvium derived from the parent materials in the basin. Uncontrolled filling is also often encountered in these zones.

3.4 Groundwater

In the absence of long term groundwater monitoring data we have undertaken a review of groundwater information for the growth cells. From experience in working within the Hamilton and Waipa Basin it is possible to draw some conclusions about the groundwater within the identified geomorphic zones (Table 3.2). However, it is not possible to assign groundwater levels in an area to the level of certainty required to refine this liquefaction assessment without long term groundwater monitoring records of sufficient density to build a reliable groundwater model.

Table 3.2: General groundwater observations for the geomorphic zones within the study area.

Geomorphic Zone	Groundwater observations
Low hills	Higher ground and often lower permeability soils leading to deeper groundwater levels relative to other geomorphic zones.
River/Gullies	Deposits in gully bases normally at or close to the median water table. River terraces generally coincident with river level. Presence of perched water normally results in the development of gullies and instability.
Alluvial plain	Relatively shallow groundwater when not controlled by localised drainage associated with river terraces, gullies and deep swales. Phreatic surfaces can be steep at slope margins depending on the underlying conditions.

3.5 Site ground conditions

The ground conditions at growth cells T6 and T11 are summarised in Table 3.3 and Table 3.4, respectively. Geomorphic zone maps are provided in Appendix A.

Table 3.3 Summary of the ground conditions at grown cell T6

Geology	Walton subgroup (eQa ~2ma to ~17 ka) Piako Subgroup (IQa – between ~128 to 12 ka) – alluvium Holocene Alluvium (Q1a) Investigations undertaken for the Haultain Street subdivision at the south eastern corner of the site indicate that the site is underlain by silts, sands and clays in this location. The geological unit was not noted, however, the descriptions are consistent with the Piako Subgroup.
Geomorphology / landforms	Low hills (Walton subgroup) Alluvial plains (Piako subgroup) Stream gullies (Recent alluvium)
Groundwater	Varied terrain including a shallow gully system that will locally control the level of the ground water. For parts of the site located away from these topographical relief features, relatively high groundwater levels could be expected. This is evidenced by the presence of shallow drain features in the growth cell. Investigations undertaken for the Haultain Street subdivision at the south eastern corner of the site indicates that groundwater levels of 1.5 m bgl are to be expected in this location. Low Hills areas likely to have relatively deep groundwater.

Table 3.4: Summary of the ground conditions at grown cell T11

Geology	Walton subgroup (eQa ~2ma to ~17 ka) Piako Subgroup (IQa – between ~128 to 12 ka) Holocene Alluvium (Q1a) No subsurface investigation are available for this growth cell. A review of aerial photography for the site has shown an area of non-engineered filling to the west of the commercial centre
Geomorphology / landforms	Low hills (Walton subgroup) Alluvial plains (Piako subgroup) Stream gullies (Recent alluvium)
Groundwater	The river and gully systems typically have the effect of lowering groundwater levels on the elevated areas of the plains. The Mangaohoi stream is located at the south of the growth cell at an RL of 43 m, local water levels are likely to be governed by this. The presence of farm drains in the centre of the site at a depth of 1.5 to 2 m suggests that groundwater may be coincident with the base of these features in this location. The alluvial plains are likely to have groundwater depths in the region of 1.5 to 3 m depending on proximity to the Mangaohoi Stream. Low Hills areas likely to have relatively deep groundwater.

4 Liquefaction assessment

4.1 Seismic site subsoil class

The seismic subsoil class in accordance with NZS 1170.5:2004 (Section 3.1.3) for the site is considered to be 'Class D – Deep Soil Sites'. This assumption is based on recent research by The University of Waikato (Jeong, 2019) which suggests that the majority of the Hamilton and Waipa Basin should be categorised as site Class D except on the basin margins. Although the growth cells are on the fringes of the study, the Waikato and Waipa Basin can be seen to extend further south.

4.2 Ground shaking hazard

The seismic hazard in terms of Peak Ground Acceleration (PGA) for the area has been assessed based on the NZTA Bridge Manual in accordance with the approach recommended in NZGS Module 1 (NZGS/MBIE, 2016).

For the purposes of this study, we have assumed that the growth cells will be used for residential development consisting of Importance Level 2 buildings with a 50 year design life. Consequently, the 25 and 500 year return periods correspond to Serviceability Limit State (SLS) and Ultimate Limit State (ULS) design events in this case.

Table 4.1 presents the return periods for earthquakes with various 'unweighted' PGAs with corresponding earthquake magnitudes.

