Sensitivity: General

Tahunanui Level B Liquefaction Assessment

Prepared for Nelson City Council
Prepared by Beca Limited

13 April 2022

Contents

Appendices

Revision History

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1	Sarah Barrett	Draft for client comment	14 April 2022
2	Sarah Barrett	Final	25 August 2022

Document Acceptance

Action	Name	Signed	Date
Prepared by	Sarah Barrett		25/08/2022
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on behalf of	Beca Limited		

Executive Summary

Beca Ltd (Beca) has been commissioned by the Nelson City Council (NCC) to complete a liquefaction vulnerability assessment of the Tahunanui area to a 'Level B – Calibrated Desktop Assessment' level of detail as per the joint MBIE/ MfE (2017) '*Planning and engineering guidance for potentially liquefaction-prone land'* guidance. This Level B assessment is a refinement of the regional "Level A – Basic Desktop" liquefaction assessment completed for the Nelson region by Beca (2021) .

The study area covers the low-lying area of Tahunanui between Tahunanui Beach and the abandoned sea cliff near Monaco. The 1:250,000 geological map (QMap; Rattenbury et al. 1998) and 1:25,000 map (Johnston, 1979) identifies the area as underlain by Holocene sand dune deposits and ocean beach deposits associated with sea level regression. The liquefaction susceptibility of these deposits was identified in the regional liquefaction assessment by Johnson (2013) which used geologic descriptions, geomorphology, and local experience. Tonkin and Taylor (2013 and 2014) further assessed the susceptibility of these deposits using quantitative assessments of geotechnical data. The 2013 study confirmed that Tahnuanui contains deposits susceptible to liquefaction while the 2014 study concluded that the effects of liquefaction would be lower in the north-eastern part of Tahunanui which is underlain by Muritai Gravels. Johnson (2017) subsequently recommended that the area mapped as Tahunanui Sand in 1:25,000 geologic map (Johnson 1979) be included in a "liquefaction planning overlay' with area underlain by 'Muritai gravels' excluded from the overlay. These assessments were completed prior to the MBIE/MfE (2017) guidance. The Beca (2021) regional 'Level A' desktop assessment further identified the deposits in Tahunanui area as 'Liquefaction damage is possible' based on the geologic setting and description of the underlying soils. The assessment did not include quantitative analysis as (i) this is not required for that level of assessment, and (ii) there is insufficient coverage of geotechnical data for a regional assessment.

The MfE/MBIE (2017) guidance presents four levels of assessment detail ranging from a 'Level A' basic qualitative desktop study to a 'Level D' site-specific quantitative liquefaction assessment. A Level B assessment considers geologic, geomorphic, and ground investigation data supplemented with quantitative liquefaction assessments to estimate the degree of liquefaction-induced ground damage for selected earthquake scenario(s). The assessment aims to identify areas of consistent ground performance which are classified according to the land damage criteria outlined in Figure 0-1. Liquefaction vulnerabilities (i.e. *Very Low, Low, Medium* or *High*) may be assigned where there is sufficient information on the predicted land damage.

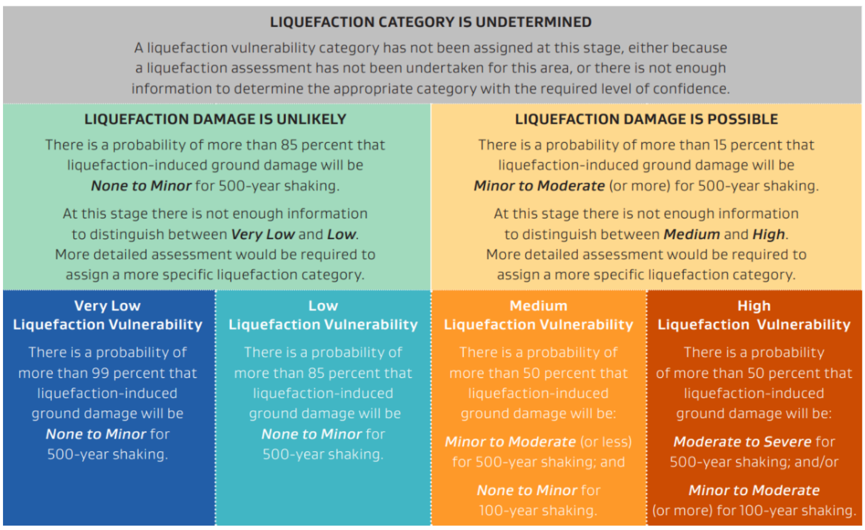


Figure 0-1: Performance criteria for determining the liquefaction vulnerability category from the joint MfE/MBIE guidelines for Level A, B, C, and D assessments.

Our Level B assessment of the Tahunanui area was completed as a desktop exercise using ArcGIS Pro at a scale of 1:15,000 and considered the following aspects:

- Ground model of anticipated ground conditions developed from geologic, geomorphic, and ground investigation data available from the New Zealand Geotechnical Database (NZGD).
- Quantitative liquefaction assessments of cone penetration tests (CPT) from the NZGD to assess the degree of liquefaction-induced ground damage predicted for 500-year, 100-year, and 25-year earthquake scenarios using groundwater levels adopted from investigation data.
- Liquefaction vulnerability classes were assigned for each CPT using the predicted liquefaction-induced ground damage for the selected earthquake scenarios and using the criteria outlined in Figure 0-1.
- Assigned liquefaction vulnerability categories for each CPT were compared with the ground model to identify areas of consistent expected ground performance which were assigned the corresponding liquefaction vulnerability category.

The map output is shown in Figure 0-1 and differentiates areas of 'High Liquefaction Vulnerability' and 'Medium Liquefaction Vulnerability' from areas where 'Liquefaction Damage is Unlikely' and where 'Liquefaction Damage is Possible'.

