Appendix H: Median and Mean LSN Technical Note

H1 Introduction

Land damage observations from the 2010 to 2011 Canterbury Earthquake Sequence (**CES**) showed that the groundwater depth (**GWD**) is one of several key factors in many areas of Christchurch influencing whether or not liquefaction related land damage is likely to occur. In many parts of Christchurch, the vulnerability to liquefaction is sensitive to changes in the GWD because the groundwater table is close to the ground surface.

In order to use the LSN parameter for the assessment of liquefaction vulnerability, it is necessary to determine how to address seasonal variation in vulnerability. The groundwater level in the Christchurch area varies naturally from season to season, and from year to year. For the parts of the Christchurch area where ground surface subsidence has occurred, this range of variation in the depth to the groundwater is typically 0.5m above and below the median groundwater surface (van Ballegooy et al. (2014a).

Because the groundwater levels are seasonally fluctuating, the liquefaction vulnerability of the land (as represented by the LSN parameter) also fluctuates above and below the median value. However, because the LSN parameter has a depth-weighting factor, the LSN value increases more due to a rise in the groundwater level than it decreases due to a lowering in the groundwater level. This means that the variability in the LSN value over time is not equally distributed about the median. Furthermore, the presence of layers of non-liquefying soils within the range of groundwater fluctuation will affect the distribution of LSN over time.

A significant amount of work was undertaken to investigate the difference between the median and mean liquefaction vulnerability across Christchurch as a result of the seasonally fluctuating groundwater levels.

H1.1 Purpose and Outline

The purpose of this appendix is to summarise the difference between the median and mean estimated LSN values, describe how the mean LSN values are estimated, and assess the influence they have on the on the assessment on liquefaction vulnerability in Christchurch as it relates to the assessment of ILV.

The appendix is structured as follows:

- Section H2 discusses the influence the estimated mean and median LSN values have on the assessment of liquefaction vulnerability by presenting some hypothetical cases and discusses the differences between the estimated median and mean LSN values and provides examples of when these situations may arise;
- Section H3 discusses the processed involved in estimating the mean LSN values along with maps showing the spatial distribution of estimated median and mean LSN values across Christchurch;
- Section H4 discusses the differences between the estimated mean and median LSN values across Christchurch;
- Section H5 provides discussion of the results and presents the conclusions from this appendix.

H2 Median v. Mean – Influence on the Liquefaction Vulnerability

The groundwater level in Christchurch varies naturally from season to season, and from year to year. For the parts of Christchurch where significant ground surface subsidence has occurred, this range of variation is usually less than 0.5m above and below the median.

This means that the liquefaction vulnerability (estimated by the LSN parameter) also fluctuates above and below the median value. However, because LSN has a depth-weighted factor, the LSN value responds more to a rise in the groundwater level than it does to a lowering in the level. This means that the variability in the LSN value over time is not equally distributed about the median. Also, the presence of layers of non-liquefying soils within the range of groundwater fluctuation are likely to affect the distribution of LSN over time. This non-uniform distribution is incorporated as part of the ILV land damage assessment process.

This non-uniform variation in liquefaction vulnerability is incorporated into the liquefaction vulnerability assessment process to estimate the mean value of LSN over time. However, this is not a straight forward exercise and requires the LSN to be estimated at a range of groundwater levels in order to ultimately estimate the mean LSN.

Four hypothetical case studies are presented on the following pages and their respective median and mean LSN values are estimated for a change in GWD from 1.8m to 1.5m (i.e. 300mm of ground surface subsidence as a result of the CES). These hypothetical examples show the pre-CES GWD fluctuating sinusoidally between 1.3m and 2.3m, with a median value of 1.8m. Due to the 0.3m of ground surface subsidence, the post-CES GWD fluctuates sinusoidally between 1m and 2m, with a median value of 1.5m.

The four examples are:

i. All soils within the range of groundwater fluctuation are liquefiable (refer to green and pink areas in Figure H2.1)

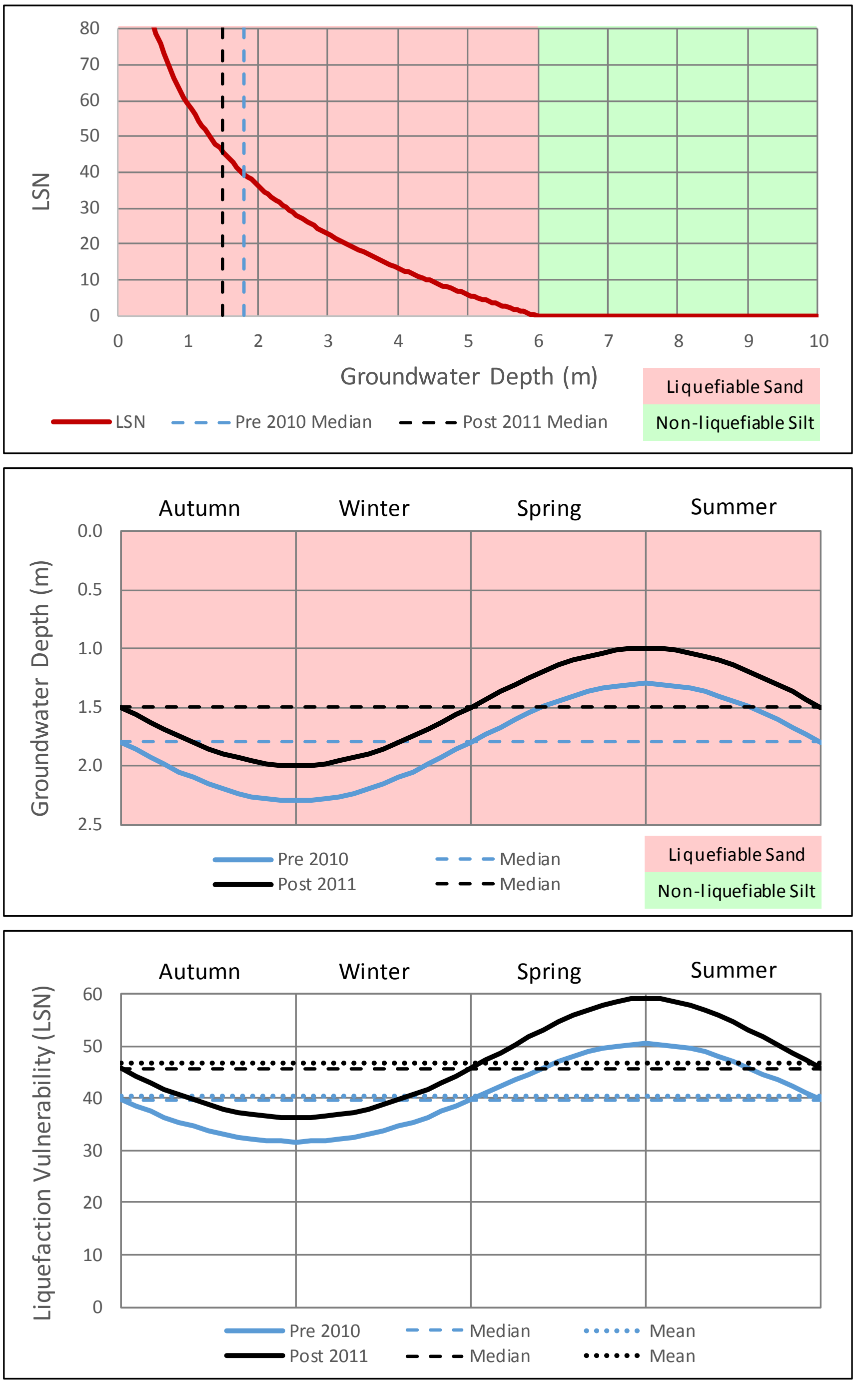
ii. Range of groundwater fluctuation straddles the boundary between non-liquefying soil and an overlying liquefying soil (refer to green and pink areas in Figure H2.2)

