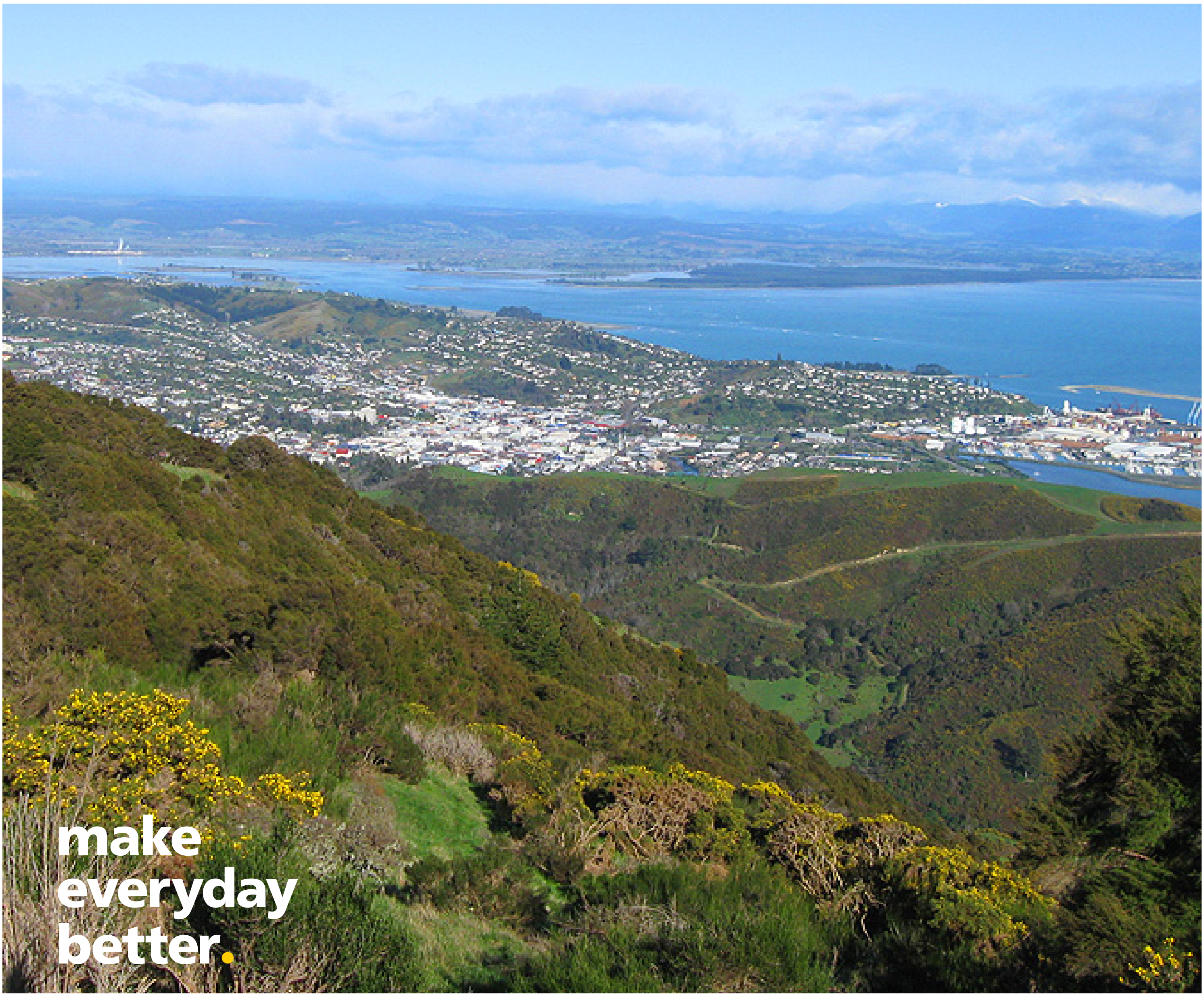
Nelson Regional Liquefaction Assessment

Prepared for Nelson City Council
Prepared by Beca Limited

23 November 2021



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on behalf of	Beca Limited		

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Executive Summary

Beca Ltd (Beca) has been commissioned by the Nelson City Council (NCC) to undertake a regional soil liquefaction assessment in accordance with a 'Level A – Basic Desktop Assessment' as per the joint MBIE/MfE (2017) guidance '*Planning and engineering guidance for potentially liquefication-prone land'*. The level of assessment was selected by NCC and meets the requirements placed on NCC by the November 2019 updates to the Building Code to identify areas with deposits that are potentially susceptible to liquefaction.

Liquefaction occurs as strong ground shaking, such as during earthquakes, causes loose and saturated sediments to lose strength and behave as a fluid. Liquefied deposits may be transported downslope and/or towards a free face, such as a riverbank, termed lateral spreading. Surface effects of liquefaction may include the ejection of liquefied material and groundwater, differential settlement of the ground surface, and cracking of the ground-surface associated with lateral-spreading. Structures founded on soils that have liquefied may experience bearing failure, differential settlements, and/or large horizontal displacements, while buoyant structures buried in liquefied soils, such as tanks, pipes and manholes, may rise to the surface. Soils susceptible to liquefaction are typically geologically young (i.e. <10,000 years), saturated, and non-plastic sands and silts, and in some cases loose gravels. These deposits are typically located in relatively flat areas close to active or abandoned waterways and/or areas of uncompacted or poorly compacted fill.

The Nelson Territorial Area spans the Tasman Bay coastline from Cape Soucis in the north to Champion Road in the south and inland to the Bryant Range. The landscape is topographically varied ranging from steep mountainous areas to low-lying coastal and alluvial plains. There are no historical records of liquefaction despite at least five large earthquakes being felt in the last in the area in the last 170 years including the 1848 Marlborough, 1855 Wairarapa, 1868 Cape Farewell, 1929 Murchison and 2016 Kaikoura earthquakes.

The MfE/MBIE (2017) guidance outlines a risk-based approach for regional and territorial/district authorities in managing liquefaction related risk in land use planning and development. The guidance represents current recommended industry practice and was developed in response to recommendations made by the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquake. A 'Level A' assessment considers basic information on geology, geomorphology, regional seismicity, and where available, groundwater, to classify areas according to the following land damage criteria, as specified in the guidance:

- ***Liquefaction Damage is Unlikely*** - geological units considered not susceptible to liquefaction based on their geologic description and/or depositional setting.
  - Refined to *Very Low Liquefaction Vulnerability* where there is sufficient conclusive geological information such as the presence of shallow rock.
- ***Liquefaction Damage is Possible*** – Areas where the geologic setting suggests that the underlying geologic unit may be susceptible to liquefaction.
- ***Liquefaction Category is Undetermined*** – Areas not considered in the liquefaction assessment or where there is insufficient data to conclusively determine the liquefaction vulnerability of the underlying geologic unit.

Our assessment included a review of the following data sources and followed the methodology outlined in Figure 5-4.

- Regional Geology
- Ground surface elevations
- Aerial imagery
- Regional Seismicity
- Previous Liquefaction Hazard Assessments

The desktop assessment was completed at a scale of 1:25,000 and it is intended that any subsequent use of the map output is consistent with this scale. The map output is not considered a replacement for site-specific liquefaction assessments. The output contains residual uncertainties associated with variations in the map scales of the input datasets and inherent errors and limitations of these datasets. NCC may consider a more detailed Level B assessment to reduce residual uncertainties in the assigned liquefaction category.

Areas where 'Liquefaction Damage is Possible' warrant more detailed assessment during land development planning. The MfE/MBIE (2017) guidance presents a detailed overview of how liquefaction should be addressed in regional plans.

1 Introduction

Beca Ltd (Beca) has been commissioned by the Nelson City Council (NCC) to undertake a regional liquefaction assessment in accordance with a 'Level A – Basic Desktop Assessment' as per the joint MBIE/ MfE (2017) '*Planning and engineering guidance for potentially liquefaction-prone land'* guidance. The level of assessment detail was specified by NCC and is intended to identify areas containing deposits that are potentially susceptible to liquefaction and may warrant further assessment in building and/ or land development planning.

This report outlines the methodology and assumptions of our assessment and covers the following aspects as outlined in our proposal dated 16 April 2021:

- Desk study review of readily available information including:
  - Published large-scale regional geological and geomorphological maps and aerial imagery
  - Regional seismicity and groundwater
  - Previous liquefaction assessments
- Assessment of the liquefaction susceptibility of the deposits in the Nelson region in accordance with a 'Level A – Basic Desktop' Assessment in accordance with the joint MBIE/ MfE (2017) guidance.
- Produce a GIS map overlay outlining the results of the liquefaction assessment at a scale of 1:25,000.

The output of our assessment is a map overlay identifying areas where 'Liquefaction Damage is Possible' and where 'Liquefaction Damage is Unlikely' in accordance with the MBIE/ MfE (2017) guidance. Areas where 'Liquefaction Damage is Unlikely' have been refined to 'Very Low Liquefaction Susceptibility' where there is sufficient information that the underlying deposit is not susceptible to liquefaction, such as shallow rock. Maps showing the results of our assessment are presented in Appendix A.

2 Rationale and background

The November 2019 updates to the Building Code mean that the standard foundation options (B1 Acceptable Solution B1/AS1) can no longer be applied in areas prone to liquefaction and/or lateral spreading. The update places responsibility on regional councils to complete regional liquefaction mapping to identify areas potentially susceptible to liquefaction.

3 Liquefaction process

Liquefaction occurs when strong ground shaking, such as during earthquakes, causes loose and saturated sediments to lose strength and behave as a fluid. Liquefied deposits may be transported downslope and/or towards a free face such as a riverbank, which is termed lateral spreading. The key elements required for liquefaction are shown in Figure 3-1. Surface effects of liquefaction may include the ejection of liquefied material and groundwater, differential settlement of the ground surface, and cracking of the ground-surface associated with lateral-spreading. Structures founded on soils that have liquefied may experience bearing failure, differential settlements, and/or large horizontal displacements while buoyant structures buried in liquefied soils, such as pipes, tanks, and manholes, may rise to the surface.

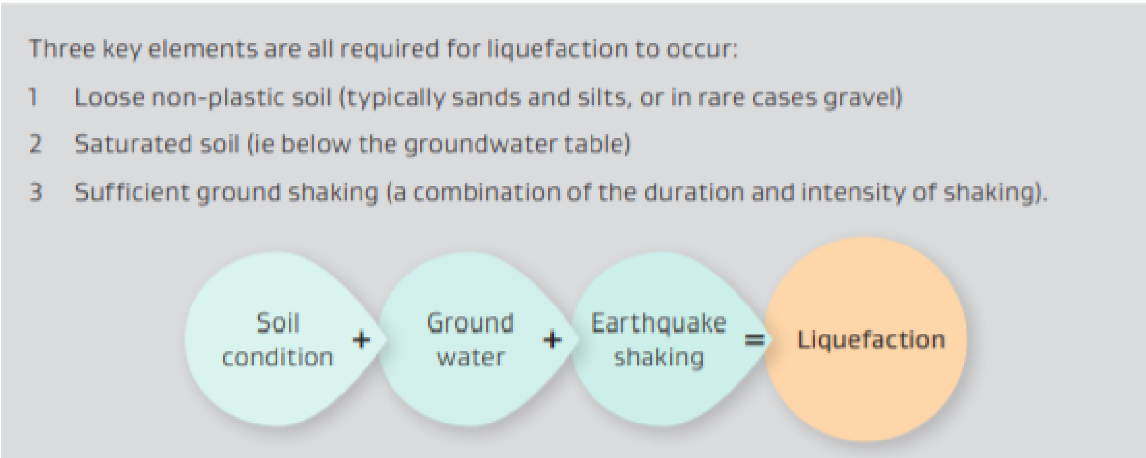

Figure 3-1:Key elements for liquefaction, as outlined by MfE/MBIE (2017).

Soils susceptible to liquefaction are typically geologically young (i.e. <10,000 years), saturated, and non-plastic sands and silts, and in some cases loose gravels. These deposits are typically located in relatively flat areas close to active or abandoned waterways including rivers, lakes, swamps, and estuaries, and/or areas of uncompacted or poorly compacted fill. Geologically older sands and silts, along with dense gravel, and higher plasticity clays generally have low vulnerability to liquefaction. Relationships between the liquefaction susceptibility of sedimentary deposits and their age have been summarised by Youd and Perkins (1978), Kramer (1996), and Idriss and Boulanger (2008). Key relationships between liquefaction susceptibility and the age of sedimentary deposits have been summarised by Youd and Perkins (1978) and are shown in Figure 3-2.

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments when Saturated would be Susceptible to Liquefaction (by Age of Deposit)			
		< 500 yr Modern	Holocene < 11 ka	Pleistocene 11 ka - 2Ma	Pre-Pleistocene > 2 Ma
(a) Continental Deposits					
River channel	Locally variable	Very High	High	Low	Very Low
Flood plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread	---	Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High	High	Low	Very Low
Esturine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Moderate	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	---	---	---

Figure 3-2: Estimated Susceptibility of Sedimentary Deposits to Liquefaction During Strong Shaking as established by Youd and Perkins (1978).

4 Nelson geologic and geomorphic setting

The Nelson Territorial Area spans the Tasman Bay coastline from Cape Soucis in the north to Champion Road in the south and inland to the Bryant Range. The landscape is topographically varied ranging from steep mountainous areas to low-lying coastal and alluvial plains and is strongly influenced by the underlying geology.

The geology of the Nelson region is presented in the 1:250,000 scale geological QMap *Geology of the Nelson Region* by Rattenbury et al. (1998) with the geology of Nelson city presented in more detail in the 1:25,000 scale geological map by Johnston (1979) and the north Nelson area Sheet O27AC Dun Mountain geological map by Johnston (1981). These maps outline the broad range and types of geologic units in the Nelson area.

Quaternary cover deposits are the youngest in the Nelson area at less than 2.6 million years old and are relevant to the liquefaction assessment (see Figure 3-2). These deposits are generally present in valleys and near the active coastline and are further subdivided into Holocene deposits, which are generally accepted to be less than approximately 10,000 years old in New Zealand, and Pleistocene deposits which are greater than 10,000 years old. The type, composition and geomorphic setting of Quaternary deposits present in the Nelson region is summarised in Appendix B.

5 Liquefaction assessment methodology

The MfE/MBIE (2017) guidance outlines a risk-based approach for regional and territorial/district authorities for managing liquefaction related risk in land use planning and development. It represents current recommended industry practice and was developed in response to recommendations made by the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquake .

The guidance outlines four levels of assessment ranging from a ‘Level A’ basic qualitative desktop study to a ‘Level D’ site-specific quantitative liquefaction assessment. The assessments all aim to identify the expected range of ground performance according to the matrix shown in Figure 5-1. A description of the corresponding liquefaction induced land damage categories is shown in Figure 5-2.

The key difference between the levels of assessment is the investigation detail and the degree of residual uncertainty in the assigned liquefaction category. Level A and B assessments generally 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, and to a degree Level B 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 based on Figure 5-1.

Level A and B Assessment Detail	**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 There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking. At this stage there is not enough information to distinguish between ***Very Low*** and ***Low***. More detailed assessment would be required to assign a more specific liquefaction category.		**LIQUEFACTION DAMAGE IS POSSIBLE** There is a probability of more than 15 percent that liquefaction-induced ground damage will be ***Minor to Moderate*** (or more) for 500-year shaking. At this stage there is not enough information to distinguish between ***Medium*** and ***High***. More detailed assessment would be required to assign a more specific liquefaction category.	
Level C and D Assessment Detail	**Very Low Liquefaction Vulnerability** There is a probability of more than 99 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	**Low Liquefaction Vulnerability** There is a probability of more than 85 percent that liquefaction-induced ground damage will be ***None to Minor*** for 500-year shaking.	**Medium Liquefaction Vulnerability** There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Minor to Moderate*** (or less) for 500-year shaking; and ***None to Minor*** for 100-year shaking.	**High Liquefaction Vulnerability** There is a probability of more than 50 percent that liquefaction-induced ground damage will be: ***Moderate to Severe*** for 500-year shaking; and/or ***Minor to Moderate*** (or more) for 100-year shaking.

