REPORT

Tonkin+Taylor

Technical report: Automated Liquefaction Vulnerability Categories mapping

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Tonkin + Taylor
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Executive summary

The Automated Liquefaction Vulnerability Category (ALVC) map is a national-scale geospatial product developed by Tonkin + Taylor as part of the National Liquefaction Model (NLM) project, commissioned by the Natural Hazards Commission Toka Tū Ake (NHC). The map classifies land across New Zealand into three liquefaction vulnerability categories following the definitions in Table 1.1 of the MBIE/MfE Guidance (2017): Liquefaction Damage is Unlikely, Liquefaction Damage is Possible, and Liquefaction Category is Undetermined. The ALVC map is produced using NLM version v2025.0.

A key methodological feature is the uncertainty masking method, which applies four automated masks to identify areas where uncertainty is too high to assign a conclusive category. The four masks address: (1) spatial uncertainty — where the liquefaction category changes with a small shift in similar-soil-polygon boundaries; (2) groundwater uncertainty — where the category changes with plausible variations in groundwater depth or sea-level rise; (3) Liquefaction Severity Number (LSN) uncertainty — where the uncertainty of the LSN distribution makes assigning a category difficult; and (4) local knowledge uncertainty — where existing district- or regional-scale LVC maps assign a different category to the category that would be assigned with this process. Any cell flagged by one or more masks is assigned Liquefaction Category is Undetermined.

The ALVC map is intended to support local councils and regional authorities in developing or updating LVC maps under the MBIE/MfE Guidance (2017). They provide a nationally consistent baseline that can be compared and refined using local information. The maps do not incorporate local knowledge, expert review, or stakeholder engagement. They are not suitable for individual property decisions, valuations, insurance pricing, or regulatory determinations, and should not be used in place of district- or regional-scale LVC maps produced by local authorities.

1 Introduction

1.1 Purpose of this report

This report explains the Automated Liquefaction Vulnerability Category (ALVC) map that is produced as part of the National Liquefaction Model (NLM) project. In broad terms, the map shows where the ground may be more or less likely to be affected by liquefaction during a strong earthquake. It has been created using a nationally consistent process so that results can be compared across New Zealand and help communities, councils, and other users understand regional patterns of liquefaction risk.

This is a technical report intended for people who are involved with the development of district- or regional-scale liquefaction vulnerability category maps. There is a more succinct companion report (Tonkin + Taylor, 2026b) that provides an overview of what the ALVC map is, which is intended for a general audience. The outputs described in this report are produced using the NLM model v2025.0. The NLM technical report (Tonkin + Taylor, 2026a) provides details on the NLM model.

1.2 Purpose of the ALVC map

The ALVC map is intended to:

- Provide a nationwide overview of potential liquefaction vulnerability using one consistent approach.
- Support awareness and communication about earthquake-related ground hazards.
- Support local councils to develop and/or update liquefaction vulnerability maps produced under the 2017 Ministry of Business, Innovation and Employment and Ministry for the Environment's liquefaction guidance (the MBIE/MfE Guidance (2017)).
- Support central government with policy planning and decision making such as consideration of the implications of updating the MBIE/MfE Guidance (2017).
- Assist the Natural Hazards Commission in consideration of strategic, regional-scale issues rather than individual properties.

Note that the ALVC map is not the same as, and does not replace, district- or regional-scale liquefaction vulnerability category maps produced or commissioned by local authorities under the MBIE/MfE Guidance (2017) and do not serve any regulatory function. They do not remove the requirement for resource or building consent applicants to undertake more detailed assessment of liquefaction hazard as part of the consent process, where necessary.

1.3 What is liquefaction

Liquefaction happens when loose, water-saturated soils lose their strength during an earthquake. The shaking increases water pressure between soil particles, causing the ground to behave like a liquid for a short time. This can lead to ground settlement, cracking, or sideways movement, which in turn can damage buildings, roads, pipes, and other buried infrastructure. The key elements required for liquefaction to occur are summarised in Figure 1.1.

Liquefaction is more likely to occur in flat, low-lying areas near rivers, lakes or the coast, where sandy or silty soils and shallow groundwater are common. It does not occur everywhere—some materials, such as rock and dense gravel, are not prone to liquefaction.

Three key elements are all required for liquefaction to occur:

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

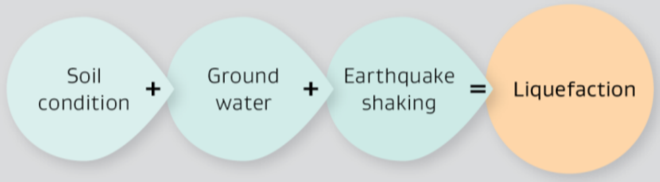

Figure 1.1: The key elements required for liquefaction from MBIE/MfE Guidance (2017).

1.4 What the ALVC map and masks show

The ALVC map groups land into three broad liquefaction vulnerability categories (LVC) based on the inferred likelihood of liquefaction damage during a major earthquake:

- **Liquefaction Damage is Unlikely** – areas where the model suggests little or no liquefaction-related damage.
- **Liquefaction Damage is Possible** – areas where the model suggests liquefaction could occur, potentially causing some ground deformation.
- **Liquefaction Category is Undetermined** – areas where the modelled data are uncertain or incomplete, or where more local information is required before a conclusion can be drawn.

These categories follow the same definitions used in Table 1.1 of the MBIE/MfE Guidance (2017). They are intended for **broad planning and awareness**, not for detailed engineering design.

The uncertainty masks show areas with significant uncertainty in the LVC such that it is assigned **Liquefaction Category is Undetermined**. Each mask is for a different source of uncertainty:

- **Spatial uncertainty:** this mask identifies where a small change in the location of the boundary of a similar-soil-polygon (the polygons that classify different liquefaction response), or in the location of the boundary between flat and sloping land, would change the assigned LVC.
- **Groundwater uncertainty:** this mask identifies where a change in the assumed groundwater depth (plus/minus one standard deviation) would change the assigned LVC.
- **Liquefaction Severity Number (LSN) uncertainty:** this mask identifies where a modest change in the assumed LSN (plus/minus one standard deviation) would change the assigned LVC.
- **Local knowledge uncertainty:** this mask identifies where district- or regional-scale LVC maps show a different LVC than the automated LVC.

1.5 Key limitations and recommendations

The ALVC map is an automated national-scale product, and therefore it:

- Does not include local knowledge, ground behaviour in previous seismic events, expert review, site walkover, ground-truthing, stakeholder engagement and consideration of the local context, which are essential parts of the methodology outlined in the MBIE/MfE Guidance (2017).
- Does not replace site-specific assessments required for subdivision, building or engineering design.
- Is not suitable for property-specific decisions, valuations, or insurance pricing.

- May differ from district- or regional-scale LVC maps that have been refined using additional information.
- Is mapped at a 100-metre grid spacing, meaning it does not provide full spatial coverage between these points (although the output is converted to raster cells for display). Furthermore, spatial uncertainty of the liquefaction vulnerability model can be 2-3 km especially in areas with few or no ground investigations.
- Should always be interpreted alongside other local hazard information.
- Is based on a simplified assessment of liquefaction, including considering uncertainties and probabilities through binary thresholds that may not reflect the nuances and causes of the uncertainties. Furthermore, the probability of damage calculated in the NLM does not account for liquefaction-induced lateral spreading.

Further limitations are detailed in Section 6.

1.6 District- or regional-scale LVC maps

The Resource Management Act 1991 (RMA) requires an assessment of natural hazard risk to support applications for subdivision consent, and therefore there is a need for consenting authorities and applicants to understand whether that land is likely to be affected by liquefaction or not. The MBIE/MfE Guidance (2017) provides a nationally-consistent methodology to carry out liquefaction assessments, with a specific focus on RMA and Building Act 2004 aspects.

