



HAZARD ASSESSMENT

Regional Liquefaction Vulnerability Assessment – Far North District

Prepared for

Far North District Council

20/01/2023

Report Information Summary

Job no.	J15221
Report Author	Ben Perry, Dan Simmonds, Logan Ashmore
Report Reviewer	Grant Murray
Version No.	2
Status	Final
Date	20/01/2023

Version No.	Date	Description
1	21/12/2022	Final document issued.
2	20/01/2023	Minor change to stream line width on map.

Document Acceptance

Action	Name	Signed	Date
Author	Ben Perry		20/01/2023
Author	Dan Simmonds		20/01/2023
Author	Logan Ashmore		20/01/2023
Reviewer	James Grant Murray		20/01/2023



Vision Consulting Engineers Ltd
Level 1, 62 Kerikeri Road
Kerikeri 0230

Limitations

This report has been prepared by Vision Consulting Engineers Limited (VISION) based on the scope of our engagement. It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. VISION does not accept any liability or responsibility in relation to the use of this report contrary to the above, or to any person other than the Client. Any use or reliance by a third party is at that party's own risk. Where information has been supplied by the Client or obtained from other external sources, it has been assumed that it is accurate, without independent verification, unless otherwise indicated. No liability or responsibility is accepted by VISION for any errors or omissions to the extent that they arise from inaccurate information provided by the Client or any external source.

The map outputs of this report were developed with input from many sources, along with years of experience. Every effort has been made to ensure the accuracy of the GIS database, but it is not feasible to completely verify all of the original input data. The maps generated are based on data available as of the date of publication. Future changes to the mapped geology, topography, or other data inputs may render this map locally inaccurate. Because of these limitations the map outputs are intended for broad scale purposes only and cannot replace site-specific investigations. However, the map outputs can serve as a useful tool for understanding the vulnerability of the district and as a starting point for future detailed site-specific investigations and mapping. Please contact the Far North District Council if errors and/or omissions are found so that they can be corrected in future versions of this report and its outputs.



Vision Consulting Engineers Ltd
Level 1, 62 Kerikeri Road
Kerikeri 0230

Contents

Section

Page

Acronyms and Abbreviations.....	vi
1 Introduction and Context	1
1.1 Prior Studies.....	2
2 Risk Identification	2
2.1 Target Level of Detail and Scope	2
2.2 Base information review.....	3
2.2.1 Ground surface levels	3
2.2.2 Geology and geomorphology	4
2.2.3 Geotechnical investigations.....	6
2.2.4 Groundwater.....	6
2.2.5 Seismic hazard	7
2.2.6 Historic observations of liquefaction.....	10
2.3 Uncertainty assessment.....	10
2.3.1 Ground surface levels	10
2.3.2 Geology and geomorphology	11
2.3.3 Geotechnical investigations.....	11
2.3.4 Groundwater.....	11
2.3.5 Seismic hazard	11
2.3.6 Historic observations of liquefaction.....	11
2.3.7 Expected degree of liquefaction-induced ground damage	12
2.3.8 Liquefaction vulnerability category assessed against performance criteria	12
2.4 Level of detail supported by the available information.....	13
3 Risk analysis	14
3.1 Groundwater levels for analysis	14
3.2 Earthquake scenarios for analysis.....	14
3.3 Sub areas of similar expected performance	15
3.4 Liquefaction vulnerability category assessed against performance criteria	15
3.4.1 Category Classification Discussion.....	16
4 Conclusion and recommendations.....	17
References.....	19



Appendix

Appendix A Mapping Output

Table(s)

Table 1. Landforms

Table 2. Notable Earthquakes

Table 3. Annual Reoccurrence Interval - Peak Ground Accelerations

Table 4. Assumed Groundwater Depths for Analysis

Table 5. Earthquake scenarios for analysis

Figure(s)

Figure 1. Key elements for liquefaction to occur

Figure 2. Types of damage associated with liquefaction

Figure 3. Map of the Level A study area

Figure 4. Topography of the Far North District

Figure 5 – Geotechnical Investigations available on the NZGD as of October 2022.

Figure 6 – Groundwater borehole locations and mapped water bodies.

Figure 7 – Location and magnitude of recorded earthquakes in the Far North District.

Figure 8. Inactive and Closest Active Faults

Figure 9. Liquefaction Vulnerability Category

Figure 10. Level of Detail Supported Map

Figure 11. Liquefaction Vulnerability Category Map



Acronyms and Abbreviations

ARI	Annual Reoccurrence Interval
DEM	Digital Elevation Model
FNDC	Far north District Council
GNS	Institute of Geological & Nuclear Sciences Limited
LiDAR	Light Detection And Ranging
km	kilometers
LINZ	Land Information New Zealand
m	metres
M	(earthquake) Magnitude
MBIE	Ministry of Business Innovation and Employment
MfE	Ministry for the Environment
MM	New Zealand Modified Mercalli
NRC	Northland Regional Council
NZGD	New Zealand Geotechnical Database
PGA	Peak Ground Acceleration
VISION	Vision Consulting Engineers Limited



1 Introduction and Context

Vision Consulting Engineers Limited (VISION) was engaged by the Far North District Council to undertake a regional liquefaction vulnerability study for the Far North District.

Liquefaction occurs when intense shaking of saturated loosely-packed sediments near the ground's surface lose strength and behave similar to a liquid; these key elements are summarised in Figure 1.

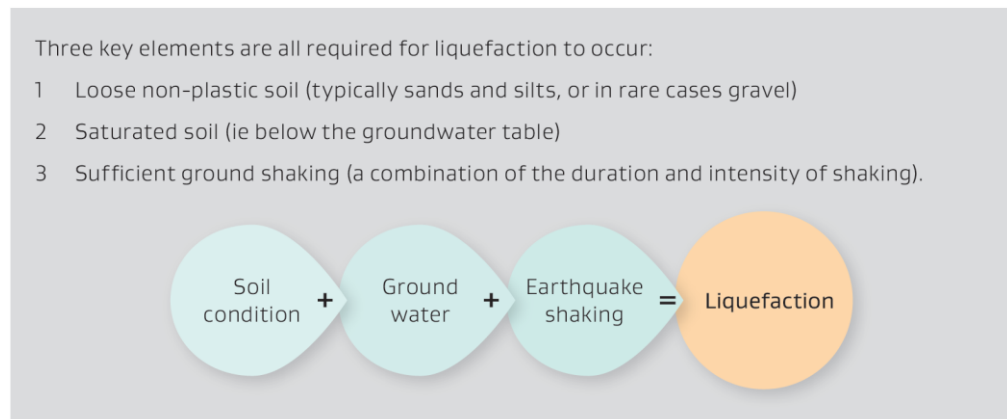


Figure 1. Key elements for liquefaction to occur

The elements soil condition, groundwater and shaking combination to trigger liquefaction (MBIE Guideline 2017).

An earthquake with sufficient shaking (duration and intensity) can induce liquefaction resulting in light objects floating, heavy objects sinking and permanent ground deformation. Liquefaction can significantly increase the risk of damage to infrastructure and buildings. The types of damage typically associated with liquefaction are presented in Figure 2.

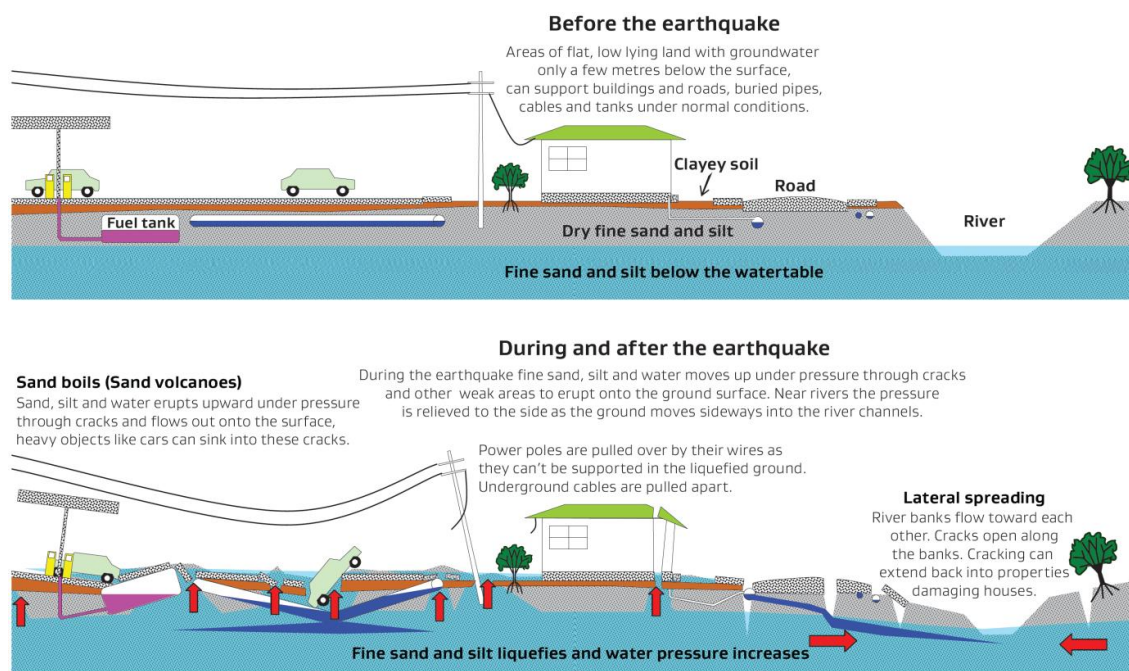


Figure 2. Types of damage associated with liquefaction

The infographic shows types of ground deformation and some effects on infrastructure and buildings that can result from liquefaction. (MBIE Guideline 2017).



In response to the extensive damage from liquefaction triggered by the Canterbury Earthquakes, changes have been made to the New Zealand Building Code and council's are designing resilience into infrastructure.

The Far North District Council has commissioned this study to inform future resource management land use planning (spatial planning and assessment of land use, subdivision consents), covered by the Resource Management Act, and engineering design, covered by the Building Act.

1.1 Prior Studies

At the time of preparing this study, published information on the liquefaction hazard in the Far North District is from a 2004 report prepared by the Institute of Geological & Nuclear Sciences Limited titled *A review of natural hazards information for Northland region (GNS 2004)*.

The *review of natural hazards* addresses seismic hazard identifying at the time that a MM6 (New Zealand Modified Mercalli) felt earthquake magnitude shaking occurs approximately every 1,000 years and MM7 shaking approximately every 7,000 years. The area of Northland is identified to be at low risk of seismic hazard. There are no active faults known in the Far North. Small earthquakes will give short duration shaking that may not have enough cycles to cause liquefaction. Microzoning studies are probably not required as the hazard is low (*GNS 2004*). The *review of natural hazards* notes that "The felt intensities and the likelihood of damage from an earthquake may be greater in [areas with thick fill, lacustrine, swamp or alluvial deposits], where liquefaction and surface settlement might occur within poorly consolidated sediments, although the small [earthquakes with a New Zealand Modified Mercalli Intensity factor of five (MM5)] or less [intense] earthquakes seen in the historical record are unlikely to have enough energy or cycles of strong shaking to cause liquefaction. The long recurrence interval for [earthquakes with a New Zealand Modified Mercalli Intensity factor of seven] (MM7), the intensity of shaking when liquefaction begins to occur, indicates that the risk is low."

The FNDC is not aware of any reported cases of liquefaction or lateral spreading occurring in the district, any cases of earthquake damage that have occurred in the district and does not have data on significant or measurable earthquakes that have occurred in the district. Site specific engineering liquefaction assessments carried out in the district have not been reviewed as this was outside the scope of work for this liquefaction vulnerability study.

An update to the New Zealand National Seismic Hazard Model was published while preparing this liquefaction vulnerability study. While not liquefaction specific, the updated model represents the current understanding of seismic risk across New Zealand. A key finding of the model is that the seismic risk in Northland is now considered to be greater than previously identified. This is discussed further in Section 2.2.5 of this report.

