Appendix L: Summary of Worked Example 5 North New Brighton

L1 Worked Example 5 - North New Brighton

L1.1 Introduction

The Stage 2 properties in this worked example required further manual assessment because the liquefaction vulnerability analyses of the CPT in this area indicates high levels of variability at M6 0.3g levels of earthquake shaking. This variability is with respect to both the assessment of material liquefaction vulnerability and the assessment of material change in liquefaction vulnerability.

The purpose of this worked example is to demonstrate an area where there are subtle changes in ground conditions resulting in variable predicted performance of the land making the application of the ILV criteria challenging. The assessment process for the Stage 2 properties in this worked example required the evaluation of the significant factors for each property. It also required the assessment of whether the ILV qualification is more appropriately based on the individual property assessment using the predicted behaviour from CPT profiles within each property, or whether the ILV qualification is more appropriately based on the assessment of a block of land. This is similar to the appropriate approach to liquefaction assessment for foundation design purposes in this area as described in Russell et al. (2015b).

Due to the very high density of CPT undertaken in this area and large number of Stage 2 properties included into this worked example, the assessment process has been broken down into four smaller areas (areas A, B, C and D) as shown in Figure L1.1. While these areas have been discussed separately, they need to be considered concurrently because each area performs differently and contrast between these areas helps to improve understanding of why some areas qualify for ILV and other do not.

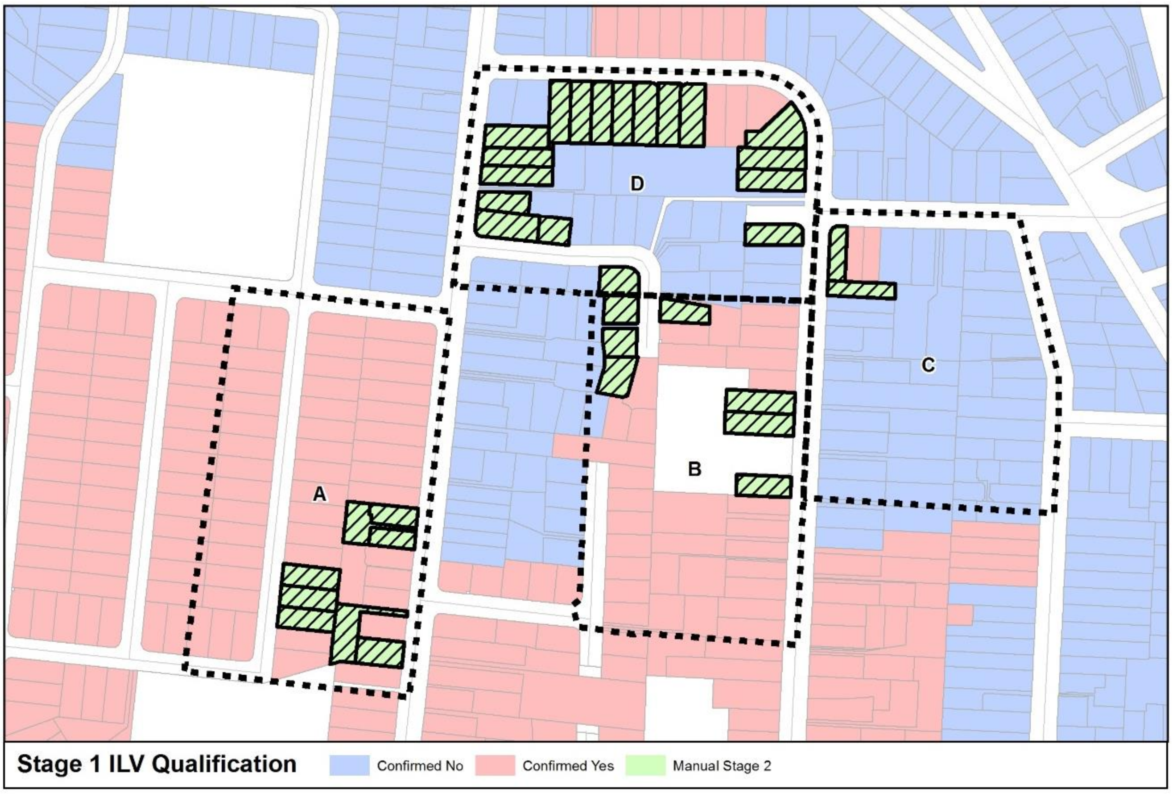

Figure L1.1: The location of the Stage 2 properties requiring further manual assessment in North New Brighton. Areas A, B, C and D indicate the location of the four sub areas presented in the Stage 2 ILV assessment example.

L2 Stage 1 Assessment

L2.1 Area A

Review of the automated ILV model indicates that three of the Stage 2 properties in Area A are unlikely to qualify for ILV. While the other five properties are indicated as likely to qualify for ILV based on the automated model, CPT analyses adjacent to or on the properties are indicating variable results.

L2.2 Area B

Review of the automated ILV model indicates that all except one of the Stage 2 properties in Area B are unlikely to qualify for ILV.

L2.3 Area C

Review of the automated ILV model indicates that the Stage 2 properties in Area C are unlikely to qualify for ILV.

L2.4 Area D

Review of the automated ILV model indicates that three of the Stage 2 properties in Area D are likely to qualify for ILV, six are marginal and the remaining nine properties are unlikely to qualify for ILV.

L3 Stage 2 Assessment

L3.1 Summary of stage 2 assessment

L3.1.1 Area A

As a result of the Stage 2 ILV assessment, all of the Stage 2 properties in Area A have been assessed as qualifying for ILV based on engineering judgement.

L3.1.2 Area B

As a result of the Stage 2 ILV assessment, this automated result has been overturned and all of these properties have been assessed as qualifying for ILV based on engineering judgement.

L3.1.3 Area C

As a result of the Stage 2 ILV assessment, both of these properties have been assessed as qualifying for ILV based on engineering judgement.

L3.1.4 Area D

As a result of the ILV Stage 2 assessment, the four Stage 2 properties to the east have been assessed as qualifying for ILV whereas the fourteen properties to the west have been assessed as not qualify for ILV based on engineering judgement.

The full example pack including discussion and analysis of all the information listed in Section 10.2.2 along with the regional, specific and local analyses (described in Sections 10.2.3, 10.2.4 and 10.2.5 respectively) is included in the supplementary information titled “Worked Example Material”. This full pack demonstrates the complete process for determining the ILV decision of these properties. A summary of the pertinent reasons for this ILV assessment outcome are as follows:

L3.2 Regional Assessment (Task 1)

The land requiring Stage 2 ILV assessment in the four areas (areas A, B, C and D) is located approximately 650m to the north east of the Avon River and approximately 1km to the west of New Brighton beach. The land slopes gently downwards in a south westerly direction towards the Avon River and is at a typical elevation of between 3 to 4m RL.

No land damage was observed in September 2010 (equivalent to M6 0.24 levels of earthquake shaking) apart from some at the southern end where land damage was minor-to-moderate. The land damage was moderate-to-severe in the west (where the groundwater is shallower) and minor-to-moderate in the east (where the groundwater is deeper and the soil is denser) in the February 2011 earthquake (equivalent to M6 0.5g levels of earthquake shaking) and minor-to-moderate in June 2011 (equivalent to M6 0.25g levels of earthquake shaking) and December 2011 (equivalent to M6 0.36g levels of earthquake shaking).

It is noted that both the June 2011 and December 2011 events were preceded by large foreshocks 80 minutes prior to the main earthquake. These foreshocks will have resulted in some development of excess pore water pressure in the soil layers with the lowest resistance to liquefaction triggering (Quigley et al., 2015) which may have resulted in more severe and extensive liquefaction triggering in the soil profile and corresponding damage at the ground surface than would otherwise be anticipated for the estimated levels of ground shaking for the two earthquake events. Accordingly, the land damage observations for these two events relative to the estimated levels of ground shaking should be interpreted with caution.

Ground surface subsidence is variable but typically 0.2m to 0.3m for the properties towards the east and generally 0.5m to 1m for the properties towards the west. Review of the estimated vertical tectonic movement indicates that this ground surface subsidence is predominantly attributable to liquefaction related effects. An error band continues across the southern part of the area. However, the effect from the error band is considered to be relatively minor.