iii. Range of groundwater fluctuation straddles the boundary between liquefiable soil and an overlying non-liquefying soil (refer to green and pink areas in Figure H2.3)

iv. All soils within the range of groundwater fluctuation are liquefiable, except for a thin non-liquefying layer (refer to green and pink areas in Figure H2.4)

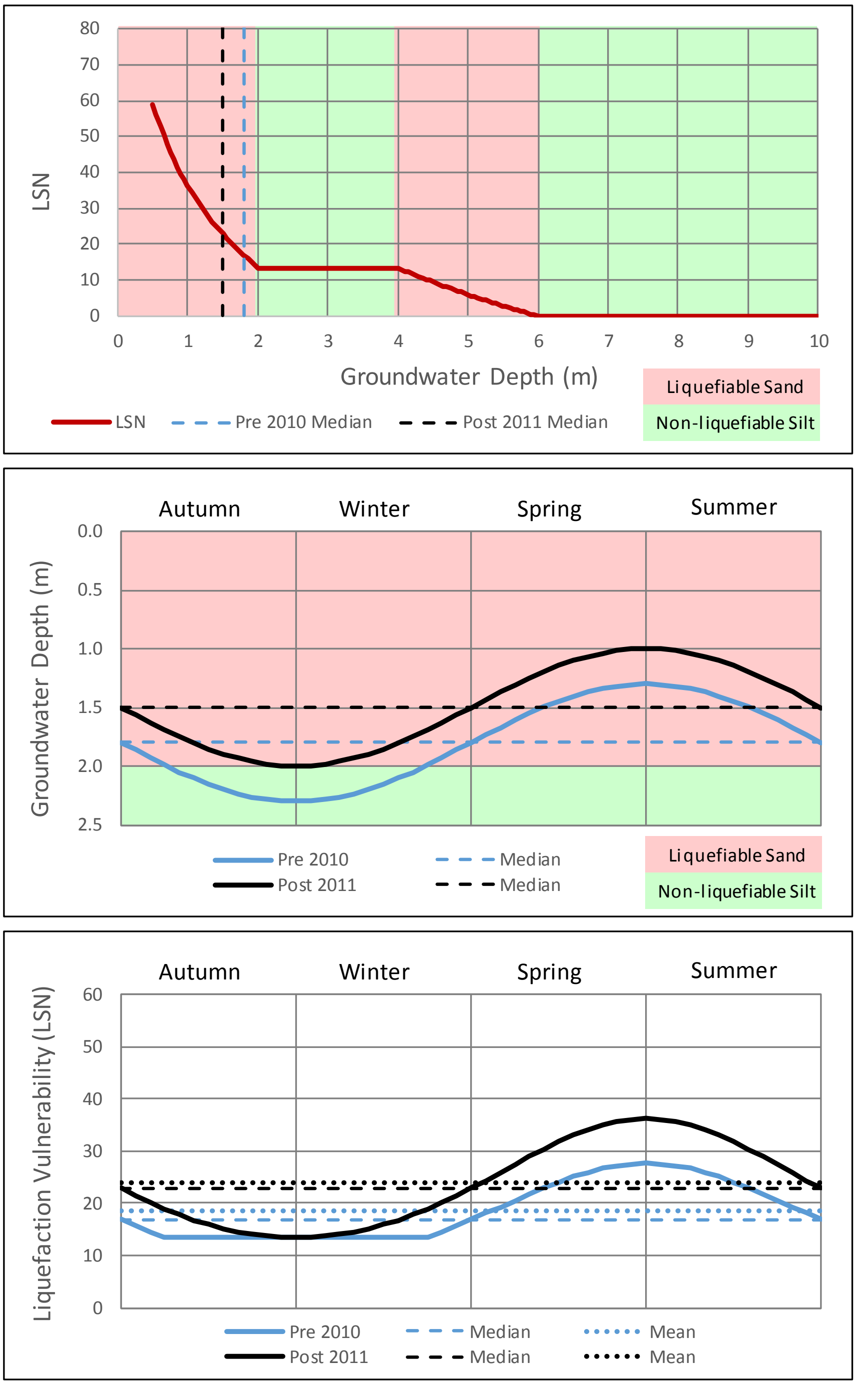
These case studies show that the median LSN and the mean LSN, and the change in LSN (ΔLSN) due to ground surface subsidence, respond differently to different soil profiles:

