REPORT

Tonkin+Taylor

Christchurch Liquefaction Vulnerability Study

Prepared for
Christchurch City Council
Prepared by
Tonkin & Taylor Ltd
Date
July 2020
Job Number
1000273.v1.2

Exceptional thinking together
www.tonkintaylor.co.nz

Document control

Title: Christchurch Liquefaction Vulnerability Study					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
Sep-19	1.0	Initial issue	MLO/MEJ	MEJ	PRC
Nov-19	1.1	Minor updates responding to peer review comments	MLO/MEJ	MEJ	PRC
Jul-20	1.2	Updated Section 6 to clarify that new Liquefaction Vulnerability Categories do not supersede existing hazard management maps and processes.	MLO/MEJ	MEJ	PRC

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Christchurch City Council	1 PDF copy
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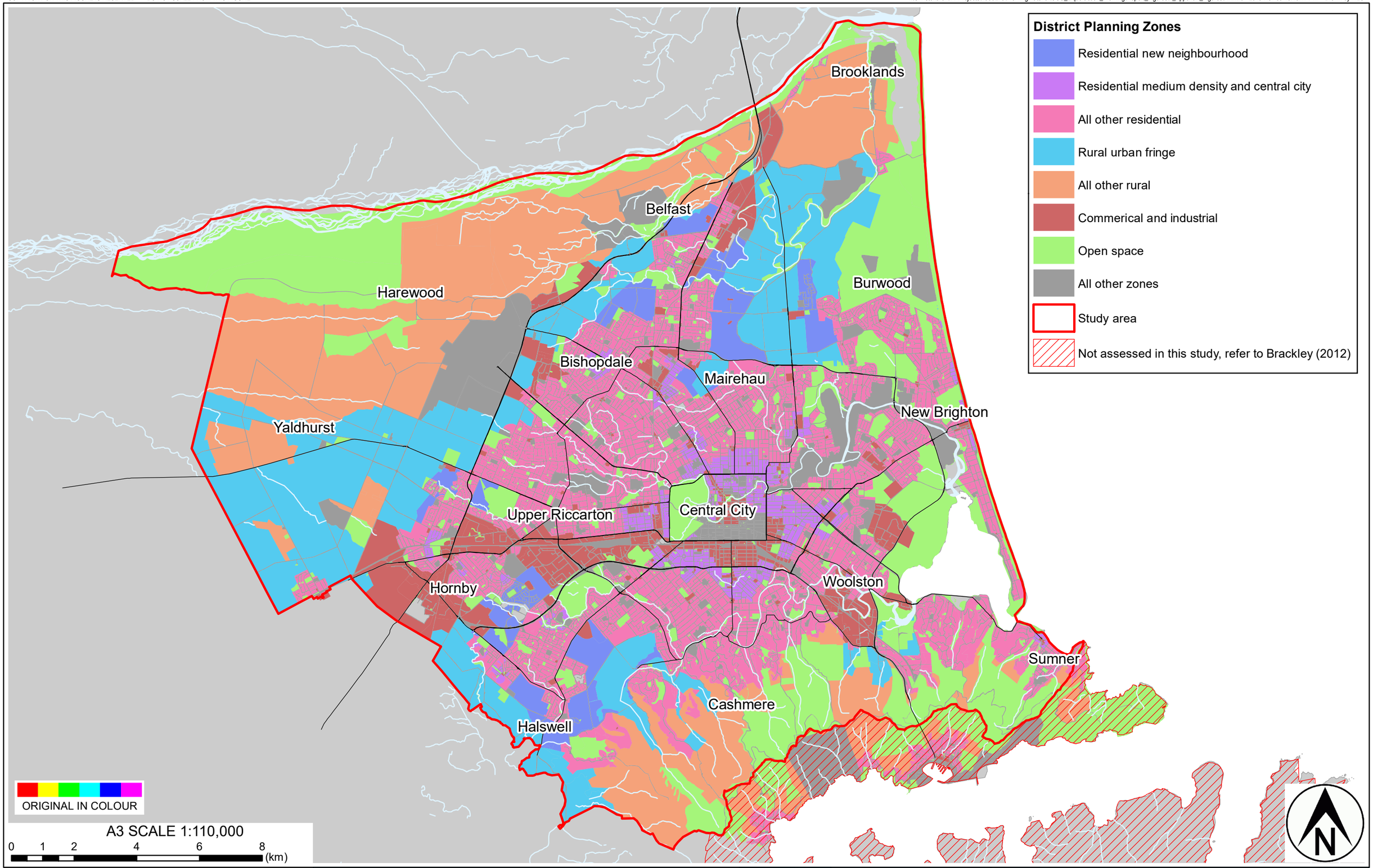

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NOTES:

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1	Initial issue	MLO	MEJ	06/09/19
2	Minor updates	MLO	MEJ	08/11/19

LOCATION PLAN

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APPROVED		27-JUL-2020

CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE SUMMARY OF DISTRICT PLANNING ZONES

SCALE (A3) 1:110,000 FIG No. FIGURE A1 REV 2

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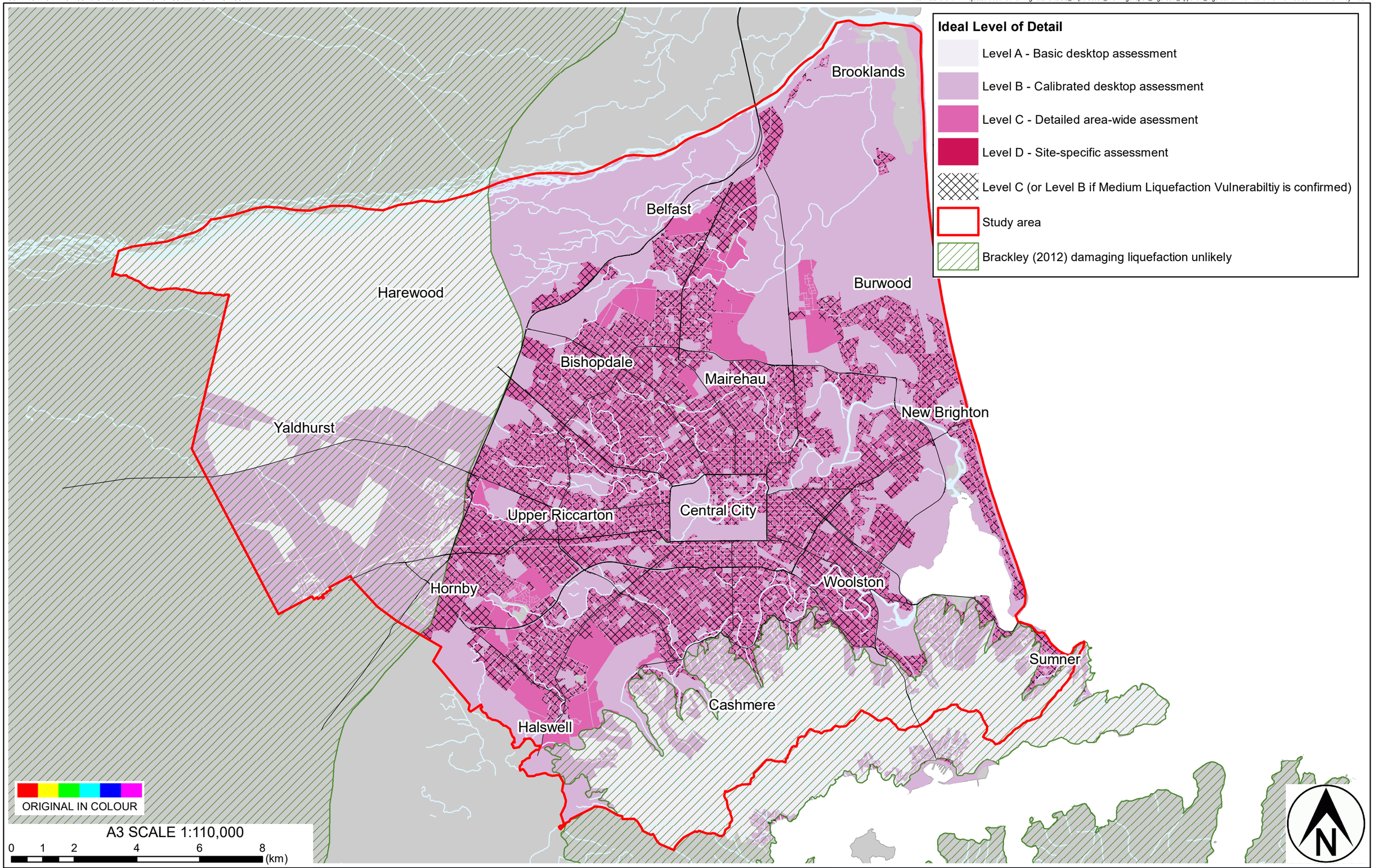

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TITLE TARGET LEVEL OF DETAIL

SCALE (A3) 1:110,000 FIG No. FIGURE A2 REV 2

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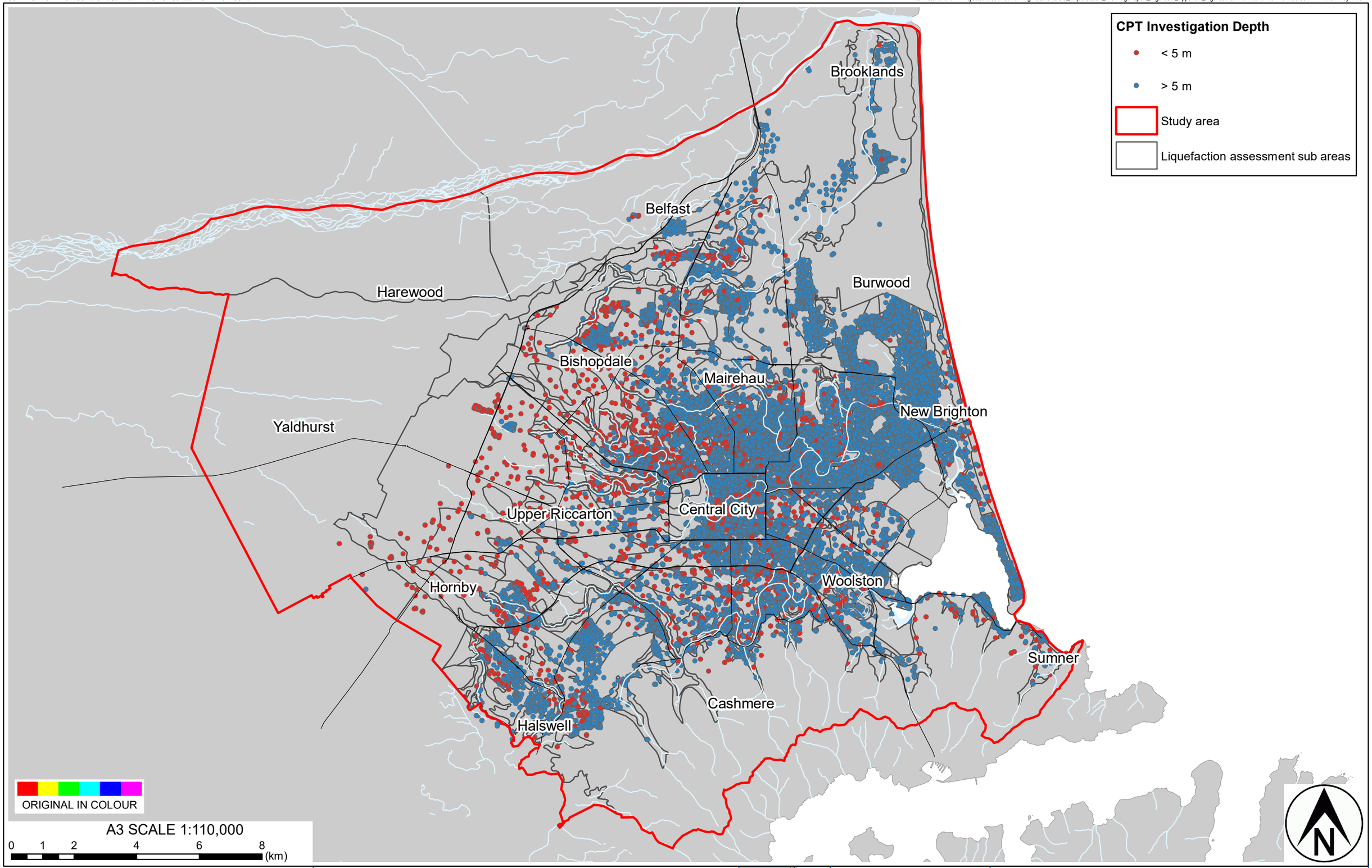

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PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE SUMMARY OF CPT INVESTIGATIONS

SCALE (A3) 1:110,000 FIG No. FIGURE A3 REV 2

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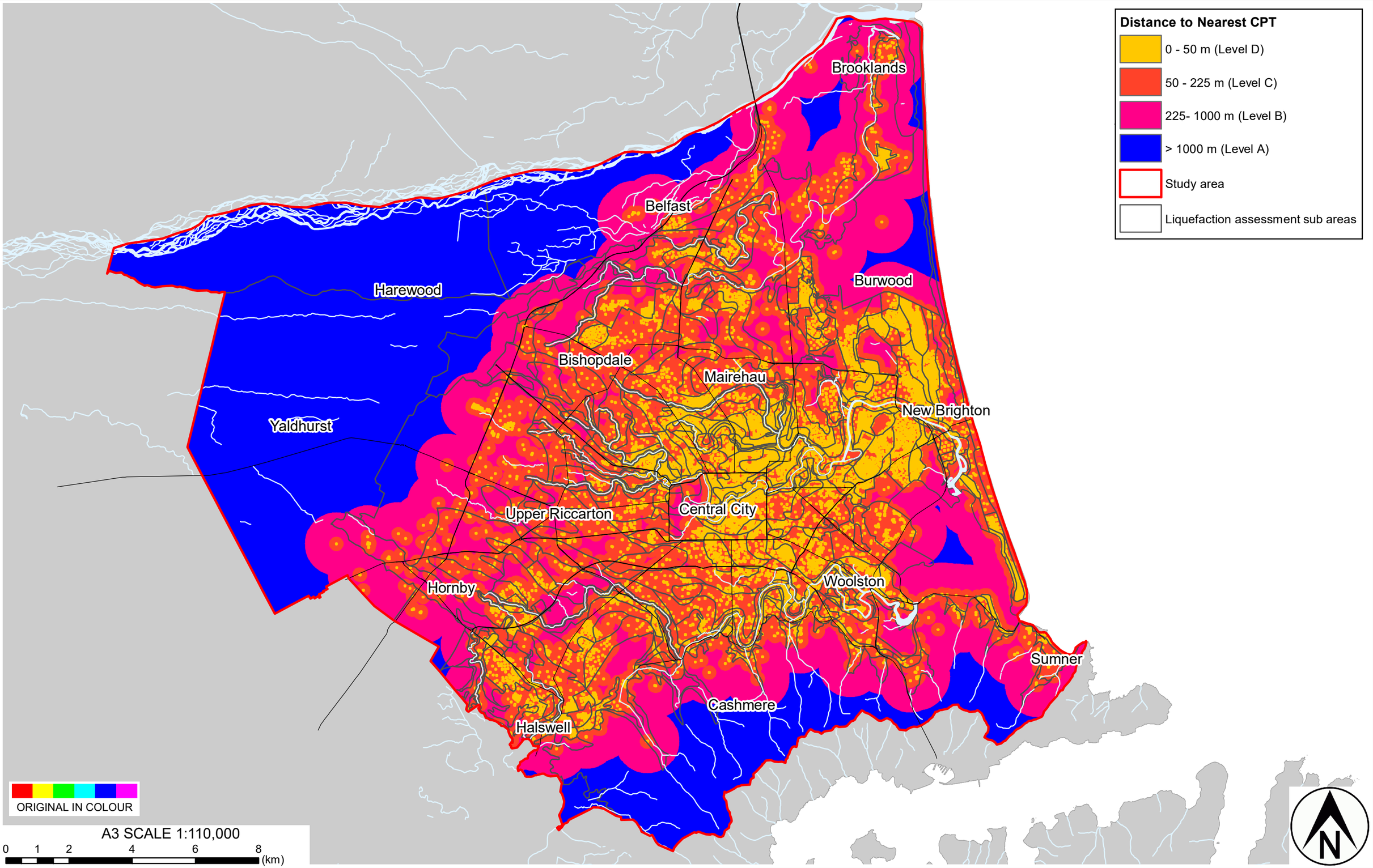