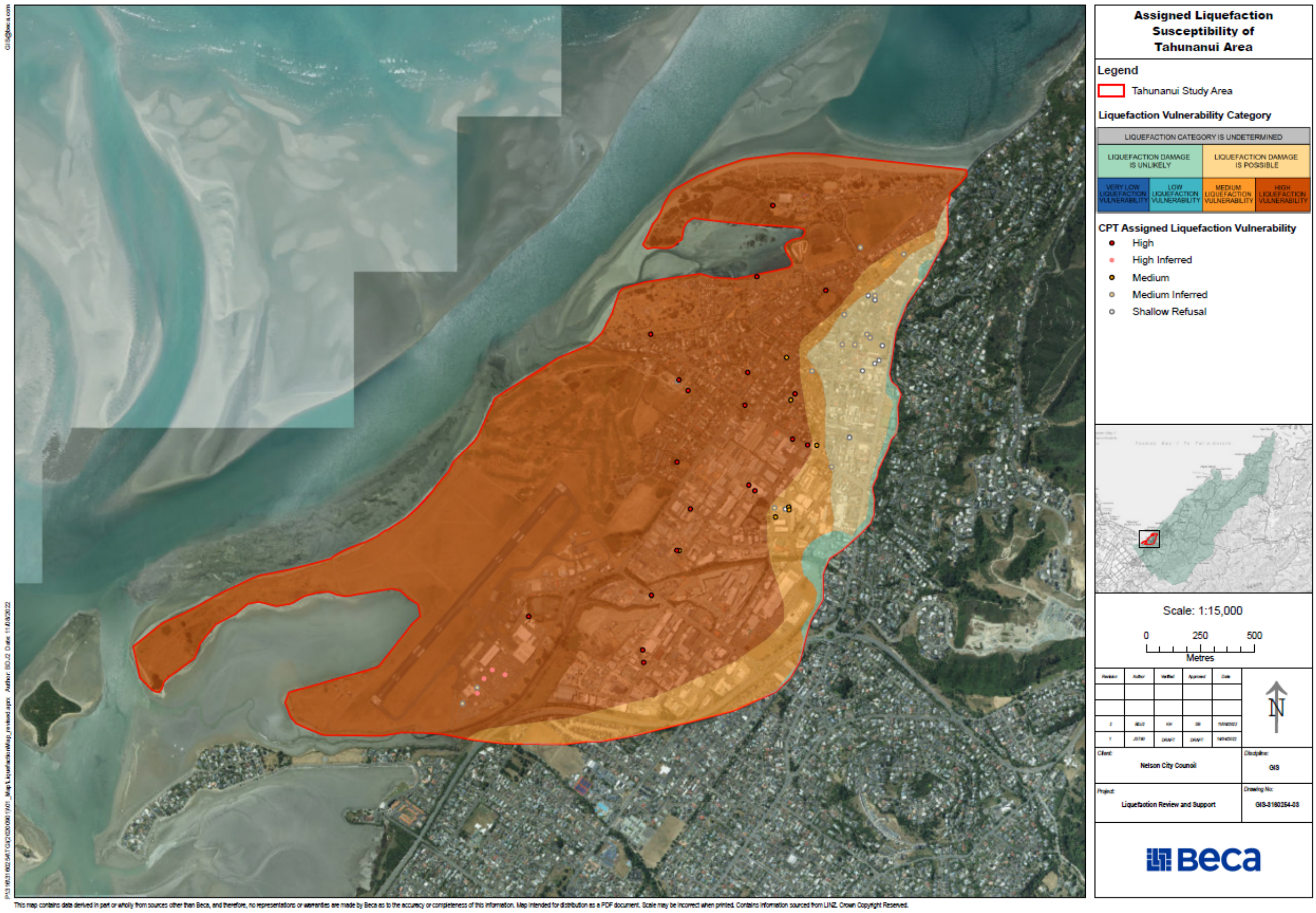


Figure 0-1: Assigned liquefaction susceptibility of Tahunanui area

- *High Liquefaction Vulnerability'* assigned for areas underlain by loosely consolidated sands to silts where the water table is generally <1.5m below ground level (Tahunanui Sands).
- *Medium liquefaction vulnerability'* assigned for:
  - Areas underlain by loosely consolidated sands to silts (Tahunanui Sands) at elevations >4m asl and where the CPT traces suggests the deposits may be locally interfingered with Rabbit Island Gravels.
  - Areas mapped as Rabbit Island Gravels in 1:25,000 geologic map by Johnson (1979) and comprising loosely consolidated sands to gravels where the water-table is 1.0 to 1.5 m bgl.
- *'Liquefaction damage is possible*' assigned for the area identified as Muritai Gravel by Tonkin and Taylor (2014) where the geotechnical investigations are too shallow to adequately predict the range of liquefaction-induced surface effects. The age, geologic description, and inferred depth to groundwater means that the susceptibility of these deposits cannot be discounted without geotechnical testing.
- *'Liquefaction damage is unlikely'* assigned to areas mapped as Stoke Fan Gravels in Johnson (1979) where the geologic description and age indicates that these deposits are unlikely to be susceptible to liquefaction however the susceptibility cannot be refined due to a lack of geotechnical data.

The level of assessment detail is considered sufficient to inform resource management plans and meets the requirements placed on NCC under the November 2019 updates to the Building Code relating to the identification of areas potentially susceptible to liquefaction. The map output is not a replacement for site-specific liquefaction assessments and contains residual uncertainties associated with variations in the map scales used in the assessment and inherent errors and limitations in the input datasets. NCC may consider collecting additional geotechnical data to further characterize and assess the liquefaction vulnerability of the Muritai and Stoke Fan Gravels. Additional sensitivity analyses considering the impacts of sea level rise on the assigned liquefaction vulnerability may be considered by NCC to cover the timeframe considered by planning provisions. The MfE/MBIE (2017) guidance outlines how the result of the liquefaction assessment can be incorporated into resource management plans.

1 Introduction

Beca Ltd (Beca) has been commissioned by the Nelson City Council (NCC) to complete a liquefaction vulnerability assessment of the Tahunanui area to a 'Level B – Calibrated Desktop Assessment' level of detail as per the joint MBIE/ MfE (2017) '*Planning and engineering guidance for potentially liquefaction-prone land'* guidance This assessment is a refinement of the regional "Level A – Basic Desktop" liquefaction assessment completed for the Nelson region by Beca and covering only the Tahunanui area (Beca, 2021).

This report outlines the methodology and assumptions of our Level B assessment and covers the following aspects as outlined in our proposal dated 1 December 2021:

- Detailed geomorphic assessment of the Tahunanui area to identify local features of relevance to the liquefaction assessment
- Review of existing deep geotechnical investigation data available on the New Zealand Geotechnical Database.
- Review of existing information on the depth to groundwater in the Tahunanui area
- Assessment of design seismic events to inform the quantitative liquefaction assessment.
- Quantitative liquefaction assessment of the subsurface deposits in the Tahunanui area.
- Review of the assigned liquefaction susceptibility of the deposits in the Tahunanui area considering the results of the quantitative liquefaction assessment and detailed geomorphic assessment.
- Produce a GIS map outlining the results of the Level B assessment.