- Figure H2.1 shows a common situation – when all soils within the groundwater range are liquefiable, then mean values for LSN and the ΔLSN are only slightly higher than the median values. For these cases, properties marginally not qualifying for ILV using a median LSN approach would qualify using a mean LSN approach.
- Figures H2.2 and H2.3 show that when the presence of a non-liquefying soil layer "truncates" the LSN vs. time response before or after the earthquake sequence, the estimated LSN is higher but the ΔLSN is moderately less for the mean compared with the median approach. For these cases, properties that marginally qualifying for ILV using a median LSN approach would not qualify using a mean LSN approach.
- Figure H2.4 shows that when the pre-earthquake median groundwater level lies within a thin non-liquefying layer, then the ΔLSN can be much greater for the mean than the median. For these cases, properties marginally not qualifying for ILV using a median LSN approach would qualify using a mean LSN approach.



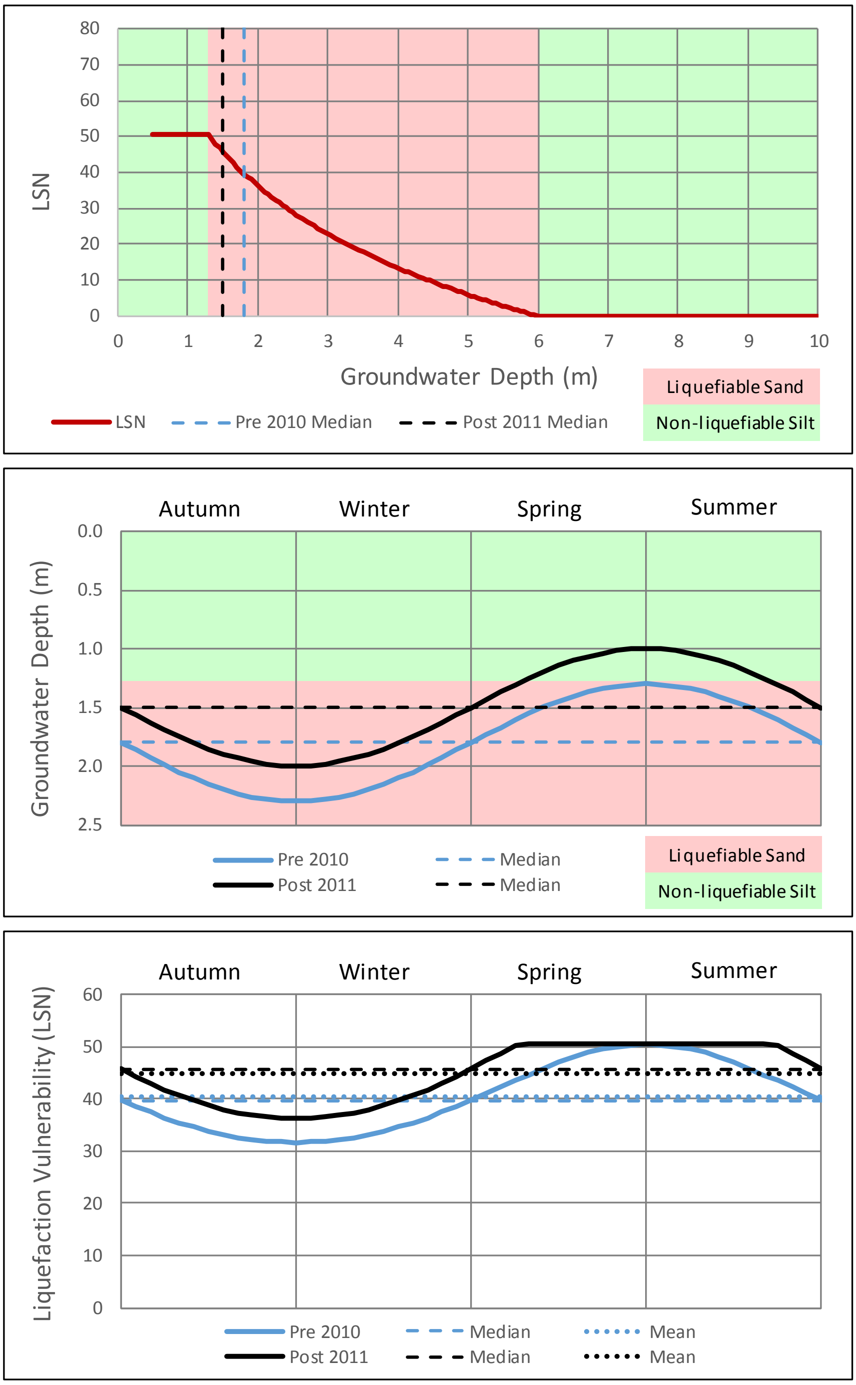
	Pre 2010	Post 2011	Change
Median groundwater depth:	1.80 m	1.50 m	- 0.30 m
85th percentile groundwater depth:	1.37 m	1.07 m	- 0.30 m
15th percentile groundwater depth:	2.23 m	1.93 m	- 0.30 m
Median LSN:	39.7	45.7	+ 6.0
Mean LSN:	40.4	46.7	+ 6.3

Figure H2.1: Case study 1 comparing median and mean LSN assessment where all soils within the range of groundwater fluctuation are liquefiable.