Figure 5-1: 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 5-2: Degrees of liquefaction-induced ground damage taken from the MfE/MBIE guidelines and corresponding to the damage described in Figure 4-1.

5.1 Datasets considered in our assessment

NCC have requested that the regional liquefaction assessment be completed in general accordance with a 'Level A' assessment as per the MBIE/MfE guidance. The assessment is a desk-based exercise which considers regional datasets and does not include site-specific geotechnical investigations nor quantitative liquefaction triggering assessments. The following datasets available for the Nelson region have been considered in our assessment:

5.1.1 Regional Geology

The 1:250,000 scale geologic (QMap) of the Nelson Area and accompanying textbook (Rattenbury et al., 1998).

- This map presents the regional geology of the Nelson area including geologic descriptions of the mapped units. The map outlines the distribution of Quaternary deposits with geologic descriptions suggesting that they may be susceptible to liquefaction.
- The scale of mapping means that spatial variations within the geologic units, such as abandoned river channels, are not identified, and that the geologic boundaries do not always precisely align with geomorphic features (i.e. hillslopes and terrace risers).

5.1.2 Local Geology

The 1:25,000 scale geologic map of the Nelson urban area and accompanying text (Johnson, 1979) and 1:50,000 scale geologic map of Sheet O27 AC Dun Mountain (North Nelson area; Johnson 1981).

- These maps present more detail on the geologic units in the Nelson urban area including further subdividing the mapped Quaternary deposits, identifying the position of the c. 1850 shoreline, and outlining areas of reclamation filling.
- The scale of mapping means that spatial variations within the geologic units are not captured, however the dataset provides more detail in the types of deposits in the map area compared to the 1:250,000 scale map.
- The mapped geologic boundaries do not always precisely align with geomorphic boundaries observable in aerial imagery and elevation datasets (i.e. hillslopes).

5.1.3 Elevation Datasets

Hillshade model created from a Digital Elevation Model (DEM) with a 1m spatial resolution and accompanying 1m elevation contours which were supplied by NCC.

- The 1m spatial resolution model highlights topographic variability not captured in the geologic maps and assists in identifying geomorphic features of relevance to the liquefaction assessment. These features include, but are not limited to:
  - Raised terraces separated from active alluvial plains by terrace risers.
  - The steepness and widths of stream channels within alluvial valleys as inferred from elevation contours.
  - Changes in the topographic profiles along alluvial plains and within alluvial valleys indicating the locations and extents of alluvial fans and landslide deposits.

The resolution enables geologic boundaries to be refined and modified to correspond with observed geomorphic features.

5.1.4 Aerial Imagery

Aerial imagery is available for the Nelson region as a basemap in ArcGIS. The layer consists of stitched aerial and satellite imagery with a minimum resolution of 1m.

- The dataset assists with identifying geomorphic features of relevance to the liquefaction assessment including:
  - Changes in stream profiles such as decreasing channel widths and changes from braided to meandering channels.
  - Locations of terrace risers and down-cut stream channels indicating older alluvial surfaces and areas where groundwater is expected to be deeper.
  - The position of the active coastline and recent/active alluvial plains surrounding waterways.

5.1.5 Regional Seismicity

The New Zealand Seismic Hazard Model (Stirling et al., 2012) identifies the Nelson region as a zone of contractional faulting associated with continental collision to the northwest of the northern portion of the Alpine Fault. The area is characterised by normal faults that are re-activated as range-bounding reverse faults. The region has a 475-year return period shallow soil Peak Ground Acceleration (PGA) of between 0.2 to 0.3g and a 2500-year shallow soil return period PGA of 0.4 to 0.5g. The New Zealand Active Faults Database identifies the Waimea Fault as trending southwest to northeast along the Grampian Range behind Nelson with a recurrence interval of 5,000 to 10,000 years.

Saunders and Berryman (2012) report that a PGA of 0.1g or greater is sufficient to trigger damaging liquefaction in highly susceptible soils hosting high-water tables based on recent earthquakes in New Zealand. The region is therefore likely to experience liquefaction under a 475- return period PGA.

5.1.6 Historical Records of liquefaction

Areas that have historically experienced liquefaction contain deposits that are susceptible to liquefaction during future earthquakes. The Nelson region has experienced at least five large earthquakes in the last 170 year including:

- 1848 Marlborough Earthquake
- 1855 Wairarapa Earthquake
- 1868 Cape Farewell Earthquake
- 1929 Murchison Earthquake
- 2016 Kaikoura Earthquake

No records of liquefaction associated with these events have been identified. These events have not been centred in the Nelson area and historical records suggest that the shaking intensities during these events may not have been high enough to trigger liquefaction (Modified Mercalli Scale; MMI). It is also possible that localised liquefaction occurred in events prior to 2016 and went unreported due the lack of knowledge of liquefaction and the sparser population.

5.1.7 Previous Liquefaction Hazard Assessments

The liquefaction susceptibility of the deposits in the Nelson region has previously been assessed by Johnson (2013) who considered geologic descriptions, geomorphology, and local experience. The assessment was completed prior to the MBIE/MfE guidance and does not follow the recommended terminology. The study suggested that the distribution of soils considered susceptible to liquefaction is limited to areas adjacent to the coast and alluvial valleys. The following specific areas were identified as potentially containing deposits potentially susceptible to liquefaction:

- *Alluvial Valleys* containing Quaternary deposits <10,000 years old and comprising gravel with some sands that are sufficiently saturated.
- *The Whangamoa and Delaware Inlets* which contain silty clay to sand.
- *Glenduan ('The Glen')* which consists of a low-lying and poorly drained area that has been slowly infilling with fine-grained saturated sediments.
- *Southern end of Nelson Haven to Port Nelson* which is largely infilled with gravel deposited by the Maitai River overlain by estuarine and marine sediments. This area partially includes reclamation fill.
- *ToiToi Valley* which was formerly an embayment associated with the ca.1850 coastline and comprises silty sediments.
- *Port Nelson* which comprises reclamation fill sitting on estuarine deposits comprised of silt with localised sand.
- *Tahunanui* covering the area north of the abandoned sea cliff that extends from Monaco to Annesbrook and underlain by marine, beach, dune, and beach ridge deposits of sand to silt locally inter-layered with sandy gravel.

The liquefaction potential of the sediments underlying the Tahunanui area were further assessed by Tonkin & Taylor (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) seismic event. Lateral spreading, where liquefied deposits are transported downslope and/or towards a break in slope, is additionally expected to occur during a ULS seismic event and extend 100 to 200m inland. The 2014 study further assessed the liquefaction potential of the sediments in the north-eastern part of the Tahunanui area where the previous assessment indicated a reduced thickness of sediments with a high liquefaction potential. The study area corresponds with the area mapped by Johnson (1979) as comprising Rabbit Island Gravels. The 2014 study concluded that liquefaction induced settlements in this area would be between 0 and 10mm for a SLS seismic event and between 0 and 100mm for a ULS seismic event. Johnson (2017) subsequently proposed that the area predominantly underlain by Tahunanui Sand be included in a liquefaction planning overlay due to the susceptibility of the underlying deposits, and the area underlain by Rabbit Island Gravels excluded from the overlay.

The liquefaction susceptibility of the deposits in the Glenduan area, located to the northeast of the Nelson city centre, were also assessed by Tonkin and Taylor (2015). The study comprised a desktop review of geotechnical investigations completed approximately 1.5km east of the Glenduan residential area and concluded that there is generally a low risk of liquefaction for a ULS (500-year return period) however identified the potential for localised liquefiable soils resulting in liquefaction.

5.2 Steps taken in our assessment

Our desktop assessment was completed using the computer software ArcGIS Pro and included a detailed review of mapped geology and local geomorphology considering the relationships outlined by Youd and Perkins (1978) and shown in Figure 3-2 and the semi-quantitative screening criteria presented in the MfE/MBIE (2017) guidance and shown in Figure 5-3. The assessment considered the geologic descriptions and geomorphic settings of the deposits summarised in Appendix B and aimed to classify the region into the following liquefaction vulnerability categories as per the MfE/MBIE guidelines and shown in Figure 5-1:

- ***Liquefaction Damage is Unlikely*** - geological units considered not susceptible to liquefaction based on their geologic description and/or depositional setting.
  - Refined to *Very Low Liquefaction Vulnerability* where there is sufficient conclusive geological information that the underlying deposit is not susceptible to liquefaction i.e. shallow rock and fractured rock comprising landslide deposits in mountainous areas.
- ***Liquefaction Damage is Possible*** – Areas where the geologic setting suggests that the underlying geologic unit may be susceptible to liquefaction.
- ***Liquefaction Category is Undetermined*** – Areas not considered in the liquefaction assessment or where there is insufficient data to conclusively determine the liquefaction vulnerability of the underlying geologic unit.

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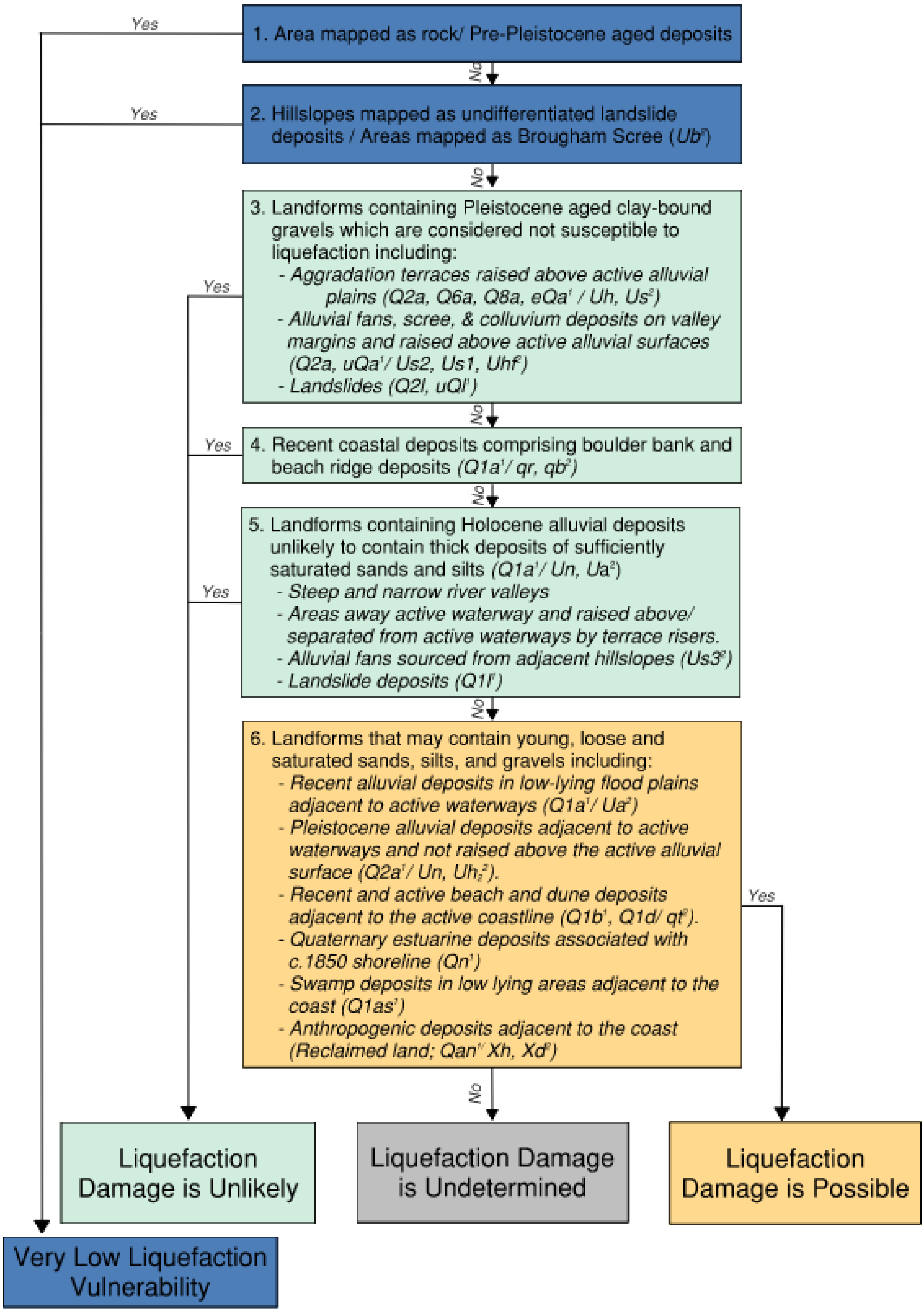
A methodology tree outlining the steps taken in our assessment is presented in Figure 5-4and is summarised below. Geologic descriptions for the units listed in Figure 5-4 and summarised below are (i.e. Q1a) presented in Appendix B. The boundaries of the geologic units were refined from those shown in the geologic maps based on local geomorphology observed in the elevation and aerial imagery datasets. Land owned by the Department of Conservation was excluded from our assessment and is assigned 'Liquefaction Damage is Undetermined'

TYPE OF SOIL DEPOSIT	A LIQUEFACTION VULNERABILITY CATEGORY OF LIQUEFACTION DAMAGE IS UNLIKELY CAN BE ASSIGNED IF EITHER OF THESE CONDITIONS IS MET:	
	DESIGN PEAK GROUND ACCELERATION (PGA) FOR 500-YEAR INTENSITY OF EARTHQUAKE SHAKING[1]	DEPTH TO GROUNDWATER[2]
Late Holocene age Current river channels and their historical floodplains, marshes and estuaries, reclamation fills	Less than 0.1 g[3]	More than 8 m
Holocene age Less than 11,000 years old	Less than 0.2 g	More than 6 m
Latest Pleistocene age Between 11,000 and 15,000 years old	Less than 0.3 g	More than 4 m

Figure 5-3: Semi-quantitative screening criteria presented in MfE/MBIE (2017).