Despite the relatively large distance from the Avon River, ground cracking observations and horizontal ground movements measured using LiDAR data indicate that the area has been affected by lateral spreading in a south west direction (i.e. towards the Avon River). Similar to the foreshocks prior to the June 2011 and December 2011 events, the complex interactions between lateral spread and liquefaction induced subsidence in this area also affect the land damage observations and accordingly the land damage observations for the June and December 2011 events should be interpreted with caution.

Groundwater surface maps indicate that the median groundwater surface is typically 1 – 2m below the ground surface. There are some areas where the groundwater is shallower, between 0 to 1m below the ground surface, to the west and east of the properties requiring Stage 2 ILV assessment.

Geological maps indicate that the area is predominantly underlain by sand of fixed and semi-fixed dunes. This is supported by the regional I_c map which indicates the presence of sandy material. Evidence of the sand dunes is apparent in the ground surface elevation maps although anthropogenic land form changes appear to have removed these features in most areas.

The regional q_{C1N} map indicates variability in the density of the subsoils in this area. This may be partly attributable to the land development as the tops of the sand dunes were trimmed off exposing denser sands below and the fill material being pushed into the interdune depressions resulting in localised areas of looser sand deposits. Even though density of the subsoils is variable, there is a spatial trend with relatively looser soils to the west of the stage 2 properties (Area A) and relatively denser soils to the east of the stage 2 properties.

L3.3 Area A

L3.3.1 Local and Specific Assessment (Tasks 2 and 3)

Figure L3.1a shows that the land slopes gently downwards towards the south west corner of Area A. The depth to groundwater map shows that the groundwater surface is approximately 1m below ground level beneath the Stage 2 properties.

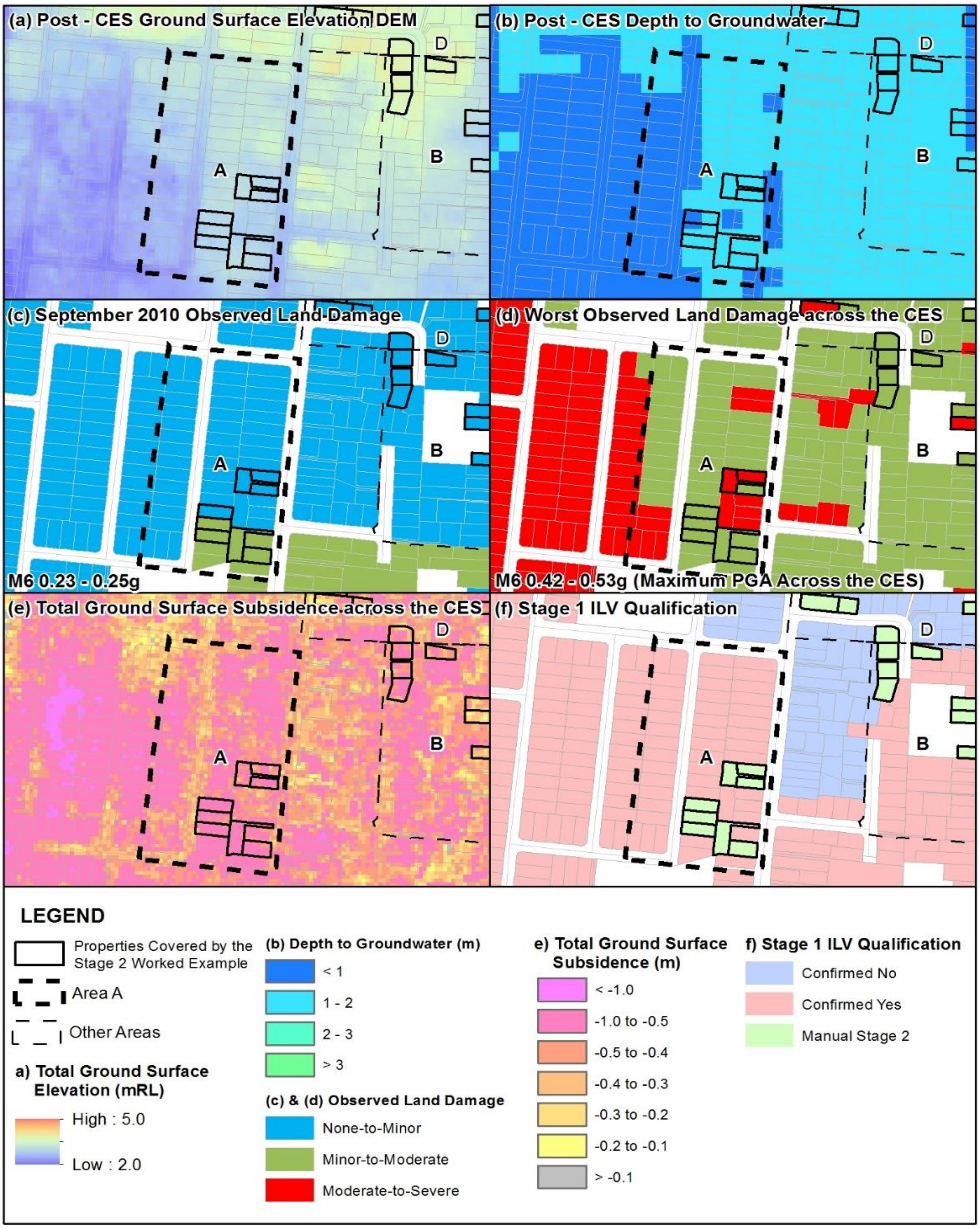

Figure L3.1: A series of maps used when assessing Area A using the Stage 2 qualification process. (a) post-CES ground surface elevation; (b) post-CES depth to groundwater surface; (c) September 2010 observed land damage; (d) worst observed land damage across the CES; (e) total ground surface subsidence across the CES; (f) Stage 1 ILV qualification results.

Inspection of Figure L3.1c shows that some Stage 2 properties in the southern end of Area A had minor-to-moderate observed land damage following the September 2010 earthquake (equivalent to M6 0.24). The worst observed land damage across the CES is either minor-to-moderate or moderate-to-severe for all properties in Area A (refer to Figure L3.1d).

Ground surface subsidence of the Stage 2 properties in Area A is typically between 0.5 and 1m (refer to Figure L3.1e). The majority of the properties surrounding the Stage 2 properties were qualified for ILV during the Stage 1 assessment process (refer to Figure L3.1f). These general observations of land damage and ground surface subsidence for the Stage 2 properties are consistent with the adjacent properties which were assessed as qualifying for ILV using the Stage 1 process.

Figure L3.2 shows that the CPT-based liquefaction vulnerability analyses within this area are generally classified as ✓. One of the Stage 2 properties within the area has two CPT-based liquefaction vulnerability analyses classified as ×. Two Stage 2 properties have four NC CPT within the property boundaries. As discussed in Section 8, the automated model has variable prediction including No, Marginal and Yes qualifications for ILV in this area.

Figure L3.2: The location and classification of the CPT and boreholes and the ILV qualification of the properties for the Stage 2 manual assessment pack in Area A.

The plots of q_c and I_c vs depth for, all the CPTs in Area A, in Figure L3.3 indicate that the subsoils are typically sands steadily increasing in density with depth, with the exception of a loose slightly silty layer at about 3 to 4m depth.