The MBIE/MfE Guidance (2017) is important because territorial authorities and regional councils had previously taken varying approaches to this assessment. From collated information to date, mapping has been undertaken for 46 of the 67 territorial authorities across New Zealand using criteria/categories consistent with the guidance. Some of these also have published information about the interpretation of these maps to support the resource consent and building consent process. Of the remaining 21, 2 have no coverage, 6 only have partial coverage and 13 are produced using criteria/categories that are not consistent with the MBIE/MfE Guidance (2017). Most of these maps are produced at Level A (i.e. the lowest level of detail).

2 Use of the ALVC map

The ALVC map has been produced to support the development of LVC maps by territorial authorities and regional councils. **However, it is not suitable for direct application without further manual review** (and likely localised adjustments) by suitably qualified and experienced geo-professionals.

When making use of the ALVC map and other NLM outputs, the following recommendations apply:

1. Compare district- or regional-scale LVC maps with the ALVC map to identify areas of agreement and where differences may warrant further assessment.
2. Compare changes in ALVC output due to updates in liquefaction science, and improved mapping of seismic hazard, groundwater and ground conditions, which may prompt a review of council maps.
3. Review the uncertainty masks and whether those uncertainties can be addressed within district- or regional-scale LVC maps.
4. Understand where ground investigation density is higher which may allow more refined mapping.
5. Use the flatland boundary as reference to check whether a similar sloping land criteria is applicable for the region.
6. Use the geomorphology model and the geospatial model to provide a reference national-scale ground response that can be refined with local knowledge and local ground investigations.

7 Consider how the methodology used to develop the NLM may affect the model output for the specific ground conditions present, for example:

- Does the underlying liquefaction vulnerability model (which is locally refined only where ground investigations are available) provide a reasonable base representation of likely ground conditions?
- Does the exclusion of short ground investigations bias the model outputs?
- Does relying only on CPTs and digital boreholes bias the model outputs?

8 Use the groundwater model (with suitable critical review) to inform the likely groundwater depth and how it impacts the ground response.

9 It should be understood that district- or regional-scale LVC maps produced or commissioned by local authorities are the relevant reference for liquefaction hazard within the applicable regulatory context.

10 It is not appropriate to apply the NLM at an individual property level.

11 When developing local LVC maps, the level of detail criteria outlined in the MBIE/MfE guidance (e.g. minimum number of ground investigations needed) should be applied within the local context rather than relying on national databases. I.e. national scale calibrations of liquefaction performance for certain geologic units may not represent local conditions.

12 As the ground investigations and groundwater databases produced as part of the NLM are assessed at a national scale, differences can be expected when assessed in more detail.

3 Method

3.1 Overview

The MBIE/MfE Guidance (2017) defines the following liquefaction categories:

- ***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% that liquefaction-induced ground damage will be None-to-Minor for 500-year shaking.
- ***Liquefaction Damage is Possible***: There is a probability of more than 15% that liquefaction-induced ground damage will be Minor-to-Moderate (or more) for 500-year shaking.

The NLM maps for probability of Minor-to-Moderate land damage for 500-year return period are aligned with the criteria for the latter two categories. However, the NLM maps do not consider some causes of uncertainty that are needed within the context of the MBIE/MfE Guidance (2017), such as:

- The spatial extent of local ground investigations and the density of ground investigations.
- The handling of groundwater (GW) seasonal variability, GW uncertainty and sea level rise (SLR) (e.g. see NLM technical report Figure 11.14 to Figure 11.15).
- The spatial uncertainty, particularly related to the classification of flatland, geomorphology boundaries and the liquefaction vulnerability similar soil polygon (SSP) boundaries.
- The incorporation of local knowledge and context as well as calibration/validation using other information (e.g. observations from previous earthquakes).

This report adopts binary methods to evaluate each of the above differences using explicit thresholds, referred to here as the uncertainty masking method and illustrated in Figure 3.1. This approach is advantageous as it is similar to the approach adopted for most of the existing district- or regional-scale LVC maps and provides explicit highly interpretable reasons for why a cell is assigned ***Liquefaction Category is Undetermined***, through a mask overlay. However, it should be recognised that alternative thresholds or alternative approaches could result in different outcomes, and a simple binary approach does not reflect nuances of the causes of the differences in potential outputs.

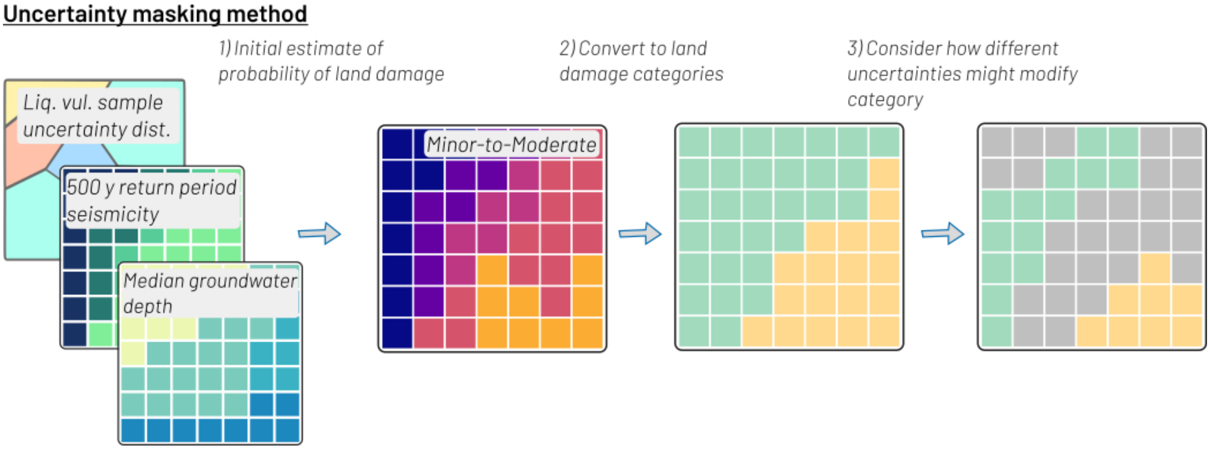

Figure 3.1: High level steps to obtain the ALVC map using the uncertainty masking method.

3.2 Inputs

The automated mapping process uses the following datasets as inputs (note: all NLM outputs presented in this report are from version v2025.0):

1 NLM scenario maps of the Probability of Minor to Moderate (or greater) land damage at 500-year return period shaking using the fitted fragility curves and probability of liquefaction[1], P_L, of 50% (see NLM technical report Section 11.3):
   a Produced using the updated (sample uncertainty) distribution and median groundwater depth.
   b Produced using the updated (sample uncertainty) distribution with plus and minus one standard deviation groundwater depth.
   c Produced using the updated (sample uncertainty) distribution and median groundwater depth with 1 m sea level rise (SLR).
   d Produced using the geospatial model distribution and median groundwater depth.
2 NLM scenario maps of Liquefaction Severity Number (LSN) distributions at 500-year return period shaking and P_L of 50% (see NLM technical report Section 11.3):
   a Produced using the sample uncertainty distribution and median groundwater depth.
   b Produced using the geospatial model distribution and median groundwater depth.
3 NLM Similar-soil-polygons (see NLM technical report Section 8.1).
4 NLM Coordinates per-GI (ground investigation) (see NLM technical report Section 7.1).
5 NLM Geomorphology model (see NLM technical report Section 6).
6 Existing district- or regional-scale LVC maps (see Appendix A and Appendix B).

[1] The probability of liquefaction (P_L) adjusts the calculation of the factor of safety against triggering of liquefaction.