ORIGINAL IN COLOUR

A3 SCALE 1:110,000

0 1 2 4 6 8 (km)

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PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE CPT INVESTIGATION DENSITY

SCALE (A3) 1:110,000 FIG No. FIGURE A4 REV 2

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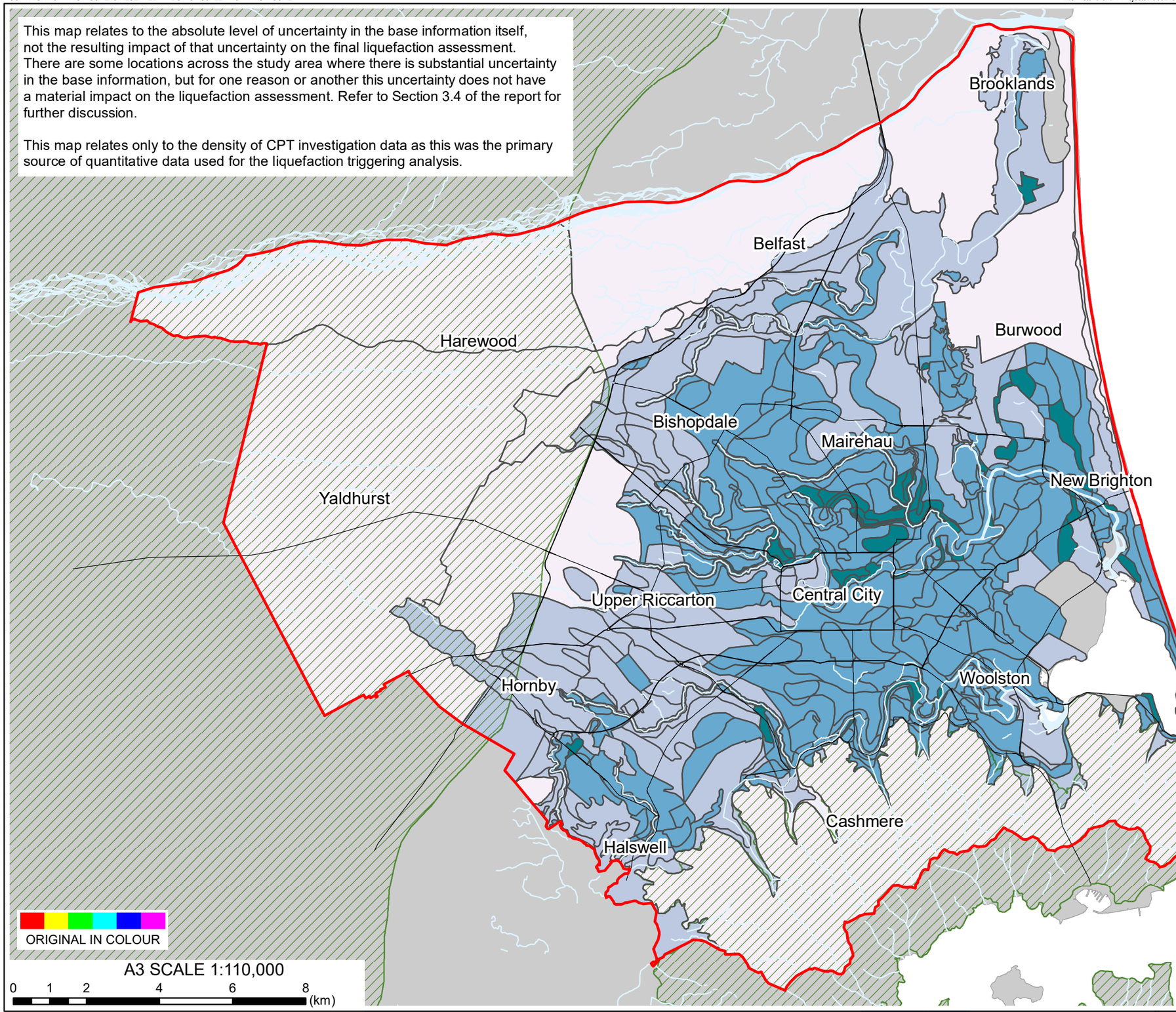
This map relates to the absolute level of uncertainty in the base information itself, not the resulting impact of that uncertainty on the final liquefaction assessment. There are some locations across the study area where there is substantial uncertainty in the base information, but for one reason or another this uncertainty does not have a material impact on the liquefaction assessment. Refer to Section 3.4 of the report for further discussion.

This map relates only to the density of CPT investigation data as this was the primary source of quantitative data used for the liquefaction triggering analysis.



Ground Conditions Uncertainty

- More Uncertainty in Ground Conditions
- Less Uncertainty in Ground Conditions
- Study area
- Liquefaction assessment sub areas
- Brackley (2012) damaging liquefaction unlikely

Because there is less quantitative investigation data in this area there is more uncertainty in the absolute soil profile and strengths. However, the known geological nature of this land indicates that Liquefaction Damage is Unlikely, so the uncertainty in ground conditions does not have a material impact on the liquefaction vulnerability assessment.

ORIGINAL IN COLOUR

A3 SCALE 1:110,000

0 1 2 4 6 8 (km)

N

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TITLE GROUND CONDITIONS UNCERTAINTY

SCALE (A3) 1:110,000 FIG No. FIGURE A5 REV 2

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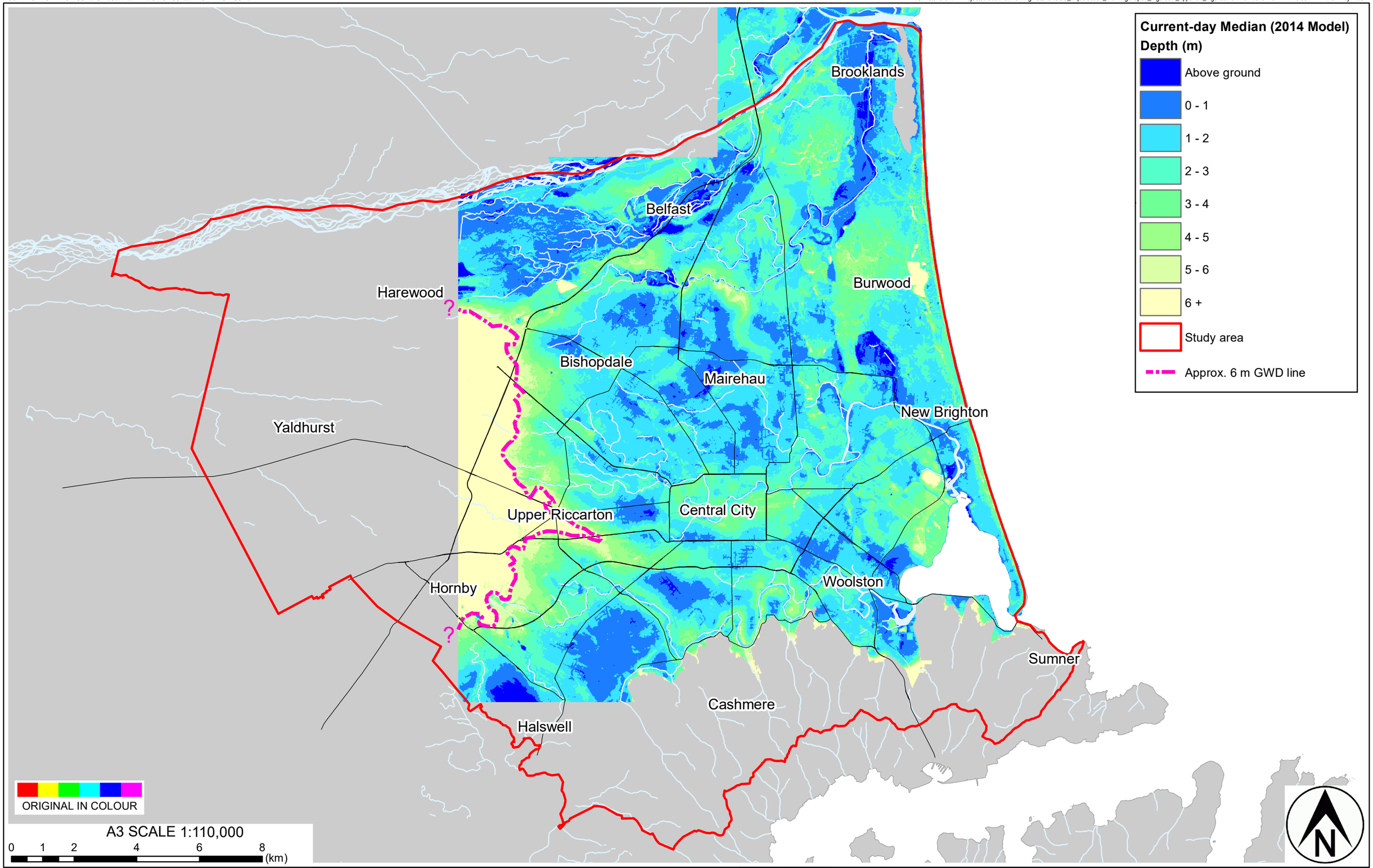

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TITLE DEPTH TO GROUNDWATER TABLE
CURRENT-DAY MEDIAN (2014 MODEL)

SCALE (A3) 1:110,000 FIG No. FIGURE A6 REV 2

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This map relates only to the density of the EQC/ECAN/CCC piezometers and river/stream monitoring as this was the primary source of quantitative data used for the development of the van Ballegooy et al. (2014) groundwater model.

Groundwater Uncertainty

- More Uncertainty in Groundwater Conditions
- Less Uncertainty in Groundwater Conditions
- Study area
- Approx. 6 m GWD line

Contour of 6 m depth to groundwater from van Ballegooy et al. (2014) median model. West of this line uncertainty in the absolute groundwater levels does not have a significant impact on the final liquefaction vulnerability assessment.

Brooklands
Belfast
Burwood
Harewood
Bishopdale
Mairehau
New Brighton
Yaldhurst
Upper Riccarton
Central City
Hornby
Woolston
Sumner
Cashmere
Halswell

ORIGINAL IN COLOUR

A3 SCALE 1:110,000

0 1 2 4 6 8 (km)

N

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TITLE GROUNDWATER UNCERTAINTY

SCALE (A3) 1:110,000 FIG No. FIGURE A7 REV 2

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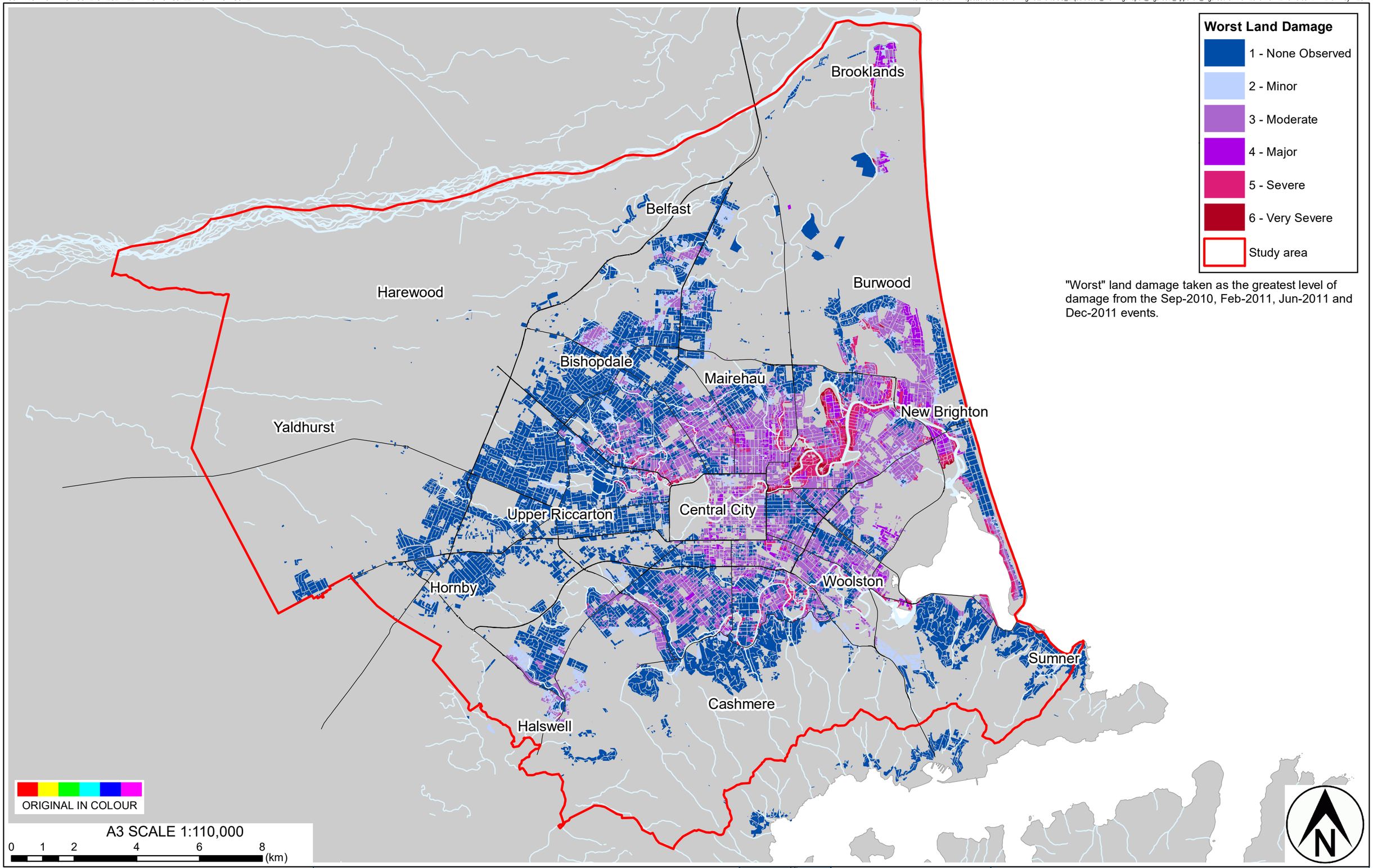

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TITLE WORST LAND DAMAGE OBSERVATIONS FROM THE CANTERBURY EARTHQUAKES

SCALE (A3) 1:110,000 FIG No. FIGURE A8 REV 2

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This map relates only to the land damage mapping undertaken by EQC/T+T in urban areas and ECAN/GNS in rural areas.

Land Damage Observation Uncertainty

- More Uncertainty in Land Damage Observations
- Less Uncertainty in Land Damage Observations
- Study area
- Extent of "well tested" : south of this line there is a 95% confidence that PGA (M7.5) was greater than 0.13 g during the Canterbury earthquakes.