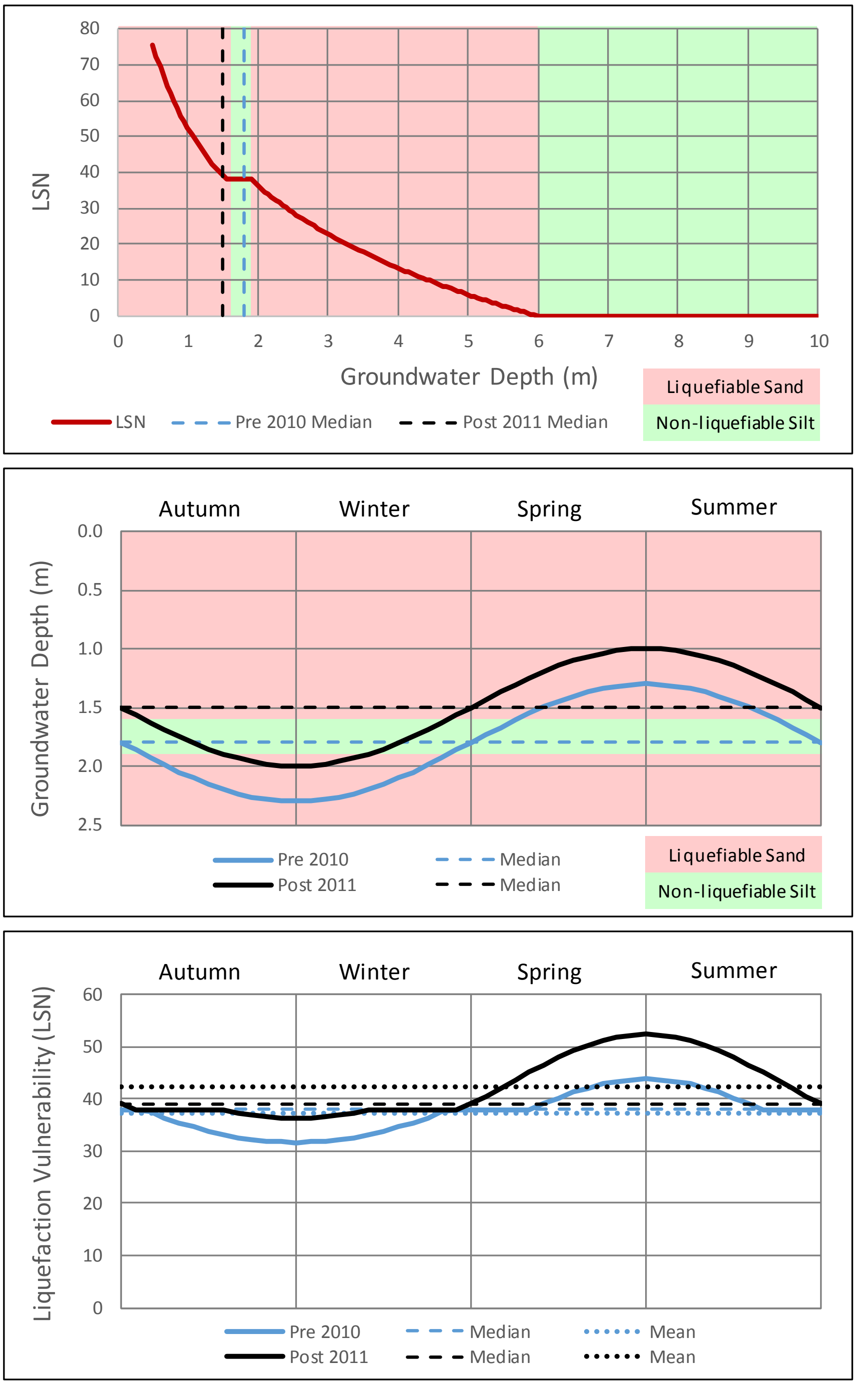
	Pre 2010	Post 2011	Change
Median groundwater depth:	1.80 m	1.50 m	- 0.30 m
85th percentile groundwater depth:	1.37 m	1.07 m	- 0.30 m
15th percentile groundwater depth:	2.23 m	1.93 m	- 0.30 m
Median LSN:	16.9	22.9	+ 6.0
Mean LSN:	18.6	23.8	+ 5.2

Figure H2.2: Case study 2 comparing median and mean LSN assessment where the range of groundwater fluctuation straddles the boundary between non-liquefying soil and an overlying liquefying soil.



	Pre 2010	Post 2011	Change
Median groundwater depth:	1.80 m	1.50 m	- 0.30 m
85th percentile groundwater depth:	1.37 m	1.07 m	- 0.30 m
15th percentile groundwater depth:	2.23 m	1.93 m	- 0.30 m
Median LSN:	39.7	45.7	+ 6.0
Mean LSN:	40.4	44.7	+ 4.3

Figure H2.3: Case study 3 comparing median and mean LSN assessment where the range of groundwater fluctuation straddles the boundary between liquefying soil and an overlying non-liquefying soil.



	Pre 2010	Post 2011	Change
Median groundwater depth:	1.80 m	1.50 m	- 0.30 m
85th percentile groundwater depth:	1.37 m	1.07 m	- 0.30 m
15th percentile groundwater depth:	2.23 m	1.93 m	- 0.30 m
Median LSN:	37.9	39.0	+ 1.1
Mean LSN:	37.4	42.3	+ 4.9

Figure H2.4: Case study 4 comparing median and mean LSN assessment where all soils within the range of groundwater fluctuation are liquefying, except for a thin non-liquefying layer.

These cases studies demonstrate that in considering the mean and median LSN values and their respective ΔLSN values, neither is more technically correct than the other. In general, it could be considered that:

- Because engineering design is likely to be based on the median groundwater level, the median LSN is more representative of the level of engineering effort (e.g. ground improvement or enhanced foundations) that would be specified in practice if works were to be undertaken.
- Because the liquefaction vulnerability has a non-uniform variation with time, the mean LSN is more representative of the average exposure to the liquefaction hazard over time.