3.3 Key steps

Implementation of the method comprises several processes:

1 **Process to develop knitted categories map**. This develops an initial ALVC map from NLM land damage probability maps that consider the ground investigation density (see Section 3.4).

2 **Development of uncertainty masks**. Several subprocesses develop specific masks due to different uncertainties (see Section 3.5).

3 **Development of final ALVC map**. Combining the base knitted categories map with the uncertainty masks to produce a final map (see Section 3.6).

3.4 Process to develop knitted categories map

The knitted categories map combines LVCs from the NLM geospatial model output (i.e. an output that does not consider local ground investigations) and the updated output that considered local ground investigations. The combination is governed by the density of local ground investigations. This step means that liquefaction vulnerability categories are influenced by ground investigations (i.e. the categorisation is based on the updated (sample uncertainty) distribution) when close to them but not if they are more than 1000 m away. The following steps are applied:

1 **Develop the ground investigation (GI) mask**. This assigns a mask to a location if it is within 1000 m of a ground investigation that is within the same SSP. By only using GIs within the SSP, this considers only the GIs that are used in the development of the updated land damage estimate.

2 **Develop filled initial maps**. A filled initial map is a map that has liquefaction categories in all locations except for waterbodies. For each grid point convert the probability of Minor-to-Moderate land damage for a 500-year event to initial liquefaction categories. If the probability is greater than or equal to 15% that liquefaction-induced ground damage will be Minor-to-Moderate (or more) then categorise as ***Liquefaction Damage is Possible.*** *If less than 15% then* ***Liquefaction Damage is Unlikely***. The probability of land damage output is only produced where there are SSP. Gaps that are part of the flatland area are assigned ***Liquefaction Category is Undetermined*** (this consists of some active river channels that are not assigned a geomorphology polygon), and non-flat land is assigned ***Liquefaction Damage is Unlikely***. All remaining cells are waterbodies and are left empty. The process to develop these maps using the geospatial model output and the updated output is illustrated in Figure 3.2.

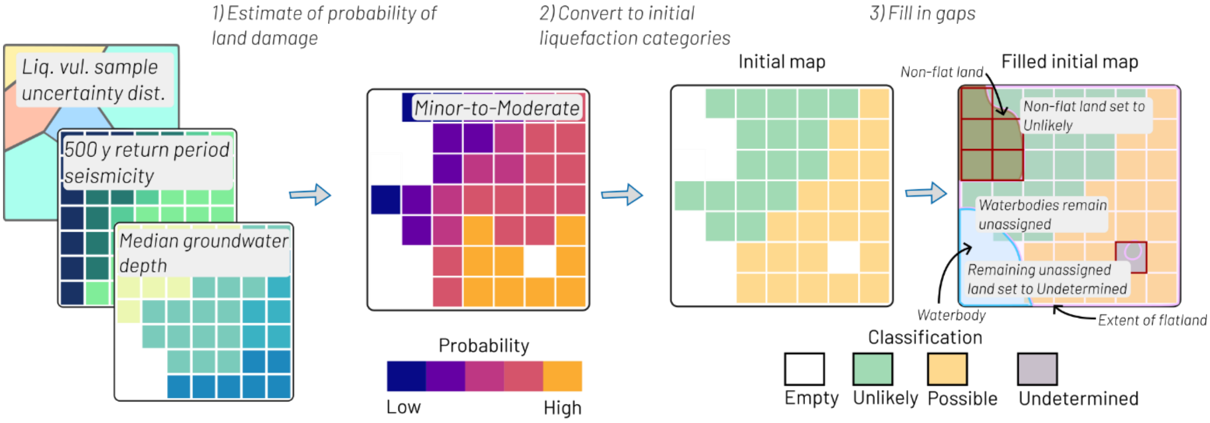

Figure 3.2: Process to develop a filled initial map.

3 **Develop the knitted categories map.** Combine the filled initial maps from the geospatial and updated output distributions, where the categories from the updated output are used in place of the ones from the geospatial distribution when the mask is true.

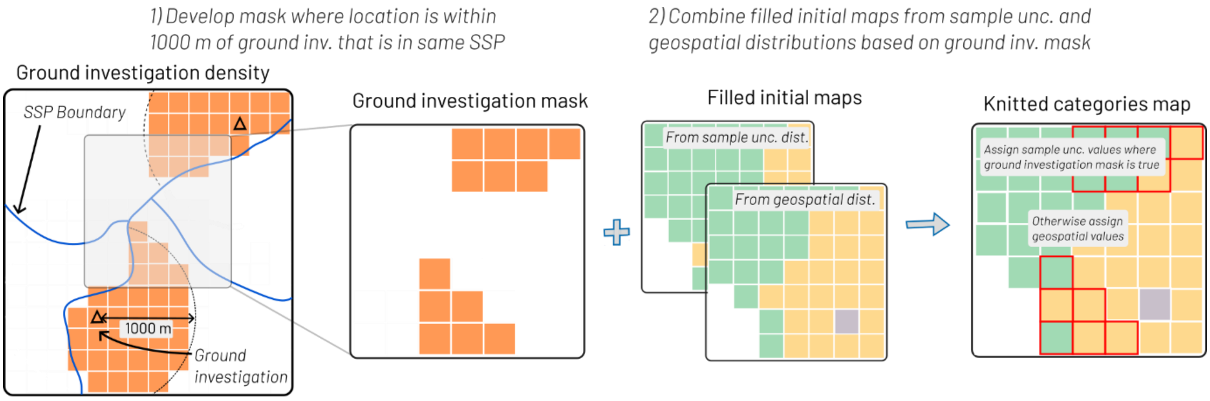

Figure 3.3: Overview of steps to generate knitted categories map.

3.5 Development of uncertainty masks

The different masks are outlined in the following subsections, many of them make use of a knitted map. The knitted base map is the knitted categories map determined from the median groundwater, while a knitted scenario map has a different groundwater scenario.

3.5.1 Spatial uncertainty mask

As outlined in Figure 3.4 the spatial uncertainty mask is generated by flagging cells that have adjacent neighbours with differing categories (excluding ***Liquefaction Category is Undetermined***).

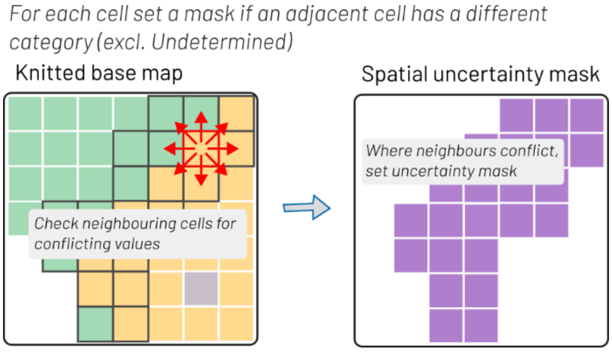

Figure 3.4: Overview of process to generate spatial boundary uncertainty mask.

3.5.2 Groundwater uncertainty masks

As outlined in Figure 3.5, a groundwater (GW) uncertainty mask is generated by comparing categories from a GW scenario versus the base map, with a mask applied to cells where the change in groundwater would cause a change in the liquefaction vulnerability category. Three different scenarios are considered as follows:

1 Median groundwater depth plus one standard deviation of depth uncertainty.

2 Median groundwater depth minus one standard deviation of depth uncertainty.

3 Median groundwater depth plus one metre of sea level rise.

Note that the knitted scenario maps are generated using the same process as the knitted base map except that the groundwater is different.