The output of our assessment is a map outlining the assigned liquefaction vulnerabilities of the Tahunanui study area in accordance with the MBIE/ MfE (2017) guidance. Maps showing the results of our assessment are presented in Section 3 and Appendix B results of the quantitative liquefaction assessment are presented in Appendix A. The output of the assessment meets the requirements placed on NCC under the November 2019 updates to the Building Code to identify areas potentially susceptible to liquefaction where standard foundation options (B1 Acceptable Solution B1/AS1) are no longer able to be applied.

1.1 Geologic Setting

Our assessment covers the low-lying area extending from Tahunanui Beach in the north to the abandoned sea cliff between the SH6 roundabout at Annesbrook and Monaco spit in the south and extending inland to the base of the Port Hills. The 1:250,000 geological map of the Nelson area (QMap; Rattenbury et al. 1998) identifies the area adjacent to the active coastline as underlain by Holocene sand dune deposits with Holocene ocean beach deposits mapped inland from the coast and extending to the base of the Port Hills. Localised reclamation fill is shown within the airport boundary.

The 1:25,000 scale geological map of the Nelson urban area (Johnston, 1979) presents more detail on the geologic units in the study area and is shown in Figure 1-1. The map identifies the following deposits:

- Rabbit Island Gravel (qt) comprising pebbles, cobbles, and boulders that form beach ridges sub-parallel to the present coastline and present at the base of the Port Hills. These sediments were deposited during sea level regression following the mid-Holocene high stand which formed the sea-cliff at Monaco approximately 7,000 years before present.

- Tahunanui Sand (qt) which consists of loose beach sand, gravel ridges, sand dunes, and local estuarine and swamp deposits including peat. These deposits reflect regression of the coastline to its present location and are mapped in the low-lying area near the present coastline. The contact with Rabbit Island Gravel is considered transitional over at least 50m. Beach and dune ridge morphologies have largely been destroyed by development in the area.
- Reclamation fill (xd) consisting of hard and domestic fill is shown to be locally present near the airport.
- Swamp and infilled swamp deposits are locally mapped within the Tahunanui Sand and generally correspond with active and former stream channels including the former estuary at the mouth of Jenkins Creek.
- Stoke Fan Gravel (Us3) consisting of poorly sorted clay-bound platy gravel which are present on the alluvial fan of Jenkins Stream at the mouth of Marsden Valley.

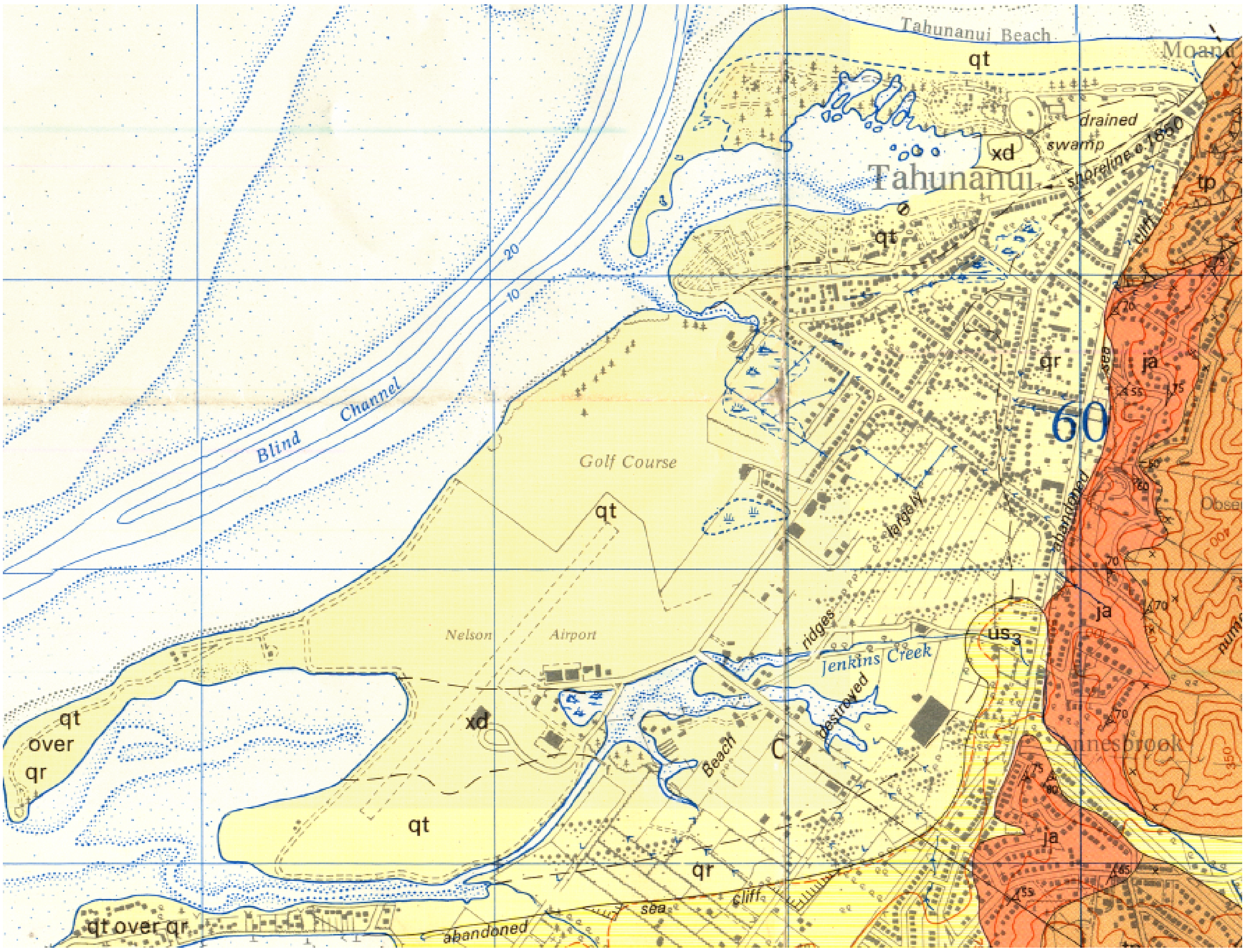


Figure 1-1: 1:25,000 geological map of the Tahunanui area by Johnson (1979).

1.2 Previous Liquefaction Assessments

The liquefaction susceptibility of the deposits in the Tahunanui area was initially identified in the Nelson regional assessment completed by Johnson (2013) which considered geologic descriptions, geomorphology, and local experience. Tonkin and Taylor further assessed the susceptibility of these deposits in 2013 and 2014. The 2013 study confirmed that the area contains deposits susceptible to liquefaction with liquefaction induced settlements expected to be:

- Between 5 and 25mm during an SLS (Serviceability Limit State) seismic event and
- Between 130mm and 290mm during an ULS (Ultimate Limit State) event.