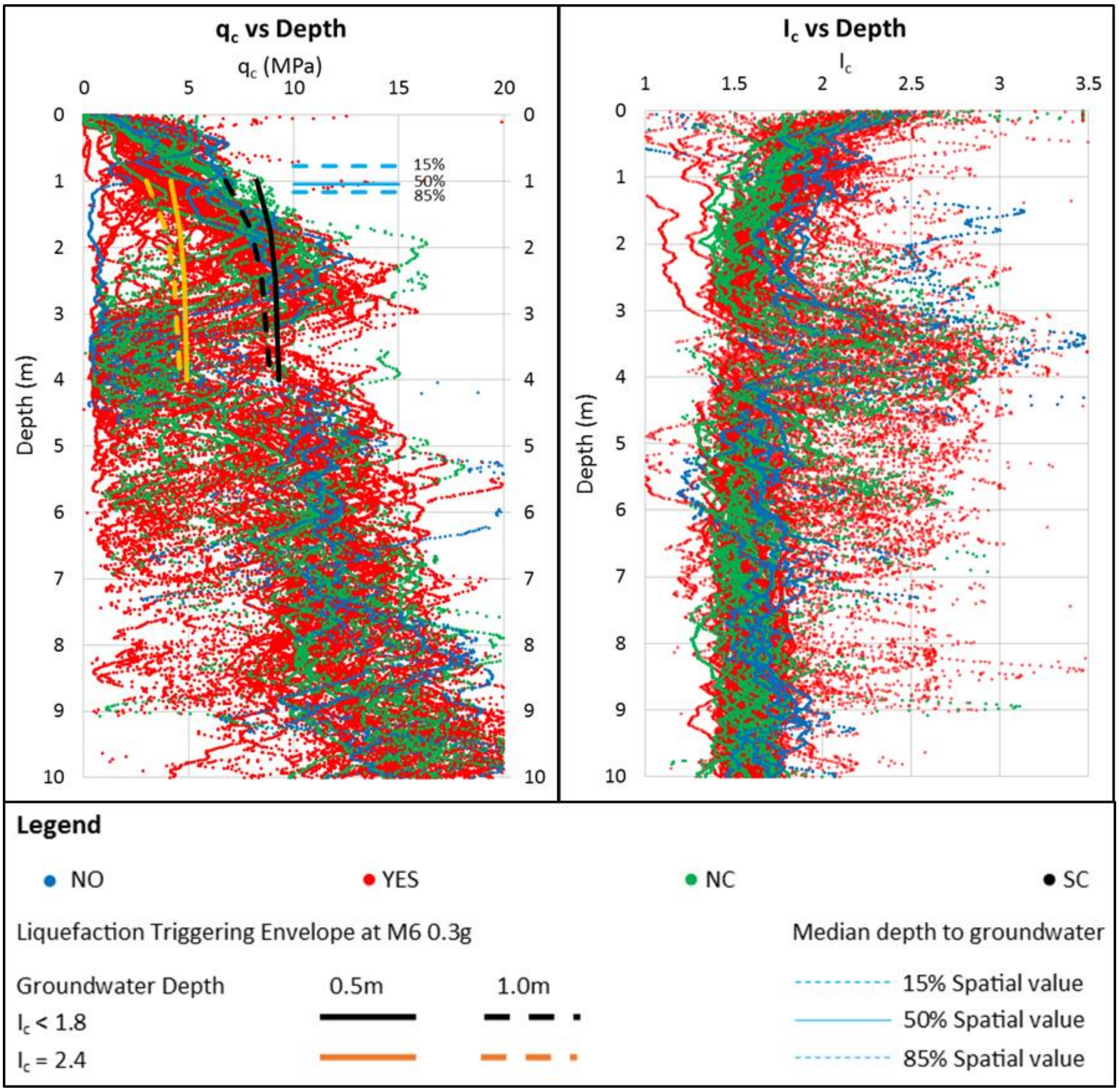

Figure L3.3: Plots of qc and Ic vs depth for CPT grouped by CPT classifications for the CPT identified in Figure L3.2.

As discussed above with reference to Figure L3.3 the majority of CPT are classified as ✓ within Area A. The CPT-based liquefaction vulnerability analysis classified as × or NC fit well within the overall envelope of the q_c and I_c vs depth plots and are generally similar to the ✓ CPT. It appears that the differences between the CPT classified as ✓, × or NC depends on minor variation in the sand and silt layers. As discussed in Russell et al. (2015b) this variability could reasonably be expected over a residential property and hence if additional CPT were to be obtained around the relatively few × and NC CPT, it is reasonable to expect that some of them would be given a ✓ classification.

L3.3.2 ILV Qualification Assessment (Task 4)

The Stage 2 properties within this area have been assessed as qualifying for ILV based on the following:

- Review of the land damage observations provides no reason to differentiate between the performance of the surrounding properties that were assessed as qualifying for ILV during the Stage 1 ILV assessment and the Stage 2 properties;

- For this particular area, interrogation of the subsoil conditions indicates that the differences between the CPT that were classified as × and NC and those classified as ✓ is due to minor variation in the sand and silt layers;
- The majority of the CPT in this area are classified as ✓ and this classification reconciles well with the land performance, the ground surface subsidence which occurred and the soil conditions in this area;

Accordingly these stage 2 properties have been marked with a ☑ on Figure L3.2 to indicate that based on engineering judgement both *engineering criteria* have been satisfied in accordance with the objectives outlined in Section 2.6 and therefore these three properties qualify for ILV.

L3.4 Area B

L3.4.1 Local and Specific Assessment (Tasks 2 and 3)

Review of Figure L3.4a shows that the land in Area B is relatively flat with a gentle slope from the northwest to the southeast. This is reflected in the depth to groundwater map (Figure L3.4b) which shows the groundwater is shallower along the eastern boundary of Area B.

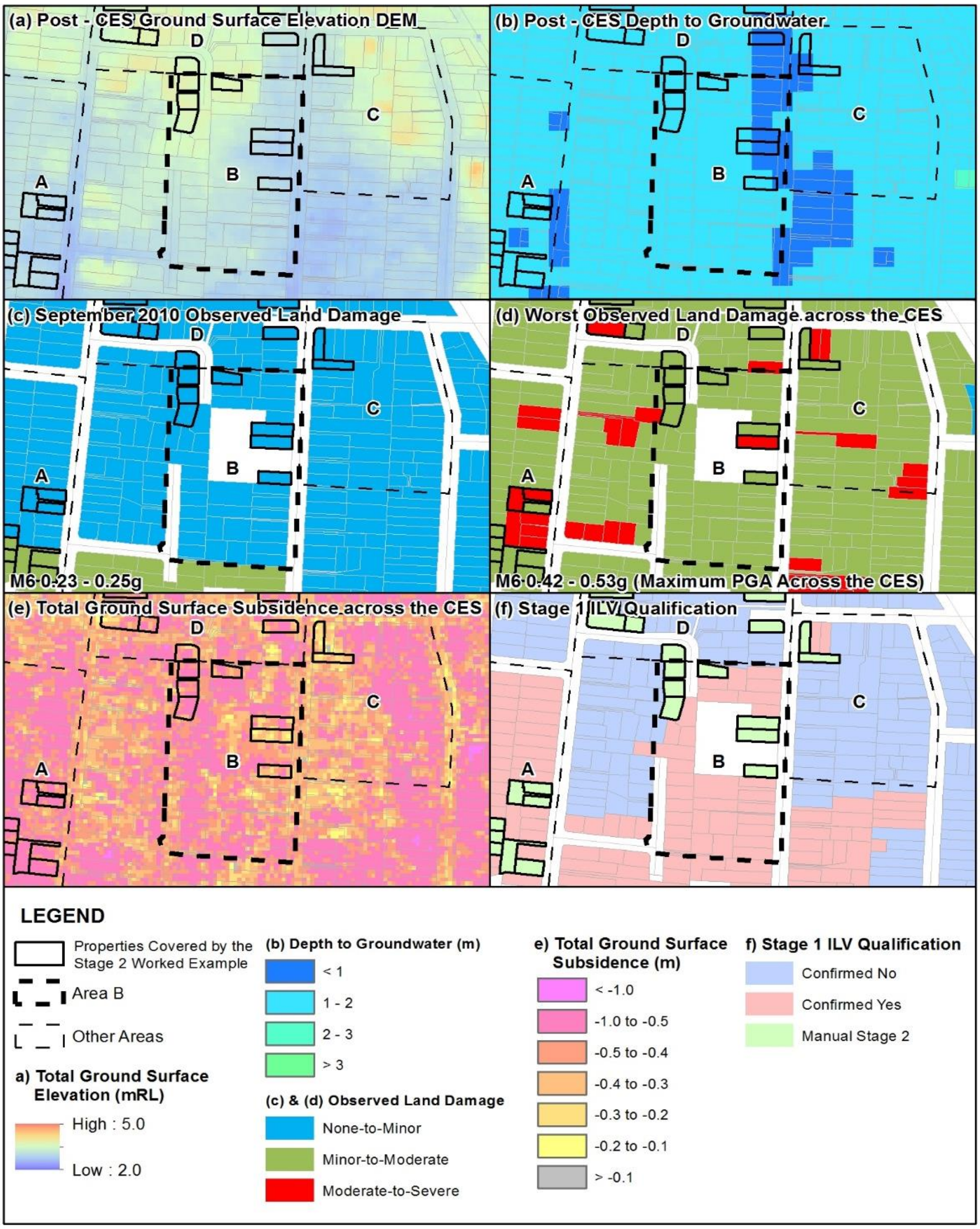

Figure L3.4: A series of maps used when assessing Area B using the Stage 2 qualification process. (a) post-CES ground surface elevation; (b) post-CES depth to groundwater surface; (c) September 2010 observed land damage; (d) worst observed land damage across the CES; (e) total ground surface subsidence across the CES; (f) Stage 1 ILV qualification results.