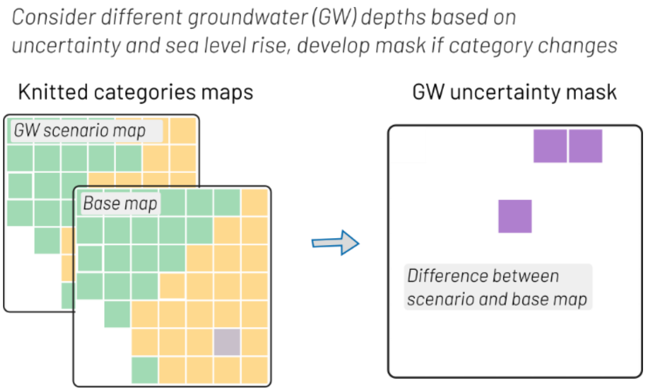

Figure 3.5: Overview of process to generate uncertainty masks for ground water and sea level rise scenarios.

3.5.3 LSN uncertainty mask

As outlined in Figure 3.6, the LSN uncertainty mask is created by combining the LSN from the geospatial distribution and updated output distribution based on the GI mask to produce a map of knitted LSN distributions. Each distribution is then evaluated against an LSN threshold, LSN_{thres}. Specifically, if the 15th percentile LSN is greater than the threshold, or the 85th percentile is less than the threshold, then no mask is assigned, otherwise a mask is assigned. LSN_{thres} is taken as 5 which is the LSN value that corresponds to a 15% probability of Minor-to-Moderate (or greater) land damage based on the fitted fragility curves, see NLM technical report Section 10.2.5.

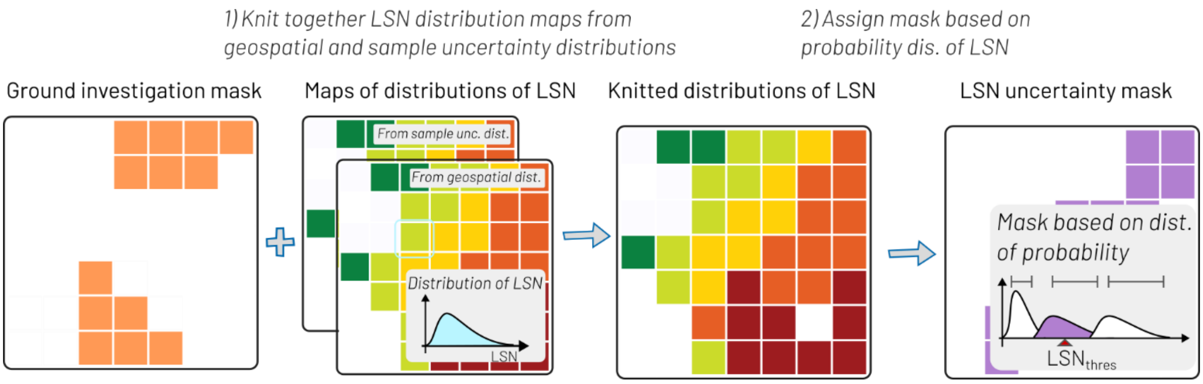

Figure 3.6: Process to develop the LSN uncertainty mask.

Since the distributions from the sample uncertainty model are only used near GI and the geospatial distributions (which have larger uncertainty) are used elsewhere, this step implicitly accounts for both the GI density and the expected level of damage. Particularly, if there are no ground investigations but the geospatial estimate has very high LSN values then there is reasonable basis to assign ***Liquefaction Damage is Possible***. On the contrary, if the geospatial model has modest LSN values with a wide range, then there is high uncertainty in the response and the mask is applied.

3.5.4 Local knowledge uncertainty mask

As outlined in Figure 3.7, the local knowledge uncertainty mask is generated by comparing the knitted base map with existing district- or regional-scale LVC maps, flagging cells where the categorisations differ. This comparison excludes differences for the ***Liquefaction Category is Undetermined*** category. Existing district- or regional-scale LVC maps sometimes have higher precision liquefaction categories (e.g. ***Very Low Liquefaction Vulnerability***), in these cases the higher precision categories are transformed back to low precision categories as outlined in Table 3.1. In locations where multiple existing maps had assigned categories, the higher level of detail map is used (e.g. Level B took precedence over Level A).

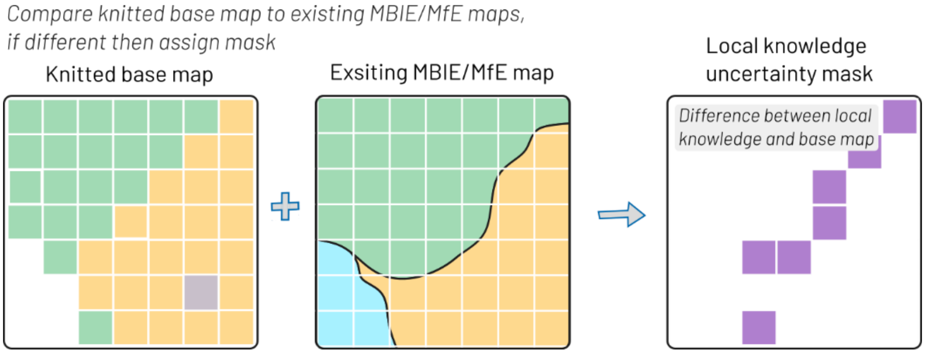

Figure 3.7: Overview of process to generate local knowledge uncertainty mask.

Table 3.1: Transform from higher to lower precision categories for existing MBIE/MfE maps

Higher precision category	Low precision category
Very Low Liquefaction Vulnerability	Liquefaction Damage is Unlikely
Low Liquefaction Vulnerability	Liquefaction Damage is Unlikely
Medium Liquefaction Vulnerability	Liquefaction Damage is Possible
High Liquefaction Vulnerability	Liquefaction Damage is Possible

3.6 Combine all masks

As outlined in Figure 3.8, all individual uncertainty masks are combined into a single mask, and flagged cells are set to ***Liquefaction Category is Undetermined*** in the final ALVC map which is generated from the knitted base map.

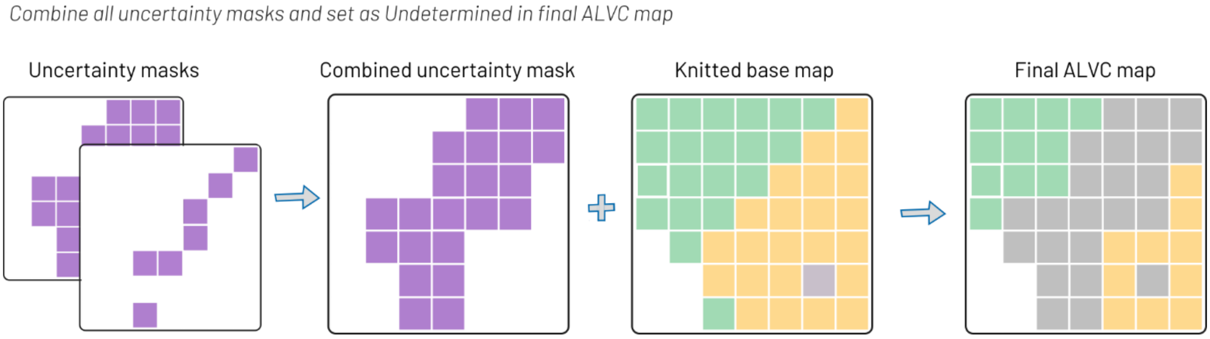

Figure 3.8: Overview of process used to combine all uncertainty masks and generate final ALVC map.

4 Outputs

The full outputs are contained in the digital supplement: *ALVC-map-outputs*, described in Table 4.1.