Lateral spreading was predicted to occur during a ULS seismic event and was anticipated to extend 100 to 200m inland from the active coastline and waterways. The 2014 study further assessed the liquefaction potential of the sediments in the north-eastern part of the Tahunanui area where the 2013 assessment indicated a reduced thickness of sediments with a high liquefaction potential. The assessment identified this area as containing gravels locally named the ‘Muritai gravel’ and confirmed that the effects of liquefaction in this area would be lower with settlements of between 0 and 10mm predicted for a SLS seismic event and between 0 and 100mm for a ULS seismic event. Johnson (2017) proposed that the area predominantly underlain by Tahunanui Sand be included in a liquefaction planning overlay with the area underlain by Rabbit Island Gravels excluded from the overlay. These assessments were completed prior to the MBIE/MfE (2017) guidance.

A regional liquefaction assessment was completed for the Nelson region in accordance with a ‘Level A – Basic Desktop’ assessment as per the MfE/MBIE (2017) guidance by Beca (2021). The assessment was completed as a desktop exercise considering regional and local geological maps, geomorphology inferred from ground elevation datasets and aerial imagery, and previous liquefaction assessments. The assessment aimed to differentiate areas where liquefaction damage is ‘possible’, and which warrant further consideration in land development planning, from land where liquefaction damage is ‘unlikely’. Areas identified as containing loosely consolidated saturated sands, silts, and gravels, such as Tahunanui were classified as ‘Liquefaction Damage is Possible’. The level of assessment detail did not consider soil types inferred from geotechnical testing nor did it include quantitative liquefaction assessments due to the lack of regional coverage of geotechnical data and as this level of detail is not required for a Level A assessment.

2 Liquefaction Assessment Methodology

The MfE/MBIE (2017) guidance presents four levels of assessment detail that are intended to assist regional and territorial/district authorities in managing liquefaction related risk in land use planning and development. The guidance is considered current industry practice and was developed following recommendations made by the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquakes.

The assessments range from a 'Level A' basic qualitative desktop study to a 'Level D' site-specific quantitative liquefaction assessment. The assessments aim to identify the expected range of ground performance according to the matrix shown in Figure 2-1and which correspond to the liquefaction land damage categories shown in Figure 2-2. The key difference between the levels of assessment is the level of detail and the degree of residual uncertainty in the assigned liquefaction category. Level A assessments aim to differentiate areas where 'Liquefaction Damage is Possible' from areas where 'Liquefaction Damage is Unlikely' at a regional scale (see Figure 5-1). Level C and D assessments aim to assess the liquefaction vulnerability of a given area or site and assign the area as 'Very Low', Low, Medium, or 'High' Liquefaction Vulnerability as shown in Figure 2-1. A Level B assessment sits between the two levels of detail and aims to identify the liquefaction susceptibility of a given area and refine this to a vulnerability category where there is sufficient information from geologic, geomorphic, and ground investigation data supplemented with a quantitative liquefaction assessment.

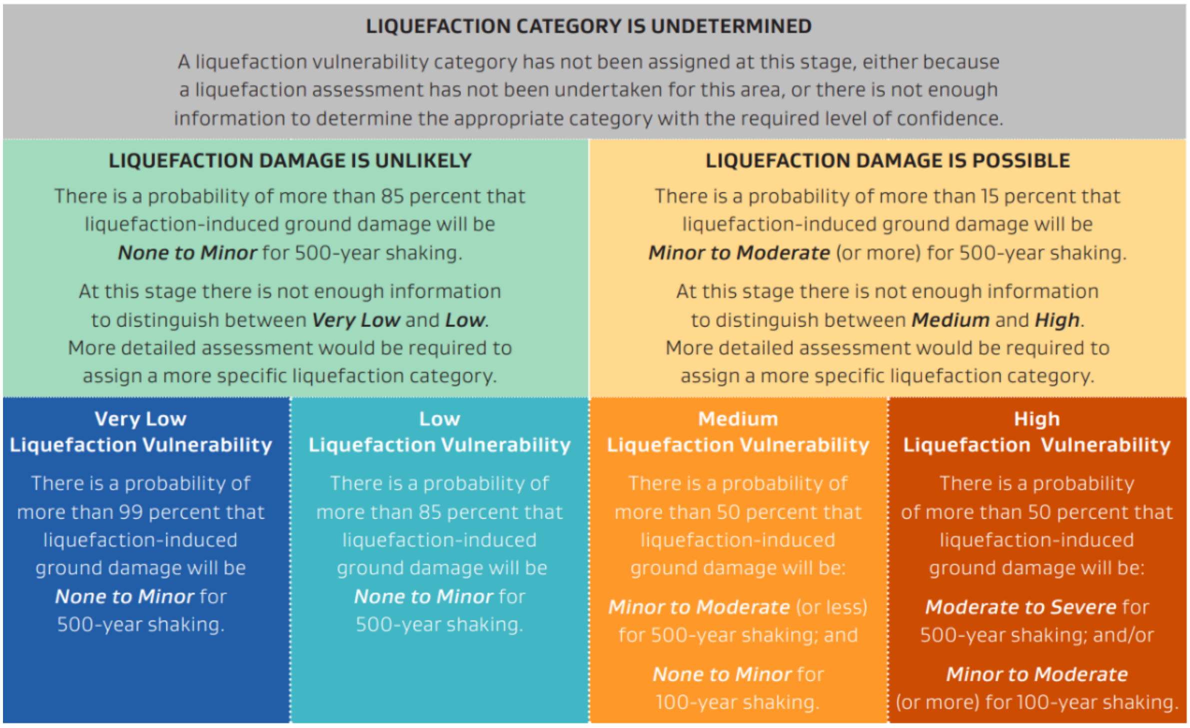


Figure 2-1: Performance criteria for determining the liquefaction vulnerability category from the joint MfE/MBIE guidelines for Level A, B, C, and D assessments.

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

Figure 2-2: Degrees of liquefaction-induced ground damage taken from the MfE/MBIE guidelines and corresponding to the damage described in Figure 4-1.

2.1 Tahunanui Ground Model

A ground model of the Tahunanui study area was developed from detailed geomorphic mapping, depths to groundwater, and geotechnical data available from the New Zealand Geotechnical Database (NZGD). The ground model aimed to characterise spatial variations in the subsurface ground conditions which may result in variations in the predicted liquefaction-induced ground damage. Input datasets used to develop the ground model are summarised below.