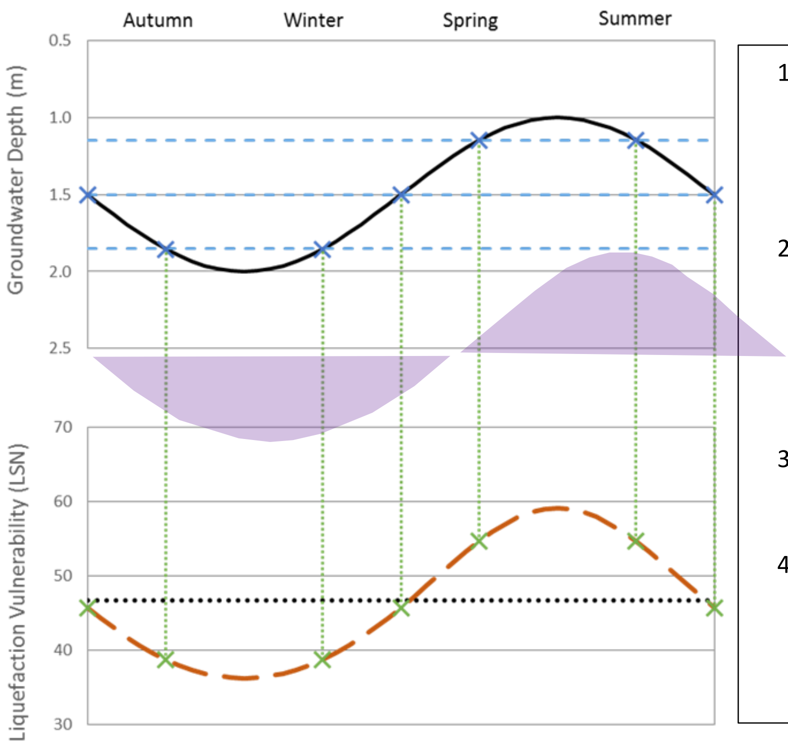
Because the median and the mean estimated LSN respond differently to different soil profiles, it is not possible to choose a single approach which is technically more correct than the other. Therefore, the ILV Assessment Methodology incorporates both approaches.

H3 Estimating the Mean LSN

In order to estimate the mean LSN and the mean ΔLSN for properties in Christchurch, the LSN needs to be estimated for a minimum of three different groundwater values. Consequently, the sinusoidal curve can be assumed and modelled around these values and a mean LSN can be estimated assuming a best fit. The process is outlined in Figure H3.1.

In order to estimate a mean LSN value, the 15th percentile, median and 85th percentile GWDs are required. The groundwater surfaces published by GNS (van Ballegooy et al., 2014a) have been used for this study. A difference between the post-CES LiDAR DEM and the respective groundwater surfaces created the 15th percentile, median and 85th percentile GWD grids required for this study.

These surfaces have been used in conjunction with the automated liquefaction analysis model to estimate the post-CES 2011 median and mean LSN values across Christchurch (shown in Figures H3.2 and H3.3) as well as the median ΔLSN and mean ΔLSN values across Christchurch (shown in Figures H3.4 and H3.5).



1) Estimate three GWD values at each property – 15th percentile, median, 85th percentile (refer to the blue dashed lines)
2) Estimate the corresponding LSN values for the three GWD values stated above (refer to the green crosses at the bottom of the green dashed lines)
3) Fit a curve to the LSN values estimated in step 2 (refer to the orange dashed line)
4) Estimate a mean LSN off the modelled curve -mean is where area above the line is equal to the area below the line (refer to the purple area)

Figure H3.1: Step-by-step process on how to estimate a mean LSN value.

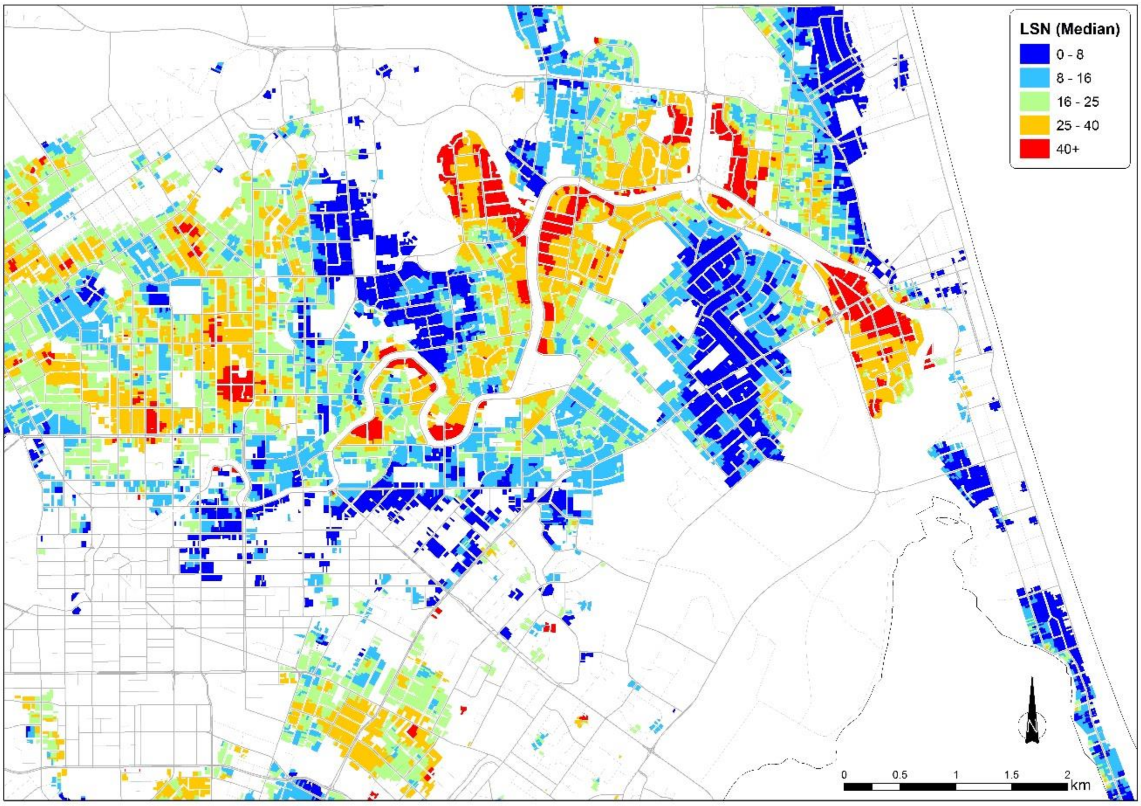


Figure H3.2: Map showing the spatial distribution of the median LSN (based on the post-CES GWD) using the default liquefaction vulnerability assessment parameters summarised in Appendix A.

