REPORT

Tonkin+Taylor

New Plymouth District Liquefaction Vulnerability Assessment

Prepared for
New Plymouth District Council

Prepared by
Tonkin & Taylor Ltd

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LIQUEFACTION ASSESSMENT SUMMARY	
This liquefaction assessment has been undertaken in general accordance with the guidance document 'Assessment of Liquefaction-induced Ground Damage to Inform Planning Processes' published by the Ministry for the Environment and the Ministry of Business, Innovation and Employment in 2017. https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/	
Client	New Plymouth District Council (NPDC)
Assessment undertaken by	Tonkin & Taylor Ltd, PO Box 317, Tauranga 3140
Extent of the Study Area	The Study Area aligns with New Plymouth District Council boundary.
Intended RMA planning and consenting purposes	To provide NPDC with a district-wide liquefaction vulnerability assessment to identify areas of land susceptible to liquefaction. The technical report and resulting map outputs will be used to inform land use, subdivision and building consent applications.
Other intended purposes	Not applicable
Level of detail	Level A (basic desktop assessment)
Notes regarding base information	The available base information provides enough information for a Level A (basic desktop assessment) level of detail across the Study Area. The main factor controlling this level of detail is the spatial extent of the available geotechnical investigations, groundwater information and high-resolution elevation data across the Study Area. Further studies could be undertaken at higher levels of detail once additional information becomes available.
Other notes	This assessment has been made at a broad scale across the entire region and is intended to approximately describe the typical range of liquefaction vulnerability across neighbourhood-sized areas. It is not intended to precisely describe liquefaction vulnerability at individual property scale. This information is general in nature, and more detailed site-specific liquefaction assessment may be required for some purposes (e.g., for design of building foundations). A key consideration of the liquefaction vulnerability categorisation undertaken in accordance with the MBIE/MfE Guidelines (2017) is the degree of uncertainty in the assessment. Discussion about the key uncertainties in this assessment is provided in sections 3.3 and 3.4 of this report.

1 Introduction

The purpose of this report is to summarise the approach adopted for the assessment of liquefaction vulnerability in New Plymouth District by Tonkin & Taylor Ltd (T+T) and the associated results. This assessment has been undertaken in accordance with the Ministry of Business Innovation and Employment (MBIE) & Ministry for the Environment (MfE) guidance document: *Planning and engineering guidance for potentially liquefaction prone land* (referred to as the MBIE/MfE Guidance (2017)). This assessment provides a risk-based assessment of liquefaction vulnerability across the region.

Figure 1.1 shows the extent of the Study Area, which aligns with the New Plymouth District territorial boundary.

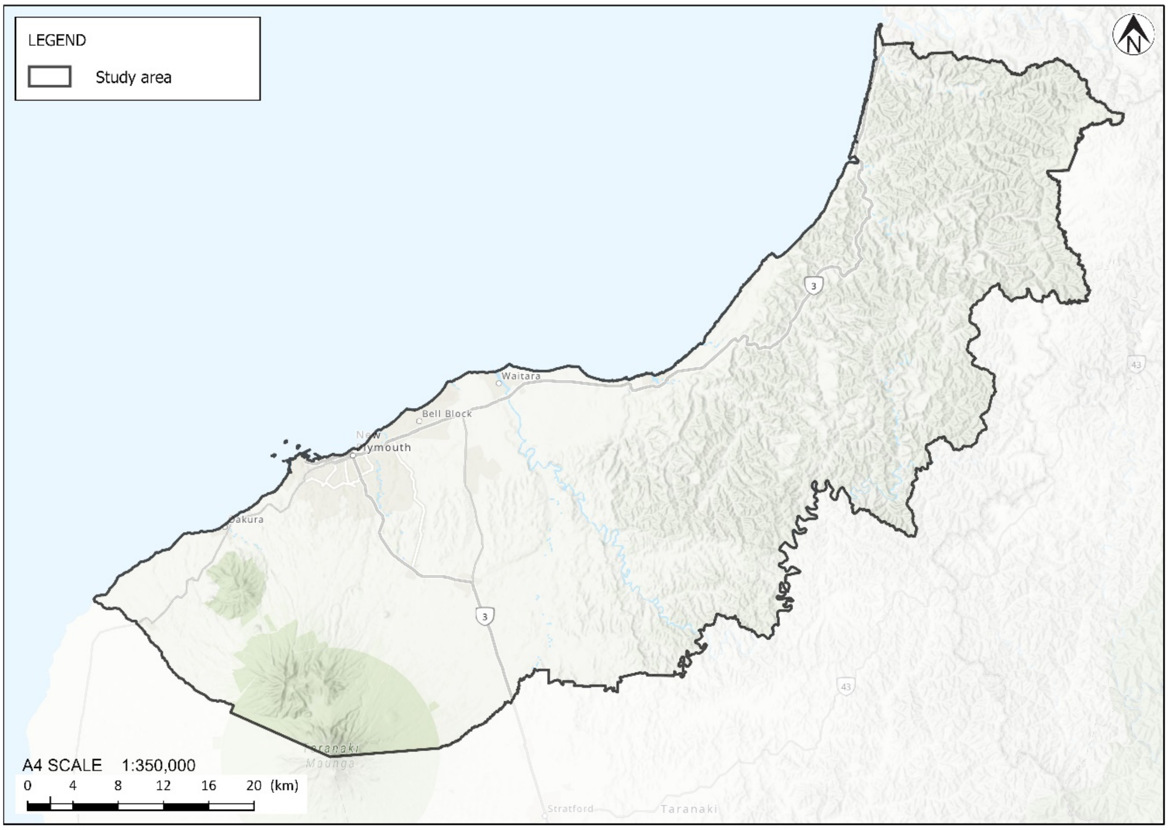


Figure 1.1: Map showing the extent of the Study Area

This report includes:

- The context in which this assessment has been undertaken, the intended purposes for its use, and a summary of previouslycollated information about liquefaction across the Study Area (Section 2).
- A summary of collated base information that is relevant to the assessment of liquefaction for the Study Area (Section 3.2).
- Analysis of the uncertainty associated with the collated base information (Section 3.3).
- The evaluation of groundwater levels and earthquake scenarios to be assessed, and the delineation of the Study Area into zones of similar expected ground performance (sections 4.1, 4.2, and 4.3).
- The determination of the expected degree of liquefaction-induced ground damage for the chosen groundwater levels and earthquake scenarios (Section 4.4).
- The assessment of liquefaction vulnerability as determined from the performance criteria provided in the MBIE/MfE Guidance (2017) (Section 4.4).
- Discussion about the results of this assessment and a summary of the key conclusions (Section 5).

The liquefaction vulnerability assessment and the layout of this report follows the risk management process recommended in ISO 31000:2018, as shown in Figure 1.2.

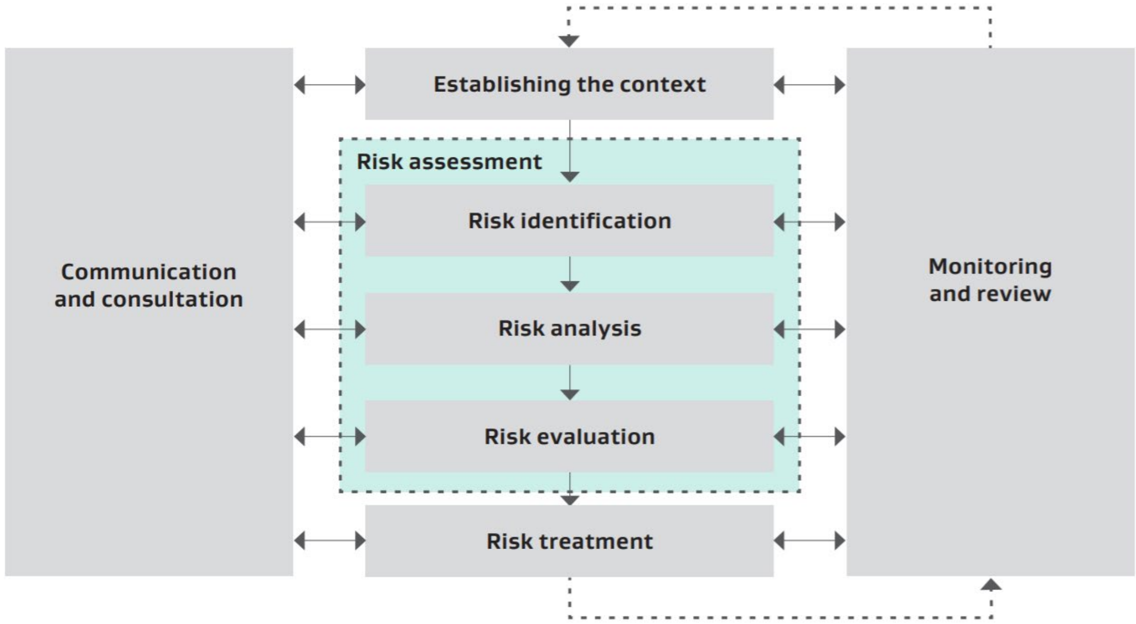


Figure 1.2: Risk management process defined in ISO 31000:2009, which has been used to guide the liquefaction vulnerability assessment and the layout of this report - from MBIE/MfE Guidance (2017). Note, this figure has been slightly modified in the ISO 31000:2018 standard, however the general concepts remain unchanged.

It is emphasised that the discussion in this report regarding vulnerability categories and options for further geotechnical assessment relate only to liquefaction hazard. There are various other natural hazards and geotechnical constraints which would also need to be considered as part of any future land development or building activities.

2 Context

2.1 MBIE/MfE Guidance (2017)

The MBIE/MfE Guidance (2017) presents a risk-based approach to the management of liquefaction-related risk in land use planning and development decision-making. The guidance was developed in response to the Canterbury Earthquake Sequence 2010-2011 as a result of recommendations made by the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquakes[1].

The focus of the MBIE/MfE Guidance (2017) is to assess the potential for liquefaction-induced ground damage to inform Resource Management Act (RMA) and Building Act planning and consenting processes. However, there are a number of ways in which liquefaction information may be used which are outside of the planning and consenting process and the following is a non-exhaustive list that is provided in Section 1.2 of the guidance document:

- Long term strategic land use and planning.
- Developing planning processes to manage the effects of natural hazard events and related risks.
- Design of land development, building and infrastructure works.
- Informing earthquake-prone building assessments.
- Improving infrastructure and lifelines resilience.
- Civil defence and emergency management planning.
- Catastrophe loss modelling for insurance, disaster risk reduction and recovery planning.

While there may be specific additional information required to inform the uses above that are outside of the planning and consenting process, many of the concepts presented in the MBIE/MfE Guidance (2017) are likely to be relevant and provide useful information to support these uses.

[1] The MBIE/MfE Guidance (2017) does not provide technical guidance on liquefaction analysis or earthquake engineering. Detailed information about this topic can be found in the NZGS/MBIE Earthquake Geotechnical Engineering Practice series (NZGS/MBIE, 2016; NZGS/MBIE, 2017a – 2017f).

The MBIE/MfE Guidance (2017) includes the overview of the recommended process for categorising the potential for liquefaction-induced ground damage shown in Figure 2.1. This figure shows the key steps in this categorisation process as establishing the *Context, Risk Identification, Risk Analysis, and Monitoring and Review* broken down into high level tasks. Comparison of Figure 2.1 with Figure 1.2 also demonstrates how the process maps to the risk management process defined in ISO 31000:2018.

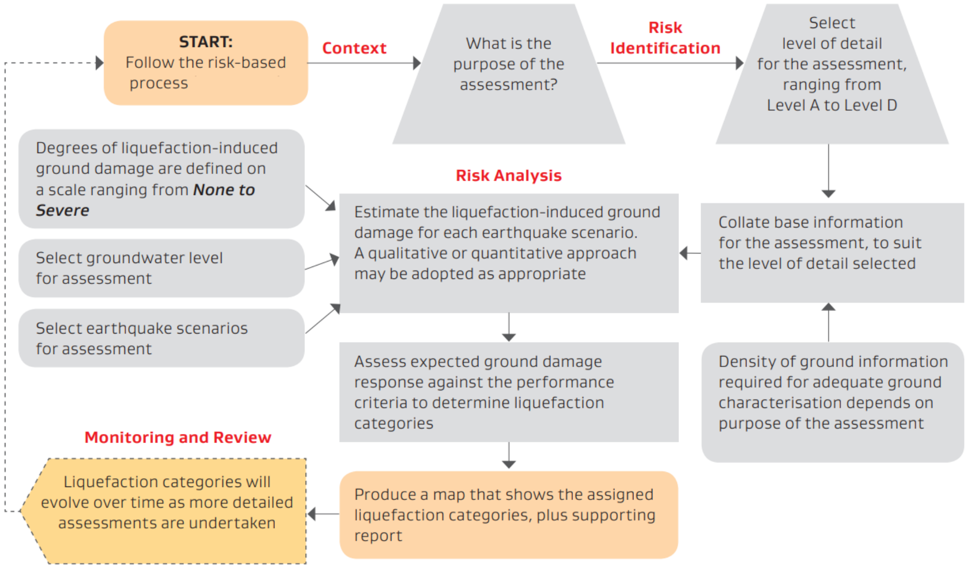
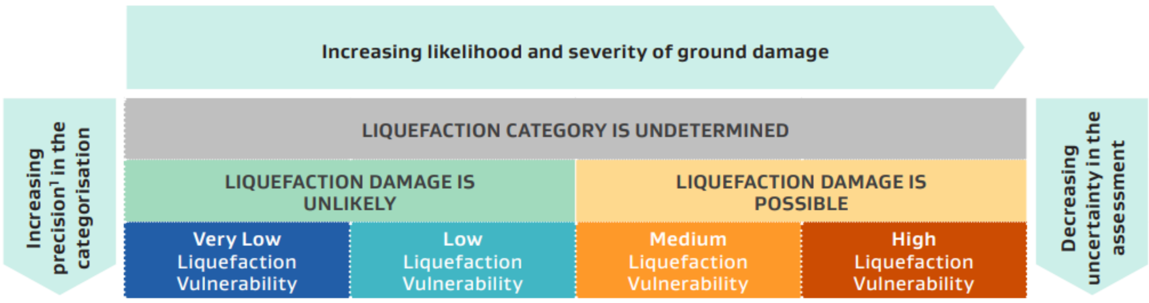


Figure 2.1: Overview of the recommended process for categorising the potential for liquefaction-induced ground damage - from MBIE/MfE Guidance (2017).

The MBIE/MfE Guidance (2017) provides a performance-based framework for categorising the liquefaction vulnerability of land to inform planning and consenting processes. That framework is based on the severity of liquefaction-induced ground damage that is expected to occur at various intensities of earthquake shaking. Figure 2.2 shows the recommended liquefaction vulnerability categories for use in that performance-based framework.



Note:

1 In this context the 'precision' of the categorisation means how explicitly the level of liquefaction vulnerability is described. The precision is different to the accuracy (ie trueness) of the categorisation.

Figure 2.2: Recommended liquefaction vulnerability categories for use in liquefaction assessment studies to inform planning and consenting processes - from MBIE/MfE Guidance (2017).

As shown in Figure 2.2, the liquefaction vulnerability categories established in the MBIE/MfE Guidance (2017) are a function of both the *precision in the categorisation* and the *degree of uncertainty* in the assessment. To provide guidance on how to manage these aspects, recommendations are provided in the MBIE/MfE Guidelines (2017) for the minimum level of detail required in the liquefaction assessment for specific applications. Figure 2.3 shows the categories used to define the levels of detail for liquefaction vulnerability studies.

LEVEL OF DETAIL
Level A – Basic Desktop Assessment
Level B – Calibrated Desktop Assessment
Level C – Detailed Area-Wide Assessment
Level D – Site-Specific Assessment

Figure 2.3: Categories of level of detail used to define the levels of detail for liquefaction vulnerability studies - from MBIE/MfE Guidance (2017).

Regional scale studies, such as this one, are typically undertaken to a Level A or Level B level of detail. Level C and Level D assessments are typically associated with site-specific development to support subdivision and building consent applications.

It is important to note that regional scale studies typically result in categorisation of the land into one of the top three vulnerability categories of “Liquefaction Category is Undetermined” or “Liquefaction Damage is Unlikely” or “Liquefaction Damage is Possible”. The categorisation of the liquefaction vulnerability of the land within New Plymouth District into one of the categories shown in Figure 2.2 is one of the key deliverables of this assessment.

The key feature defining each level of detail is the degree of "residual uncertainty" in the assessment, such that the residual uncertainty is reduced as the level of detail in the liquefaction assessment increases. It is likely that substantial residual uncertainty will remain in some locations, and this has been acknowledged, recorded, and clearly conveyed. Further information about the level of detail hierarchy and residual uncertainty is provided in Section 3.1. Section 3.3 discusses the key sources of uncertainty associated with this assessment.

2.2 Background to this project

New Plymouth District Council has commissioned this project to identify areas of land within the district that have potential for liquefaction-induced ground damage. The district spans across a variety of landscapes that have varying vulnerability to liquefaction-related hazards. Identifying areas of the region that are prone to liquefaction-induced damage will help to make communities safer by enabling an appropriate land use planning response.

This assessment is intended to improve the understanding of liquefaction vulnerability in the district and will produce a liquefaction vulnerability map that can be utilised by different stakeholders. The outputs of the assessment will have two specific uses, the first being related to recent changes to the Building Act and the second being Resource Management Act applications.

Regarding the Building Act changes, in November 2019 the Building Code was amended with respect to ground prone to liquefaction and/or lateral spreading. The changes were:

- Limiting the application of the B1 Acceptable Solution B1/AS1 so that it may not be used on ground prone to liquefaction or lateral spreading.
- Limiting the application of B1/AS1 Foundation Design buildings to those that are on "Good Ground" that is not prone to liquefaction or lateral spreading.

The outputs of the vulnerability assessment provide information to users that can relate to these two Building Code amendments. To categorise land as "prone to liquefaction or lateral spreading" within the context of these Building Code amendments we recommend the following:

- Land that has been categorised as "Liquefaction Damage is Possible" as part of this assessment is considered to be "prone to liquefaction or lateral spreading" and therefore does not meet the definition of "Good Ground" as outlined in the Building Code amendments. Note that subsequent liquefaction vulnerability assessment at a higher level of detail may result in reclassification of the land into a different category and whether it meets the definition of "Good Ground" should be reconsidered based on that new information.
- Land that has been categorised as "Liquefaction Damage is Unlikely" as part of this assessment is considered to be "not prone to liquefaction or lateral spreading" within the context of the definition of "Good Ground" as outlined in the Building Code amendments. Note there may be other reasons why the definition of "Good Ground" is not satisfied at a particular site (e.g., the presence of compressible or expansive soils) and the person specifying the foundation solution will need to undertake their own assessment for these factors.
- For land that has been categorised as "Liquefaction Category is Undetermined" as part of this assessment, there is currently insufficient information to determine whether it is "prone to liquefaction or lateral spreading" within the context of the definition of "Good Ground" as outlined in the Building Code amendments. Note that subsequent liquefaction vulnerability assessment at a higher level of detail will likely result in reclassification of the land into a different category and whether it meets the definition of "Good Ground" should be reconsidered based on that new information.

Regarding Resource Management Act applications, the outputs of the vulnerability assessment will provide applicants with a base information source to determine the liquefaction vulnerability for the land associated with their resource consent application. This information will allow the applicant to address the potential liquefaction hazard in the early stages of their project, and may result in the hazard being mitigated or taken off the table prior to the building consent stage.

2.3 Liquefaction hazard

Liquefaction is a natural process where earthquake shaking increases the water pressure in the ground in some types of soil, resulting in temporary loss of soil strength.

The following three key elements are all required for liquefaction to occur:

1. Loose non-plastic soil (typically sands and silts, or in some cases gravel).
2. Saturated soil (i.e., below the groundwater table).
3. Sufficient ground shaking (a combination of the duration and intensity of shaking).

These elements are shown in Figure 2.4 , and Figure 2.5 summarises the process of liquefaction with a schematic representation.

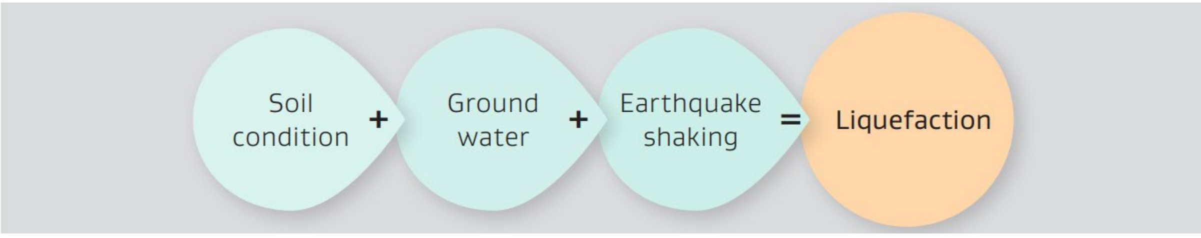


Figure 2.4: Three key elements required for liquefaction to occur - reproduced from MBIE/MfE Guidance (2017).

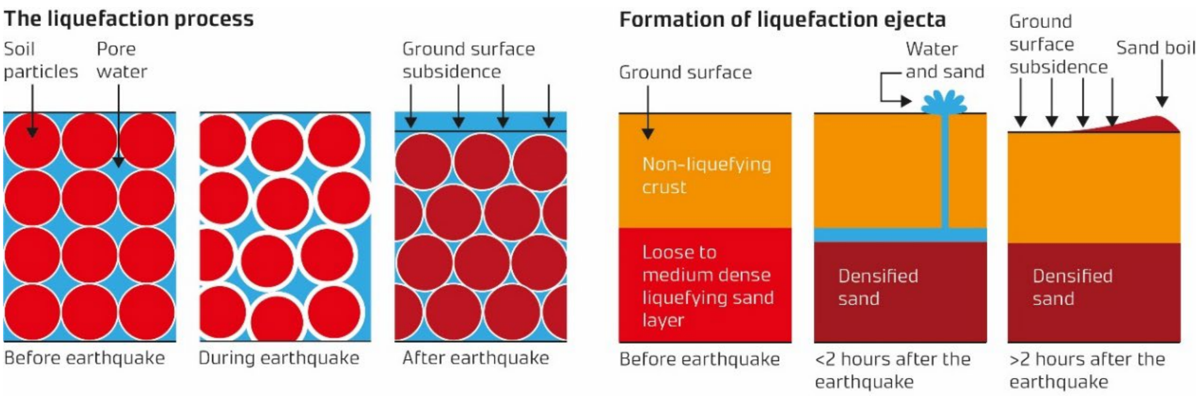


Figure 2.5: Schematic representation of the process of liquefaction and the manifestation of liquefaction ejecta - reproduced from MBIE/MfE Guidance (2017).

Liquefaction can give rise to significant land and building damage through, for example, the ejection of sediment to the ground surface, differential settlement of the ground due to volume loss in liquefied soil and lateral movement of the ground (known as lateral spreading). These effects are schematically presented in Figure 2.6 and summarised in Table 2.1.

Liquefaction and its effects (Source: IPENZ)

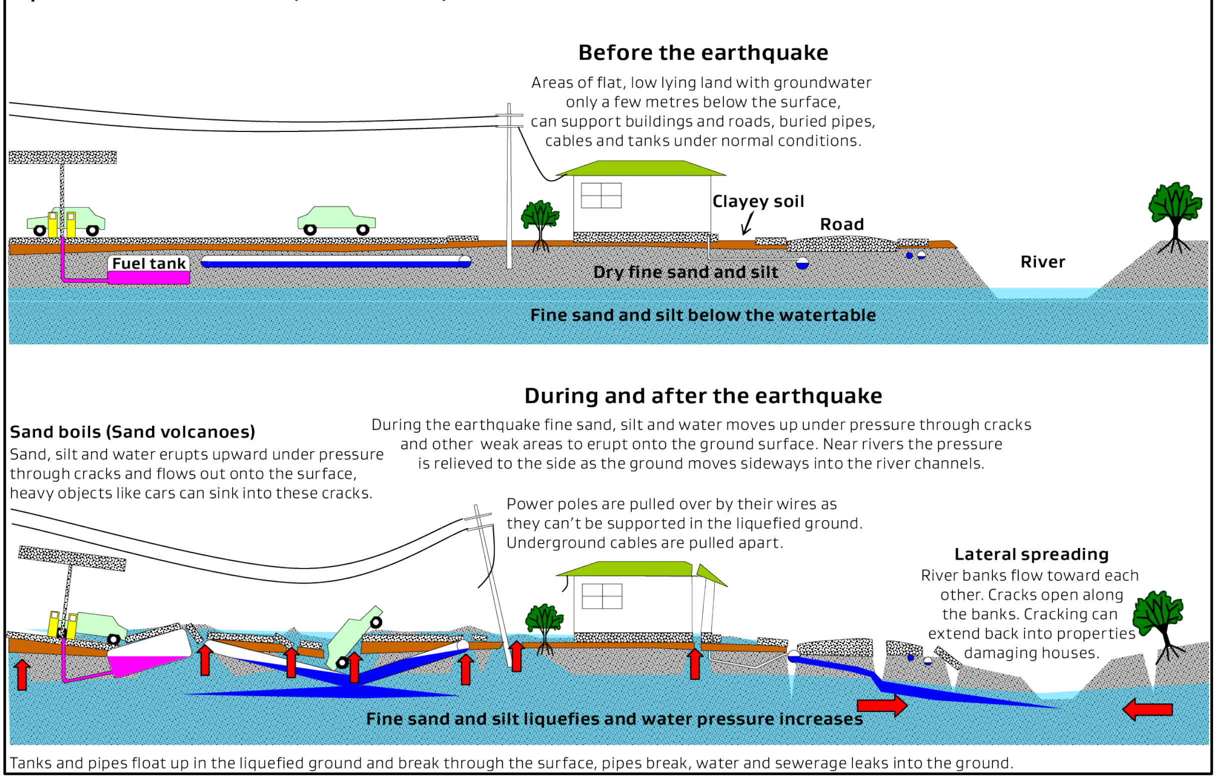


Figure 2.6: Visual schematic of the consequences of liquefaction - reproduced from the MBIE/MfE Guidance (2017).