Table 4.1: Ground seismic hazard

Event	Return period (years)	PGA (g)	Magnitude (M_{eff})
SLS	25	0.056	5.9
ULS	500	0.223	5.9

4.3 Results

Liquefaction vulnerability for the site has been assessed by geological screening with qualitative calibration and using semi-quantitative screening criteria based on age, peak ground acceleration expected, depth to groundwater and experience in undertaking quantitative assessments in these geological materials. Table 4.2 provides an outline of the general vulnerability of the geomorphic zones, their relevance to the growth cells is described in section 4.3.1 and 4.3.2 below. The following additional observations are made about the results of this assessment:

- With additional investigation and analysis it is possible that significant areas of the Low Hills geomorphology could be categorised as *Liquefaction Damage Is Unlikely*. This is due to the relatively large proportion of soils that are likely to exhibit clay like behaviour (i.e. not susceptible to liquefaction) and that it is more likely that relatively deep (i.e. deeper than 4 m) groundwater would be encountered in these areas.
- The current categorisation of *Liquefaction Damage Is Possible* for the other geomorphic zones does not preclude the later categorisation of these areas into *the Liquefaction Damage Is Unlikely* category (or *Low* or *Very Low* categories) if appropriate based on additional local investigation and analysis.

Table 4.2: Summary of liquefaction vulnerability of each geomorphic zone

Geomorphic zone	Summary of results	Liquefaction vulnerability category	Key uncertainties	Site specific information required to refine the liquefaction assessment
Low hills	The low hills generally represent areas of the Walton Subgroup. Experience in working within these materials indicates that this zone typically has lower liquefaction vulnerability than the other zones in the study area. A large proportion of the units within the Walton Subgroup exhibit clay-like behaviour, so site-specific confirmation of the presence of clay-like soil may lead to assigning a category of "*Liquefaction Damage Is Unlikely*". However, because specific groundwater depths across the area and the underlying geology are unknown a category of "*Liquefaction Category is Undetermined*" has been assigned. Groundwater likely to be deeper within this zone.	*Liquefaction Category Is Undetermined*	• Presence and thickness of soils exhibiting clay-like behaviour • Groundwater levels • Thickness and distribution of liquefiable layers • Proportion of pumiceous particles	• Confirm geological unit, i.e. Walton Subgroup • Confirm clay-like soils present • Confirm whether groundwater is present within top 4 m • Determine soil type to sufficient depth depending on the geological formation (top 4 m if Walton Subgroup or Hinuera Formation are confirmed, deeper for more vulnerable units) • Assess soil relative density if non-plastic
Stream gullies	The gully bottoms are likely to contain looser, younger material and may often have high groundwater, meaning that greater levels of damage may occur in this zone. Uncontrolled fill is a common feature of gully slopes, where this is present the risk will also increase. The presence of a free face in these locations is likely to present a lateral spreading risk. Development within this zone may is likely to require engineering assessment due to the presence of unstable slopes. The geological mapping has been undertaken at a scale that may lead to some CPTs being assigned to the incorrect geomorphic zone in the statistical analysis undertaken for this study. Confirmation of the geological unit/s present should be the first step in the assessment of liquefaction vulnerability within this area. Deposits in gully bases are normally at or close to the median water table.	*Liquefaction Damage Is Possible*	• Groundwater levels at slope margins • Geological unit • Perched water • Thickness and distribution of liquefiable layers • Proportion of pumiceous particles • Slope angles • Slope height	• Confirm whether groundwater is present within top 4 m • Determine geological unit • Determine soil type • Confirm whether uncontrolled fill is present • Assess soil relative density • Proximity to free faces • Height of free faces
Alluvial plains	The alluvial plains are highly variable in geology both laterally and vertically. Land damage of *"None to Minor"* through to *"Moderate to Severe"* are all possible within the alluvial plains, therefore it is important to have a good understanding of the underlying geology. The site may be underlain by a great thickness of liquefiable soils or may only have thin, intermittent layers of liquefiable soils interbedded with medium dense to dense gravels. A site with a high water table and the presence of non-plastic soils may require CPT investigations to determine the land damage category applicable. Groundwater is typically relatively shallow when not controlled by localised drainage associated with gullies and deep swales. Phreatic surfaces can be steep at slope margins depending on the underlying conditions.	*Liquefaction Damage Is Possible*	• Groundwater levels • Thickness and distribution of liquefiable layers • Proportion of pumiceous particles • Geomorphology	• Confirm geological unit • Confirm whether groundwater is present within top 4 m • Determine soil type to sufficient depth depending on the geological formation (top 4 m if Hinuera Formation is confirmed, deeper for more vulnerable units) • Consider proximity to slopes including swales • Determine pedological soil class • Determine what landforms are present • Assess soil relative density

4.3.1 Liquefaction vulnerability growth cell T6

Figure B1 in Appendix B shows liquefaction the vulnerability categories determined for the T6 growth cell based on the information available and the uncertainties that exist. The low hills geomorphic zone dominates the growth cell with alluvial plains forming the central low lying parts of the cell and the stream gully zone present along the existing tributaries of the Puniu River.