- Geomorphic mapping of the Tahunanui area was completed as part of the Level B assessment and presented in Appendix A. Mapping was completed at a scale of 1:10,000 in ArcGIS Pro and considered the datasets listed below:
  - The 1:25,000 scale geologic map of the Nelson urban area by Johnson (1979) which outlines the inferred extents of Tahunanui Sand and Rabbit Island Gravel along with local features such as areas of reclamation filling, swamp deposits, and/or abandoned stream channels. The scale of mapping means that mapped boundaries do not always precisely align with features observable in the aerial imagery and elevation datasets (i.e. stream banks).
  - Hillshade model created from a 1m resolution Digital Elevation Model (DEM) and supplied by NCC. The dataset highlights topographic variability that assists with identifying geomorphic features such as stream channels, depressions associated with former swamps, and topographic features representing active and paleo-dune fields and beach ridges.
  - 1948 aerial imagery which was downloaded from Retrolens (https://retrolens.co.nz/) . The imagery outlines the position of dune ridges, stream channels which have since been infilled or re-aligned, extents of swamp-land, and the position of the abandoned sea-cliff at Monaco.
- Geotechnical borehole and Cone Penetration Test (CPT) data were downloaded from the New Zealand Geotechnical Database and compared with the mapped geology and geomorphology to identify typical subsurface soil types and spatial variability across the area.

The geomorphic settings and typical soil types identified from our review of the available data sources is summarised in Table 2-1.

Table 2-1: Summary of geomorphic settings and ground conditions encountered in the Tahunanui study area

Setting	Description/ Location	Geotechnical data	Inferred soil type	Inferred depth to groundwater (m bgl)
Active beach deposits	Adjacent to the active coastline	N/A	Loose sand to gravel	<1.0m
Relic beach ridges	Recognisable in the 1948 aerial imagery as trending subparallel to the sea-cliff at Monaco and present in area mapped as Tahunanui sand. These have largely been destroyed by development in the area and individual features are not recognisable in the DEM.	Lumped as Tahunanui Sand; individual features not identified	Sand underlain by gravel at between 9 to 15m depth	Variable from <1.0m to 1.5m
Back beach swamps	Inferred between the relic dune ridges however individual features not recognisable.		Inferred to contain soft sand to silt and/or localised peat deposits underlain by beach sand.	
Active and abandoned stream channels	Adjacent to Jenkins Creek and partially infilled stream to the south of Tahunanui estuary.	N/A	Inferred to contain loose sands to silts	Inferred as ≤1.0m adjacent to the coast to ≥1.8m near Port Hills.
Active and relict sand dunes	Active dunes located along the Tahunanui spit with relict dune field present in Nelson golf course and near airport.	N/A	Inferred as clean sand to gravel underlain by sand to gravels comprising beach deposits.	≤1.0m to 1.5m
Active and former swamps	Mapped by Johnson (1979) as locally present adjacent to abandoned stream channels however destroyed by development.	N/A	Loosely consolidated sand, silt, and/or peat underlain by beach and marine sand to gravel	Inferred as ≤1.0m adjacent to the coast to ≥1.8m inland.
Alluvial fan at base of Port Hills	Base of Port Hills near Muritai Street and identified as Muritai gravel by Tonkin and Taylor (2014).	CPT which refuse on shallow gravel layer at between 2.2 and 6.5m bgl.	Loosely consolidated gravel sourced from Port Hills underlain by Rabbit Island Gravels	1.8 to 2.0m
Jenkins Creek Alluvial fan	Associated with Jenkins Creek at the mouth of Marsden Valley	Boreholes	Clay bound gravel	>2.0m

2.2 Groundwater Scenarios

Liquefaction requires susceptible soil be saturated and therefore is directly related to groundwater level. A groundwater model is not available for the Tahunanui area however observations of groundwater levels are available for previous geotechnical investigations on the NZGD.

Reported groundwater for CPT available on the NZGD were spatially plotted in ArcGIS and overlain with the DEM to identify trends across the study area. The reported values indicate that groundwater generally falls to the north-west from approximately 2m at the base of the Port Hills near Muritai Street to approximately 0.8m near Tahunanui Beach. Inferred depths to groundwater for the geologic and geomorphic units identified in the Tahunanui area are summarised in Table 2-1. Tidal variations are expected in groundwater levels adjacent to the coast while groundwater near the base of the Port Hills may be subject to seasonal fluctuations.

Groundwater levels recorded with the CPT were adopted for the quantitative liquefaction assessment. CPT with no reported groundwater depths were assigned representative groundwater values based on proximal values and ground surface elevations. It is noted that the measurements were generally taken by the CPT operator after testing when groundwater may not have become static. Values were spot-checked with that reported for other testing on the NZGD and compared with ground surface elevations.

Rising sea levels will also cause groundwater levels to rise which may increase the surface effects of liquefaction where more susceptible sediments are saturated. The impacts of sea level rise on groundwater levels in Tahunanui was not assessed as part of this assessment.

2.3 Seismic Hazard

Liquefaction assessments need to consider the probability that a given shaking intensity will occur over land use planning horizons. The following scenarios are considered for the Tahunanui liquefaction assessment:

- 500-year earthquake scenario which represents an intensity of shaking that is considered to have a low likelihood of being exceeded within the land use planning horizon. This scenario aligns with the Ultimate Limit State (ULS) design case for most 'normal' buildings as specified in the New Zealand Standard for structural design actions (NZS 1170.0:2002).
- 100-year earthquake scenario which represents an intensity of shaking that is considered to have a high likelihood of occurring within the land use planning horizon.
- 25-year earthquake scenario which generally aligns with the Serviceability Limit State (SLS) design case specified in the standard for structural design actions (NZS 1170.0:2002). This scenario focuses on the potential for loss of amenity during the lifetime of the building.

Recommended ground motion parameters for these earthquake scenarios are provided in Module 1 of the Earthquake geotechnical engineering practice guidance (NZGS/MBIE, 2021a) and are listed in Table 2-2. These ground motion parameters are recommended for all site classes and were defined for the Nelson region using the hazard definition methodology in the NZTA-Bridge Manual (NZTA, 2018).