Table 2.1: Overview of potential consequences of liquefaction (reproduced from MBIE/MfE Guidance (2017))

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 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 weather tightness of the building. • Loss of foundation-bearing capacity, resulting in settlement of the structure. • Stretch of the foundation due to lateral spreading, pulling the structure apart. • Damage to piles due to lateral ground movements, and settlement of piles due to downdrag 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 deformations (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 stopbanks, 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 are 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).

These consequences can have severe impacts that range from land damage through to social disruption as seen in the 2010-2011 Canterbury Earthquake Sequence.

The risk identification and analysis undertaken for this assessment considered how the severity of these consequences at any particular location can vary depending on a range of factors, such as:

- **Soil condition –** Liquefaction typically occurs in loose non-plastic soils i.e., silts and sands and in some cases loose gravels. Liquefaction does not typically occur in soils with higher plasticity such as clay and does not occur in rock or dense gravel.
- **Depth to groundwater –** Soil can only liquefy if it is fully saturated, so deeper groundwater can mean there is a thicker surface “crust” of non-liquefied soil at the ground surface that helps to reduce the consequences from liquefaction below.
- **Strength of earthquake shaking –** Stronger shaking can mean that greater thickness of the soil profile liquefies, resulting in more severe consequences.
- **Layering of the soil profile –** The way in which a soil was deposited (e.g., by a river, an estuary, or the sea) can influence how the soil profile is layered. If there are thick continuous layers of liquefied soil, then this can have more severe consequences than if there are thinner isolated layers of liquefied soil interbedded between layers of non-liquefied soil.
- **Proximity to free faces or sloping ground –** For lateral spreading to occur, liquefiable soils must be within close proximity to a free face (such as a river channel or a road cut) or sloping ground. Typically, a location that is closer to these topographic features will sustain more severe consequences than a location that is further away.

2.4 Intended purpose and scope of works

The information produced from this liquefaction vulnerability assessment will be used to inform land use planning and consenting requirements under the RMA and Building Act for New Plymouth District. In particular, the liquefaction vulnerability information produced from this assessment can be used to address the changes that have occurred to the New Zealand Building Act related to liquefaction and lateral spreading (as discussed in Section 2.1). Note that in some cases, a more detailed site-specific assessment of liquefaction vulnerability may be required to meet the requirements of the amended Building Act. Section 3.5 of the MBIE/MfE Guidelines (2017) provides guidance for more detailed liquefaction vulnerability assessments depending on the particular activity under consideration.

2.5 Previous information about liquefaction in New Plymouth District

In 2013, GNS Science was engaged by four local authorities in Taranaki to undertake an assessment of the liquefaction hazard in the Taranaki Region. The findings of the GNS Science assessment were published in a report titled “Liquefaction Hazard in the Taranaki Region”. Three liquefaction susceptibility maps at 1:50,000 scale were produced as outputs from the GNS report for the Taranaki Region. One of these maps covered New Plymouth District (Figure 2.7). The maps identified land within the district that had very low, low, moderate, high, and very high liquefaction susceptibility.

One of the conclusions of the GNS report is that there are only a few areas in the Taranaki Region that have a significant liquefaction hazard. This conclusion is drawn based on the assumption that the region lacks geologically young, non-cohesive, fine-grained sediments with associated shallow ground water conditions.

This GNS liquefaction hazard assessment pre-dated the development of the MBIE/MfE Guidance document (2017), and there is no direct correlation between the GNS “Susceptibility Class” and the MBIE/MfE “Liquefaction Vulnerability Category”.

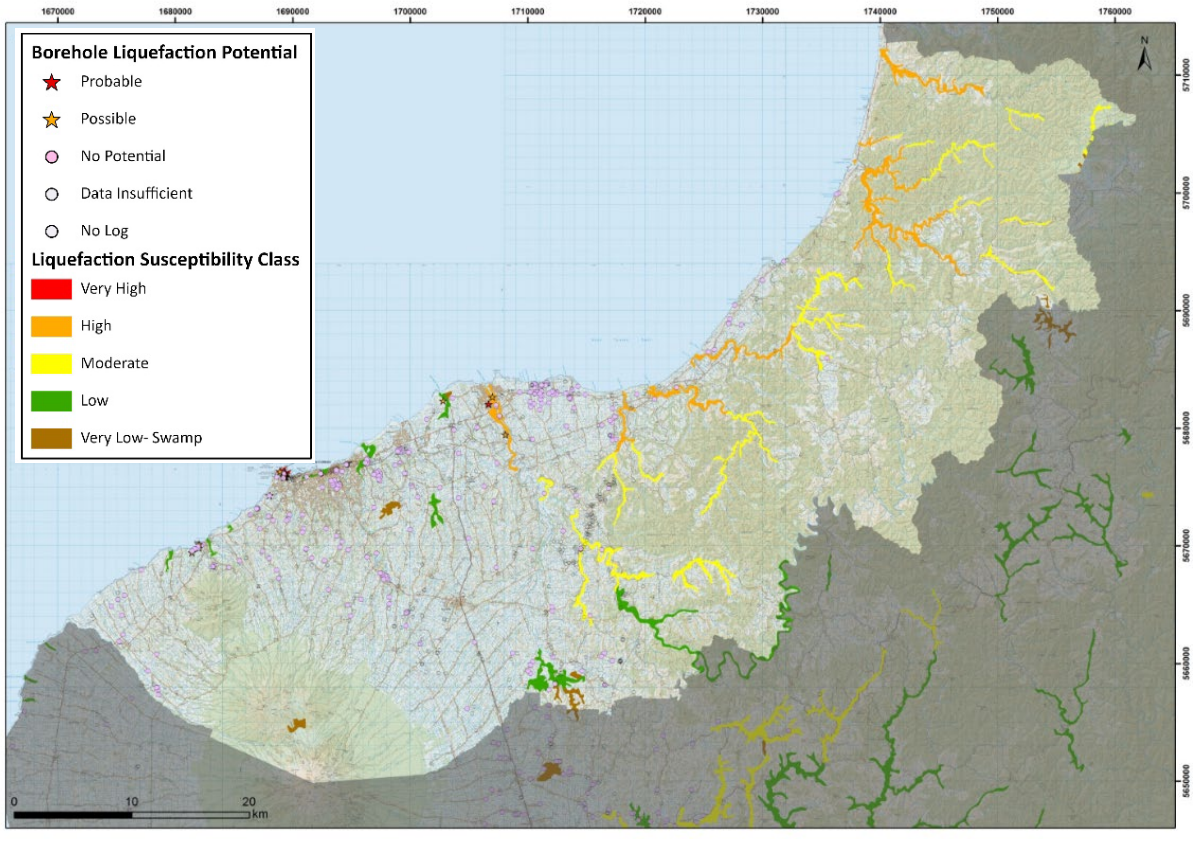


Figure 2.7: The liquefaction susceptibility map produced by GNS in 2013 – reproduced from (Dellow & Ries, 2013).

3 Risk identification

3.1 Level of detail

This section outlines the risk identification that has been carried out for the liquefaction vulnerability assessment for the region.

The first task is the determination of the level of detail required for the intended purposes (refer to Section 3.1.2). This requires consideration of the key features associated with each level of detail as established by the MBIE/MfE Guidance (2017) and consideration of NPDC's intended purposes for undertaking the liquefaction vulnerability assessment.

The second task is review of the base information currently available for this liquefaction vulnerability assessment (refer to Section 3.2). The base information that has been reviewed for this region includes the following:

- Ground surface levels (refer to Section 3.2.1).
- Geology and geomorphology (refer to Section 3.2.2).
- Geotechnical investigations (refer to Section 3.2.3).
- Groundwater (refer to Section 3.2.4).
- Seismic hazard (refer to Section 3.2.5).
- Historical observations of liquefaction (refer to Section 3.2.6).

3.1.1 Level of detail hierarchy

The MBIE/MfE Guidance (2017) provides recommendations for four different levels of detail ranging from the least detailed (Level A) to the most detailed (Level D). Figure 3.1 shows the key features associated with each level of detail.

LEVEL OF DETAIL	KEY FEATURES
Level A **Basic desktop assessment**	Considers only the most basic information about geology, groundwater and seismic hazard to assess the potential for liquefaction to occur. This can typically be completed as a simple 'desktop study', based on existing information (eg geological and topographic maps) and local knowledge. **Residual uncertainty:** The primary focus is identifying land where there is a ***High*** degree of certainty that ***Liquefaction Damage is Unlikely*** (so it can be 'taken off the table' without further assessment). For other areas, substantial uncertainty will likely remain regarding the level of risk.
Level B **Calibrated desktop assessment**	Includes high-level 'calibration' of geological/geomorphic maps. Qualitative (or possibly quantitative) assessment of a small number of subsurface investigations provides a better understanding of liquefaction susceptibility and triggering for the mapped deposits and underlying ground profile. For example, the calibration might indicate the ground performance within a broad area is likely to fall within a particular range. It may be possible to extrapolate the calibration results to other nearby areas of similar geology and geomorphology, however care should be taken not to over-extrapolate (particularly in highly variable ground such as alluvial deposits), and the associated uncertainties (and potential consequences) should be clearly communicated. Targeted collection of new information may be very useful in areas where existing information is sparse and reducing the uncertainty could have a significant impact on objectives and decision-making. **Residual uncertainty:** Because of the limited amount of subsurface ground information, significant uncertainty is likely to remain regarding the level of liquefaction-related risk, how it varies across each mapped area, and the delineation of boundaries between different areas.
Level C **Detailed area-wide assessment**	Includes quantitative assessment based on a moderate density of subsurface investigations, with other information (eg geomorphology and groundwater) also assessed in finer detail. May require significant investment in additional ground investigations and more complex engineering analysis. **Residual uncertainty:** The information analysed is sufficient to determine with a moderate degree of confidence the typical range of liquefaction-related risk within an area and delineation of boundaries between areas, but is insufficient to confidently determine the risk more precisely at a specific location.
Level D **Site-specific assessment**	Draws on a high density of subsurface investigations (eg on or very close to the site being assessed), and takes into account the specific details of the proposed site development (eg location, size and foundation type of building). **Residual uncertainty:** The information and analysis is sufficient to determine with a ***High*** degree of confidence the level of liquefaction-related risk at a specific location. However, the scientific understanding of liquefaction and seismic hazard is imperfect, so there remains a risk that actual land performance could differ from expectations even with a high level of site-specific detail in the assessment.

Increasing level of detail and decreasing degree of uncertainty

Figure 3.1: Levels of detail for liquefaction assessment studies and the defining key features - from MBIE/MfE Guidance (2017).

As highlighted in Figure 3.1, the key feature of the level of detail assessment is the degree of residual uncertainty in the assessment. This refers to the uncertainty which remains after the available information has been analysed. The concept of residual uncertainty is important because it informs the suitability of the information for the intended purpose and helps guide risk evaluation and risk treatment.

There are two key parts to the determination of the level of detail as follows:

1 **Determination of the level of detail required for the intended purpose.** This step involves consultation with the key stakeholders and a review of the different applications where this information will be applied (refer to this Section 3.1.2 of this report); and

2 **Determination of the level of detail supported by the currently available base information.** This step involves collation and review of the base information available for the assessment (refer to Section 3.2 of this report) including consideration of the uncertainty associated with that information (refer to Section 3.3 of this report).

3.1.2 Level of detail required for intended purposes

The MBIE/MfE Guidance (2017) provides recommendations about the minimum level of detail likely to be appropriate for a liquefaction assessment, depending on the intended purpose, likelihood/severity of ground damage and the development intensity. Refer to Section 3.5 of the MBIE/MfE Guidance (2017) for further detail.

The target level of detail for the assessment (in accordance with MBIE Guidance (2017)) that is required for NPDC's intended purposes was discussed in a workshop held with key stakeholders from New Plymouth District Council on 29 and 30 June 2021. Following the workshop, NPDC confirmed on 20 July that a Level A (Basic Desktop Assessment) level of detail across the entire district would be suitable for the intended purposes of the assessment. This establishment of the target level of detail included consideration of the following:

- The range of intended purposes for the liquefaction vulnerability assessment.
- The target level of detail required for those intended purposes.
- The availability and spatial density/extent of data required for assessment at the selected level of detail.
- Whether a better overall outcome could be achieved by adopting a higher target level of detail than the minimum requirements.

As shown in Figure 3.2 and Figure A1 in Appendix A, a Level A (Basic Desktop Assessment) level of detail was targeted for the for the entire Study Area.

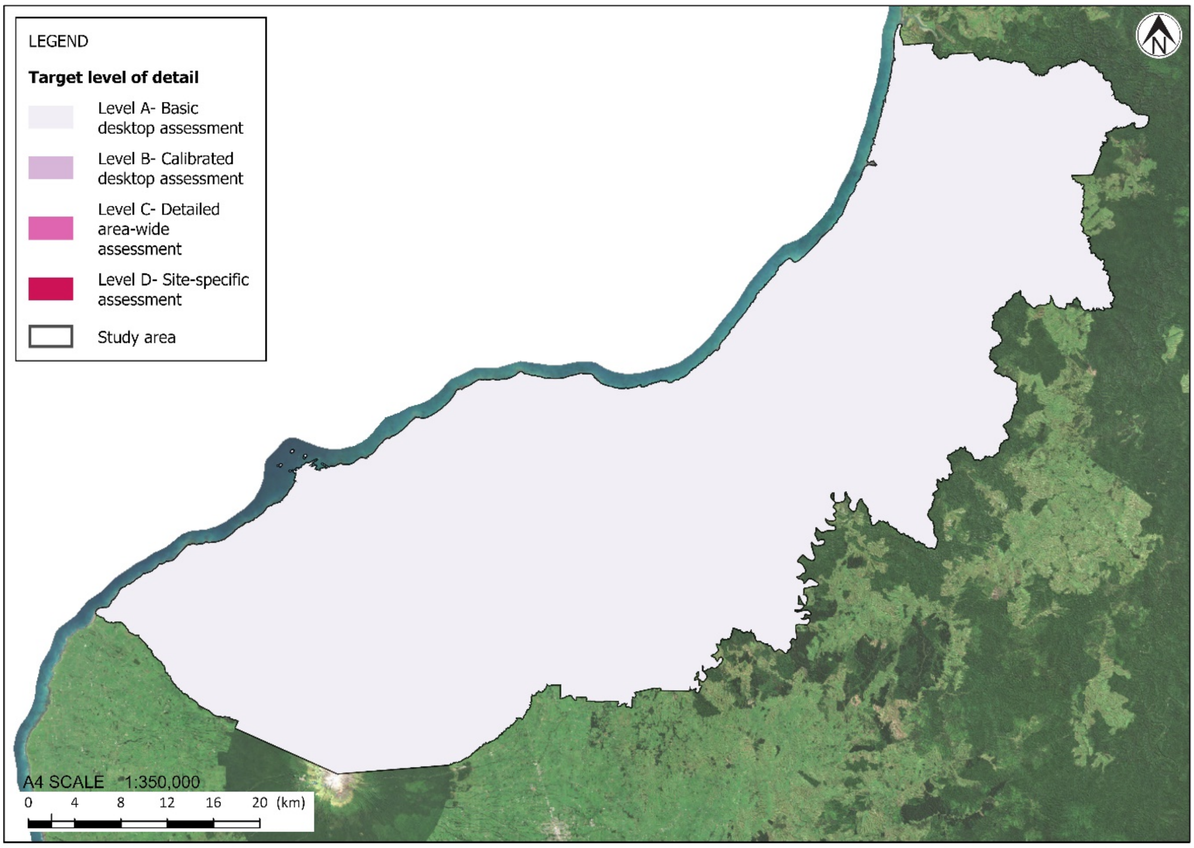


Figure 3.2: Target level of detail for New Plymouth District – Level A (Basic Desktop Assessment) for the entire Study Area.

3.2 Base information currently available

This section of the report collates and documents the available base information and how the information was used in the risk assessment process.

3.2.1 Ground surface levels

The ground surface level of New Plymouth District is characterised by three digital elevation models (DEM). Two of the DEMS have been derived from LiDAR and cover the Kaitake Range and the Urban areas of New Plymouth District. Both of these DEMS have a 1 m horizontal resolution. The third DEM covers the entire Study Area and has been derived from the LINZ Topo50 20 m contours to a horizontal resolution of 8 m. The LiDAR-derived DEM provides data with a higher degree of precision and accuracy than the DEM derived from the LINZ Topo50 20 m contours. We understand Taranaki Regional Council is in the process of procuring LiDAR-derived DEM for the entire Study Area. Table 3.1 provides information about the DEM that are available for this liquefaction hazard assessment and Figure 3.3 shows the extent of each of the LiDAR-derived DEM across the Study Area.

Table 3.1: Available DEM datasets for New Plymouth District

Year of acquisition	Acquired by	DEM horizontal resolution (m)	Coverage of Study Area	Degree of precision and accuracy
2012	Geographx	8.0	Entire	Lower
2018	Landpro Ltd	1.0	Kaitake Range	Higher
2019	Landpro Ltd	1.0	New Plymouth urban areas	Higher

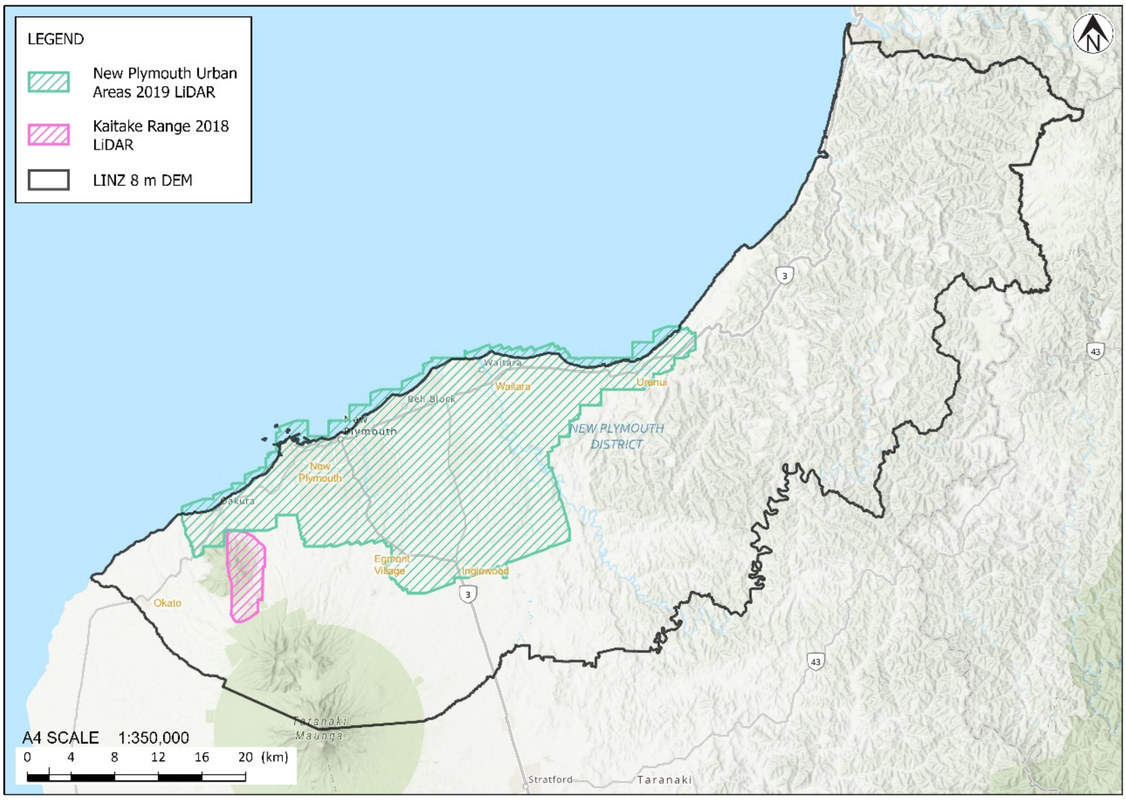


Figure 3.3: Extent of LiDAR survey data across the Study Area.

As shown in Figure 3.4 and Figure A2 in Appendix A, the ground surface elevation within New Plymouth District is highly variable, varying from 0 m RL along the coastline to 2,510 m RL (NZTM 2000) at the highest point. The topography is defined by coastal terraces, river plains, lahar deposits, volcanic cones, and sedimentary rock ranges.

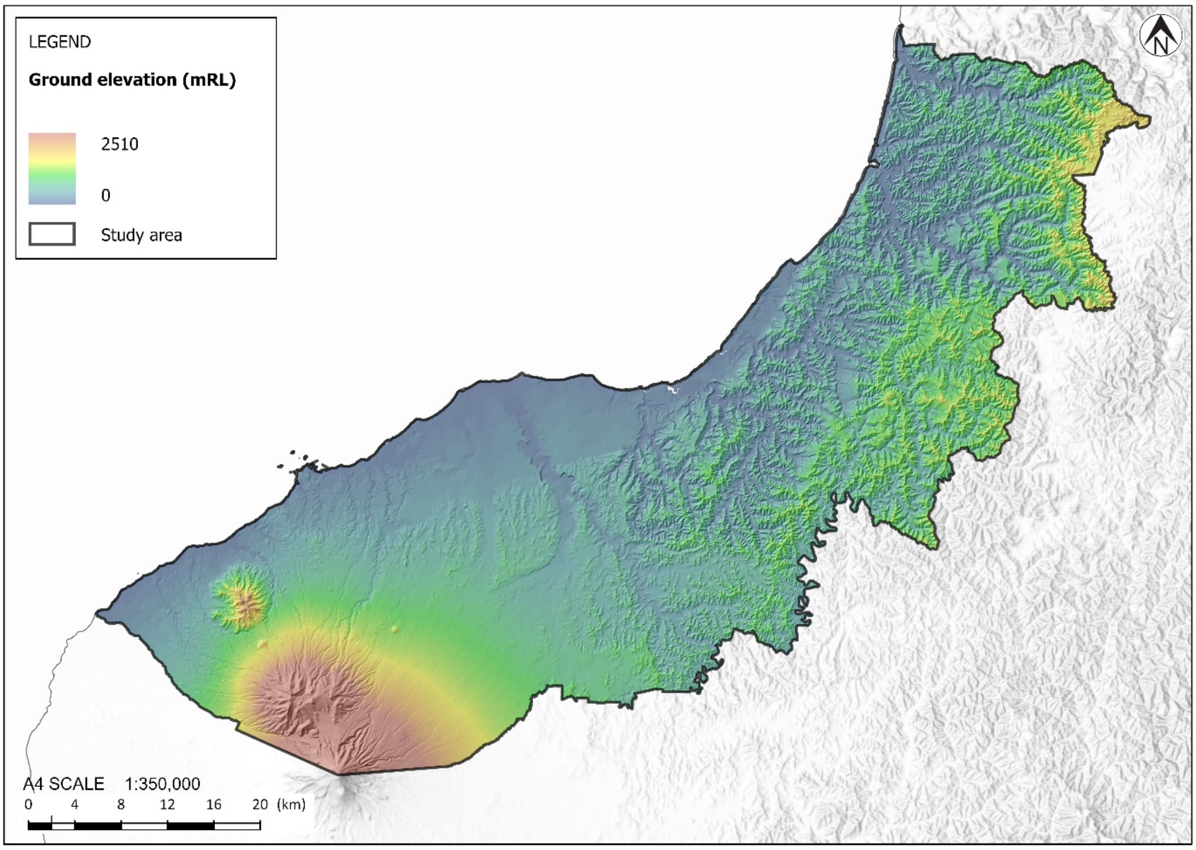


Figure 3.4: Ground surface elevations derived from the 8 m DEM across the Study Area.

A topographical screening tool was developed to quantitatively interpret ground surface levels across the Study Area from both the 1.0 m resolution New Plymouth LiDAR-derived DEM and the 8 m DEM. The purpose of the screening tool was to provide a means of identifying different topographical features from both of the DEM datasets.

The screening tool is based on the method proposed by Stepiniski and Jasiewicz (2011) and considers single elevation points from a DEM dataset in relation to adjacent elevation points at a set distance. The adjacent elevation points are interpreted to be above, below or in-line with the initial elevation point, and an algorithm is used to categorise these patterns into broad landform classifications, which are known as geomorphons. For the purposes of this assessment, three landform types were considered. These geomorphons were:

- Flat Land,
- Valley and Toe Slopes, and
- Sloping land.

The geomorphons generated from this algorithm are shown in Figure 3.5 and Figure A3 in Appendix A. Figure 3.5 shows the geomorphons produced from the higher resolution New Plymouth urban areas LiDAR-derived DEM alongside the geomorphons produced from the lower resolution LINZ Topo50 20 m contour derived DEM.