2 Risk Identification

2.1 Target Level of Detail and Scope

The project objective is to provide the Far North District Council (FNDC) a liquefaction vulnerability study for the district to inform spatial planning and assessment of land use, subdivision and building consents. The study is to be a Level A – Basic Desktop Assessment carried out in general accordance with the Ministry of Building, Innovation and Employment (MBIE) and Ministry for the Environment (MfE) *Planning and engineering guidance for potentially liquefaction-prone land*, dated September 2017 (referred to as MBIE Guidance 2017). The main purpose of this study is to provide a district wide map that can be utilised to inform policy, planning and consenting processes which covers the Far North District as shown in Figure 3.

It should be appreciated that a 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. 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.

It is important to assess the level of detail that can be provided based on the currently available base information. The following sections of this report present the base information used for this study including uncertainties associated with each set of base data. The level of detail may be restricted by the accuracy and precision of the base information.

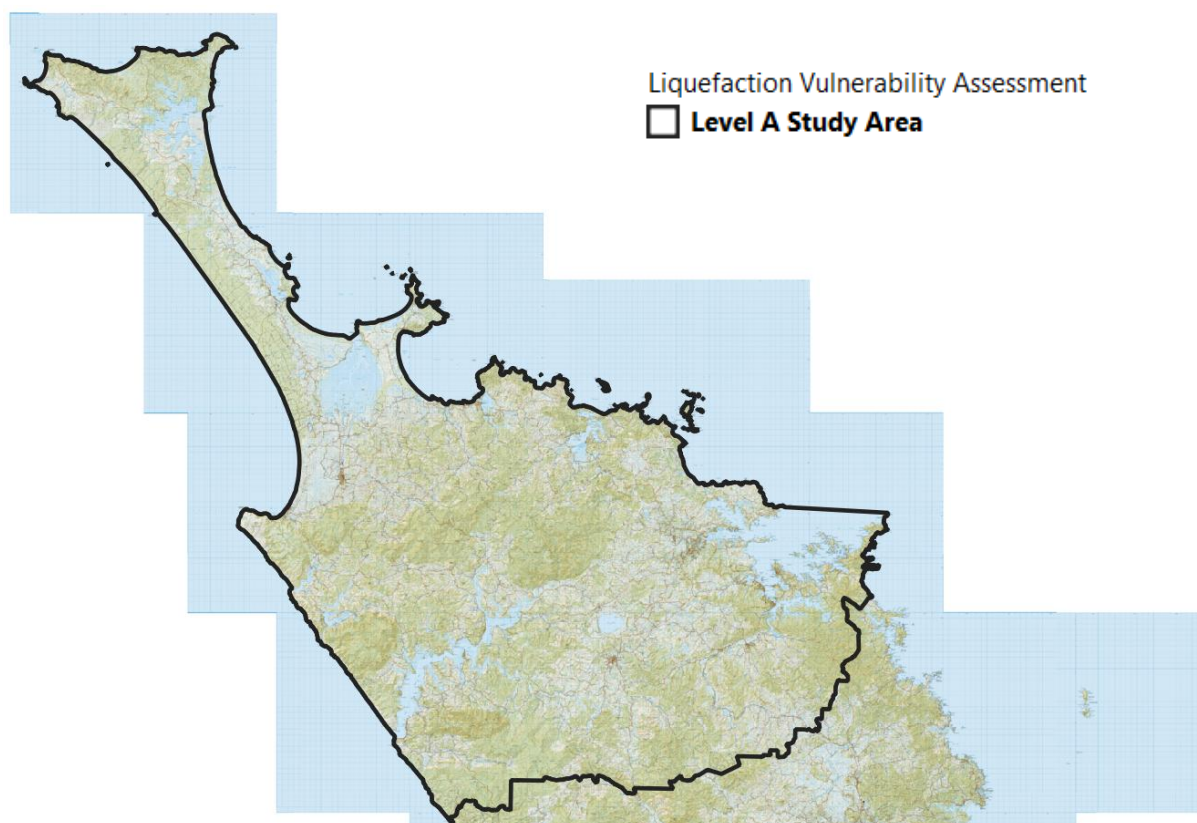


Figure 3. Map of the Level A study area

This Level A – Basic Desktop Assessment covers the area of the Far North District.

2.2 Base information review

2.2.1 Ground surface levels

The ground surface levels for this liquefaction vulnerability study were derived from LiDAR (or Light Detecting and Ranging). LiDAR is an aerial survey method that uses laser scanning technology capable of collecting millions of elevation points across a surveyed area. The LiDAR is simplified for analysis into 3D computer graphics representations of elevation data known as Digital Elevation Models (DEM).

LiDAR was captured for the Northland Region LiDAR Project carried out on behalf of Northland Regional Council (NRC) by RPS Group between December 2018 and July 2019, subsequent flights were conducted in February 2020. The LiDAR has a point pulse density specification at a minimum of three pulses per square metre and four pulses per square metre in nominated forestry areas. This LiDAR was interpolated into a 1 m DEM available from the Northland Regional Council. The 1 m DEM was used to develop hill-shade models to aid in the assessment of topographic features identifying



geomorphic land forms such as hilltops, ridges, and valleys. The topography of the Far North District is presented in Figure 4.

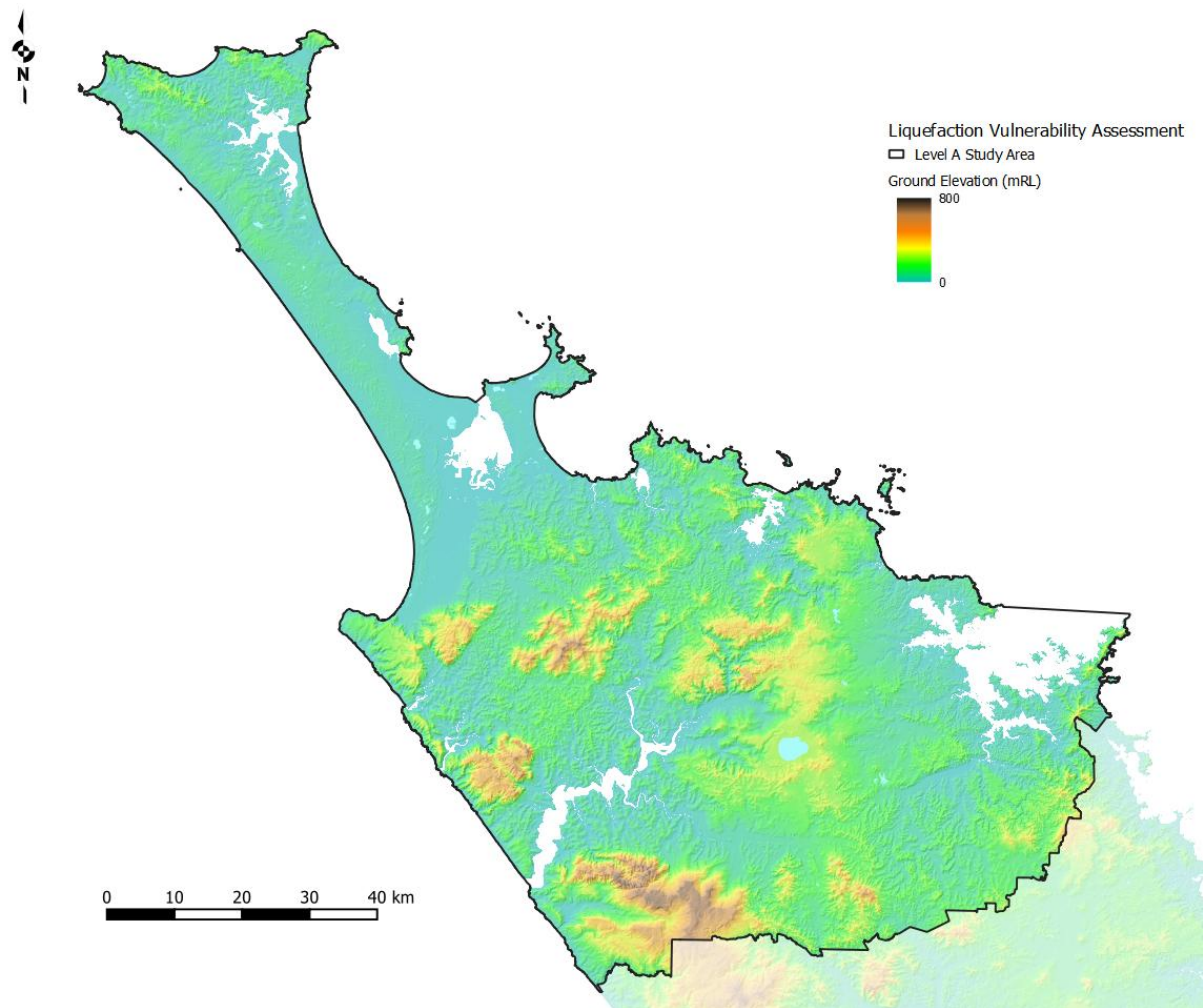


Figure 4. Topography of the Far North District
Topography of the district shown with elevations graded by colour and minor hill-shade relief.

The northern tips of the Far North District consist of rock outcrops that are connected to the remainder of the Far North by isthmus of dune sands. The remainder of the district is generally hill ranges with elevations averaging approximately 150 m above sea level. Mountain ranges are present within the south-western portion of the Far North, with the highest peak being Te Raupua, some 781 m above sea level within the Waima Forest.

2.2.2 Geology and geomorphology

2.2.2.1 Geology

Geology deals with the study of the history of rocks and soils of the earth. It is a fundamental part of understanding the types of soil and rock present beneath the grounds surface, and is therefore is a fundamental data source for liquefaction studies.

The geology of the Far North District is published on the following geological maps produced by GNS Science:

- 1:250,000 geological map, Geology of the Kaitia Area, Isaac (compiler), 1996
- 1:250,000 geological map, Geology of the Whangarei Area, Edbrooke and Brook (compilers), 2009



The digital version of the maps, the New Zealand QMAP, was used in this assessment, along with the accompanying text books. The maps present geology at a regional scale (1:250,000) and include descriptions of the mapped geological units. The geological units present within the district range from recent anaphoric deposits (fill) and Holocene beach deposits to Jurassic age Waipapa Group.

2.2.2.2 Geomorphology

Geomorphology is the observation of landforms and the interpretation of what forces have acted on the land to understand the development of different landform shapes. Landform shapes are readily identified by reviewing LiDAR ground surface levels projected as hill-shade or other 3D models for assessment. This combined with an understanding of the underlying geology is useful because it can be used to group areas and infer the likely performance under seismic shaking.

A geomorphologic assessment of various landforms across terrains of the Far North was undertaken to help understand their susceptibility to liquefaction. Larger terrain categories have been sub-grouped by landforms to provide greater detail of the geomorphic setting (where appropriate). The terrains and landforms used in this assessment are presented in Table 1 and were generally developed through assessment of topographic relief and underlying geology. Hills and mountains are less susceptible to liquefaction; however gullies and streams within this terrain could be susceptible to lateral spreading. The fluvial and alluvial terrain is retained as a single landform because this terrain may include layers of gravel, sand, and silt sediments.

A summary of the landforms used as a part of this assessment, along with a brief description is presented in Table 1.

Table 1. Landforms

A summary of landforms used in this assessment.