Figure L3.4c shows that the land damage observations in this area were none-to-minor in the September event (equivalent to M6 0.24g) and that the worst observed land damage over the CES was typically minor-to-moderate (Figure L3.4d).

Figure L3.4e shows that the estimated ground surface subsidence across the CES is typically 0.5 to 1m. The notable exception to this is the middle property of the three eastern most Stage 2 properties which has estimated subsidence of approximately 0.2 to 0.4m. Given that the land damage observations for this property across the CES are moderate-to-severe it is likely that this attributable to LiDAR measurement noise rather than a true measure of ground surface subsidence.

CPT classifications within this area are generally ✓, with some ✗ and NC dispersed throughout the area (refer to Figure L3.5). Three of the eastern properties have CPT classified as ✗ on the properties. The cluster of Stage 2 properties in the north west of the area have variable CPT classifications within or adjacent to the properties.

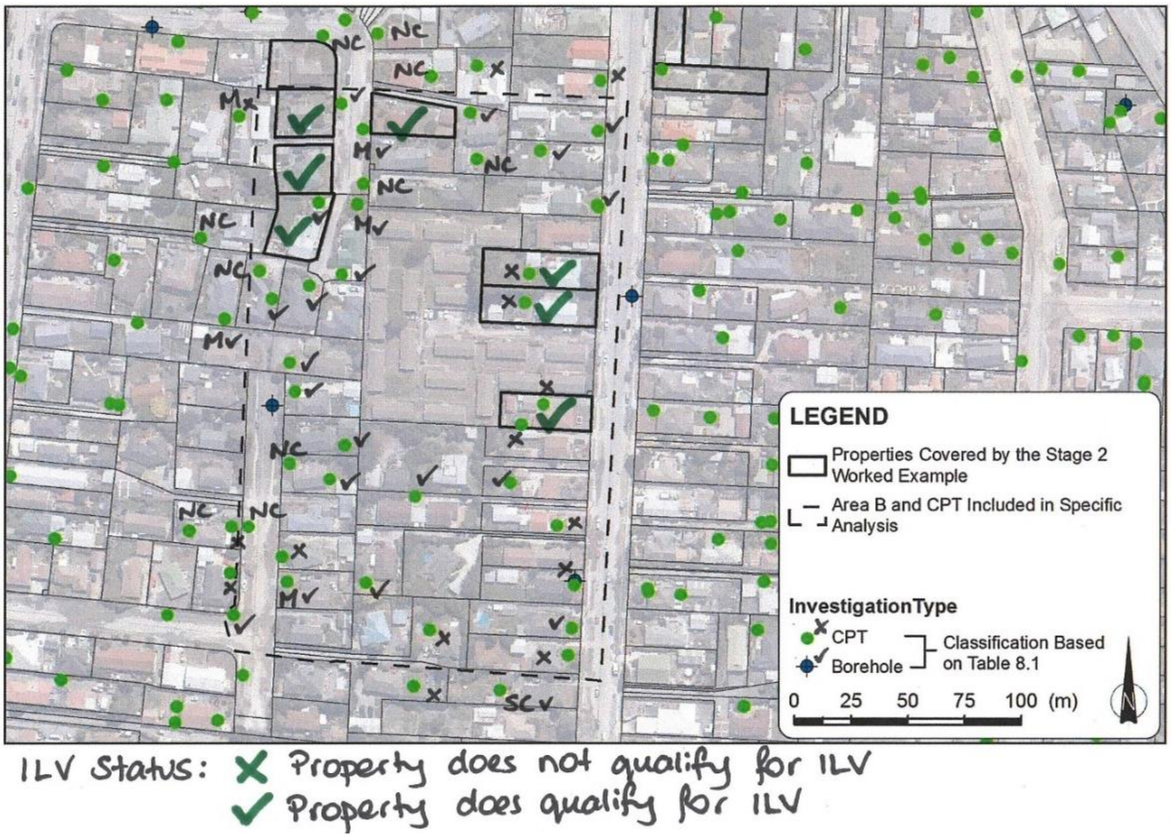

Figure L3.5: The location and classification of the CPT and boreholes and the ILV qualification of the properties for the Stage 2 manual assessment pack in Area B.

Based on the automated ILV model (refer to "Worked Example Material") most of the Stage 2 properties are unlikely to qualify for ILV and are classified as either Automated Marginal or Automated No. The exception to this is the north western most Stage 2 property which is classified as Automated Yes.

The plots of q_c and I_c vs depth in Figure L3.6 indicate that the subsoils are typically sands increasing in density with depth. The density of the top 3 to 4m of these typically sand soils is generally less than the liquefaction triggering envelope for a soil with $I_c < 1.8$ (i.e. clean sands) and therefore liquefaction triggering of the upper 3 to 4m soils is likely at M6 0.3g levels of earthquake shaking. Between 3 and 5m there is an increase in density such that the sands below this depth are unlikely to liquefy at M6 0.3g levels of earthquake shaking. In summary, the CPTs in this area indicate that it is typically underlain by clean sands and that variations in liquefaction triggering and calculated LSN values are typically controlled by smaller variations in the soil density as well as small variations in the layer sequencing.

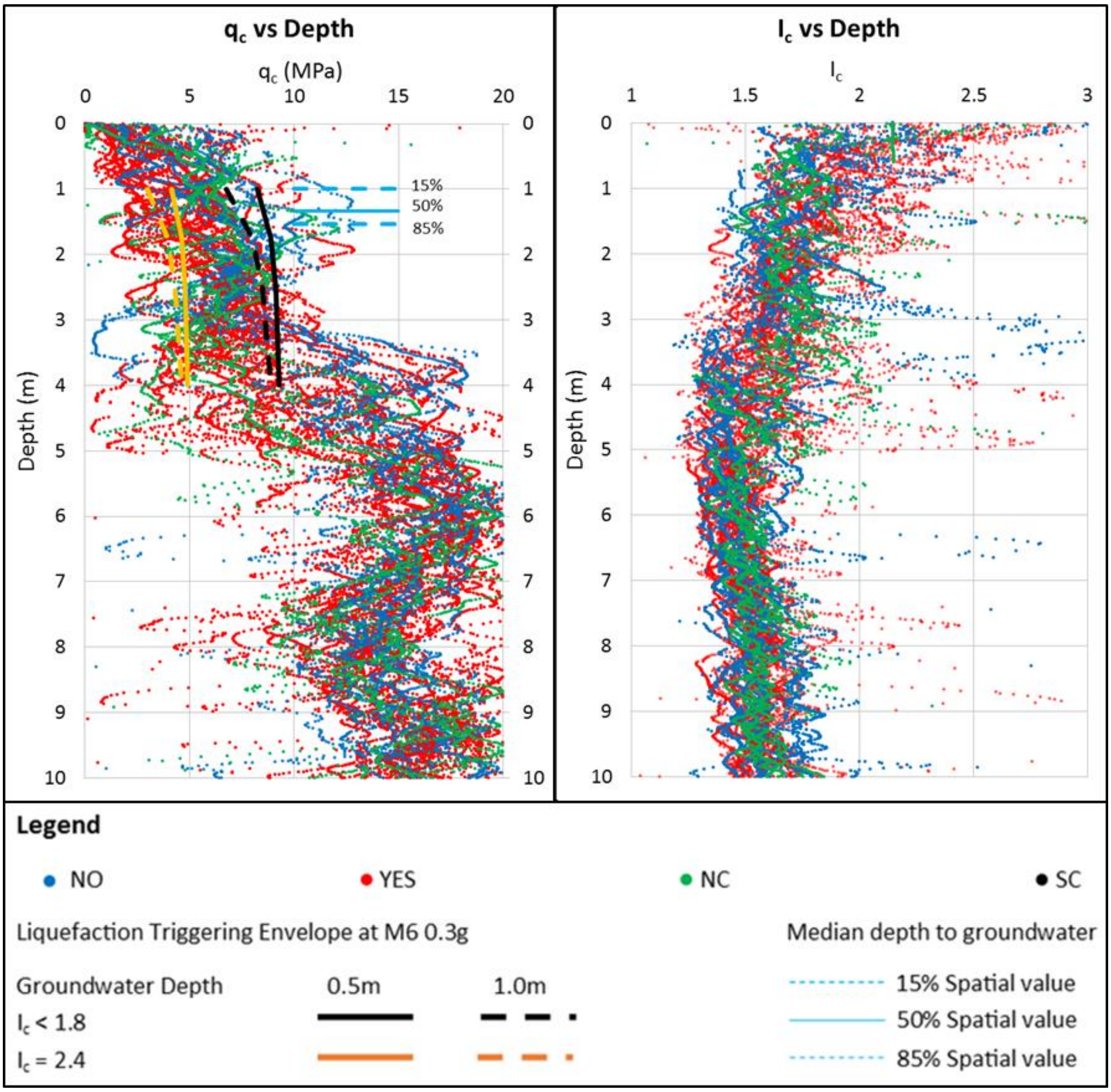

Figure L3.6: Plots of q_c and I_c vs depth for CPT grouped by CPT classifications for the CPT identified in Figure L3.5.