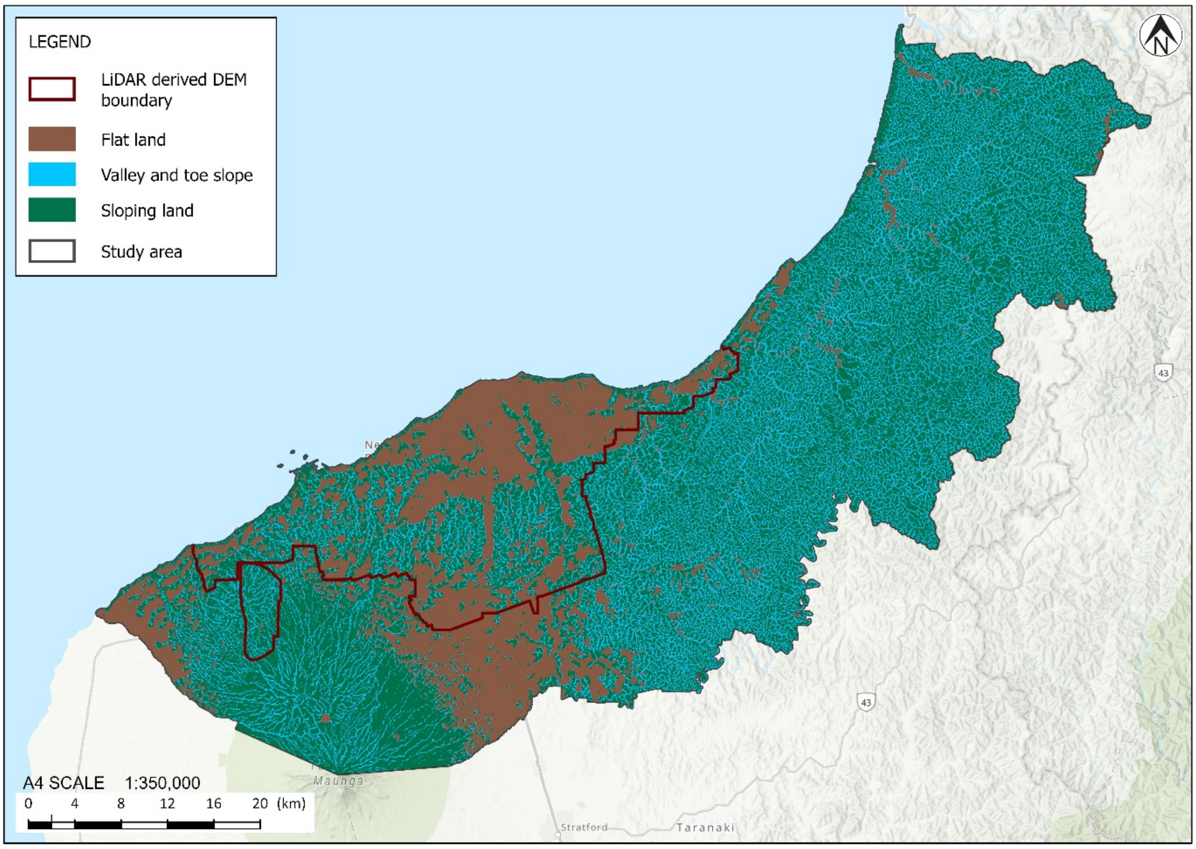


Figure 3.5: Geomorphons produced by the screening tool across the Study Area.

3.2.2 Geology and geomorphology

Geology

The geology of New Plymouth District is represented by a 1:250,000 scale geological map compiled by GNS (Townsend, et al., 2008). This geological map is a compilation of approximately 31 geological reports, theses and monographs related to the region and 21 published scientific papers. For the purposes of this vulnerability assessment and level of detail required, the 1:250,000 scale geological map compilation produced by GNS has been used. Figure 3.6 shows the main geological units for New Plymouth District.

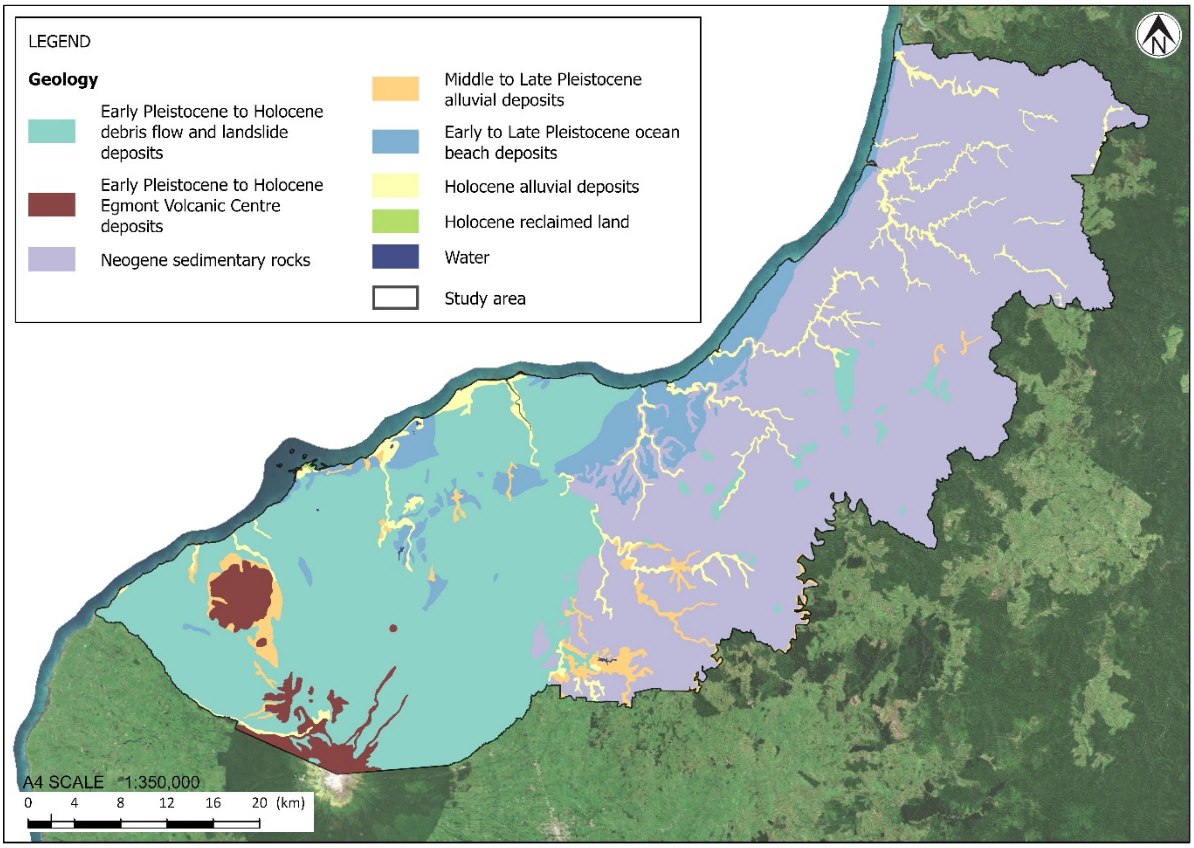


Figure 3.6: Main geological units associated with New Plymouth District (Townsend, et al., 2008).

New Plymouth District lies within the Taranaki Basin and is dominated by Neogene sedimentary rocks, andesitic volcanoes, Quaternary volcanic deposits and volcaniclastic deposits, Quaternary marine terraces, and Late Pleistocene to Holocene alluvial deposits. These geological units are described below:

- The Neogene sedimentary rocks cover more than half of the Study Area and dominate the northern extent of New Plymouth District. These rocks are predominantly sandstones and mudstones with interbedded conglomerates and typically form steep hill country dissected with many small streams and valleys.
- The major andesitic volcanoes within the Study Area are known as Taranaki Maunga, the Pouakai Ranges and the Kaitake Ranges. These volcanoes are located along the southern boundary of the Study Area and erupted during the Quaternary period.
- Directly related to the andesitic volcanoes outlined above, quaternary volcaniclastic deposits (lahars, volcanic ash, debris avalanches etc) dominate the southern half of the Study Area. These deposits, known as the “Taranaki Ring Plain” are predominantly lahars and debris flows

and they all flow from Taranaki Maunga in a radial pattern. These deposits mantle the landscape forming undulating, elevated land features. In some cases, these deposits also form hummocky terrain. The composition of these volcaniclastic sediments is highly variable, ranging from unconsolidated and consolidated bedded sands and conglomerates to broken tree trunks and pyroclastic material. Due to the undulating surface of these deposits, surficial peat deposits are also common above this geological unit.

- Marine terraces have formed during the Quaternary period along the New Plymouth coastline. These terraces have been preserved by late Quaternary regional tectonic uplift and represent historic shorelines across the district. GNS describe these terraces as comprising shallow marine conglomerate, shell beds, dune sands and peat.

The late Pleistocene to Holocene alluvial deposits are typically associated with the dune systems bordering the present-day shoreline and the main rivers throughout the district (Waiwhakaiho, Waitara, Onaero, Urenui, and Tongaporutu rivers). The sediments typically associated with these deposits are gravels, sands, silts, and clays.

Geomorphology

Geomorphic terrains have been defined and mapped to help identify areas of potential liquefaction vulnerability. Terrains expected to be underlain by silt, sand and gravel sediments (e.g. flood plains etc.) are more likely to be vulnerable to liquefaction. As a result, these terrains have been categorised in more detail for this assessment compared to the various types of hill country and volcanic landforms within the region, which are less likely to be vulnerable to liquefaction. The geomorphic terrain mapping methodology is summarised in Table 3.2.

Table 3.2: Geomorphic terrain mapping and methodology

Data sources:	Geological maps – see this section Ground surface levels – see Section 3.2.1 Current and historical aerial imagery – obtained from LINZ and Retrolens Topographical screening tool and associated geomorphons – see Section 3.2.1
Terrain definition:	Geomorphic terrain categories have been defined based on their general susceptibility to liquefaction following guidance outlined in MBIE (2017) and research by Youd and Perkins (1978). Areas expected to be more vulnerable to liquefaction have been divided into more detailed terrain units (i.e., alluvial channels, alluvial flood plains etc.) compared with hill and rocky areas which are less likely to contain soils that are susceptible to liquefaction.
Terrain mapping:	Terrain mapping has been undertaken as a desktop assessment largely based on the ground surface levels, associated geomorphons and the QMAP geological units. Surface elevation data was used to infer landform features, such as areas of low-lying and elevated land, gently sloping to steeply sloping land, volcanic depressions and volcanic domes etc. These areas of land often reflect sedimentary depositional processes that relate to liquefaction vulnerability of soils. The QMAP geological units have also been rationalised into the geomorphic terrain categories and incorporated into the landform feature interpretation listed above. The resulting geomorphic terrains have been reviewed against aerial imagery and the geomorphons produced by the topographical screening tool. During this process, terrain extents can be modified or re-classified.
Mapping Scale	1:25,000[2]

[2] In practice, we have reviewed or drawn terrain boundaries within GIS at an onscreen scale between 1:25,000 to 1:15,000.

The geomorphic mapping process identified seven different geomorphic terrains across the Study Area. These geomorphic terrains are described as follows:

- **Hills, Ranges and Mountains:** One of the most extensive geomorphic terrains across the district (covers 61% of the Study Area). Represents the elevated, sloping land features that dominate the northern extent of the Study Area. Incised, steep, stream valleys and alluvial features are common throughout this terrain, however, they do not characterise the dominant geomorphic processes in this terrain. Typically, this terrain has rock near the ground surface and therefore, it is less likely to contain soils that are susceptible to liquefaction.
- **Lahars:** This terrain covers approximately 30% of the Study Area and is characterised by variable mid Pleistocene to Holocene sediments that vary spatially across the Study Area. These sediments are predominantly volcaniclastic, ranging from unconsolidated and consolidated bedded sands and conglomerates to broken tree trunks and pyroclastic material. This terrain also includes the subsidiary sediments that have accumulated at the ground surface following the lahars being deposited. It is difficult to determine the typical liquefaction susceptibility of this terrain due to the geological age and variability of the associated sediments.
- **Alluvial Plains and River Flats:** This terrain represents the late Pleistocene to Holocene sediments deposited by active and historic river systems across the region and is generally flat to gently sloping. This terrain covers less than 1% of the Study Area. It is likely to include sand and silt deposits that are susceptible to liquefaction.
- **Coastal Terraces:** These terraces typically comprise middle to late Pleistocene-aged alluvium comprising shallow marine conglomerates, shell beds, dune sands and peat. This terrain is dominant along the coastline northeast of the New Plymouth township and covers approximately 4% of the Study Area. It is difficult to determine the typical liquefaction susceptibility of this terrain due to the geological age of the sediments.
- **Wetlands and Swamps:** This terrain is characterised by present day large wetlands and swamps that can be observed at a 1:25,000 scale. Sediments within this terrain are expected to be fined grained organic soils. Terrain covers less than 1% of the Study Area. It is difficult to determine the typical liquefaction susceptibility of this terrain due to the characteristics of the sediments.
- **Coastal Dunes:** Represents the coastal dune system that is actively subject to wind/aeolian and coastal processes. Associated with the present-day shoreline along the western extent of the Study Area. This terrain covers less than 1% of the Study Area. It should be noted that the Study Area boundary often transects this terrain, with most of the Coastal Dunes being positioned outside of the Study Area. The Holocene-aged silts and sands associated with this terrain are likely to be susceptible to liquefaction.
- **Reclamation Fill:** This terrain represents historic filling operations that have resulted in land being reclaimed from marine/coastal areas. The fill material could be either uncontrolled or engineered but, for the purposes of this report, it has not been differentiated. Reclamation Fill has been mapped at two locations around Port Taranaki, covering less than 1% of the Study Area. As the two locations are in close proximity to the coastal environment, they are likely to include sand and silt deposits that are susceptible to liquefaction.

The larger towns and infrastructure projects throughout the Study Area are typically located within the Holocene-aged geomorphic terrains that are likely to include sand and silt deposits that could be susceptible to liquefaction (e.g., Alluvial Plains and River Flats, Coastal Dunes and Coastal Terraces). This is due to flat land in the region being historically valued for residential development and the relative ease of transportation via waterways (e.g., rivers and streams).

The geomorphic map of the Study Area is shown in Figure 3.7 and Figure A4 in Appendix A.

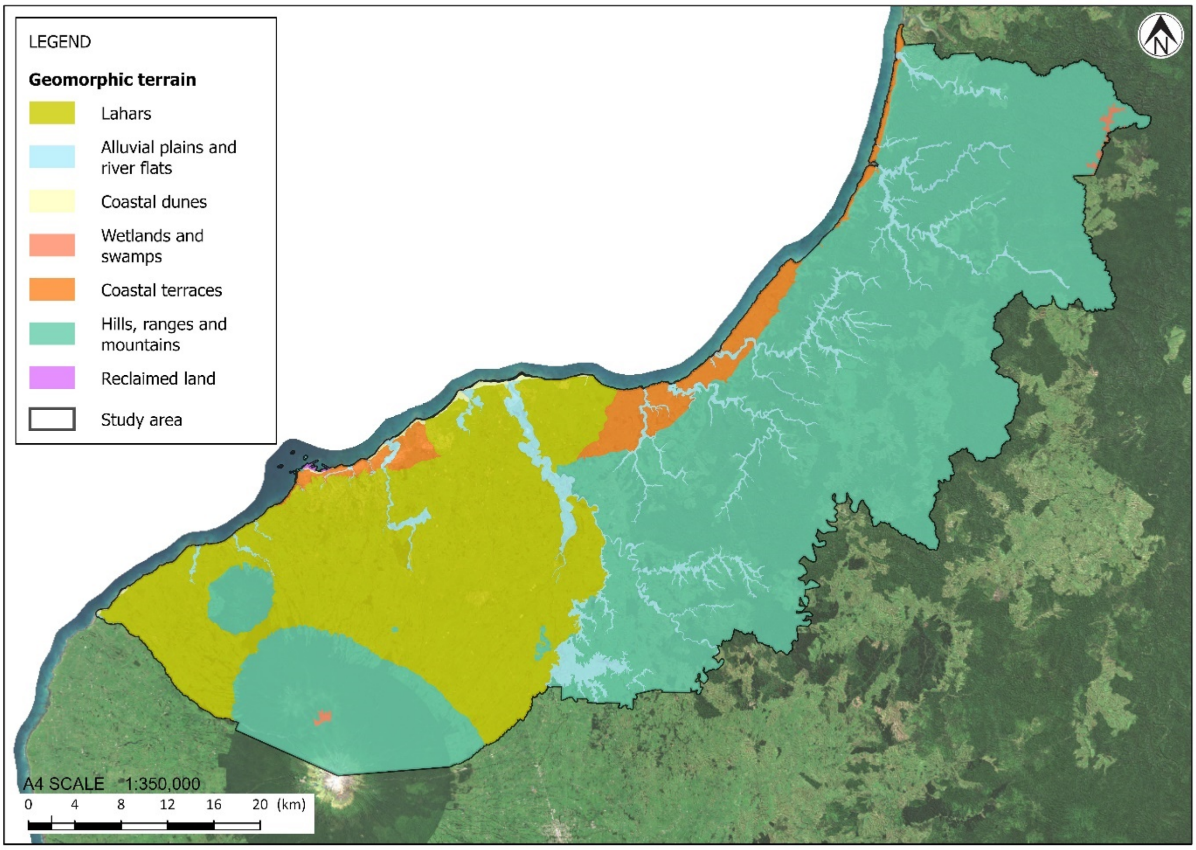


Figure 3.7: Geomorphic map of Study Area.

3.2.3 Geotechnical investigations

Existing geotechnical investigations from the publicly available New Zealand Geotechnical Database (NZGD) and from T+T's records have been considered for this assessment. This includes 294 No. Cone Penetration Tests (CPT), 128 No. Boreholes (BH), 66 No. Test Pits (TP), and 438 No. Hand Augers (HA). The number of CPT, BH, TP, and HA within each geomorphic terrain is shown in Table 3.3.

Table 3.3: Geotechnical investigation count from NZGD and T+T's records by geomorphic terrain as at 1 June 2021.

Geomorphic terrain	CPT count (No.)	BH count (No.)	TP Count (No.)	HA count (No.)
Coastal dunes	0	0	0	0
Wetlands and swamps	0	0	0	0
Alluvial plains and river flats	70	17	24	14
Lahars	72	23	5	251
Coastal terraces	51	23	9	83
Hills, ranges and mountains	101	65	28	82
Reclamation fill	0	0	0	8

Most of the geotechnical investigations in the Study Area are concentrated around the New Plymouth township.

Figure 3.8 and Figure A6 in Appendix A show the location of the geotechnical investigations available on the NZGD as at 1 June 2021.

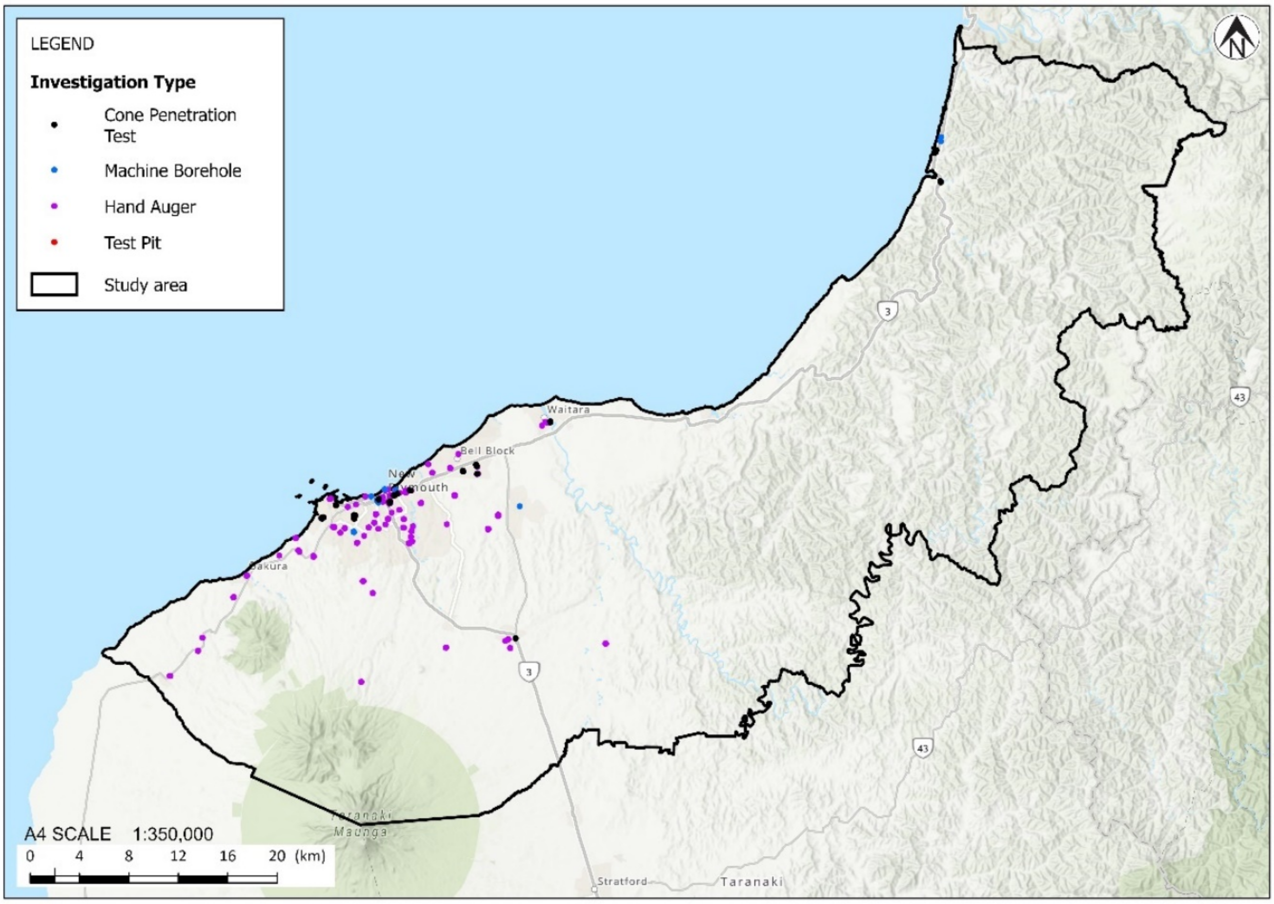


Figure 3.8: Geotechnical investigations available on the NZGD as at 1 June 2021. Note there are fewer investigations shown on this figure than in Table 3.2 because the figure does not include investigations from T+T's records. All geotechnical investigations that T+T has permission to upload are currently available on the NZGD.

3.2.4 Groundwater

Groundwater data

Within the Study Area, there are 367 mapped bore locations recorded in the Taranaki Regional Council (TRC) Open Data database as of 12 August 2021. Additional attributes such as static groundwater levels and depth of bore was provided to T+T from TRC on 30/8/2021. The bores have been installed for a variety of reasons (e.g., water supply, water monitoring etc.). Monitoring data from 11 of the TRC groundwater sites were obtained from Land, Air, Water Aotearoa (LAWA). The monitoring is generally on a monthly frequency; however, some wells only have between 2 and 5 groundwater level data points.

T+T applied the following screening criteria to identify which bores are likely to be representative of shallow groundwater (water table) and therefore can be used to provide information about the groundwater surface elevation:

1. Bore depth less than or equal to 20 m (and not equal to 0) because bores of greater depth may not be representative of the shallow unconfined groundwater; and
2. Measured water depth (mbgl) greater than 0, so as to filter out any artesian wells and any bores with measurement error.

A total of 64 investigations met these screening criteria, and of these, 15 have multiple readings over a period of months to years.

In addition, based on the New Zealand Geotechnical Database, there are 120 geotechnical investigations within the Study Area of which 70 have recorded groundwater levels and the depth of the investigations within the filtered range above.

LAWA has an additional 11 monitoring bores within the Study Area (of which some are overlapped with the TRC data). However, the LAWA bore data doesn't have any information of bore depth, therefore, only bores which have bore attribute data available in the TRC dataset have been used in this analysis.

The spatial distribution of the in-situ groundwater data is shown in Figure 3.9 and Figure A7 in Appendix A. Table 3.4 summarises this in-situ groundwater data for each of the geomorphic terrains (as outlined in Section 3.2.2) within the Study Area. Comments are also provided in Table 3.4 on the distribution of the groundwater data points within the individual terrains, for example, whether the data points are clustered in discrete locations or distributed evenly around the Study Area.

Table 3.4: Count of groundwater data type points per geomorphic terrain

Geomorphology unit	Monitoring points	Static points	Distribution
Alluvial plains and river flats	3	24	Clustered
Coastal Dunes	-	1	-
Coastal Terraces	3	28	Distributed in the southern area, clustered in the northern area
Hills, ranges and mountains	2	38	Clustered
Lahars	7	27	Distributed/low density
Reclaimed Land	-	1	-

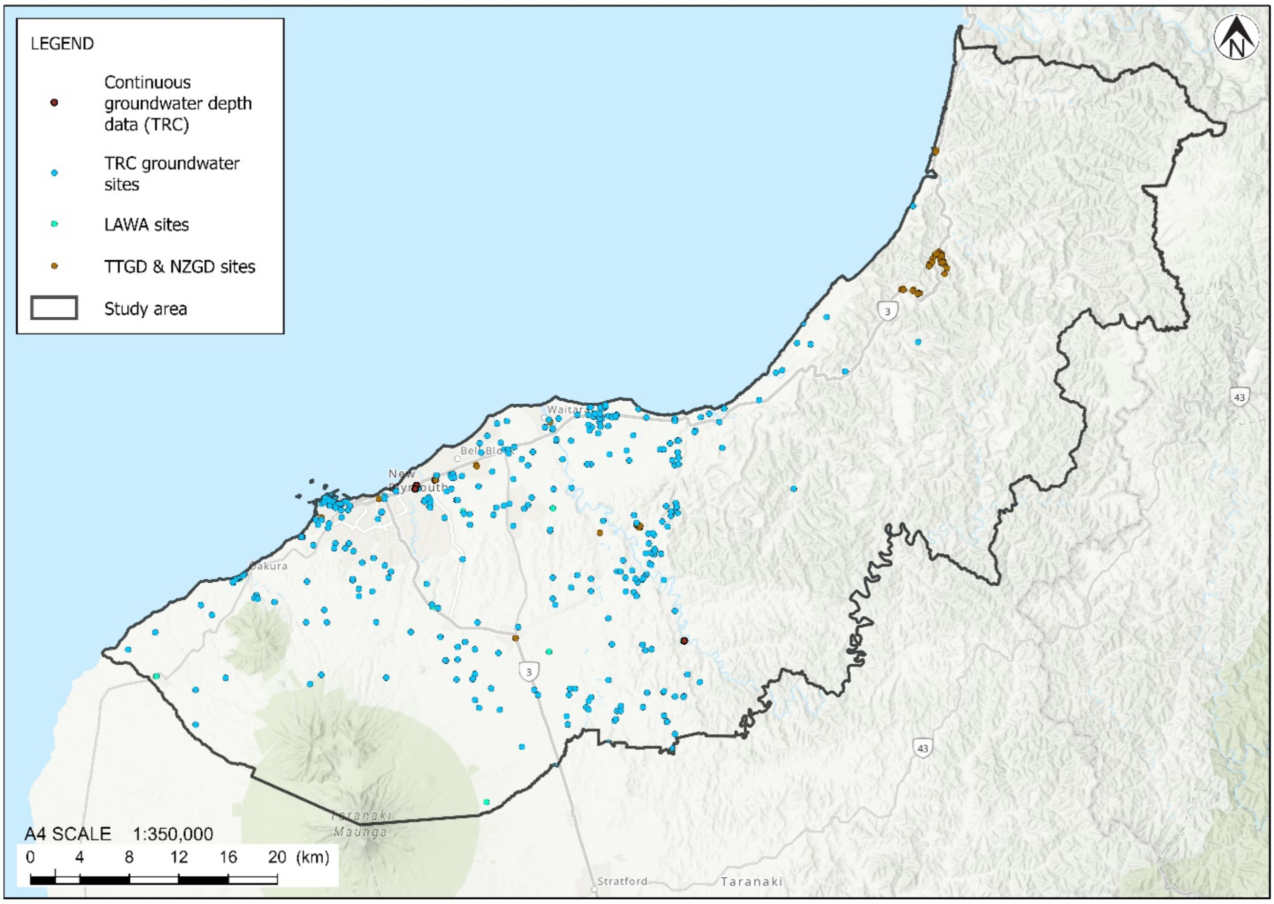


Figure 3.9: Spatial distribution of in-situ groundwater data in the Study Area.