Brooklands
Belfast
Harewood
Burwood
Bishopdale
Mairehau
New Brighton
Yaldhurst
Upper Riccarton
Central City
Hornby
Woolston
Sumner
Cashmere
Halswell

ORIGINAL IN COLOUR

A3 SCALE 1:110,000

0 1 2 4 6 8 (km)

N

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PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE LAND DAMAGE OBSERVATION UNCERTAINTY

SCALE (A3) 1:110,000 FIG No. FIGURE A9 REV 2

T:\Christchurch\TT Projects\1000273\WorkingMaterial\CCC_Liquefaction_Working\Report_Figures\1_Appendix_Figures\A10.mxd 2019-Nov-12 10:42:00 AM Drawn by MLO

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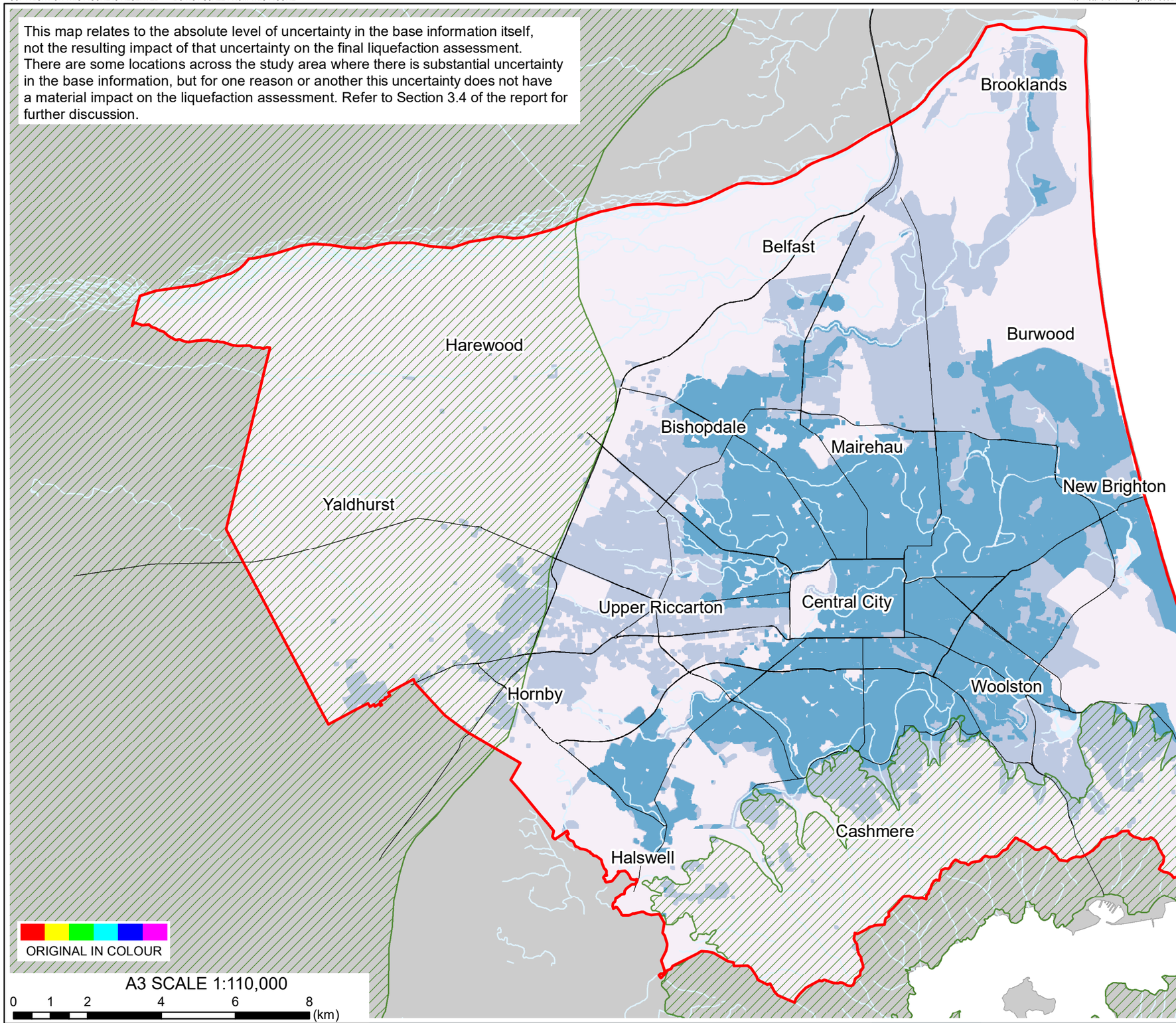

Aggregated Uncertainty

- More Uncertainty in Ground Conditions
- Less Uncertainty in Ground Conditions
- Study area
- Brackley (2012) damaging liquefaction unlikely

This aggregation recognised that liquefaction vulnerability can be assessed either by theoretical analysis (based on the soil profile and groundwater level) or by empirical analysis (based on observed performance). If there is more uncertainty in the soil or groundwater information, then the impacts on the final liquefaction assessment can be offset to some extent if there is less uncertainty in the observation information (and vice versa).

ORIGINAL IN COLOUR

A3 SCALE 1:110,000

0 1 2 4 6 8 (km)

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PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE AGGREGATED UNCERTAINTY

SCALE (A3) 1:110,000 FIG No. FIGURE A10 REV 2

Appendix B: Risk analysis maps

- Figure B1 - Comparison of land damage observations and model predictions
- Figure B2 – GNS Geomorphology with Liquefaction Assessment Sub Areas
- Figure B3 – Liquefaction Vulnerability Categories
- Figure B4 – Level of Detail Supported by Currently Available Base Information
- Figure B5 – Difference between ideal and achieved Level of Detail

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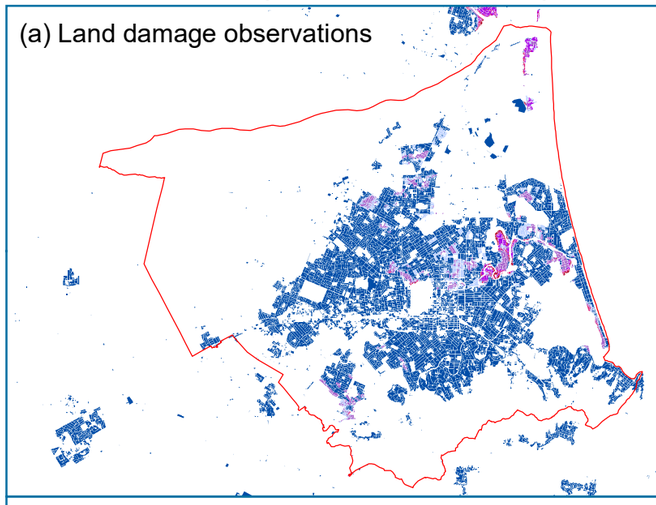
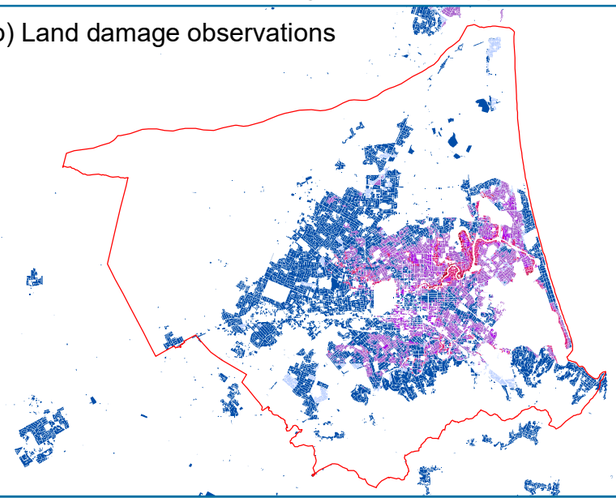
September 2010 Earthquake

February 2011 Earthquake

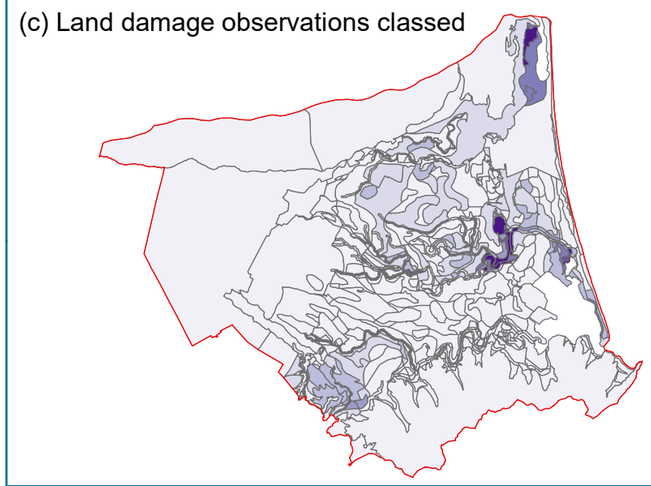
(a) Land damage observations



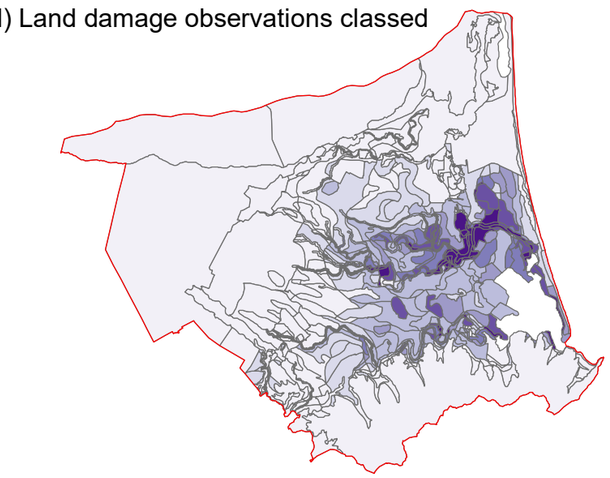
(b) Land damage observations



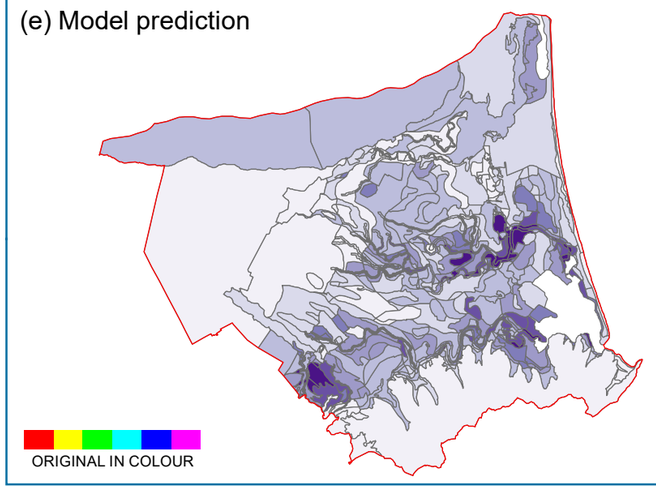
(c) Land damage observations classed



(d) Land damage observations classed

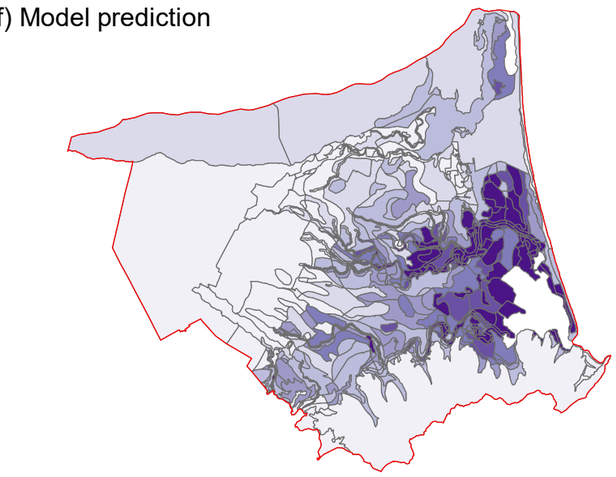


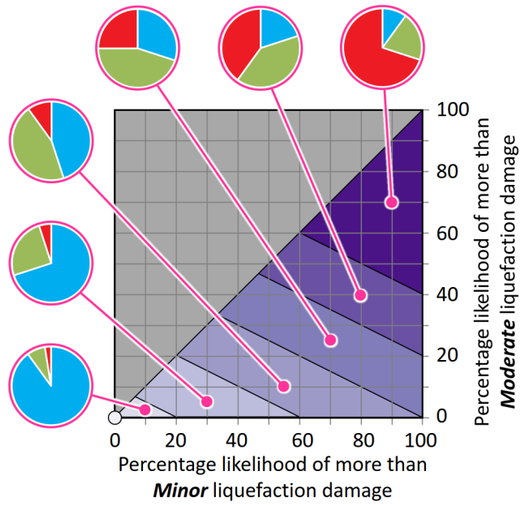
(e) Model prediction



ORIGINAL IN COLOUR

(f) Model prediction



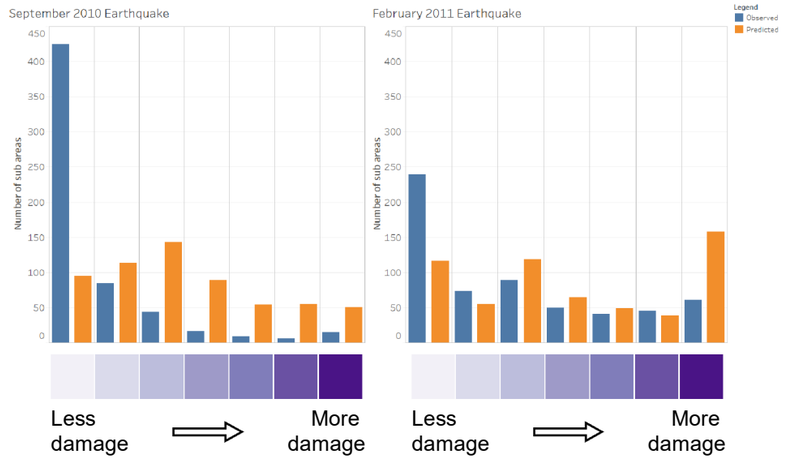


Shades of purple provide a simplified picture of the extent and severity of liquefaction induced ground damage:

Less damage ⇨ More damage

Pie charts provide examples of the distribution of damage at different points on the chart.