[1]Geologic unit described in Table B-1 in Appendix B
[2]Geologic unit described in Table B-2 in Appendix B

Figure 5-4: Methodology tree outlining the steps taken in our regional liquefaction assessment

Further explanation of the steps included in the methodology tree:

1. Areas underlain by pre-Pleistocene aged deposits (>2.6 million years) including rock and cemented gravels are not considered susceptible to liquefaction due to their composition and age. These deposits were assigned as 'Very Low Liquefaction Vulnerability'.
2. Hillslope areas mapped as landslide deposits composed of rock fragments / shattered rock and areas identified as Brougham Scree (Ub) in the Johnson (1979) map are unlikely to be contain fine grained sediments that are sufficiently saturated to be susceptible to liquefaction. These areaswere assigned as 'Very Low Liquefaction Vulnerability'.
3. Landforms containing Pleistocene-aged deposits comprised of slightly to highly weathered clay-bound gravels raised above the surrounding active alluvial plains including aggradation terraces, alluvial fans, scree, colluvium, and landslides (Q2a, Q6a, Q8a, eQa in Rattenbury et al. (1998) / Uh and Us in Johnson (1979/ 1981) were assigned as 'Liquefaction Damage is Unlikely'. The age, degree of weathering, and precipitation of secondary cements suggests that these deposits have a low susceptibility to liquefaction however the presence of localised landforms containing liquefiable material, such as recent abandoned stream channels, cannot be discounted.
4. Holocene beach deposits (Q1b) comprised of dense boulders and gravels are unlikely to contain thick deposits of loosely consolidated sand due to their depositional settings. These deposits correspond with the Boulder bank (Qb) in Johnson (1981) and are assigned as 'Liquefaction Damage is Unlikely'
5. Landforms comprising Holocene alluvial deposits that are considered unlikely to contain thick deposits of loosely consolidated and saturated sands, silts, and gravels, were assigned as 'Liquefaction Damage is Unlikely' as the presence of local saturated sand lenses cannot be discounted. These include
   - Alluvial fans, scree, colluvium, and landslide deposits which are predominantly composed of gravel and raised above active alluvial plains. These deposits are generally considered too coarse to be susceptible to liquefaction and are unlikely to be sufficiently saturated.
   - Steep and narrow river valleys within the hillslope and mountain ranges inland from the coast which are typically underlain by coarse gravels to boulders sourced from the surrounding hillslopes.
   - Areas located away from and/ or raised above active waterways where the surficial deposits are unlikely to be sufficiently saturated to liquefy. These include Nelson Alluvium (Un) and Appleby Gravel (Ua).
6. Landforms that may contain young, loosely consolidated, and saturated sands, silts, and gravels were classified as 'Liquefaction Damage is Possible'. These deposits are generally considered susceptible to liquefaction however there is not enough information to refine the liquefaction vulnerability category further. Specific landforms include
   - Recent alluvial deposits (Q1a) in low-lying flood plains adjacent to active waterways corresponding with the Appleby Gravel
   - Pleistocene alluvial deposits (Q2a) located near rivers and streams in low-lying alluvial valleys and not raised above Q1a, such as parts of Nelson Alluvium.
   - Recent alluvial fan deposits in low-lying areas near the coast and at consistent elevations to surrounding alluvial plains (Q1a and Uh_2)
   - Swamp deposits (Q1as) in low-lying areas adjacent to the coast.
   - Recent and active beach (Q1b/ qt) and dune (Q1d) deposits present near the active coastline including the estuaries deposits within the ToiToi Valley.
   - Areas of reclamation fill adjacent to the coast (Qan/Xh/Xd)

6 Areas potentially susceptible to liquefaction damage

The results of our regional liquefaction assessment are presented in the map series included in Appendix A. The assessment identified the following general areas where 'Liquefaction Damage is Possible':

- Whangamoa Inlet
  - Holocene aged alluvial, estuarine, and swamp deposits at the mouths of the Whangamoa River and ToiToi Stream.
- Whangamoa Valley
  - Low-lying Holocene aged alluvial deposits adjacent to the Whangamoa River between Collins Valley and the river mouth at Whangamoa Inlet.
- Delaware Bay and Cable Bay.
  - Holocene alluvial deposits within the recent flood plain of the Wakapuaka River between Hira and Cable Bay.
  - Holocene beach deposits composed of sand and located along the active coastline and forming sand spits.
- Glenduan
  - Low-lying swamp deposits in the area between Wakapuaka Road and the existing coastline and covering the low-lying area extending to the foot of the Marybank hillslope.
- Todds Valley
  - Low-lying recent alluvial deposits in the recent floodplain at the base of the valley and immediately adjacent to Todds Stream.
- Dodsons valley
  - Low-lying Holocene alluvial deposits at the valley mouth and adjacent to Nelson Haven.
- Nelson city
  - Area of reclamation filling near Trafalgar and Neale Parks and Port Nelson.
  - Low lying alluvial deposits extending between Washington Valley and Church Hill and corresponding with the inferred position of the ca. 1850 shoreline.
- Brook Valley
  - Low-lying Holocene alluvial deposits adjacent to the Brook Stream and within the active floodplain extending between the Brook Valley Holiday Park and the mouth of the Brook Valley.
- Maitai Valley
  - Low-lying Holocene alluvial deposits adjacent to the Maitai River and within the active river floodplain present from the valley mouth to where the river narrows and becomes confined between hillslopes to the southeast of the Maitai Valley Motor Camp.
- Tahunanui
  - Low-lying areas underlain by Tahunanui Sands and extending north from the abandoned seacliff between Monaco and Annesbrook.
  - The area underlain by Rabbit Island Gravel was assigned as 'Liquefaction Damage is Unlikely'.

7 Assumptions and limitations

Regional liquefaction mapping was completed for the Nelson Region at a scale of 1:25,000 in accordance with a Level A assessment as per the MfE/MBIE (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 it is intended that any subsequent use is 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 1:250,000 QMap and local maps by Johnson (1979 and 1981) adds uncertainty that the mapped geology may not align with geomorphic features nor represents the actual underlying deposits.
- The assessment does not consider site-specific information on the nature of the underlying deposits nor does it consider development or modifications to the landscape such as ground improvement under existing development.
- 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.

8 Suggestions for future work

- NCC may consider additional work to reduce residual uncertainty in the assigned liquefaction vulnerability categories and/or refine the extents of areas identified as 'Liquefaction Damage is Possible'. Residual uncertainties reflect the potential that surface features and/or mapped geology do not accurately reflect the underlying soil types. The level of uncertainty may be reduced by increasing the level of assessment detail.
- A Level B 'Calibrated desktop assessment' may be completed for areas of existing or proposed development and identified as 'Liquefaction Damage is Possible' in the Level A assessment in order to reduce residual uncertainties. A Level B assessment involves high-level calibration of mapped geology and geomorphology with deep subsurface investigations based on a 500-year return period earthquake scenario.
  - The assessment considers a minimum of three investigations per geological sub-unit to assess typical subsurface soil types.
  - The assessment would reduce uncertainty in the assigned liquefaction vulnerability categories and potentially reduce the extent of land classified as 'Liquefaction Damage is Possible'.
- Level C and D assessments involve site-specific liquefaction assessments and are typically not required for a regional plan. This level of assessment detail may be considered for specific developments and involves quantitative assessments of liquefaction triggering.

9 Planning Considerations

Our regional liquefaction assessment differentiates areas where 'Liquefaction Damage is Possible' from areas where 'Liquefaction Damage is Unlikely'. The level of assessment detail is considered sufficient to inform regional policy statements 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 MfE/MBIE (2017) guidance presents a detailed overview of how liquefaction should be addressed in regional plans. The guidance recommends that maps outlining land where 'Liquefaction Damage is Possible' be used to support objectives and policies in the regional policy statement and be called 'Regional Policy Statement – Liquefaction Assessment Requirement Maps' and use the legend shown in Figure 9-1. We recommend that NCC refer to the guidance in for the Whakamahere Whakatū Nelson Plan.

Legend

Liquefaction assessment required
Liquefaction Damage is Possible – further liquefaction assessment will be needed as part of the planning and consenting process for any intensification of land use or buildings in this area.

Liquefaction assessment not required
Liquefaction damage is unlikely – there is no need for further liquefaction assessment as part of the planning and consenting process unless:

a more detailed or site-specific information indicates otherwise, or

b specific high-intensity or high-importance activities are proposed.

Figure 9-1: Recommended legend for regional policy statement liquefaction assessment maps from the MfE/MBIE (2017) guidance.

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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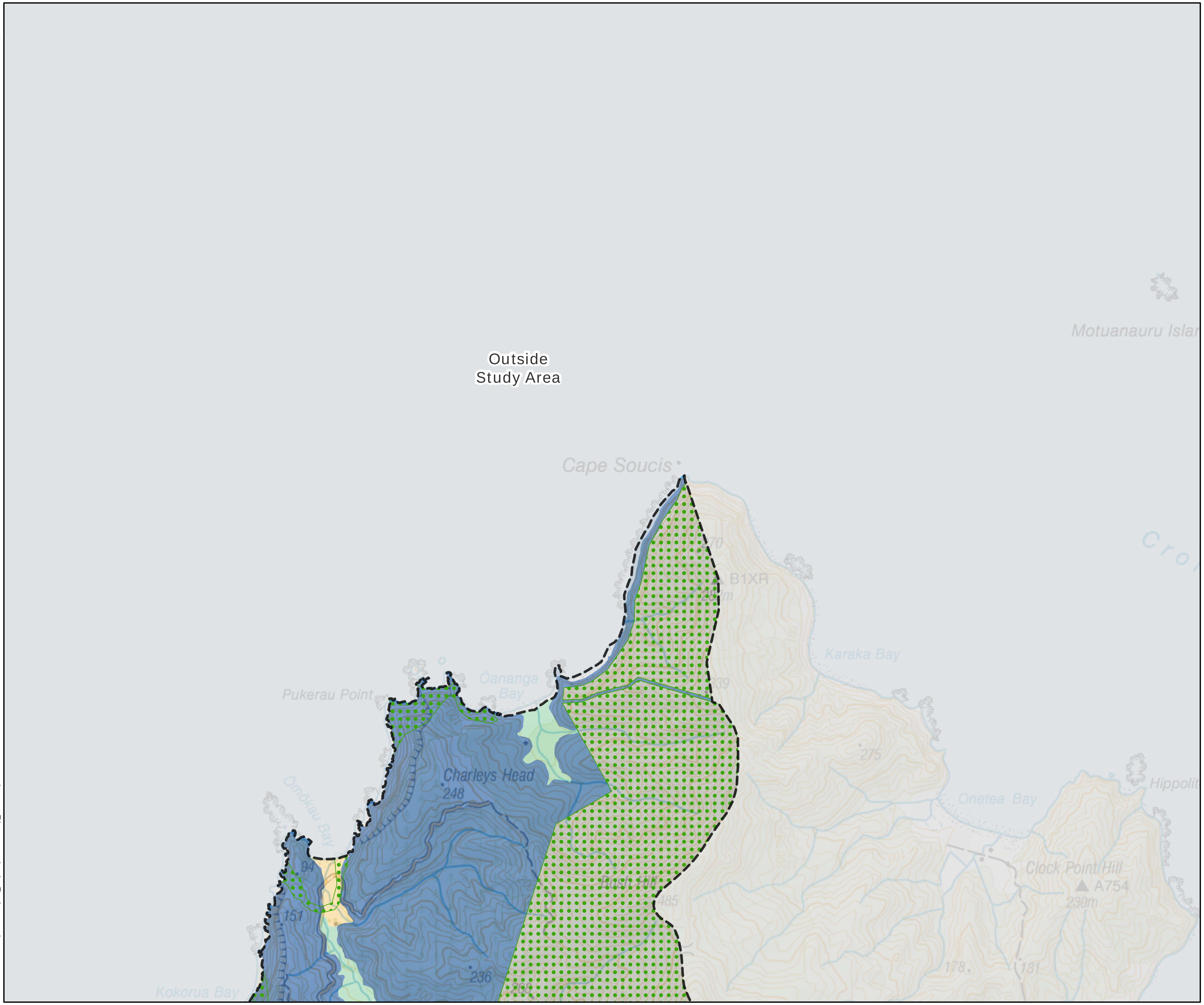
A

Appendix A – PDF Map Outputs



Nelson City Liquefaction Assessment

Map : A5	Page 1 of 17

Legend

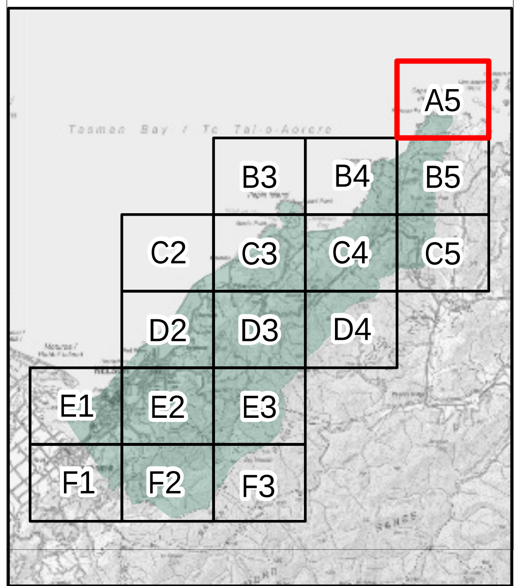
- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined

Liquefaction Damage is Unlikely

Very Low Liquefaction Vulnerability

Liquefaction Damage is Possible



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1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-A5

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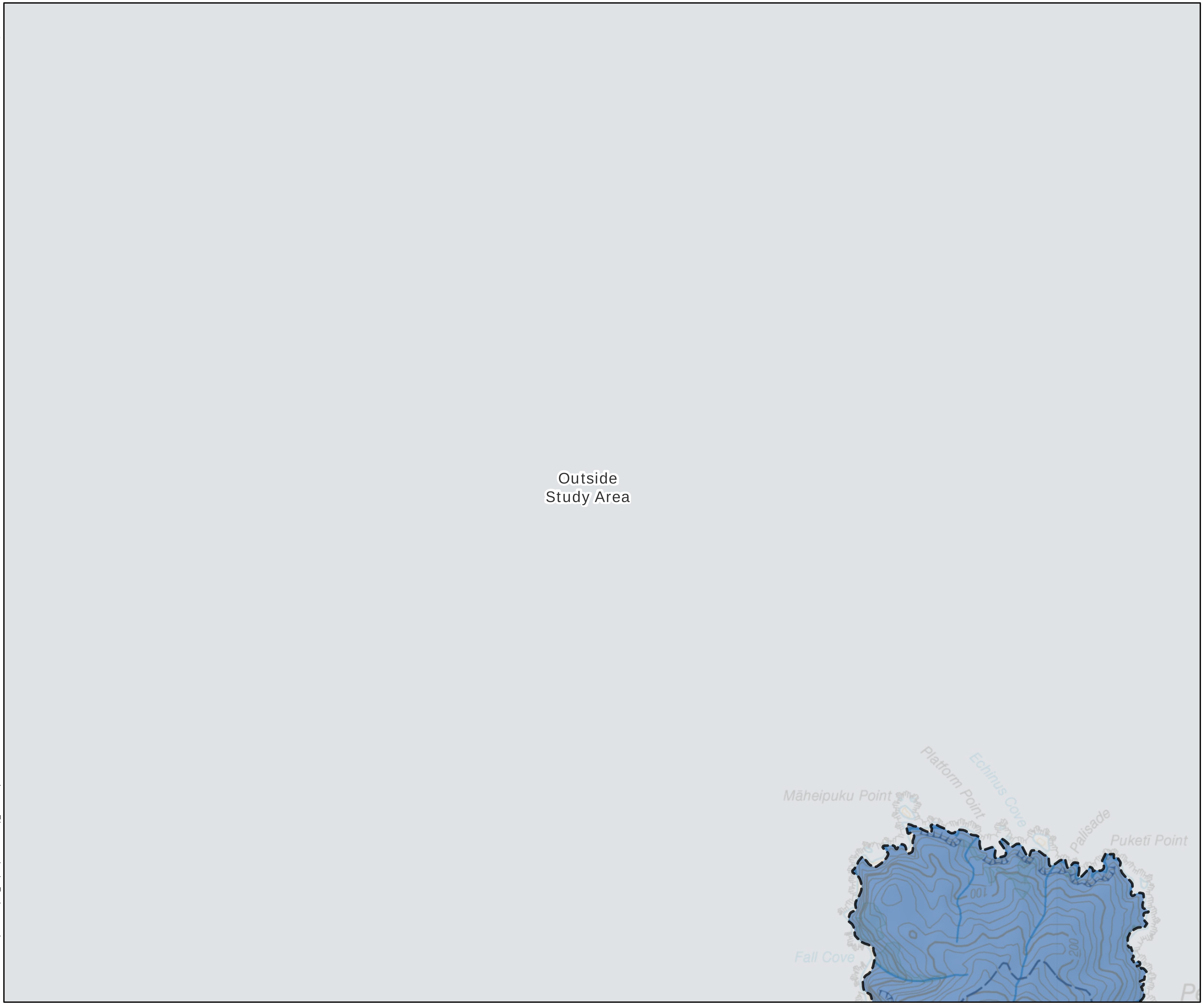