The spatial distribution of water bodies across the Study Area is shown in Figure 3.10. This provides useful information because the groundwater is likely to be shallow near these mapped water bodies.

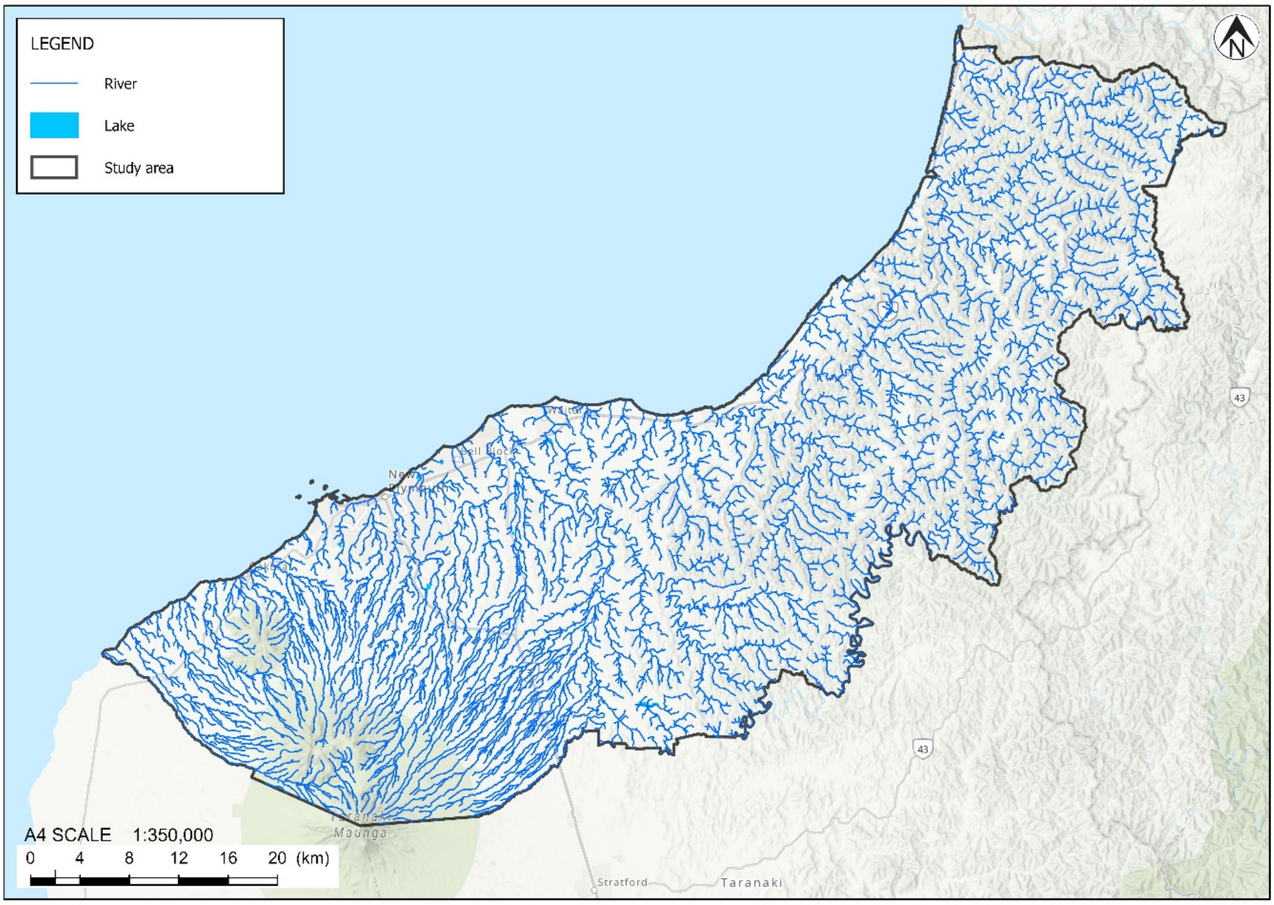


Figure 3.10: Spatial distribution of water bodies within the Study Area.

Groundwater models and studies

The Taranaki Volcanics and the Marine Terraces are the main unconfined aquifers in the region. The Taranaki volcanic deposits contain coarse material, such as sands, breccia, agglomerates, as well as, fine materials, such as clay, tuff and ash, resulting in a complex groundwater system of multiple perched aquifer systems. Along the coast, marine terrace deposits are up to 40 m thick and include multiple unconfined/perched aquifers (White & Rosen, 2001).

We considered the modelled water table depth from the National Water Table (NWT) dataset which is a coarse resolution (250 m x 250 m) modelled water table for NZ (Westerhoff, et al., 2018). This dataset provides a high-level overview of the groundwater conditions for New Zealand but is not suitable for district scale studies and terrain analyses such as this one. There are no other known or readily available mapped groundwater surface studies within the Study Area. The following has been summarised from Groundwaters of New Zealand (White and Rosen, 2001):

Sea-level rise

Sea-level rise has the potential to elevate groundwater levels in low-lying areas within close proximity to the coast. These low-lying areas are generally highly valued for development and as a result, are typically associated with townships across New Zealand. The actual impact of the predicted sea-level rise on the groundwater conditions within these low-lying areas is not fully understood. However, preliminary research suggests that, in some locations, the effects on liquefaction vulnerability could be wide reaching ((Quilter, et al., 2015), (Risken, et al., 2015) and (Tonkin & Taylor Ltd, 2020)).

Due to the presence of the terraces and cliffs around the coastal margin, the majority of the Study Area within close proximity to the coast is at relatively high elevation. Therefore, elevated groundwater levels in response to sea-level rise is unlikely to be widespread. Following review of the available information about ground surface levels (refer to Section 3.2.1) we have created Figure 3.11 and Figure 3.12 which show two low-lying (ground surface level less than 10 m RL (NZVD2016)) areas of existing urban development within the district. Figure 3.11 shows the low-lying land around the Waitara township and Figure 3.12 shows low-lying land within the New Plymouth Central Business District (CBD). Within the context of this project (refer to Section 2), particular attention should be given to the potential effects of sea-level rise on groundwater in these locations. We note that the impact of sea-level rise on groundwater elevation would likely extend beyond these areas. There are also other parts of the district where low-lying land is within close proximity to the coast and large waterbodies, such as Port Taranaki (Figure 3.13) and the New Plymouth Wastewater Treatment Plant (Figure 3.14).

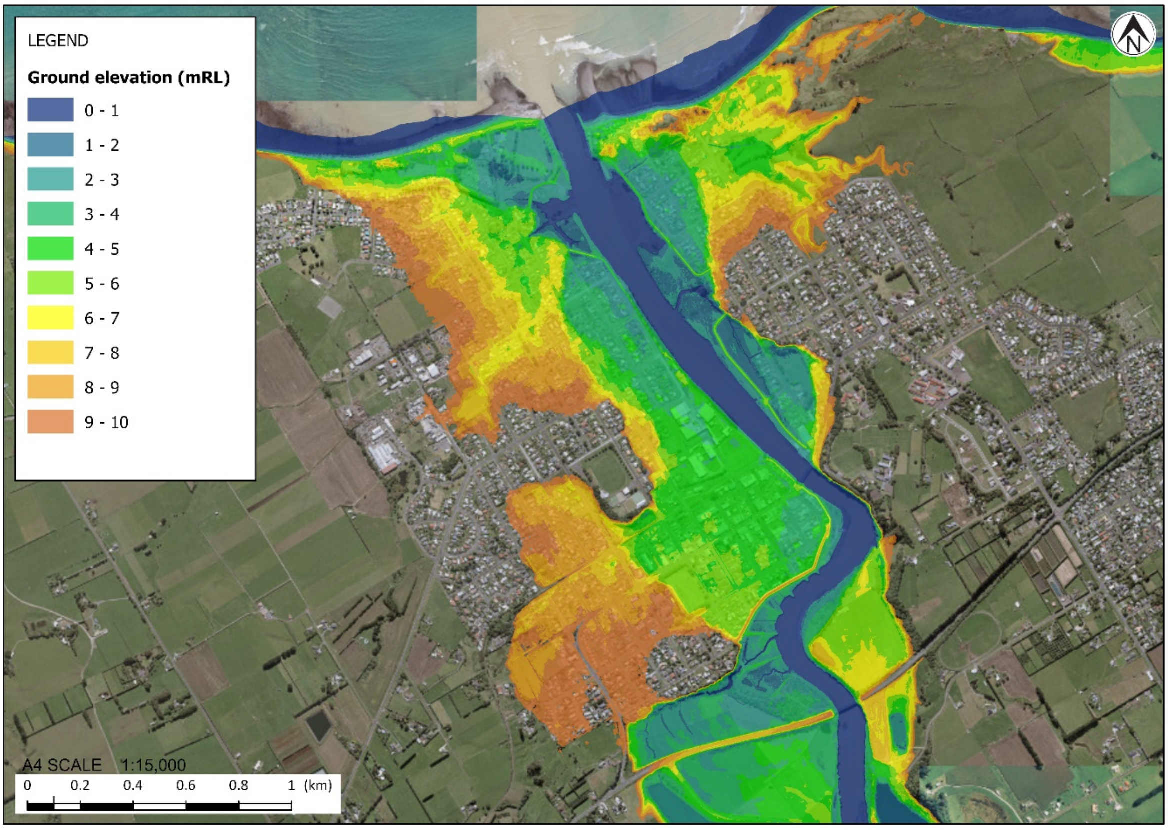


Figure 3.11: Ground surface elevations less than 10 m RL (NZVD 2016) around Waitara.

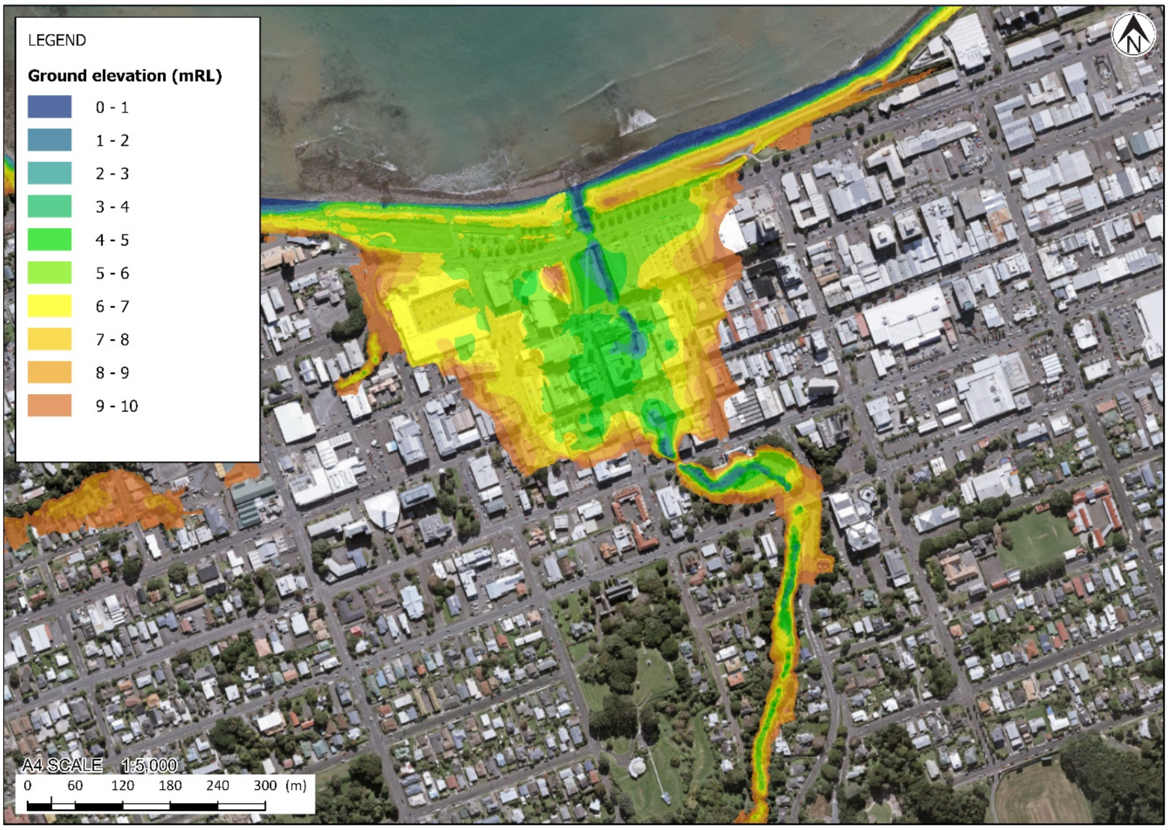


Figure 3.12: Ground surface elevations less than 10 m RL (NZVD 2016) around New Plymouth CBD.

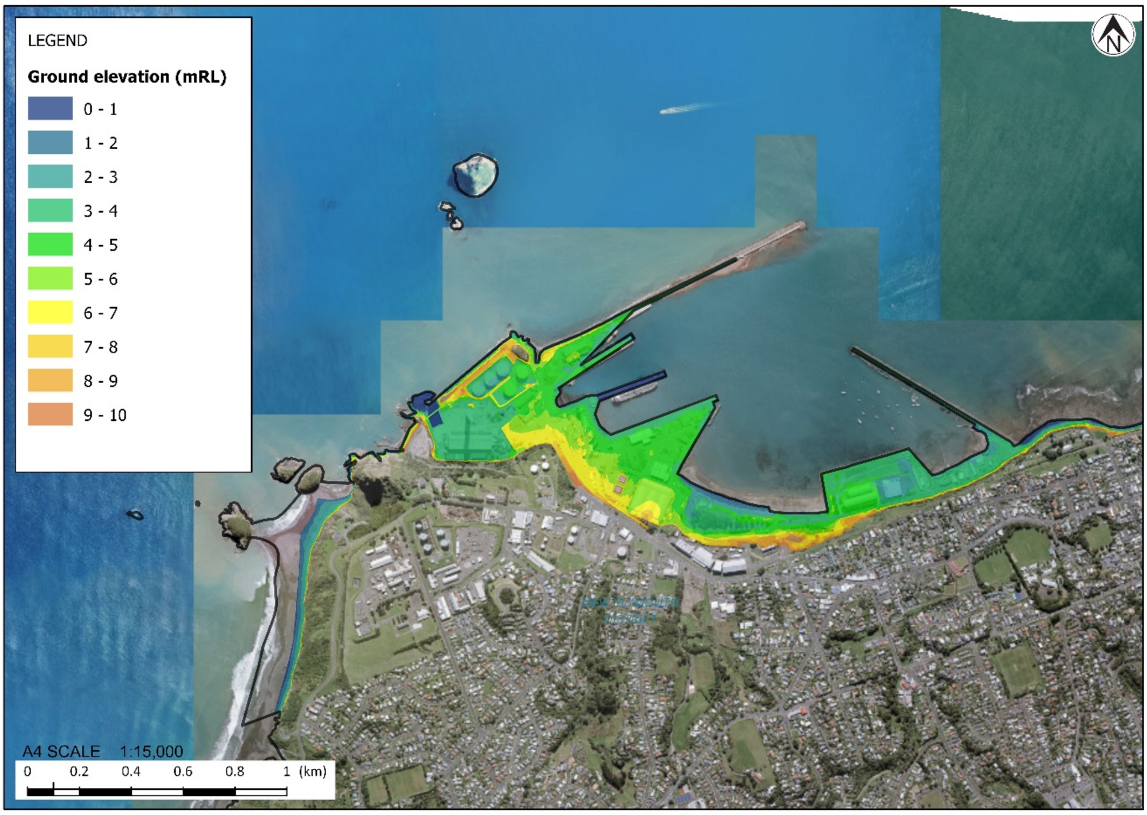


Figure 3.13: Ground surface elevations less than 10 m RL (NZVD 2016) around Port Taranaki.

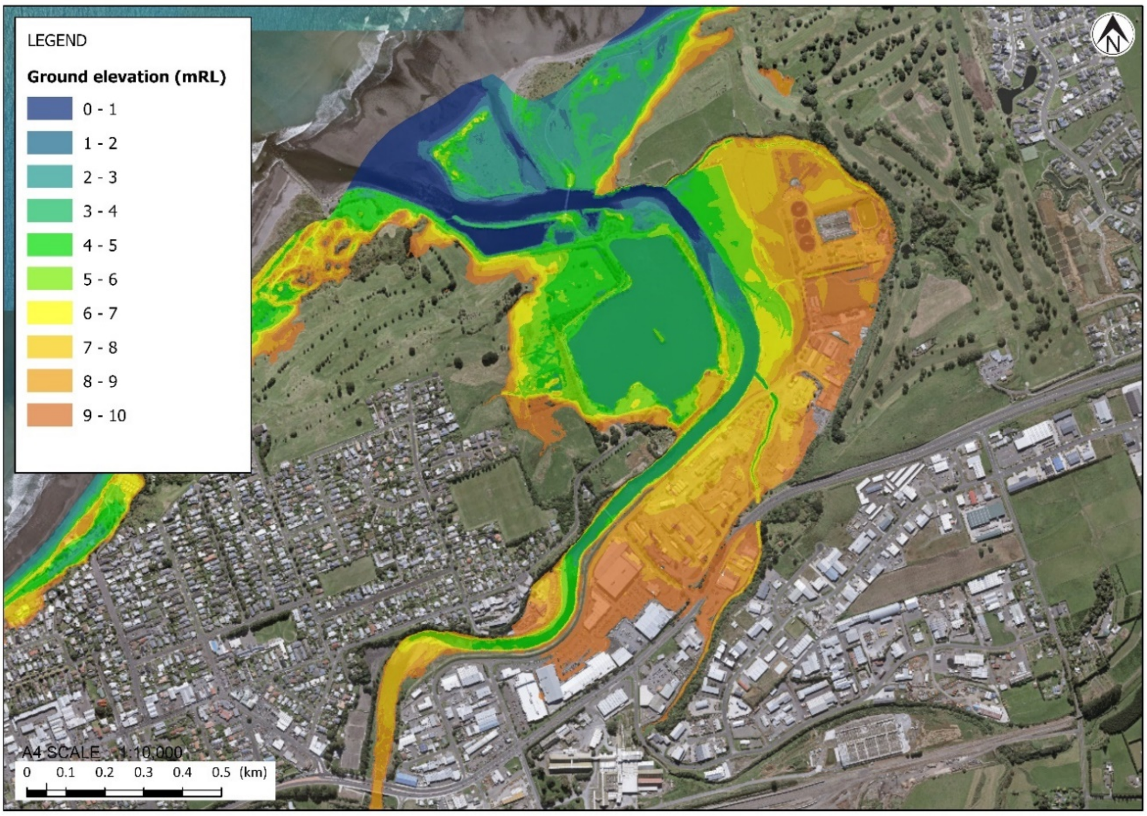


Figure 3.14: Ground surface elevations less than 10 m RL (NZVD 2016) around the New Plymouth Wastewater Treatment Plant.

3.2.5 Seismic hazard

Soils that are susceptible to liquefaction require a particular level of earthquake shaking (duration and intensity of ground shaking) to cause them to liquefy. A key source of uncertainty in liquefaction analyses is the intensity of shaking that will occur at a particular location in future earthquake events. The following is a summary of the available seismic hazard information for New Plymouth District.

Tectonic setting

New Plymouth District is positioned on the Australian tectonic plate to the west of the Hikurangi margin (the area where the Pacific Plate subducts below the Australian Plate). Due to the significant distance between New Plymouth District and the Hikurangi Margin, the district is not directly influenced by the tectonic contraction, dextral strike-slip faulting and tectonic rotation related to the plate boundary. The district is, however, subject to tectonic extension and normal faulting (Townsend, et al., 2008).

As a result of tectonic extension, there are a number of known active faults within the region. Figure 3.15 below, which was taken from the National Seismic Hazard Model (NSHM) for New Zealand (Stirling, et al., 2012), illustrates the known active faults in the region.

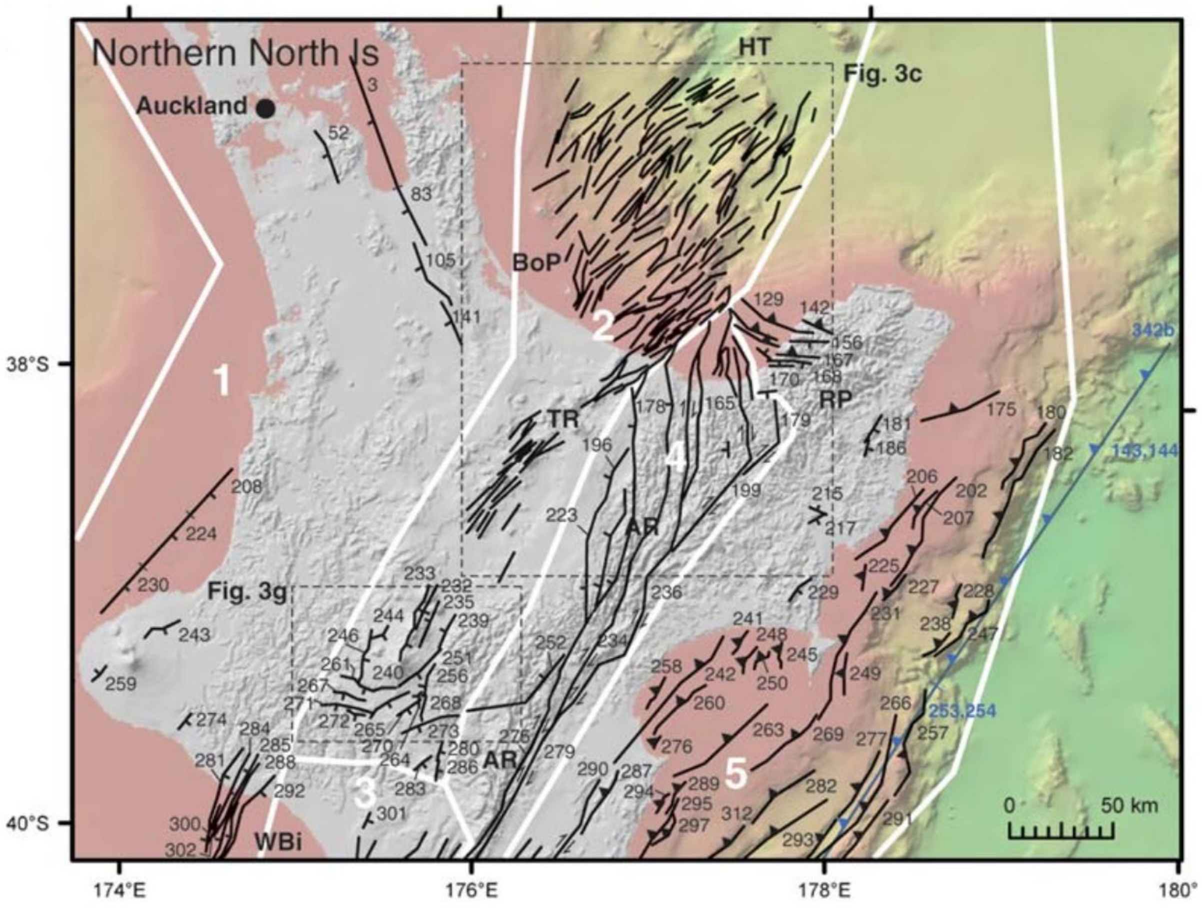


Figure 3.15: Known active faults in the Northern North Island. Faults 208, 224, 230 and 243 are the closest to New Plymouth District (Stirling et al, 2012).

As shown in Figure 3.15, there are two known active faults located on and offshore that are within or close to New Plymouth District. Fault sections 208, 224 and 230 represent the Turi Fault while Fault 243 represents the Inglewood Fault.

The following provides a summary of the characteristics of these faults:

- **Turi Fault:** The NSHM (2012) defines this offshore fault as a 94 km long normal fault with a potential moment magnitude of 6.8. This fault has a recurrence interval of between 3500 and 5000 years (i.e., RI Class III).
- **Inglewood Fault:** The NSHM (2012) defines the Inglewood Fault as having a span of approximately 20 km and has a potential moment magnitude of 6.5. This fault is located within close proximity to the Inglewood township and has an estimated recurrence interval of between 3500 and 5000 years (i.e., RI Class III).

The hazard assessment associated with this vulnerability assessment has considered the possibility of unmapped/unknown active faults within New Plymouth District by utilising the earthquake design loadings outlined in the NZTA Bridge Manual (2018). These design loadings include a contribution from "background seismicity" to allow for the possibility of unmapped/unknown active faults.

Seismic hazard information available for this assessment

The primary sources of seismic hazard information used as reference for this assessment is the New Zealand Transport Agency Bridge Manual (2018). For routine engineering projects, the NZTA Bridge Manual is currently the commonly accepted method for determination of seismic hazard for liquefaction analysis in New Zealand in the absence of a site-specific assessment or regional study. However, it should be noted that the seismic information for New Zealand is continually being updated. For example, recent research completed by Cubrinovski et al (2021) shows that the NZTA Bridge Manual and NZS 1170.5 (structural loading standard) both under-predicts and over-predicts the seismic hazard in parts of New Zealand.