For the purposes of development, the current concept plan (Revision I) shows that the majority of the development is within the Low Hills geomorphic zone with the Alluvial Plains and Stream Gully zones being mostly used as green spaces.

Minimal investigations should be able to determine a classification of *Liquefaction Damage is Unlikely* in the Low Hills geomorphic zone. Experience in working with the materials of the Alluvial Plains suggests that damage could be anything from none to severe, CPT and determination of the water table will be required in the Alluvial Plains to quantify the liquefaction risk. The stream gully geomorphic group will be retained as open spaces, the potential for liquefaction at stream crossings will need to be further assessed once road layouts are confirmed.

Where development is occurring within land where a classification of *Liquefaction Damage is Possible* has been determined, consideration should be also given to the proximity to existing free faces or the construction of road swales in order to determine the potential effects of lateral spreading.

A Level C liquefaction assessment should be targeted at reducing the uncertainties in each zone based on the intended land use as outlined in Table 4.2 above. Potential mitigation approaches are presented in Section 4.5.

4.3.2 Liquefaction vulnerability growth cell T11

Figure B2 in Appendix B shows liquefaction vulnerability categories determined for the T11 growth cell based on the information available and the uncertainties that exist. Vulnerability areas follow the geomorphic assessment given in Table 4.2 above with the addition of an area of high vulnerability in the area of known non-engineered fill in the western part of the growth cell.

For the purposes of development, the current concept plan (Revision B) shows three areas of development due to the presence of a significant flood hazard in the lower lying central areas. The majority of the eastern development is situated in the Low Hills geomorphic zone fringed by the alluvial plains to the east, south and west. It is likely then that the liquefaction vulnerability and the subsequent mitigation will vary across this area. Subsequent to the completion of the geomorphological and liquefaction assessments, parts of T14 growth cell have been incorporated in to T11. It is recommended that the assessments are extended include these additional areas.

The central development is situated almost entirely on an area that has been subject to non-engineered filling in the 1960s. The presence of this fill and the likely high groundwater has led a classification of High Vulnerability in this area, however, it is likely that this material will require removal due to the presence of ground contamination and/or other geotechnical considerations. The removal of this material will not remove the liquefaction hazard completely as the level of vulnerability will be determined by the underlying soil.

The western development is situated in an area of Low Hills although this should be confirmed by site investigation during consenting.

Minimal investigations within the Low Hills geomorphic zone should determine a classification of *Liquefaction Damage is Unlikely*. Experience in working with the materials of the Alluvial Plains suggests that damage could be anything from none to severe, CPT and determination of the water table will be required in the Alluvial Plains to quantify the liquefaction risk. Development within the Stream Gullies geomorphic zone is not anticipated in this growth cell.

Where development is occurring within land where *Liquefaction Damage is Possible*, consideration should be also given to the proximity to existing free faces or the construction of road swales in order to determine the potential effects of lateral spreading.

A Level C liquefaction assessment should be targeted at reducing the uncertainties in each zone based on the intended land use as outlined in Table 4.2 above. Potential mitigation approaches are presented in Section 4.5.

4.4 Lateral spreading vulnerability

Observations from previous earthquakes demonstrate that liquefaction-induced lateral spreading can cause significant damage to buildings, infrastructure and the environment. Therefore consideration of the potential for lateral spreading should be applied when undertaking a liquefaction vulnerability assessment.

When considering the potential for lateral spreading adjacent to a free-face, the Planning and engineering guidance for potentially liquefaction-prone land (MBIE/MfE/EQC, 2017) notes that *"It is less likely (but not impossible) for lateral spreading to occur if there is no liquefied soil within a depth of 2H of the ground surface (where H is the height of the free-face)."* Zhang, Robertson, & Brachman (2004) define H as the difference in height from the toe of the embankment (frequently the invert of a river or other water surface body) to the top of the embankment for which lateral spreading is being assessed (see Figure 4.1).