Terrain	Landform	Features
Hills & Mountains	Hilltop	The highest part of a hill typically being the summit, ridges and land elevated above hillslopes.
	Hillslopes	A landform that rises higher than the land surrounding it at the base or toe of hills. These are generally at the flanks of valleys and can contain eroded material from higher elevated slopes.
	Hill Gully or Valley	Formed by the process of erosion, gullies and valleys in hill terrain can contain colluvial and alluvial deposits.
Fluvial & Alluvial	Alluvial terrain	Channels, flat plains and delta associated with sediments deposited by rivers and streams. This includes wetlands, bogs and swamps not located along the coastal margin.
Coastal	Beach and Dunes	Sediments along the coast or lakes accumulating from wind- and water- driven processes.
	Dune Ridges	An elevated landform rising higher than the surrounding land, generally shaped by windblown sand and water erosion processes.
	Estuary and Coastal Margins	Wetland, marshes, bogs and swamps associated with coastal margins.
Anthropic	Fill	Man-made fill, construction fill, consisting of re-compacted or poorly compacted materials.

These geomorphic features have been mapped at a target scale of 1:25,000.



2.2.3 Geotechnical investigations

Readily available geotechnical information within the Far North District is limited to the New Zealand Geotechnical Database (NZGD). It is noted that some limited borehole information is also contained within the Northland Regional Council groundwater database.

The NZGD contains 72 CPT geotechnical investigation logs within the Far North District. The distribution of geotechnical investigations as shown in the NZGD as of December 2022 is presented in Figure 5. Due to the limited number and sporadic location of geotechnical investigations across the district, this information has not been used as a part of this assessment.

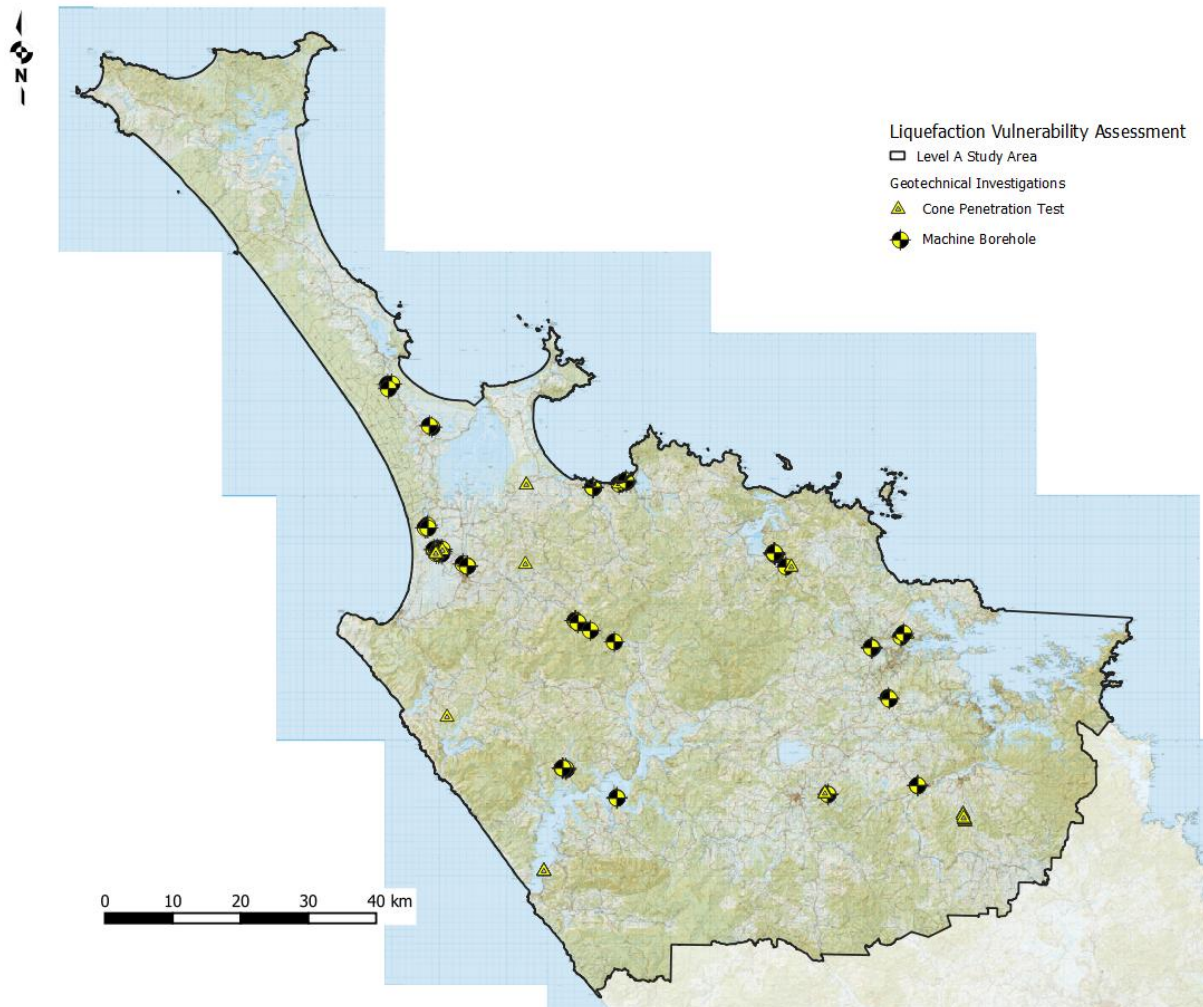


Figure 5 – Geotechnical Investigations available on the NZGD as of October 2022.

2.2.4 Groundwater

Groundwater levels recorded within the District are readily available from the Northland Regional Council Groundwater Database. The database contains 2317 groundwater bores within the Far North District, however not all bore records provided measured groundwater levels. It is noted that recorded groundwater levels are a single reading only and do not include seasonal variations. The approximate location of the groundwater bores is presented in Figure 6.

Due to the limited number and sporadic location of groundwater bores and uncertainty in regard to the accuracy of the recorded groundwater levels, the NRC groundwater levels have not been used as a part of this assessment.

In addition to groundwater bores, the location of surface water bodies (lakes, rivers, swamps etc.) can provide an indication of areas where the groundwater level is shallow. For the purpose of this



assessment, water bodies mapped on the LINZ Topo50 Map have been used to estimate local groundwater levels. The approximate location of the water bodies is presented in Figure 6.

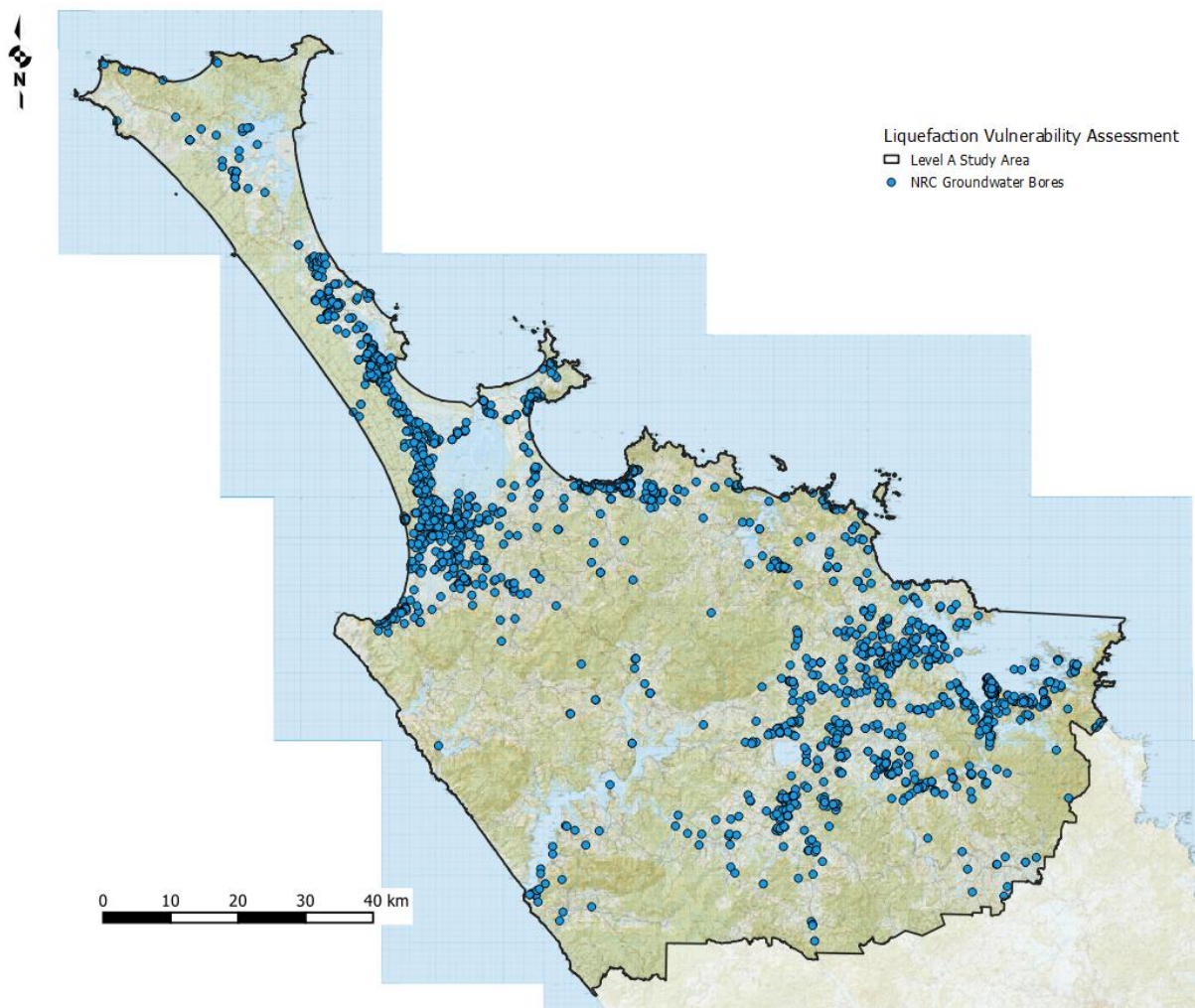


Figure 6 – Groundwater borehole locations and mapped water bodies.

2.2.5 Seismic hazard

The Regional seismic risk in Northland is generally considered to be low compared to the rest of the country, however this does not mean that Northland does not experience earthquakes. Records of historic seismic activity have been accessed on the Geonet New Zealand earthquake database (GNS, 2022). There have been 24 earthquakes recorded within or near the Far North since 1960. Of these two have been less than or equal to 2 M, nine less than 3 M, eight less than 4 M and five less than 5 M. The largest recorded earthquake in the Far North occurred on the 22nd of December in 1963 at 1:35PM near Peria with a magnitude of 4.825 M.

Prior to 1960, there are two earthquakes within the database logged with a magnitude of 4.5 M dated in 1830 and 1844 that occurred near Matauri Bay. A summary of notable earthquakes is provided in Table 2.

The location and magnitude of earthquakes recorded since 1960 are presented in Figure 7.