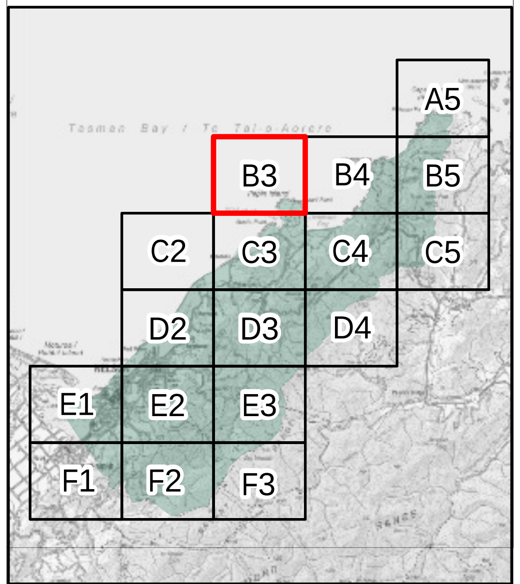
Nelson City
Liquefaction Assessment

Map : B3

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely Very Low Liquefaction Vulnerability	Liquefaction Damage is Possible



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1	BDJ2	DRAFT	DRAFT	13/10/2021

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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-B3

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GIS@beca.com

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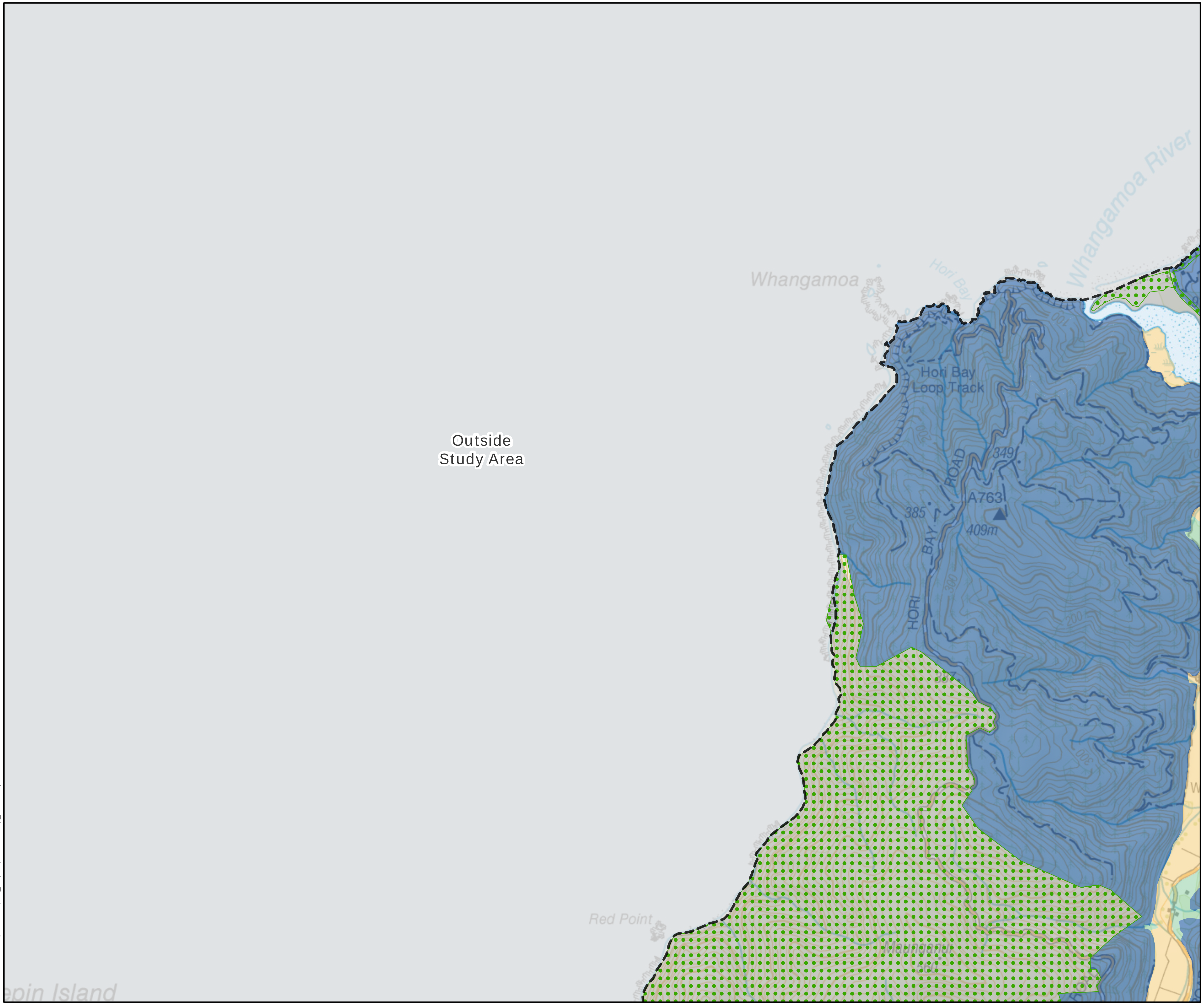


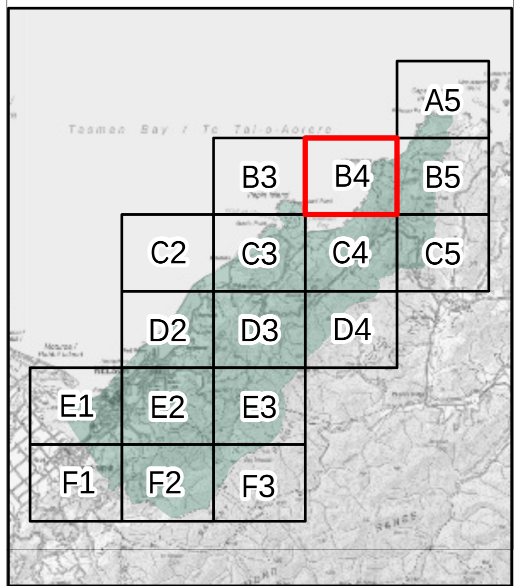
Nelson City Liquefaction Assessment

Map : B4	Page 3 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely Very Low Liquefaction Vulnerability	Liquefaction Damage is Possible



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Revision	Author	Verified	Approved	Date
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1	BDJ2	DRAFT	DRAFT	13/10/2021

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Client: Nelson City Council	Discipline: GIS
Project: Liquefaction Review and Support	Drawing No: GIS-3160254-01-B4

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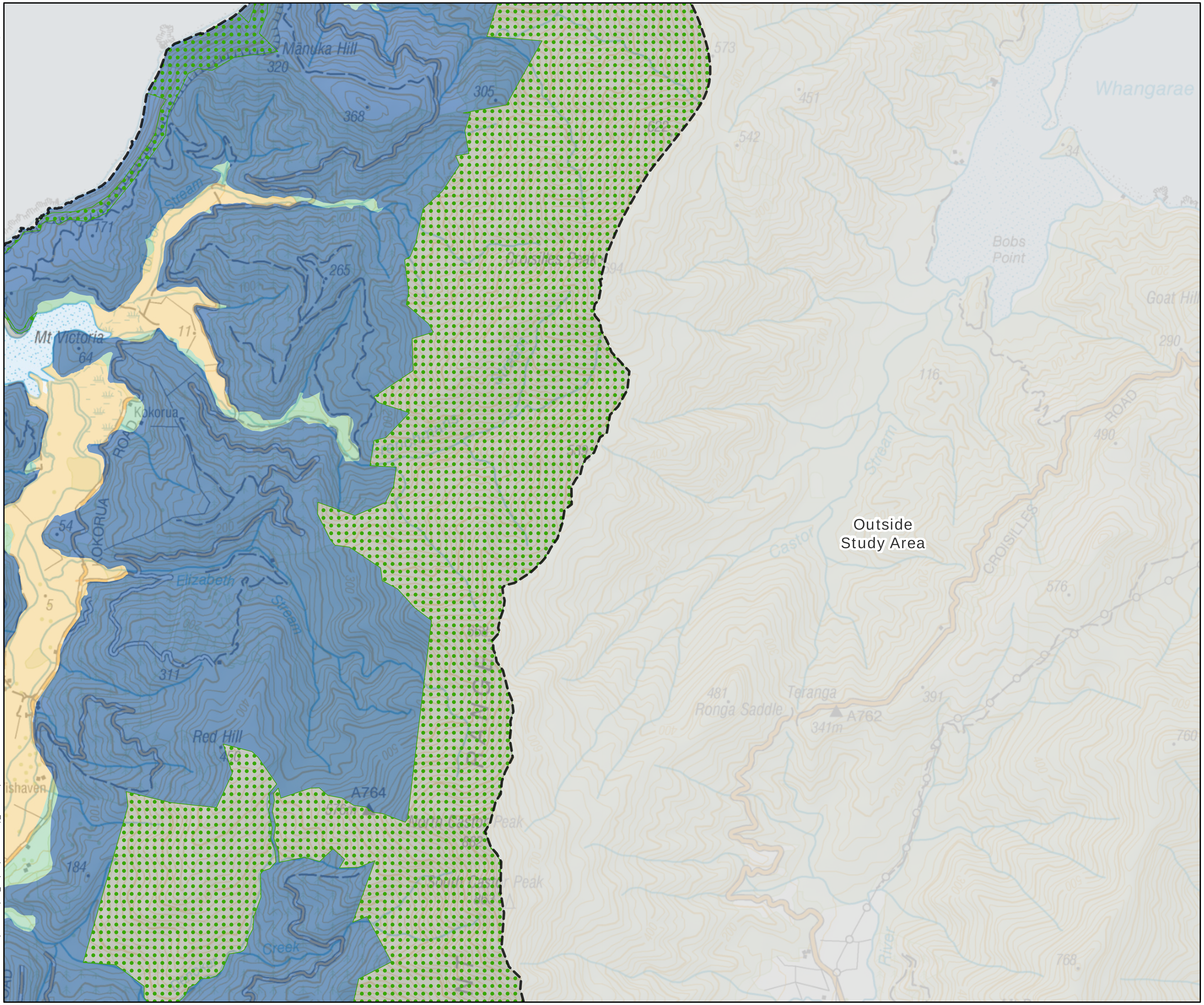


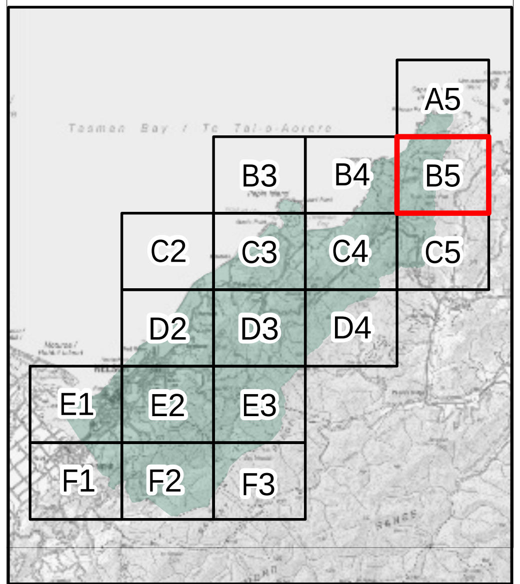
Nelson City Liquefaction Assessment

Map : B5

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



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1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-B5

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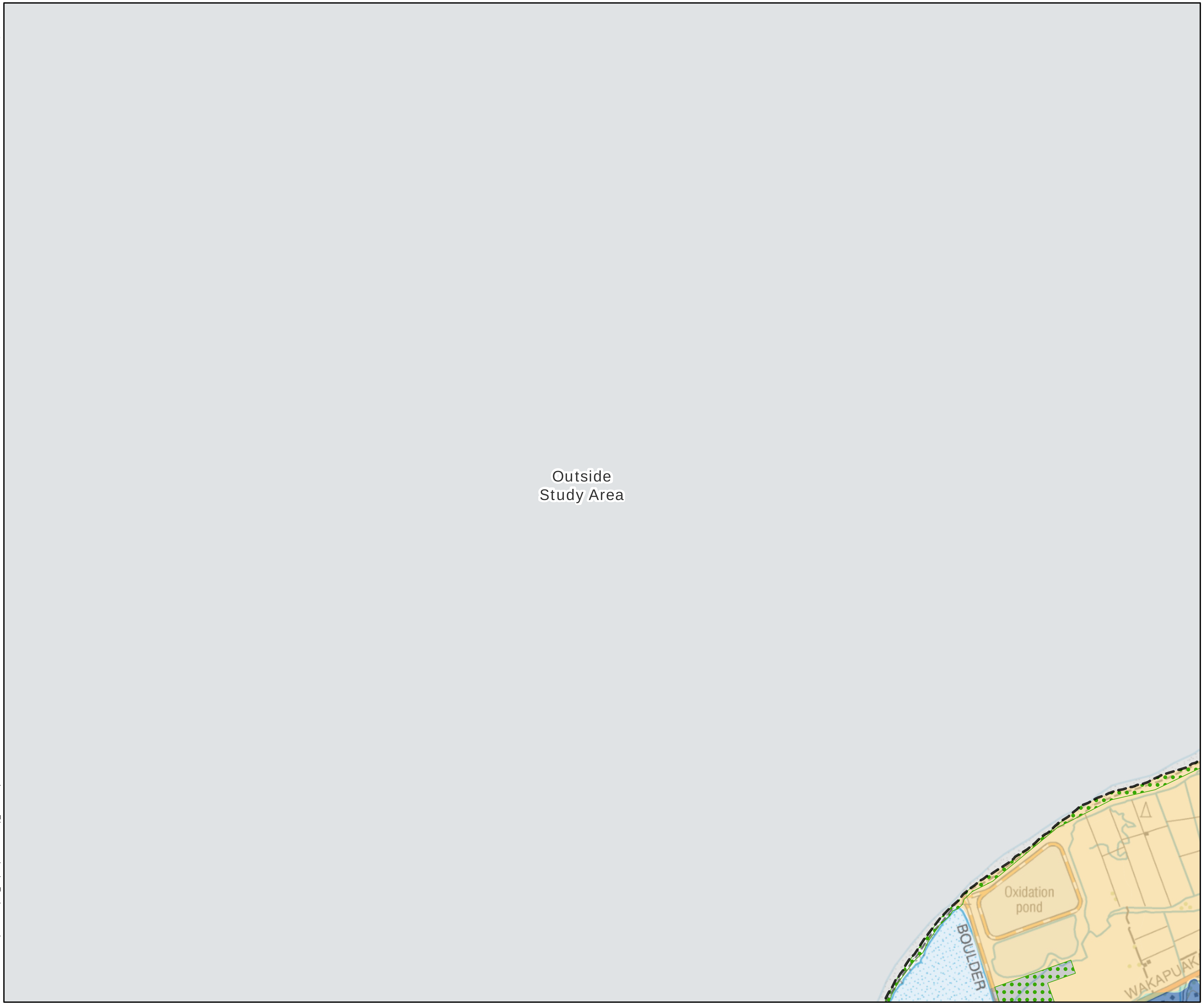