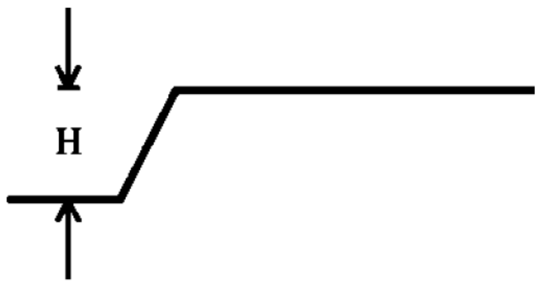

Figure 4.1: Free face height (H) as defined by Zhang et al. (2004)

However, with the information available for this study it is difficult to accurately define the free face height (H). This is primarily because it is difficult to confirm whether or not Digital Elevation Models (DEM) derived from LiDAR data are accurately estimating the elevation of the invert due to it frequently being obscured by water or vegetation.

The Planning and engineering guidance for potentially liquefaction-prone land (MBIE/MfE/EQC, 2017) recommends that particular attention should be given to land that is susceptible to liquefaction within 100 m of a free face less than 2 m high; or within 200 m of a free face greater than 2 m high. That is not to say that lateral spreading is likely to extend this far, however, the effects need to be considered to these extents.

Also, particular attention should be given to the potential for lateral spreading to occur on land within the Stream Gullies geomorphic zone. This is because of a combination of the land being categorised as *Liquefaction Damage Is Possible*, the potential for relatively shallow groundwater and there being a significant number of free faces associated with rivers and streams in this zone.

4.5 Potential risk treatment options

There are various potential options available to manage liquefaction-related risk, as summarised in Section 6 of MBIE (2017).

One potential solution is to avoid exposure to the hazard by not constructing within liquefaction-prone land. Further investigation will allow WDC to refine the liquefaction vulnerability areas and may allow uncategorised areas to be reclassified as low vulnerability.

Another potential solution is to reduce or mitigate liquefaction-related risk by reducing the likelihood of liquefaction occurring and/or reducing the consequences if liquefaction occurs. Potential foundation design and ground improvement options to mitigate the damaging effects of liquefaction are discussed in the series of guidance documents produced by MBIE for repairing and rebuilding houses affected by the Canterbury earthquakes (MBIE, 2012). Generally, the type of damage experienced may result in differential settlements, global settlements and ingress of liquefaction ejecta that could damage infrastructure and buildings. The risk of damage such as this is normally treated in one or a combination of the following ways:

- Undertake **ground improvement** so that a higher level of earthquake shaking is required to trigger liquefaction. In some cases it may be possible to change the fundamental behaviour of the ground (e.g. by physically removing or cementing susceptible soil) so that liquefaction will not occur even under the highest levels of earthquake shaking expected.
- Specify **robust foundation systems** that are able to tolerate liquefaction related land damage, such as thick reinforced foundations or stiff platforms. The importance level of the structure and the specific ground conditions at the site would inform the performance standard required for these foundation systems.
- Specify **readily repairable foundation systems** that are able to be reinstated relatively easily following liquefaction induced land damage.
- Specify the use of **lightweight building materials** for construction of buildings. Adopting lightweight cladding and roofing materials reduces the required bearing strength of the underlying soils and the severity of structural shaking imposed on the foundations. As such, lightweight building materials reduce the potential for liquefaction-induced foundation and building damage to occur.

There are various potential opportunities for Territorial Authorities to take an active role in managing liquefaction-related risk, while also facilitating development by simplifying site-specific ground investigation and foundation design requirements where appropriate. Possible examples include:

- Defining succinct geotechnical information requirements for resource and building consent applications, which focus on resolving the key uncertainties in the liquefaction assessment relevant for each geomorphic zone.
- Identifying standard foundation solutions which can be applied “off the shelf” once the liquefaction vulnerability category has been confirmed with sufficient certainty.
- Undertaking a widely-spaced grid of ground investigations and/or groundwater monitoring across the growth cells. This would provide greater certainty in the assessment of liquefaction vulnerability, and could allow some types of development to proceed relying only on the existing information without the need for site-specific investigations (where appropriate, and subject to a requirement for robust foundations).

4.6 Recommendations for further assessment

Further assessment of the liquefaction risk should be undertaken at subdivision stage in order to satisfy the requirements of s106 of the RMA. In terms of the MBIE (2017) guidance, this should consist of a Level C assessment that will provide a quantitative assessment of the liquefaction vulnerability of the growth cells that is specific to the proposed land use and tailored to the geomorphic zones. The level of uncertainty will be reduced so that a more precise liquefaction vulnerability category can be assigned and appropriate risk treatment options can be determined.