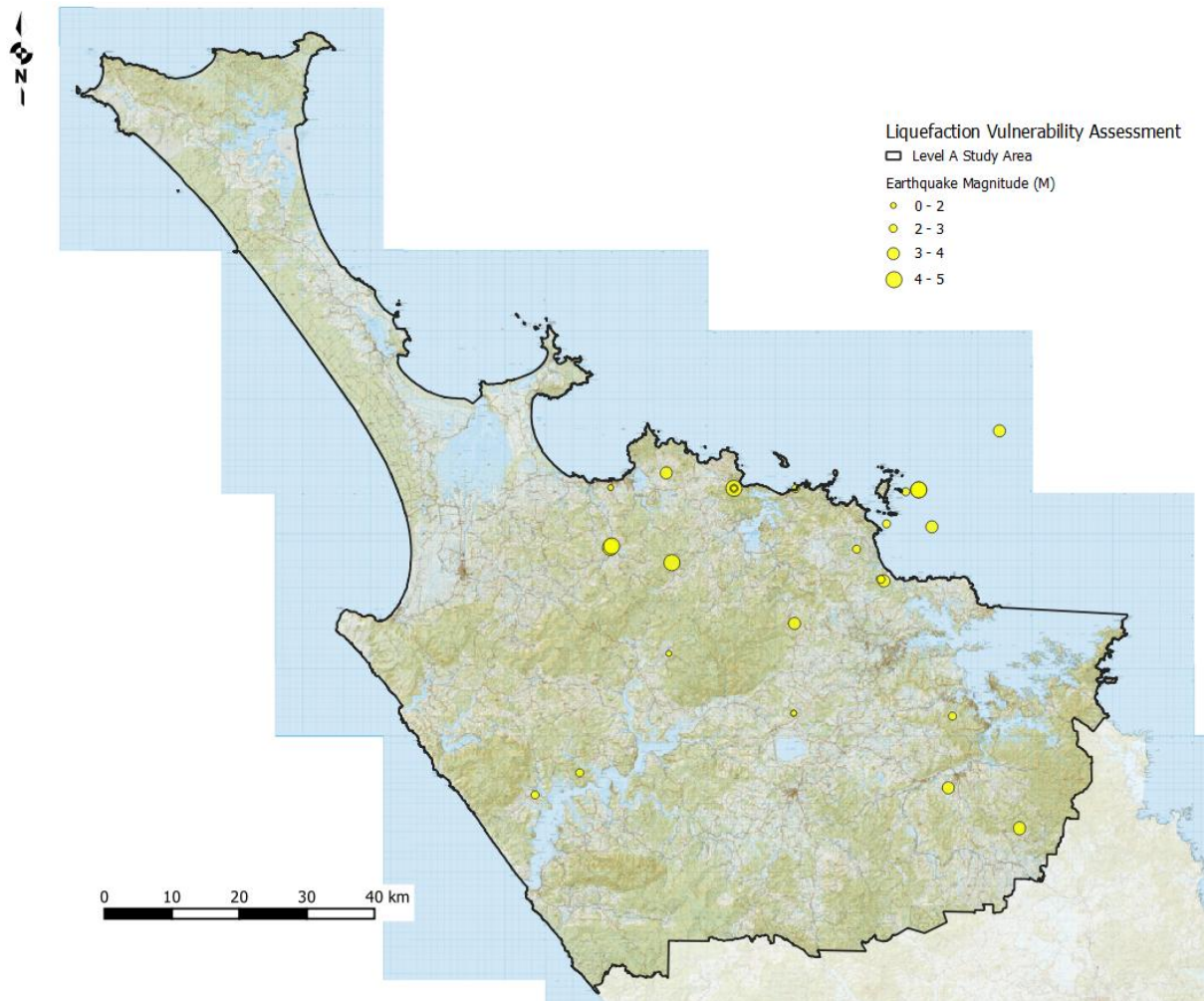


Figure 7 – Location and magnitude of recorded earthquakes in the Far North District.

Table 2. Notable Earthquakes

A summary of notable historic earthquakes within the Far North.

Date	Location	Magnitude (M)	Depth (km)
22/12/1963	Peria (23 kilometres E-NE of Kaitaia)	4.825	12
18/09/1964	31 kilometres E of Kaitaia	4.5	25
25/04/1964	Taupo Bay (34 kilometres NW of Kerikeri)	4.5	25
18/01/1844	9 kilometres NE of Matauri Bay	4.5	25
01/03/1830	9 kilometres NE of Matauri Bay	4.5	25
22/12/1963	Peria (23 kilometres E-NE of Kaitaia)	4.36	12

The nearest active fault in the GNS New Zealand Active Faults Database is the Waikopua fault, which is located approximately 175 km to the southeast of southern boundary of the Far North District.

Geological studies have identified many faults in the Far North district but they are classified as inactive faults, having had no known activity within the last 100,000 years. Figure 8 shows the extent of the inactive faults within the Far North and the location of the Waikopua fault relative to the Far North.



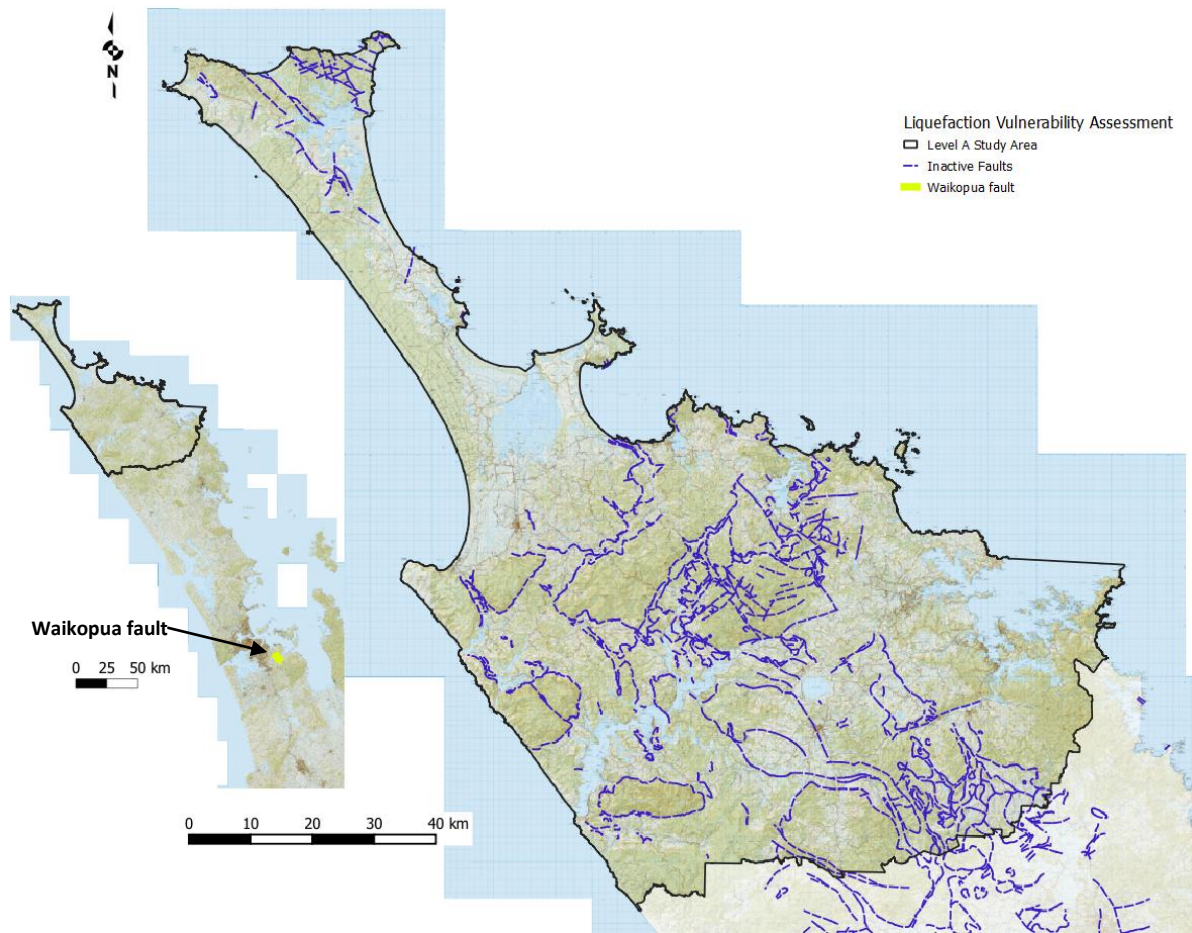


Figure 8. Inactive and Closest Active Faults

The inset image shows the proximity of the closest active fault, Waikopua fault, to the Far North. Inactive faults mapped on the GNS QMap series within the Far North are shown as blue dashed lines.

It should be appreciated that it is possible that unmapped faults exist within or near the study area that are capable of generating earthquakes. The uncertainty this causes is discussed further in Section 2.3.5 of this report.

The information on historic earthquakes and fault locations is used to help develop the National Seismic Hazard Model (NSHM) which provides estimates of the likelihood and strength of earthquake ground shaking at any given site in New Zealand.

An updated National Seismic Hazard Model (NSHM) developed by GNS, MBIE, and the Earthquake Commission was released on the 4th October 2022. This updated model represents significant advancements in earthquake modeling in the 12 years since the previous model. The model includes upgrades to key components that are combined to assess the overall seismic risk. In general the model found that the seismic risk in the Far North is greater than previously thought.

It should be appreciated that engineers and building professionals must design to the current laws, technical standards, and guidance documents to ensure that their designs comply with the New Zealand Building Code.

In the future these design guides and standards may be updated by MBIE taking into consideration the recent changes to the NSHM. At present, the prevailing guidance document is *Module 1 - Overview of earthquake geotechnical engineering practice guidelines - Version 1* (Module 1, 2021). Because this Level A assessment is to inform policy, planning and consenting processes (Module 1, 2021) forms the basis to estimating the PGA of the assessment.



Table 3. Annual Reoccurrence Interval - Peak Ground Accelerations

A summary from Module 1, 2021 of design earthquake magnitude (M) and PGAs for various return periods within the Far North District.

ARI	Magnitude	Peak Ground Acceleration¹
(years)	(M)	(g)
1 in 25	5.8	0.03
1 in 50	5.8	0.05
1 in 100	5.8	0.07
1 in 250	5.8	0.10
1 in 500	5.8	0.13
1 in 1000	5.8	0.17
1 in 2500	5.8	0.24
<u>Lower Bound²</u>	<u>6.5</u>	<u>0.19</u>

¹ Peak ground acceleration is listed for Soil Class C as defined in NZS 1170.5 Structural design actions part 5 Earthquake actions – New Zealand (NZS 1170.5) being C (shallow soil).

² As a lower bound, the damage control limit state effects to be designed for shall not be taken to be less than those due to a 6.5 magnitude earthquake at 20km distance using these coefficients for ARI events of 1 in 500 years or less frequent events.

For the purposes of this Level A assessment, a qualitative analysis is required to assess if it is plausible that liquefaction could occur in the Far North District given current design standards. The design standard is based on the Lower Bound as shown in Table 3 for a 1 in 500 year ARI with a PGA of 0.19g for a subsoil class C.

Saunders and Berryman (2012) report that a PGA of 0.1g or greater is sufficient to trigger damaging liquefaction based on recent earthquakes in New Zealand.

Therefore it is considered that the district could experience liquefaction during a 500-year ARI earthquake.

2.2.6 Historic observations of liquefaction

There are no known observations of liquefaction in the Far North.

2.3 Uncertainty assessment

Understanding the uncertainty associated with the base data sets is critical to understanding the level of detail supported by this assessment. The following sections provide commentary on quantitative uncertainties where available and quantitative comment where no quantitative uncertainty is quoted.

2.3.1 Ground surface levels

As discussed in Section 2.2.1, the ground surface level used as a part of this assessment was derived from the NRC LiDAR 2018-2019.

The NRC LiDAR has a reported vertical accuracy specification of ± 0.2 m (95%) and a horizontal accuracy specification of ± 1.0 m (95%).

The NRC LiDAR derived DEM has a relatively high resolution and is considered suitable for use as a part of this Level A Regional Liquefaction Vulnerability Assessment, however the following issues/limitations should be appreciated:



- 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.

Note these issues are particularly relevant for the assessment of the heights of free faces to support the assessment of lateral spreading potential.

2.3.2 Geology and geomorphology

As discussed in Section 2.2.2, the geology of the Far North District has been based on the New Zealand QMAP at a 1:250,000 scale. The geomorphology of the District was developed using the NRC LiDAR data, geology maps, and engineering judgment.

2.3.2.1 Geology

The QMAP data was compiled from numerous published and unpublished sources. The geological data was captured by manual digitisation from 1:50,000 maps and is expected to have a locational accuracy of between +/- 100 m and +/- 250 m.

It should be appreciated that some simplification has been necessary to represent the geology at the publication scale. Consequently data should be used with care at scales greater than 1:250,000, and should not be used for site-specific purposes. The use of the data is unrestricted and the data is licensed under a Creative Commons Attribution 3.0 New Zealand License (CC-BY) by GNS Science.