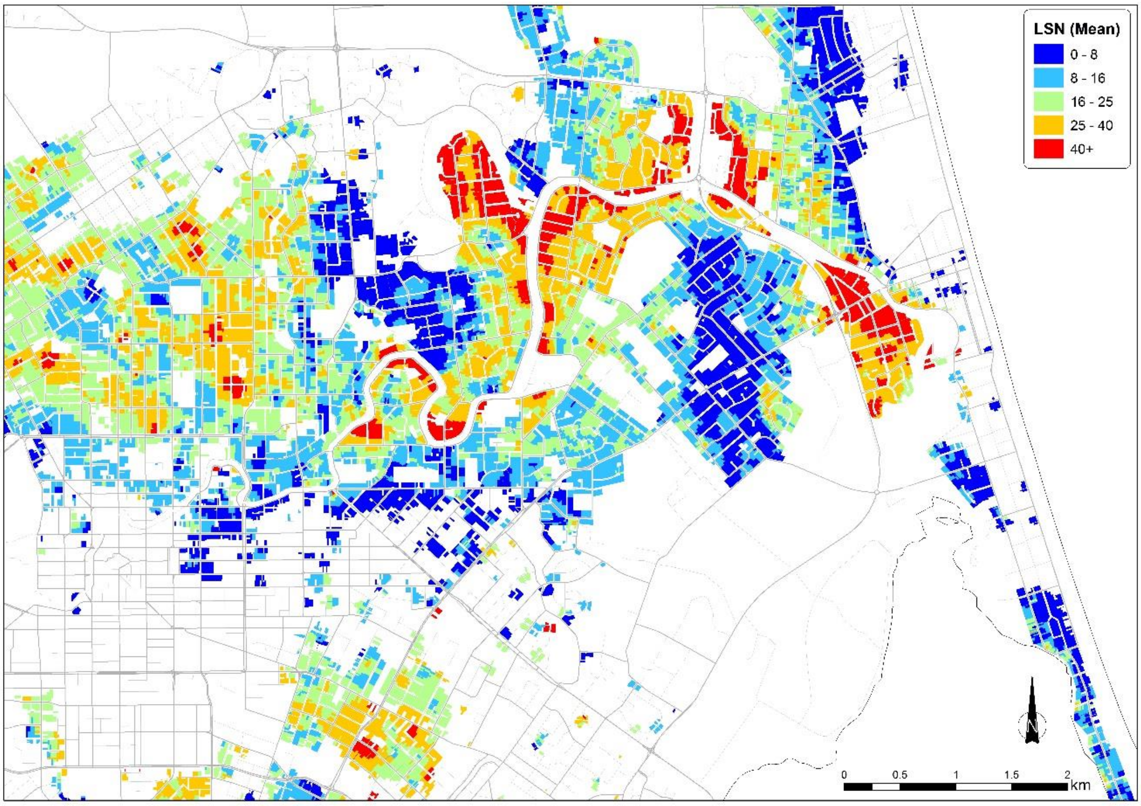


Figure H3.3: Map showing the spatial distribution of the mean LSN (based on the post-CES GWD) using the default liquefaction vulnerability assessment parameters summarised in Appendix A.

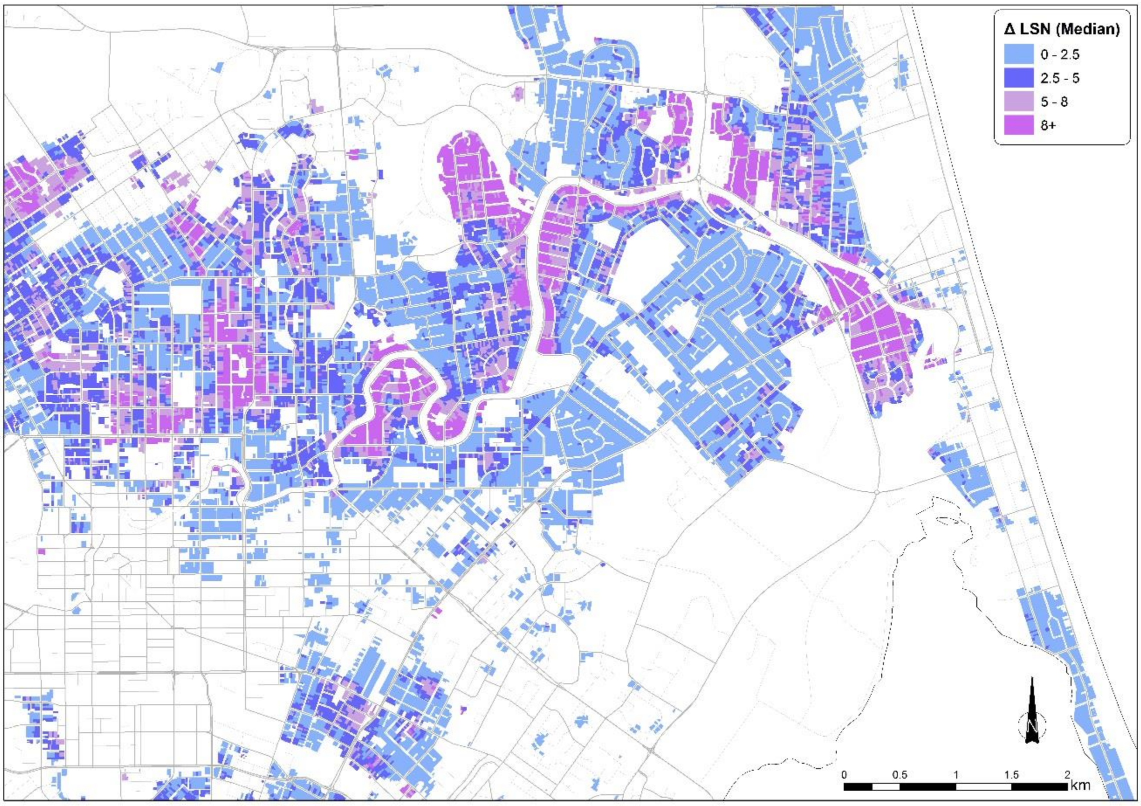


Figure G3.4: Map showing the spatial distribution of the median ΔLSN using the default liquefaction vulnerability assessment parameters summarised in Appendix A.