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6 Applicability

This report has been prepared for the exclusive use of our client Boffa Miskell Ltd, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
John Brzeski Engineering Geologist	Glen Nicholson Project Director

Report technically reviewed by Michael Triggs – Geotechnical Engineer

JJBR
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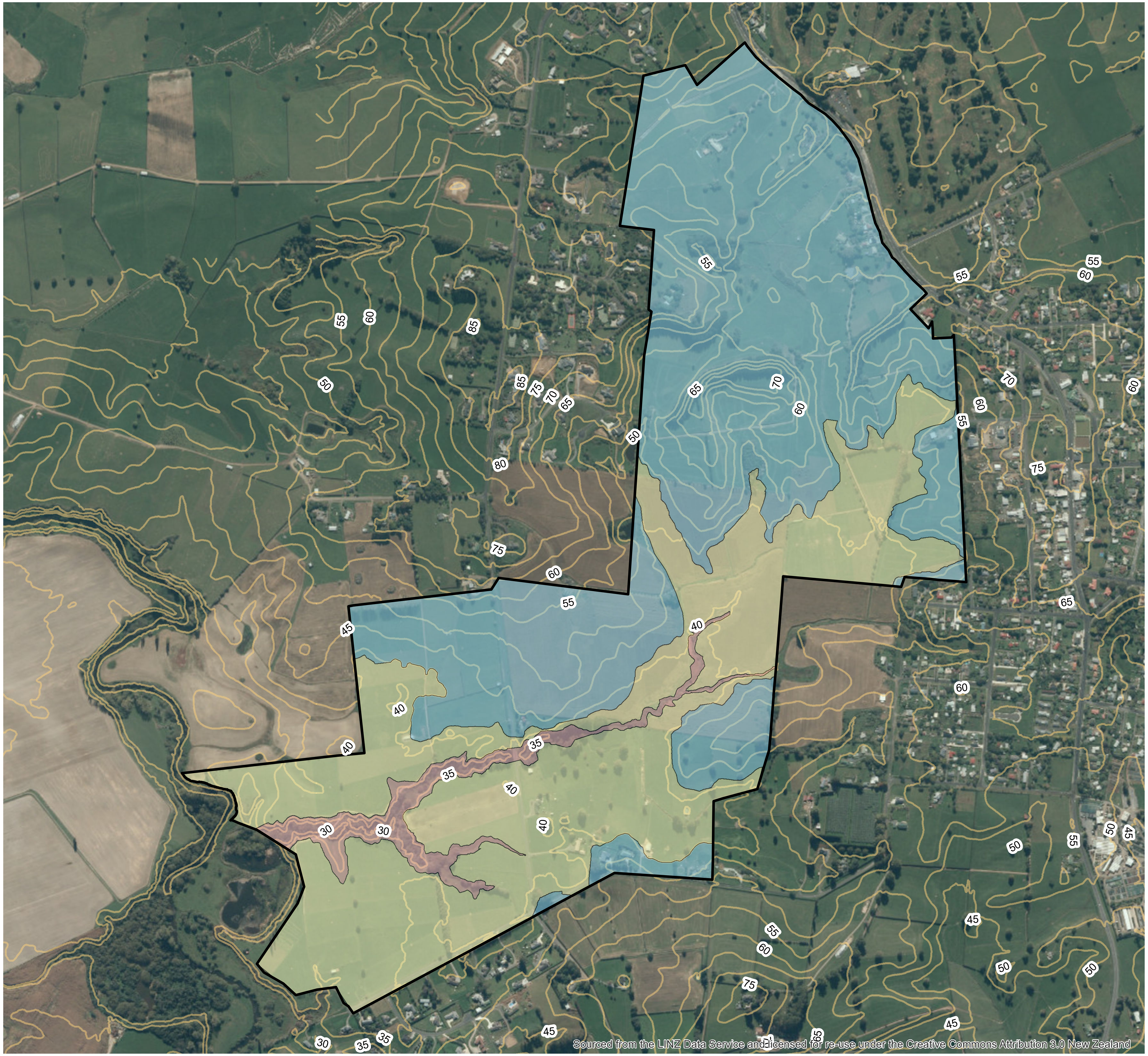
Appendix A: Geomorphic Zones