2.3.2.2 Geomorphology

The QMAP data used as a part of this assessment is at a scale of 1:250,000 where as the geomorphology assessed using the NRC LiDAR data is considered to have a nominal scale of 1:25,000. Due to the difference in scales, the geomorphology does not always match the QMAP geology. This difference has been taken into consideration.

2.3.3 Geotechnical investigations

As discussed in Section 2.2.3, due to the limited number and sporadic location of geotechnical investigations across the district contained within the NZGD, this information has not been used as a part of this assessment.

2.3.4 Groundwater

As discussed in Section 2.2.4, due to the limited number and sporadic location of groundwater bores and uncertainty in regard to the accuracy of the recorded groundwater levels, the NRC groundwater data has not been used as a part of this assessment.

2.3.5 Seismic hazard

Given that the NSHM 2022 had only just been released at the time of preparing this report, no current engineering standards and guidance documents have been revised to adopt the outputs of the NSHM 2022.

Current best practice when considering seismic design is to adopt the recommendations of MBIE document (Module 1, 2021) where site-specific studies have not been undertaken.

While Module 1 appears to be conservative when compared to the NSHM 2022, it should be appreciated that this is a design guide that includes inherent factors of safety for the protection of people and property and allows for uncertainty associated with unmapped faults.

2.3.6 Historic observations of liquefaction

As there are no known observations of liquefaction within the Far North District, it is difficult to quantitatively assess the uncertainty. The MBIE Guidance 2017 document suggests that liquefaction may have historically occurred and provides the following examples:



- 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 occurring, but the observation was not recorded or was attributed to some other cause such as flooding.

2.3.7 Expected degree of liquefaction-induced ground damage

The main objective of a Level A study is to identify land where there is a high degree of certainty that “Liquefaction Damage is Unlikely”. This study uses an evidence-based approach to classify land areas as “Liquefaction Damage is Unlikely”.

Due to the uncertainties described in the proceeding sections, there are large areas where insufficient information is available to provide a clear consensus on the degree of liquefaction-induced ground damage. Until further information and an improved understanding of these areas are available, it is pragmatic to classify them as “Liquefaction Vulnerability Category is Undetermined”.

This is discussed further in the following section.

2.3.8 Liquefaction vulnerability category assessed against performance criteria

The MBIE Guidance 2017 provides the performance criteria to determine the liquefaction vulnerability category for a particular area of land at the scale of a Level A assessment. These are summarised in Figure 9.

LIQUEFACTION CATEGORY IS UNDETERMINED	
A liquefaction vulnerability category has not been assigned at this stage, either because a liquefaction assessment has not been undertaken for this area, or there is not enough information to determine the appropriate category with the required level of confidence.	
LIQUEFACTION DAMAGE IS UNLIKELY	LIQUEFACTION DAMAGE IS POSSIBLE
There is a probability of more than 85 percent that liquefaction-induced ground damage will be None to Minor for 500-year shaking.	There is a probability of more than 15 percent that liquefaction-induced ground damage will be Minor to Moderate (or more) for 500-year shaking.
At this stage there is not enough information to distinguish between Very Low and Low . More detailed assessment would be required to assign a more specific liquefaction category.	At this stage there is not enough information to distinguish between Medium and High . More detailed assessment would be required to assign a more specific liquefaction category.

Figure 9. Liquefaction Vulnerability Category
Performance criteria identified in MBIE Guidance 2017.

The performance criteria makes reference to probabilities of a particular 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. It is also important to recognise that these probabilities relate to the total effect of all uncertainties in the assessment, a characteristic that makes rigorous probabilistic calculation particularly challenging (MBIE Guidance 2017).

For this Level A liquefaction vulnerability study the level of confidence is ultimately evaluated qualitatively. A degree of judgement is used, with Figure 9 providing guidance, to determine the liquefaction vulnerability category for each area of land and there is inherent uncertainty associated with this subjective process.

Given the uncertainties associated with the base information as outlined in Section 2.3, this study minimises the areas identified as “Liquefaction Damage is Possible”. As new information becomes available or as further site specific assessments are undertaken, these categories could be re-



mapped. Areas that are on the margins of “Liquefaction Damage is Possible” are categorised as “Liquefaction Damage is Undetermined”. This approach is beneficial because it allows future investigation of “Undetermined” land areas at an appropriate scale, rather than classifying the land as “Liquefaction Damage is Possible” requiring robust and potentially costly geotechnical investigations.

2.4 Level of detail supported by the available information

The uncertainty assessment provided in Section 2.3 provides key input to the evaluation of the level of detail supported by the currently available information. The currently available information is considered to be suitable to support a Level A desktop assessment only. The MBIE Guidance 2017 in Table 3.1 summarises the degree of residual uncertainty associated Level A study as follows:

- The primary focus is identifying 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). For other areas, substantial uncertainty will likely remain regarding the level of risk.

The extent covered by this Level A assessment is presented in Figure 10.

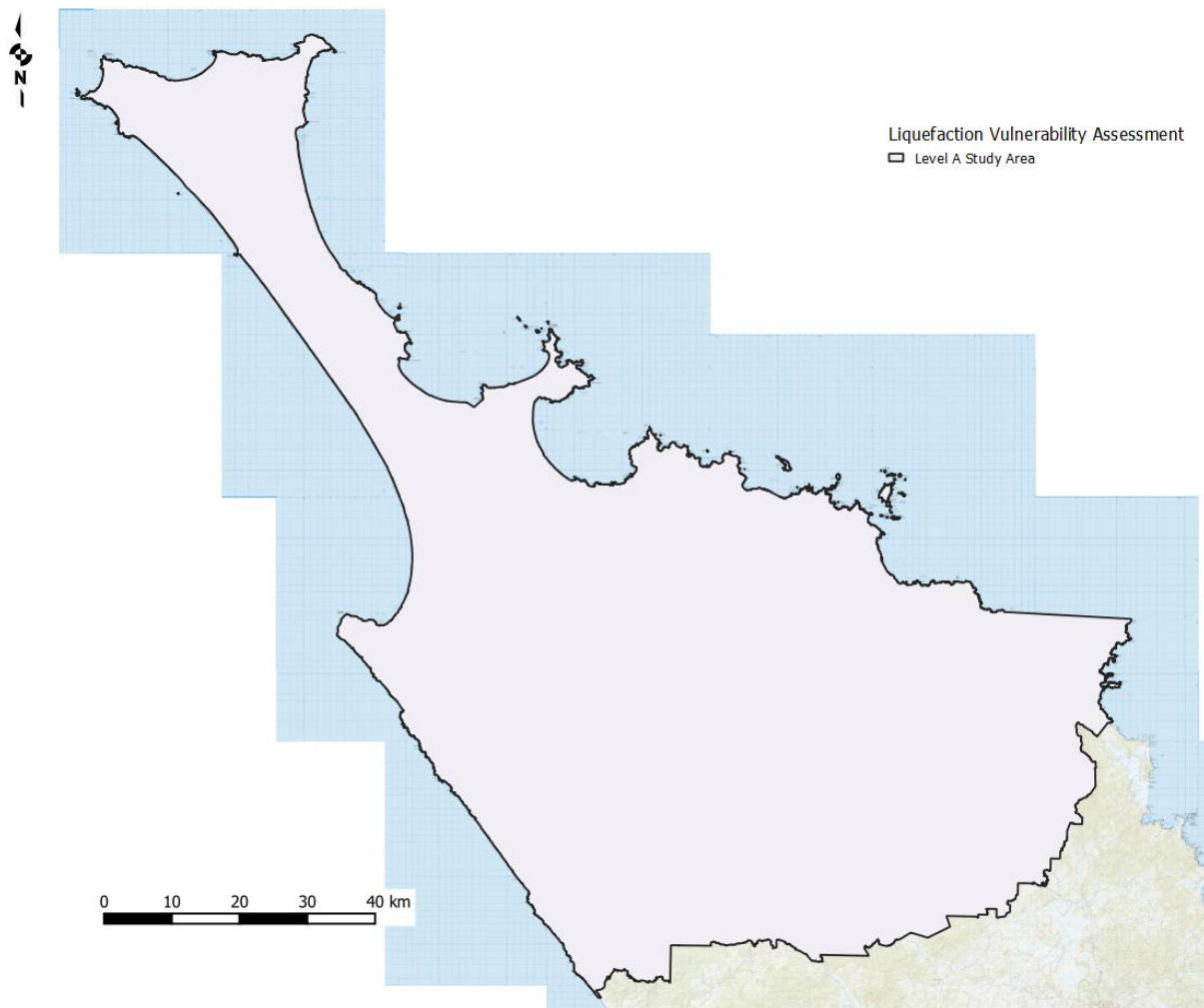


Figure 10. Level of Detail Supported Map

The level of detail supported by current information is Level A – Basic Desktop Assessment covering the entire area of the Far North District.



3 Risk analysis

3.1 Groundwater levels for analysis

As discussed earlier in this report, data on water bores across the study area were accessed from the NRC borehole database. A data quality check found inconsistencies exist within the dataset and that there does not appear to be a clear attribute definition with data quality enforcement. Given the apparent data input errors the dataset is considered to be unreliable.

A National Water Table interactive map was published by GNS in 2018 (Westerhoff et al., 2018). However upon spot checking groundwater data against data within VISION's archives the model was found to be inconsistent with observed groundwater. Given the discrepancy between the model and observed ground water levels the dataset is considered to be unreliable.

In the absence of detailed groundwater conditions, including seasonal variability, typical depths to groundwater were assumed across landform areas. This includes assumptions about the areas where there is the potential for sea level rise to influence groundwater depth. Assumed depth to average groundwater levels are summarised in Table 4.

Table 4. Assumed Groundwater Depths for Analysis

Landform	Assumed depth to groundwater	Affect of Sea Level Rise
Hilltop	Greater than 8 m	Where hilltops are near the sea the depth to groundwater could reduce, otherwise groundwater depths are unlikely to be affected.
Hillslopes	Less than 4 m, expected to be highly variable	Where hillslopes are near the sea the depth to groundwater could reduce, otherwise groundwater depths are unlikely to be affected.
Hill Gully or Valley	Less than 4 m	Areas adjacent to the coastline or of low elevation the depth to groundwater could reduce, otherwise groundwater depths are unlikely to be affected.
Alluvial terrain	Less than 4 m	Areas adjacent to the coastline or of low elevation the depth to groundwater is likely to reduce, otherwise groundwater depths are unlikely to be affected.
Beach and Dunes	Less than 4 m, expected to be highly variable	Areas adjacent to the coastline or of low elevation the depth to groundwater is likely to reduce, otherwise groundwater depths are unlikely to be affected.
Dune Ridges	Greater than 8 m	Where hilltops are near the sea the depth to groundwater could reduce, otherwise groundwater depths are unlikely to be affected.
Estuary and Coastal Margins	Less than 4 m	The depth to groundwater is likely to reduce
Reclamation Fill	Less than 4 m, expected to be highly variable	Areas adjacent to the coastline or of low elevation the depth to groundwater is likely to reduce, otherwise groundwater depths are unlikely to be affected.

3.2 Earthquake scenarios for analysis

The MBIE Guidance 2017 document recommends that the minimum earthquake scenario adopted for a regional assessment is the 500-year return period.

For Level A studies, MBIE Guidance 2017 also recommends considering an Extreme (low probability) earthquake scenario as a sensitivity test for the liquefaction vulnerability classification; calculated by multiplying the 500-year return period PGA by 150 percent.

This approach is also particularly useful for managing any residual uncertainty in the seismic hazard information. If the extreme scenario results in a large step-change worsening of land performance



compared to the 500-year scenario (enough to materially impact the engineering solution that would be adopted), then this might indicate higher liquefaction vulnerability than a situation where there is only a minor incremental change to the land performance (MBIE Guidance 2017).

The earthquake scenario outlined in Table 5 has been adopted for this Level A assessment.