- *Severe*
- *Moderate*
- *Minor*
- *None*



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CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE COMPARISON OF LAND DAMAGE OBSERVATIONS AND MODEL PREDICTIONS

SCALE (A3) 1:350,000 FIG No. FIGURE B1 REV 1

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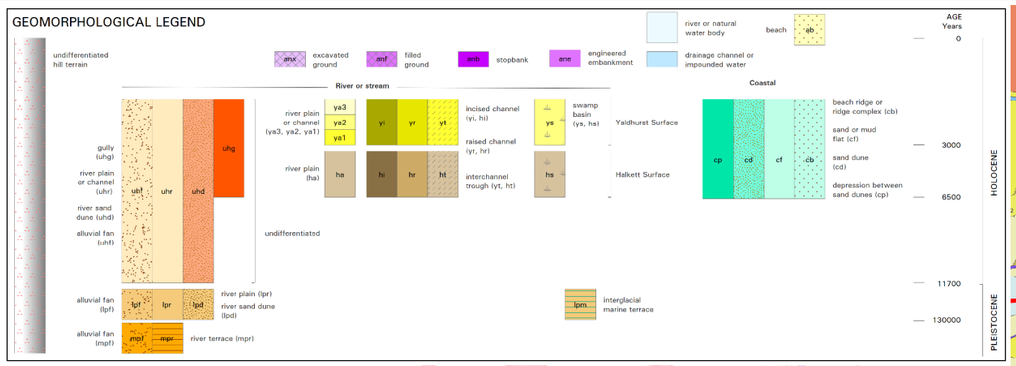

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PROJECT	CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY
TITLE	GNS GEOMORPHOLOGY WITH LIQUEFACTION ASSESSMENT SUB AREAS
SCALE (A3)	1:110,000
FIG No.	FIGURE B2
REV	2

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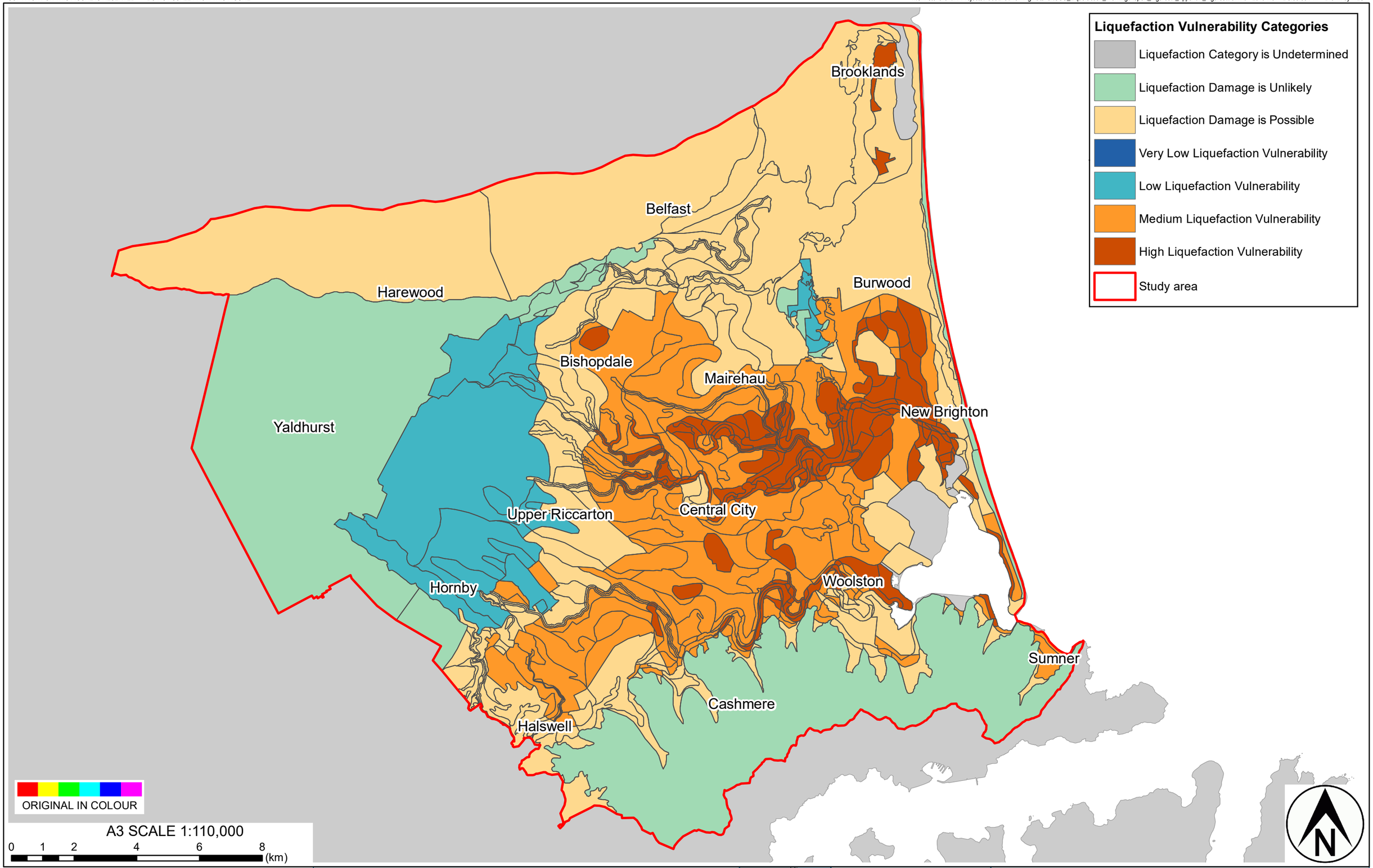

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2	Minor updates	MLO	MEJ	12/11/19

LOCATION PLAN

PROJECT No.	1000273	
DESIGNED	MLO	NOV.19
DRAWN	MLO	NOV.19
CHECKED	MEJ	NOV.19
APPROVED		27-JUL-2020

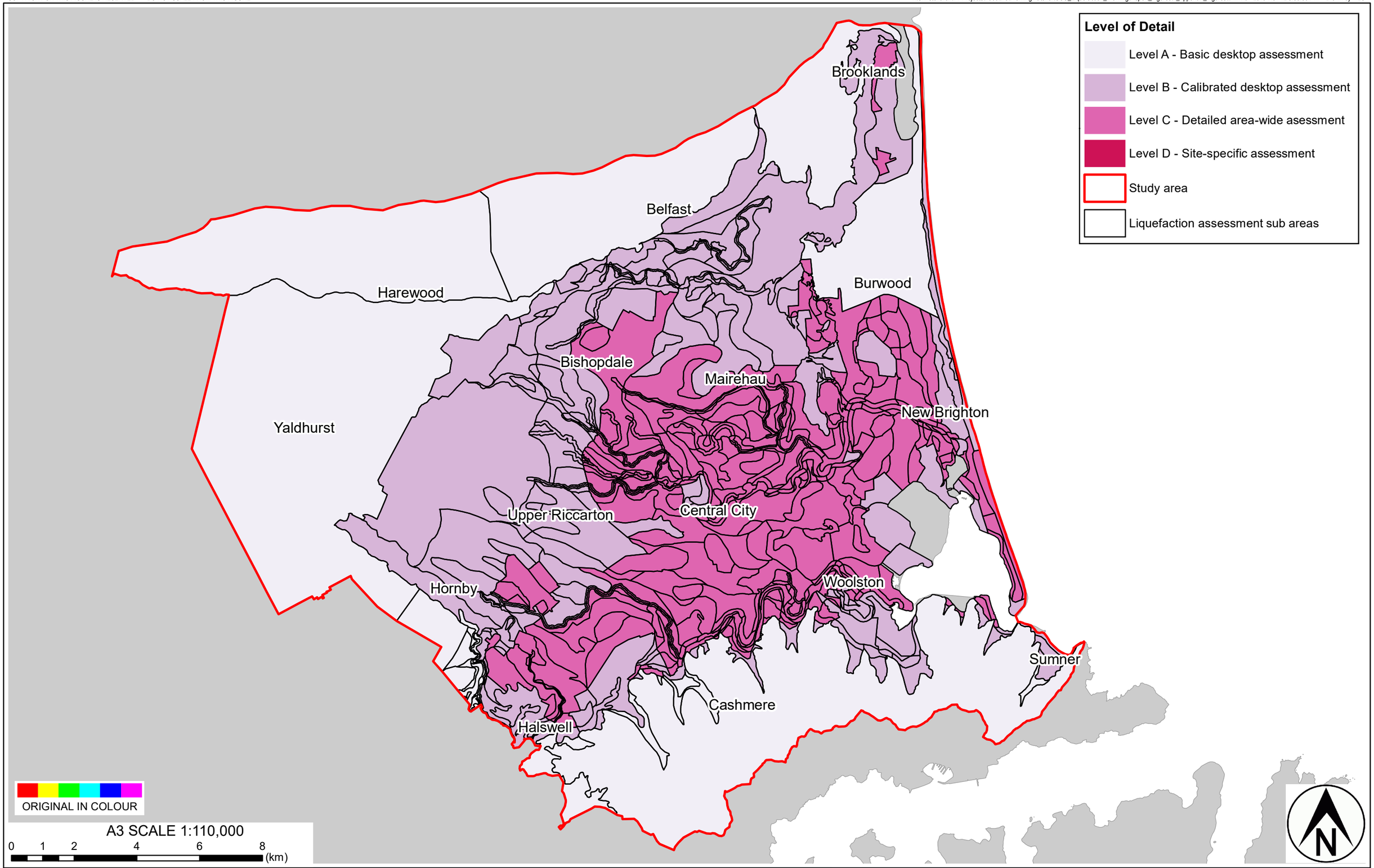
CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE LIQUEFACTION VULNERABILITY CATEGORIES

SCALE (A3) 1:110,000 FIG No. FIGURE B3 REV 2

T:\Christchurch\TT Projects\1000273\WorkingMaterial\CCC_Liquefaction_Working\Report_Figures\1_Appendix_Figures\B4.mxd 2019-Nov-12 3:56:56 PM Drawn by MLO



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NOTES:

This map is part of the report "Christchurch Liquefaction Vulnerability Study" prepared by T+T for CCC in 2019. Refer to the report for further detail and applicability limitations.

REV	DESCRIPTION	GIS	CHK	DATE
1	Initial issue	MLO	MEJ	06/09/19
2	Minor updates	MLO	MEJ	08/11/19

LOCATION PLAN

PROJECT No.	1000273	
DESIGNED	MLO	NOV.19
DRAWN	MLO	NOV.19
CHECKED	MEJ	NOV.19
APPROVED		27-JUL-2020

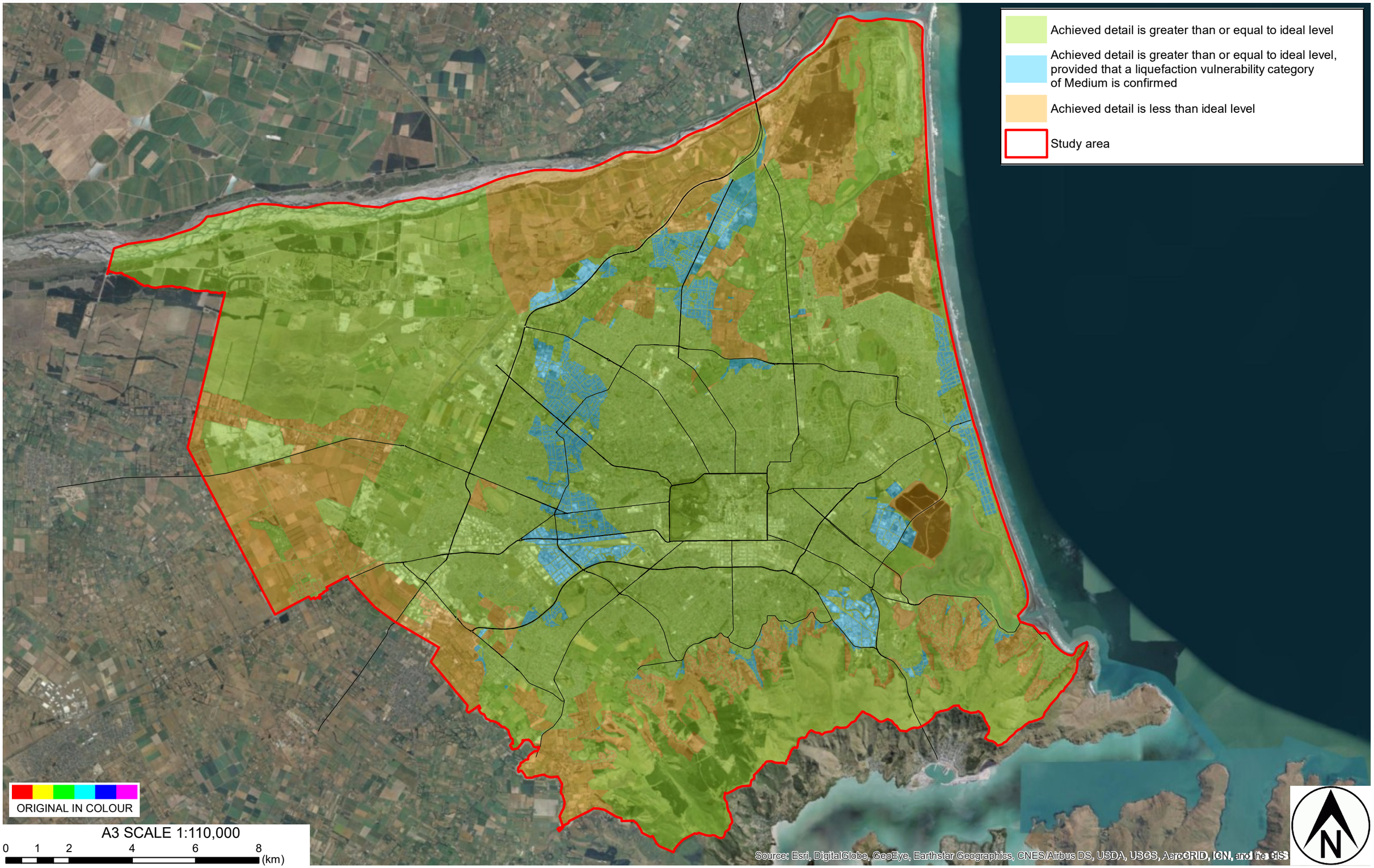
CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE LEVEL OF DETAIL SUPPORTED BY CURRENTLY AVAILABLE BASE INFORMATION

SCALE (A3) 1:110,000 FIG No. FIGURE B4 REV 2

T:\Christchurch\TT Projects\1000273\WorkingMaterial\CCC_Liquefaction_Working\Report_Figures\1_Appendix_Figures\B5.mxd 2019-Nov-14 3:40:44 PM Drawn by MLO



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NOTES:

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REV	DESCRIPTION	GIS	CHK	DATE
1	Initial issue	MLO	MEJ	08/11/19

LOCATION PLAN

PROJECT No.	1000273	
DESIGNED	MLO	NOV.19
DRAWN	MLO	NOV.19
CHECKED	MEJ	NOV.19
APPROVED	27-JUL-2020	DATE

CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE DIFFERENCE BETWEEN IDEAL AND ACHIEVED LEVEL OF DETAIL

SCALE (A3) 1:110,000 FIG No. FIGURE B5 REV 2

Appendix C: Communication and consultation maps

- Figure C1 – “Liquefaction Lab” Public Awareness Tool Example Ground Damage Scenarios

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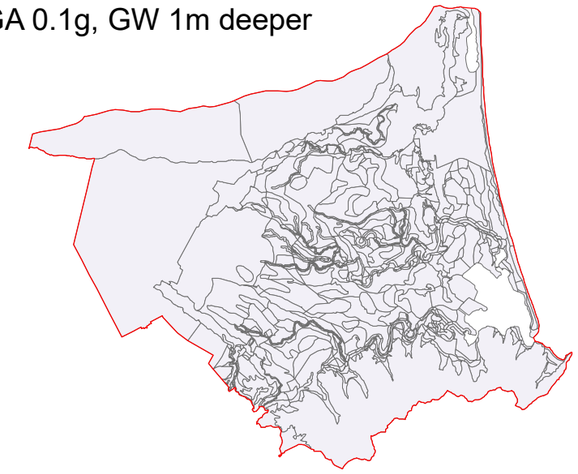
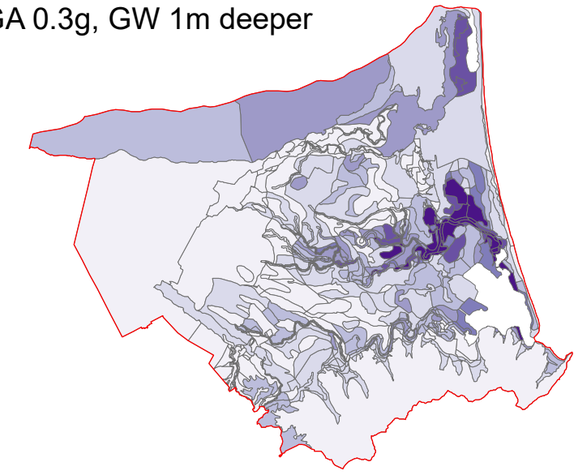
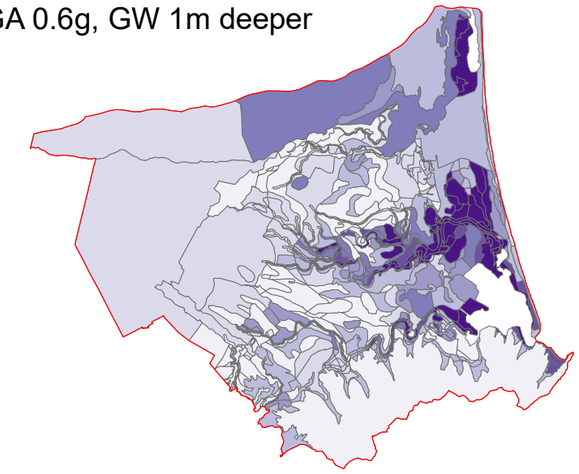
PGA 0.1g, GW 1m deeper



