A1 Introduction

This Appendix provides details of the assessment methodology used to determine the liquefaction vulnerability severity ("severity") classifications and change in liquefaction vulnerability severity ("change in severity") classifications for properties with ILV land damage in Canterbury. This Appendix is organised into the following sections:

- The framework for the classification assessment methodology; and
- Details of the classification assessment process.

This Appendix must be read in conjunction with the main body of the Practical Implications Report. The objectives and principles adopted for the classification assessment process are consistent with those set out in Section 2 of the Practical Implications Report.

A2 Severity and change in severity classification assessment methodology framework

This section describes the framework for classification of severity and change in severity of properties with ILV land damage including:

- Relationship to the ILV Assessment Methodology;
- Return periods at which severity and change in severity classification were determined;
- Information taken into account when determining the severity and change in severity classifications; and
- Severity and change in severity classifications.

A2.1 Relationship to the ILV Assessment Methodology

A detailed methodology for assessing properties that qualified and did not qualify as having ILV land damage is set out in the ILV Assessment Methodology Report (T+T, 2015). An overview of the qualification assessment methodology is provided in Section 4 of that report.

Following the qualification of properties for ILV land damage, a diminution of value (**DoV**) methodology was developed by EQC's valuation and legal advisors for the purpose of enabling EQC to settle residential land claims for ILV land damage on the basis of a payment of DoV in appropriate circumstances. EQC's valuation advisors requested information regarding the practical implications of ILV land damage in order to determine what, if any, DoV a residential property has suffered as a consequence of ILV land damage.

In order to provide details of the practical implications for ILV land damage, T+T, in conjunction with EQC's valuation advisors and legal advisors, have established a set of severity and change in severity classifications for all properties with ILV land damage in Canterbury. Importantly, the assessment of severity and change in severity has been aligned to the ILV Assessment Methodology.

A2.2 Return periods at which severity and change in severity were determined

Severity and change in severity classifications were assigned to properties with ILV land damage for both 100 year return period levels of earthquake shaking (i.e. M_w = 6.0 and PGA = 0.30g) and 25 year return period levels of earthquake shaking (i.e. the greater of the M_w = 7.5 and PGA = 0.13g, and M_w = 6.0 and PGA = 0.19g scenarios). These levels of earthquake shaking are consistent with the values used in the ILV Assessment Methodology (T+T, 2015) and specified in the MBIE Guidance (MBIE, 2014a; MBIE, 2015).

The reasons for the selection of the 100 year return period level of shaking is discussed in Section 6.3.1 of the ILV Assessment Methodology Report (T+T, 2015). The 25 year return period level of earthquake shaking was selected at the request of EQC's valuation advisors for the reasons discussed in Section 3.1.1.1 of the main body of this report.

A2.3 Information taken into account

In order to undertake the severity classification and change in severity classification assessments for properties with ILV land damage, the following datasets (available in the Canterbury Geotechnical Database (CGD)) were considered:

- Land damage observations, including liquefaction and lateral spreading, following the September 2010, February 2011, June 2011 and December 2011 events, as well as liquefaction observations following the February 2016 event[1] including:
  - Aerial photography; and
  - Observed land damage from road based and property based liquefaction and land damage mapping.
- Estimated levels of earthquake shaking for the September 2010, February 2011, June 2011 and December 2011 events, as well as the February 2016 event[1];
- Estimated total change in ground surface elevation across the CES derived from the LiDAR surveys;
- Estimated liquefaction-induced change in ground surface elevation across the CES (i.e. excluding the estimated tectonic component) derived from the LiDAR surveys;
- The ground surface elevation, relative to sea level, estimated using a Digital Elevation Model (DEM) derived from LiDAR surveys of the greater Christchurch area;
- Mapping of lateral spread caused by the CES; and
- Event specific and median groundwater surface elevations.

In addition, the following models were used in the assessment of severity and change in severity classifications:

- Estimated pre-CES Liquefaction Severity Number (LSN) values extracted from the automated ILV model (for both 100 year and 25 year return period levels of earthquake shaking);
- Estimated post-CES LSN values extracted from the automated ILV model (for both 100 year and 25 year return period levels of earthquake shaking); and
- Estimated change in LSN (ΔLSN) values across the CES extracted from the automated ILV model (for both 100 year and 25 year return period levels of earthquake shaking).

Sections 7 and 8.2 of the ILV Assessment Methodology Report (T+T, 2015) provide in-depth discussion about the LSN index and how it is calculated on an automated basis at 100 year return period levels of shaking for the urban residential properties in Canterbury. The same methods were used to generate the automated models at 25 year return period levels of earthquake shaking.

A2.4 Severity and change in severity classifications

Liquefaction vulnerability severity is defined as the relative extent of the exposure of land to damage at the ground surface from soil layers liquefying. It describes how severe the liquefaction vulnerability of a property is relative to other properties and has been developed for the purpose of determining the practical implications of liquefaction related land damage, which is best assessed as:

[1] Observations from the February 2016 event are not yet available on the CGD at the time of writing this report.