LEGEND

T6 Growth cell extent

T6 Growth cell extent

T6 Geomorphic Zones

Alluvial Plains

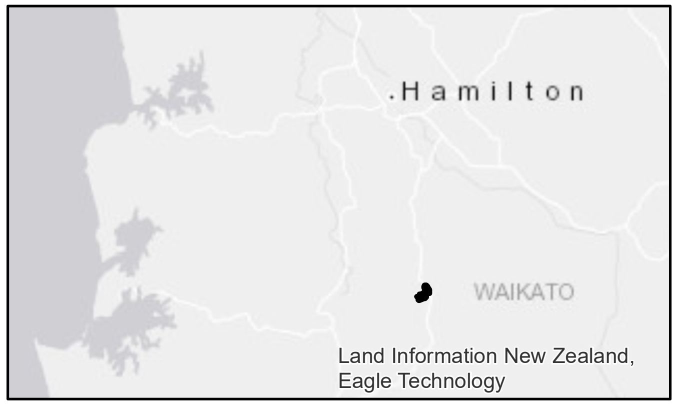
Low Hills

Stream Gullies

A3 SCALE:1:9,000

0 70 140 210 280 350 Meters

N



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This figure has been prepared with respect to the particular brief given to Tonkin + Taylor.
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The basis of geomorphic zones are the geological mapping (Edbrooke, 2005), a Digital Elevation Model (DEM) derived from LiDAR data and a site walkover undertaken in January 2019.
This plan should be read in conjuction with accompanying growth cell structure plan report

DRAWN	JJBR	Jun.19
CHECKED	MJTT	Jun. 19
APPROVED	GGN	Aug.19

ARCFILE
T6_geomorph_map_20190116.mxd

SCALE (AT A3 SIZE)
1:9,000

PROJECT No.
1008305.1000

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WAIPA STRUCTURE PLAN
T6 GROWTH CELL
Geomorphic Zones

Figure A1: T6 Geomorphic Zones

LEGEND

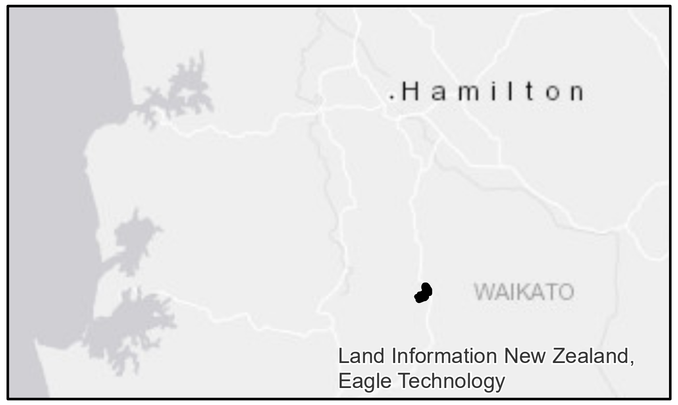
T11 Geomorphic Zones

- Alluvial Plains
- Low Hills
- Non-engineered Fill
- Stream Gullies

A3 SCALE:1:5,405

0 40 80 120 160 200 Meters

N



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T11_geomorph_map_20190116.mxd