PGA 0.3g, GW 1m deeper

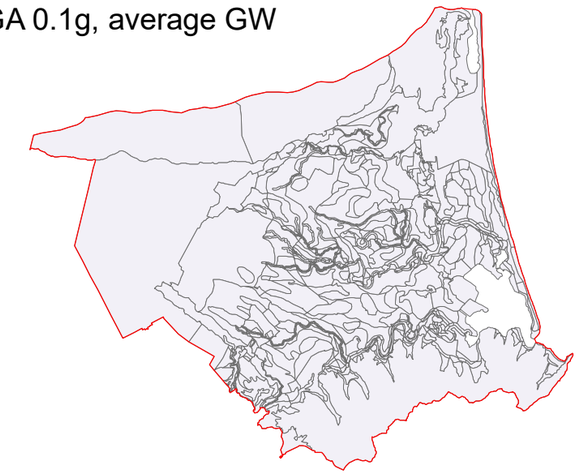


PGA 0.6g, GW 1m deeper

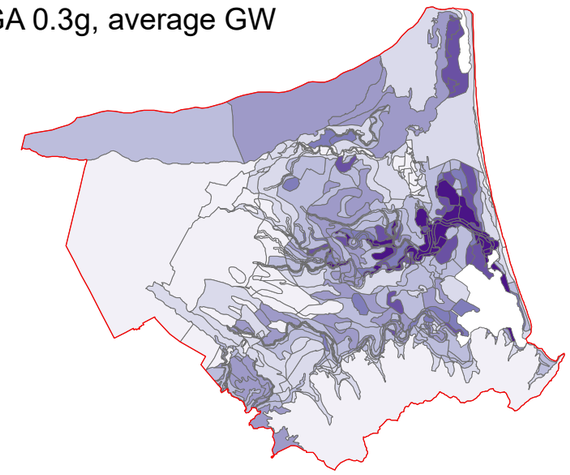


N

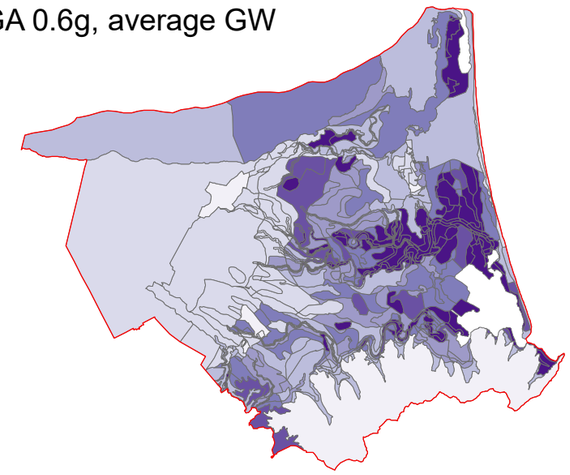
PGA 0.1g, average GW



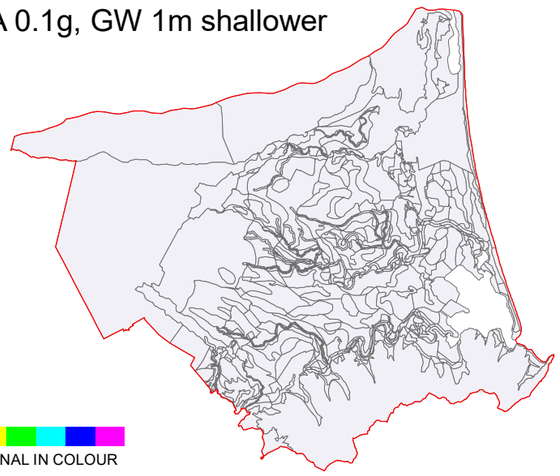
PGA 0.3g, average GW



PGA 0.6g, average GW

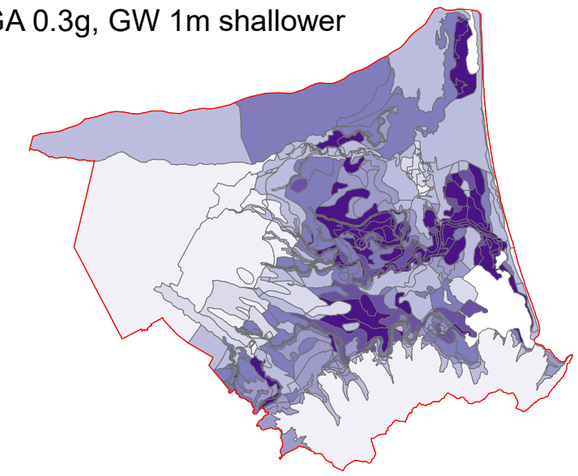


PGA 0.1g, GW 1m shallower

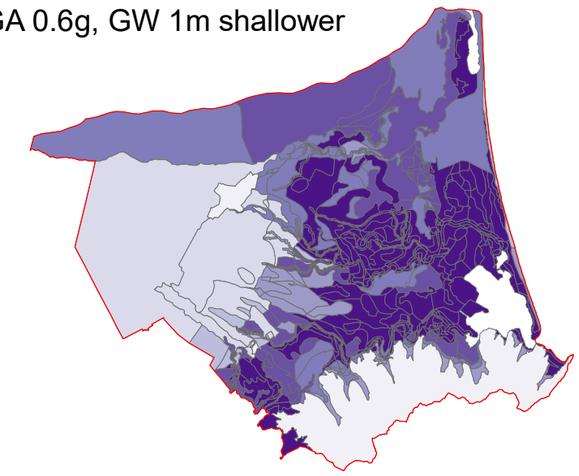


ORIGINAL IN COLOUR

PGA 0.3g, GW 1m shallower



PGA 0.6g, GW 1m shallower



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NOTES:

This map is part of the report "Christchurch Liquefaction Vulnerability Study" prepared by T+T for CCC in 2019. Refer to the report for further detail and applicability limitations.

REV	DESCRIPTION	GIS	CHK	DATE
1	Initial issue	MLO	MEJ	06/09/19
2	Minor updates	MLO	MEJ	08/11/19

LOCATION PLAN

PROJECT No.	1000273	
DESIGNED	MLO	NOV.19
DRAWN	MLO	NOV.19
CHECKED	MEJ	NOV.19
APPROVED		27-JUL-2020

CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE "LIQUEFACTION LAB" PUBLIC AWARENESS TOOL EXAMPLE GROUND DAMAGE SCENARIOS

SCALE (A3) 1:100,000 FIG No. FIGURE C1 REV 2

Appendix D: Calibration examples

- Figure D1 – Calibration Example 1: Sandy soils, CPT analysis gives good prediction
- Figure D2 – Calibration Example 2: Silty interlayered soils, CPT analysis over-predicts damage
- Figure D3 – Calibration Example 3: Shallow groundwater, CPT analysis over-predicts damage

Calibration Example 1: Sandy soils, CPT analysis gives good prediction

Sub-area ID = {D8E6030D-B72C-461E-A6AF-E669915FCCBD}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which are generally well aligned with observations during the Canterbury earthquakes. Examination of the base data identified some minor potential sources of bias in the damage observations and CPT locations. But on balance the model appears to be reasonable without any manual calibration required.

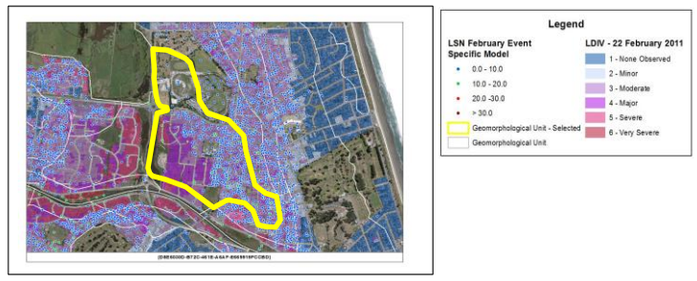
BASE INFORMATION

Sub area {D8E6030D-B72C-461E-A6AF-E669915FCCBD}

Association ID: 15

Number of Associated Polygons: 2

Load Calibration | Save Calibration



Liquefaction vulnerability category

Pre-calibration	HIGH
Post-calibration	HIGH

Design earthquake scenarios (Mw6 equivalent)

100-yr PGA	0.3
500-yr PGA	0.52

Metadata notes

Note - base info	Dune geomorph, good CPT density in eastern half only.
Note - uncertainties	Bias in CPTs to better performing green zone land.
Note - other	CPT-based liquefaction analysis appears to correspond well with observations

Model PGA Value *[Mw6 Equivalent]*

CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.5	1.9	4.5	7.1	11.6	14.8	17.0	19.4	20.9
10	0.0	0.0	0.0	0.7	2.6	5.8	9.1	14.2	17.9	20.1	22.1	23.5
15	0.0	0.0	0.0	0.8	3.0	7.1	10.9	16.2	19.9	22.6	24.2	25.3
20	0.0	0.0	0.0	1.0	3.6	8.0	12.2	18.1	21.7	24.4	26.1	27.3
25	0.0	0.0	0.1	1.1	4.1	8.8	12.9	19.0	23.0	25.1	27.0	28.3
30	0.0	0.0	0.1	1.3	4.6	9.5	13.9	20.0	24.0	26.3	28.0	29.3
35	0.0	0.0	0.1	1.4	5.2	10.1	14.8	21.0	24.8	27.4	29.3	30.3
40	0.0	0.0	0.1	1.6	5.7	11.0	15.4	22.0	25.8	28.6	30.1	31.3
45	0.0	0.0	0.2	1.8	6.2	11.6	16.3	23.2	26.9	29.3	31.0	32.4
50	0.0	0.0	0.2	1.9	6.8	12.4	17.6	24.2	28.1	30.6	32.1	33.3
55	0.0	0.0	0.2	2.2	7.2	13.2	18.8	26.1	29.4	31.5	33.2	34.5
60	0.0	0.0	0.3	2.3	8.0	14.2	20.1	27.2	31.1	33.2	34.8	35.7
65	0.0	0.0	0.3	2.4	8.5	15.6	21.3	28.4	32.3	34.5	35.8	36.7
70	0.0	0.0	0.4	2.7	9.1	16.4	23.0	30.1	33.7	36.0	37.1	38.1
75	0.0	0.0	0.4	3.1	10.4	17.9	24.1	31.8	35.2	37.2	38.5	39.4
80	0.0	0.0	0.5	3.5	12.2	19.5	26.5	33.2	36.6	38.5	39.7	40.5
85	0.0	0.0	0.6	4.2	13.3	23.1	29.8	35.9	39.1	40.4	41.4	41.9
90	0.0	0.0	0.8	5.0	15.0	25.3	32.5	38.3	41.1	43.5	44.3	45.1
95	0.0	0.0	1.0	6.8	19.5	30.4	37.0	44.9	46.9	48.1	48.9	49.6
100	0.0	0.0	3.7	22.1	39.4	48.5	55.1	63.5	67.6	69.1	69.5	69.7

Land damage index thresholds

LSN None-Minor	9
LSN Minor-Moderate	14
LSN Moderate - Severe	40

QPID and CPT Comment

Good QPID and CPT count but biased to green zone properties, justifies scaling model up. Tight curves, slow steady climb indicating clean sand profiles.

Observation and CPT statistics

Median model base CPT count	467
Event specific model CPT count	476
Property observation count	848

	Sep	Feb	Jun	Dec	Post-EQ
None to minor	95%	2%	2%	6%	
Minor to moderate	4%	25%	27%	17%	
Moderate to severe	0%	73%	71%	77%	

PGA and GWD statistics

Median GWD (per CPT)	1.87	1.78	1.89	1.24	1.27
Median PGA (per CPT), Mw6 equivalent	0.24	0.45	0.25	0.36	
Median GWD (by area)	1.76	1.65	1.79	1.12	
Median PGA (by area), Mw6 equivalent	0.23	0.42	0.25	0.35	

Physical explanation of differences between model and observation

Model side

1. Miss-prediction of event PGA.
2. Event groundwater inaccuracies.
3. Systematic over/under prediction of calculated severity, e.g. silty soils, thick sand deposits.
4. LSN limits for severity classes.
5. LSN hypersensitivity to shallow groundwater.
6. Lateral spread increasing ejecta.
7. Bias for CPTs to be located where damage occurred.

Observation side

8. Systemic overstating of observed land damage.
9. Extrapolation of LDI/V for June and December.

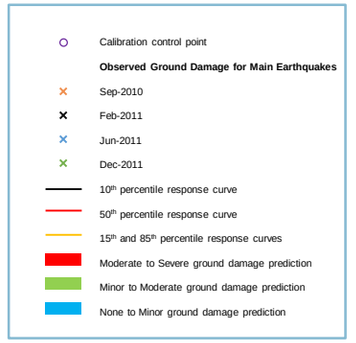
1	Between stations that over/under predict PGA, no basis for shifting helpers.
2	Large shift, justifies shifting helpers down for September, February and June.
3	1 m crust overlying thick, clean sand. Model expected to perform well.
4	OK
5	OK
6	Lateral spreading in western part but would be severe given soil profile so no need to adjust model.
7	CPTs biased to better performing part of sub area. Justifies scaling model up.
8	OK
9	June and December potentially overstated in redzone.

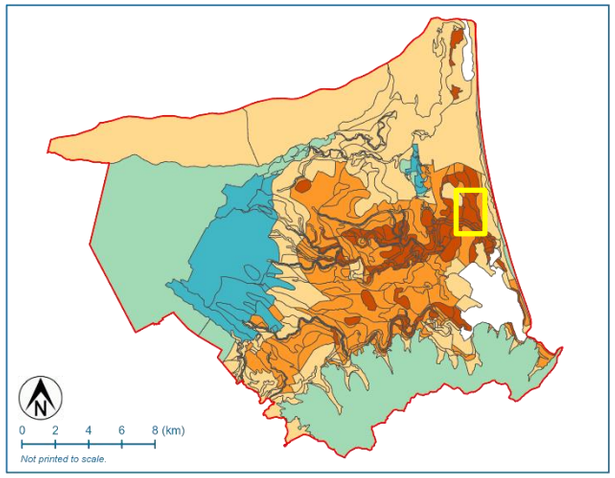
Groundwater Comment

CPT biased towards area of deeper groundwater.

PGA Comment

Between stations that over/under predict PGA, so perhaps ok.

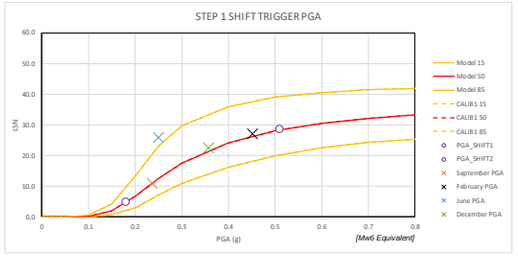


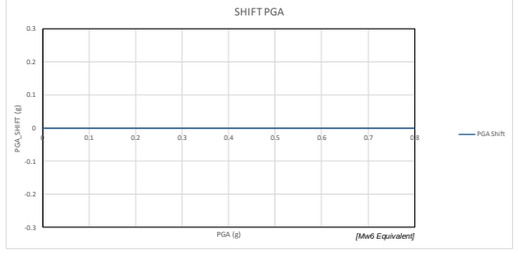


STEP 1 SHIFT TRIGGER PGA

Parameter name	Value adopted		Description
PGA_SHIFT1		0.18	PGA value of 1st control point (g)
PGA_SHIFT2		0.51	PGA value of 2nd control point (g)
PGA_SHIFT_DIST1		0	PGA shift for 1st control point (g)
PGA_SHIFT_DIST2		0	PGA shift for 2nd control point (g)

MODEL_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
	0	0	0	0	0	0	0	0	0	0	0	0
CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8





Notes: Refer to T+T report prepared for Christchurch City Council "Christchurch Liquefaction Vulnerability Study (2019)".