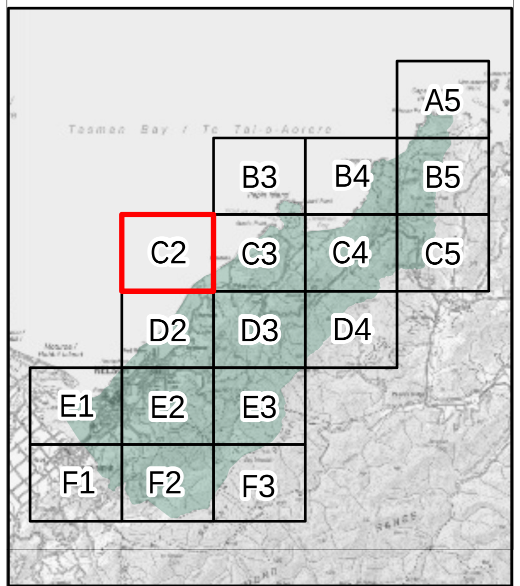
Nelson City Liquefaction Assessment

Map : C2

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-C2

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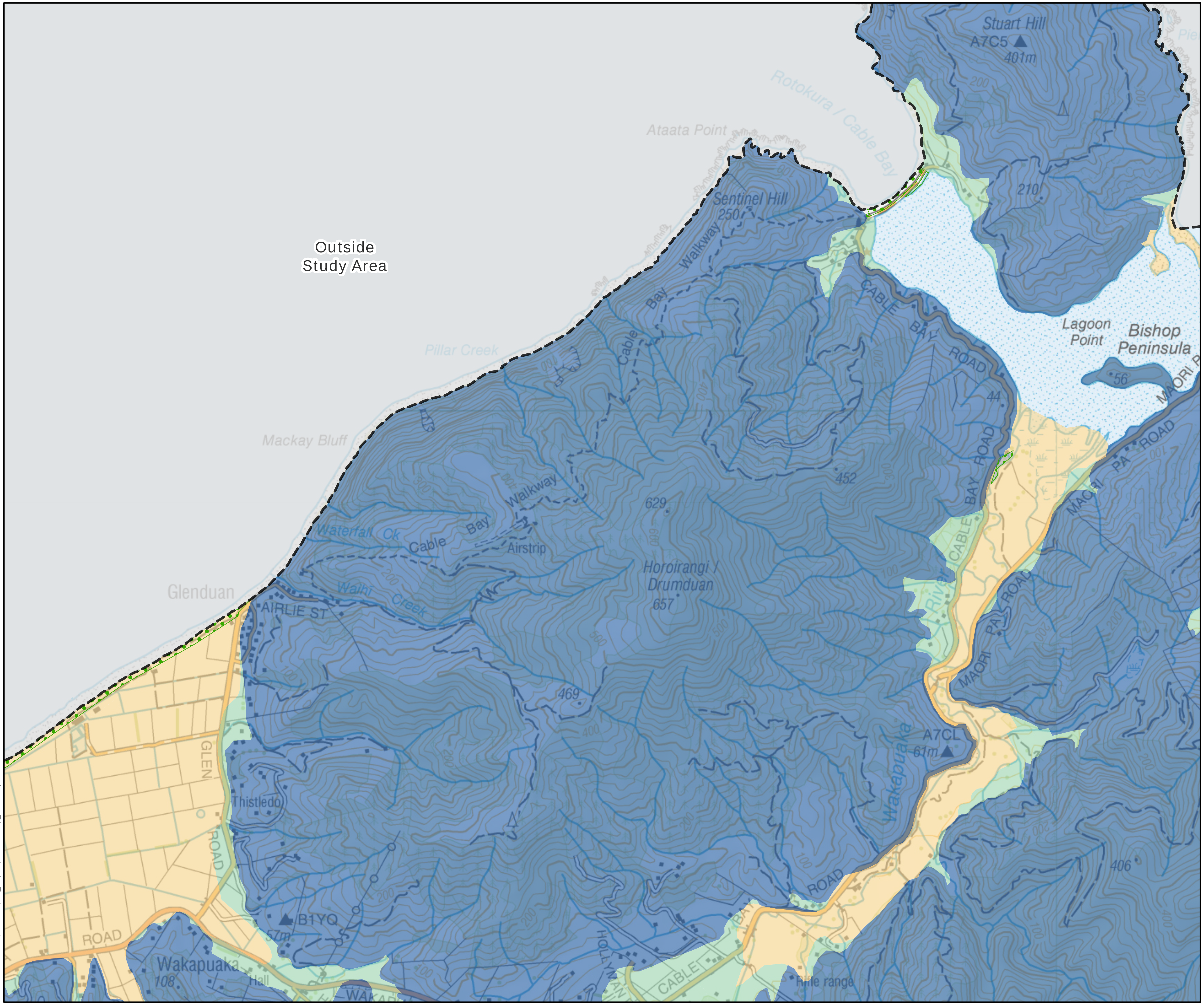

Nelson City Liquefaction Assessment

Map : C3 — Page 6 of 17

Legend

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- Nelson City Study Area
- DOC Land (Not assessed)

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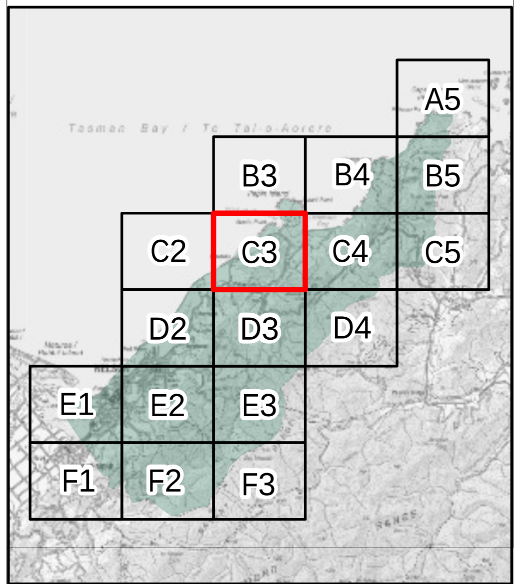
Liquefaction Damage is Unlikely (Very Low Liquefaction Vulnerability)	Liquefaction Damage is Possible



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-C3

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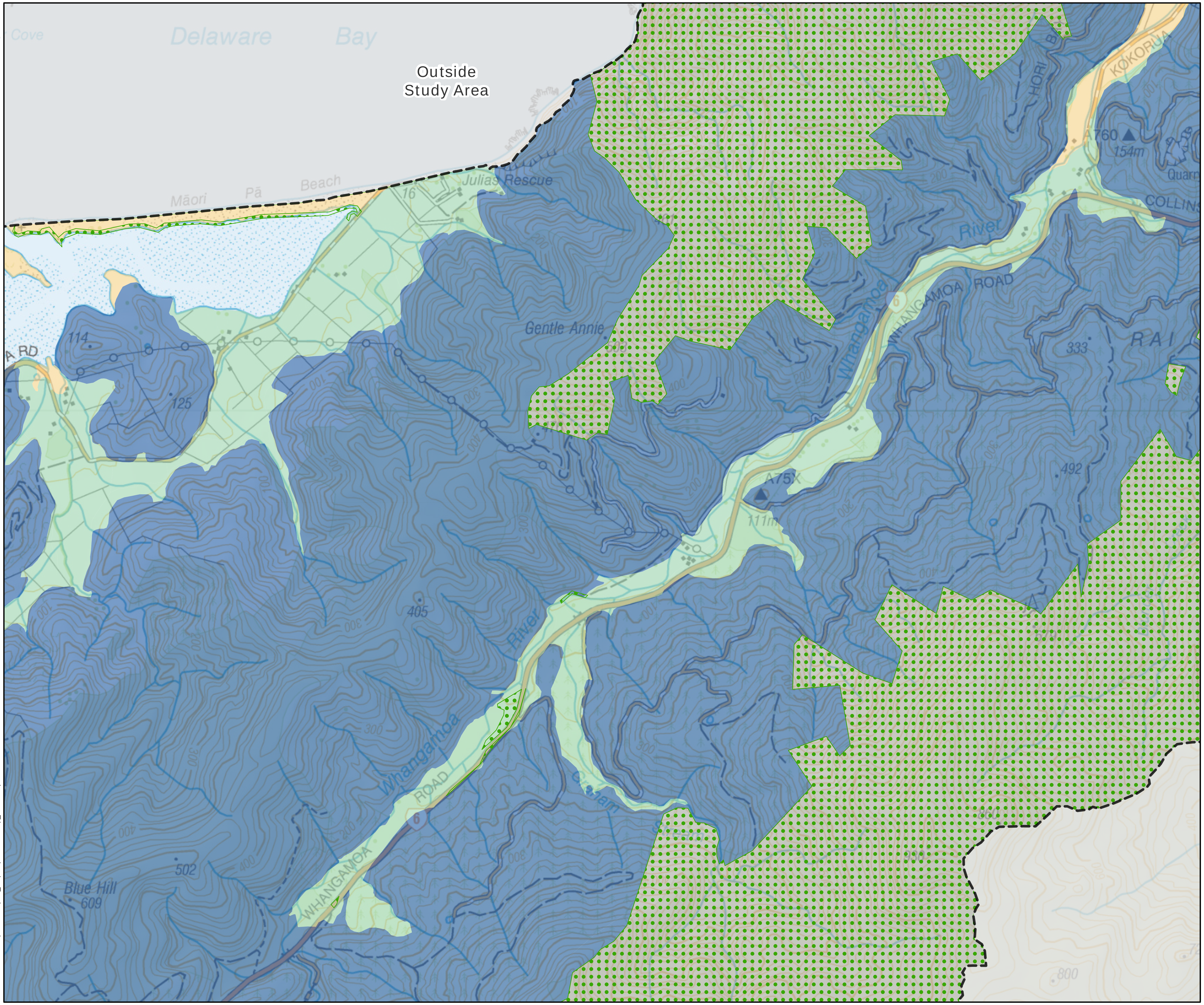

Nelson City Liquefaction Assessment

Map : C4

Legend

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- Nelson City Study Area
- DOC Land (Not assessed)

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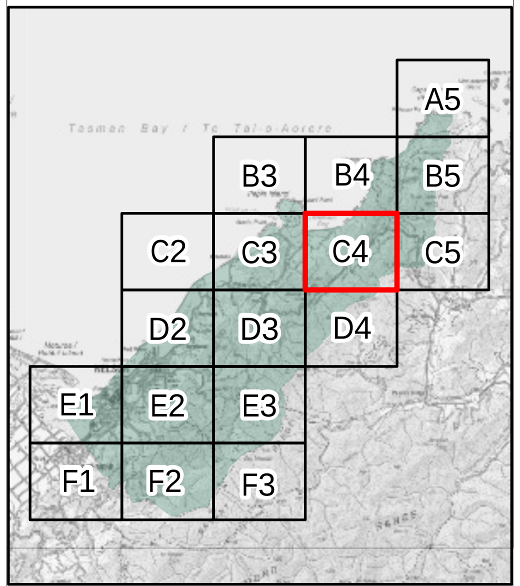
Liquefaction Damage is Unlikely (Very Low Liquefaction Vulnerability)	Liquefaction Damage is Possible



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-C4

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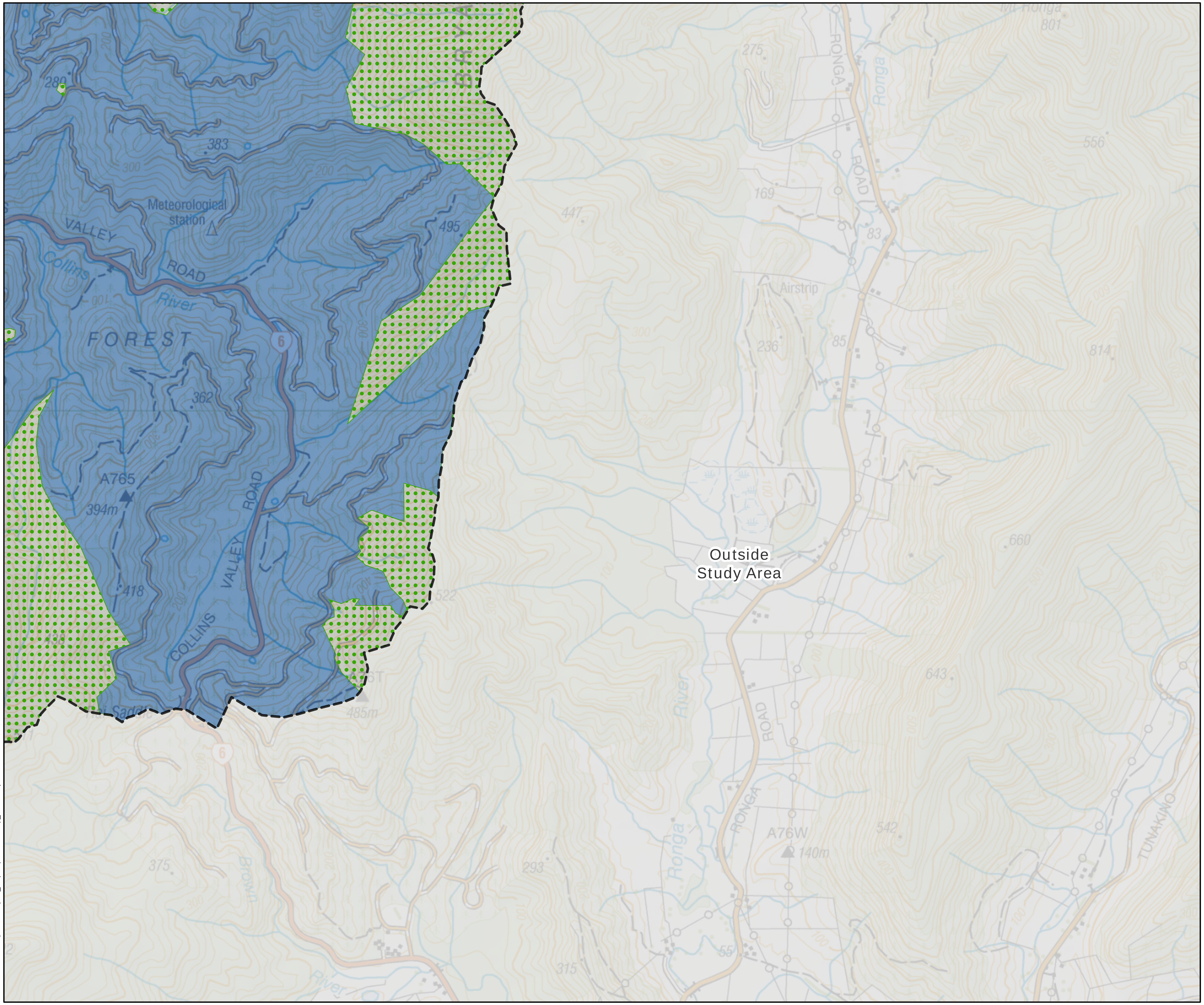
Nelson City Liquefaction Assessment

Map : C5 | Page 8 of 17



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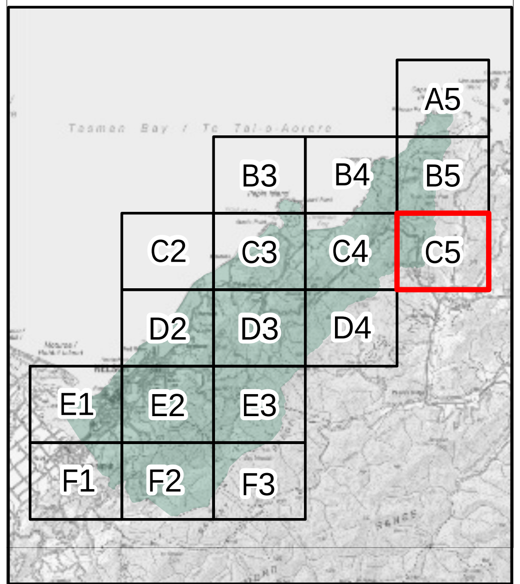
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-C5