Table 4.1: Files included in the ALVC digital supplement

Name	Description
ALVC s3 filled initial map from geospatial pl50.tif	Filled initial map using geospatial distributions
ALVC s3 filled initial map from sample unc pl50.tif	Filled initial map using sample uncertainty distributions
ALVC s4 substep alvc combined base pl50.tif	Knitted categories base map
ALVC s5 mask boundary unc pl50.tif	Uncertainty mask for spatial uncertainty
ALVC s6 mask minus gw unc pl50.tif	Uncertainty mask for minus 1 standard deviation of groundwater depth
ALVC s6 mask plus gw unc pl50.tif	Uncertainty mask for plus 1 standard deviation of groundwater depth
ALVC s7 mask slr unc pl50.tif	Uncertainty mask for groundwater depth with 1m sea level rise
ALVC s8 mask local knowledge unc pl50.tif	Uncertainty mask for local knowledge (i.e. where the ALVC doesn't match the existing district- or regional-scale LVC maps)
ALVC s9 mask lsn unc pl50.tif	Uncertainty mask for LSN uncertainty
ALVC s10 final alvc pl50.tif	Final ALVC map
ALVC s10 substep alvc no local unc pl50.tif	ALVC map without local knowledge mask applied
ALVC s11 mask undetermined pl50.tif	Combined masks

Figure 4.1 - 4.6 show example outputs for Christchurch, Hawkes Bay and Wellington. The first figure for each region shows the 500-year return period earthquake shaking (Peak Ground Acceleration or PGA), the probability of land damage from the updated output distribution for the 500-year earthquake shaking with median groundwater depth, and the final ALVC map. The second figure shows the ALVC map without the local knowledge uncertainty mask applied, the existing district- or regional-scale LVC maps, and the local knowledge uncertainty mask.

The local knowledge uncertainty mask is developed from a comparison of the knitted base map to the existing district- or regional-scale LVC maps, and therefore there is a mask in some areas where it would be mapped as ***Liquefaction Category is Undetermined*** for other reasons (e.g. groundwater uncertainty). In areas around Christchurch and Wellington the ALVC map without the local knowledge uncertainty mask shows significant areas of ***Liquefaction Damage is Possible***, where existing maps show ***Liquefaction Damage is Unlikely***. This mismatch is mostly attributable to the lack of local knowledge considered in the ALVC map. Other potential reasons are listed in the limitations in Section 6.

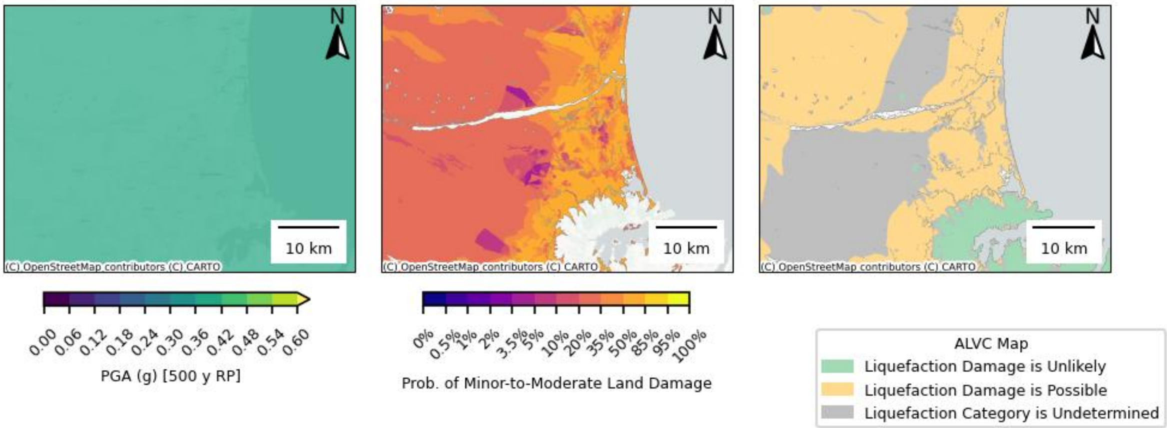

Figure 4.1: Christchurch area: PGA map (left), Probability of land damage map (centre), ALVC map (right).

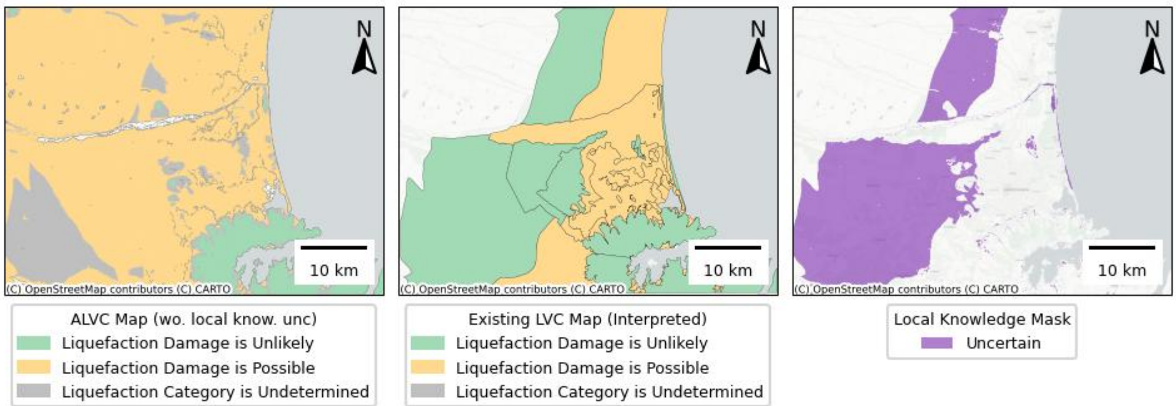

Figure 4.2: Christchurch area: ALVC map without local knowledge mask applied (left), existing district-scale LVC map (centre), local knowledge mask (right).

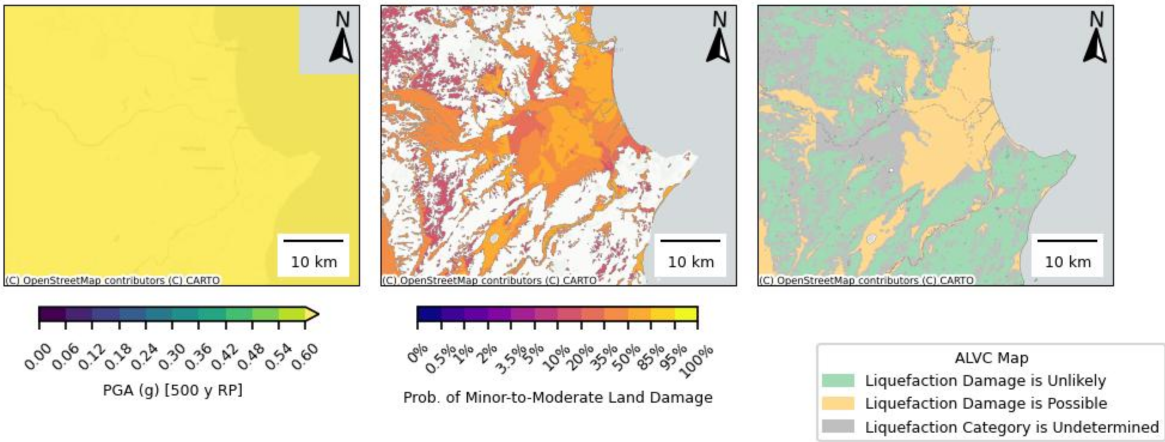

Figure 4.3: Hawkes Bay region: PGA map (left), probability of land damage map (centre), ALVC map (right).