Table 2-2: Recommended peak ground acceleration and earthquake magnitudes for the Nelson area

Earthquake return period	Earthquake Magnitude (Mw)	PGA (g)
25-year	6.1	0.10
100-year		0.20

500-year		0.41

2.4 Quantitative Liquefaction Assessment

Quantitative liquefaction assessments identify the range of liquefaction-induced ground damage predicted for selected earthquake scenario(s) from geotechnical data. These results may be extrapolated across similar geologic and/or geomorphic setting where there is insufficient or lacking geotechnical data.

A quantitative liquefaction assessment was completed for the Tahunanui area in accordance Module 3 of the Earthquake geotechnical engineering practice guidance (NZGS/MBIE, 2021b). The assessment aimed to identify the range of liquefaction-induced damage predicted for the Tahunanui area for the 25, 100, and 500-year seismic events listed in Table 2-2. The CPT available on the NZGD were assessed using the Boulanger and Idriss (2014) simplified liquefaction triggering methodology with a probability of liquefaction (PL) of 15% and the assigned representative depths to groundwater. Ground surface settlements were predicted from the results of the triggering assessment using Zhang et al. (2002) while the surface effects of the predicted liquefaction were assessed through the Liquefaction Potential Index (LPI; Iwasaki et al., 1978) and Liquefaction Severity Number (LSN; van Ballegooy et al., 2014).

Locations of the CPT considered in the assessment are shown in Appendix A and results of the assessment are presented in Appendix B. The density of investigations within the Tahunanui Sand and Rabbit Island Gravels meets the minimum recommended density for a Level B assessment of 3 investigations for each geological sub-unit with a minimum depth of 10m. The Muritai Gravel and Stoke Fan Gravels do not have the recommended density of investigations.

2.5 Estimated degree of liquefaction-induced ground damage

The MBIE/MfE Guidance (2017) describes three degrees of liquefaction-induced ground damage which correspond to ranges of predicted ground surface settlements, LPI, and LSN as outlined in Table 2-3. The categories in Table 2-3 are coloured to match that used for the corresponding damage categories shown Figure 2-2. The MBIE/MfE (2017) guidance presents a flow chart (Figure 2-3) and conceptual ground damage curves (Figure 2-4) which correlate the predicted liquefaction-induced damage to the liquefaction vulnerability categories.

Table 2-3: Land Damage Categories identified in MfE/MBIE (2017) guidance

Degree of liquefaction-induced ground damage	Description	Corresponding Values
None to Minor	No observed liquefaction-related land damage through to minor observed ground cracking but with no observed ejected liquefied material at the ground surface	Settlement = <25mm LSN = <20 LPI =<5
Minor to Moderate	Observed ground surface undulation and minor-to-moderate quantities of observed ejected liquefied material at the ground surface but with no observed lateral spreading	Settlement = 25 - 100mm LSN = 20-40 LPI = 5-15
Moderate to Severe	Large quantities of observed ejected liquefied material at the ground surface and severe ground surface undulation and/or moderate to severe lateral spreading	Settlement = >100mm LSN = >40 LPI = >15

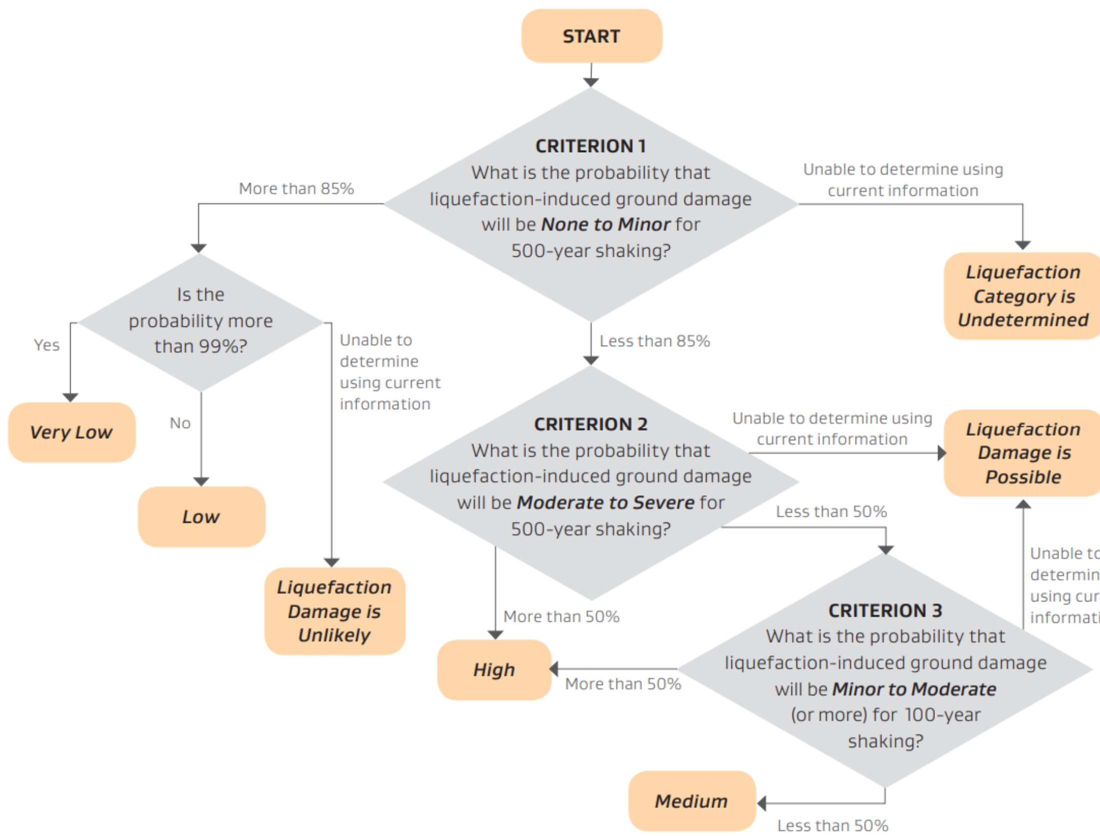


Figure 2-3: Flow chart from MBIE/MfE Guidance for determining liquefaction vulnerability categories