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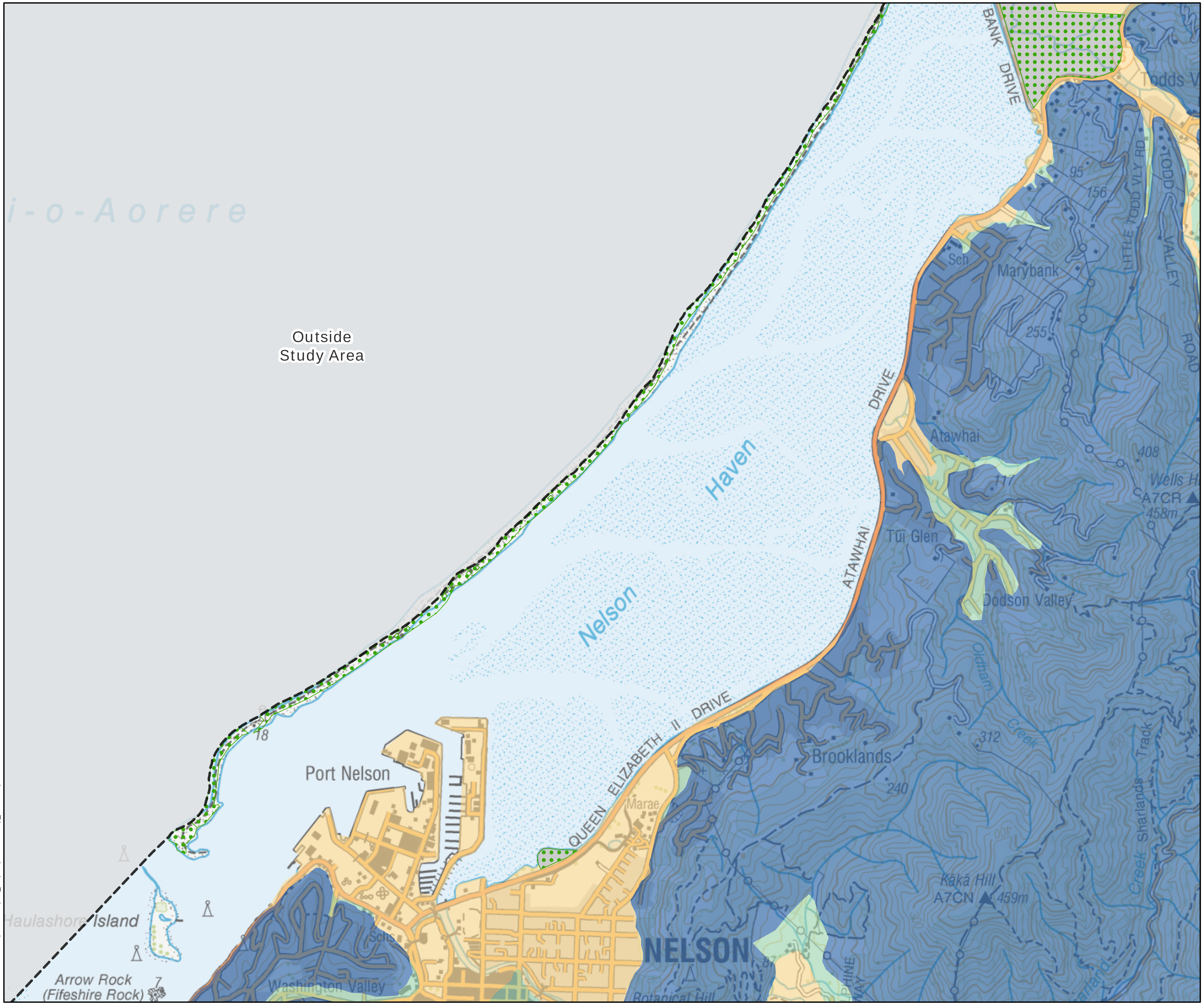


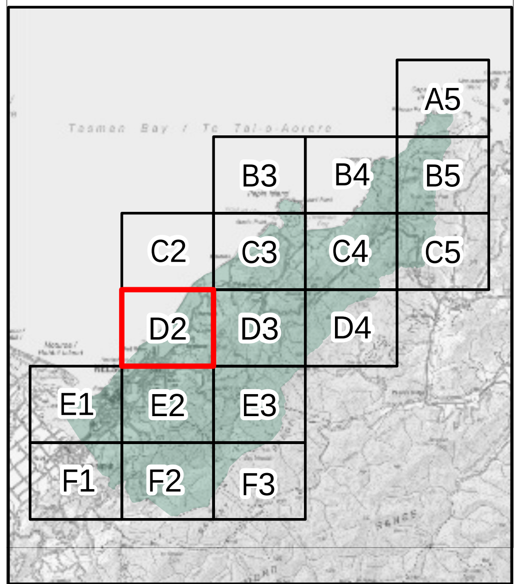
Nelson City Liquefaction Assessment

Map : D2 | Page 9 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-D2

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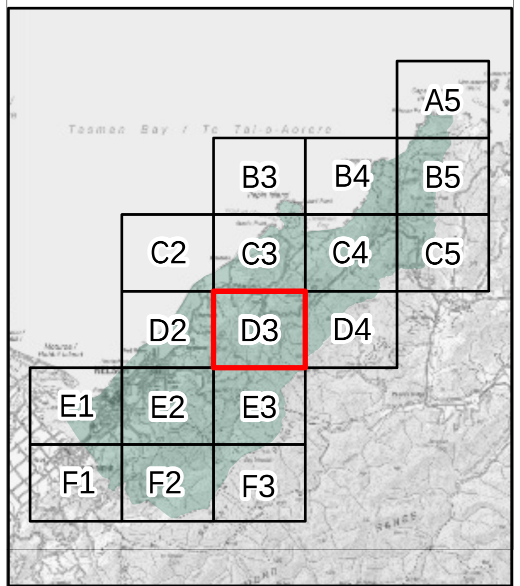
Nelson City Liquefaction Assessment

Map : D3	Page 10 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined		
Liquefaction Damage is Unlikely		Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability		



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-D3

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GIS@beca.com

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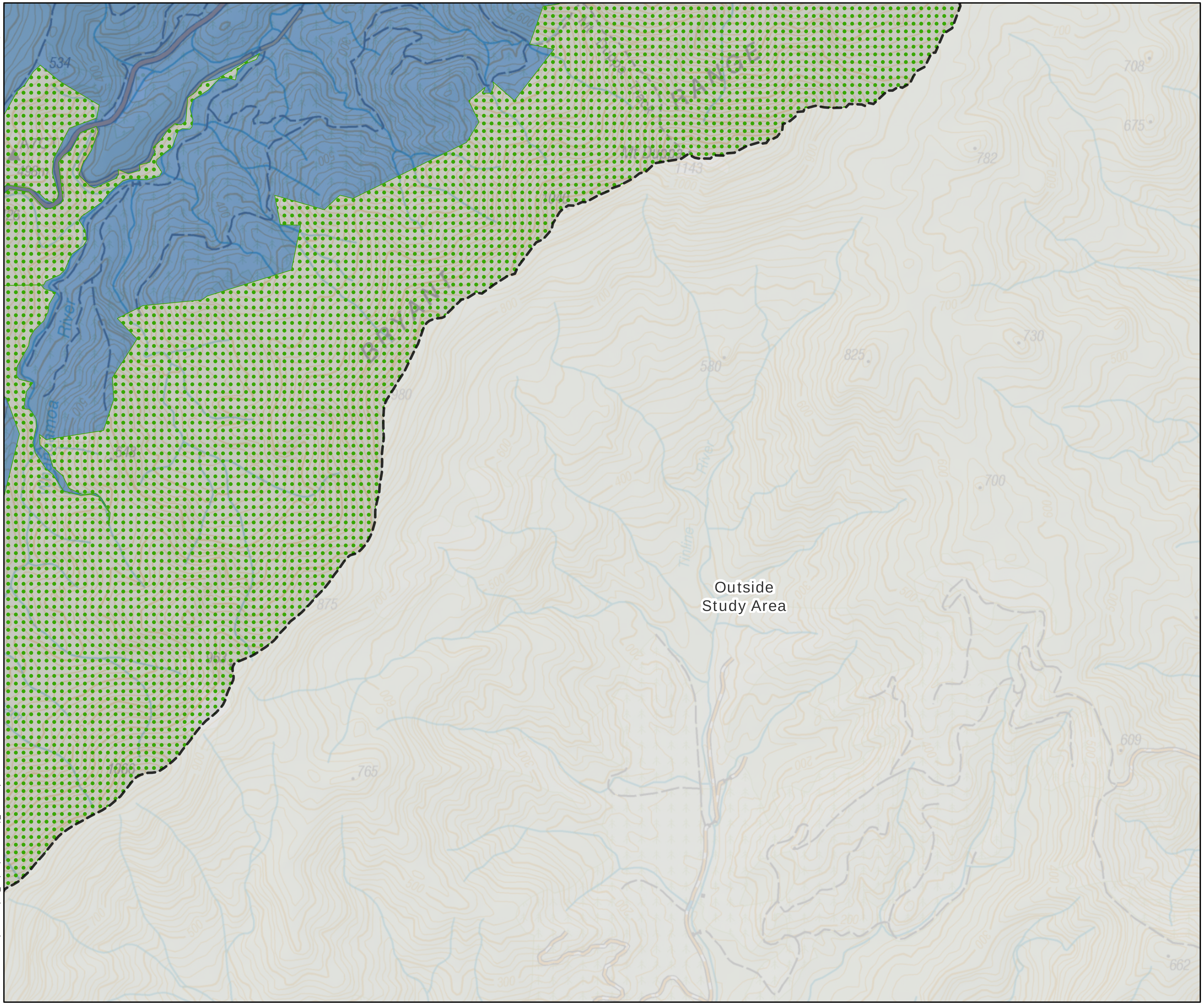


Nelson City Liquefaction Assessment

Map : D4

Legend

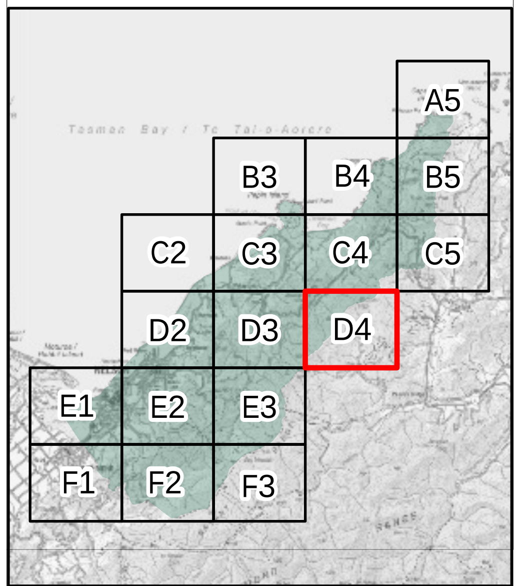
- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined

Liquefaction Damage is Unlikely

Very Low Liquefaction Vulnerability

Liquefaction Damage is Possible



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Metres

Revision	Author	Verified	Approved	Date
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1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

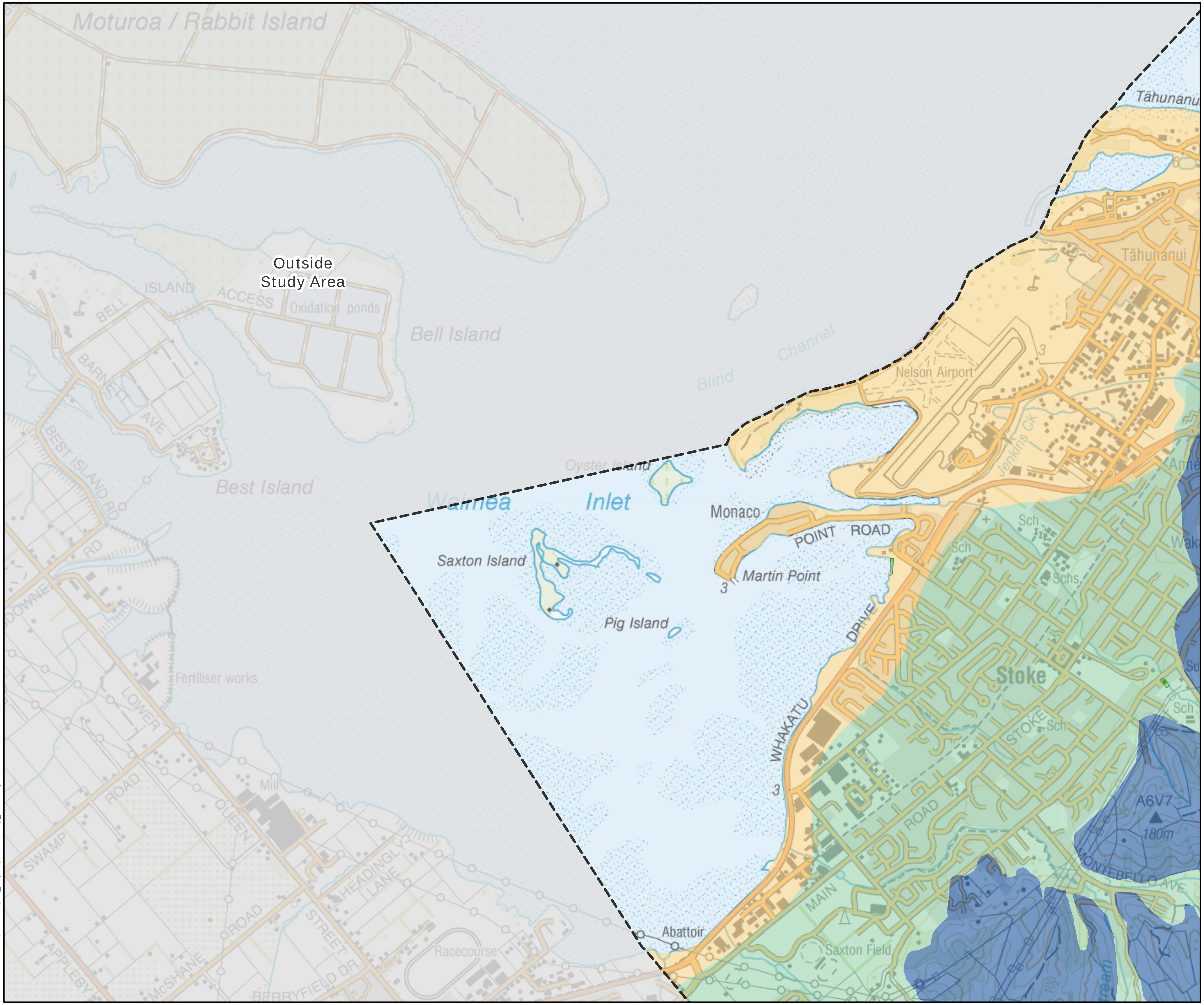
Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-D4