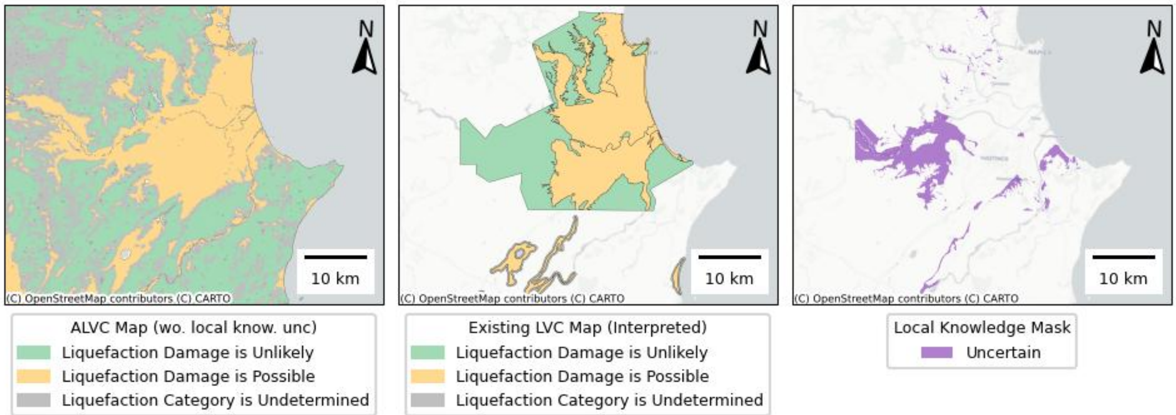

Figure 4.4: Hawkes Bay region: ALVC map without local knowledge mask applied (left), existing district-scale LVC map (centre), local knowledge mask (right).

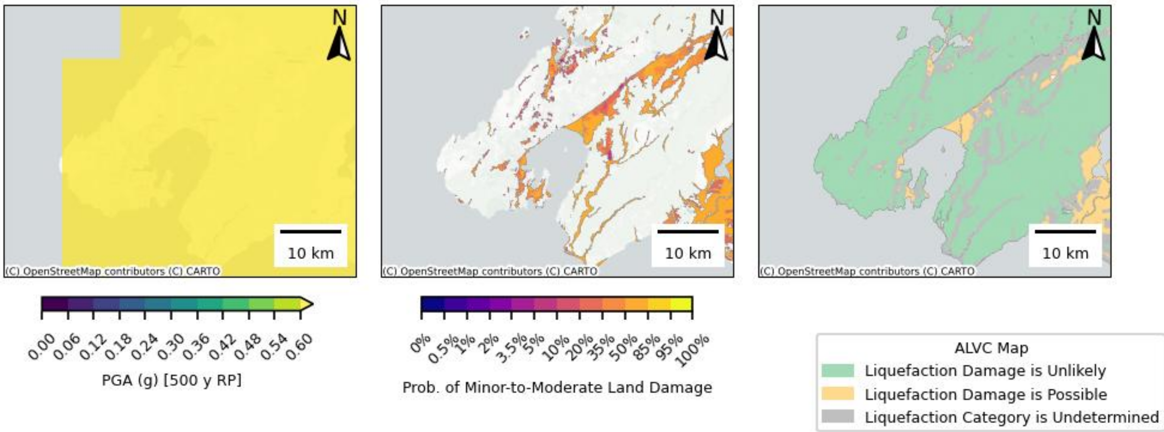

Figure 4.5: Wellington region: PGA map (left), probability of land damage map (centre), ALVC map (right).

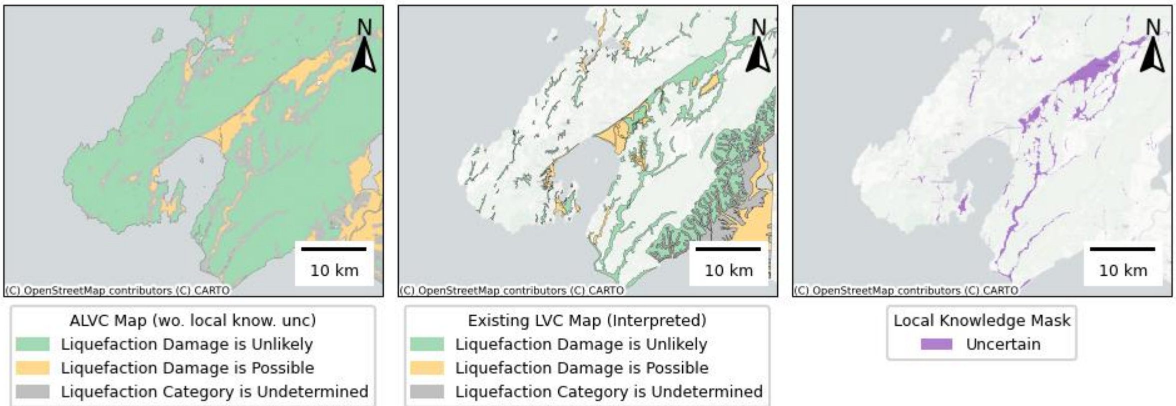

Figure 4.6: Wellington region: ALVC map without local knowledge mask applied (left), existing regional-scale LVC map (centre), local knowledge mask (right).

5 Discussion

The 2017 MBIE/MfE Guidance framework allows for different levels of precision to manage uncertainty, and in particular the assignment of ***Liquefaction Category is Undetermined*** in areas where there is a higher potential for misclassification due to a range of uncertainties.

However, the choice of when to assign ***Liquefaction Category is Undetermined*** within the ALVC map is not simple, primarily because the MBIE/MfE Guidance (2017) is written for regional-level mapping (e.g. recommendations regarding numbers of ground investigations within geomorphology units are not directly applicable). Second, there are both benefits and drawbacks of assigning conclusive categories (e.g. it is informative to assign a category of ***Liquefaction Damage is Possible*** rather than ***Liquefaction Category is Undetermined***, but misclassification can be very unhelpful). Finally, the extent of land that is assigned a conclusive category influences the perceived accuracy (e.g. if there are only small areas where an assignment is made then there would be an expectation that these areas are more likely to be accurate).

Simple thresholds are adopted within the ALVC mapping process, however, alternative thresholds could also be justified, and those thresholds should be tied into the broader risk management objectives relating to the intended use of the map.

6 Limitations

The following limitations should be noted for the ALVC map:

1. The map depends on the NLM liquefaction vulnerability and groundwater models, the land damage fragility curves, and the scenario outputs process and therefore all the limitations outlined in the NLM technical report (Sections 8.9, 9.5, 10.5 and 11.4) apply to these outputs.
2. The ALVC map is not the same as district- or regional-scale liquefaction vulnerability category maps produced or commissioned by local authorities under the MBIE/MfE Guidance (2017) for the reasons detailed in Section 1.5.
3. The map is generated through explicit consideration of different sources of uncertainty and handling the variability with binary classifications, some examples include:
   a. Use of either probability of land damage from the geospatial distributions or the updated output distributions.
   b. Application of a mask for ***Liquefaction Category is Undetermined*** or not.

   While this process is highly interpretable it does not reflect that many of the uncertainties are not completely independent and vary more subtly than a binary switch. This can cause abrupt changes in the output due to only small changes in the expected liquefaction response. For the development of the ALVC map this limitation is deemed suitable due to the benefit of clearly documenting (using masks) why areas are assigned a particular category.
4. The outputs are determined from parameters sampled at the centre point of each raster, and therefore the raster cell approximation is an extrapolation of the output to fill the raster cell. This means that locations near the edge of a polygon boundary may be assigned a category based on the parameters of an adjacent polygon instead of the polygon that contains that location.
5. The assessment of probability of land damage is performed using the Draft TS1170.5 (Standards New Zealand, 2024) seismic demands for 500-year return period for site class V (soft or loose soil). Sensitivity of the response to other return periods or different site classes is not considered, the seismic demands have been revised in the published TS1170.5 (Standards New Zealand, 2025).
6. The scenario outputs potentially double-count uncertainty in the calculation of LSN, as detailed in Section 11.1 of the NLM technical report. The overestimation of uncertainty generally results in an increase in land damage probability for low LSNs, therefore the probability of obtaining 15% Minor-to-Moderate land damage may be overestimated particularly in higher uncertainty areas.