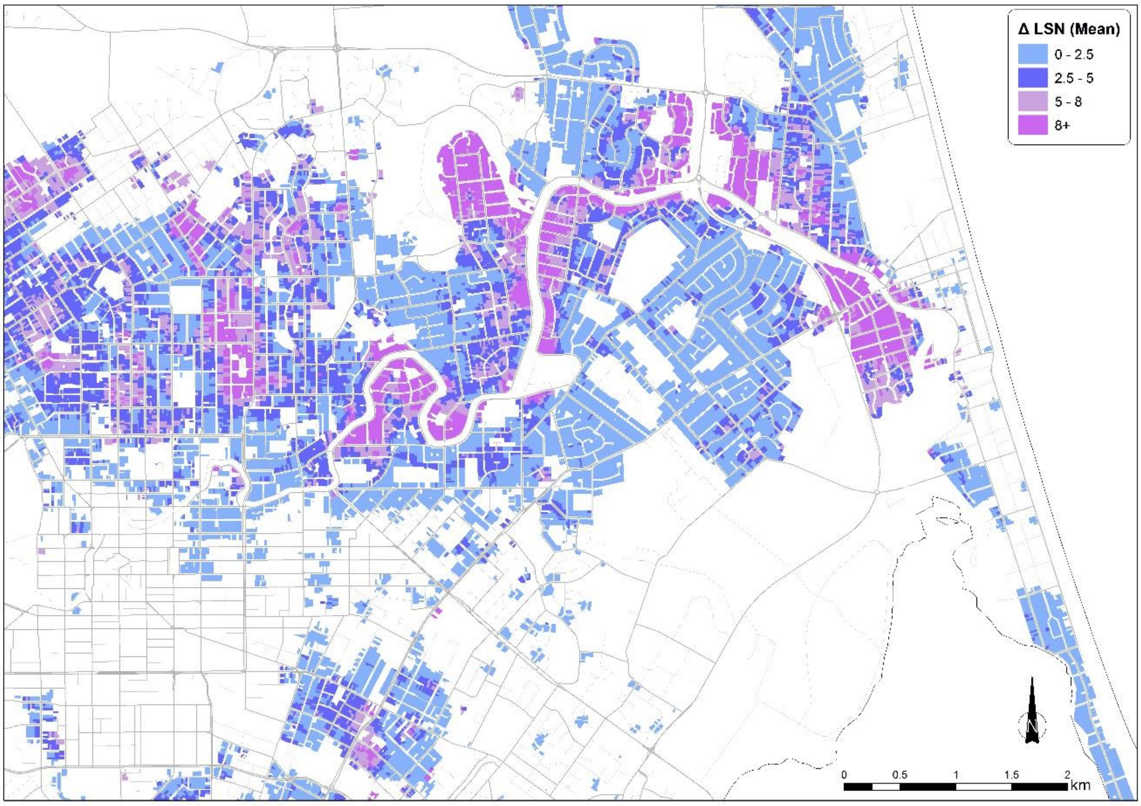


Figure G3.5: Map showing the spatial distribution of the mean ΔLSN using the default liquefaction vulnerability assessment parameters summarised in Appendix A.

H4 Differences Between the Median and Mean LSN

The comparison of Figures H3.2 and H3.3 shows that there is not much difference between the spatial distribution of the median LSN and the mean LSN. Figure H4.1 shows the difference between the median LSN and the mean LSN where positive areas (red and orange) indicate that the estimated mean LSN is higher than the estimated median LSN and conversely, negative areas (dark blue and light blue) indicate where the estimated mean LSN is lower than estimated median LSN.