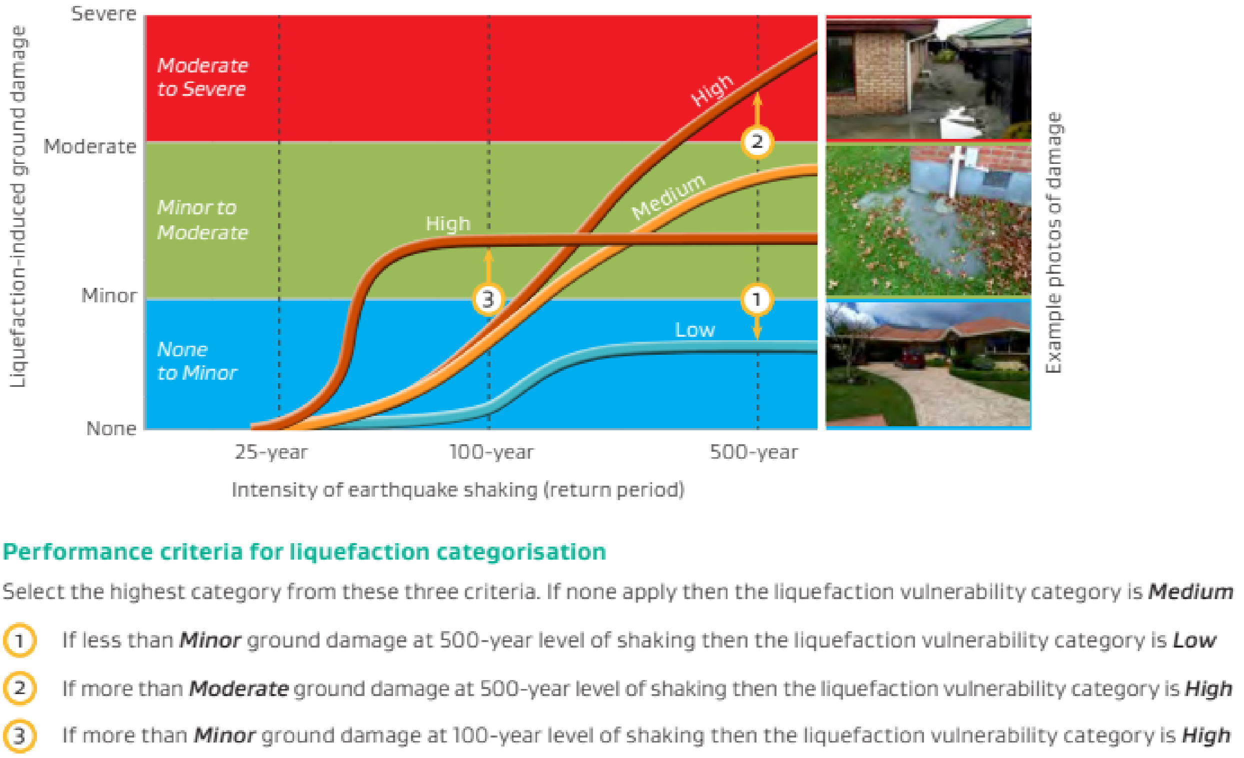


Figure 2-4: Conceptual example of ground damage response curves for low, medium and high liquefaction vulnerability categories, and performance criteria used for liquefaction categorisation as per the MfE/MBIE guidance.

The liquefaction-induced ground damage predicted for each CPT for the 500-year and 100-year quantitative liquefaction assessments were compared with the performance criteria outlined in Table 2-3, Figure 2-3, and Figure 2-4 in order to determine the representative liquefaction vulnerability category. The adopted liquefaction vulnerability category for each CPT is listed in Table 2-4 along with the corresponding predicted land damage. These values were used to inform the revised liquefaction categorisation of the Tahunanui area as outlined in Section 3.

CPTs that terminated at less than 10m depth are excluded from Table 2-4 as these are considered too shallow to adequately predict the range of ground surface effects during seismic events. This is consistent with the MBIE/MfE (2017) guidance which recommends that investigations be deep enough to characterise the ground to at least 10–15 m depth below ground level for residential or light commercial development.

Table 2-4: Summary of calculated liquefaction damage parameters and assigned liquefaction vulnerability category

NZGD CPT ID	CPT Depth (m)	Ground water (m bgl)	500-year			100-year			Liquefaction vulnerability category
			Settlement (mm)	LPI	LSN	Settlement (mm)	LPI	LSN	
171651	10.0	1.0	128	21	27	90	5	17	High
171655	23.3	1.4	231	35	49	148	8	28	High
171653	26.6	1.0	204	21	41	70	1	15	High
172822	23.3	1.4	186	20	26	72	2	9	High
157910	15.4	1.7	108	12	13	33	1	4	Medium
128472	20.7	1.0	202	21	30	97	3	12	High
128856	10.0	1.0	143	25	35	109	9	25	High
171659	25.9	1.5	196	22	30	74	2	9	High
172821	18.4	1.4	116	11	12	23	0	2	Medium
171648	17.5	1.7	175	26	38	99	5	20	High
171652	18.4	1.6	160	20	21	51	1	6	High
171654	25.4	1.0	180	21	28	64	1	10	High
171656	25.4	0.7	194	20	37	81	2	12	High
121436	10.4	1.0	177	30	41	117	8	22	High
115935	13.6	1.5	68	8	10	26	1	3	Medium
115932	10.1	1.5	90	13	19	38	1	9	Medium
134847	10.3	1.0	80	12	18	38	2	6	Medium
121437	10.7	0.8	130	20	31	74	4	17	High
121438	10.0	1.7	125	18	23	75	5	13	High
105847	13.0	1.2	77	9	9	17	0	2	Medium
134845	10.8	1.0	111	17	25	60	3	10	High
115930	10.2	1.5	88	13	16	36	1	6	Medium
171649	20.0	1.0	182	20	30	101	3	17	High
105845	11.9	0.8	70	9	15	18	0	3	Medium
171202	21.0	2.0	263	30	35	139	4	15	High

3 Refined liquefaction vulnerability of Tahunanui

The refined liquefaction vulnerability of the Tahunanui area was assessed using ArcGIS Pro at a scale of 1:15,000. The assessment considered the following aspects:

- Ground model of anticipated ground conditions as developed from consideration of geologic, geomorphic, and ground investigation data (CPTs)
- Estimated degree of liquefaction-induced ground damage for the selected earthquake scenario(s) based on representative groundwater levels
- Comparison of the expected ground damage against the liquefaction vulnerability performance criteria

The liquefaction vulnerabilities assigned to each CPT were overlain with the geomorphic map to identify spatial variations across the study area. Analysis of CPTs and geomorphic boundaries were used to assign revised liquefaction categories. The liquefaction vulnerability assigned to CPT between 6 and 10m depth were additionally plotted as 'inferred' values along with the refusal depth and were used for cross-checking. CPT that refused at less than 6m depth were identified as having shallow refusal. Observations that formed the basis for the assigned liquefaction vulnerability categories are outlined below.