Similar to area A, the CPT-based liquefaction vulnerability analysis classified as × or NC fit well within the overall envelope of the q_c and I_c vs depth plots and are generally similar to the ✓ CPT. It appears that the differences between the CPT classified as ✓, × or NC depends on minor variations in the density of the sandy soils in this area (similar to the observations made in Russell et al., 2015b).

L3.4.2 ILV Qualification Assessment (Task 4)

The Stage 2 properties within this area have been assessed as qualifying for ILV based on the following:

- Review of the land damage observations provides no reason to differentiate between the performance of the surrounding properties that were assessed as qualifying for ILV during the Stage 1 ILV assessment and the Stage 2 properties.

- The measured ground surface subsidence is generally 0.5 to 1m. The exception to this is the middle property of the three eastern most Stage 2 properties which has measured ground surface subsidence of approximately 0.2 to 0.4m. Based on the consistency of the land damage observations in this area this is attributed to LiDAR survey noise rather than a true measure of ground surface subsidence.
- For this particular area, interrogation of the subsoil conditions indicates that the differences between the CPT that were classified as ✗ and NC and those classified as ✓ is due to minor variations in the density of the sandy soils in this area;
- The majority of the CPT in this area are classified as ✓ and this classification reconciles well with the observed land performance and soil conditions; and
- These general observations for the Stage 2 properties are consistent for the properties which were assessed as qualifying for ILV with the Stage 1 properties.

  Accordingly these seven properties have been marked with a ☑ on Figure L3.5 to indicate that based on engineering judgement both *engineering criteria* have been satisfied and therefore the stage 2 properties in Area B all qualify for ILV.

L3.5 Area C

L3.5.1 Local and Specific Assessment (Tasks 2 and 3)

Review of Figure L3.7a shows that the land in Area C slopes from the northern corner to the southern corner. Similar to Area B, this is reflected in the depth to groundwater (refer to Figure L3.7b) which shows a localised area of shallower groundwater along the west boundary.

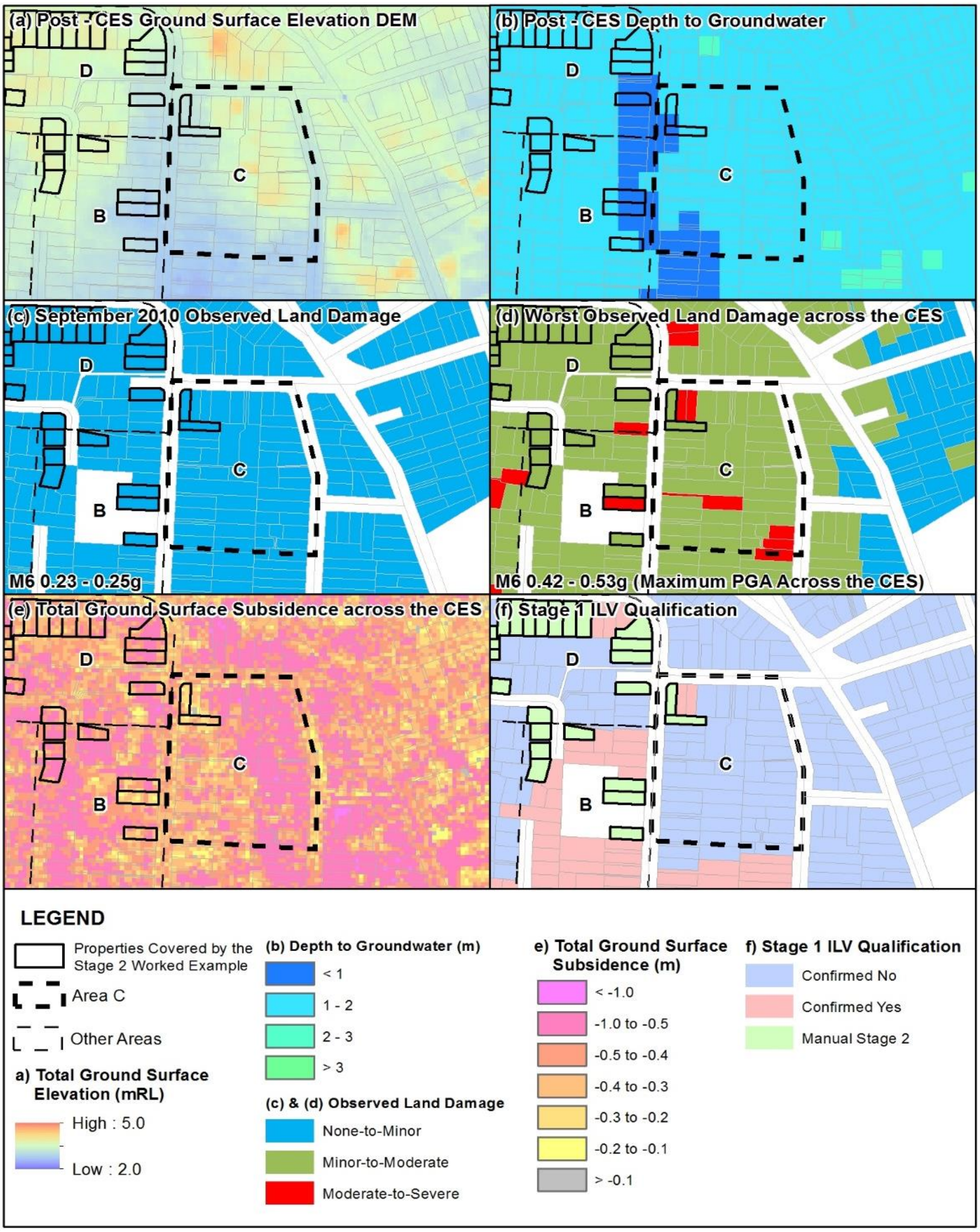

Figure L3.7: A series of maps used when assessing Area C using the Stage 2 qualification process. (a) post-CES ground surface elevation; (b) post-CES depth to groundwater surface; (c) September 2010 observed land damage; (d) worst observed land damage across the CES; (e) total ground surface subsidence across the CES; (f) Stage 1 ILV qualification results.

Figure L3.7c shows that the land damage observations in this area were none-to-minor in the September event (equivalent to M6 0.24g) and that the worst observed land damage over the CES was typically minor-to-moderate (Figure L3.7d). It is noted that the land to the east of Area C transitions from minor-to-moderate to none-to-minor as the worst observed land damage over the CES.

Figure L3.7e shows that the ground surface subsidence is typically 0.2 to 0.4m in the southwest of the area. In the north eastern area, coinciding with the land at a higher elevation, it is generally 0.5 to 1m. This correlation between ground surface subsidence and elevation is potentially attributable to localised topographic re-levelling and/or the lateral spreading that was occurring at a regional level.

The majority of the properties in Area C did not qualify for ILV based on the Stage 1 assessment process (refer to Figure L3.7f). This correlates with the majority of the CPT in Area C being classified as × (refer to Figure L3.8). The exception to this is the group of CPTs in the north western corner of the area which are predominantly classified as ✓. These ✓ CPT are correlated with the properties that qualified for ILV during Stage 1.