7 Potential future improvements

Potential future opportunities, based on insights from developing the NLM and the ALVC map described in this report, include:

1. **Collate additional remaining district- or regional-scale LVC maps**. Some district- or regional-scale LVC maps are currently under development or could not be easily obtained. Following up with councils to obtain these maps could improve the consideration of local context and knowledge.
2. **Multiple land damage measures.** Obtain the probability of land damage from multiple land damage measures (i.e. not only LSN). This approach is often applied during development of the existing district- or regional-scale LVC maps as it helps to mitigate some of the limitations of LSN.
3. **Lateral spreading.** Extend the NLM and the ALVC map to consider liquefaction-induced lateral spreading.
4. **Regular updates.** Provide regular updates of the ALVC map as the NLM model and seismic demands are updated.

8 References

MBIE/MfE. (2017). *Planning and engineering guidance for potentially liquefaction-prone land: Resource Management Act and Building Act aspects* (Rev 0.1). Ministry of Business, Innovation & Employment. https://www.building.govt.nz/assets/Uploads/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction.pdf

Standards New Zealand. (2024). *TS1170.5 Public consultation Draft—Structural design actions Part 5: Earthquake actions—New Zealand* (DZ TS 1170.5:2024). https://consultations.standards.govt.nz/draft-standards/ts1170-5-public-consultation/user_uploads/20240215-ts-1170.5---public-comment-draft_v2.pdf

Standards New Zealand. (2025). *TS1170.5 Structural design actions—Part 5: Earthquake actions—New Zealand*.

Tonkin + Taylor. (2026a). *National Liquefaction Model—Final Technical Report* (V5.1; p. 293). https://nzlm.co.nz

Tonkin + Taylor. (2026b). *Summary report: Automated Liquefaction Vulnerability Categories Mapping* (No. V1). Natural Hazards Commission.

9 Applicability

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

Tonkin & Taylor Ltd

Report prepared by:

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Maxim Millen
Technical Director - Data + Digital Solutions

Authorised for Tonkin & Taylor Ltd by:

....

James Russell
Project Director

Technically Reviewed by:

....

Mike Jacka
Expertise Director - Geotechnical

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Appendix A Existing district or regional-scale LVC maps

Location	Commissioned or produced by	Level	External Link
Far North	Far North District Council (2023)	A	https://experience.arcgis.com/experience/df5f99f47450498f978166472b3500eb/page/Page?views=Hazards
Whangarei	Whangarei District Council (2020)	A	https://www.arcgis.com/apps/mapviewer/index.html?url=https://geo.wdc.govt.nz/server/rest/services/Liquefaction/MapServer&source=sd
Auckland	Auckland Council (2021)	A	https://data-aucklandcouncil.opendata.arcgis.com/datasets/aucklandcouncil::liquefaction-vulnerability-basic-assessment-1/explore
Hamilton	Hamilton City Council (2019)	B	
Waikato	Waikato Regional Council (2021)	A	https://data-waikatolass.opendata.arcgis.com/datasets/waikatoregion::waikato-liquefaction-level-a/explore
New Plymouth	New Plymouth District Council (2021)	A	https://experience.arcgis.com/experience/754cda6a13374346b0afa822519f1cd4
Bay of Plenty	Bay of Plenty Regional Council (2021)	A	https://maps.boprc.govt.nz/datasets/bay-hazards-liquefaction/explore
Mount Maunganui	Tauranga City Council (2020)	B/C	https://gis.tauranga.govt.nz/liquefaction/
Tauranga	Tauranga City Council (2020)	A/B	https://maps.boprc.govt.nz/datasets/bay-hazards-liquefaction/explore?location=-38.228492%2C176.921147%2C9.58
Gisborne	Gisborne District Council (2015)	Different	https://geoportal-gizzy.opendata.arcgis.com/datasets/land-areas-susceptible-to-liquefaction-/explore
Hawkes Bay	Hawke's Bay Regional Council (2017)	Different	https://hbrcopendata-hbrc.opendata.arcgis.com/datasets/8c0b6f4f66fd492fb5b231e57410435a_0/explore
Napier	Hawke's Bay Regional Council (2017)	Different	https://hbrcopendata-hbrc.opendata.arcgis.com/datasets/53a60e8296764f879eed707bee61fd0b_4/about
Horowhenua	Horowhenua District Council (2023)	B	https://www.horowhenua.govt.nz/files/assets/public/v/1/building-consents/hdc-options-for-liquefaction-assessment-in-the-horowhenua-district-june-2023.pdf
Manawatu-Whanganui	Horizons Regional Council (2015)	Different	https://experience.arcgis.com/experience/3f7b4ec2f6f14503af1146ce412de39e/page/Liquefaction
Wairarapa	Greater Wellington Regional Council (2018)	A	
Wellington	Greater Wellington Regional Council (2018)	Different	https://opendata.gw.govt.nz/datasets/GWRC::wellington-region-liquefaction-potential/explore
Palmerston North	Palmerston North City Council (2011)	B	
Tararua	Tasman District Council (2021)	A	https://storymaps.arcgis.com/stories/50eb39cb250542388e77329bf2c0c2ae

Location	Commissioned or produced by	Level	External Link
Nelson	Nelson City Council (2021)	A	https://experience.arcgis.com/experience/4854afe0019e43c9adb51723d78a28db
Tahunanui	Nelson City Council (2013)	B	https://experience.arcgis.com/experience/4854afe0019e43c9adb51723d78a28db
Marlborough	Marlborough District Council (2021)	A/B	https://smartmaps.marlborough.govt.nz/smapviewer/?map=f94aa3aaff0a4d6eb4da7298f412e8f8
Tasman	Tasman District Council (2021)	A	https://tdc.maps.arcgis.com/apps/webappviewer/index.html?id=819fd6f518b9467d88293a732f063ac4%20
Kaikoura	Kaikoura District Council & Environment Canterbury (2019)	A	https://opendata.canterburymaps.govt.nz/maps/23e01f789514469198a0fd937da0a40b
West Coast	West Coast Regional Council (2021)	A	https://www.arcgis.com/home/item.html?id=fcbbe03a9cd34aeba65b6e5b1fcfe1b7
Eastern Canterbury	Environment Canterbury (2012)	A	https://opendata.canterburymaps.govt.nz/datasets/a1d1e268681f4f9896b551b26a6e8bbc_3/
Christchurch	Christchurch City Council (2020)	A/B/C	https://opendata-christchurchcity.hub.arcgis.com/datasets/ChristchurchCity::liquefaction-vulnerability-opendata/explore
Ashburton	Environment Canterbury (2024)	A	https://opendata.canterburymaps.govt.nz/maps/1588bc2547764146ba5cf3ed192862c7
Timaru	Environment Canterbury (2013)	Unsure	https://opendata.canterburymaps.govt.nz/maps/2fcc5cc506214648b86743338fda3489
Mackenzie	Environment Canterbury (2023)	A	https://opendata.canterburymaps.govt.nz/maps/62581b83eef949c485ac7923d6df98e0
Waimate	Waimate District Council (2022)	A	https://opendata.canterburymaps.govt.nz/maps/f22756fbb4f04ec3ac4d370abbf0087d
Waitaki	Environment Canterbury (2020)	A	https://www.arcgis.com/apps/mapviewer/index.html?layers=34db4f0f4e294d7289ae1adc2ed9c3ab
Otago	Otago Regional Council (2019)	A	https://www.arcgis.com/apps/mapviewer/index.html?layers=712447df3b3d4489944f5044fd6d7de8
Invercargill	Invercargill City Council (2022)	A	https://www.icc.govt.nz/repository/libraries/id:2swc6cbtp1cxby8vraxn/hierarchy/assets/rates-building-and-property/liquefaction/Appendix_FIGB1.pdf
Glenorchy	Otago Regional Council (2022)	C	
Southland	Southland Regional Council (2012)	A?	https://data-esgis.opendata.arcgis.com/datasets/esgis::southland-liquefaction-risk-2006-2012/explore