SCALE (AT A3 SIZE)
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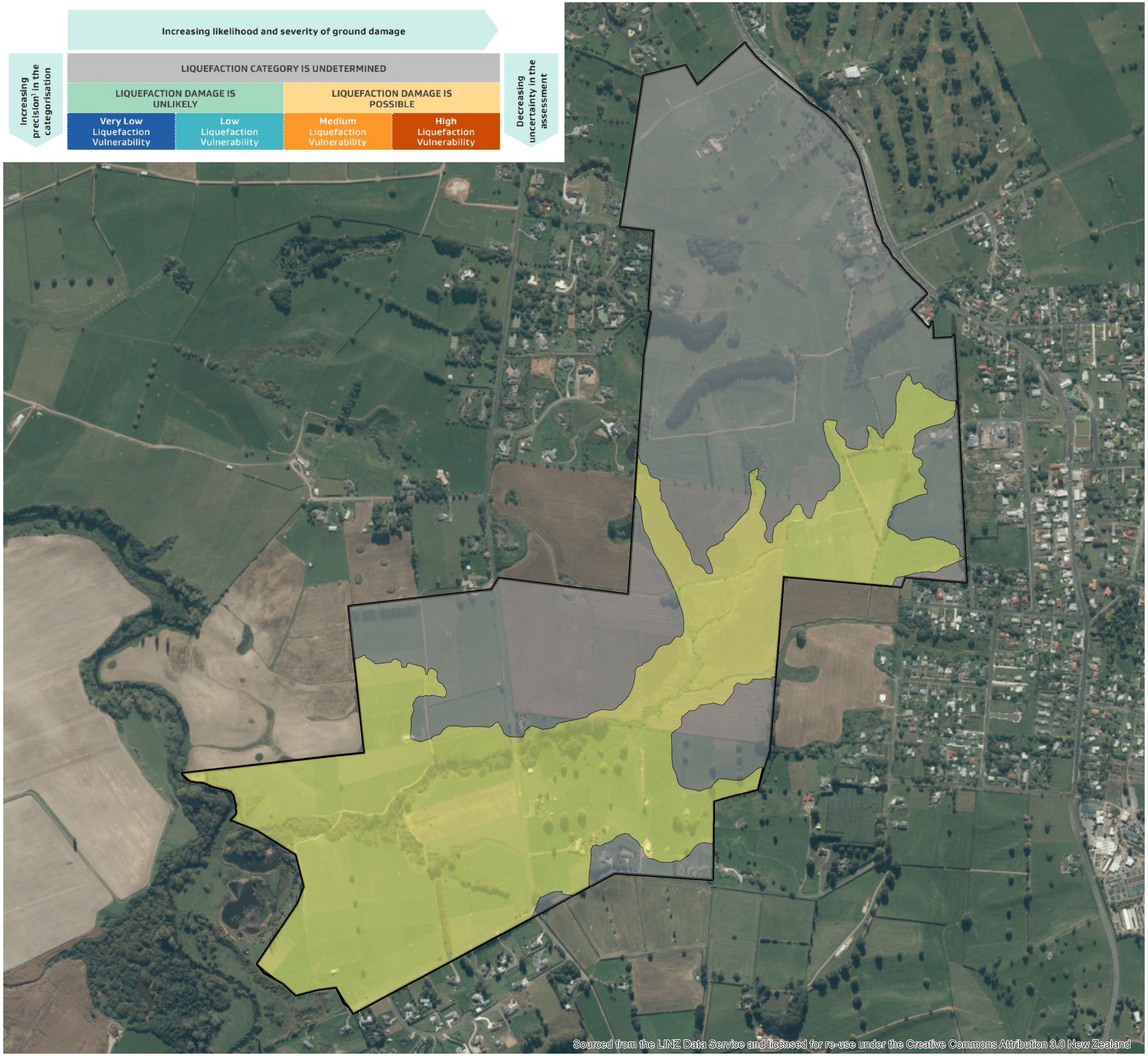
Geomorphic Zones