- the likelihood of moderate-to-severe liquefaction related land damage;
- the likelihood of significant liquefaction related residential building damage; and
- increased ground improvement and building foundation requirements for new residential buildings.

Four primary severity classifications were developed for assessing the pre-CES and post-CES liquefaction vulnerability severity of properties in Canterbury that qualified for ILV land damage, which are presented below in order of increasing severity:

- Not Vulnerable (NV)[2];
- Medium (M);
- High (H); and
- Very High (VH).

Three primary classifications were developed for assessing the change in liquefaction vulnerability severity of properties in Canterbury that qualified for ILV land damage, which are presented below in order of increasing extent of change:

- No Change (NC)[3];
- Minor (Min); and
- Major (Maj).

In addition to the primary classifications, three additional severity classifications and two additional change in severity classifications were developed. These additional classifications are called 'OR' classifications and describe a broader range of severity and change in severity assessments. The reasons why the 'OR' classification are required is discussed in Section A3.2. The 'OR' severity classifications are identified as:

- Not Vulnerable OR Medium (NV or M)
- Medium OR High (M or H)
- High OR Very High (H or VH)

The 'OR' change in severity classifications are identified as:

- No Change OR Minor (NC or M)
- Minor OR Major (Min or Maj)

The different classifications and the relationships between the 'OR' classifications and the primary classifications are presented in Figure A2.1 and Figure A2.2 for the severity classifications and change in severity classifications respectively (repeated from Figure 3.1 and Figure 3.2 in the main body of this report). The range of LSN and ΔLSN values for the different classifications are presented in the Figures and are discussed in Section A2.4.1.

The specific meaning and use of the severity and change in severity classifications in this report, particularly the range of LSN and ΔLSN for each classification, may have different definitions and meanings in other literature. The classifications have been developed for the specific purpose outlined in Section 2 of the main body of this report.[4]

[2] Not Vulnerable refers to no material vulnerability, with materiality set out in Section 7.3 of the ILV Assessment Methodology Report (T+T, 2015).
[3] No change refers to no material change, with material change in liquefaction vulnerability set out in Section 7.4 of the ILV Assessment Methodology Report (T+T, 2015).
[4] The recently released New Zealand Geotechnical Society (NZGS) and Ministry of Business Innovation & Employment (MBIE) Earthquake Geotechnical Engineering Practice in New Zealand - Module 3: Identification, assessment and mitigation

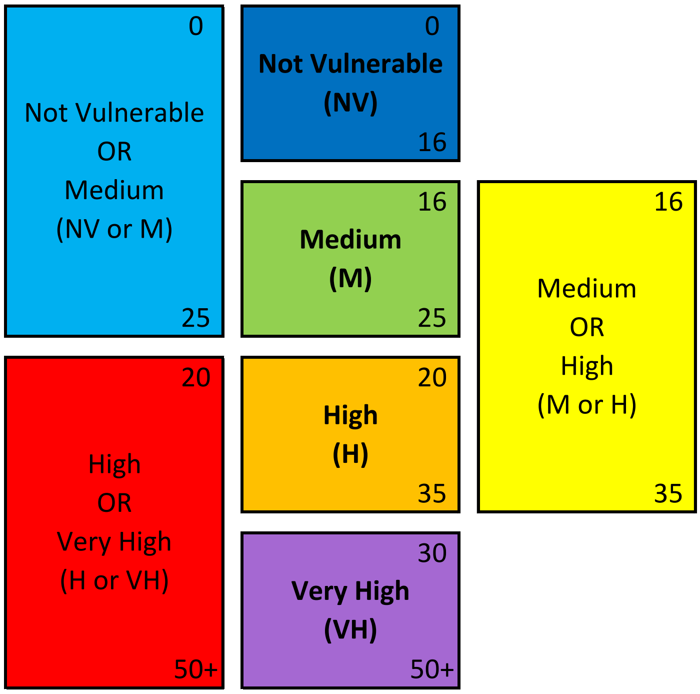

*Figure A2.1: The **pre-CES** and **post-CES** liquefaction vulnerability severity classifications, divided into four primary classifications (in bold) and three 'OR' classifications with the range of LSN values for each classification indicated in the bottom and top right hand corners of the boxes.*