Appendix B Third Party Data Attributions

1 Existing local map for Far North was provided by Far North District Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://experience.arcgis.com/experience/df5f99f47450498f978166472b3500eb/page/Page?views=Hazards

2 Existing local map for Whangarei was provided by Tonkin + Taylor. Can be accessed from https://www.arcgis.com/apps/mapviewer/index.html?url=https://geo.wdc.govt.nz/server/rest/services/Liquefaction/MapServer&source=sd

3 Existing local map for Auckland was provided by Auckland Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://data-aucklandcouncil.opendata.arcgis.com/datasets/aucklandcouncil::liquefaction-vulnerability-basic-assessment-1/explore

4 Existing local map for Hamilton was provided by Tonkin + Taylor.

5 Existing local map for Waikato was accessed from https://data-waikatolass.opendata.arcgis.com/datasets/waikatoregion::waikato-liquefaction-level-a/explore with permission from Waikato Regional Council for use in the ALVC map.

6 Existing local map for New Plymouth was provided by Tonkin + Taylor. Can be accessed from https://experience.arcgis.com/experience/754cda6a13374346b0afa822519f1cd4

7 Existing local map for Bay of Plenty was obtained from the Bay of Plenty Regional Council website. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Can be accessed from https://maps.boprc.govt.nz/datasets/bay-hazards-liquefaction/explore

8 Existing local map for Mount Maunganui was provided by Tonkin + Taylor. Can be accessed from https://gis.tauranga.govt.nz/liquefaction/

9 Existing local map for Tauranga was obtained from the Bay of Plenty Regional Council website. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Can be accessed from https://maps.boprc.govt.nz/datasets/bay-hazards-liquefaction/explore?location=-38.228492%2C176.921147%2C9.58

10 Existing local map for Gisborne was provided by Gisborne District Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://geoportal-gizzy.opendata.arcgis.com/datasets/land-areas-susceptible-to-liquefaction-/explore

11 Existing local map for Hawkes Bay was provided by Tonkin + Taylor. Can be accessed from https://hbrcopendata-hbrc.opendata.arcgis.com/datasets/8c0b6f4f66fd492fb5b231e57410435a_0/explore

12 Existing local map for Napier was provided by Tonkin + Taylor. Can be accessed from https://hbrcopendata-hbrc.opendata.arcgis.com/datasets/53a60e8296764f879eed707bee61fd0b_4/about

13 Existing local map for Horowhenua was provided by Tonkin + Taylor. Can be accessed from https://www.horowhenua.govt.nz/files/assets/public/v/1/building-consents/hdc-options-for-liquefaction-assessment-in-the-horowhenua-district-june-2023.pdf

14 Existing local map for Manawatu-Whanganui was obtained from Horizons Regional Council with permission. Accessed from https://experience.arcgis.com/experience/3f7b4ec2f6f14503af1146ce412de39e/page/Liquefaction

15 Existing local map for Wairarapa was provided by Tonkin + Taylor.

16 Existing local map for Wellington was provided by Greater Wellington Regional Council with permission. Accessed from https://opendata.gw.govt.nz/datasets/GWRC::wellington-region-liquefaction-potential/explore

17 Existing local map for Palmerston North was provided by Tonkin + Taylor.

18 Existing local map for Tararua was provided by Tonkin + Taylor. Can be accessed from https://storymaps.arcgis.com/stories/50eb39cb250542388e77329bf2c0c2ae

19 Existing local map for Nelson was provided by Nelson City Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://experience.arcgis.com/experience/4854afe0019e43c9adb51723d78a28db

20 Existing local map for Tahunanui was provided by Nelson City Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://experience.arcgis.com/experience/4854afe0019e43c9adb51723d78a28db

21 Existing local map for Marlborough was provided by Marlborough District Council. Accessed from https://smartmaps.marlborough.govt.nz/smapviewer/?map=f94aa3aaff0a4d6eb4da7298f412e8f8

22 Existing local map for Tasman was provided by Tasman District Council. Accessed from https://tdc.maps.arcgis.com/apps/webappviewer/index.html?id=819fd6f518b9467d88293a732f063ac4%20

23 Existing local map for Kaikoura was provided by Kaikoura District Council & Environment Canterbury. Accessed from https://opendata.canterburymaps.govt.nz/maps/23e01f789514469198a0fd937da0a40b

24 Existing local map for West Coast was provided by West Coast Regional Council. Accessed from https://www.arcgis.com/home/item.html?id=fcbbe03a9cd34aeba65b6e5b1fcfe1b7

25 Existing local map for Eastern Canterbury was provided by Environment Canterbury. Licensed under Creative Commons Attribution 3.0 International (CC BY 3.0). Accessed from https://opendata.canterburymaps.govt.nz/datasets/a1d1e268681f4f9896b551b26a6e8bbc_3/

26 Existing local map for Christchurch was provided by Tonkin + Taylor. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Can be accessed from https://opendata-christchurchcity.hub.arcgis.com/datasets/ChristchurchCity::liquefaction-vulnerability-opendata/explore

27 Existing local map for Ashburton was provided by Environment Canterbury. Licensed under Creative Commons Attribution 3.0 International (CC BY 3.0). Accessed from https://opendata.canterburymaps.govt.nz/maps/1588bc2547764146ba5cf3ed192862c7

28 Existing local map for Timaru was provided by Environment Canterbury. Licensed under Creative Commons Attribution 3.0 International (CC BY 3.0). Accessed from https://opendata.canterburymaps.govt.nz/maps/2fcc5cc506214648b86743338fda3489

29 Existing local map for Mackenzie was provided by Environment Canterbury with permission. Accessed from https://opendata.canterburymaps.govt.nz/maps/62581b83eef949c485ac7923d6df98e0

30 Existing local map for Waimate was provided by Waimate District Council. Licensed under Creative Commons Attribution 3.0 International (CC BY 3.0). Accessed from https://opendata.canterburymaps.govt.nz/maps/f22756fbb4f04ec3ac4d370abbf0087d

31 Existing local map for Waitaki was provided by Environment Canterbury with permission. Accessed from https://www.arcgis.com/apps/mapviewer/index.html?layers=34db4f0f4e294d7289ae1adc2ed9c3ab

32 Existing local map for Otago was provided by Otago Regional Council. Accessed from https://www.arcgis.com/apps/mapviewer/index.html?layers=712447df3b3d4489944f5044fd6d7de8

33 Existing local map for Invercargill was provided by Tonkin + Taylor. Can be accessed from https://www.icc.govt.nz/repository/libraries/id:2swc6cbtp1cxby8vraxn/hierarchy/assets/rates-building-and-property/liquefaction/Appendix_FIGB1.pdf

34 Existing local map for Glenorchy was provided by Tonkin + Taylor.

35 Existing local map for Southland was provided by Southland Regional Council. Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). Accessed from https://data-esgis.opendata.arcgis.com/datasets/esgis::southland-liquefaction-risk-2006-2012/explore