Beca

Nelson City Liquefaction Assessment

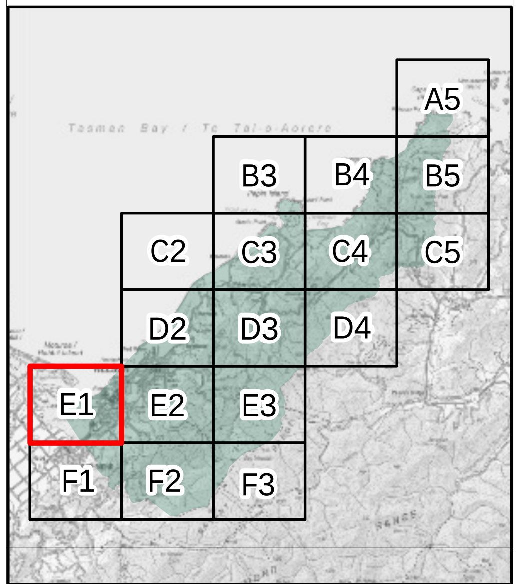
Map : E1 | Page 12 of 17



Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



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N

Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-E1

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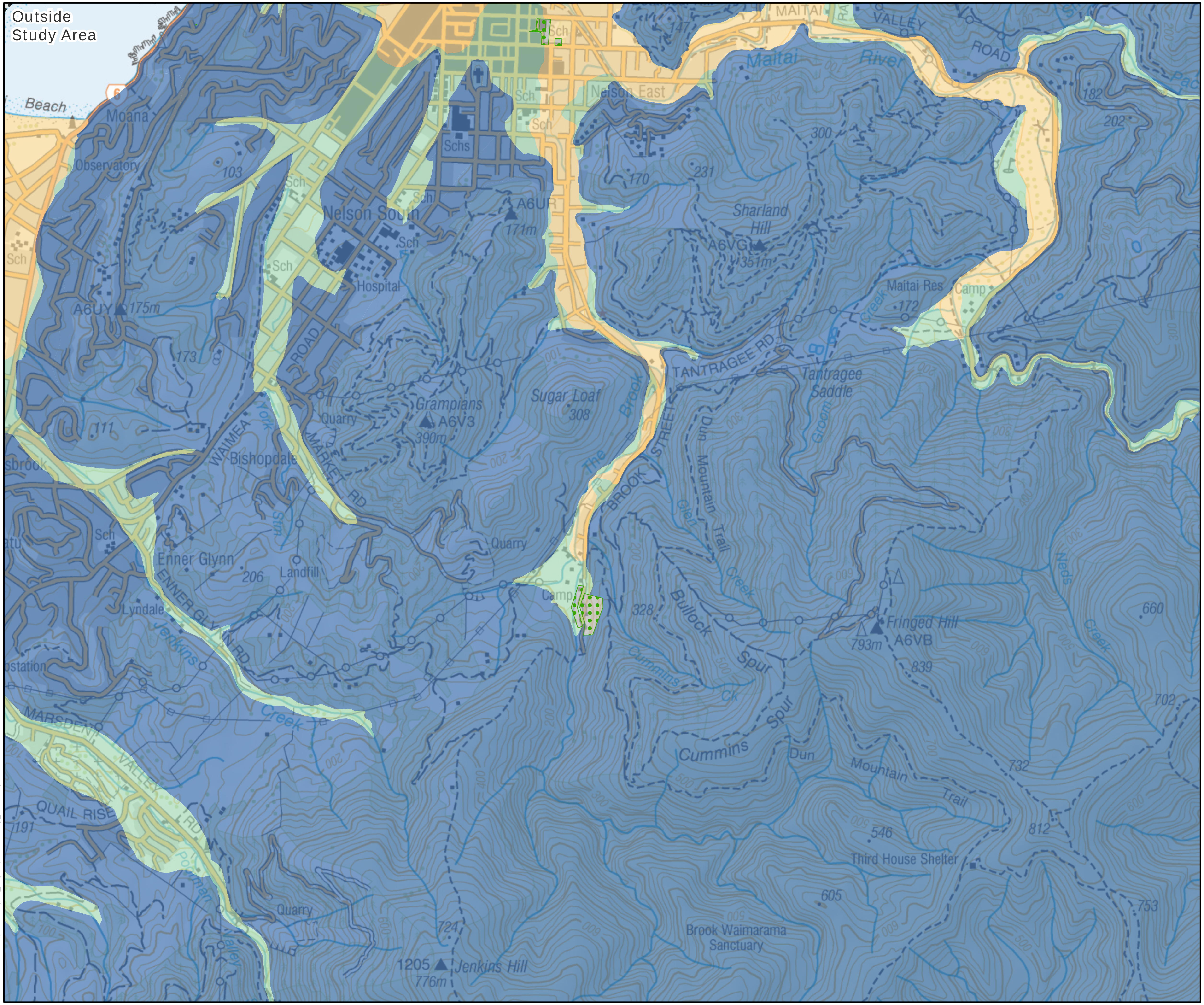
GIS@beca.com



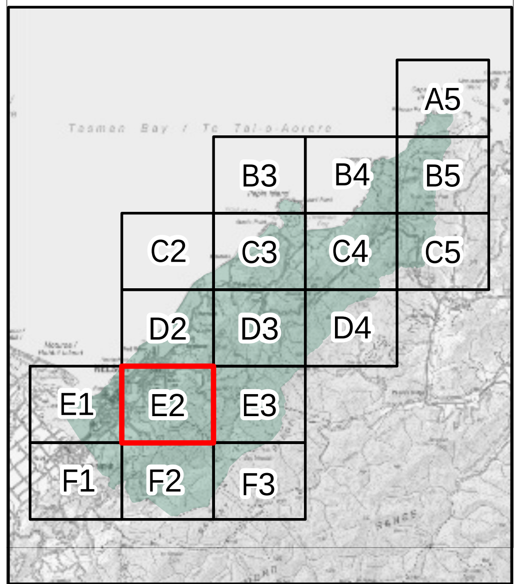
Nelson City Liquefaction Assessment

Map : E2 | Page 13 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely Very Low Liquefaction Vulnerability	Liquefaction Damage is Possible



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Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-E2

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GIS@beca.com
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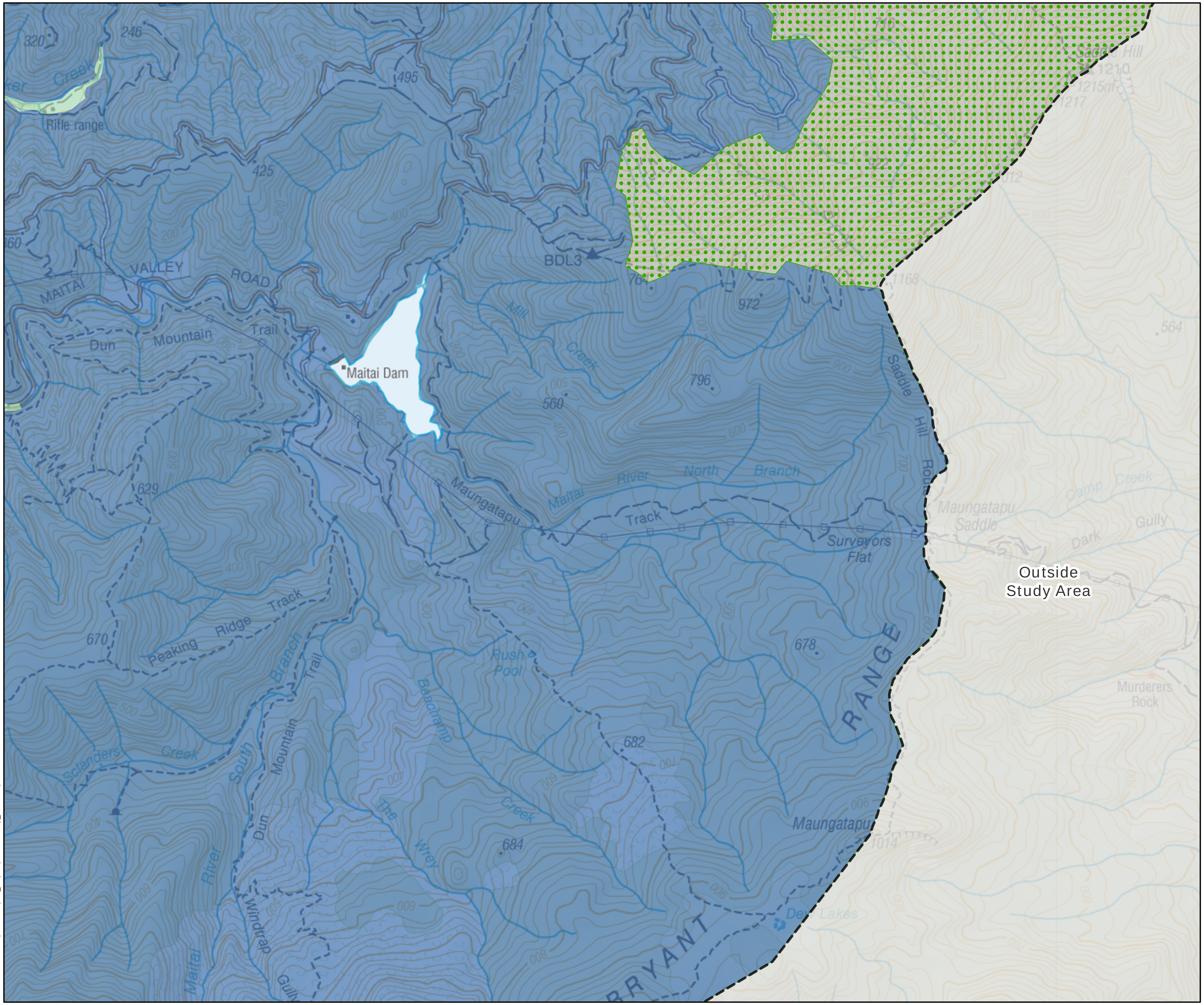


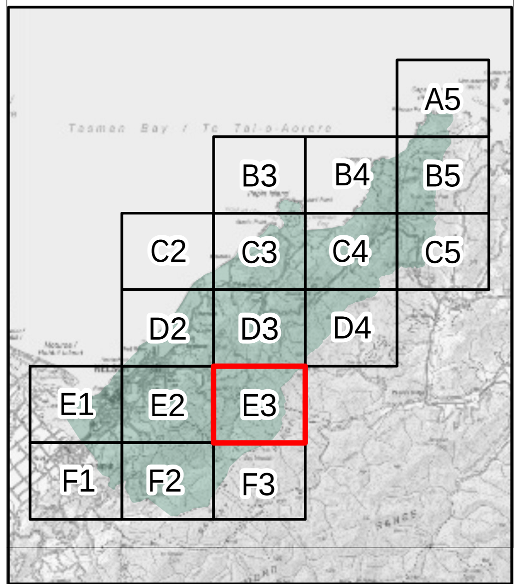
Nelson City Liquefaction Assessment

Map : E3	Page 14 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined		
Liquefaction Damage is Unlikely		Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability		



Map Scale @ A3: 1:25,000

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Metres

Revision	Author	Verified	Approved	Date
2	BDJ2	MM	SB	24/11/2021
1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

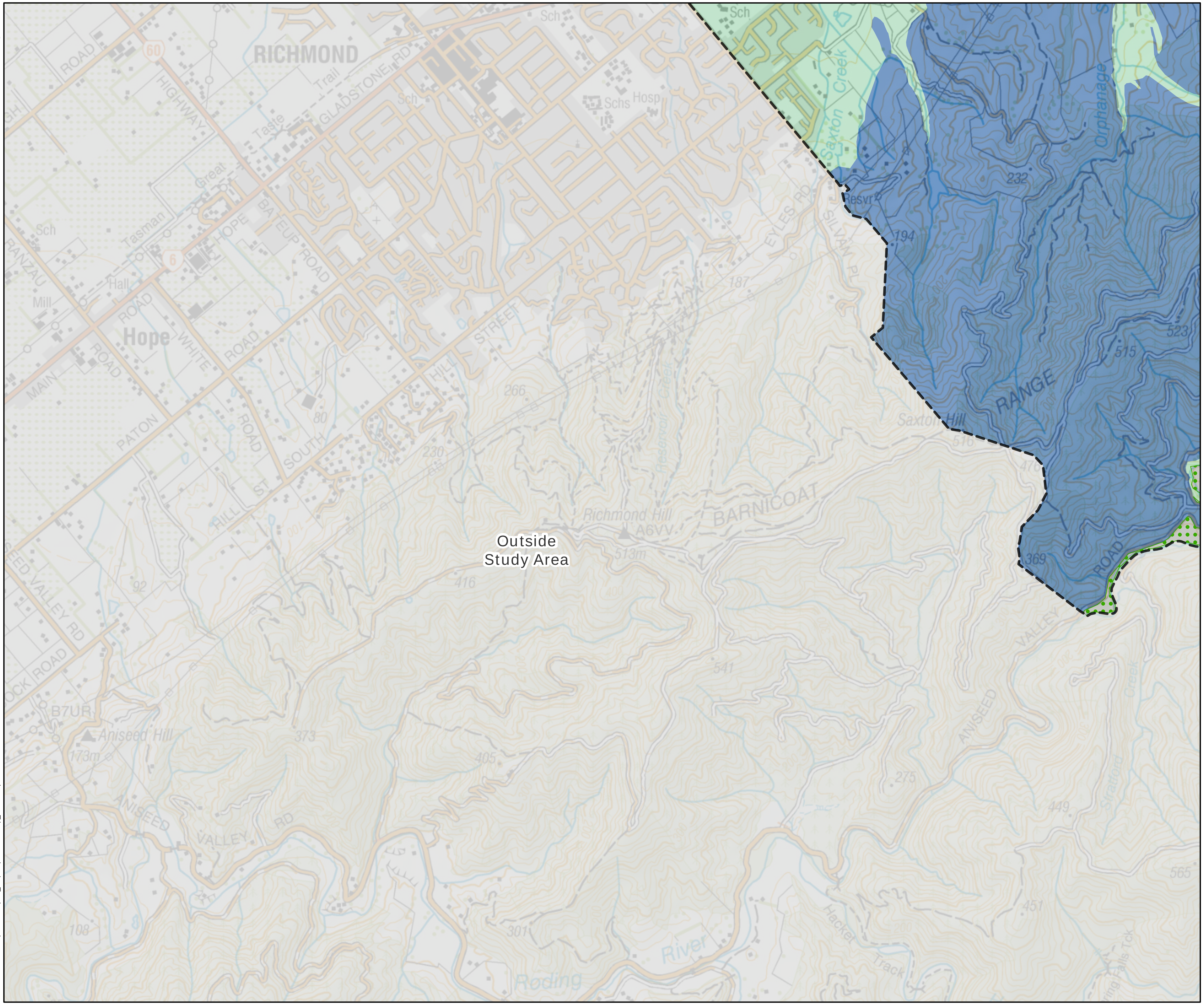
Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-E3

Beca

GIS@beca.com

P:\316\3160254\TGI(20200901)\01_Map\LiquefactionMap_revised.aprx Author: BDJ2 Date: 24/11/2021



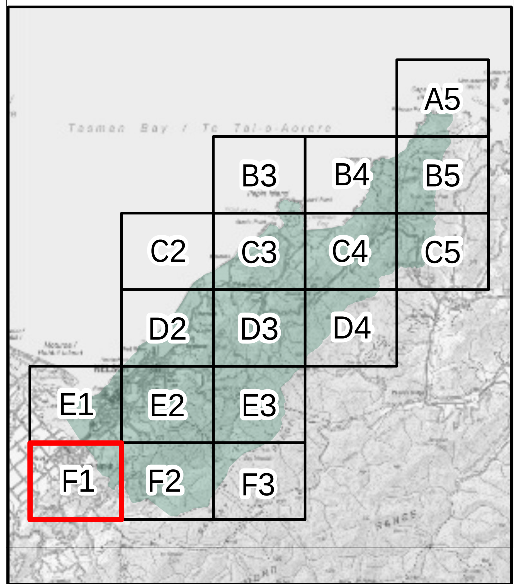
Nelson City Liquefaction Assessment

Map : F1

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely Very Low Liquefaction Vulnerability	Liquefaction Damage is Possible