Seismic hazard design parameters

Estimated Peak Ground Accelerations (PGA) and Magnitude (M_{eff}) for 1 in 100-year and 1 in 500-year return period earthquakes for towns within New Plymouth District based on the NZTA Bridge Manual methodology (NZTA, 2018) are provided in Table 3.5. These calculations have been based on Class D and Class E soils across the region. Table A2 in Appendix A provides estimates of PGA and M_{eff} derived using the NZTA Bridge Manual methodology (NZTA, 2018) for a range of return period earthquake and class D (deep or soft) and E (very soft) soils.

Table 3.5: Seismicity considered for the Study Area[1]

Town	Return period and estimated PGA		Magnitude (M_{eff})
	1 in 100	1 in 500	
New Plymouth	0.13	0.25	6.0
Waitara	0.12	0.25	6.0
Inglewood	0.12	0.25	6.1

[1] Estimated Peak Ground Accelerations (PGA) and Magnitude (M_{eff}) for 1 in 100-year and 1 in 500-year return period earthquakes based on the NZTA Bridge Manual methodology (NZTA, 2018)

3.2.6 Historical observations of liquefaction

The previous liquefaction hazard report for the Taranaki region published by GNS (Dellow & Ries, 2013) outlines historic earthquakes in New Zealand and their associated Modified Mercalli Intensities (MMI) felt in New Plymouth. These seismic events are summarised in Table 3.6. Research suggests that for liquefaction to occur in the most susceptible sediments, a MMI of 7 or larger is required (Hancox, et al., 2002). The GNS report (Dellow & Ries, 2013) provides a Modified Mercalli seismic intensity scale for New Zealand alongside the liquefaction hazard report. The scale describes the likely effects of each of the MMI. The likely *environmental effects* (that include descriptions of liquefaction) of MMI greater than 6 are shown in Table 3.7.

Table 3.6: Historic earthquakes and their MMI felt in New Plymouth (Dellow & Ries, 2013)

Historic Earthquake	MMI felt in New Plymouth
1848 Marlborough	6
1855 Wairarapa	6 – 7
1868 Cape Farewell	7 – 8
1929 Buller	5 – 6
1931 Hawke's Bay	5
1932 South Taranaki Bight	6
1934 Horoeka	5
1942 Wairarapa 1	4
1942 Wairarapa 2	4 – 5
1974 Opunake	5

As shown in Table 3.6, there have been two historic earthquakes in New Zealand that resulted in MMI in New Plymouth that could have caused liquefaction. The GNS report states that no historical accounts of liquefaction could been found that can be related to these earthquake events. However, as summarised in Table 3.7, the liquefaction phenomena associated with a MMI6 to MMI7 are relatively minor and, given those earthquakes occurred in the mid 1800s any liquefaction effects may not have been observed or recorded at that time. Further discussion about this potential source of uncertainty is provided in Section 3.3.7.

Table 3.7: Modified Mercalli Intensity scale for New Zealand and resultant environmental effects provided by GNS (Dellow & Ries, 2013)

Modified Mercalli Intensity	**Environmental effects associated with given MMI as per Appendix 1 of the GNS report (Dellow & Ries, 2013)**
MMI6	A few minor cases of liquefaction (sand boil) in highly susceptible alluvial and estuarine deposits
MMI7	A few instances of non-damaging liquefaction (small water and sand ejections) in alluvium
MMI8	Evidence of soil liquefaction common, with small sand boils and water ejections in alluvium, and localised lateral spreading (fissuring, sand and water injections and settlements along banks of river, lakes and canals
MMI9	Liquefaction effects widespread with numerous sand boils and water ejections on alluvial plains, and extensive, potentially damaging lateral spreading (fissuring and sand ejections) along banks of rivers, lakes, canals etc. Spreading and settlement of river stopbanks likely
MMI10	Liquefaction effects (as for MMI9) widespread and severe. Lateral spreading and slumping may cause rents over large areas, causing extensive damage, particularly along riverbanks, and affecting bridges, wharves, port facilities, and road and rail embankments on swampy, alluvial or estuarine areas

3.3 Uncertainty assessment

This Section of the report presents an assessment of the uncertainty associated with the base information available for the Study Area. The key output from this assessment is determination of the level of detail supported by the available base information.

In general, the MBIE/MfE Guidance allows for the management of uncertainty by assigning less precise liquefaction vulnerability categories where greater residual uncertainty exists. In this section, we have also noted where steps have been undertaken to manage specific sources of uncertainty as applicable.

3.3.1 Ground surface levels

As described in Section 3.2.1, the available information to define the ground surface levels comprises two DEM datasets. That being the higher resolution LiDAR-derived 1.0 m DEM for the urban areas of New Plymouth District and the other being the 8.0 m DEM derived from the LINZ Topo50 20 m contours. For this assessment, this data is used primarily in the development of the geomorphic map. It would also be a key data source in the development of any future depth to groundwater models and the identification of free faces for lateral spreading assessment. The key uncertainties associated with the ground surface levels are discussed below.

Uncertainty due to the accuracy and limitations of the 1.0 m LiDAR-derived DEM

While this LiDAR-derived DEM is high resolution and considered fit for the purposes of this liquefaction assessment, the following accuracy limitations generally associated with this survey technique should also be acknowledged:

- Measurement error associated with the LiDAR point cloud collection method.
- Localised error due to interpolation in areas with low density of ground classified points.
- Spatial resolution of the DEM and the accuracy and appropriateness in representing the ground surface elevation.

In most cases these limitations will have a relatively minor effect on the representation of the ground surface for liquefaction assessment. However, there are some specific applications which result in significant uncertainty in the assessment. A key example of this is the inability of LiDAR to penetrate water bodies. This limits the usefulness of LiDAR data for mapping free faces in water features because when water bodies are present at the invert of free faces, the height of the free face may be under-estimated resulting in under prediction of the extent and severity of lateral spreading.

Uncertainty due to the accuracy and limitations of the 8.0 m Topo50 20 m derived DEM

This DEM dataset extends across the entire country and was used in this assessment for areas of the district where the higher resolution LiDAR-derived DEM did not cover. This DEM is very low resolution and was developed from the LINZ Topo50 20 m contours. LINZ state that this dataset should only be used for cartographic visualisation only as it was created by digital interpolation of the 20 m contour dataset associated with the 1:50,000 topographical data available for New Zealand.

As a result, this DEM dataset has a significantly lower resolution compared to the 1.0 m LiDAR-derived DEM and may misinterpret landform features across the Study Area. This DEM dataset often over-represents flat land features across the Study Area, which are often associated with liquefaction susceptible soils.

To manage this source of uncertainty, the 8 m DEM and the geomorphons that have been derived from it have been used only to assess the general characteristics of the terrains and landforms that make up the Study Area rather than as a means to map discrete boundaries between terrains.

We understand that a higher resolution LiDAR-derived DEM is being developed for the entire district. This will provide a valuable resource for a number of different applications including higher level liquefaction vulnerability studies that may be undertaken. Figure 3.16 compares the resolution of the 1.0 m LiDAR-derived DEM and the 8.0 m Topo50 20 m derived DEM. Hillshade models have been generated for both DEM datasets for the same area within New Plymouth District.

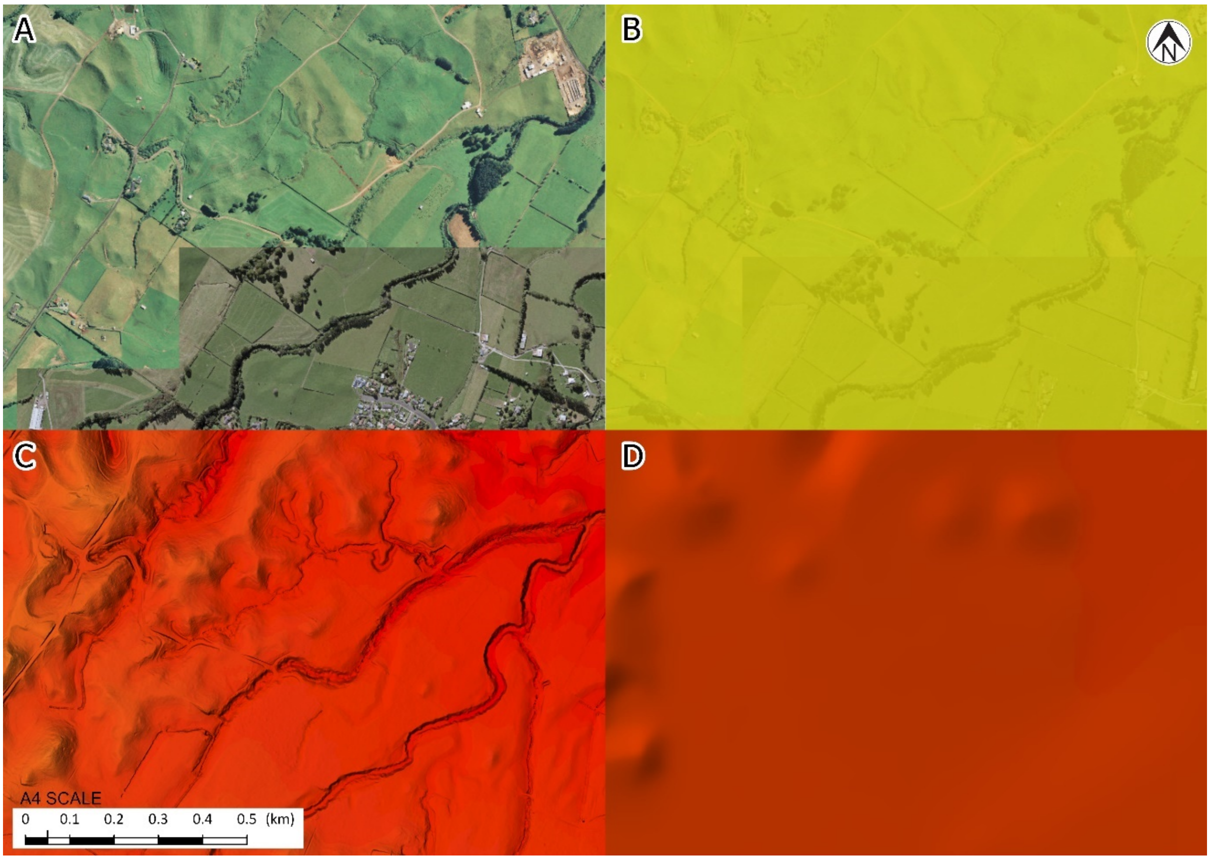


Figure 3.16: Four panel figure illustrating the differences between the two DEM datasets for the district. Each panel represents the same area within the Study Area. Panel A – Aerial image of subject area, Panel B – Geomorphic terrain within subject area (Lahar Terrain), Panel C – 1.0 m DEM hillshade model of subject area, Panel D – 8.0 m Topo50 20 m contour derived DEM hillshade model of subject area.

Uncertainty due to temporal changes in ground surface elevation

To a greater or lesser extent, any ground surface will be undergoing change in elevation. These changes may be attributable to natural processes (e.g., tectonic movement and earthquake-induced ground deformation) or anthropogenic (man-made) changes (e.g., land development activities). It is not feasible to predict with any reasonable degree of accuracy the extent and degree of future changes in ground surface elevation.

As discussed in Section 3.2.2, areas of reclamation fill have been identified while undertaking the geomorphic mapping and have been utilised in the liquefaction vulnerability classification process. Note that mapping from historic aerial imagery may not capture all areas of reclamation fill. The historic images may not cover the period when filling occurred, or the modification was simply not visible in the imagery. This historic filling is an example of the ground surface elevation changing within the Study Area.

Future studies or assessments should account for temporal changes in ground surface elevation by reviewing the most recent ground surface elevation datasets for the Study Area and considering the proposed finished landform.

3.3.2 Geology and geomorphology

As discussed in Section 3.2.2 the geology and geomorphology of the Study Area are presented in the form of maps. The mapped information is used in the liquefaction assessment to group areas of similar expected performance. The key uncertainties associated with the geology and geomorphology are discussed below.

Uncertainty due to the precision of mapping and the accuracy of boundaries between terrains

This can result in the incorrect categorisation of the land (if placed into the wrong geomorphology type) and hence incorrect estimation of ground performance. The specification of a scale of approximately 1:25,000 for the geomorphic mapping provides an indication of the degree of uncertainty and areas where there is more uncertainty associated with the location of the boundary have been identified.

Additionally, the geological map of the Taranaki region (Townsend, et al., 2008) that was used during the geomorphic mapping process was produced at a 1:250,000 scale. It became evident during the geomorphic mapping that some of the geological boundaries shown on the geological map did not align with the latest elevation data or aerial imagery. In particular, the geological boundaries associated with the coastal terraces and lahar deposits appeared to be incorrect in some locations. This is mainly due to the difference in scales of the geomorphic map compared to the geological map as the geological boundaries are generalised for a 1:250,000 scale.

This uncertainty has been allowed for by providing buffer zones of “Liquefaction Damage is Undetermined” in the liquefaction vulnerability classification map where an area classified as “Liquefaction Damage is Possible” is adjacent to an area classified as “Liquefaction Damage is Unlikely.”

Uncertainty due to anthropogenic landform changes

Some anthropogenic landform changes, in particular those associated with large infrastructure or land development projects, can result in changes to the severity of liquefaction-related land damage under seismic load. In some cases, these changes will result in an improvement of liquefaction performance (e.g. ground improvements such as dynamic compaction or stone columns) or in some instances there will be a degradation in liquefaction performance (e.g. reduction of the ground surface elevation resulting in a reduced depth to groundwater). An example of this is the New Plymouth CBD area. Historic aerial imagery, the LiDAR-derived DEM and geotechnical investigations show the landforms in this area have been dramatically changed and altered during the development of the CBD. As a result, it is likely that there are significant areas of unmapped fill within the CBD area.

The level of detail targeted by this assessment (i.e. Level A) means that incorporating the site-specific information that would be required to assess the effects of these landform changes is not included in the scope for this project. Except for reclamation fills (which are mapped as their own geomorphic terrain), areas of anthropogenic landform change are assessed as performing in a manner that is consistent with the geomorphic terrain in which they are situated. More detailed assessment incorporating site-specific information (i.e., Level C or D) would be required to differentiate these areas.

Uncertainty due to liquefaction susceptibility of Lahar terrain

As outlined in Section 3.2.2 and Section 3.2.3, the sediments comprising the Lahar terrain across the Study Area appear to be spatially variable. The geological maps show the lahar deposits having different geological descriptions varying from fine to coarse grained soils. The limited amount of geotechnical investigation data available within the terrain shows that the surficial soils overlying the lahar deposits are also highly variable and appear to be comprised material that is likely to be susceptible to liquefaction. Figure 3.17 is a sketch of the Lahar terrain which illustrates the characteristics described here.

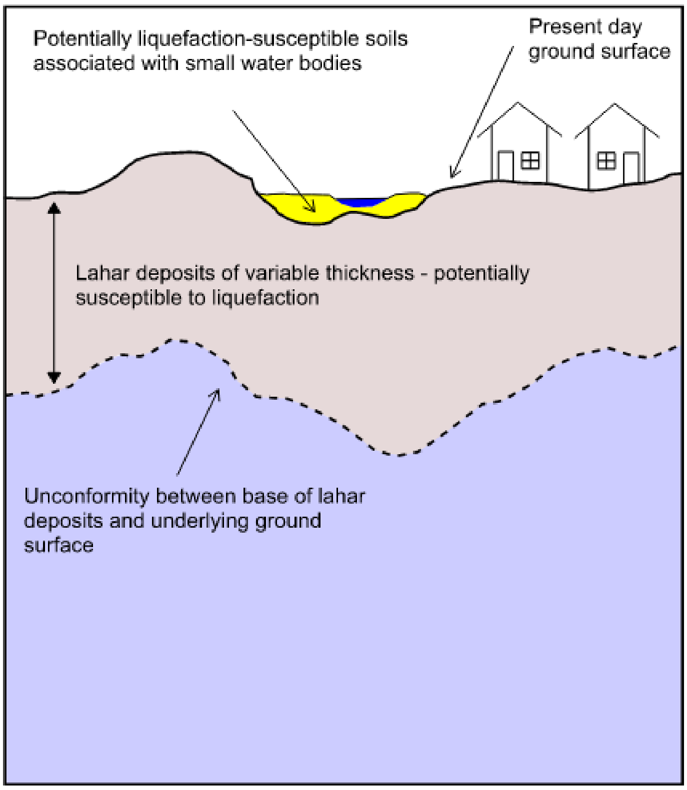


Figure 3.17: Sketch showing the composition of the Lahars terrain with potentially liquefiable deposits associated with small water bodies near the ground surface

There are also international case histories where lahar deposits and other volcanically derived soils (e.g., volcanic ashes etc.) have liquefied in earthquakes (Dragovish, et al., 1995). However, lahar deposits are highly variable and their sediment composition can differ depending on the source.

Furthermore, there are many small water bodies across the Lahars terrain that are not suitable to be mapped at a 1:25,000 scale. Sediments that are susceptible to liquefaction may be present within these water bodies. This introduces a significant source of uncertainty for a large part of the Study Area as the scope of the study does not enable mapping of all of these features. Figure 3.18 shows an example location where surficial landform features across the Lahars terrain could contain soils that are susceptible to liquefaction.

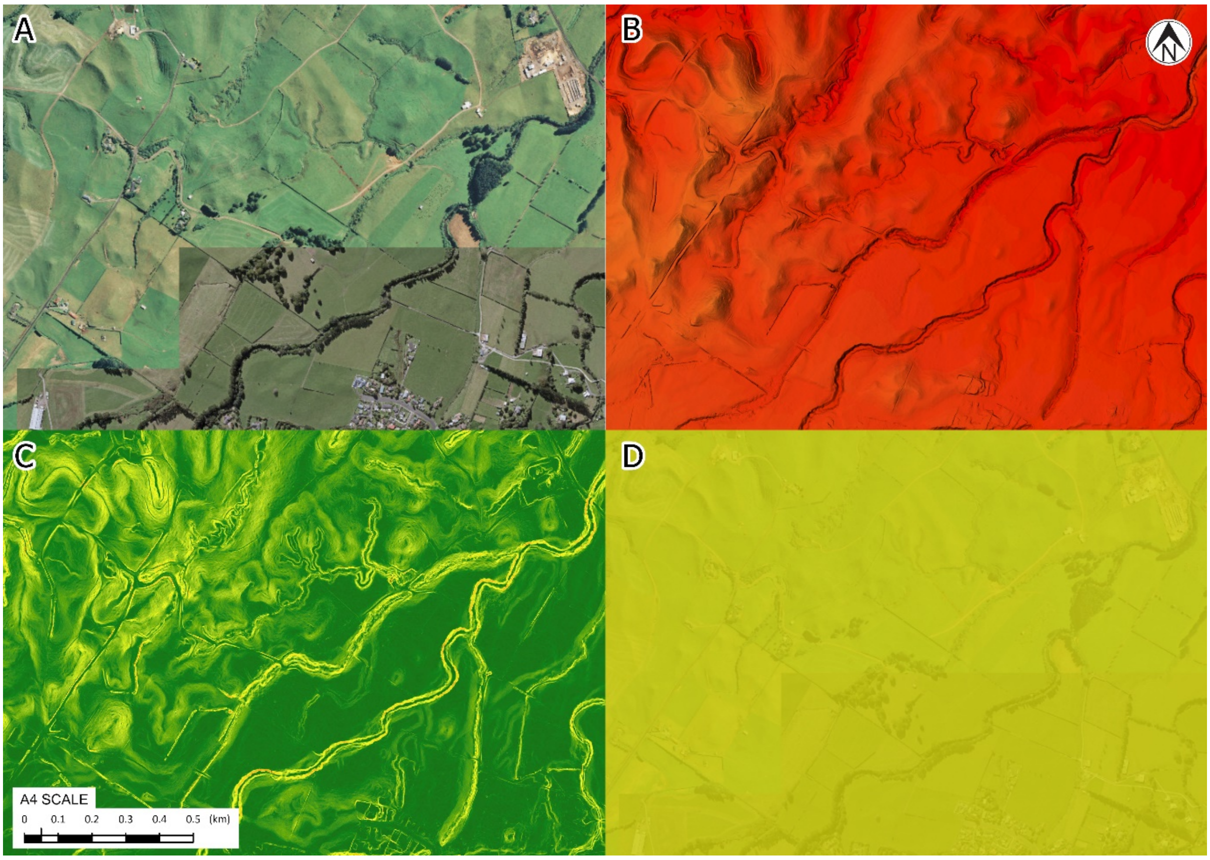


Figure 3.18: Four panel figure illustrating the landform variability within the Lahars terrain. Each panel represents the same area within the Study Area. Panel A – Aerial image of subject area, Panel B – Hillshade model of subject area, Panel C – slopes within subject area, Panel D – geomorphic terrain within subject area (Lahar Terrain). Note the river and stream systems that can be seen in panels A, B and C that are likely to be associated with liquefaction-susceptible soils.

This uncertainty has been managed by grouping all of the lahar deposits within the district into the single Lahar terrain and qualitatively assessing the potential impact of the identified source of uncertainty on the liquefaction vulnerability criteria assigned.

Uncertainty due to liquefaction vulnerability of Coastal Terraces

As outlined in Section 3.2.2 and Section 3.2.3, the sediments comprising the Coastal Terraces are typically middle to late Pleistocene-aged shallow marine conglomerates, shell beds, dune sands and peat deposits. Due to the typical age of these sediments, there is some uncertainty associated with liquefaction vulnerability of this terrain.

As sediments age, chemical and physical changes (particle interlocking and bonding) can occur between soil particles that increase the resistance of the soil to liquefaction triggering. This process is known as the "aging effect." Based on early research, it was suggested that due to these chemical and physical changes, Pleistocene-aged soils generally require higher levels of earthquake shaking to trigger liquefaction (Youd & Perkins, 1978). However, the direct relationship between aging effects and liquefaction triggering is not clearly defined and is still an active area of research (Clayton & Johnson, 2013). Furthermore, there is uncertainty associated with the actual age of the whole geomorphic terrain. For example, the Geology of Taranaki area report (Townsend, et al., 2008) notes that the marine terrace deposits are "*…often overlain by marginal marine swamp and/or dune deposits*" and "*…Older dunes occur sporadically as swales and hummocks on many of the older marine and alluvial terraces…*". As a result, there is significant uncertainty associated with the liquefaction vulnerability of the Coastal Terraces terrain.

This uncertainty has been allowed for by assigning this terrain a liquefaction vulnerability category that could be refined by undertaking a higher level of detail study. We note that the MBIE/NZGS earthquake engineering modules (in particular Module 3 ((NZGS/MBIE, 2016)) are currently being updated to provide guidance for engineers on methods that can be used to assess aging effects for site-specific liquefaction assessments.

3.3.3 Geotechnical investigations

As discussed in Section 3.2.3, there are a range of geotechnical investigations available on the NZGD within the Study Area. These geotechnical investigations can be used to estimate (both quantitatively and qualitatively) the expected liquefaction-related performance of the land. The key uncertainties associated with the geotechnical investigations are discussed below.

Uncertainty due to geotechnical investigation data quality

Each geotechnical investigation has inherent data quality issues. Some of these are readily identifiable, are logged as part of the investigation and can be allowed for in the analysis (e.g., post ground improvement investigations and portions of predrilled CPTs). Others are not readily identifiable without being able to refer to the data source and must be considered using engineering judgement (e.g., incorrectly logged borehole data).

The relatively low concentration of geotechnical investigations within the Study Area and the level of detail targeted (i.e., Level A) mean that this source of uncertainty does not contribute significantly to the overall uncertainty in the assessment.

Uncertainty due to variability in ground conditions within geomorphic terrains

Within each geomorphic terrain there is a degree of natural variability in ground conditions that results in subsequent variability in expected liquefaction-related performance. Some geomorphic terrains, such as the Coastal Dunes, are likely to have a low degree of variability and this is reflected in a relatively uniform estimate of liquefaction-related performance for a constant depth to groundwater. Other geomorphic terrains, such as the Lahars and Coastal Terraces, are likely to have much more variable soil conditions and this is reflected in a variable estimate of liquefaction-related performance for a constant depth to groundwater.

This source of uncertainty is managed by considering the likely variability in soil conditions within each geomorphic unit as part of the liquefaction vulnerability categorisation process. The results of this are discussed in Section 4.4.

Uncertainty due to spatial density of geotechnical investigations

Section 3.4 of the MBIE/MfE Guidance (2017) provides guidance about the required spatial density of ground information. It emphasises that the key features which define the level of detail for a particular assessment are the nature of the assessment undertaken and the residual uncertainties, not simply the investigation density. Specifically, it states that:

"*The key requirement is that the investigations should be sufficient for adequate ground characterisation for the specific purpose of the assessment and ground conditions encountered.*"

With that noted, the guidance provides the indicative spatial density of deep ground investigations for adequate ground characterisation for liquefaction assessments (see Figure 3.19).

LEVEL OF DETAIL IN THE LIQUEFACTION ASSESSMENT [1,2]	AVERAGE INVESTIGATION DENSITY	AVERAGE SPACING BETWEEN	MINIMUM TOTAL NUMBER OF INVESTIGATIONS
Level A[3] Basic desktop assessment	0.01 to 1 per km^2	1 to 10 km	–
Level B Calibrated desktop assessment	0.5 to 20 per km^2	220 to 1400 m	3 for each geological sub-unit
Level C Detailed area-wide assessment	0.1 to 4 per Ha	50 to 320 m	5 if area > 1 Ha 3 if area 0.25 – 1 Ha 2 if area < 0.25 Ha
Level D[4] Site-specific assessment	2 to 40 per Ha	15 to 70 m	2 within or very close to the building footprint

Notes:

1 Investigation densities listed in this table are cumulative – suitable data from investigations undertaken in previous stages of work should be incorporated in subsequent stages.

2 The key feature defining each level of detail is the degree of residual uncertainty in the assessment (refer Table 3.1), not necessarily the spatial density of ground investigations. In some circumstances a significantly higher or lower investigation density might be appropriate to provide the required degree of certainty for a particular target level of detail or purpose. For example, the lower end of the recommended minimum range might be appropriate where investigations show ground conditions to be reasonably consistent (eg some marine or lake deposits), while the upper end of the range may be more appropriate if ground conditions prove to be highly variable (eg many river deposits).