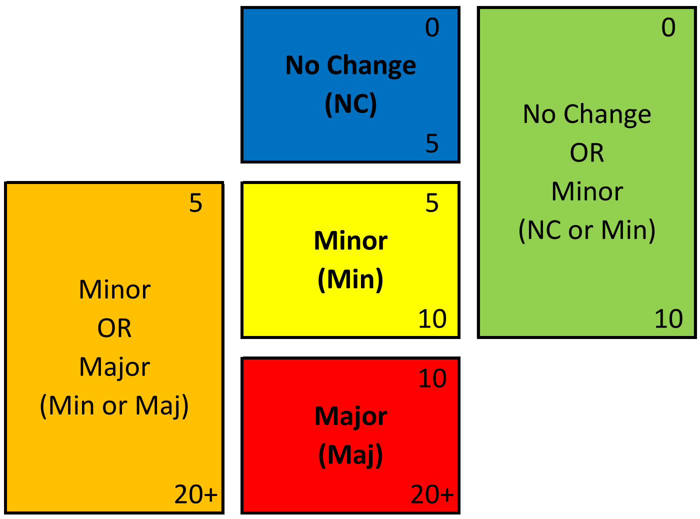

*Figure A2.2: The extent of **change** in liquefaction vulnerability severity from **pre-CES** to **post-CES** divided into three primary classifications (in bold) and two 'OR' classifications with the range of change in LSN values for each classification indicated in the bottom and top right hand corners of the boxes.*

A2.4.1 LSN and ΔLSN values for the severity and change in severity classifications

The ranges of LSN values for the different severity classifications are presented in the boxes in Figure A2.1 and the ranges of ΔLSN values for the different change in severity classifications are presented

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of liquefaction hazards, provides performance levels for liquefied deposits that include characteristic LSN values. The purpose and scope of these performance levels are different from the severity classifications presented in this report, however, the severity classifications in this report are broadly consistent with the performance levels presented in the NZGS and MBIE Module 3 with regard to the definitions provided.

in the boxes in Figure A2.2. The value in the top right corner of each box is the lower bound value for that classification and the value in the bottom right corner is the upper bound value.

The LSN and ΔLSN values from the automated ILV models were used in conjunction with all of the other information and datasets described in Section A2.3 to assess the severity and change in severity classifications as a matter of engineering judgement, as detailed in Section A3.2. As was noted in the ILV Assessment Methodology Report (T+T, 2015), the LSN and ΔLSN values used in the assessment of liquefaction vulnerability and change in vulnerability are not strict threshold values. Rather, they are indicator values that are considered amongst other assessment tools when the severity classifications and change in severity classifications are assigned using engineering judgement.

A2.4.1.1 LSN and severity classifications

The ranges of LSN values for the liquefaction vulnerability severity classifications were determined using the frequency of moderate-to-severe liquefaction related land damage[5] observed in the main earthquake events in the CES. For all earthquake events, the likelihood of moderate-to-severe land damage increased as LSN increased, as outlined in Section 7 of the ILV Assessment Methodology Report (T+T, 2015) and discussed in Section 4.1 of the main body of this report.

The ranges of LSN values shown in Figure A2.1 were chosen for each severity classification to represent the likelihood of moderate-to-severe land damage at that severity level. For example, the Very High severity classification represents a 60% to 90% chance of moderate-to-severe land damage as presented in Figure 4.1 in the main body of this report, which was indicated by an LSN greater than 30.

Overlap of the lower and upper bound LSN values between the Medium and High, and High and Very High severity classifications was included. For example, the upper bound LSN value for Medium is 25 while the lower bound LSN value for High is 20. This was considered appropriate because the liquefaction vulnerability for all properties lie on a continuum and do not have predefined boundaries separating them. Limitations in the liquefaction analysis and how this translates into actual observations of moderate-to-severe liquefaction related land damage mean that overlap of the severity classifications was considered necessary.

A2.4.1.2 ΔLSN and change in severity classification

The selection of the ranges of ΔLSN for the change in severity classifications took into account the assessment of a material change in vulnerability, and that the LSN parameter has a number of inputs which have limitations. This is discussed in detail in Section 7.4 of the ILV Assessment Methodology Report (T+T, 2015).

Having regard to what is considered to be a material change in vulnerability as described in the ILV Assessment Methodology Report (T+T, 2015), a ΔLSN of 5 provides the minimum value for Minor change in liquefaction vulnerability severity and the transition from No Change to Minor. A ΔLSN of 5 indicates a 5% to 10% increase in the likelihood of moderate-to-severe land damage or Building Damage Ratio (BDR)[6] greater than 0.5 and this is considered the minimum change that would be taken into account, as a matter of engineering judgement, for re-evaluating foundation design assumptions and land use decisions.

A ΔLSN of 10 is the minimum value for a Major change in liquefaction vulnerability severity because it represents significant increase in material change. A ΔLSN of 10 was considered an appropriate value for having a high level of confidence that there would be a significant change in vulnerability.

[5] Refer to Appendix C for descriptions of moderate-to-severe liquefaction related land damage.
[6] Refer to Section 4.2 of the main body of this report for an explanation of BDR.

Being double the minimum practical value for material change in liquefaction vulnerability, it represents about a 10% to 20% increase in the likelihood of moderate-to-severe land damage or a BDR greater than 0.5.