Table 5. Earthquake scenarios for analysis

A summary of the magnitude and peak ground accelerations considers for this Level A assessment.

ARI	Magnitude	Peak Ground Acceleration ¹
(years)	(M)	(g)
1 in 500	5.8	0.13
<i>Extreme</i>	<i>5.8</i>	<i>0.20</i>

¹ Peak ground acceleration is listed for Soil Class C as defined in NZS 1170.5 Structural design actions part 5 Earthquake actions – New Zealand (NZS 1170.5) being C (shallow soil).

3.3 Sub areas of similar expected performance

For this liquefaction vulnerability study, sub-areas of similar expected performance were created by grouping areas of land according to the following characteristics:

- **Geomorphic sub-areas** – geomorphic landforms formed the primary basis to evaluate the likely soil conditions within each sub-area. This is described in Section 2.2.2 to help delineate areas of similar expected performance. Landforms were selected based on geological map data combined with geomorphic assessment.
- **Topographic sub-areas** – the elevation information derived from LiDAR data was used to further divide the landforms such as hilltops, ridges and elevated land, sloping land and flat lowland areas. This is a useful means of sub-categorisation because it allows further refinement of the qualitative assessment of groundwater depth (MBIE Guidance 2017). This topographic screening approach is reasonable for this assessment because of the accuracy of the LiDAR derived elevation data.
- **Lateral spread sub-areas** – The MBIE Guidance 2017 notes that attention should be given to liquefaction susceptible land within 200 m of a free face greater than 2 m high. Given the scale and available detail of this assessment, a 200 m buffer has been applied to Dune Ridges so that land that was identified as “Liquefaction Damage is Unlikely” are categorised as “Liquefaction Damage is Undetermined”. In all other areas, it is considered that the geomorphic sub-area landforms and subsequent liquefaction category provide sufficient buffers to not require a blanket 200 m buffer to allow for lateral spread in other areas.

3.4 Liquefaction vulnerability category assessed against performance criteria

The final step of this liquefaction vulnerability assessment is to categorise each sub area of similar expected performance in accordance with the MBIE Guidance 2017. There are three categories for a Level A assessment:

- Liquefaction damage category is undetermined (insufficient information to support categorisation)
- Liquefaction damage is possible (susceptible landforms)
- Liquefaction damage is unlikely (non-susceptible landforms)

Figure 11 provides the output of this liquefaction vulnerability assessment with the Far North District mapped into the three liquefaction damage categories. The liquefaction vulnerability map is also provided in Appendix A.



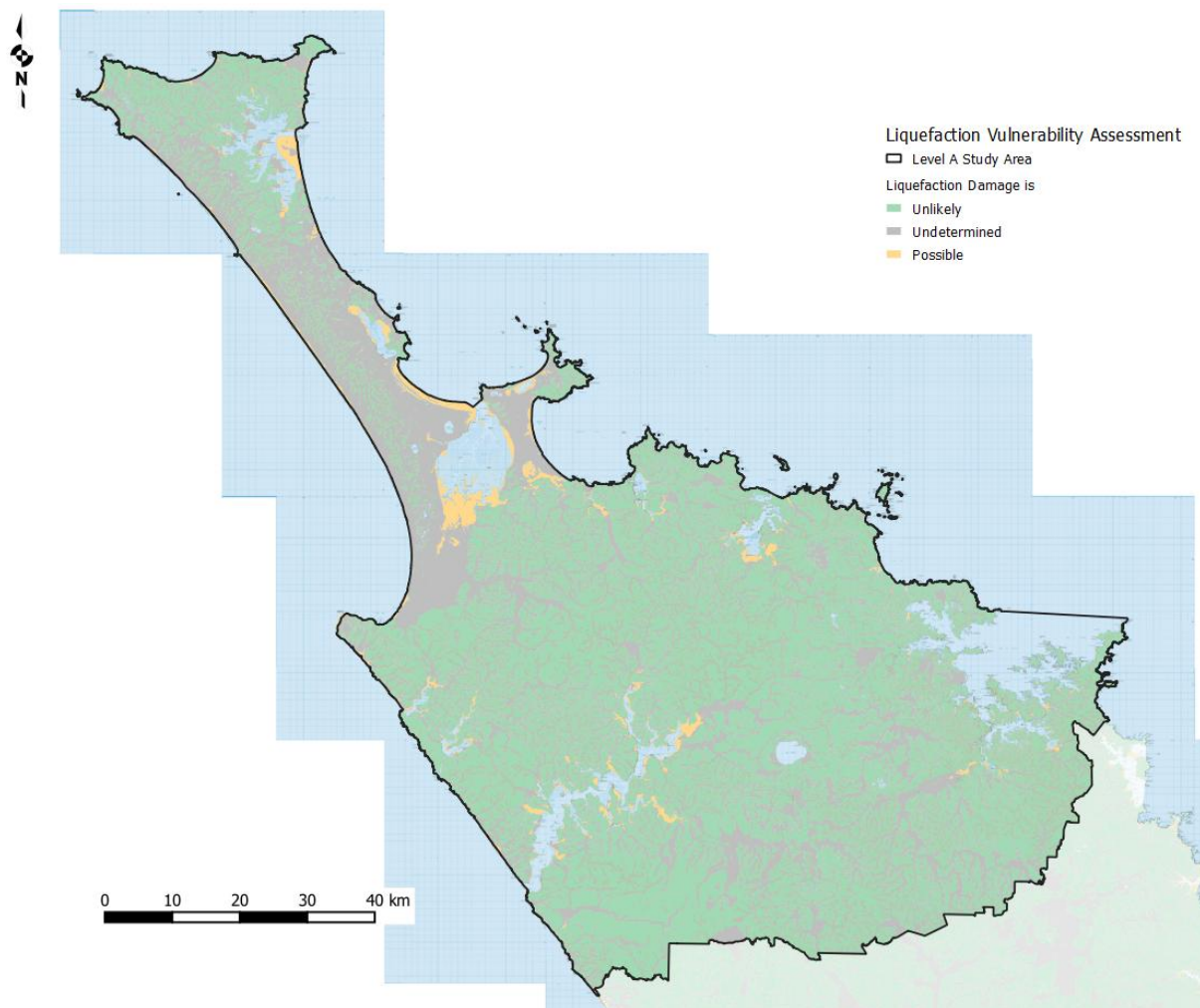


Figure 11. Liquefaction Vulnerability Category Map

The final project map shows the three categories of the liquefaction assessment 'possible', 'undetermined' and 'unlikely' covering the entire area of the Far North District.

3.4.1 Category Classification Discussion

3.4.1.1 Hills and Mountains

Hill and mountain terrain were assessed based on geomorphic mapping (1:25,000 scale) combined with underlying geology groupings (1:250,000 scale). Hilltops are generally where the geomorphic mapping identified the highest part of a hill typically being the summit, ridges and land elevated above hillslopes and being underlain by geologic units comprising residual soils overlying weathered rock, or exposed rock. Residual soils are likely to be clay-like materials not considered to be susceptible to liquefaction. Therefore these areas have been assigned the "Liquefaction damage is unlikely" category. However if a hilltop has an elevation at or below 8 m above sea level it has been assigned "Liquefaction damage category is undetermined" due to the potential for lateral spreading to occur and inaccuracies of the mapped geology.

3.4.1.2 Hillslopes

Hillslopes were assessed based on geomorphic mapping (1:25,000 scale) combined with underlying geology groupings (1:250,000 scale). Where the underlying geologic units indicated that it is likely to be residual soils overlying weathered rock, or exposed rock. Residual soils are likely to be clay-like materials or rock which is not considered to be susceptible to liquefaction. Hillslopes are elevated above gullies and valleys. For these reasons this landform is categorised as "Liquefaction damage is unlikely".



3.4.1.3 Hill Gully or Valley

Hill Gully or Valley terrain were assessed based on geomorphic mapping (1:25,000 scale) combined with underlying geology groupings (1:250,000 scale). The flanks of valleys and gullies have been included as these can contain eroded material from higher elevated slopes. This landform is generally fluvial, colluvial or alluvial deposits. These deposits can be highly variable with layers of silts, sands, and gravels. For this reason this landform is categorized as “Liquefaction damage category is undetermined” (insufficient information to support categorisation).

3.4.1.4 Fluvial & Alluvial

Fluvial & Alluvial terrain has been assigned “Liquefaction damage category is undetermined” because insufficient information is available to support a specific categorisation. However, where Alluvial Terrain is adjacent to Estuary and Coastal Margins, it has been identified as “Liquefaction damage is possible” due to the increased potential for the deposit to contain potentially liquefiable material and the likely presence of a high groundwater table.

3.4.1.5 Beach and Dunes

Beach and Dunes comprise sands, gravels, mud and shells being both mobile and fixed deposits which are normally considered to be prone to liquefaction due to their composition (sands and silts) and age (Holocene depots). Where these features are low in elevation, they have been assigned “Liquefaction damage is possible” otherwise this landform has been assigned “Liquefaction damage category is undetermined”.

3.4.1.6 Dune Ridges

Dune Ridges are a subset of Beach and Dunes where it is considered unlikely that groundwater levels are within 8 m of the surface due to their elevation (these areas are well elevated and geomorphically identified as the summit and ridge of a hilltop) and/or where cemented sands are likely to be present. Due to the likely depth to groundwater and/or presence of cemented sands, Dune Ridges have been assigned “Liquefaction damage is unlikely”.

3.4.1.7 Estuary and Coastal Margins

Estuary and Coastal Margins are where recent estuarine, swamp and alluvial deposits are near the sea/estuary or adjacent to Beach and Dunes assigned the category of “Liquefaction damage is possible” these have been assigned the category “Liquefaction damage is possible” as they are considered likely to comprise sand and silts and be within an area with a high groundwater table.

3.4.1.8 Reclamation Fill

Reclamation fill is not mapped as being present with the Far North District, however it is anticipated that reclamation fill may present in low lying areas adjacent to harbours. Reclamation fill is typically highly variable material and due to it being potentially present where a high groundwater table is present, it has been assigned “Liquefaction damage is possible”.

4 Conclusion and recommendations

VISION has undertaken a liquefaction vulnerability study in general accordance with MBIE Guideline 2017 for the Far North District. The following are conclusions and recommendations from this study:

- The LiDAR data covering the entire study area proved to be the most significant data input for this Level A liquefaction vulnerability assessment. This is because this data set provided the highest level of detail available for analysis. This enabled geomorphic mapping at a scale of 1:25,000 for this study.
- The geology information available at the time of preparing this report is mapped with a nominal accuracy of ± 250 m for maps generated at a scale of 1:250,000. The accuracy of the geology information leads to uncertainty when compared to the more detailed geomorphic mapping. To



allow for this uncertainty this study mapped Beaches and Dunes so that the geology information was allowed to override the geomorphic mapping. This is expected to over predict the area covered by Beaches and Dunes, which are the most sensitive landform assessed in this study. Ideally geologic mapping would be improved over the study area to match the target scale of 1:25,000.

- There are a limited number of geotechnical investigations within the study area uploaded into the New Zealand Geotechnical Database. In order to progress to the next level of detailed mapping (Level B) appropriately spaced geotechnical investigations are required. This allows a professional practitioner to qualitatively calibrate the likely performance of the landforms during earthquake shaking. The Far North District Council could require building professionals and practitioners to upload testing data to the New Zealand Geotechnical Database through updated requirements in the engineering standards, as consent conditions, and/or as a contractual requirement of council funded projects.
- The unreliability of groundwater data within the study area limits the ability to undertake the next level of detailed mapping (Level B). To progress to a Level B liquefaction vulnerability study, additional groundwater level data will be required. Groundwater measurements should be at sufficient spacing between measurements and taken for an adequate duration to understand seasonal variability of groundwater levels for a given assessment area. Over time, council could install a monitoring network to better understand groundwater levels targeted to high-growth “Possible” or “Undetermined” areas.
- The recently released National Seismic Hazard Model 2022 (NSHM 2022) in general predicts that peak ground accelerations for specific return period events across the Far North District are higher than previously reported and are closer to the Lower Bound design standards. At the anticipated Lower Bound accelerations it is possible that liquefaction could be triggered in the Far North District. It is anticipated that the government and their advisors will carefully consider the recently released NSHM 2022 and whether changes will need to be made to building design and planning standards. It may be beneficial to review this Level A liquefaction vulnerability assessment if changes are implemented that affect earthquake design standards/guidance documents.
- VISION has undertaken a liquefaction vulnerability assessment to provide Level A mapping across the Far North District. This assessment classifies liquefaction damage categories of “Possible”, “Undetermined” and “Unlikely” based on currently available information. This level of detail is considered sufficient to inform policy, planning, and consenting processes within the Far North District.