3 There are no minimum investigation density requirements for a ***Level A*** liquefaction assessment. However, the geological maps that are normally used for a ***Level A*** assessment have often been 'ground-truthed' at approximately the density shown. New ground investigations are unlikely to be required, provided that existing information such as geology, geomorphology and groundwater maps is suitable (relative to the scale and purpose of the assessment), and categories are assigned with appropriate consideration of the uncertainties.

4 For a ***Level D*** assessment, the key requirement is to confidently characterise the ground conditions at the specific location of the proposed building. Therefore the particular arrangement and proximity of investigations within and surrounding the building footprint will often be of greater importance than the minimum investigation density criteria.

Figure 3.19: Indicative spatial density of deep ground investigation for adequate ground characterisation for liquefaction assessments to inform planning and consenting processes.

Compared to other parts of New Zealand there are relatively few geotechnical investigations within the Study Area on the NZGD and within T+T's records. As shown in Figure 3.8, the few available investigations are predominantly associated with the main town centres (New Plymouth and Waitara). This low spatial density means that it is not possible to reliably calibrate the soil conditions from the available geotechnical investigations for the majority of the Study Area.

While calibration with geotechnical investigations is not required for a Level A assessment, it does help reduce some of the uncertainty associated with inferences about ground conditions within a particular area. To manage this issue, we have carefully considered this source of uncertainty in the assignment of liquefaction vulnerability categories, and areas with significant residual uncertainty about the nature of the soil conditions have been mapped as "Liquefaction Category is Undetermined".

3.3.4 Groundwater

As discussed in Section 3.2.4, there are a number of in-situ groundwater data records within the Study Area, the majority of which are single measurements from boreholes that are sourced from the Taranaki Regional Council Open Data database. The key uncertainties associated with the available groundwater data are discussed below.

Uncertainty due to spatial density of groundwater data

The available groundwater data records are predominantly widely spaced throughout the region leaving significant gaps between these records. This makes meaningful interpolation of the depth to groundwater between locations with groundwater records challenging.

While not critical for the Level A level of detail, this uncertainty becomes increasingly important in areas where quantitative analysis is required to support a higher level of detail.

Uncertainty due to length of groundwater data records

Most of the groundwater data that T+T has been able to source to date are single point measurements of groundwater. There are only 15 locations within the Study Area with multiple readings over a period of months to years.

While not critical for the Level A level of detail, this information becomes increasingly important at higher levels of detail because it helps to understand the range of fluctuation in groundwater levels between seasons and years.

Uncertainty due to the effects of climate change

Climate change introduces further uncertainty regarding the groundwater conditions that could exist at some time in the future when an earthquake occurs. The key effects of climate change on the future groundwater conditions may include:

- Changes in the intensity and distribution of rainfall influencing the recharge rate of the groundwater surface.
- Reduction in the depth to groundwater due to the effects of sea-level rise.

Validation and possible ground truthing of existing records would be a useful first step to reduce some of the uncertainty associated with the existing records and effects of climate change. More detailed analysis would require installation of a network of piezometers to monitor groundwater level fluctuations over time. Development of groundwater models from this information would provide valuable information for climate change studies and other applications.

Validation and ground truthing of the existing groundwater information would provide a significant reduction in uncertainty in the assessment and potentially enable more detailed classification of the liquefaction vulnerability in the area. In addition, monitoring in these areas could infer potential relationships between groundwater and sea-level rise, and provide a foundation for future management of sea-level rise hazards from groundwater. As discussed in Section 3.2.4, the data shown in Figure 3.11 and Figure 3.12 can be used to identify those areas that are likely to be most sensitive to the effects of sea-level rise. In this assessment, this data has been used to identify those geomorphic units which are likely to be most sensitive to the effects of sea-level rise on groundwater. It is also useful information to inform the scope of any potential future groundwater monitoring studies.

Uncertainty due to the accuracy of mapped water bodies

Sourcing an accurate database of waterbodies in the Study Area was difficult for this assessment as several of the main data sources did not accurately represent the rivers in the district when visually checked against aerial imagery. Spatial waterbody data was required for this assessment to visually represent the many rivers in the district on GIS and to allow potential lateral spreading to be assessed.

Visual observations determined that the MfE River Flows dataset was the best for the district. However, this dataset was not 100% accurate and did not identify all of the active river or stream channels within the Study Area. In the Hills, Ranges and Mountains terrain these unmapped waterbodies are predominantly located in the upper catchments. This means they are deeply incised into sedimentary rocks and are unlikely to have significant fine-grained alluvial deposits associated with them. Therefore, assigning a vulnerability category of "Liquefaction Damage is Unlikely" was deemed appropriate. Where this occurs within the other geomorphic terrains, the uncertainty is managed by the appropriate assignment of the liquefaction vulnerability category i.e., assigned as either "Liquefaction Damage is Possible" or "Liquefaction Category is Undetermined".

Uncertainty associated with the assumed depth of groundwater within each geomorphic terrain

It has generally been assumed that groundwater is likely to be deep in some of the geomorphic terrains (e.g., Coastal Terraces) across the Study Area due to the higher elevation of the associated deposits (Dellow & Ries, 2013). As a result, the potential for liquefaction to occur in these terrains has been precluded. However, as shown in Table 3.8, statistical analysis of the available groundwater data in the Study Area does not support this general assumption. For example, based on the available information, measured groundwater conditions within the Coastal Terraces terrain ranges between 1.0 m and 16.2 m below ground level.

Table 3.8: Groundwater depth for all groundwater observation wells by geomorphic terrain

Geomorphology unit	Measurement count	Mean (mbgl[1])	Median (mbgl[1])	Min (mbgl[1])	Max (mbgl[1])
Alluvial plains and river flats	59	2.6	2.3	0.2	7.0
Coastal Dunes	1	3.5	3.5	3.5	3.5
Coastal Terraces	107	4.3	3.7	1.0	16.2
Hills, Ranges and Mountains	50	6.1	4.6	1.0	14.0
Lahars	137	5.2	5.7	0.2	11.7
Reclaimed Land	1	2.5	2.5	2.5	2.5

[1]Metres below ground level.

Where long term groundwater monitoring records are available, a seasonal groundwater analysis was undertaken for individual geomorphic terrains. These analyses indicated that seasonal groundwater fluctuations vary based on geomorphic terrain, for example, the Lahars terrain displays seasonal groundwater fluctuations of 4 m, whereas the Alluvial Plains and River Flats terrain and Coastal Terraces terrain both have seasonal fluctuations on the scale of 1 to 2 m. These seasonal groundwater fluctuations contribute further to the uncertainty associated with the depth to groundwater in each geomorphic terrain.

3.3.5 Seismic hazard

Seismic parameters have been derived for this assessment based on the NZTA Bridge Manual methodology (New Zealand Transport Agency, 2018). However, Module 1 of the NZGS Earthquake Geotechnical Engineering Practice Guidelines (NZGS/MBIE, 2016) notes the following issues have been identified with this approach:

1. Compatibility issues between the magnitude weighting factors embedded in the hazard evaluation and the magnitude scaling factors in the liquefaction evaluation procedures adopted in this guideline series.
2. The use of an “effective earthquake magnitude”.
3. The need to incorporate updates in the National Seismic Hazard Model. The NZTA Bridge Manual methodology is based on the Stirling (2002) NSHM and not the updated Stirling et al (2012) NSHM.

It should also be noted that the National Seismic Hazard Model for New Zealand is currently being updated. This update could result in some locations in New Plymouth District having a decreased seismic hazard. These issues indicate there is a significant degree of uncertainty associated with the estimation of seismic hazard using this methodology.

The primary focus of a Level A level of detail is to identify land where there is a high degree of certainty that “Liquefaction Damage is Unlikely” (so that it can be taken off the table without further assessment) (refer to Figure 3.1). This involves the use of qualitative methods that do not rely heavily on the precise seismic hazard parameters adopted.

Regardless of the method used, the 500-year level of earthquake shaking (i.e., PGA and magnitude pairing) across New Plymouth District is well above the level of shaking required to trigger liquefaction in most susceptible soils. This is the primary consideration in this qualitative assessment of liquefaction vulnerability. Therefore, due to a Level A level of detail being targeted in this assessment, the uncertainty associated with the methods used to calculate seismic hazard parameters does not contribute significantly to the residual uncertainty in the current assessment.

3.3.6 Historical observations of liquefaction

As detailed in Section 3.2.6, there are no documented accounts of liquefaction occurring in New Plymouth District following significant historic earthquakes. The absence of any liquefaction records in the district does not necessarily mean that liquefaction has not occurred in the past. The key uncertainty associated with the absence of historical observations of liquefaction is discussed below.

Uncertainty due to evidence of liquefaction that was not observed

It is possible that liquefaction may have occurred in the past, but it was not documented. Based on the MMI scale provided by GNS in the Taranaki Region Liquefaction Hazard Report (Dellow & Ries, 2013), it is likely that evidence of liquefaction in New Plymouth District would only be visible at MMI 8 or larger. As detailed in Table 3.6, there has only been one recorded earthquake event felt in New Plymouth with a MMI between 7 – 8 (1868 Cape Farewell). MBIE/MfE guidance (2017) provides the following examples of why liquefaction-related land damage might not be observed following an earthquake even if soils are susceptible:

- It is possible that the soil is susceptible to liquefaction, but the intensity and/or duration of shaking was not sufficient to trigger liquefaction.
- It is possible that liquefaction was triggered at depth in the soil but there was no surface evidence of liquefaction, and greater intensity and/or duration of shaking may be required to induce liquefaction damage at the ground surface.
- There may have been surface evidence of liquefaction, but the observation was not recorded or was attributed to some other cause such as flooding.

3.3.7 Assess ground damage response against performance criteria

The MBIE/MfE Guidance (2017) provides the performance criteria shown to determine the liquefaction vulnerability category for a particular area of land.

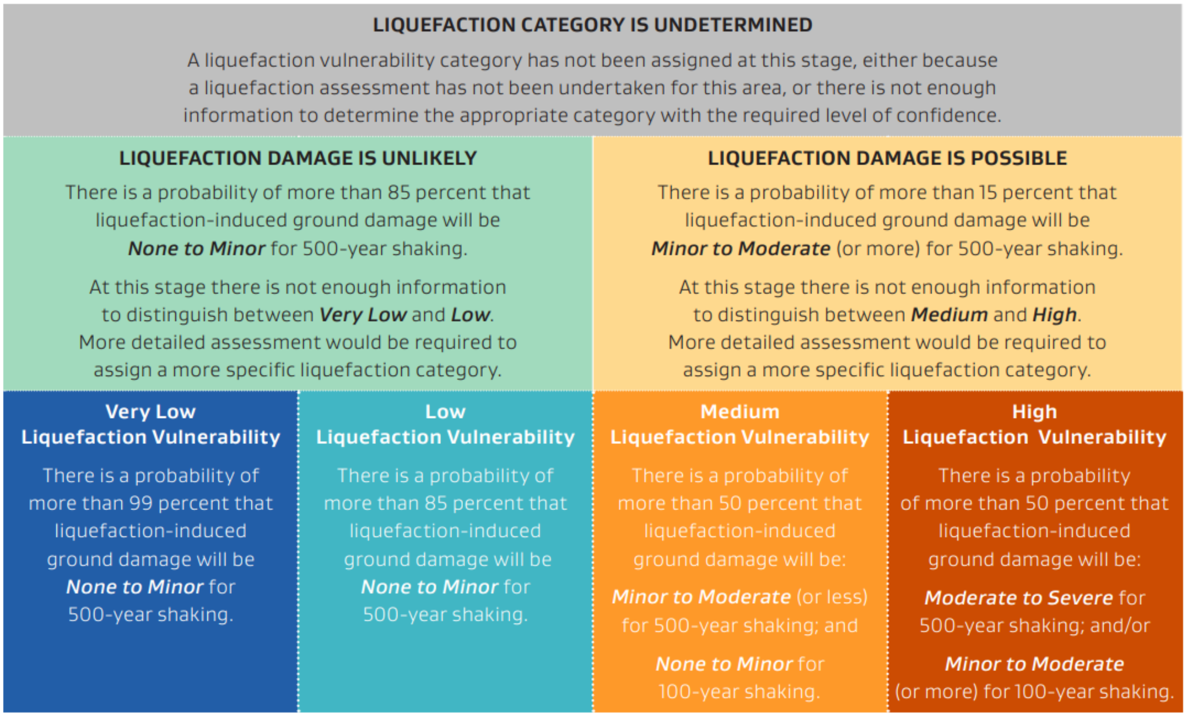


Figure 3.20: Performance criteria for determining the liquefaction vulnerability category – reproduced from MBIE/MfE Guidance (2017).

As discussed in Section 4.5.2 of the MBIE/MfE Guidance (2017), the performance criteria make reference to particular probabilities of a certain degree of damage occurring. These probabilities are intended to provide an indication of the level of confidence required to assign a particular category, rather than specific numerical thresholds to be calculated for each category. It is also important to recognise that these probabilities relate to the total effect of all uncertainties in the assessment, a characteristic that makes probabilistic calculation particularly challenging.

For this liquefaction vulnerability assessment, the level of confidence has been evaluated qualitatively with these indicative probabilities used as guidance. As with any qualitative assessment, it is necessary to apply a degree of judgement to determine the liquefaction vulnerability category for each area of land within the Study Area and there is inherent uncertainty associated with this subjective process.

For typical buildings and infrastructure, the consequences (or costs) of over-predicting the hazard are incurred upfront in the form of unnecessary capital expenditure on overly robust solutions. Conversely the costs of under-prediction are incurred at some time in the future when sufficiently strong earthquake shaking occurs and the buildings and infrastructure must be rebuilt or repaired. The potential consequences of this uncertainty in characterising the liquefaction vulnerability are discussed further in Appendix J of the MBIE/MfE Guidance (2017) and are reflected in the relativity between indicative probabilities specified for various categories in Figure 3.20.

For the current assessment, a key outcome of this balanced cost/benefit approach to uncertainty can be seen in areas where there is currently insufficient certainty to assign a category of "Liquefaction Damage is Unlikely" (i.e., an indicative confidence level of less than 85%). In many of these areas the nature of the expected ground conditions means that if more detailed site-specific assessment was undertaken in the future, then this would likely indicate a category of "Low Liquefaction Vulnerability".

Rather than assign the areas described above an interim category of "Liquefaction Damage is Possible" in the current assessment "just to be safe" (imposing upfront costs from over-prediction), these have been assigned "Liquefaction Category is Undetermined". This lack of a definitive category might appear to be unhelpful because it does not immediately tell people whether their land is vulnerable to liquefaction damage. Therefore, supporting information should be provided which draws on the technical work undertaken to date to provide clear direction on the process that people can follow to efficiently determine which liquefaction vulnerability category applies.

Section 4.4 discusses key aspects for future assessments in each geomorphic terrain. For example, in some geomorphic terrains, undertaking simple shallow hand auger boreholes and plasticity testing of soil samples would likely be sufficient to demonstrate "Low Liquefaction Vulnerability". This supporting information will be provided via the GIS metadata, which accompanies each sub area of similar expected performance.

3.4 Level of detail achieved in this assessment

As shown in Figure 3.21, a Level A – basic desktop assessment was targeted across the Study Area and this is the level of detail that has been achieved in this assessment.

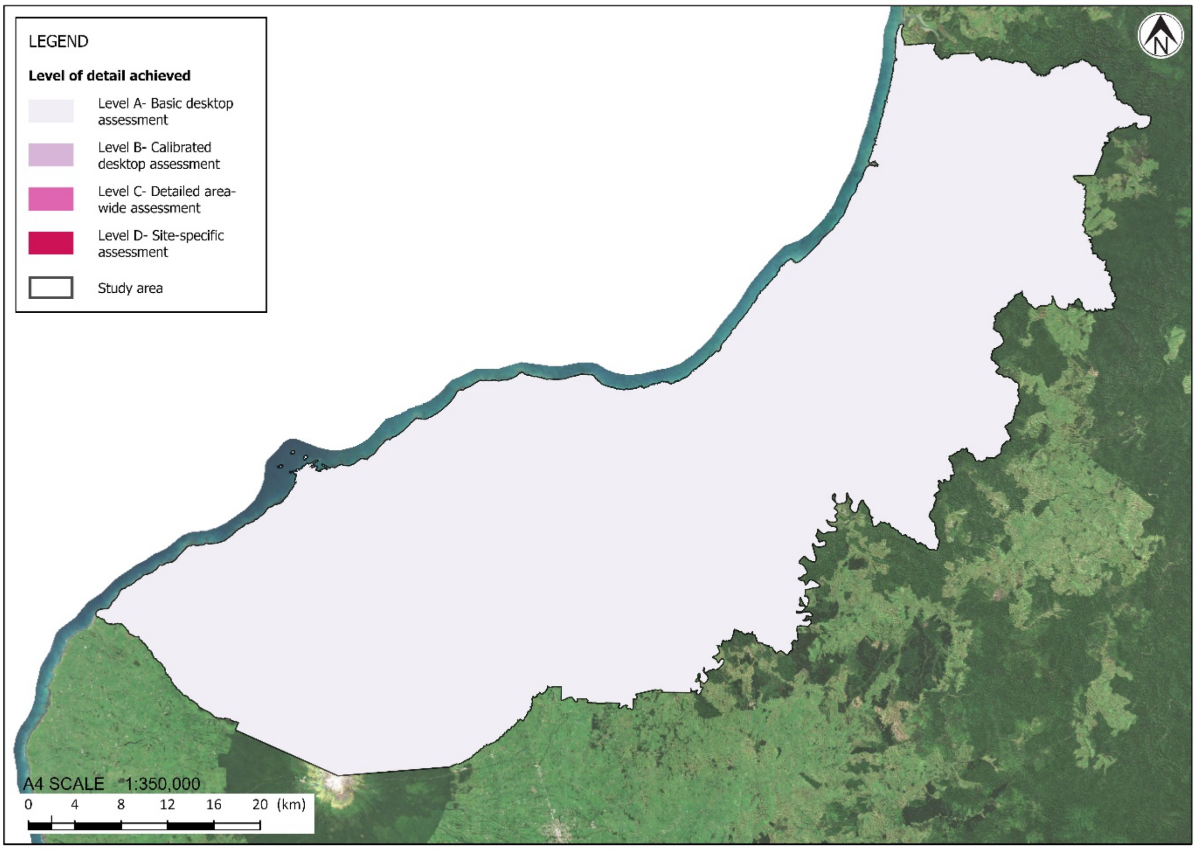


Figure 3.21: Level of detail achieved in this assessment (Level A throughout Study Area).

4 Risk analysis

The Section outlines how the base information was analysed to determine the liquefaction vulnerability of the land within the Study Area. The key tasks in this step involve the following:

- Choosing groundwater levels to support the analysis.
- Choosing earthquake scenarios to support the analysis.
- Identifying sub-areas of similar expected performance.
- Evaluating the expected degree of liquefaction-induced ground damage.
- Assessing the liquefaction vulnerability category against the performance criteria.

Each of these key tasks are discussed in further detail below.

4.1 Groundwater levels for analysis

As described in Section 3.2.4 and Section 3.3.4, within the Study Area there are relatively few in-situ groundwater data points available. This makes it challenging to establish precise groundwater levels to apply across a geomorphic terrain and to make allowances for seasonal groundwater level fluctuations. However, based on the analysis of the available data (refer Section 3.3.4), assumptions have been made for the purpose of qualitative screening, and engineering judgement has been applied to estimate the typical range of depth to groundwater in each of the geomorphic terrains as shown in Table 4.1. An accompanying evaluation of the potential effects of sea-level rise has also been made.

Table 4.1: Assumed depth to groundwater and potential influence of climate change in each geomorphic terrain

Geomorphic terrain	Assumed depth to groundwater (below existing ground level)	Potential influence of climate change on groundwater
Reclaimed Land	Less than 4 m	Likely to become shallower (located close to the coast so could be influenced by sea-level rise).
Coastal Dunes	Less than 4 m	Likely to become shallower (located close to the coast so could be influenced by sea-level rise).
Wetlands and Swamps	Less than 4 m	Undetermined (variable weather patterns).
Alluvial Plains and River Flats	Less than 4 m (however likely to be more variable than other alluvial terrains)	Areas of low elevation adjacent to coastal margins are likely to become shallower (sea-level rise). Areas of high elevation could be affected (variable weather patterns).
Coastal Terraces	Variable	Undetermined (variable weather patterns).
Lahars	Variable	Undetermined (variable weather patterns).
Hills, Ranges and Mountains	Ridge lines and elevated areas assumed to be more than 8 m depth. Sloping land assumed to be highly variable depending on antecedent rainfall and position on slope. Bottom of valleys and gullies assumed to be less than 4 m	Areas of low elevation adjacent to coastal margins are likely to become shallower. Areas of high elevation unlikely to be affected (sea-level rise and variable weather patterns).

4.2 Earthquake scenarios for analysis

The 500-year return period is the recommended minimum earthquake scenario for Level A and B studies (as per MBIE/MfE Guidance, 2017). The 500-year level of earthquake shaking (i.e., PGA and magnitude pairing) across New Plymouth District is well above the level of shaking required to trigger liquefaction in most susceptible soils. This is the primary consideration in this qualitative assessment of liquefaction vulnerability (at a Level A level of detail).

To understand the variability in seismic hazard across the Study Area we have considered three earthquake shaking scenarios (PGA) of 0.1 g, 0.2 g, and 0.3 g. The approximate equivalent return periods using the NZTA Bridge Manual Methodology (2018) and the associated Magnitude (M_{eff}) for each of these scenarios are shown Table 4.2. Based on this information and to inform this assessment, we have considered uniform shaking across the Study Area to provide a consistent basis for analysis.

Table 4.2: Earthquake shaking scenarios for analysis

Town	Earthquake Shaking Scenario (Return Period)			Effective Magnitude (M_{eff})
	1 (PGA = 0.1 g)	2 (PGA = 0.2 g)	3 (PGA = 0.3 g)	
New Plymouth	1 in 65 year	1 in 290 year	1 in 800 year	6.0
Waitara	1 in 70 year	1 in 310 year	1 in 865 year	6.0
Inglewood	1 in 70 year	1 in 310 year	1 in 865 year	6.1

4.3 Sub areas of similar expected performance

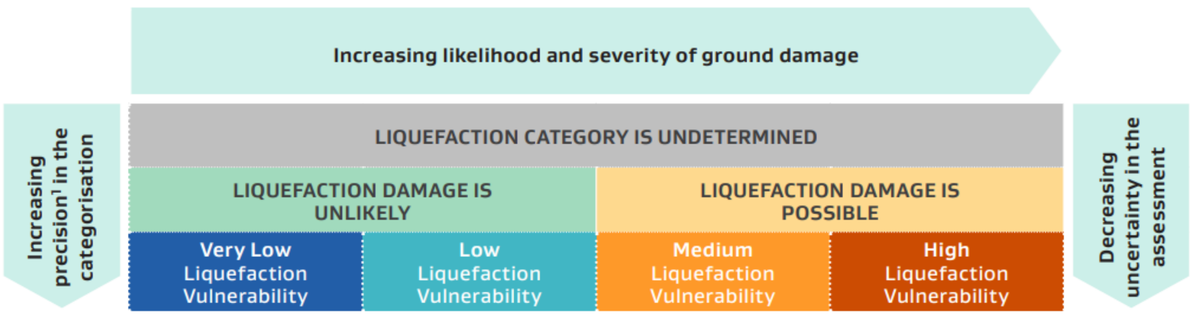
Sub-areas of similar expected performance have been delineated by grouping areas of land according to the following characteristics:

- **Geomorphic screening** – as described in Section 3.2.2, the Study Area has been mapped according to the dominant geomorphic processes shaping each region. This is used as the primary basis for evaluating the likely soil conditions within each sub-area of similar expected performance. Where available, selected geotechnical investigations have been utilised to inform the potential variability in soil conditions within a given terrain.
- **Lateral spread screening** – A high level screening of areas where lateral spreading is more likely to be possible has been undertaken by applying a buffer to the water bodies identified in the MfE River Flows dataset. This dataset provides a more accurate representation of the waterbodies within the Study Area when compared to other sources. For example, when comparing the PCE River Environment Classification dataset against aerial imagery of the Study Area, significant discrepancies of the mapped stream locations are observed.

4.4 Liquefaction vulnerability assessed against performance criteria

Using the available information, the liquefaction vulnerability of each sub-area has been assessed against the performance criteria. Each sub-area is then assigned one of the corresponding liquefaction vulnerability categories shown in Figure 4.1. The liquefaction vulnerability map of the Study Area is shown in Figure 4.2 and Figure B2 in Appendix B.

It is emphasised that the discussion in this report regarding vulnerability categories and options for further geotechnical assessment relate only to liquefaction hazard. There are various other natural hazards and geotechnical constraints which would also need to be considered as part of any future land development or building activities.



Note:

1 In this context the 'precision' of the categorisation means how explicitly the level of liquefaction vulnerability is described. The precision is different to the accuracy (ie trueness) of the categorisation.

Figure 4.1: Recommended liquefaction vulnerability categories for use in liquefaction assessment studies to inform planning and consulting processes – from MBIE/MfE Guidance (2017).