A3 Severity and change in severity assessment process

This Section describes the assessment process for the classification of severity and change in severity of properties with ILV land damage. The manual process was divided into three steps as presented in Figure A3.1. An area/neighbourhood approach was deemed the most appropriate for assessing the severity and change in severity classifications for the portfolio of properties with ILV land damage. Therefore, the properties with ILV land damage were spatially grouped into assessment areas that had similar land performance in the CES events and that also subsided similarly over the CES. Thereafter, the severity and change in severity classifications were defined for these assessment areas and the final classifications confirmed following an internal review.

	Step	Information used
1	**Define areas/neighbourhoods:** Determine groups of properties with ILV land damage in areas/ neighbourhoods with similar performance in the CES and similar subsidence over the CES to be used to undertake severity and change in severity assessments.	• Land damage observations in the earthquake events; • Estimated change in ground surface elevation across the CES; • Ground surface elevation; and • Mapping of lateral spreading caused by the CES.
2	**Severity and change in severity classification assessment:** Determine the pre-CES severity, post-CES severity, and change in severity of each area for: a. 100 year return period levels of shaking; and b. 25 year return period levels of shaking.	**Pre-CES and post-CES severity:** • Pre-CES and post-CES LSN for the return period being considered; • Land damage observations and estimated levels of shaking in the earthquake events; and • Estimated liquefaction-induced change in ground surface elevation. **Change in severity:** • ΔLSN for the return period being considered; • Estimated change in ground surface elevation across the CES; and • Land damage observations and estimated levels of shaking in the earthquake events.
3	**Review severity and change in severity classifications:** Undertake internal review of the initial classifications and finalise results.	• Mapping of initial severity and change in severity classifications; • Land damage observations and estimated levels of shaking in the earthquake events; • Estimated change in ground surface elevation across the CES; • Pre-CES LSN, post-CES LSN, and ΔLSN; and • Statistical correlations and logic checks regarding the initial classifications and datasets used to make those classifications.

Figure A3.1: Overview of the ILV severity and change in severity classification manual process.

A3.1 Step 1 - Define areas/neighbourhoods

The ILV Assessment Methodology (T+T, 2015) qualified a portfolio of properties as sustaining ILV land damage. In that methodology, individual properties were assessed as qualifying for ILV land damage, with suitable assessment tools developed and sufficient geotechnical investigations obtained to complete that task. However, unlike the ILV Assessment Methodology, an area/neighbourhood approach was employed for severity and change in severity classification purposes rather than a property specific assessment. The reasons for this are as follows:

- An area wide assessment is considered the most appropriate for assessing liquefaction vulnerability in the context of the practical scenario that T+T was asked to assess, given that wider ground investigations in an area of geologic similarity should be considered when characterising performance (Russell et al., 2015);
- The engineering advice for a buyer or seller of a property is anticipated to utilise existing information and not require detailed site specific analysis, primarily due to cost constraints inherent in a typical property pre-purchase due-diligence assessment;
- The existing geotechnical investigation data was obtained and collated as part of the ILV Assessment Methodology.[7] As such, the density of available investigation data does not allow individual properties to be classified into various extents of severity and change in severity but does support an area/neighbourhood severity assessment;
- The science of the prediction of liquefaction vulnerability used for ILV qualification has been developed specifically to assess whether a property is materially vulnerable to liquefaction at 100 year return period levels of earthquake shaking. It was not developed to determine the extent of severity and extent of change in severity once a property qualifies for ILV land damage at 100 year return period levels of shaking;
- The science of the prediction of liquefaction vulnerability has also been developed and calibrated for the larger (100 to 500 year) return period levels of shaking and is not tuned for assessment at 25 year return period levels of shaking (as was demonstrated by prediction versus observations of liquefaction in the February 2016 earthquake where shaking was close to 25 year return period levels in parts of Canterbury); and
- Undertaking severity and change in severity assessments for individual properties assessed as qualifying for ILV land damage in Canterbury is not likely to significantly improve the results for those properties compared to an area/neighbourhood assessment methodology given the limitations in the information and science used to make assessments.

A3.1.1 Identification of the areas/neighbourhoods of properties with ILV land damage

In identifying the areas/neighbourhoods, groups of properties with similar observed land performance through the CES, ground surface subsidence over the CES, and topographical characteristics were identified prior to assessing the severity and change in severity classifications. The datasets outlined in Figure A3.1 were utilised to identify these assessment areas.

Land damage observations, including inspection of aerial photography and observed land damage mapping, were primarily used in the first instance to establish the assessment areas. For each of the main earthquake events, areas with similar land damage observations were identified by looking at each event individually and then reviewing observations through the CES until assessment areas with similar performance across the CES were identified.