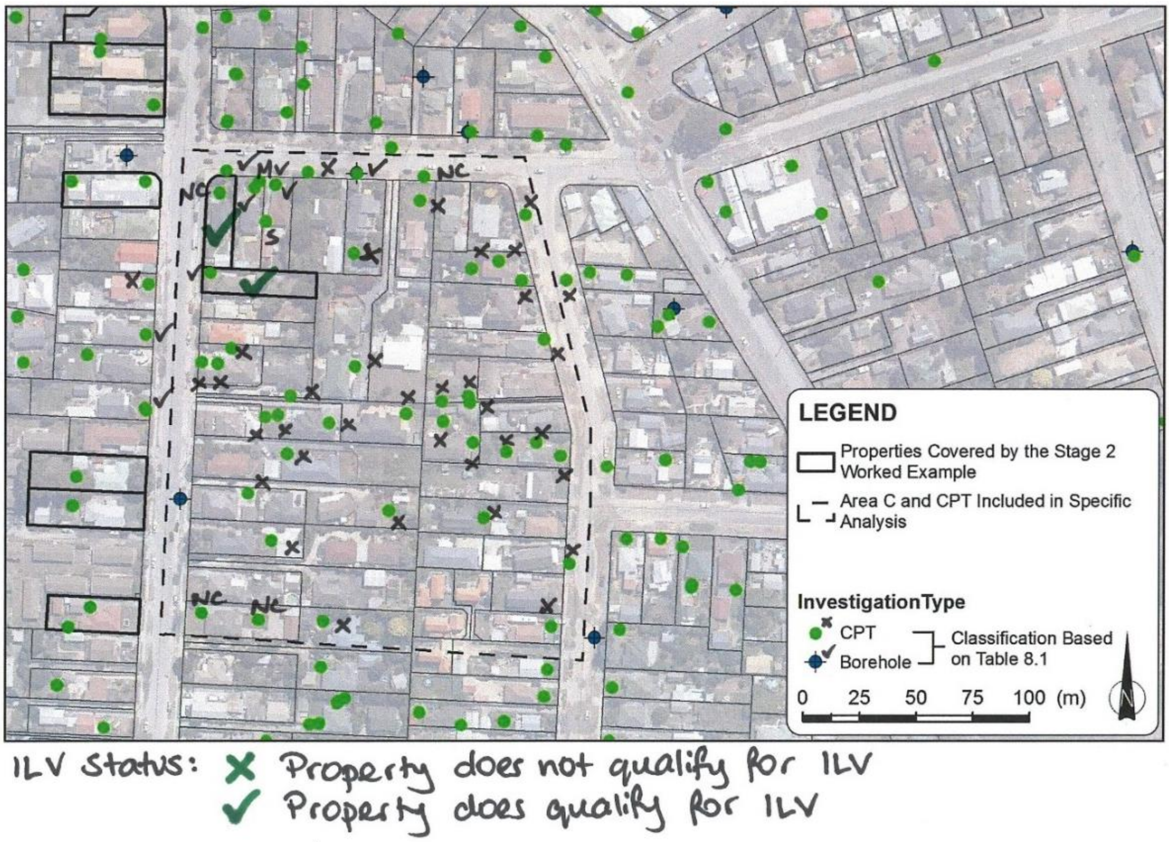

Figure L3.8: The location and classification of the CPT and boreholes and the ILV qualification of the properties for the Stage 2 manual assessment pack in Area C.

Review of the plots of q_c and I_c vs depth in Figure L3.9 shows that, similar to the plots produced for Area B, the site is typically underlain by clean sand material which increases in density with depth. The key difference between these two plots is that Area C typically has denser material in the top 4m of the soil profile.

Based on the liquefaction triggering envelopes shown on the plots, only some parts of the sandy material in the top 4m of Area C is only marginally likely to liquefy at M6 0.3g levels of ground shaking. This is the main reason for the different predominant CPT classifications for Area C (×) compared with Area B (✓).

Closer inspection of Figure L3.9 shows that the top 4m of the CPT which were classified as ✓in the north west corner of Area C are significantly looser than those which were classified as ✗ indicating a distinct spatial difference between the soils profiles in the northwest corner compared to the rest of Area C.

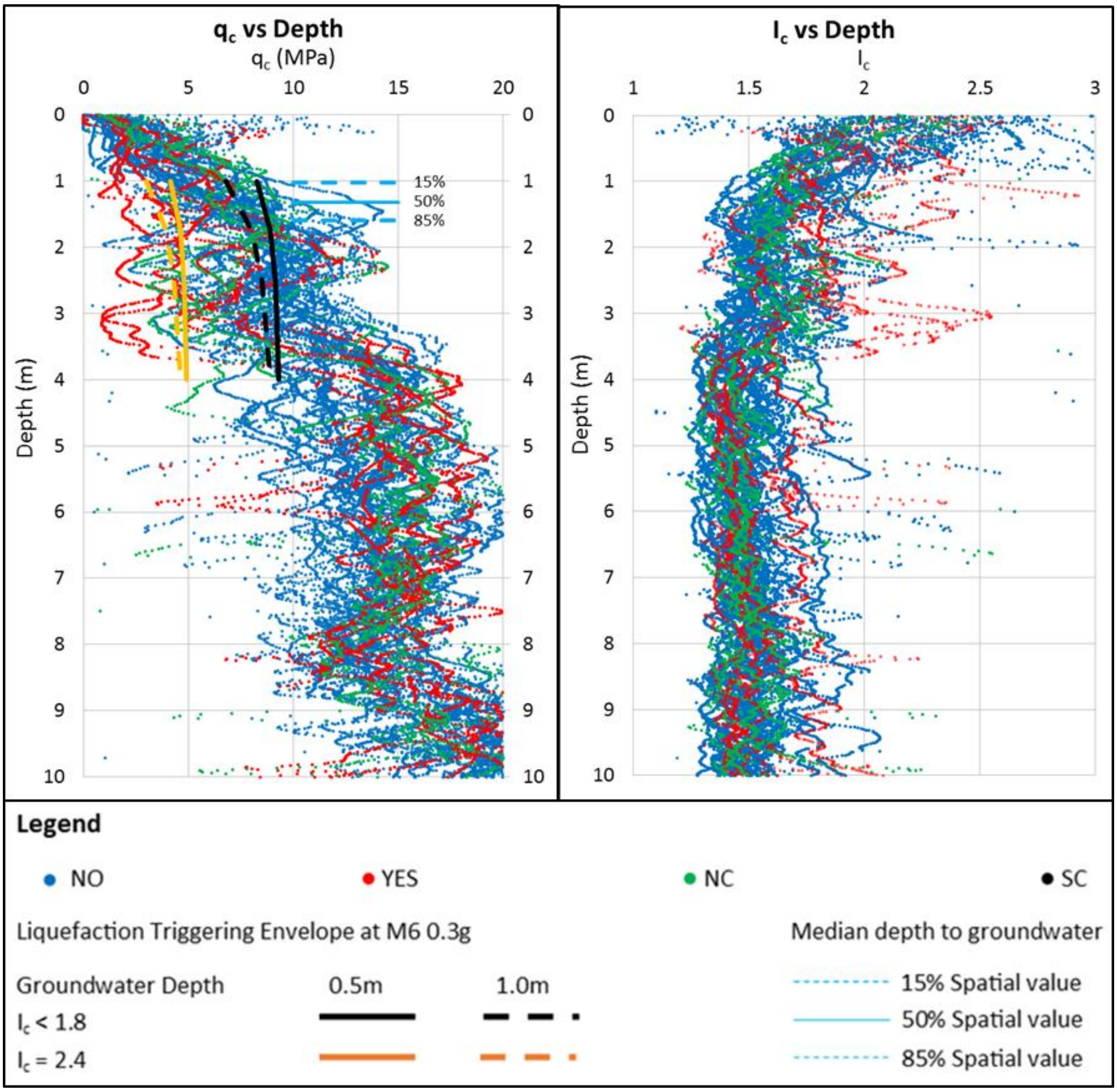

Figure L3.9: Plots of qc and Ic vs depth for CPT grouped by CPT classifications for the CPT identified in Figure L3.8.

L3.5.2 ILV Qualification Assessment (Task 4)

The analysis shows that the properties that were already considered as not qualifying for ILV as part of the stage 1 process were appropriately assessed (i.e. the stage 2 process has confirmed the stage 1 ILV decisions). On the other hand, the Stage 2 properties within this area have been assessed as qualifying for ILV based on the following:

- Analysis of the plots of q_c and I_c vs depth shows that there is a significant difference in the density of the CPT classified as ✓ and those classified as ✗;
- The ✓ CPT are contained within a localised area with consistent results indicating that there is a zone of looser soil in the north west of Area C.