PROJECT No.	1000273		
DESIGNED	MLO	SEP.19	
DRAWN	MLO	SEP.19	
CHECKED	MEJ	NOV.19	
APPROVED	27-JUL-2020	DATE	

CLIENT: CHRISTCHURCH CITY COUNCIL

PROJECT: CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY

TITLE: CALIBRATION EXAMPLE 1
SANDY SOILS, CPT ANALYSIS GIVES GOOD PREDICTION

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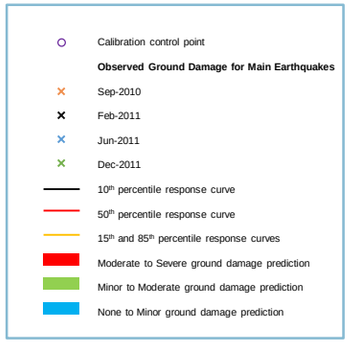
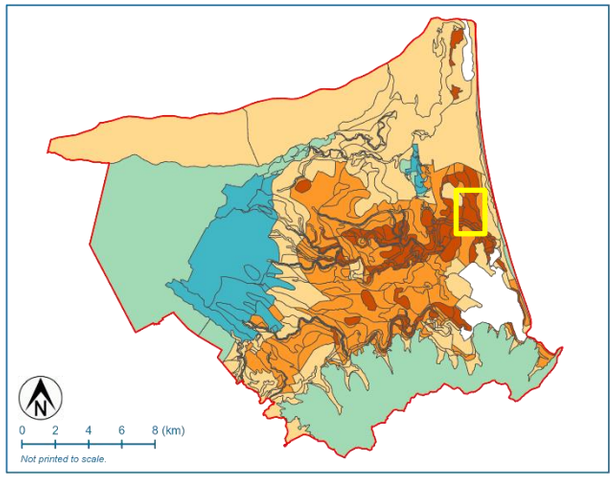
Calibration Example 1: Sandy soils, CPT analysis gives good prediction

Sub-area ID = {D8E6030D-B72C-461E-A6AF-E669915FCCBD}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which are generally well aligned with observations during the Canterbury earthquakes. Examination of the base data identified some minor potential sources of bias in the damage observations and CPT locations. But on balance the model appears to be reasonable without any manual calibration required.

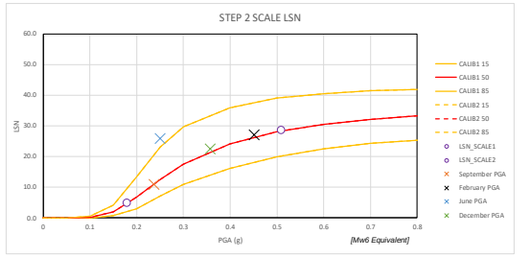


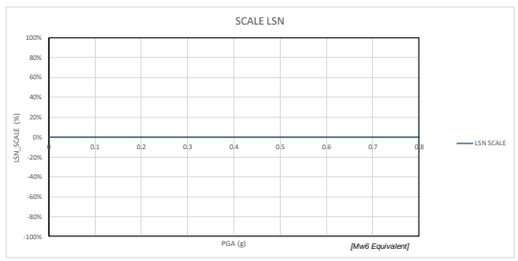


STEP 2 SCALE LSN

Parameter name	Value adopted		Description
LSN_SCALE1	0.18		PGA value of 1st control point (g)
LSN_SCALE2	0.51		PGA value of 2nd control point (g)
LSN_SCALE_DIST1	0		LSN shift for 1st control point
LSN_SCALE_DIST2	0		LSN shift for 2nd control point

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_SCALE_VECTOR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

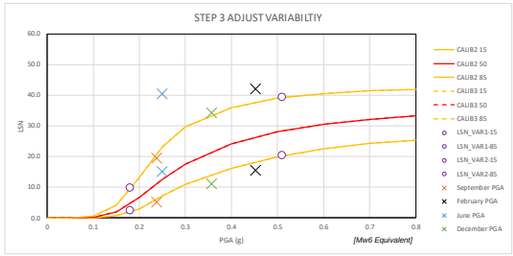


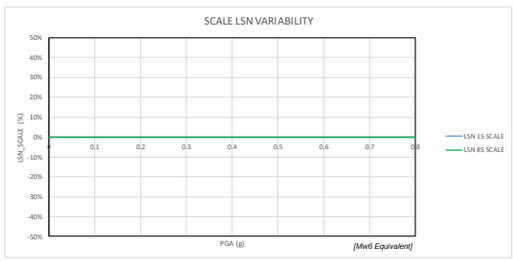


STEP 3 ADJUST VARIABILITY

Parameter name	Value adopted		Description
LSN_VAR1	0.18		PGA value of 1st control point (g)
LSN_VAR2	0.51		PGA value of 2nd control point (g)
LSN_VAR_DIST1-85	0		LSN shift for 1st control point, 85th percentile
LSN_VAR_DIST1-15	0		LSN shift for 1st control point, 15th percentile
LSN_VAR_DIST2-85	0		LSN shift for 2nd control point, 85th percentile
LSN_VAR_DIST2-15	0		LSN shift for 2nd control point, 15th percentile

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_15_SCALE_VECTOR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LSN_85_SCALE VECTOR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%



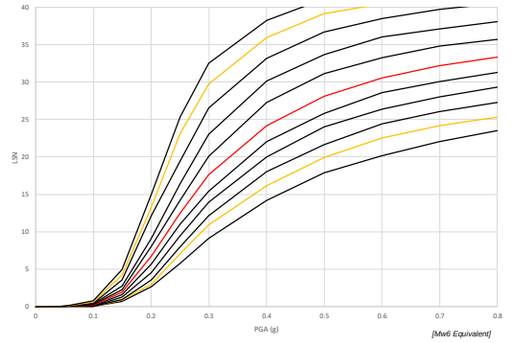


FINAL OUTPUT

CALIB3_LSN_MATRIX *[Mw6 Equivalent]*

	Model PGA Value											
CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.5	1.9	4.5	7.1	11.6	14.8	17.0	19.4	20.9
10	0.0	0.0	0.0	0.7	2.6	5.8	9.1	14.2	17.9	20.1	22.1	23.5
15	0.0	0.0	0.0	0.8	3.0	7.1	10.9	16.2	19.9	22.6	24.2	25.3
20	0.0	0.0	0.0	1.0	3.6	8.0	12.2	18.1	21.7	24.4	26.1	27.3
25	0.0	0.0	0.1	1.1	4.1	8.8	12.9	19.0	23.0	25.1	27.0	28.3
30	0.0	0.0	0.1	1.3	4.6	9.5	13.9	20.0	24.0	26.3	28.0	29.3
35	0.0	0.0	0.1	1.4	5.2	10.1	14.8	21.0	24.8	27.4	29.3	30.3
40	0.0	0.0	0.1	1.6	5.7	11.0	15.4	22.0	25.8	28.6	30.1	31.3
45	0.0	0.0	0.2	1.8	6.2	11.6	16.3	23.2	26.9	29.3	31.0	32.4
50	0.0	0.0	0.2	1.9	6.8	12.4	17.6	24.2	28.1	30.6	32.1	33.3
55	0.0	0.0	0.2	2.2	7.2	13.2	18.8	26.1	29.4	31.5	33.2	34.5
60	0.0	0.0	0.3	2.3	8.0	14.2	20.1	27.2	31.1	33.2	34.8	35.7
65	0.0	0.0	0.3	2.4	8.5	15.6	21.3	28.4	32.3	34.5	35.8	36.7
70	0.0	0.0	0.4	2.7	9.1	16.4	23.0	30.1	33.7	36.0	37.1	38.1
75	0.0	0.0	0.4	3.1	10.4	17.9	24.1	31.8	35.2	37.2	38.5	39.4
80	0.0	0.0	0.5	3.5	12.2	19.5	26.5	33.2	36.6	38.5	39.7	40.5
85	0.0	0.0	0.6	4.2	13.3	23.1	29.8	35.9	39.1	40.4	41.4	41.9
90	0.0	0.0	0.8	5.0	15.0	25.3	32.5	38.3	41.1	43.5	44.3	45.1
95	0.0	0.0	1.0	6.8	19.5	30.4	37.0	44.9	46.9	48.1	48.9	49.6
100	0.0	0.0	3.7	22.1	39.4	48.5	55.1	63.5	67.6	69.1	69.5	69.7

Distribution of liquefaction-induced ground damage response curves



Notes: Refer to T+T report prepared for Christchurch City Council "Christchurch Liquefaction Vulnerability Study (2019)".

PROJECT No.	1000273	
DESIGNED	MLO	SEP.19
DRAWN	MLO	SEP.19
CHECKED	MEJ	NOV.19
APPROVED		DATE 27-JUL-2020

CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE CALIBRATION EXAMPLE 1
SANDY SOILS, CPT ANALYSIS GIVES GOOD PREDICTION

Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

Calibration Example 2: Silty interlayered soils, CPT analysis over-predicts damage

Sub-area ID = {6105AB10-D9BF-4E2D-84EA-A4CAD6DC2150}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which appear to overstate the damage when compared to observations during the Canterbury earthquakes. Examination of the base data identified factors such as silty interlayered soils, an intermediate gravel layer and model hypersensitivity due to shallow groundwater which provide a physical explanation as to why the model over-predicts damage. Therefore the model was scaled down to a degree appropriate for these factors which provided better agreement with the damage observed in the September 2010 and February 2011 earthquakes and the lack of damage observed in the June 2011 and December 2011 earthquakes.

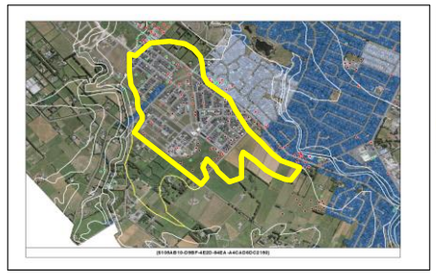
BASE INFORMATION

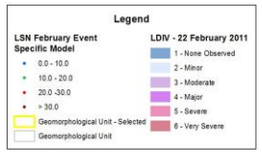
Sub area {6105AB10-D9BF-4E2D-84EA-A4CAD6DC2150}

Association ID: 62

Number of Associated Polygons: 8

Load Calibration | Save Calibration





Liquefaction vulnerability category

Pre-calibration	HIGH
Post-calibration	MEDIUM

Design earthquake scenarios (Mw6 equivalent)

100-yr PGA	0.3
500-yr PGA	0.52

Metadata notes

Note - base info	River channel raised. Greenfield in 2010-11, so limited observations.
Note - uncertainties	Short CPTs and limited GW information.
Note - other	Layered silty soils and intermediate gravel help to limit liquefaction damage.

Model PGA Value *[Mw6 Equivalent]*

CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	1.1	3.4	7.6	8.9	10.5	11.3	11.4	11.4	11.4
10	0.0	0.0	0.1	1.1	4.0	9.0	12.0	13.1	13.1	13.7	13.8	13.8
15	0.0	0.0	0.1	1.4	5.3	9.7	13.4	14.6	14.7	14.7	15.4	15.8
20	0.0	0.0	0.2	1.8	6.7	12.2	14.9	16.8	16.9	16.9	16.9	16.9
25	0.0	0.0	0.3	2.2	8.6	14.6	17.1	18.2	18.5	18.5	18.5	18.5
30	0.0	0.0	0.4	2.6	9.4	15.7	18.2	19.2	19.4	19.5	19.5	19.5
35	0.0	0.0	0.4	2.8	10.3	16.9	19.3	20.9	21.0	21.0	21.0	21.0
40	0.0	0.0	0.5	3.0	11.2	18.0	19.8	22.5	22.5	22.5	22.5	22.5
45	0.0	0.0	0.5	3.5	13.3	18.6	22.1	24.2	24.9	25.1	25.2	25.2
50	0.0	0.0	0.7	4.3	14.2	20.1	24.2	25.8	26.0	26.0	26.0	26.0
55	0.0	0.0	0.9	5.0	16.5	23.8	25.7	27.6	27.7	28.5	28.6	28.6
60	0.0	0.0	1.1	5.4	18.3	25.0	29.1	31.3	31.4	31.4	31.5	32.3
65	0.0	0.0	1.2	6.8	20.6	26.4	31.5	33.2	33.5	33.5	33.6	33.6
70	0.0	0.0	1.5	7.5	21.5	29.6	33.1	36.4	36.6	36.6	36.7	36.7
75	0.0	0.0	1.6	9.0	23.4	31.8	36.0	40.9	42.0	42.2	42.3	42.4
80	0.0	0.0	2.0	11.8	26.1	35.9	40.6	44.4	44.9	44.9	44.9	44.9
85	0.0	0.0	2.0	12.9	30.3	37.8	42.8	48.4	48.8	49.0	49.0	49.0
90	0.0	0.0	2.6	17.4	33.2	42.1	50.2	54.3	54.9	55.3	55.5	55.7
95	0.0	0.0	3.3	18.8	37.0	51.6	60.8	70.0	70.6	70.8	71.0	71.1
100	0.0	0.0	4.6	30.6	51.6	70.6	82.3	87.8	88.5	88.6	88.6	88.7

Land damage index thresholds

LSN None-Minor	9
LSN Minor-Moderate	14
LSN Moderate - Severe	40

QPID and CPT Comment

Number of CPTs <5 m (due to shallow gravel) filtered out of analysis, potential for overprediction. QPID- land damage breakdown based on aerial/ECAN data.

Localised damage to the east, worst in September. ECAN damage observations suggest moderate levels of damage in September and then traces in February.

Observation and CPT statistics

Median model base CPT count	101
Event specific model CPT count	118
Property observation count	16

	Sep	Feb	Jun	Dec	Post-EQ
None to minor	60%	80%	100%	100%	
Minor to moderate	40%	20%	0%	0%	
Moderate to severe	0%	0%	0%	0%	

Physyical explanation of differences between model and observation

Model side

1. Miss-prediction of event PGA.
2. Event groundwater inaccuracies.
3. Systematic over/under prediction of calculated severity, e.g. silty soils, thick sand deposits.
4. LSN limits for severity classes.
5. LSN hypersensitivity to shallow groundwater.
6. Lateral spread increasing ejecta.
7. Bias for CPTs to be located where damage occurred.