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[7] Refer to Section 5.5 of the ILV Assessment Methodology Report (T+T, 2015) that describes the geotechnical investigation data used in the assessment of ILV as well as Figure 4.2 and Section 4.4.2 of the ILV Assessment Methodology Report that explain the collation of geotechnical investigation data for the purpose of ILV assessment.

Once areas had been established using land damage observations, the estimated change in ground surface elevation was investigated to confirm similar subsidence was typically experienced within each assessment area. Sometimes areas were split into smaller areas and other times boundaries of the assessment areas were shifted slightly in order to maintain similar performance.

Ground surface elevation was considered relative to the assessment areas to ensure topographic features were captured. Sometimes areas were split where significant changes in elevation were present because the liquefaction performance of areas with similar elevation is likely to be similar. Mostly, however, areas with lower or higher ground surface elevation (i.e. upper and lower river terraces) confirmed the areas established using land damage observations and changes in ground surface elevation.

Other information was also considered when identifying the areas such as mapping of lateral spreading caused by the CES. This provided further confirmation or suggested adjustment of the boundaries of assessment areas that performed similarly in the CES.

Finally, subsurface information was checked against the assessment areas to consider whether adjusting boundaries or adding additional boundaries was needed. Median normalised Cone Penetration Test (CPT) resistance (q_{c1N}) and median soil behaviour type index (I_c)[8] from the CPT investigations at 1m intervals beneath the ground surface were reviewed in the areas identified. However, the complex and three dimensional nature of the information meant that refining the areas further based on this information was not possible.

In defining all of the assessment areas, none of the datasets were considered in isolation and all of the information was considered iteratively using engineering judgement to finalise the areas used to undertake the assessment of severity and change in severity classification. The final assessment areas were the smallest possible and further boundary drawing within the areas was considered not to be justified based on the limitations in the available information.

For the portfolio of properties with ILV land damage, 182 assessment areas were identified, which had similar observed land performance through the CES, ground surface subsidence over the CES, and topographical characteristics, with an average of 55 properties in each area.

A3.2 Step 2 - Severity and change in severity assessment

For each of the assessment areas identified, the pre-CES and post-CES liquefaction vulnerability severity classifications and the change in severity classification were assessed for both the 100 year and 25 year return period levels of earthquake shaking. This was typically done for all of the areas at the 100 year return period level of earthquake shaking first and then for all areas at the 25 year return period in order to maintain consistency and relativity between areas.

In assessing the severity and change in severity classifications for the assessment areas, a team based approach was employed involving at least three geotechnical engineers, including at least one expert with first-hand experience and knowledge of liquefaction land damage in the main earthquake events. The team assessed all severity and change in severity classifications, ensuring a robust and consistent assessment process.

To assign the severity and change in severity classifications for each assessment area a manual process was involved. Engineering judgment was applied utilising LSN as an indicator for the severity and ΔLSN as an indicator for change in severity classifications as well as all the other information outlined in Section A2.3. This manual process ensured that results are reasonable and appropriately account for land damage observations, ground surface subsidence, regional geological features and

[8] Refer to Section 10 of the of the ILV Assessment Methodology Report (T+T, 2015) for discussion of median q_{c1N} and median I_c data.

spatial variability of the soils. Reasons for each of the severity and change in severity classifications made in each area were recorded.

The process for assessing the pre-CES and post-CES severity is discussed first in Section A3.2.1 and then the process for assessing the change in severity is presented in Section A3.2.2. Generally, all three classifications were assessed concurrently for each group of properties at the return period level of shaking being considered.

A3.2.1 Pre-CES and post-CES severity assessments

A3.2.1.1 Pre-CES and post-CES LSN as an indicator of severity

The estimated pre-CES LSN and post-CES LSN from the automated ILV models, as well as the LSN extracted from individual CPT investigations as necessary, at the return period being considered gave an indication of the potential pre-CES and post-CES severity classifications respectively for each assessment area. The LSN values indicating the different severity classifications are presented in Figure A2.1 and the reasons for these values are presented in Section A2.4.1. As an example, if the pre-CES LSN for a group of properties ranged between 16 and 20 then the starting point for the pre-CES severity classification would potentially be Medium.

However, as stated previously, the LSN values were not strict threshold values and were considered amongst other assessment tools.

A3.2.1.2 Land damage observations and levels of earthquake shaking used to assess severity

The land damage observations in the earthquake events relative to the estimated levels of earthquake shaking, for the area being assessed, were considered in terms of what pre-CES and post-CES severity classification was appropriate. The proportion of properties with moderate-to-severe land damage relative to the estimated shaking levels provided an indication of the appropriate severity classifications.

The September 2010 and February 2011 events generally provided the most useful land damage observations for assessing the pre-CES severity classification. This is because they gave evidence of the liquefaction performance and severity of a given area in its un-subsided state. The June and December 2011 events, along with the February 2016 event, generally provided land damage observations for the post-CES severity classification in the post-subsided state. However, all events were considered together when assessing the pre-CES and post-CES severity classifications.