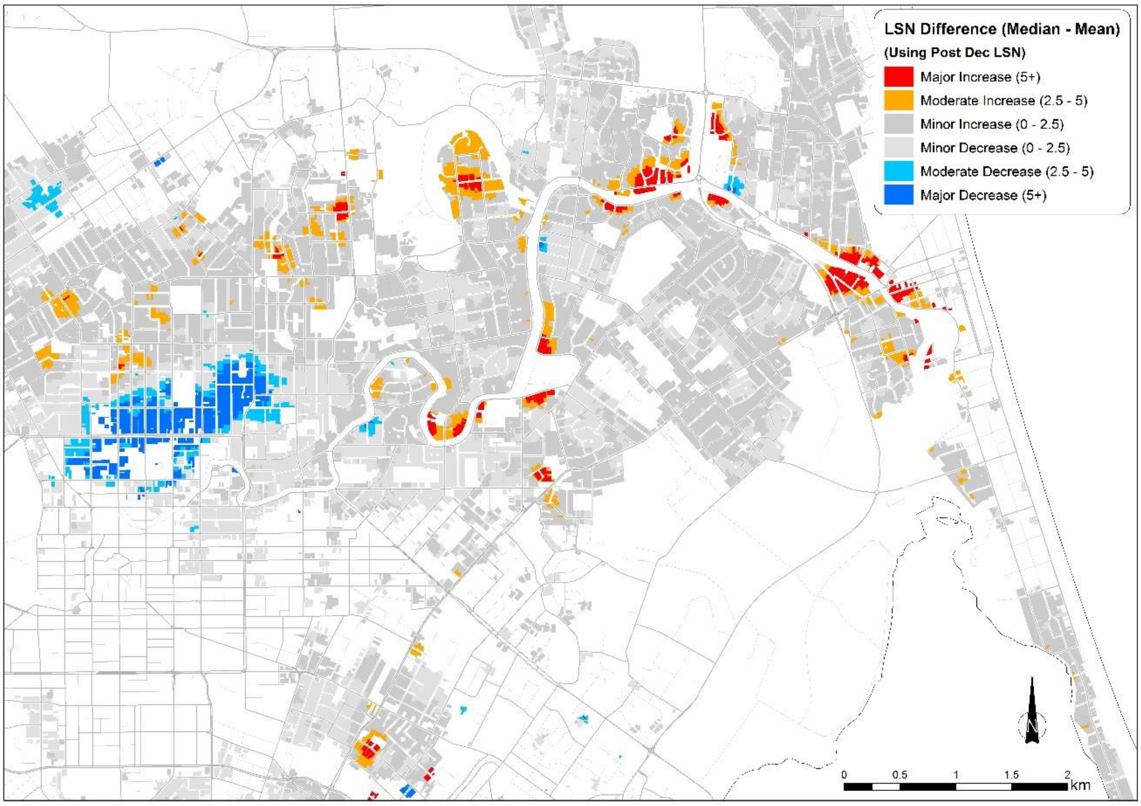


Figure H4.1: Map showing the difference between the median LSN (Figure H3.2) and the mean LSN (Figure H3.3).

Similarly, the comparison of Figures H3.4 and H3.5 shows that there is not much difference between the spatial distribution of the median ΔLSN and the mean ΔLSN. Figure H4.2 shows the difference between the median ΔLSN and the mean ΔLSN where positive areas (red and orange) indicate that the estimated mean ΔLSN is higher than the estimated median ΔLSN and conversely, negative areas (dark blue and light blue) indicate where the estimated mean ΔLSN is lower than estimated median ΔLSN.

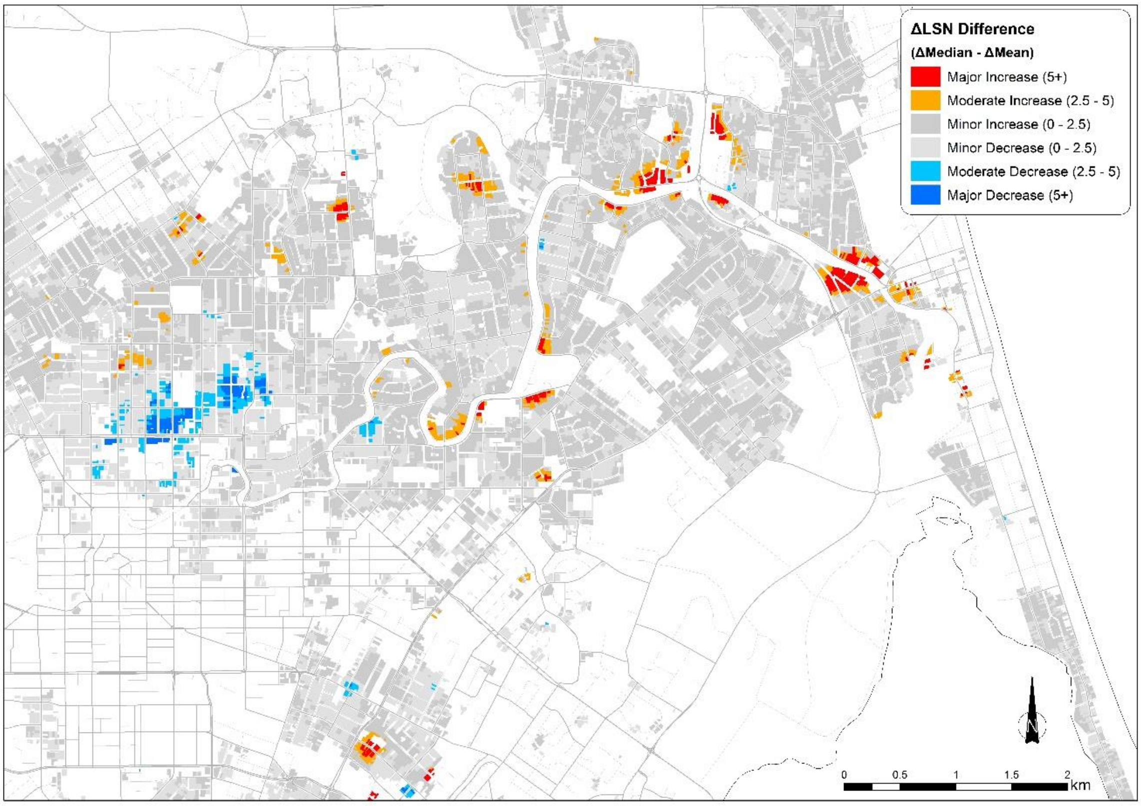


Figure H4.2: Map showing the difference between the median ΔLSN (Figure H3.4) and the mean ΔLSN (Figure H3.5).

Areas such as Horseshoe Lake and Burwood have a higher mean LSN than median LSN and a higher mean ΔLSN than median ΔLSN. These are an example of where the cases presented earlier in Figures H2.1 and H2.4 are taking place in Christchurch. In contrast, Edgeware and Richmond have a lower mean LSN than median LSN and a lower mean ΔLSN than median ΔLSN. This can be related directly to the scenario presented in Figure H2.3.

H5 Discussion and Conclusion

Across all of Christchurch, the difference between the two approaches are subtle and maps presented in Section H4 show these subtle differences. It is not possible to choose a single approach which is more technically correct compared to the other because the median and the mean LSN respond differently.

H6 References

Boulanger, R. W. & Idriss, I. M. 2014. *CPT and SPT based liquefaction triggering procedures*. (Report No. UCD/CGM-14/01). Center for Geotechnical Modelling, Department of Civil and Environmental Engineering, University of California, Davis, CA.

van Ballegooy, S., Cox, S.C., Thurlow, C., Rutter, H.K., Reynolds, T., Harrington, G., Fraser, J. & Smith, T. 2014a. *Median water table elevation in Christchurch and surrounding areas after the 4 September 2010 Darfield Earthquake Version 2*. (GNS Science report 2014/18). Institute of Geological and Nuclear Sciences, Lower Hutt.