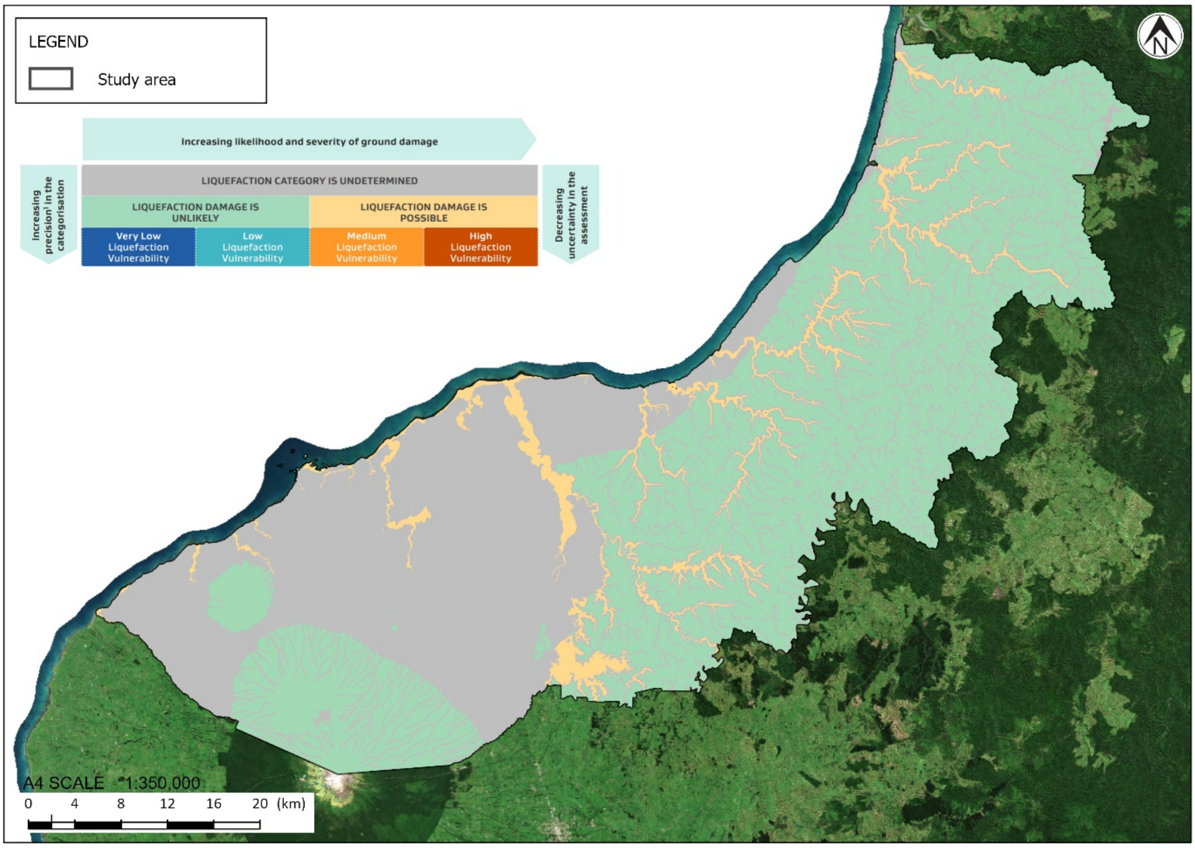


Figure 4.2: Liquefaction vulnerability classification assessed against performance criteria.

The following sections provide a summary of the assessment for each geomorphic terrain.

4.4.1 Reclamation Fill

Typically, reclaimed land is formed by placing uncompacted or poorly compacted soil within existing waterways or the sea. These deposits are considered particularly susceptible to liquefaction as they are often loose and saturated (refer to Section 2.3 of the MBIE/MfE Guidance (2017)).

Reclamation fills are typically highly variable in nature which means there is a high degree of uncertainty associated with their soil characteristics.

The Reclamation Fills mapped in the Study Area are low-lying and are adjacent to the coast. They are therefore likely to have shallow depth to groundwater (< 4 m) with the potential to be influenced by sea-level rise.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high (such as the outer edges of reclaimed areas).

Based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), "*…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*." Therefore, the Reclamation Fills have been classified as "Liquefaction Damage is Possible".

4.4.2 Coastal Dunes

The Coastal Dune terrain is likely to comprise thick (> 5 m), Holocene-age deposits of sands and silts (which are susceptible to liquefaction) and are unlikely to contain a significant proportion of plastic sediments (which are not susceptible to liquefaction). Coastal Dune sediments are typically deposited in higher energy environments, which means the soils are likely to be denser than those found in lower energy environments. The densest soils are typically found within dune deposits adjacent to the open coast.

Groundwater is also generally shallow (< 4 m) in this terrain because of the close proximity of the coastal margin and the low elevation. The proximity to coastal margins means that the depth to groundwater is likely to become shallower with sea-level rise. For these reasons, these terrains are identified as landforms that are commonly susceptible to liquefaction in Section 2.3 of the MBIE/MfE Guidance (2017).

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high.

Based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), *"…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*". Therefore, the mapped Coastal Dunes Terrain has been classified as "Liquefaction Damage is Possible."

4.4.3 Alluvial Plains and River Flats

Typically, soils found in this terrain are late Pleistocene to Holocene-aged and deposited in low energy environments forming loose and soft layers. The depth to groundwater is also likely to be shallow (< 4 m) within this terrain because it is generally associated with active and historic river systems. The MBIE/MfE Guidance (2017) typically associates these alluvial terrains as being susceptible to liquefaction.

The characteristics of the soils comprising this terrain are highly variable in nature and vary spatially across the landscape. Alluvial sediments typically range from non-plastic sands and silts to plastic clays and silts. These soils typically contain soil layers that are susceptible to liquefaction.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high (such as riverbanks, stop banks, streams, and drainage ditches).

Based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), "*…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.*" Therefore, the mapped Alluvial Plains and River Flats terrain have been classified as "Liquefaction Damage is Possible".

4.4.4 Wetlands and Swamps

The Wetlands and Swamps terrain is likely to comprise thick (> 5 m), Holocene-aged deposits of plastic silts and clays, non-plastic sands, and large amounts of organic material. These sediments have typically accumulated in a low energy environment. There is some uncertainty associated with the liquefaction susceptibility of these soils due to the large amounts of organic material that are likely to be present. However, Section 2.3 of the MBIE/MfE Guidelines identify swamp landforms as being commonly susceptible to liquefaction.

Groundwater is also likely to be shallow (< 4 m) in this terrain because of the saturated conditions required for the terrain to develop.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high. However, as described above, there is currently significant uncertainty as to whether liquefaction-susceptible soils are present in this terrain.

Due to the uncertainty associated with whether liquefaction-susceptible soils are present, there is currently insufficient information to characterise the expected land performance. Therefore, based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), in this terrain “Liquefaction Category is Undetermined” has been assigned at this time.

4.4.5 Coastal Terraces

This terrain comprises elevated land that is predominantly mid to late Pleistocene in age and includes sediments deposited in both high energy and low energy coastal environments, which have both plastic and non-plastic behaviours. The older age of these sediments means that there is the potential for ageing effects to impact on liquefaction triggering as described in Section 3.3.2. Furthermore, some younger marginal marine swamp and dune deposits also overly this terrain in some areas of the district forming surficial swales and hummocks on the older marine and alluvial terraces. As a result, there is significant uncertainty associated with the liquefaction vulnerability of this terrain

Due to the higher elevation of this terrain, the depth to groundwater is, on average, likely to be deeper (> 4 m) than the groundwater level in the previously described alluvial terrains. However, our analysis of available groundwater data indicates that there are some locations within this terrain where groundwater is shallower (< 4 m). These areas of shallow groundwater are most likely associated with gullies and streams that intersect the Coastal Terraces. Note that these gullies are small and difficult to differentiate based on the information available and therefore many of the smaller gully features have not been mapped at the target scale for the geomorphic mapping (1:25,000). This also introduces a significant source of uncertainty into the assessment of this terrain.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high (such as terrace edges and stream banks). However, as described above, there is currently significant uncertainty about the potential for ageing effects to impact on liquefaction triggering, and the depth to groundwater in the Coastal Terraces.

Due to the uncertainty associated with the ground conditions and the depth to groundwater, there is currently insufficient information to characterise the expected land performance. Therefore, based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), in this terrain “Liquefaction Category is Undetermined” has been assigned at this time.

As discussed in Section 3.3.7, in many of these areas the nature of the expected ground conditions suggests that if more detailed site-specific assessment was undertaken, it is likely that a category of "Low Liquefaction Vulnerability" could be assigned. For parts of this terrain, undertaking simple shallow hand auger boreholes to confirm soil properties and/or groundwater depths may be all that is required to determine which liquefaction vulnerability category applies[3].

4.4.6 Lahars

This terrain covers a large proportion of the Study Area and represents the lahar deposits associated with Taranaki Maunga. The mapped geological units comprising this terrain have been described as mid Pliocene to Holocene-aged bedded sands and conglomerates, laharic breccias, and volcaniclastic materials. The terrain also includes the surficial sediments overlying these geological deposits, which, based on available geotechnical investigations and aerial images, comprise volcanic ash, alluvial deposits and minor wetlands and swamps. These surficial sediments are likely to be susceptible to liquefaction. As discussed in Section 3.3.2, the spatial extent of the surficial sediments overlying the Lahar deposits is uncertain, and there is also some uncertainty associated with the liquefaction susceptibility of the Lahar deposits themselves.

Due to the higher elevation of this terrain, the depth to groundwater is, on average, likely to be deeper (> 4 m). However, our analysis of available groundwater data indicates that there are some locations within this terrain where groundwater is shallower (< 4 m). These areas of shallow groundwater are most likely associated with gullies and streams that intersect the Coastal Terraces. Note that these gullies are small and difficult to differentiate based on the information available and therefore many of the smaller gully features have not been mapped at the target scale for the geomorphic mapping (1:25,000). This also introduces a significant source of uncertainty into the assessment of this terrain.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 200 m of free faces more than 2 m high (such as gullies and stream banks). However, as described above, there is currently significant uncertainty about the liquefaction susceptibility and the groundwater depth of this terrain.

Due to the uncertainty associated with the ground conditions and the depth to groundwater, there is currently insufficient information to characterise the expected land performance. Therefore, based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), in this terrain "Liquefaction Category is Undetermined" has been assigned at this time.

As discussed in Section 3.3.7, in many of these areas the nature of the expected ground conditions suggests that if more detailed site-specific assessment was undertaken, it is likely that a category of "Low Liquefaction Vulnerability" could be assigned. For parts of this terrain, undertaking simple shallow hand auger boreholes to confirm soil properties and/or groundwater depths may be all that is required to determine which liquefaction vulnerability category applies[3].

[3] Note that these comments only apply to site-specific studies undertaken for the purposes of satisfying Resource and Building Consent requirements. We are not suggesting that simple shallow hand auger boreholes would enable easy refinement of the liquefaction vulnerability category at a regional level.

4.4.7 Hills, Ranges and Mountains

This terrain comprises elevated landforms characterised by highly dissected hills with many gullies and valleys, hills that are more rolling in nature, and steep volcanic mountains. These land features ultimately depend on the underlying geological units (which are typically Neogene aged). The ground conditions vary from exposed rock at the ground surface to thick deposits of residual soils.

Based on the available information, it is likely that the residual soils within this terrain predominantly comprise plastic soils and rock that are not considered to be susceptible to liquefaction. However, although this terrain comprises approximately 61% of the Study Area, there are relatively few geotechnical investigations available to calibrate this assumption. Furthermore, minor valley systems within this terrain may contain alluvial deposits that may not have been captured within the geomorphic map (due to the 1:25,000 target scale of the geomorphic map). This introduces additional uncertainty into the assessment.

The depth to groundwater is highly variable across this geomorphic terrain. As described in Section 4.1 and Section 4.3, it has been categorised as follows:

- In the elevated areas the depth to groundwater is likely to be more than 8 m.
- In the minor valley systems, the depth to groundwater is likely to be highly variable depending on antecedent rainfall conditions and the position of the slope.

In this terrain the potential for lateral spreading is consistent with the definition provided in the MBIE/MfE Guidelines (2017), that is in the presence of liquefaction-susceptible soils, lateral spreading is more likely to be possible in areas within 50 m of free faces more than 2 m high (such as riverbanks). This 50 m buffer zone has been applied to the mapped streams within this terrain to capture the incised valley floors where lateral spreading could occur if liquefaction-susceptible soils are present. However, as described above there is currently significant uncertainty to whether liquefaction-susceptible soils are present in the Hills, Ranges and Mountains terrain.

As a result, in the minor valley systems, due to the uncertainty associated with the presence/absence of liquefaction-susceptible soils and the depth to groundwater, there is currently insufficient information to characterise the expected land performance. Therefore, in these locations this terrain has been classified as "Liquefaction Category Undetermined" at this time.

In regard to the hilltops, ridges and elevated areas of this terrain, based on engineering judgement and in accordance with Section 4.5.2 of the MBIE/MfE Guidelines (2017), *"…there is a probability of more than 85 percent that liquefaction-induced ground damage will be none to minor for 500-year shaking."* Therefore, these areas are classified as "Liquefaction Damage is Unlikely".

5 Discussion and recommendations

T+T has completed a Level A – Basic Desktop Assessment to assess the liquefaction vulnerability of New Plymouth District in accordance with the MBIE/MfE Guidelines (2017). The key conclusions and recommendations are:

- The land within the Study Area has been classified into one of three liquefaction vulnerability categories: "Liquefaction Category is Undetermined", "Liquefaction Damage is Unlikely" or "Liquefaction Damage is Possible". The currently available information does not support further classification of the land into the other more precise categories of "Very Low", "Low", "Medium" and "High".

  This degree of liquefaction vulnerability categorisation precision is consistent with a regional scale assessment (such as this) undertaken to a Level A level of detail.
- The liquefaction outputs of this assessment provide a regional base layer which will be useful for Resource Management Act (RMA) applications within New Plymouth District. In some cases, it is likely that further liquefaction vulnerability assessments will need to be completed to a higher level of detail to satisfy RMA requirements.
- NPDC can also use the outputs of the assessment to inform evaluation of building consent applications. To assess whether land is "prone to liquefaction or lateral spreading" within the context of the upcoming Building Code amendments we recommend the following:
  - Land that has been categorised as "Liquefaction Damage is Possible" is considered to be "prone to liquefaction or lateral spreading" and therefore does not meet the definition of "Good Ground" as outlined in the Building Code amendments.
  - Land that has been categorised as "Liquefaction Damage is Unlikely" is considered to be "not prone to liquefaction or lateral spreading" within the context of the definition of "Good Ground" as outlined in the Building Code amendments.
  - For land that has been categorised as "Liquefaction Category is Undetermined" as part of this assessment, there is currently insufficient information to determine whether it is "prone to liquefaction or lateral spreading" within the context of the definition of "Good Ground" as outlined in the Building Code amendments.
- As part of the liquefaction vulnerability assessment process, we have developed a geomorphic map of the Study Area that categorises the land into the following 7 terrains: Reclaimed Land, Coastal Dunes, Wetland and Swamps, Alluvial Plains and River Flats, Lahars, Coastal Terraces and Hills, Ranges and Mountains.

  This map has been developed at a scale of approximately 1:25,000 (i.e., high-level) for the specific purpose of categorising liquefaction vulnerability, with a focus on areas of existing and currently proposed future residential development. The current geomorphic map is not intended for any other purpose, however there may be future opportunities to refine this mapping to help inform other applications (e.g., slope stability mapping).

NPDC may choose to improve the resolution of the liquefaction vulnerability output to promote additional uses of the liquefaction vulnerability information. The two main areas where additional base information would be required to support more detailed studies are geotechnical investigations and groundwater information. Potential steps to improve the available information are:

- **Geotechnical investigations:** A key source of uncertainty in this liquefaction assessment is the lack of geotechnical investigation data throughout much of the Study Area. This information is important for both the assessment of liquefaction vulnerability and for other future applications.

  To help make more geotechnical investigation data available, NPDC may wish to consider:

  - Identification of geotechnical investigations from historical projects and uploading of these investigations onto the NZGD.
  - Advocating uploading supporting geotechnical investigations onto the NZGD as part of the process of evaluating resource and building consent applications. Local engineering and scientific practitioners may need to be educated about why this sharing of information is important.
  - Engagement of suitably competent geo-professionals to undertake geotechnical investigations within given areas where more information about the ground conditions is required (e.g., areas where a Level B, C or D level of detail is targeted). Table 3.5, 3.6 and 3.7 in the MBIE/MfE Guidelines (2017) provide additional information relating to higher level of detail studies. For example, if a land use or subdivision consent application was proposed for urban residential land that had been categorised as “Liquefaction Damage is Possible”, it would be likely that a Level B or Level C level of detail assessment would be required for the consent application.
- **Groundwater information**: A key source of uncertainty in this liquefaction vulnerability assessment is the limited amount of groundwater information in the Study Area. While not critical for this Level A assessment, detailed information about shallow groundwater levels becomes increasingly important when targeting higher level of detail liquefaction vulnerability studies. It also provides a valuable data source for other purposes such as asset management and this information is likely to be particularly useful in areas where the effects of sea-level rise may influence groundwater conditions.

  To help facilitate the collection of more detailed groundwater data within the Study Area, NPDC could consider installing a network of piezometers to monitor groundwater level fluctuations over time. This data could also be used to develop depth to groundwater surface models.

The outputs of this assessment have been provided in a geospatial format which can be displayed and viewed on a GIS platform.

6 Applicability

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

Recommendations and opinions in this report are based on data from individual geotechnical investigation locations. The nature and continuity of subsoil away from these locations are inferred and it must be appreciated that the actual conditions could vary from the assumed model.

This assessment has been made at a broad scale across the defined Study Area and is intended to describe the typical range of liquefaction vulnerability across areas of similar ground conditions in an approximate way only. It is not intended to precisely describe liquefaction vulnerability at individual property scale. This information is general in nature, and more detailed site-specific liquefaction assessment may be required for some purposes (e.g., for design of building foundations).

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Appendix A: Risk identification

- **Figure A1 – Target level of detail**
- **Figure A2 – Ground surface elevation**
- **Figure A3 – Geomorphons produced from topographical screening tool**
- **Table A1 – Geomorphic terrain descriptions**
- **Figure A4 – Geomorphic map of Study Area**
- **Figure A5 – Geotechnical investigations available on NZGD within Study Area**
- **Figure A6 – Shallow groundwater monitoring locations within Study Area**
- **Table A2 – NZTA (2018) PGA calculations for Study Area**

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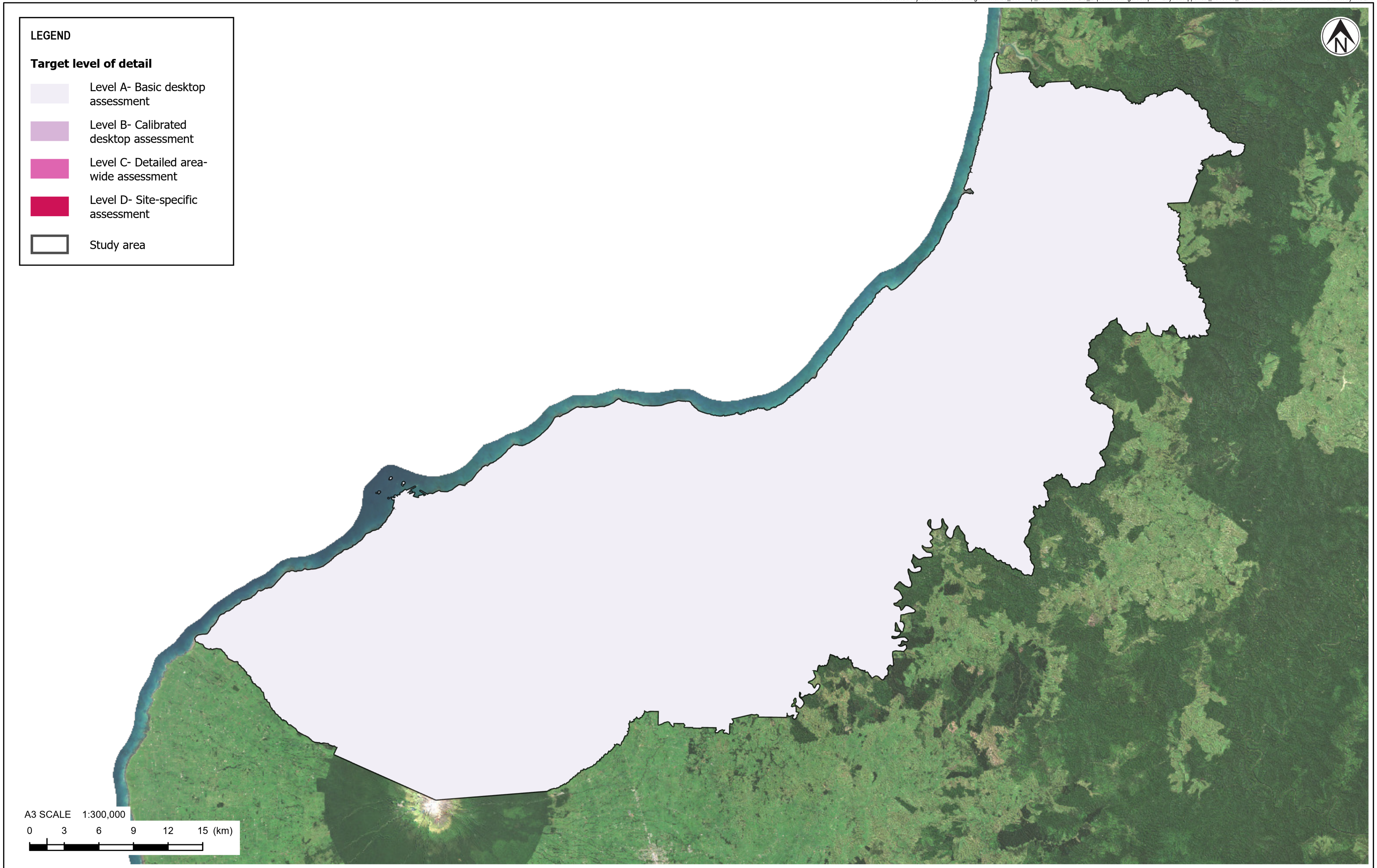

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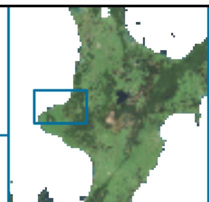
NOTES:

1. Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.
2. Map indicates the level of detail in the liquefaction assessment that will be targeted. Refer to Table 3.3 of the MBIE Guidelines (2017) for further information about the detail in the liquefaction assessment.

REV	DESCRIPTION	GIS	CHK	DATE
0.1	Draft version	MOLI	JORB	14/09/21
1.0	Final version 1.0	MOLI	JORB	15/10/21



LOCATION PLAN

PROJECT No.	1016765.000	
DESIGNED	JMB	OCT.21
DRAWN	MOLI	OCT.21
CHECKED	JICR	OCT.21
APPROVED		OCT.21 (DATE)

CLIENT NEW PLYMOUTH DISTRICT COUNCIL

PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT

TITLE TARGET LEVEL OF DETAIL IN THE LIQUEFACTION ASSESSMENT

SCALE (A3) 1:300,000 FIG No. FIGURE A1 REV 1.0

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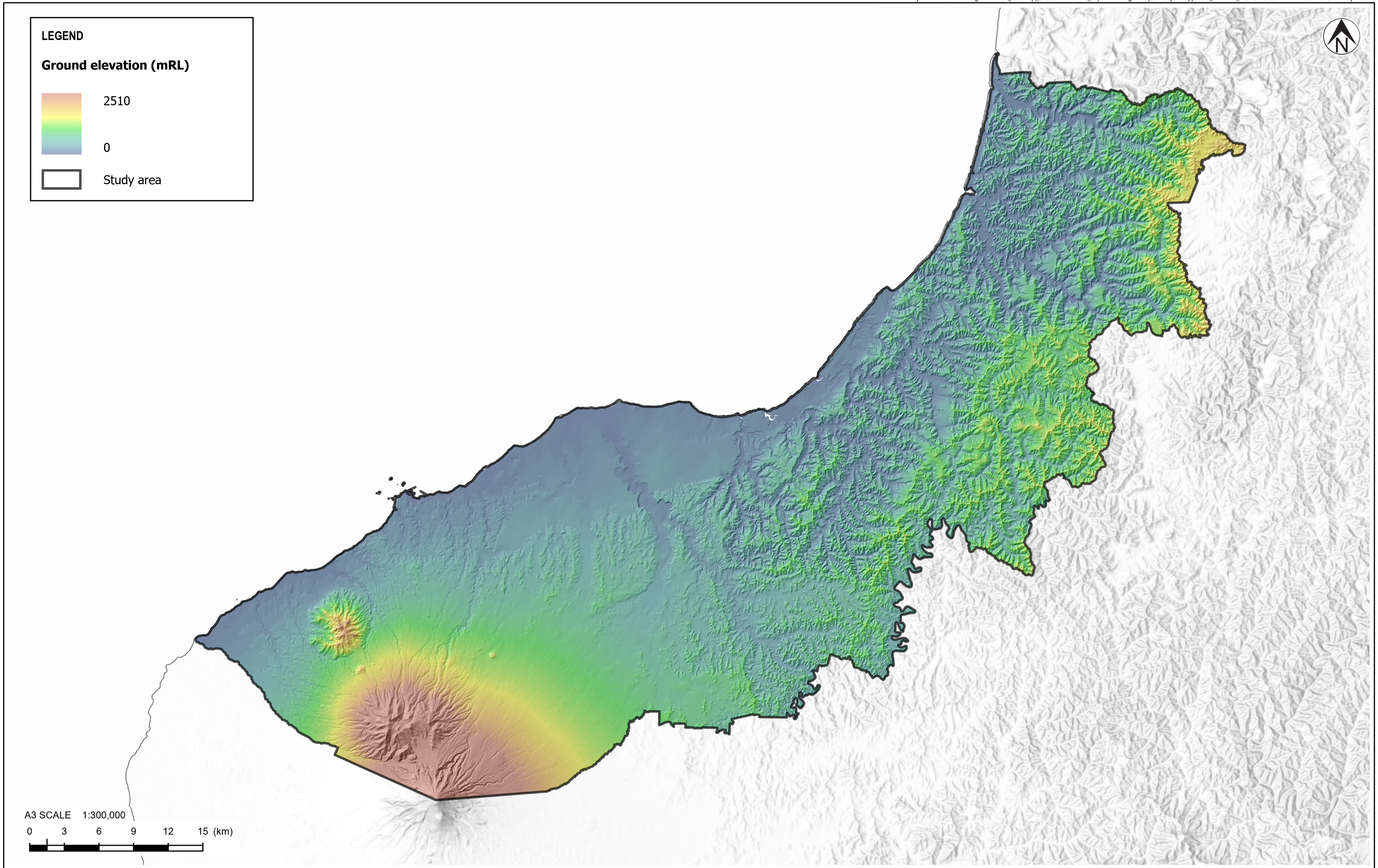

NOTES:
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2. Elevation sourced from LINZ Data Service and derived from the LINZ Topo50 20 m contours.