In all assessment areas, engineering judgement was required to interpolate or extrapolate the observed land damage to that anticipated at the 100 year and 25 year return period levels of shaking. This is because the level of earthquake shaking in each event was different for each assessment area and generally not exactly at 100 year or 25 year return period levels. For example, when assessing the post-CES severity at the 100 year return period level of shaking, an assessment area may have experienced greater than 100 year return period levels of shaking in the February 2011 event and less than 100 year return period levels of shaking in the June and December 2011 events so that land damage observations from those events would need to be interpolated to determine the interpreted land damage at a 100 year return period.

Assessing the 100 year return period severity was generally more straight-forward than assessing the 25 year return period severity with respect to the land damage observations. The four main earthquake events in the CES caused shaking typically between 50 year and 500 year return period levels in the areas of Canterbury with ILV land damage. Therefore, there were typically multiple events where land damage could be interpolated for the 100 year return period severity assessment. However, the lack of higher frequency (lower return period) events with strong ground motion shaking meant extrapolation was required for nearly all areas when assessing the 25 year return period severity, which has a greater uncertainty than interpolating between events. The February 2016 event provided reasonable land damage observations for 25 year return period post-CES classification but only for certain areas in the eastern suburbs of Christchurch where shaking was close to 25 year return period levels.

In some areas of Canterbury the level of shaking was similar in all four of the main earthquake events in the CES and often at levels between 100 year and 25 year return period levels of earthquake shaking. In these areas land damage observations did not provide a good range of evidence for assessing liquefaction vulnerability at both 100 year and 25 year return period levels of shaking. Engineering judgement was required to extrapolate observations, using the automated ILV models, to the return period being assessed and often led to including the properties in the broader 'OR' classifications.

A3.2.1.3 Interaction between LSN and the other datasets

The LSN values from the automated ILV models, as well as from individual CPT investigations as necessary, and the interpreted land damage at the assessed return period were used together to determine pre-CES and post-CES severity classifications.

In many cases engineering judgement was used to make adjustments to the automated LSN values to calibrate them to the observed liquefaction related land damage relative to the estimated levels of earthquake shaking, and to account for subsurface ground conditions and estimated liquefaction-related change in ground surface elevation. The 'adjusted' LSN values were used when determining the severity classifications of properties with ILV land damage.

Sometimes these datasets gave a clear indication of severity classification and other times there was disparity between the datasets, leading to uncertainty in the severity classifications. This would often lead to the broader 'OR' classifications being used.

A3.2.2 Change in severity assessments

A3.2.2.1 ΔLSN as an indicator of change in severity

The estimated ΔLSN values across the CES extracted from the automated ILV model, as well as from individual CPT investigations as necessary, at 100 year and 25 year return period levels of shaking were used to assess the change in severity classifications for each assessment area. The ΔLSN values indicating the different change in severity classifications are presented in Figure A2.2 and the reasons for these values are presented in Section A2.4.1. As an example, if the ΔLSN for a group of properties ranged between 5 and 8 then a change in severity classification of Minor would be suggested.

However, as stated previously, the ΔLSN values were not strict threshold values and were considered amongst other assessment tools.

A3.2.2.2 Relationship between change in severity and the pre-CES and post-CES severity

The change in severity of a group of properties was classified at the same time as the pre-CES and post-CES severity. Most importantly, the change in severity classification needed to be consistent with the pre-CES and post-CES severity classifications and vice versa.

For the 100 year return period change in severity classifications, if the same classification was assessed pre-CES and post-CES then the change in severity classification would be Minor since, by definition, properties with ILV land damage must have had at least a material change in vulnerability. If there was a significant increase in severity classification at 100 year return period levels of shaking, then a Major change would be anticipated. For the 25 year return period change in severity classifications, if the same classification was assessed pre-CES and post-CES then the change in severity could either be No Change or Minor change.

A3.2.2.3 Estimated change in ground surface elevation and land damage observations used to assess change in severity

The estimated change in ground surface elevation across the CES derived from the LiDAR surveys provided supporting evidence of the change in severity for each assessment area. For example, where ground surface subsidence was significant and the adjusted ΔLSN was 10 or greater for an area, then there was good evidence that the change in severity would be Major.

It was also necessary to understand the accuracy and limitations of the elevation models when assessing the change in severity classifications. These are discussed in detail in Appendix G of the ILV Assessment Methodology Report (T+T, 2015) and include measurement errors, localised errors due to interpolation where there is a low density of LiDAR survey data points, and the granularity in the elevation model. In some areas, the accuracy and limitations led to the broader 'OR' change in severity classifications being utilised.