Observation side

8. Systemic overstating of observed land damage.
9. Extrapolation of LDIV for June and December.

PGA and GWD statistics

Median GWD (per CPT)	1.22	1.69	1.66	1.62	1.58
Median PGA (per CPT), Mw6 equivalent	0.41	0.33	0.14	0.12	
Median GWD (by area)	0.28	0.69	0.73	0.67	
Median PGA (by area), Mw6 equivalent	0.41	0.32	0.14	0.12	

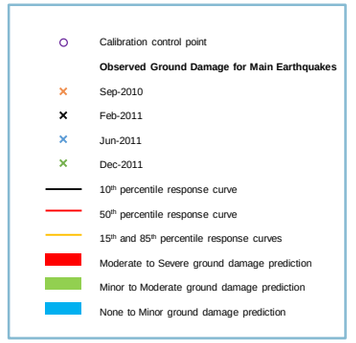
1	OK
2	OK, but shallow.
3	2 m crust over interlayered silt/sand reaching gravel ~5 m. Justifies scaling model down.
4	OK
5	Shallow groundwater, justifies scaling model down.
6	N/A
7	N/A
8	N/A
9	N/A

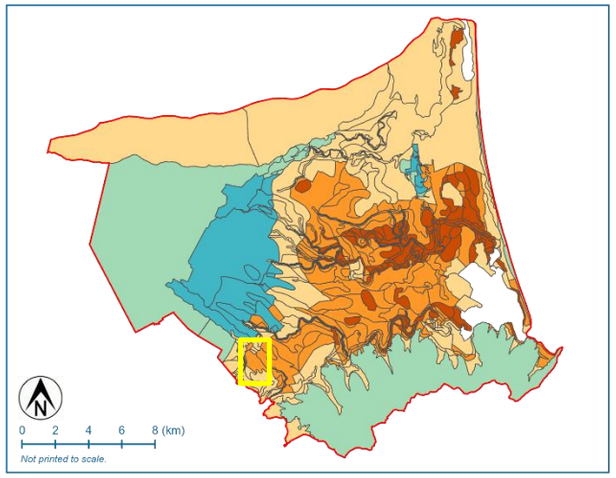
Groundwater Comment

Shallower in September.

PGA Comment

0

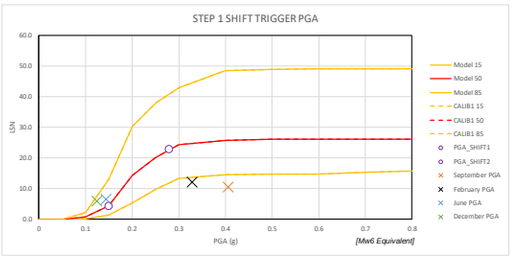


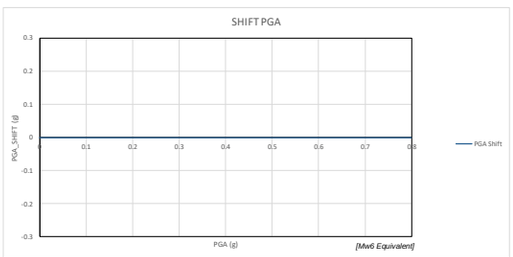


STEP 1 SHIFT TRIGGER PGA

Parameter name	Value adopted		Description
PGA_SHIFT1		0.15	PGA value of 1st control point (g)
PGA_SHIFT2		0.28	PGA value of 2nd control point (g)
PGA_SHIFT_DIST1		0	PGA shift for 1st control point (g)
PGA_SHIFT_DIST2		0	PGA shift for 2nd control point (g)

MODEL_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
	0	0	0	0	0	0	0	0	0	0	0	0
CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8





Notes: Refer to T+T report prepared for Christchurch City Council "Christchurch Liquefaction Vulnerability Study (2019)".

PROJECT No.	1000273	
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DRAWN	MLO	SEP.19
CHECKED	MEJ	NOV.19
APPROVED	27-JUL-2020	DATE

CLIENT: CHRISTCHURCH CITY COUNCIL

PROJECT: CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY

TITLE: CALIBRATION EXAMPLE 2
SILTY INTERLAYERED SOILS, CPT ANALYSIS OVER-PREDICTS DAMAGE

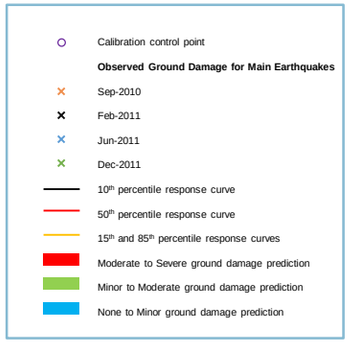
Tonkin+Taylor

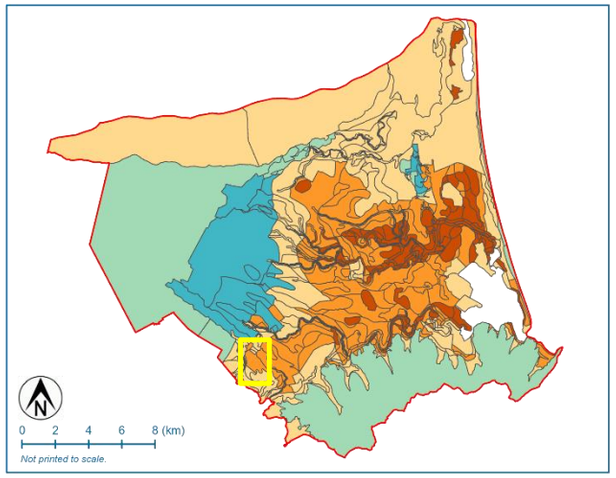
Exceptional thinking together www.tonkintaylor.co.nz

Calibration Example 2: Silty interlayered soils, CPT analysis over-predicts damage

Sub-area ID = {6105AB10-D9BF-4E2D-84EA-A4CAD6DC2150}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which appear to overstate the damage when compared to observations during the Canterbury earthquakes. Examination of the base data identified factors such as silty interlayered soils, an intermediate gravel layer and model hypersensitivity due to shallow groundwater which provide a physical explanation as to why the model over-predicts damage. Therefore the model was scaled down to a degree appropriate for these factors which provided better agreement with the damage observed in the September 2010 and February 2011 earthquakes and the lack of damage observed in the June 2011 and December 2011 earthquakes.

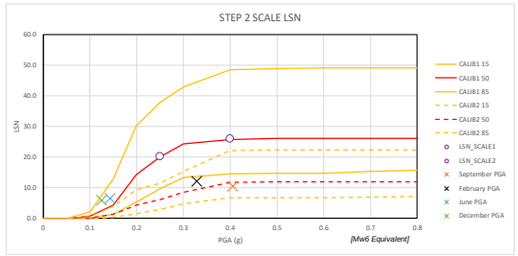


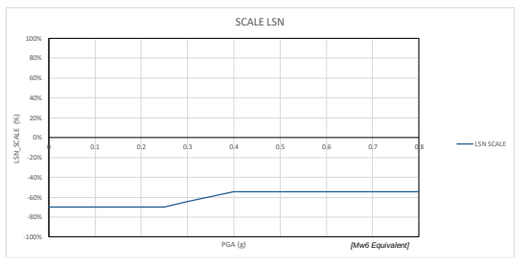


STEP 2 SCALE LSN

Parameter name	Value adopted		Description
LSN_SCALE1	0.25		PGA value of 1st control point (g)
LSN_SCALE2	0.4		PGA value of 2nd control point (g)
LSN_SCALE_DIST1	-14		LSN shift for 1st control point
LSN_SCALE_DIST2	-14		LSN shift for 2nd control point

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_SCALE_VECTOR	-70%	-70%	-70%	-70%	-70%	-70%	-64%	-54%	-54%	-54%	-54%	-54%

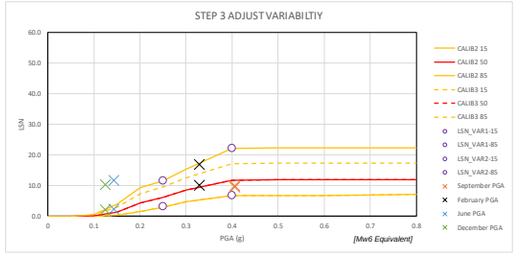


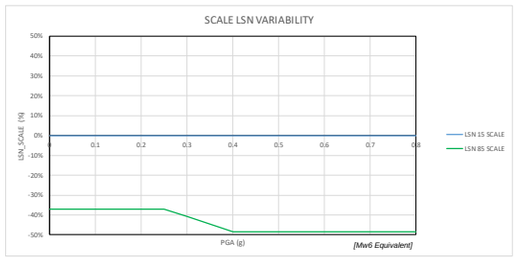


STEP 3 ADJUST VARIABILITY

Parameter name	Value adopted		Description
LSN_VAR1	0.25		PGA value of 1st control point (g)
LSN_VAR2	0.4		PGA value of 2nd control point (g)
LSN_VAR_DIST1-85	-2		LSN shift for 1st control point, 85th percentile
LSN_VAR_DIST1-15	0		LSN shift for 1st control point, 15th percentile
LSN_VAR_DIST2-85	-5		LSN shift for 2nd control point, 85th percentile
LSN_VAR_DIST2-15	0		LSN shift for 2nd control point, 15th percentile

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_15_SCALE_VECTOR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LSN_85_SCALE VECTOR	-37%	-37%	-37%	-37%	-37%	-37%	-41%	-48%	-48%	-48%	-48%	-48%



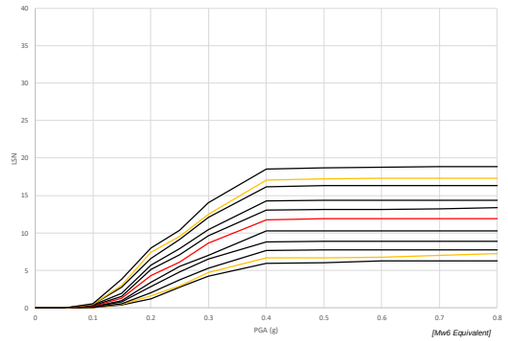


FINAL OUTPUT

CALIB3_LSN_MATRIX *[Mw6 Equivalent]*

	Model PGA Value											
CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.3	1.0	2.3	3.2	4.8	5.2	5.2	5.2	5.2
10	0.0	0.0	0.0	0.3	1.2	2.7	4.3	6.0	6.0	6.2	6.3	6.3
15	0.0	0.0	0.0	0.4	1.6	2.9	4.7	6.7	6.7	6.7	7.0	7.2
20	0.0	0.0	0.1	0.6	2.0	3.7	5.3	7.7	7.7	7.7	7.7	7.7
25	0.0	0.0	0.1	0.7	2.6	4.4	6.1	8.3	8.4	8.4	8.4	8.4
30	0.0	0.0	0.1	0.8	2.9	4.8	6.5	8.8	8.9	8.9	8.9	8.9
35	0.0	0.0	0.1	0.9	3.1	5.1	6.9	9.6	9.6	9.6	9.6	9.6
40	0.0	0.0	0.1	0.9	3.4	5.5	7.0	10.3	10.3	10.3	10.3	10.3
45	0.0	0.0	0.2	1.1	4.0	5.7	7.9	11.0	11.4	11.5	11.5	11.5
50	0.0	0.0	0.2	1.3	4.3	6.1	8.6	11.8	11.9	11.9	11.9	11.9
55	0.0	0.0	0.2	1.4	4.8	6.8	8.9	12.2	12.3	12.5	12.5	12.5
60	0.0	0.0	0.3	1.5	5.1	7.1	9.6	13.1	13.1	13.2	13.2	13.4
65	0.0	0.0	0.3	1.8	5.5	7.3	10.1	13.5	13.6	13.7	13.7	13.7
70	0.0	0.0	0.4	1.9	5.7	7.9	10.5	14.3	14.4	14.4	14.4	14.4
75	0.0	0.0	0.4	2.2	6.1	8.4	11.1	15.3	15.6	15.7	15.7	15.7
80	0.0	0.0	0.5	2.7	6.6	9.1	12.0	16.1	16.3	16.3	16.3	16.3
85	0.0	0.0	0.5	3.0	7.4	9.5	12.5	17.1	17.2	17.3	17.3	17.3
90	0.0	0.0	0.6	3.8	8.0	10.3	14.1	18.5	18.7	18.8	18.8	18.9
95	0.0	0.0	0.7	4.1	8.7	12.2	16.3	22.2	22.4	22.4	22.5	22.5
100	0.0	0.0	1.0	6.4	11.5	15.8	20.8	26.4	26.6	26.6	26.6	26.6

Distribution of liquefaction-induced ground damage response curves



Notes: Refer to T+T report prepared for Christchurch City Council "Christchurch Liquefaction Vulnerability Study (2019)".

PROJECT No.	1000273	
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DRAWN	MLO	SEP.19
CHECKED	MEJ	NOV.19
APPROVED		DATE 27-JUL-2020

CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY**

TITLE CALIBRATION EXAMPLE 2
SILTY INTERLAYERED SOILS, CPT ANALYSIS OVER-PREDICTS DAMAGE

Tonkin+Taylor

Exceptional thinking together www.tonkintaylor.co.nz

Calibration Example 3: Shallow groundwater, CPT analysis over-predicts damage

Sub-area ID = {E7588B9F-D12B-410F-971C-04D487CA0FDF}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which appear to overstate the damage when compared to observations during the Canterbury earthquakes. Examination of the base data identified factors such as silty crust and model hypersensitivity due to shallow groundwater which provide a physical explanation as to why the model over-predicts damage. Therefore the model was scaled down to a degree appropriate for these factors which provided better agreement with the damage observed during the Canterbury earthquakes.

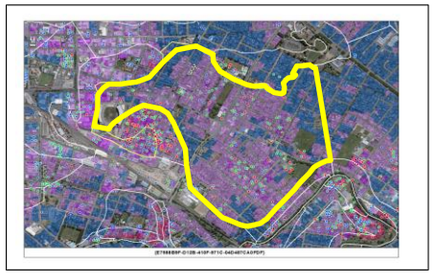
BASE INFORMATION

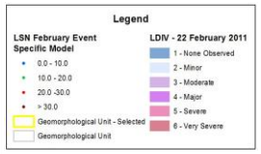
Sub area {E7588B9F-D12B-410F-971C-04D487CA0FDF}

Association ID: 0

Number of Associated Polygons: 0

Load Calibration | Save Calibration





Liquefaction vulnerability category

Pre-calibration	HIGH
Post-calibration	MEDIUM

Design earthquake scenarios (Mw6 equivalent)

100-yr PGA	0.3
500-yr PGA	0.52

Metadata notes

Note - base info	Swamp basin geomorph, good density of observations and CPT.
Note - uncertainties	Influence of shallow groundwater and silty crust.
Note - other	CPT-based liquefaction analysis appears to overpredict compared to EQ observation.

Model PGA Value *[Mw6 Equivalent]*

CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.7	2.3	4.6	6.8	10.7	12.1	12.7	13.1	13.4
10	0.0	0.0	0.0	0.9	3.0	6.9	9.9	13.0	15.2	15.9	16.4	16.7
15	0.0	0.0	0.1	1.2	4.1	8.4	11.3	14.7	16.3	17.5	18.2	18.8
20	0.0	0.0	0.1	1.3	4.8	9.2	12.0	15.3	16.8	18.1	18.7	19.2
25	0.0	0.0	0.1	1.5	5.2	10.0	12.9	15.9	17.6	19.2	19.8	20.2
30	0.0	0.0	0.2	1.7	5.9	10.8	13.6	16.5	18.4	19.7	20.6	21.1
35	0.0	0.0	0.2	1.9	6.5	11.5	14.3	16.9	18.9	20.2	21.4	22.0
40	0.0	0.0	0.3	2.1	7.3	12.1	14.7	17.6	19.6	21.1	22.0	22.7
45	0.0	0.0	0.3	2.3	7.9	12.5	14.9	18.7	20.9	21.8	22.9	23.5
50	0.0	0.0	0.4	2.4	8.1	12.8	**15.6**	19.4	**21.3**	22.7	23.4	24.0
55	0.0	0.0	0.4	2.7	8.9	13.5	16.6	20.3	22.1	23.2	24.3	25.1
60	0.0	0.0	0.4	2.8	9.4	14.3	17.2	20.8	22.9	24.2	24.9	25.6
65	0.0	0.0	0.5	3.1	10.1	15.1	18.4	22.0	24.1	25.7	27.0	27.5
70	0.0	0.0	0.5	3.3	10.7	16.7	19.9	23.7	25.9	26.8	27.5	28.0
75	0.0	0.0	0.6	3.5	11.4	17.6	21.0	25.0	27.2	28.1	28.5	29.1
80	0.0	0.0	0.6	4.2	12.7	19.2	22.7	26.5	28.6	29.7	30.7	31.2
85	0.0	0.0	0.7	4.5	14.5	21.3	24.3	27.8	**29.7**	31.3	31.9	32.3
90	0.0	0.0	0.9	4.8	15.6	22.5	26.7	30.7	31.7	32.9	33.1	33.5
95	0.0	0.0	1.1	6.0	17.4	25.7	30.3	32.4	33.9	34.3	34.5	34.9
100	0.0	0.0	1.6	8.9	20.5	37.1	43.7	45.1	45.4	45.5	45.6	45.6

Land damage index thresholds

LSN None-Minor	9
LSN Minor-Moderate	14
LSN Moderate - Severe	40

QPID and CPT Comment

Good QPID and CPT density. CPT response curves reasonably tight.