REV	DESCRIPTION	GIS	CHK	DATE
0.1	Draft version	MOLI	JORB	14/09/21
1.0	Final version 1.0	MOLI	JORB	15/10/21

LOCATION PLAN

PROJECT No.	1016765.000	
DESIGNED	JMB	OCT.21
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APPROVED		OCT.21

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CLIENT **NEW PLYMOUTH DISTRICT COUNCIL**
PROJECT **LIQUEFACTION VULNERABILITY ASSESSMENT**
TITLE GROUND SURFACE ELEVATION (2012 8 M DEM DERIVED FROM 20 M CONTOURS)
SCALE (A3) 1:300,000 FIG No. FIGURE A2 REV 1.0

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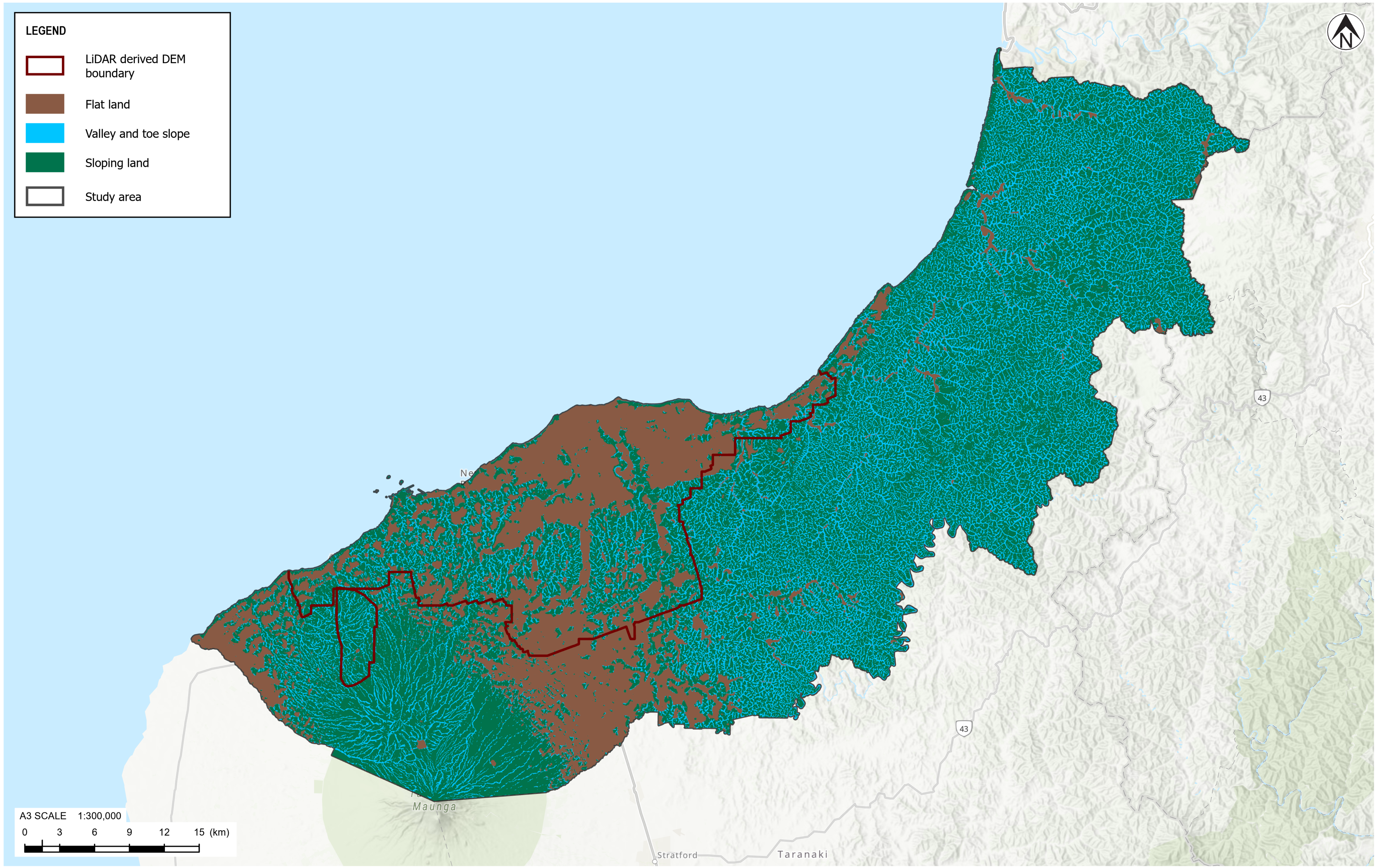

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NOTES:

1. Basemap sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand license.
2. Geomorphons produced from 2012 20 m contour derived DEM.
3. Geomorphons produced from 2019 1 m LiDAR derived DEM.

REV	DESCRIPTION	GIS	CHK	DATE
0.1	Draft version	MOLI	JORB	14/09/21
1.0	Final version 1.0	MOLI	JORB	15/10/21

LOCATION PLAN

PROJECT No.	1016765.000	
DESIGNED	JMB	OCT.21
DRAWN	MOLI	OCT.21
CHECKED	JICR	OCT.21
APPROVED		OCT.21

CLIENT **NEW PLYMOUTH DISTRICT COUNCIL**

PROJECT **LIQUEFACTION VULNERABILITY ASSESSMENT**

TITLE GEOMORPHONS PRODUCED FROM TOPOGRAPHICAL SCREENING TOOL

SCALE (A3) 1:300,000 FIG No. FIGURE A3 REV 1.0

Appendix A Table A1: Description of geomorphic terrains

Geomorphic Terrains	Terrain Description	Geological Age	Typical Groundwater Depth	Type Location	Liquefaction Vulnerability Classification
Coastal Dunes	Dune systems associated with the present day shoreline. Comprise sand dunes which are, prior to development, actively subject to windblown and coastal processes. These dunes include the current shoreline. Difficult to map accurately due to anthropogenic land use changes.	Holocene	< 4 m below ground level	Waitara Beach, Airport area	Possible
Wetlands and Swamps	Represents significant wetland and swamp deposits visible at 1:25,000 scale. Generally fine grained, cohesive organic soils.	Holocene	< 4 m below ground level	Ahukawakawa Swamp & North-East corner NP District.	Undetermined
Alluvial Plains and River Flats	This terrain represents the sediments deposited from the active and historic river systems within the district. The surface of this terrain typically increases in elevation in a landward direction from the coast.	Middle Pleistocene to Holocene	< 4 m below ground level	Mohakatino River Valley, Mokau River Valley, Tongaporutu River, Waitara River	Possible
Lahars	Major terrain in district. Reprents debris flows and lahars sourced from Mount Taranaki. GNS defines as "Laharic breccia of andesite cobbles overlain in places by well sorted dune-bedded tephric sand". GI provide evidence that suggests that the sediments comprising these terrains are highly variable. The land surface is undulating with crest and trough structures - allows fine grained sediments to accumulate in places.	Middle Pleistocene to Holocene	Variable	Inglewood	Undetermined
Coastal Terraces	Terraces comprising shallow marine conglomerate, shellbeds, dune sands and peat. Elevated above active coastline and represent historic shorelines in district. In some cases this terrain overlies the Lahar terrain. Some younger sand dune deposits are located on the surface of this terrain.	Middle Pleistocene - Late Pleistocene	Variable	Awakino, Mokau, SH3 Between Mokau and Tongaporutu	Undetermined
Hills, Ranges and Mountains	Terrain characterised by elevated topography which is often capped with volcanic ash and residual soils. This terrain typically sits above the coastal terraces and Lahars. Covers a large portion of the project area. Represents the oldest terrain in the project area.	Neogene	> 4 m below ground level	Mount Taranaki, Mount Messenger, Mt Roa, Mt Tawariki, Mt Tiger	Unlikely
Reclaimation Fill	Uncontrolled and engineered fill, reworked natural soils or construction waste, inferred to be > 3m thick.	Holocene	< 4 m below ground level	Port Taranaki	Possible

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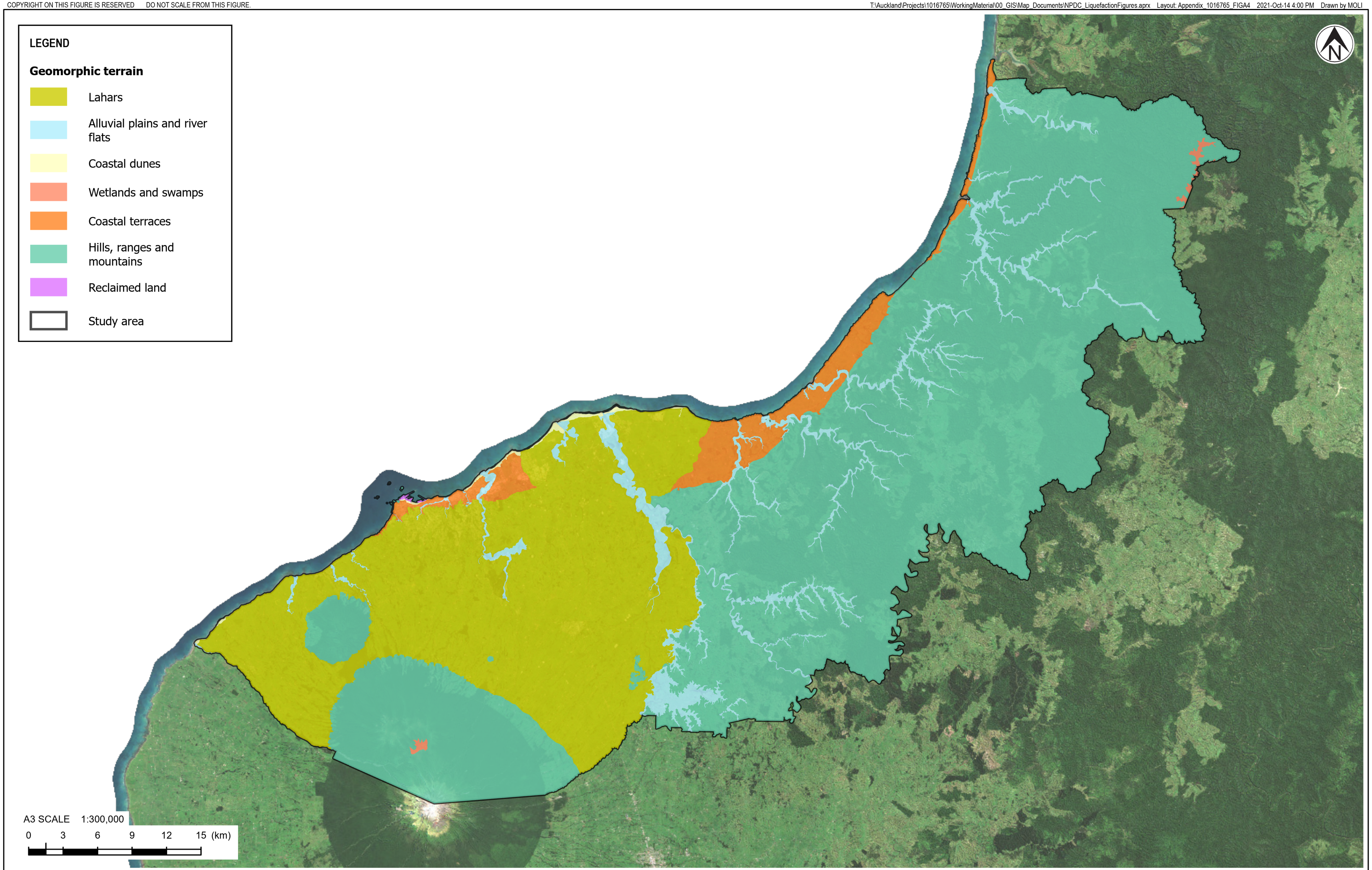

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0.1	Draft version	MOLI	JORB	14/09/21
1.0	Final version 1.0	MOLI	JORB	15/10/21

LOCATION PLAN

PROJECT No.	1016765.000	
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DRAWN	MOLI	OCT.21
CHECKED	JICR	OCT.21
APPROVED		OCT.21

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PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT
TITLE GEOMORPHIC MAP OF STUDY AREA

SCALE (A3) 1:300,000 FIG No. FIGURE A4 REV 1.0

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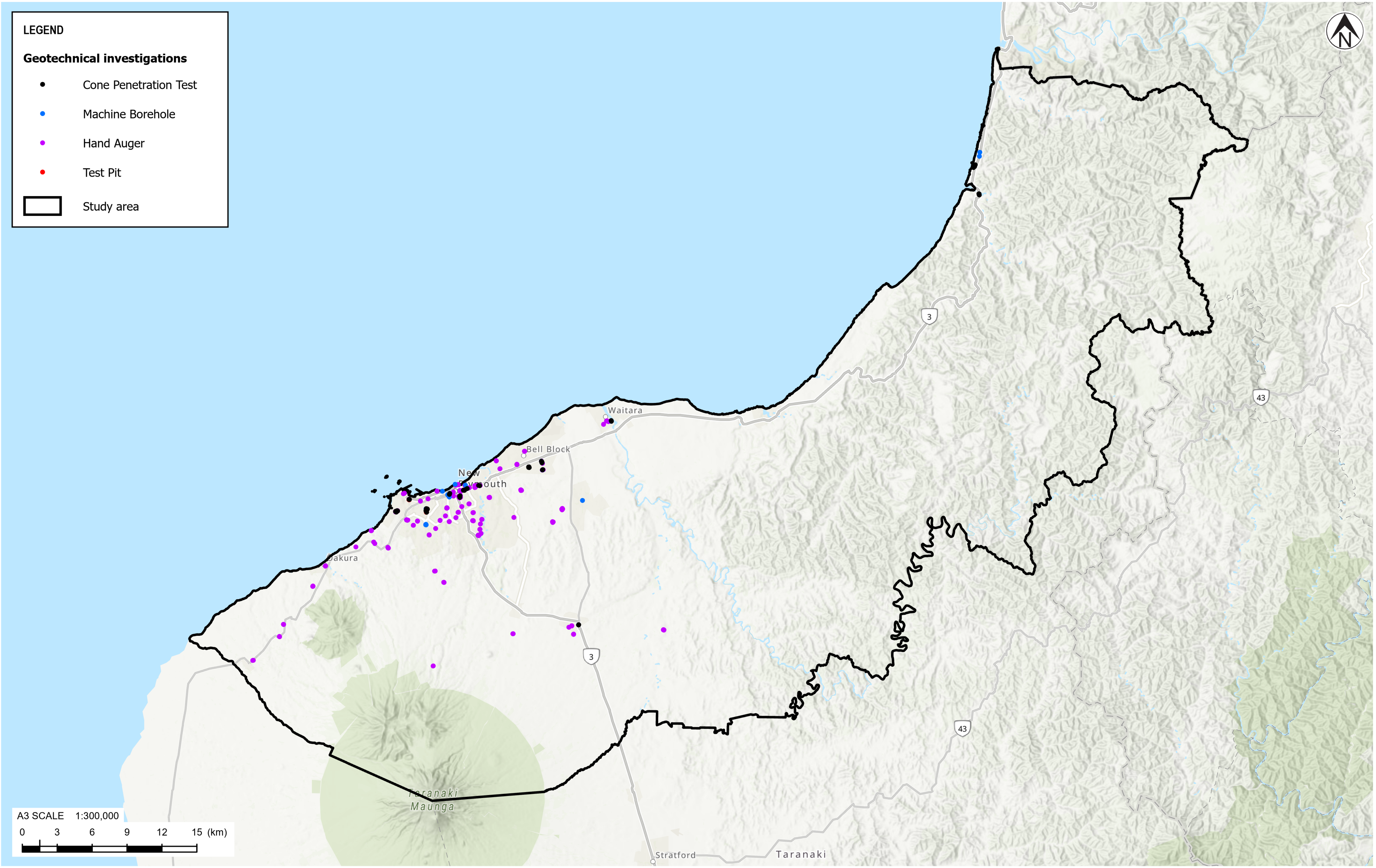

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2. Geotechnical investigations sourced from the New Zealand Geotechnical Database (NZGD).

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0.1	Draft version	MOLI	JORB	14/09/21
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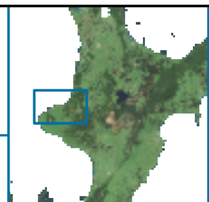

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PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT

TITLE GEOTECHNICAL INVESTIGATIONS AVAILABLE ON NZGD WITHIN STUDY AREA

SCALE (A3) 1:300,000 FIG No. FIGURE A5 REV 0

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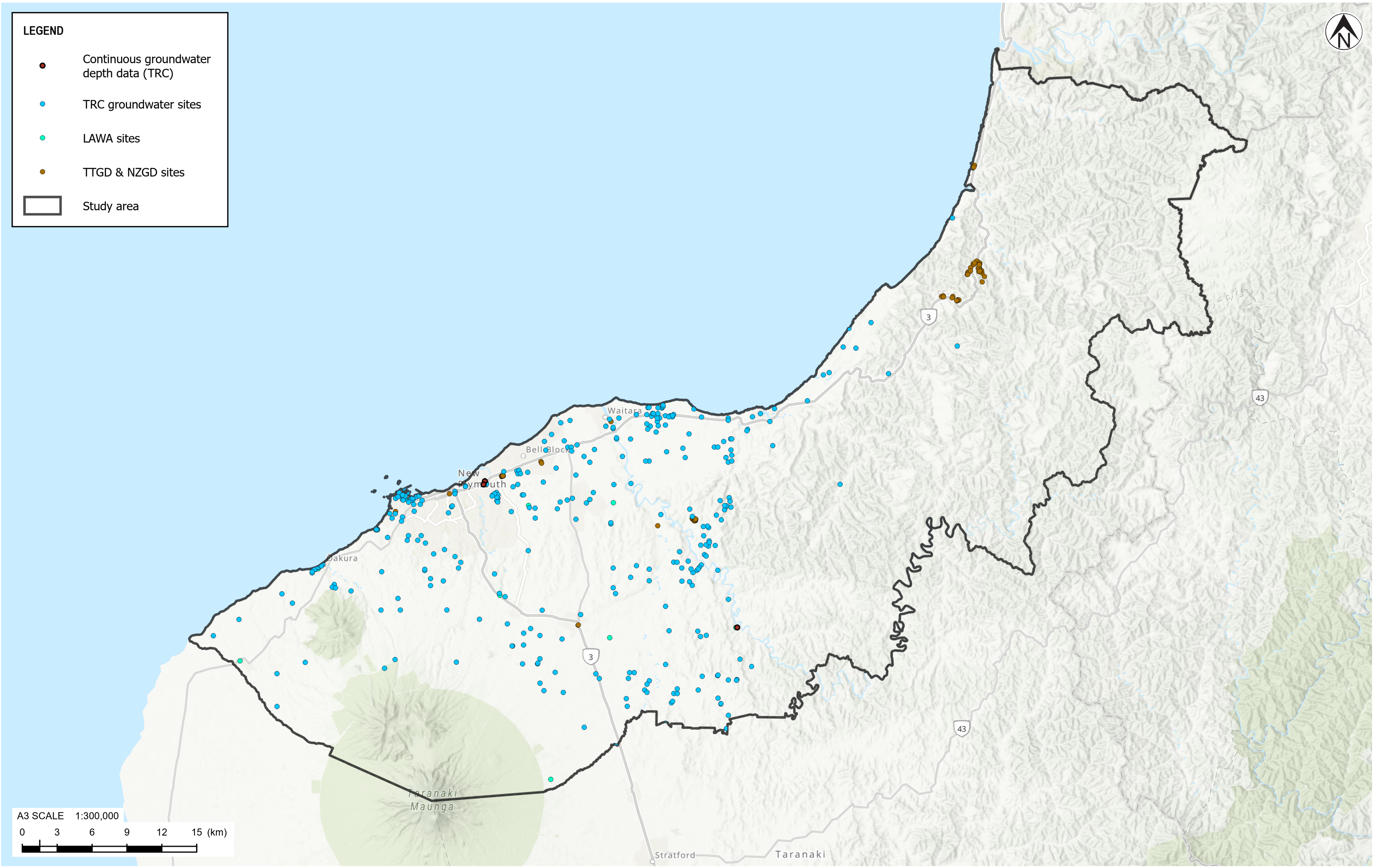

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PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT

TITLE SHALLOW GROUNDWATER MONITORING LOCATIONS

SCALE (A3) 1:300,000 FIG No. FIGURE A6 REV 0.1

Appendix A Table A2: Estimated Peak Ground Accelerations (PGA) and Magnitude (Meff) for various return period earthquakes for towns within the New Plymouth District based on the NZTA Bridge Manual Methodology (NZTA, 2018).

Town/ City	C0,1000		Effective magnitude for design return period (years)		PGA (g) 1/25			PGA (g) 1/50			PGA (g) 1/100			PGA (g) 1/250			PGA (g) 1/500			PGA (g) 1/1000			PGA (g) 1/2500		
	Class A/B rock	Class D&E deep/soft soil	500 - 2500	50 - 100	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E	Class A & Class B	Class C	Class D & Class E
New Plymouth	0.28	0.33	6.0	6.0	0.05	0.07	0.06	0.08	0.10	0.09	0.11	0.14	0.13	0.16	0.21	0.19	0.22	0.29	0.25	0.28	0.37	0.33	0.39	0.52	0.46
Waitara	0.27	0.32	6.0	6.0	0.05	0.07	0.06	0.07	0.10	0.09	0.10	0.14	0.12	0.16	0.21	0.18	0.21	0.28	0.25	0.27	0.36	0.32	0.37	0.50	0.44
Inglewood	0.27	0.32	6.1	6.1	0.05	0.07	0.06	0.07	0.10	0.09	0.10	0.14	0.12	0.16	0.21	0.18	0.21	0.28	0.25	0.27	0.36	0.32	0.37	0.50	0.44

Appendix B: Risk analysis

- **Figure B1 – Liquefaction vulnerability categories for Study Area**

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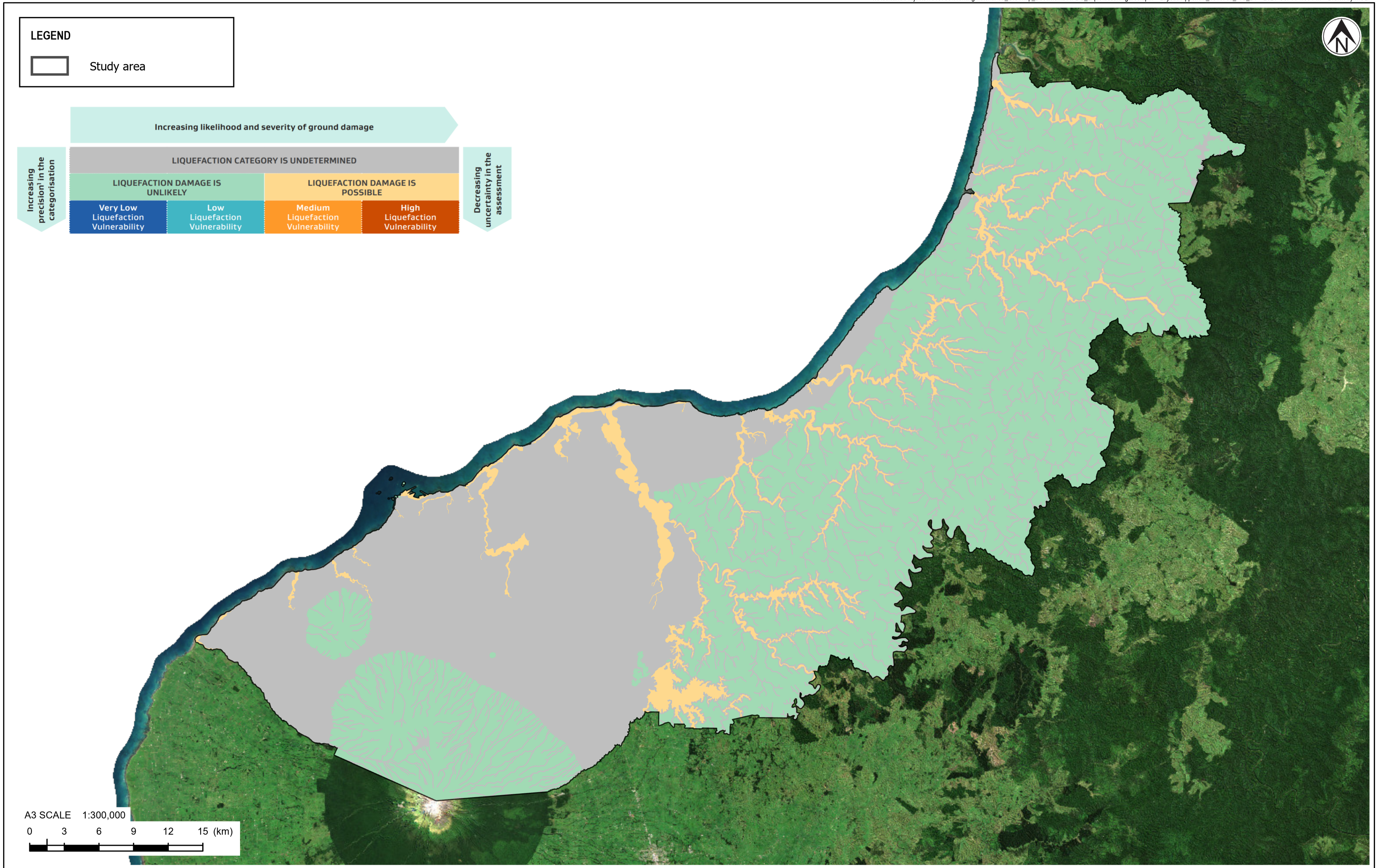

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PROJECT LIQUEFACTION VULNERABILITY ASSESSMENT

TITLE LIQUEFACTION VULNERABILITY CATEGORIES

SCALE (A3) 1:300,000 FIG No. FIGURE B1 REV 1.0