- Areas mapped as Tahunanui Sand in Johnson (1979):
  - CPT at elevations <4m above sea level (asl) are assigned *'High Liquefaction Vulnerability'*. This corresponds with areas underlain by loosely consolidated sands to silts where the water table is generally <1.5m below ground level. No differentiation can be made in the susceptibilities between geomorphic settings across this area due to the wide spatial distribution of geotechnical investigations.
  - CPT at elevations >4m asl and within approximately 50m of the mapped contact with Rabbit Island Gravel are assigned *'Medium liquefaction vulnerability'*. The CPT traces suggests that this band of deposits may be locally interfingered with the Rabbit Island Gravels.
- Areas mapped as Rabbit Island Gravels in Johnson (1979):
  - Deposits at the base of the abandoned sea cliff and at elevations <5m asl near the Port Hills are assigned *'Medium liquefaction vulnerability'.* This corresponds with loosely consolidated sands to gravels where the water-table is 1.0 to 1.5 m bgl.
  - The area at the base of the Port Hills and identified as Muritai gravel by Tonkin and Taylor (2014) is assigned as '*liquefaction damage is possible'*.
    - The CPT in this area refused on shallow gravel at between 2.2 to 6.5 m bgl meaning the investigations are considered too shallow to adequately predict the range of ground surface effects during seismic events.
    - The geologic map of the area suggests that these deposits are underlain by Rabbit Island Gravels comprised of sand and sandy gravels. The age and geologic description of these deposits means that the susceptibility of these deposits cannot be discounted without geotechnical testing.
    - Groundwater measurements suggest the water table in this area is ~2m below ground level indicating that the subsurface deposits are sufficiently saturated for liquefaction to occur.
- Areas mapped as Stoke Fan Gravels in Johnson (1979):
  - No CPT investigations are available for this area. The geologic description combined with the age of these deposits indicates that they are unlikely to be susceptible to liquefaction and are subsequently assigned '*Liquefaction damage is unlikely'.* No further refinement on the susceptibility of these deposits can be made due to the lack of geotechnical data.

The map output showing the assigned liquefaction vulnerabilities is presented in Figure3-1.

Assigned Liquefaction Susceptibility of Tahunanui Area

Legend

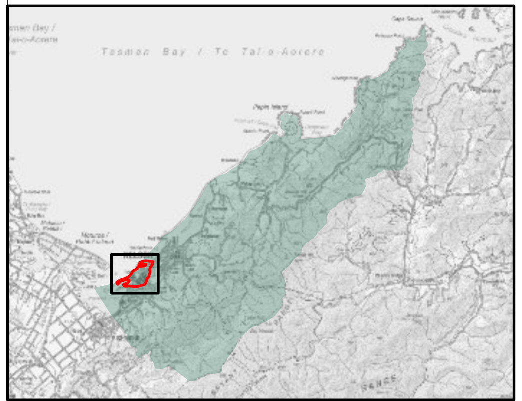
Tahunanui Study Area

Liquefaction Vulnerability Category

LIQUEFACTION CATEGORY IS UNDETERMINED			
LIQUEFACTION DAMAGE IS UNLIKELY		LIQUEFACTION DAMAGE IS POSSIBLE	
VERY LOW LIQUEFACTION VULNERABILITY	LOW LIQUEFACTION VULNERABILITY	MEDIUM LIQUEFACTION VULNERABILITY	HIGH LIQUEFACTION VULNERABILITY

CPT Assigned Liquefaction Vulnerability

- High
- High Inferred
- Medium
- Medium Inferred
- Shallow Refusal



Scale: 1:15,000

0 250 500
Metres

Revision	Author	Verified	Approved	Date
2	BDJ2	KH	SB	11/08/2022
1	JS780	DRAFT	DRAFT	14/04/2022

N

Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-03

Beca

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P:\316\3160254\TG\(20200901)\01_Map\LiquefactionMap_revised.aprx Author: BDJ2 Date: 11/08/2022

4 Assumptions and limitations

The Level B assessment of the Tahunanui area was completed a scale of 1:15,000 in general accordance with the MBIE/MfE (2017) guidance. The map is intended for use by developers, owners, and regulators to identify land where liquefaction damage is unlikely and standard foundation options can be applied. The map is not considered a replacement for site-specific liquefaction assessments and is intended to be used at a consistent or greater scale.

Specific assumptions and limitations of our assessment are outlined below.

- It is assumed that the mapped geology is representative of the underlying deposits. The use of the 1:25,000 map by Johnson (1979) adds uncertainty that the mapped geology may not represent the actual underlying deposits.
- The scale of mapping means that localised areas of susceptible soils, such as abandoned channels, are not identified within larger geological units. There is potential for localised areas of liquefaction-induced damage in areas identified as 'Liquefaction Damage is Unlikely'.
- The datasets considered in our assessment contain residual uncertainties and accuracy limitations which are not explicitly stated in the data sources. These limitations may result in boundaries that do not exactly align with geologic features and/ or variations in the subsurface deposit types.
- The assessment assumed that the measured depth to groundwater is representative of existing groundwater levels. Seasonal fluctuations and the impact of sea level rise on future ground water levels were not considered as part of this assessment.

4.1 Suggestions for further work

Further investigations to refine the conclusion of this study could include:

- Completing additional geotechnical investigations in areas identified as containing Muritai Gravels and Stoke Fan Gravels would characterise the types and behaviours of the subsurface soils in these areas. Incorporating the results of these investigations into the liquefaction assessment would reduce uncertainty and may allow for refinement of the assigned liquefaction vulnerability category.
- The potential effects of sea level rise on the predicted surface effects of liquefaction and associated assigned liquefaction vulnerability may be considered over timeframes of interest to NCC for planning purposes (i.e. 50- to 100-year periods)

5 Planning Considerations

The MfE/MBIE (2017) guidance presents a detailed overview of how liquefaction should be addressed in regional and district plans. We recommend that NCC refer to the MfE/MBIE (2017) guidance when considering incorporating the overlay into resource management plans.

Our assessment of differentiates areas of ‘High Liquefaction Vulnerability’ and ‘Medium Liquefaction Vulnerability’ from areas where ‘Liquefaction Damage is Unlikely’ and where ‘Liquefaction Damage is Possible’. The level of assessment detail is considered sufficient to inform resource management plans and meets the requirements placed on NCC under the November 2019 updates to the Building Code relating to the identification of areas potentially susceptible to liquefaction.

Applicability

This report has been prepared by Beca on the specific instructions of our Client. It is solely for our Client’s use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk.

Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

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