Observation and CPT statistics

Median model base CPT count	194
Event specific model CPT count	198
Property observation count	2413

	Sep	Feb	Jun	Dec	Post-EQ
None to minor	100%	29%	32%	65%	
Minor to moderate	0%	68%	66%	35%	
Moderate to severe	0%	4%	2%	0%	

PGA and GWD statistics

Median GWD (per CPT)	0.89	0.77	0.59	0.82	0.98
Median PGA (per CPT), Mw6 equivalent	0.30	0.60	0.35	0.24	
Median GWD (by area)	0.91	0.79	0.70	0.88	
Median PGA (by area), Mw6 equivalent	0.30	0.60	0.35	0.24	

Phsyical explanation of differences between model and observation

Model side

1. Miss-prediction of event PGA.
2. Event groundwater inaccuracies.
3. Systematic over/under prediction of calculated severity, e.g. silty soils, thick sand deposits.
4. LSN limits for severity classes.
5. LSN hypersensitivity to shallow groundwater.
6. Lateral spread increasing ejecta.
7. Bias for CPTs to be located where damage occurred.

Observation side

8. Systemic overstating of observed land damage.
9. Extrapolation of LDIV for June and December.

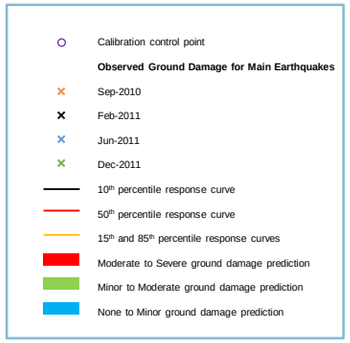
1	PGA model affected by nearby Heathcote station which showed high readings. Justifies shifting helpers left.
2	Unlikely to be an issue except in June, pay attention to groundwater shift in this case.
3	Silty crust ~3-5m overlying MD sand - model potentially over predicts slightly, justifies scaling model down.
4	N/A
5	GWD <1 m, potential hypersensitivity, partly explains overprediction, justifies scaling model down (esp June)
6	N/A
7	Bias from CPTs generally located in areas of damage - justifies scaling model down
8	N/A
9	Air photo suggests June and December damage overstated - justifies moving June/Dec helpers down.

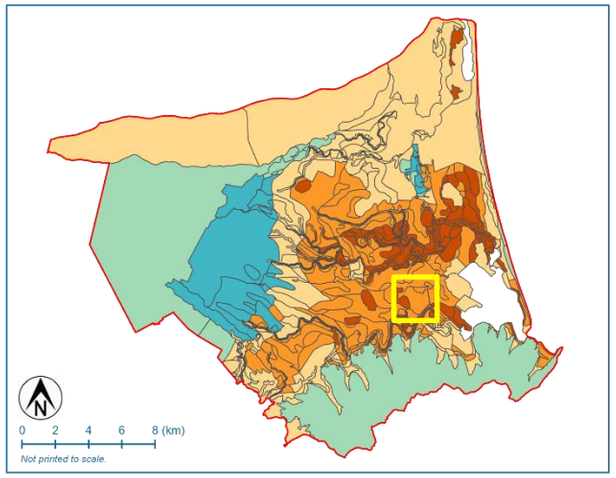
Groundwater Comment

Most events close to median except June which is 0.4 m higher.

PGA Comment

Varies 0.48-0.6 g across sub area (Mw6.2) in February. PGA model may overpredict 0.1-0.2 g.

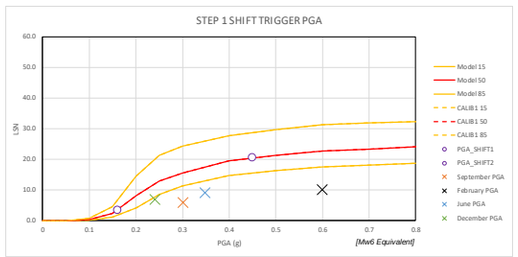


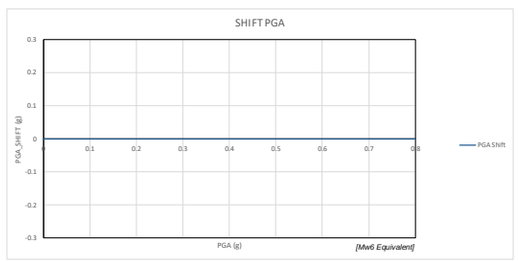


STEP 1 SHIFT TRIGGER PGA

Parameter name	Value adopted		Description
PGA_SHIFT1	0.16		PGA value of 1st control point (g)
PGA_SHIFT2	0.45		PGA value of 2nd control point (g)
PGA_SHIFT_DIST1	0		PGA shift for 1st control point (g)
PGA_SHIFT_DIST2	0		PGA shift for 2nd control point (g)

MODEL_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
	0	0	0	0	0	0	0	0	0	0	0	0
CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8





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APPROVED	27-JUL-2020	DATE

CLIENT: CHRISTCHURCH CITY COUNCIL

PROJECT: CHRISTCHURCH LIQUEFACTION VULNERABILITY STUDY

TITLE: CALIBRATION EXAMPLE 3
SHALLOW GROUNDWATER, CPT ANALYSIS OVER-PREDICTS DAMAGE

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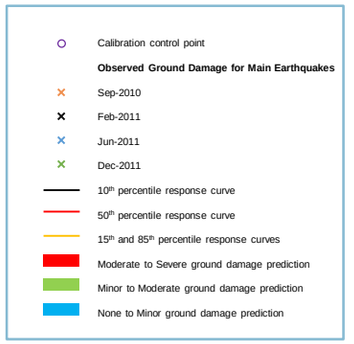
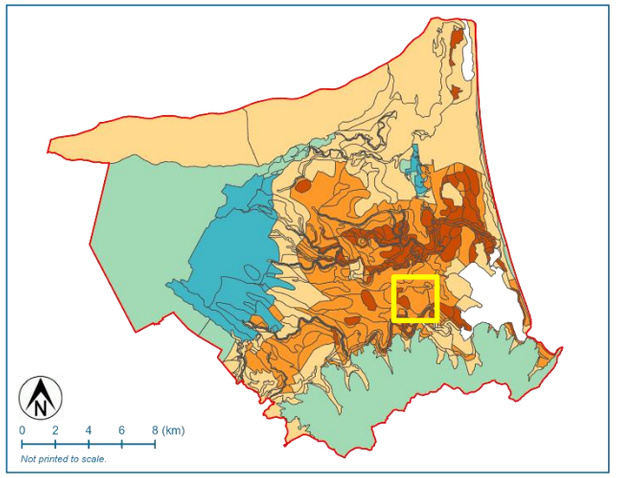
Calibration Example 3: Shallow groundwater, CPT analysis over-predicts damage

Sub-area ID = {E7588B9F-D12B-410F-971C-04D487CA0FDF}

This sub area is an example of ground conditions where the CPT-based simplified liquefaction analysis provides predictions of performance which appear to overstate the damage when compared to observations during the Canterbury earthquakes. Examination of the base data identified factors such as silty crust and model hypersensitivity due to shallow groundwater which provide a physical explanation as to why the model over-predicts damage. Therefore the model was scaled down to a degree appropriate for these factors which provided better agreement with the damage observed during the Canterbury earthquakes.

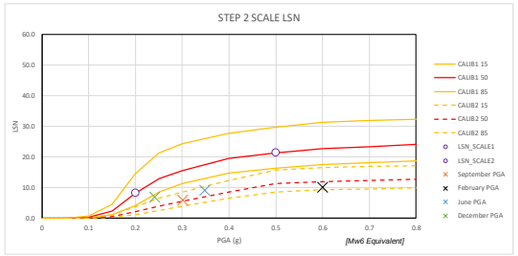


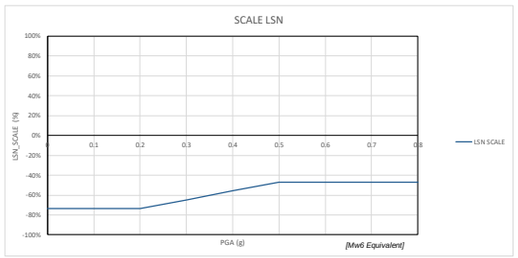


STEP 2 SCALE LSN

Parameter name	Value adopted		Description
LSN_SCALE1	0.2		PGA value of 1st control point (g)
LSN_SCALE2	0.5		PGA value of 2nd control point (g)
LSN_SCALE_DIST1	-6		LSN shift for 1st control point
LSN_SCALE_DIST2	-10		LSN shift for 2nd control point

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_SCALE_VECTOR	-74%	-74%	-74%	-74%	-74%	-69%	-65%	-56%	-47%	-47%	-47%	-47%

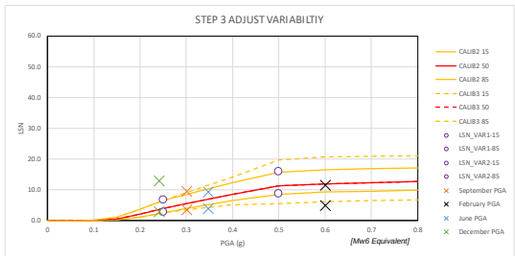


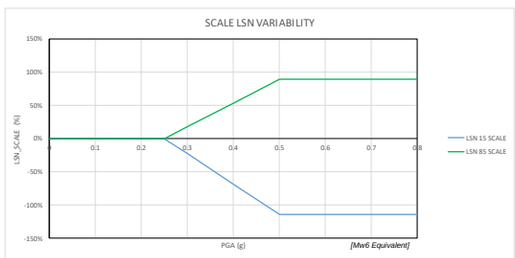


STEP 3 ADJUST VARIABILITY

Parameter name	Value adopted		Description
LSN_VAR1	0.25		PGA value of 1st control point (g)
LSN_VAR2	0.5		PGA value of 2nd control point (g)
LSN_VAR_DIST1-85	0		LSN shift for 1st control point, 85th percentile
LSN_VAR_DIST1-15	0		LSN shift for 1st control point, 15th percentile
LSN_VAR_DIST2-85	4		LSN shift for 2nd control point, 85th percentile
LSN_VAR_DIST2-15	-3		LSN shift for 2nd control point, 15th percentile

CALIB1_PGA_VECTOR	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
LSN_15_SCALE_VECTOR	0%	0%	0%	0%	0%	0%	-23%	-68%	-114%	-114%	-114%	-114%
LSN_85_SCALE VECTOR	0%	0%	0%	0%	0%	0%	18%	53%	89%	89%	89%	89%



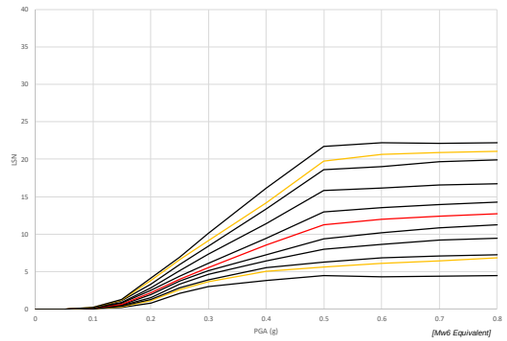


FINAL OUTPUT

CALIB3_LSN_MATRIX *[Mw6 Equivalent]*

	Model PGA Value											
CFD%	0	0.05	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.2	0.6	1.4	1.7	2.1	0.9	0.7	0.7	0.7
10	0.0	0.0	0.0	0.2	0.8	2.1	3.0	3.8	4.4	4.3	4.4	4.5
15	0.0	0.0	0.0	0.3	1.1	2.6	3.6	5.1	5.6	6.1	6.4	6.8
20	0.0	0.0	0.0	0.3	1.3	2.8	3.9	5.5	6.3	6.8	7.1	7.3
25	0.0	0.0	0.0	0.4	1.4	3.1	4.3	5.9	7.1	8.0	8.3	8.4
30	0.0	0.0	0.0	0.4	1.6	3.3	4.6	6.4	8.0	8.7	9.2	9.4
35	0.0	0.0	0.1	0.5	1.7	3.5	4.9	6.7	8.6	9.2	10.1	10.4
40	0.0	0.0	0.1	0.6	1.9	3.7	5.1	7.2	9.4	10.2	10.8	11.3
45	0.0	0.0	0.1	0.6	2.1	3.8	5.2	8.0	10.9	11.0	11.8	12.2
50	0.0	0.0	0.1	0.6	2.1	4.0	5.5	8.6	11.5	12.0	12.4	12.7
55	0.0	0.0	0.1	0.7	2.4	4.2	5.9	9.1	12.1	12.5	13.3	13.8
60	0.0	0.0	0.1	0.7	2.5	4.4	6.1	9.5	13.0	13.5	13.9	14.3
65	0.0	0.0	0.1	0.8	2.7	4.7	6.7	10.3	14.1	15.0	16.0	16.2
70	0.0	0.0	0.1	0.9	2.8	5.1	7.3	11.5	15.9	16.2	16.5	16.7
75	0.0	0.0	0.2	0.9	3.0	5.4	7.7	12.3	17.2	17.4	17.5	17.8
80	0.0	0.0	0.2	1.1	3.4	5.9	8.4	13.4	18.6	19.0	19.7	19.9
85	0.0	0.0	0.2	1.2	3.8	6.6	9.1	14.2	19.7	20.7	20.9	21.0
90	0.0	0.0	0.2	1.3	4.1	6.9	10.1	16.2	21.7	22.2	22.5	22.7
95	0.0	0.0	0.3	1.6	4.6	7.9	11.6	17.3	23.9	23.6	23.5	23.6
100	0.0	0.0	0.4	2.3	5.4	11.4	17.1	25.9	35.4	34.9	34.6	34.3

Distribution of liquefaction-induced ground damage response curves



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TITLE CALIBRATION EXAMPLE 3
SHALLOW GROUNDWATER, CPT ANALYSIS OVER-PREDICTS DAMAGE

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Applicability

This report has been prepared for the exclusive use of our client Christchurch City Council, 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.

Recommendations and opinions in this report are based on data from primarily individual CPT and in some cases borehole soundings. The nature and continuity of subsoil away from these locations is inferred and it must be appreciated that the actual conditions could vary.

The analyses carried out represent probabilistic analyses of empirical liquefaction databases under various earthquakes. Earthquakes are unique and impose different levels of shaking in different directions on different sites. The results of the liquefaction susceptibility analyses and the estimates of consequences presented within this document are based on regional seismic demand and published analysis methods, but it is important to understand that the actual performance may vary from that calculated.

This assessment has been made at a broad scale across the entire city, and is intended to approximately describe the typical range of liquefaction vulnerability across neighbourhood-sized areas. It is not intended to precisely describe liquefaction vulnerability at individual property scale. This information is general in nature, and more detailed site-specific liquefaction assessment may be required for some purposes (e.g. for design of building foundations).

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