Map Scale @ A3: 1:25,000

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Metres

Revision	Author	Verified	Approved	Date
2	BDJ2	MM	SB	24/11/2021
1	BDJ2	DRAFT	DRAFT	13/10/2021

N

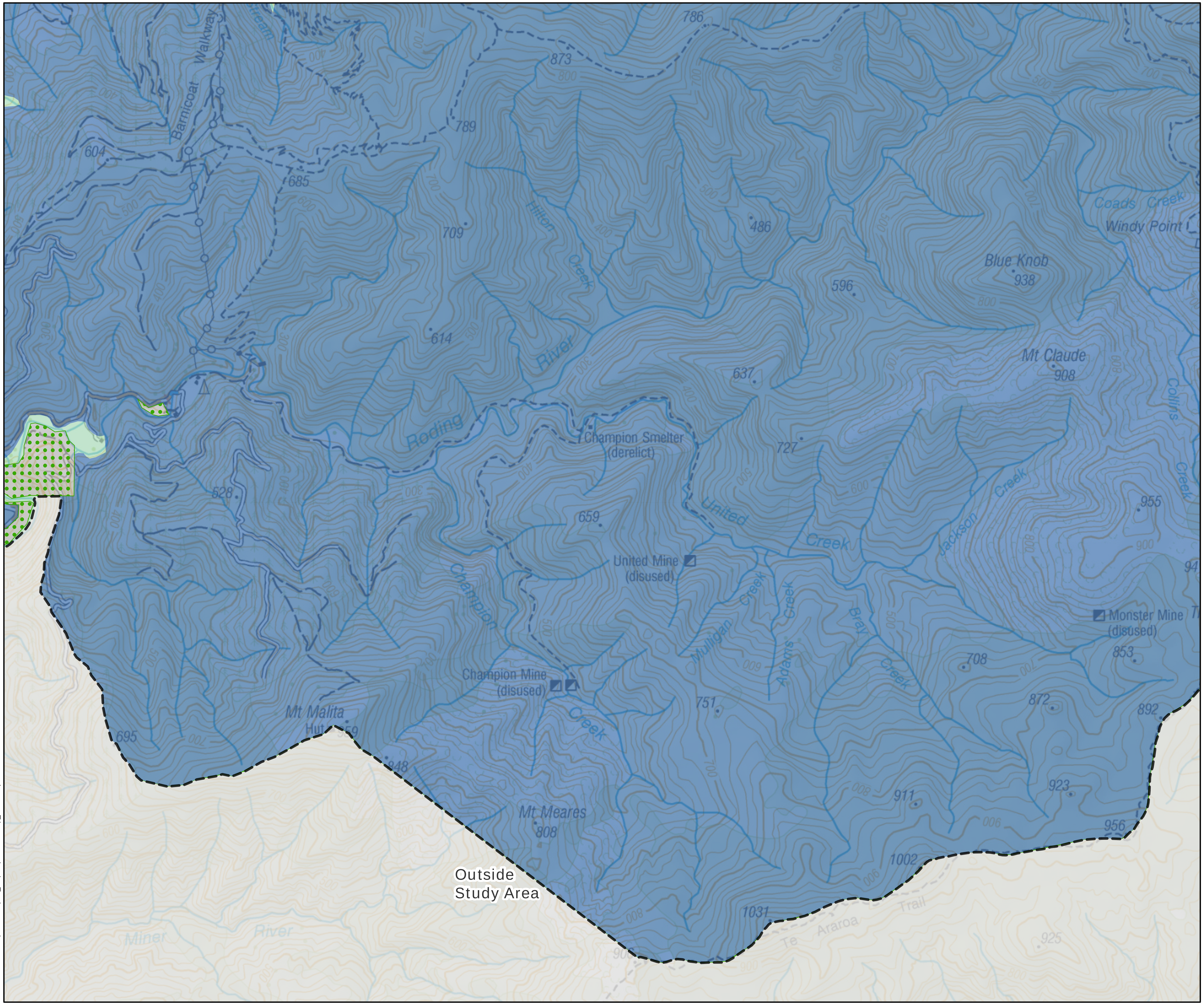
Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-F1

Beca



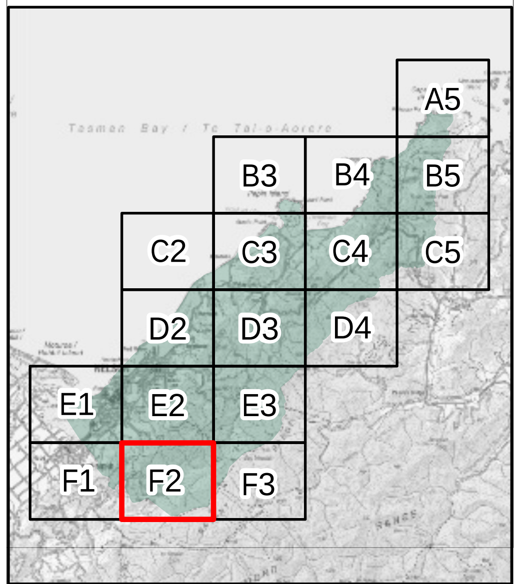
Nelson City Liquefaction Assessment

Map : F2 | Page 16 of 17

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



Map Scale @ A3: 1:25,000

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Metres

Revision	Author	Verified	Approved	Date
2	BDJ2	MM	SB	24/11/2021
1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

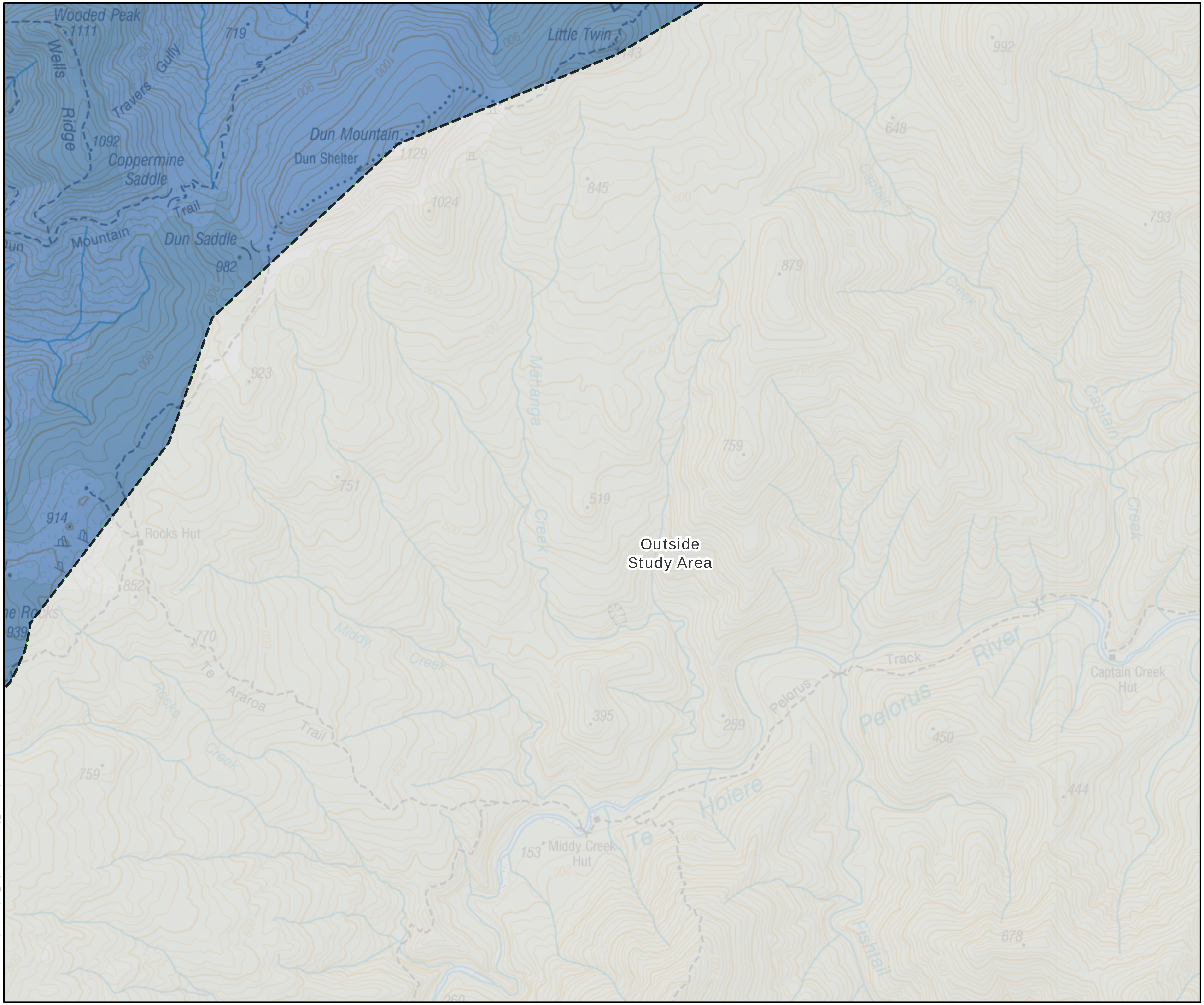
Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-F2

Beca

GIS@beca.com

P:\3160254\TG\(20200901)\01_Map\LiquefactionMap_revised.aprx Author: BDJ2 Date: 24/11/2021



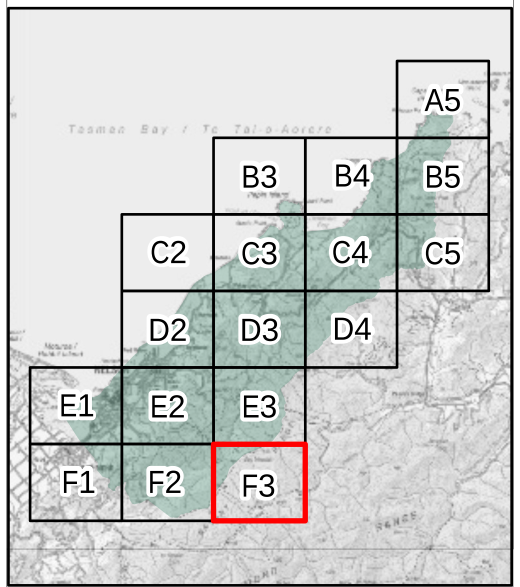
Nelson City Liquefaction Assessment

Map : F3

Legend

- Water
- Nelson City Study Area
- DOC Land (Not assessed)

Liquefaction Damage is Undetermined	
Liquefaction Damage is Unlikely	Liquefaction Damage is Possible
Very Low Liquefaction Vulnerability	



Map Scale @ A3: 1:25,000

0 500 1,000

Metres

Revision	Author	Verified	Approved	Date
2	BDJ2	MM	SB	24/11/2021
1	BDJ2	DRAFT	DRAFT	13/10/2021

N

Client: Nelson City Council

Discipline: GIS

Project: Liquefaction Review and Support

Drawing No: GIS-3160254-01-F3

B

Appendix B – Summary of Nelson Quaternary Geology

Nelson Regional (QMap) Quaternary Geology

Table B-1: Quaternary cover deposits included in the 1:250,000 geological map area

Deposit type	Map Symbol	Composition	Geomorphic Setting	Age (years)
Holocene flood plain and fan gravels	Q1a	Well sorted gravel, sand, and silt	In, and adjacent to active rivers and streams in modern flood plains	<10,000
Pleistocene alluvial gravels	Q2a	Clay-bound gravels to boulders	Lowest aggradation terraces above major rivers	10,000-24,000
Pleistocene alluvial and fan gravels	Q6a, Q8a, uQa, eQa	Slightly to very weathered clay-bound gravel	Intermediate, high, and remnant aggradation terraces	>24,000
Holocene alluvial fan, scree, and colluvial deposits	Q1a	Poorly sorted gravel	Base of currently active streams and rivers in river valleys and/or on hillslopes	<10,000
Pleistocene alluvial fan, and colluvial deposits	Q2a, uQa	Clay-bound poorly sorted gravel	Base of abandoned streams and/or outside currently active alluvial fans	>10,000
Holocene landslide deposits	Q1l	Rock fragments in a fine-grained matrix	Widespread on hillslopes across the region	<10,000
Undifferentiated landslide deposits	uQl	Shattered rock/ rock fragments in a fine-grained matrix	Widespread on hillslopes across the region	10,000 – 1,800,000
Holocene sand dunes	Q1d	Well sorted sands	Adjacent to the active coast and covering Tahunanui area	<10,000;
Holocene beach deposits	Q1b	Gravel with sand, mud, and boulder banks	Boulder bank and preserved gravel beach ridges	<10,000
Holocene peat and swamp deposits	Q1a	Poorly consolidated sand, mud, and peat.	Flat low-lying areas adjacent to the coast/ upriver from landslides	<10,000;
Deposits of human origin	Qan	Wood, domestic waste, sand, and boulders	Reclamation fill comprising hard and hydraulic fill	<150

Nelson Local Quaternary Geology

Table B-2: Quaternary cover deposits identified by from Johnston (1979) and Johnston (1981)

Deposit Name	Map Symbol & Corresponding QMap Unit	Composition	Location	Age (years)
Reclamation fill	xd (Qan)	Hard fill and domestic fill	Nelson extending over Trafalgar and Neale Parks / locally along Nelson Haven	<150
	xh (Qan)	Hydraulic fill	Port Nelson	
Nelson Alluvium	un (Q2al)	Very poorly sorted, fine-grained gravel, clay, and silt with local estuarine deposits	NW Nelson extending up valley to Bishopdale and in Dodson and Todds Valleys. Estuarine deposits in Toi Toi Valley	<10,000
Appleby Gravel	ua (Q1al)	Well sorted gravel with layers of sand and silt	Low-lying alluvial plains at the base of the Brook, Maitai, Wakapuaka and Whangamoa Valleys	<10,000
Stoke Fan Gravel	us3 (Q1af)	Poorly sorted clay-bound platy gravel forming present day fans	Stoke area extending from valleys in the Barnicoat Range	<10,000
	us2 (Q2af)	Poorly sorted clay-bound platy gravel forming fan remnants	Raised terraces in alluvial valleys within the Barnicoat Range	>10,000
	us1 (Q6a)	Poorly sorted clay-bound platy gravel forming elevated surfaces above present fans	Raised terraces on hillslopes in the Barnicoat Range	
Brougham Scree	ub (N/A)	Angular rock fragments in a silty clay matrix with grey, brown, and red clay horizons forming prominent screes	Locally present adjacent to the Flaxmore Fault in the Grampians	>10,000
Hope Gravel	uh2 (Q2al)	Poorly sorted, tight clay-bound gravel in terraces raised 3m above present flood plains	Terraces and tributary streams raised above Ua in the Maitai and Brook Valleys/ at the mouth of the Brook Valley	>10,000
	uh1 (Q6a)	Poorly sorted, tight clay-bound gravel in terraces raised 6m above present flood plains	Remnant terraces raised above Uh_2 in the Maitai Valley and at the mouth of the Brook Valley	<10,000
	uhf (Q6a)	Poorly sorted, tight clay-bound gravel fan gravels partly covering uh1 terraces	Fan deposits on hillslopes above the Maitai and Brook valleys and associated tributary streams	
Tahunanui Sand	qt (Q1d)	Sand forming beach ridges and dunes; local estuarine and swamp deposits	Tahunanui extending north of the Rabbit Island Gravel beach ridge (qr)	<10,000
Rabbit Island Gravel	qr (Q1b)	Pebbles cobbles and boulders forming beach ridges	Beach ridge extending from Monaco to Annesbrook	<10,000
Boulder Bank Gravel	qb (Q1b;	Granite, granodiorite and syenite cobbles and boulders forming Boulder Bank	Spit along outer side of Nelson Haven	<10,000