Accordingly the stage 2 properties have been marked with a ☑ on Figure L3.8 to indicate that based on engineering judgement both *engineering criteria* have been satisfied and therefore these properties qualify for ILV.

L3.6 Area D

L3.6.1 Local and Specific Assessment (Tasks 2 and 3)

Review of Figure L3.10a shows that the land in Area D is generally at a higher elevation than the land in the other areas. There is a low point in the south eastern corner and this is reflected by a localised shallower depth to the groundwater surface (refer to Figure L3.10b) in this area.

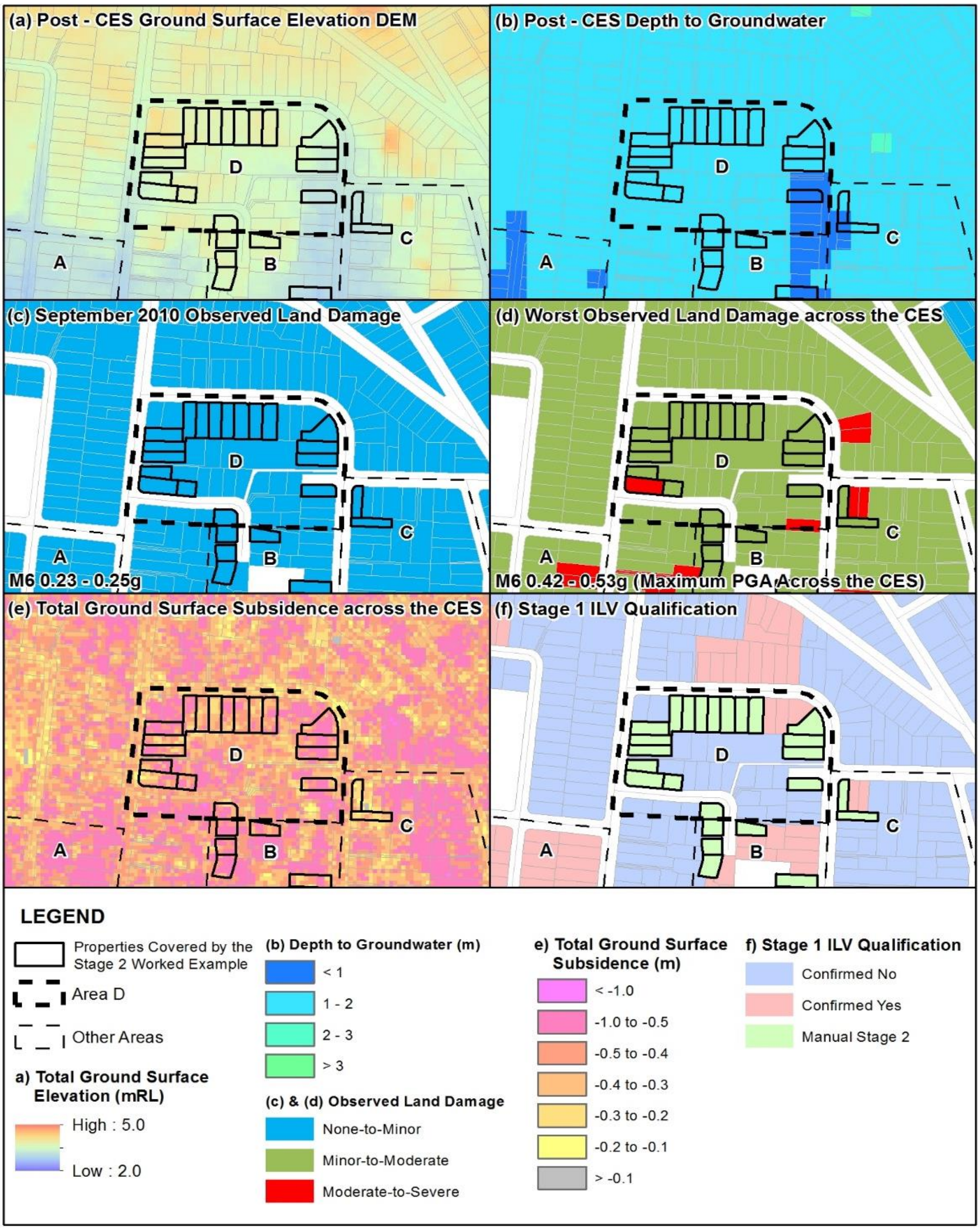

Figure L3.10: A series of maps used when assessing Area D using the Stage 2 qualification process. (a) post-CES ground surface elevation; (b) post-CES depth to groundwater surface; (c) September 2010 observed land damage; (d) worst observed land damage across the CES; (e) total ground surface subsidence across the CES; (f) Stage 1 ILV qualification results.

Land damage observations are similar to those in the other areas with none-to-minor observations for the September event (equivalent to M6 02.4g) and typically minor-to-moderate land damage observations across the CES (refer to Figures L3.10c and L3.10d).

Ground surface subsidence of the northern properties is varied from 0.2 to 0.4m with isolated zones of 0.5 to 1m (refer to Figure L3.10e). For the eastern and western stage 2 properties, ground surface subsidence is typically 0.4 to 1m.

The majority of the properties in Area D did not qualify for ILV based on the Stage 1 assessment process (refer to Figure L3.11). A significant number of properties were assessed as requiring assessment with the Stage 2 ILV process in Area D. This is attributable to the marginality of the CPT classifications in this area. However there are some spatial patterns within the CPT classifications with M and ✓ CPT tending to group around the north eastern boundary of the area adjacent to the properties which were previously qualified for ILV in the Stage 1 process. The predominant CPT classification within the rest of Area D is NC.

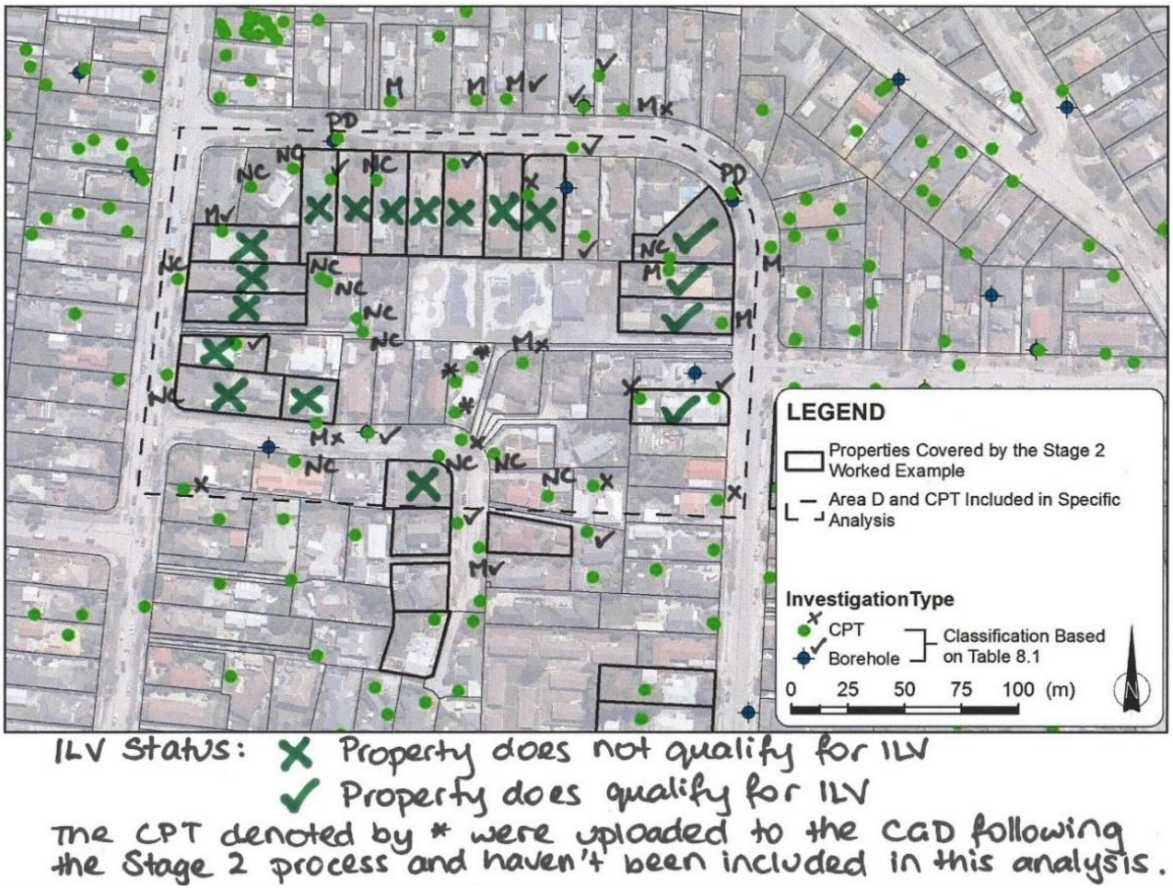

Figure L3.11: The location and classification of the CPT and boreholes and the ILV qualification of the properties for the Stage 2 manual assessment pack in Area D.