References

- Beetham R.D., M. M. (2004). *A review of natural hazards information for Northland Region*. GNS Science.
- GNS Science. (2018). *National water table model [Dataset]*. GNS Science.
<https://doi.org/10.21420/KZ52-NT28>
- GNS Science, Toka Tū Ake EQC. (2022). *GeoNet Quake [Dataset]*. GeoNet Geological hazard information for New Zealand: <https://quakesearch.geonet.org.nz/>
- Langridge, R.M., Ries, W.F., Litchfield, N.J., Villamor, P., Van Dissen, R.J., Barrell, D.J.A., Rattenbury, M.S., Heron, D.W., Haubrock, S., Townsend, D.B., Lee, J.M., Berryman, K.R., Nicol, A., Cox, S.C., Stirling, M.W. (2016). *The New Zealand Active Faults Database*. New Zealand Journal of Geology and Geophysics 59: 86-96. doi: 10.1080/00288306.2015.1112818.
- Ministry of Business, Innovation and Employment, Ministry for the Environment (2017). *Planning and engineering guidance for potentially liquefaction-prone land*. Wellington: MBIE/MfE.
- Ministry of Business, Innovation and Employment, New Zealand Geotechnical Society Inc. (2021). *Earthquake geotechnical engineering practice - Module 1: Overview of the guidelines*. Wellington: MBIE.
- Ministry of Business, Innovation and Employment, Ministry for the Environment (2021). *Regional liquefaction vulnerability assessment method statement*. Wellington: MBIE.
- New Zealand Standards. (2004). NZS 1170.5:2004. *Structural design actions. Part 5: Earthquake actions*. SANZ. Standards New Zealand.
- Northland Regional Council (2022). *Borehole Logs [Dataset]*. NRC.
- Saunders, W.S.A. and Berryman, K.R. (2012). *Just add water, when should liquefaction be considered in land use planning?*. GNS Miscellaneous Series 47, 15 p.



Appendix A

Mapping Output



Liquefaction Vulnerability Overview Map of the Far North District

2023

Hazard Assessment

Regional Liquefaction Vulnerability Assessment of the Far North District

by Ben C. Perry, Dan Simmonds, Logan Ashmore, and Grant Murray

prepared for the Far North District Council

ABOUT THIS PROJECT

An earthquake with sufficient shaking (duration and intensity) can induce liquefaction resulting in light objects floating, heavy objects sinking and permanent ground deformation. Liquefaction can significantly increase the risk of damage to infrastructure and buildings.

In response to the extensive damage from liquefaction triggered by the Canterbury Earthquakes, changes have been made to the New Zealand Building Code and the Far North District Council is designing resilience into infrastructure.

The Far North District Council has commissioned this Level A 'desktop' regional liquefaction vulnerability assessment to inform future resource management land use planning (spatial planning and assessment of land use, subdivision consents), covered by the Resource Management Act, and engineering design, covered by the Building Act. The main purpose of this project was to provide this district wide map to understand liquefaction vulnerability at a broad scale.

METHOD OVERVIEW

This liquefaction vulnerability overview map of the Far North District used these available data sets (numbers correspond to the maps below):

- 1 Elevation Map (LIDAR derived 10-m DEM)
- 2 Generalised Geology Map (2357 generalised geologic units)
- 3 Streams, Lakes and Wetlands Map

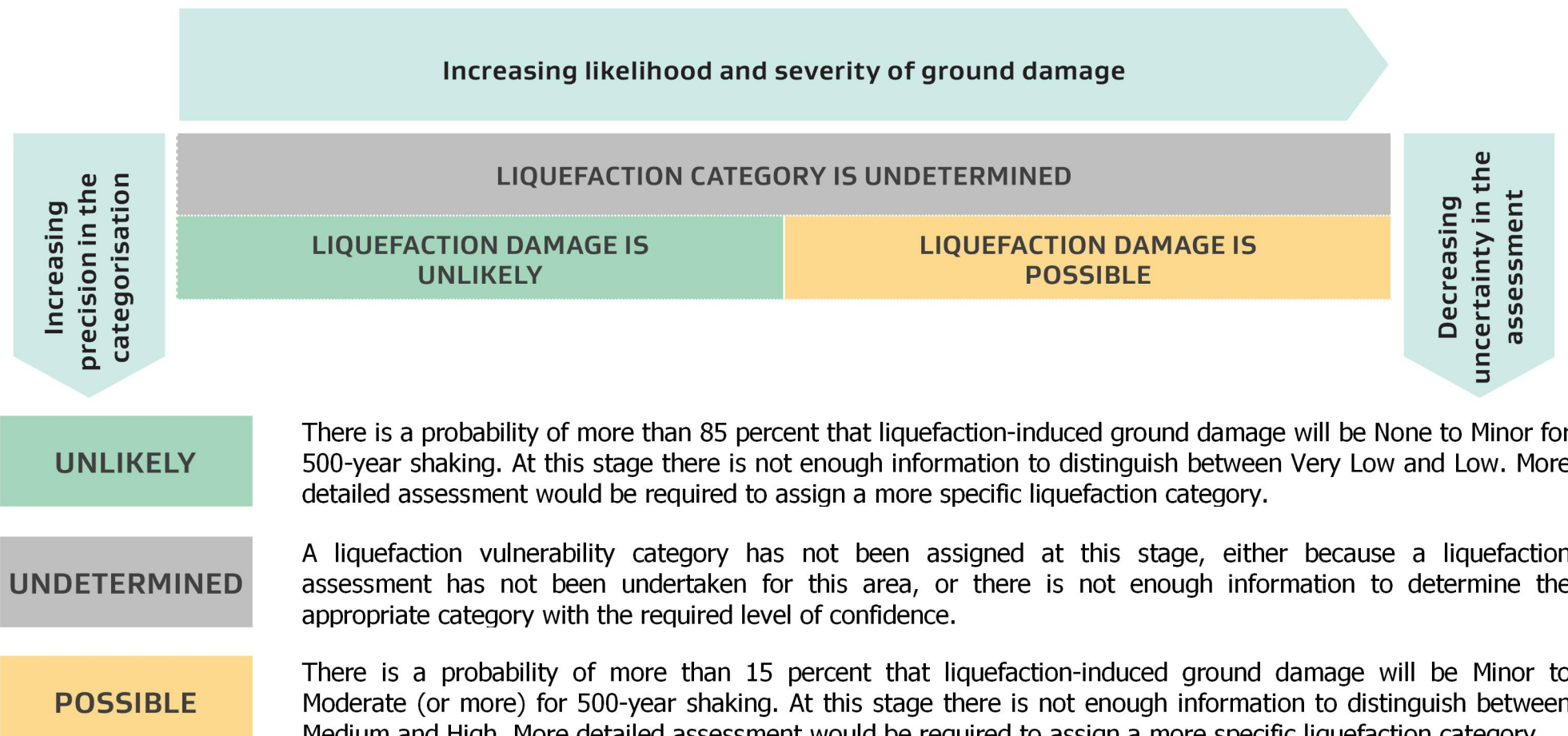
For this liquefaction vulnerability study sub areas of similar expected performance were created by grouping areas of land according to the following characteristics that tend to govern liquefaction risk; geology, topography / land form and groundwater (including mapped water courses and water bodies).

This generalised procedure was used to create the map (see accompanying report for details): First, by combining the elevation (1) and generalised geology (2) maps to determine geomorphic terrains.

Next, these terrains were further assessed into landforms to help understand their susceptibility to liquefaction through topographic analysis using elevation (1) thresholds.

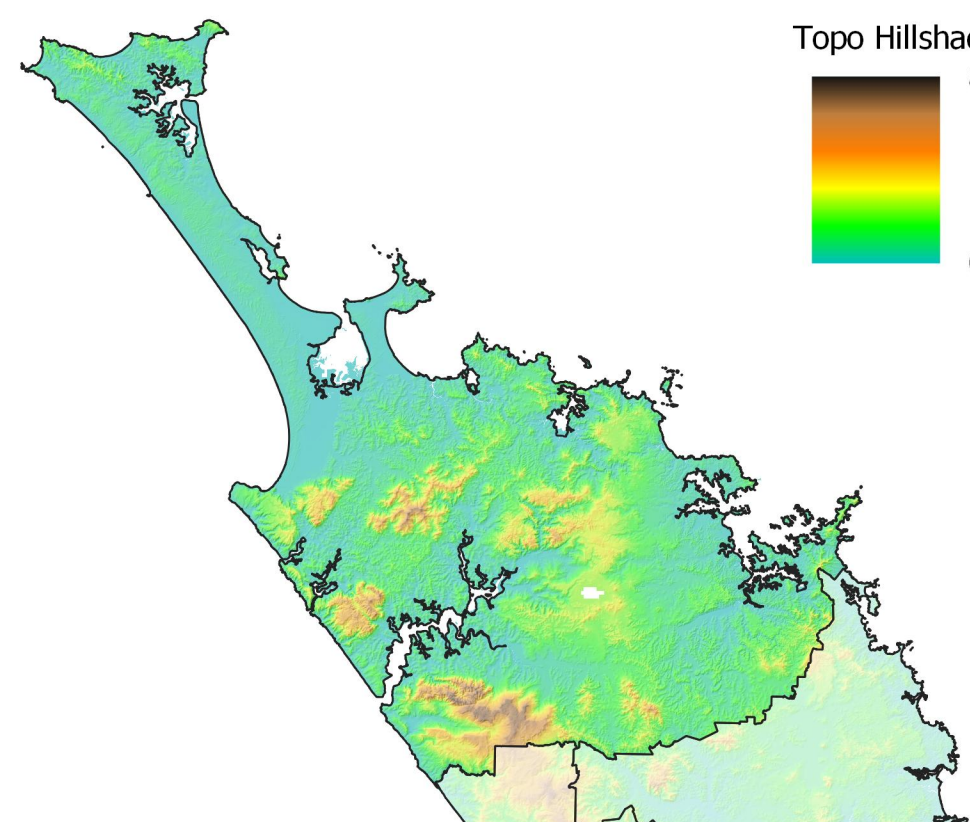
Then the stream, lakes, and wetland (3) data set was used to assess the potential for elevated groundwater conditions and potential for lateral spreading to establish the final liquefaction vulnerability overview map categories.

Liquefaction Vulnerability Categories



1 Elevation Map (lidar derived 10-m DEM)

Low laying areas are more likely to have ground and ground water conditions that present a liquefaction hazard.