Figure A2: T11 Geomorphic Zones

Appendix B: Liquefaction Vulnerability Maps



LEGEND

T6 Growth cell extent

Liquefaction vulnerability Category

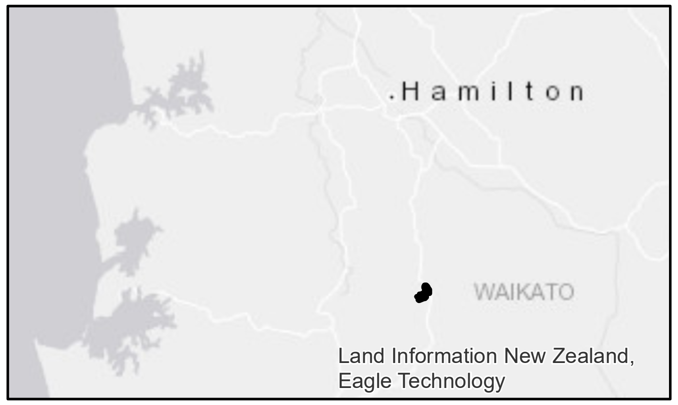
Liquefaction Category is Undetermined

Liquefaction Damage is Possible

A3 SCALE:1:9,000

0 70 140 210 280 350 Meters

N



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Liquefaction vulnerability categories determined by undertaking a Level A liquefaction assessment in line with MBIE/MfE/EQC (2017) guidelines.
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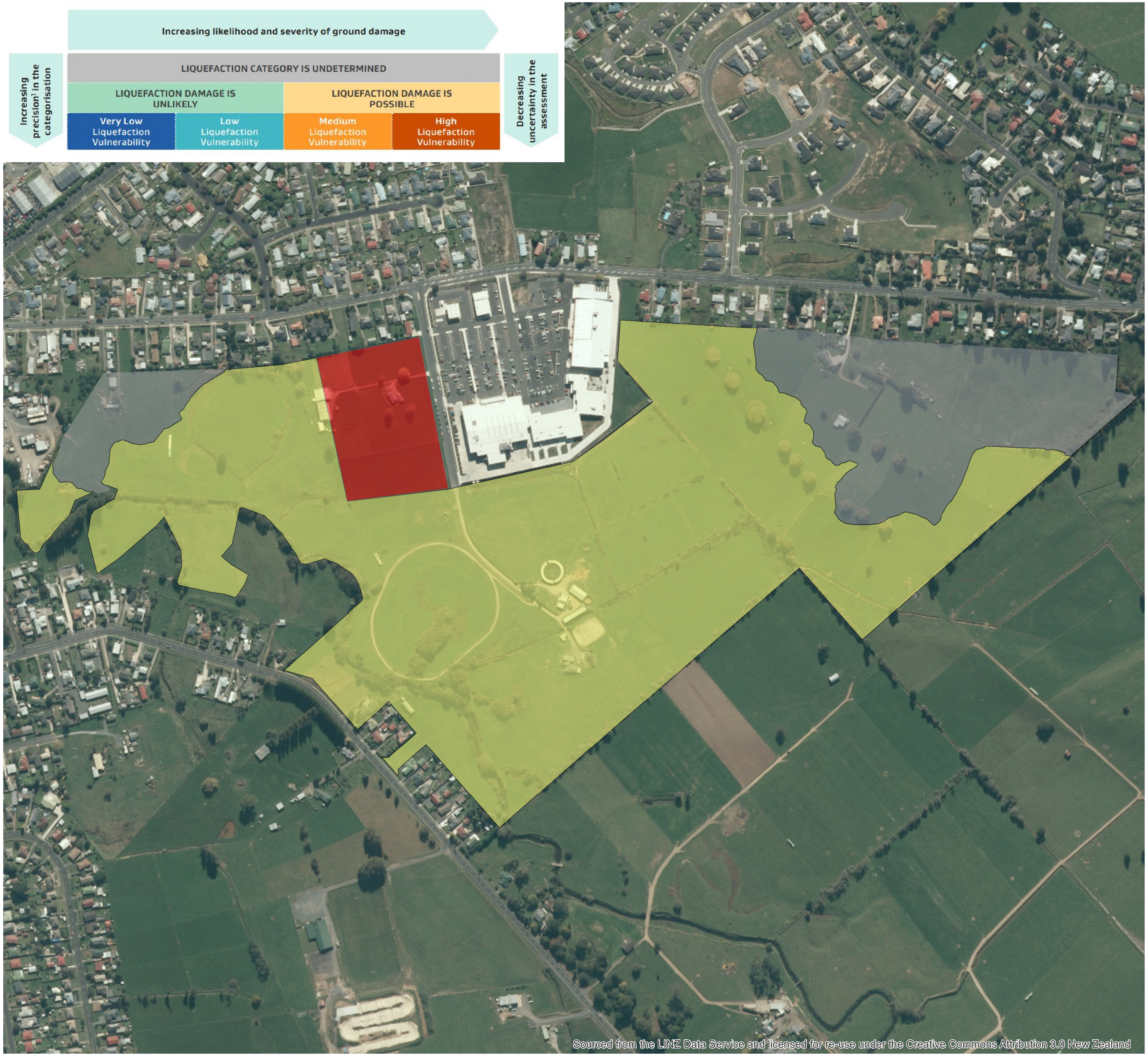
WAIPA STRUCTURE PLAN
T6 GROWTH CELL
Liquefaction Vulnerability map

Figure B1: T6 Liquefaction Vulnerability Map



LEGEND

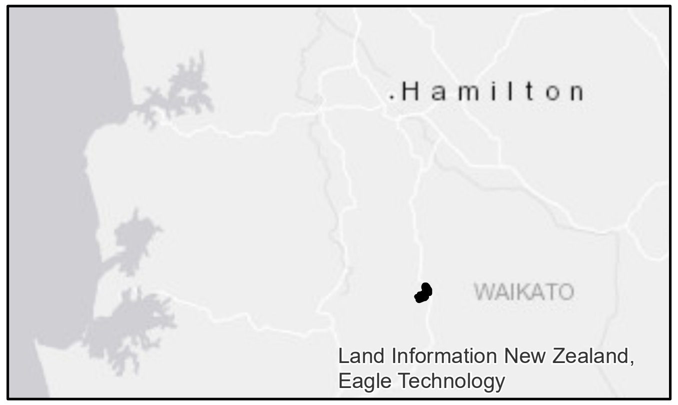
Liquefaction Vulnerability Category

- Liquefaction Category is Undetermined
- Liquefaction Damage is Possible
- High Liquefaction Vulnerability

N

A3 SCALE:1:5,000

0 40 80 120 160 200 Meters



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ARCFILE T11_liquefaction.mxd		
SCALE (AT A3 SIZE) 1:5,000		
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T11 GROWTH CELL
Liquefaction Vulnerability map

Figure B2: T11 Liquefaction Vulnerability Map www.tonkintaylor.co.nz