The results of the automatic model reflect the marginality of CPT classifications with assessments of automated yes, automated no and automated marginal distributed throughout the area (refer to "Worked Example Material").

Review of the plots of q_c and I_c vs depth (refer to Figure L3.12) indicate that typically the top 3 to 4m of the soil profiles in this area are clean sands overlying approximately 2m of loose silty material. The soils from 6 to 10m are typically dense sands which are unlikely to liquefy at M6 0.3g levels of ground shaking.

The key distinction between the CPT which are classified as ✓ and M relative to the CPT classified as NC is the density of the top 1 to 2m of the soil profile. The top 1 to 2m is critical because this is where the change in the groundwater surface is occurring. Within the top 1 to 2m of the soil profile the CPT classified as ✓ tend to have looser soils with q_c values which are less than the liquefaction triggering envelope for M6 0.3g levels of ground shaking. Whereas the CPT classified as NC tend to have relatively denser soils (compared with the CPT classified with a ✓) with q_c values which plot around the threshold of liquefaction triggering for M6 0.3g levels of ground shaking. For the CPT classified as NC this “thresholding” is resulting in a small calculated ΔLSN in areas with significant levels of ground surface subsidence (up to 1m) and at higher levels of earthquake shaking these NC CPTs would all become a ✓.

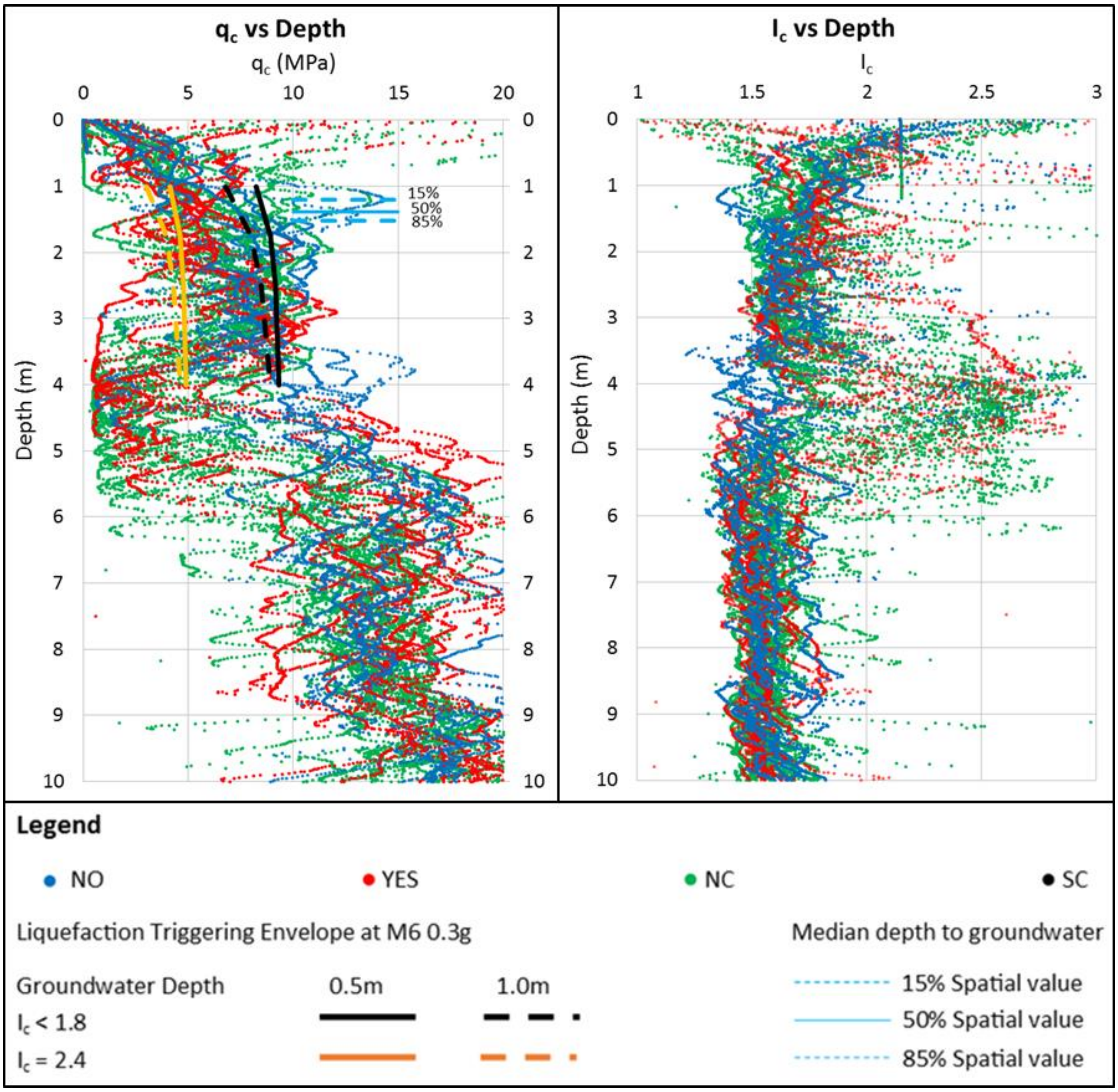

Figure L3.12: Plots of qc and Ic vs depth for CPT grouped by CPT classifications for the CPT identified in Figure L3.11.

L3.6.2 ILV Qualification Assessment (Task 4)

The Stage 2 properties in the centre and west of this Area D have been assessed as not qualifying for ILV on the basis that:

- The higher elevation results in a deeper groundwater surface and hence a thicker non-liquefying crust relative to the properties to the east;
- The classification of CPT in this area is predominantly NC with a reasonably clear spatial pattern;

- Inspection of the q_c and I_c plots shows that the CPT classification of NC results from the density of the soils in this area. The CPT classified as NC tend to be denser around the critical depth where groundwater change is occurring (i.e. 1 to 2m) with qc values which plot both around the threshold of liquefaction triggering for M6 0.3g levels of ground shaking. This "thresholding" is resulting in a small ΔLSN in areas with significant levels of ground surface subsidence (up to 1m). Therefore, despite the significant settlement in this area, the NC classification is judged to be appropriate;
- Accordingly the northern and western stage 2 properties have been marked with a ☒ on Figure L3.11 to indicate that based on engineering judgement Criterion 2 is unlikely to have been satisfied and therefore these properties do not qualify for ILV.
- The stage 2 properties to the east of this Area D have been assessed as qualifying for ILV on the basis that:
  - The lower elevation results in a shallower groundwater surface and hence a thinner non-liquefying crust relative to the properties to the west;
  - The classification of CPT in this area is predominantly ✓ and M with a reasonably clear spatial pattern;
  - Inspection of the q_c and I_c vs depth plots show that there is a distinction between the CPT classified as ✓ and M relative to the CPT classified as NC. Within the top 1 to 2m of the soil profile, the CPT classified as ✓ and M tend to have looser soils with q_c values which are less than the liquefaction triggering envelope for M6 0.3g levels of ground shaking.
- Accordingly the eastern stage 2 properties in Area D have been marked with a ☑ on Figure L3.11 to indicate that based on engineering judgement both *engineering criteria* have been satisfied and therefore these eastern stage 2 properties qualify for ILV.

L4 References

Russell, J., van Ballegooy, S., Torvelainen, E. & Gulley, R. 2015b. Consideration of ground variability over an area of geological similarity as part of liquefaction assessment for foundation design. *6th International Conference on Earthquake Geotechnical Engineering, Christchurch.*