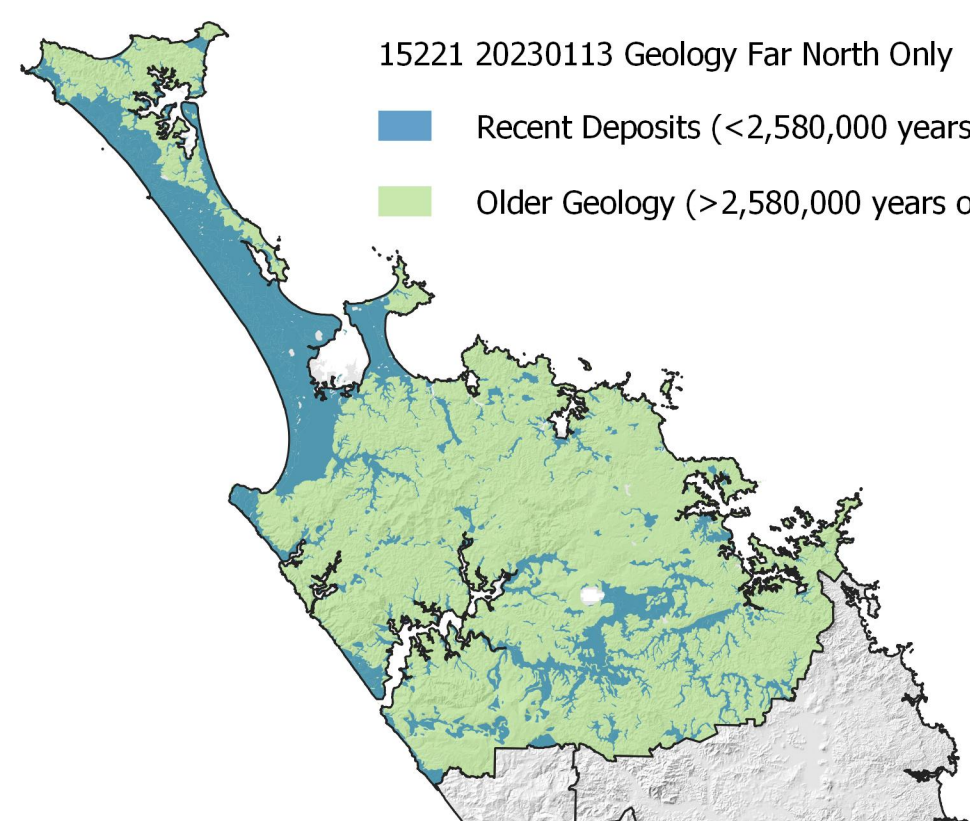
Data Source:

LIDAR was captured for the Northland Region LIDAR Project carried out on behalf of Northland Regional Council (NRC) by RPS Group between December 2018 and July 2019, subsequent flights were conducted in February 2020.

This LIDAR was interpolated as hill-shade models to aid in the assessment of geomorphic land forms such as hilltops, ridges, and valleys.

2 Generalised Geology Map (2357 generalised geologic features)

More recent geological deposits are more likely to have characteristic properties that are consistent with liquefaction potential.

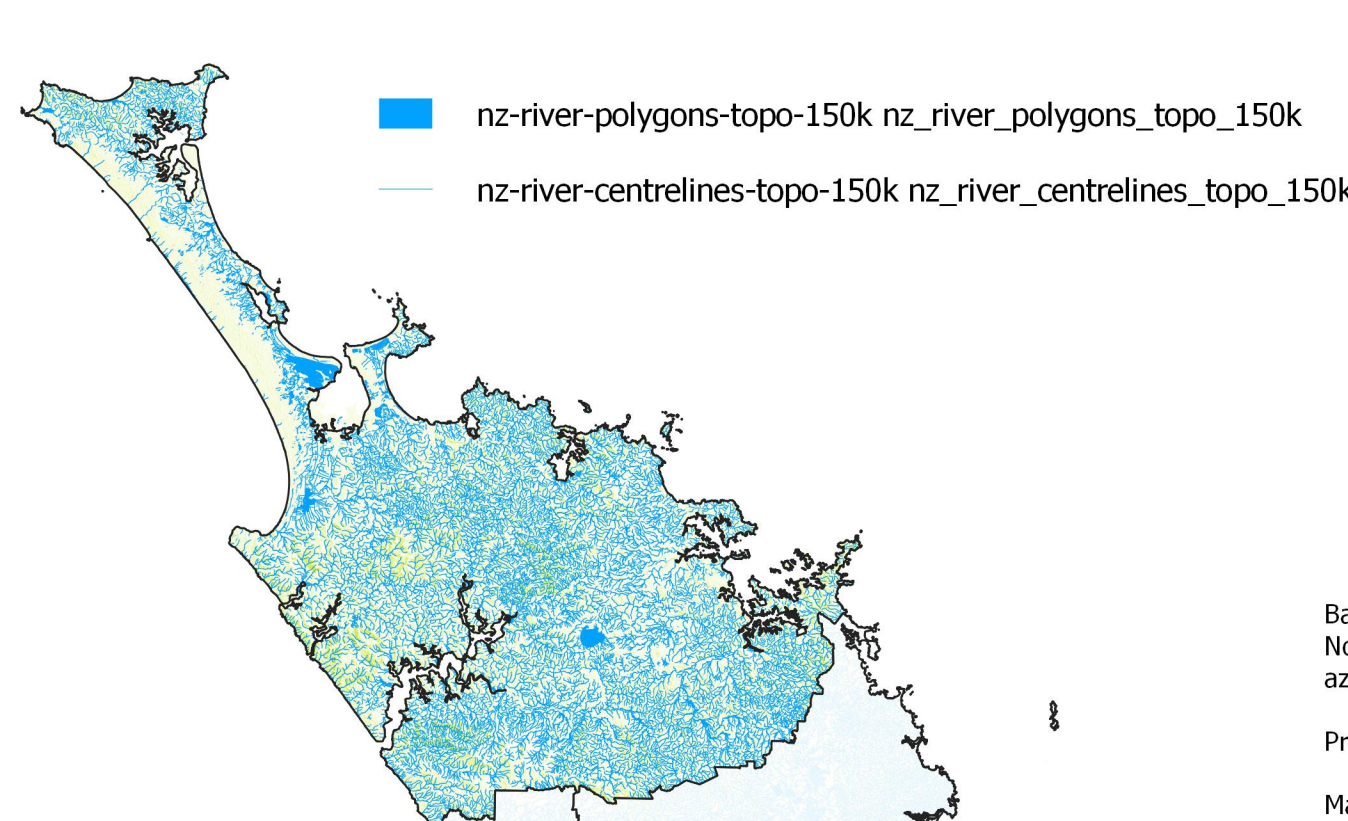


Data Source:

This project uses the digital version of the 1:250,000 geological maps along with the accompanying text books for the Geology of the Kaitia Area (Isaac 1996) and the Geology of the Whangarei Area (Edbrooke and Brook 2009). The maps present geology at a regional scale and include descriptions of the mapped geological units. The geological units present within the district range from recent anaphoric deposits (fill) and Holocene beach deposits to Jurassic age Waipapa Group.

3 Streams, Lakes and Wetlands Map

Liquefaction has a greater potential for being triggered on land with a high groundwater table.



Data Source:

Land Information New Zealand Topo50 map series including drains, canals, rivers, ponds, lakes, swamps and lagoons.

LOCATION MAP



SCALE 1:250,000

0 20,000 40,000 60,000 80,000 m

0 20 40 60 80 100 km

Cartography by Ben Perry, Vision Consulting Engineers Limited.
This map benefited from review by Grant Murray, Grant Murray and Associates Limited.

WHAT TRIGGERS LIQUEFACTION?

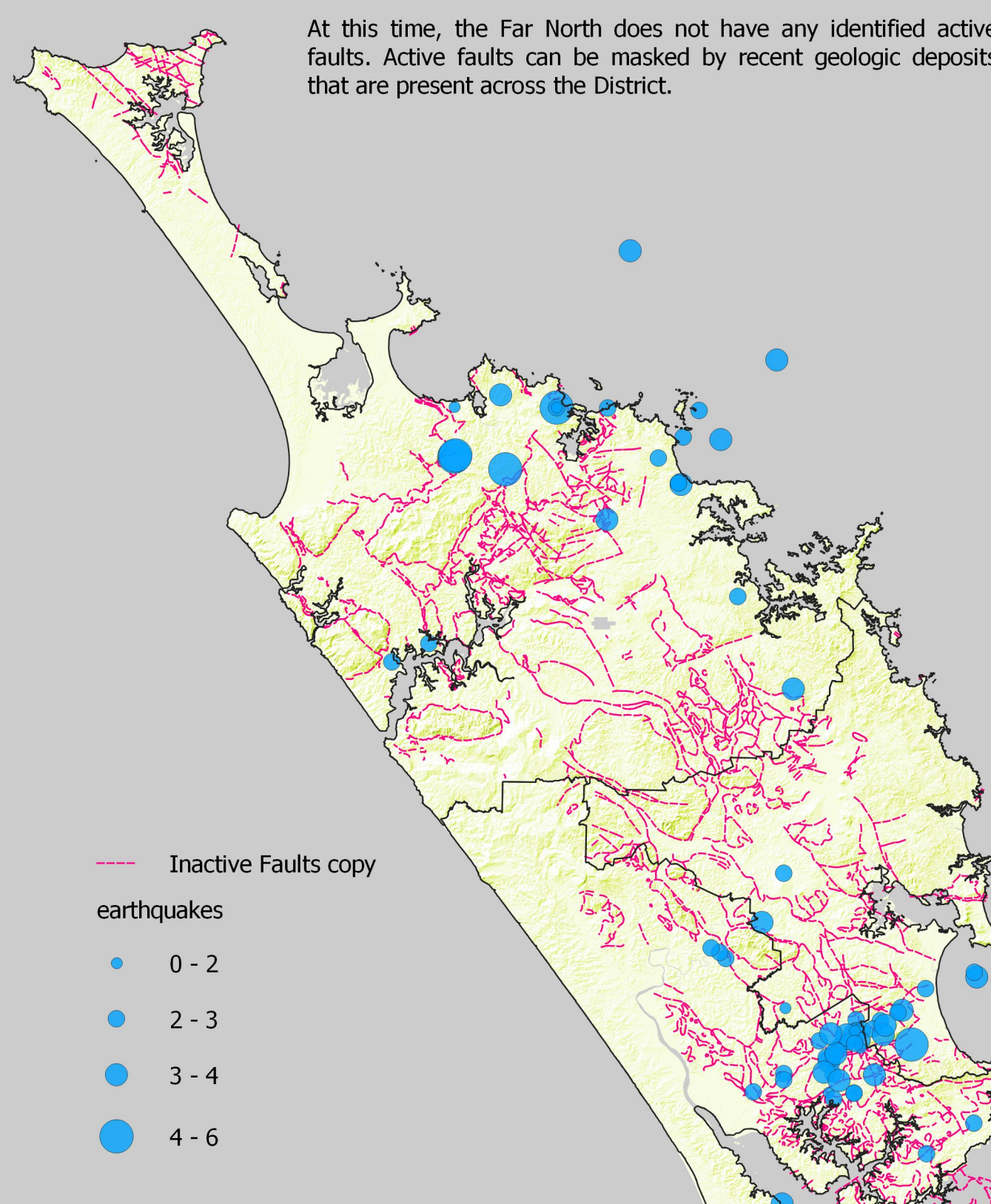
Liquefaction occurs when intense shaking of saturated loosely-packed sediments near the ground's surface lose strength and behave similar to a liquid.

- Three key elements are all required for liquefaction to occur:
- 1 Loose non-plastic soil (typically sands and silts, or in rare cases gravel)
 - 2 Saturated soil (ie below the groundwater table)
 - 3 Sufficient ground shaking (a combination of the duration and intensity of shaking)



The seismic risk in the Far North is generally considered to be low compared to the rest of the country. This is because the Far North does not contain active faults however this does not mean that the Far North does not experience earthquakes. The map below shows both the known inactive faults and recorded earthquakes in and around the Far North.

At this time, the Far North does not have any identified active faults. Active faults can be masked by recent geologic deposits that are present across the District.



INFORMATION

This map is part of a Hazard Assessment report prepared for the Far North District Council. The map and accompanying report were prepared by Vision Consulting Engineers Limited (VISION) of Kerikeri, New Zealand. VISION can be contacted via email at info@vce.co.nz or through the following website:

www.vce.co.nz

VISION project reference J15221