Land damage observations in the main earthquake events in the CES were also considered when assessing the change in severity classification. Any change in observed land damage from the September 2010 event to the December 2011 event, relative to the levels of earthquake shaking in those events, gave an indication of the change in severity across the CES. Where a significant increase in observed land damage was identified for an assessment area, the change in severity was anticipated to be greater.

A3.2.2.4 Interaction between ΔLSN and the other datasets

In many cases engineering judgement was used to make adjustments to the automated ΔLSN values to calibrate them with the change in ground surface elevation and land damage observations, as well as any other datasets used in classification. The 'adjusted' ΔLSN values were used when determining the change in severity classifications of properties with ILV land damage.

Sometimes these datasets gave a clear indication of change in severity classification and other times there was disparity between the datasets, leading to uncertainty in the change in severity classifications. This would often lead to the broader 'OR' classifications being used.

A3.2.3 Other factors to consider in the severity and change in severity classification assessments

For each assessment area there were a number of other factors that needed to be considered when assessing severity and change in severity classifications. These factors generally provided limitations in the main datasets used to assess severity and change in severity, in addition to any limitation in those datasets themselves. Details of these factors are provided below.

It is important to note that when one dataset had limitations for an assessment area there would be a greater reliance on the other datasets. Where limitations in the datasets were present there was also greater use of the broader 'OR' severity and change in severity classifications.

A3.2.3.1 Investigation data limitations

The automated LSN and ΔLSN were derived from individual CPT investigations undertaken across Canterbury. Interpolation was made between investigation locations to determine property specific LSN and ΔLSN values for use in the assessment of severity and change in severity classifications. However, the programme of geotechnical investigation was undertaken for the specific purpose of determining whether a property qualifies for ILV land damage, not to enable individual properties to be further classified into liquefaction vulnerability severity and change in severity. Therefore, in some areas, particularly in the Residential Red Zone, there is a lower density of CPT investigation and this led to greater use of the broader 'OR' severity and change in severity classifications in these areas.

In other areas, LSN and ΔLSN were potentially over-predicting because CPT investigations had been pre-drilled. This is discussed in further detail in Section 8.3.2.3 of the ILV Assessment Methodology Report (T+T, 2015). In general, higher LSN values would be calculated for these pre-drilled CPTs than would be calculated if the CPT had not been pre-drilled because low strength (readily liquefiable) material was assumed in the liquefaction analyses for the estimation of LSN values over the pre-drilled depth. ΔLSN values were particularly sensitive to pre-drill and therefore had a greater tendency for over-prediction.

While additional geotechnical investigation data and more detailed assessment could possibly help increase the level of certainty of which primary severity or change in severity classification properties could be assigned, some areas are likely to always have uncertainty associated with them due to the limits of the science and understanding around characteristics of vulnerability to liquefaction, resulting in broader 'OR' classifications.

A3.2.3.2 Variable ground conditions

In some areas it was often difficult to assign a primary severity or change in severity classifications because subsurface ground conditions in Canterbury are highly variable (see Section 3.6 of the ILV Assessment Methodology Report (T+T, 2015)).

Certain subsurface conditions led to greater variability in the predicted LSN and ΔLSN values calculated using the automated ILV model. Interlayered silty and sandy soils may result in high LSN and ΔLSN values that are inconsistent with the land damage observations during the CES. Furthermore, variable ground conditions can cause CPT investigations on nearby properties to produce differing LSN or ΔLSN values while land damage observations were similar on these properties.

Very shallow groundwater levels can also, in some instances, overestimate the predicted LSN and ΔLSN values. This is due to a hypersensitivity of LSN to shallow groundwater, as discussed in Section 8.3.2.3 of the ILV Assessment Methodology Report (T+T, 2015).

A3.2.3.3 Limitations in the LiDAR ground surface subsidence measurements

Earthworks, which have modified the ground surface level, undertaken between LiDAR surveys can affect the calculation of ground surface subsidence and the corresponding automated LSN and ΔLSN values in some areas. As the change in ground surface elevation is difficult to interpret in areas with earthworks, due to uncertain baseline ground surface elevation, the LSN and ΔLSN values have an even higher uncertainty and could potentially be under or over predicted.

A3.3 Step 3 - Review of classifications

Following assessment of pre-CES severity, post-CES severity, and change in severity classifications for each of the assessment areas at both 100 year and 25 year return period levels of shaking, an internal review process was undertaken. This review was undertaken by senior engineers and a project director independent from the team involved in the classification of severity and change in severity of all areas with ILV land damage.

The severity and change in severity classifications were shown on A1 size maps and inspected to identify areas where the distribution of classifications appeared to be inconsistent with the surrounding areas as well as known geotechnical and topographical characteristics of these areas and the observed land damage. The initial severity and change in severity classifications were also checked against land damage observations, ground surface subsidence, and LSN or ΔLSN inspected at a broad scale. In addition, logic checks and statistical correlations were made to identify assessment areas that would need more detailed review to confirm the justification of the assessed classifications were appropriate. The review involved:

- Checking across all maps for:
  - consistency between 100 year and 25 year return period return period classifications (i.e. ensuring the 100 year classifications were greater than or equal to the equivalent 25 year classifications);
  - consistency between pre-CES and post-CES classifications (i.e. ensuring the post-CES classification was greater than or equal to the equivalent pre-CES classification); and
  - consistency between the change in severity classification and the difference in severity classifications from pre-CES to post-CES;
- Checking within each map for consistency in terms of relativity between adjacent areas and to ensure that there were no significant changes in severity or change in severity for adjacent areas unless there is topographic/geological justification; and
- Statistical correlations of the results for all properties with ILV land damage to identify whether the datasets used to make severity and change in severity classifications were generally consistent with the classifications at a broad portfolio scale. For example, whether the proportion of moderate-to-severe land damage for properties classified as Medium severity was less than for properties classified as High severity.

Results of statistical correlations used in the review of the severity classifications is presented in Figure A3.2, where observed land damage is correlated with the pre-CES severity classifications at 100 year return period levels of shaking. The observed land damage statistics from the September 2010 event and the worst observed land damage during the CES (typically from the September 2010 or February 2011 events) are correlated with the pre-CES severity because these observations equate to performance prior to subsidence (i.e. the pre-CES scenario). The statistical correlations show that the proportion of properties with moderate-to-severe land damage increases as the primary severity classification increases and that the proportion of none-to-minor land damage decreases, which shows the classifications are generally consistent with observed land damage.

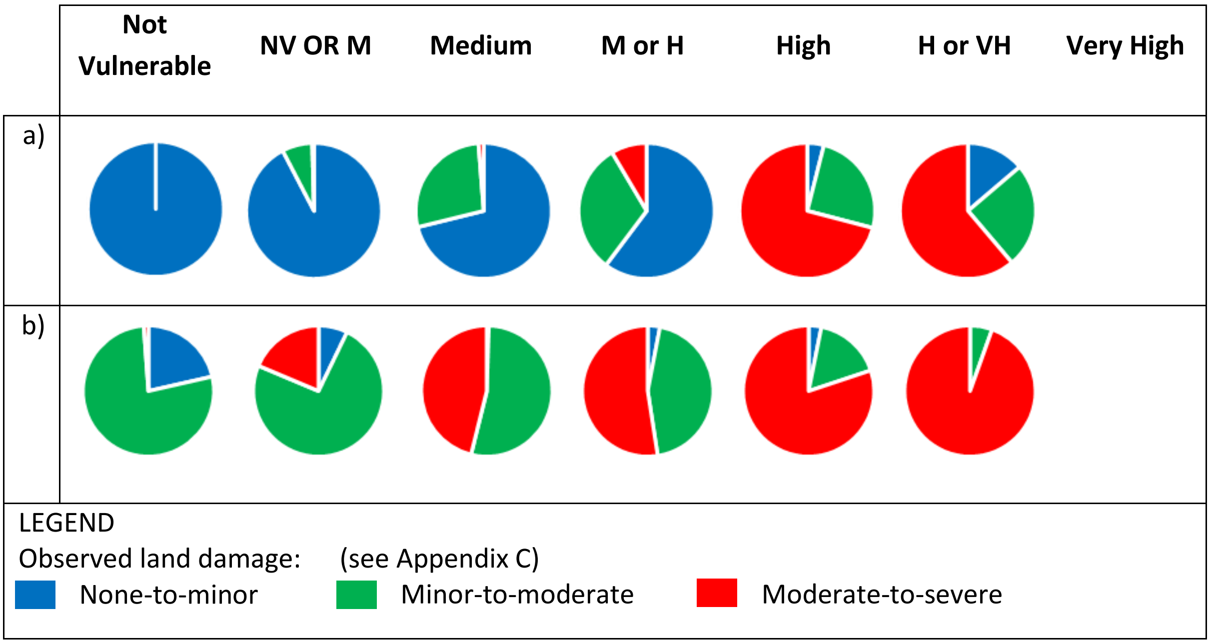

Figure A3.2: Statistical correlation of pre-CES liquefaction vulnerability severity classifications of properties with ILV land damage at 100 year return period levels of shaking with a) observed land damage following the September 2010 event and b) worst observed land damage during the CES.

As part of the review process, the severity and change in severity classifications of areas identified in the review were also reassessed by re-inspecting the datasets used to make the particular classification and the reasons recorded for the assessment decision. In most cases further review of the data and reasons supported the initial classification provided. In some cases modification was made to the initial classification to account for the review comments.

In situations where changes were made to the initial classification, the change was typically from a primary classification to an 'OR' classification. This is because upon further review it was considered that certainty of a primary classification could not be supported by the information used in the assessment and so the broader 'OR' classifications were used to capture the higher level of uncertainty.