REPORT

Tonkin & Taylor

Earthquake Commission

Canterbury Earthquakes 2010 and 2011
Land report as at 29 February 2012

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Kōmihana Rūwhenua

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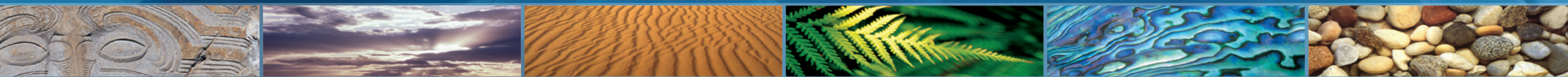

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Applicability

This report was prepared and/or compiled for the Earthquake Commission (EQC) to communicate information that may be relevant to residential land claims under the Earthquake Commission Act 1993. The report was not intended for any other purpose and may not be relied upon for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of any map(s) and data in this report or for the consequences of any other person relying on them in any way. This information is not intended to form a complete technical report on land changes in all or any part of Canterbury.

Executive summary

Introduction

The main purpose of this report is to provide information on how the Canterbury earthquake series, beginning on 4 September 2010, has changed residential land in the wider Christchurch area. It explains the technical information collected and the processes used to collect it.

Tonkin & Taylor (T&T) has collected this information to assist the Earthquake Commission (EQC) in assessing insurance claims made under the Earthquake Commission Act 1993. T&T provides land damage assessments of individual properties and advice to EQC.

T&T geotechnical experts were on the ground assessing initial land damage immediately after all four main earthquakes of 2010 and 2011 (4 September 2010; 22 February, 13 June and 23 December 2011). Preliminary mapping information gathered immediately after the events has been progressively added to with more detailed assessment techniques explained in this report.

This report includes the best available data collected at the time, following the Canterbury earthquakes of 2010 and 2011. The information provided is up-to-date as of 29 February 2012 and does not take into account any subsequent aftershocks or earthquakes that may have occurred after that date.

This report is written in plain English where possible, but it does contain technical information where this is necessary to accurately explain the nature of investigations, and the land change effects of the earthquakes. A glossary is included. The Appendices to this report provide visual explanations of land damage types and suburb specific information. Note: The glossary is at the end of the main body of the report.

The 22 February 2011 earthquake (Christchurch 1 Earthquake) was New Zealand's worst natural disaster - 185 people lost their lives and there was widespread destruction to buildings, infrastructure and land.

A declared state of national emergency stayed in force from 23 February 2011 until 30 April 2011. This was the first time in New Zealand's history that a state of national emergency had been declared as a result of a civil defence emergency.

In addition to severe shaking, causing extensive damage to residential buildings, the force of the earthquakes caused land damage previously unseen in an urban area on such a large scale.

Due to the scale and extent of land damage arising from the four main earthquakes, broad geotechnical land damage assessment has been undertaken across communities and suburbs, as well as on individual properties.

This assessment gives a clear picture of how land has changed in the worst affected residential suburbs of the Christchurch area. In addition to helping EQC settle land claims, this information is useful for professionals engaged in designing, repairing and rebuilding to understand how to avoid similar damage to homes in future earthquakes.

In consideration of that, EQC is sharing the area-wide technical data it has collected with other agencies such as territorial authorities, Canterbury Earthquake Recovery Authority (CERA), and engineering and construction professionals, to facilitate rebuilding in Canterbury.

Land damage assessment

Land damage assessments for EQC are split into two regions - the flat land of the Canterbury Plains, and the sloping land located on the Port Hills and wider Banks Peninsula area. Because of the different makeup of the soils in these areas, and the varied locations of the earthquakes, the types of land damage are different.

It should be noted that while earthquake tremors have caused damage to buildings throughout Canterbury, it does not necessarily mean that there is land damage on the property. Some properties with building damage have no land damage.

On the Plains, there are seven physical land damage categories explained in this report. These are lateral spreading, land cracking, undulations, ponding, local settlement, groundwater springs and inundation by sand and silt. In addition to this physical damage, the land has also undergone other changes. Over much of the wider Christchurch area land is now lower, higher, or in a different place to where it was before the earthquakes. The fact that the land has changed does not mean, in itself, that it is damaged.

In the Hills, there are three damage categories explained in this report. These are rock fall, large-scale land movement

Cracking as a result of lateral spreading, Christchurch city.

(such as cliff collapse and major inundation), and small-scale land movement and retaining wall failures. Much of the physical land damage in the Port Hills is ground cracking. Similar to the cracks on the Plains, these cracks can generally be repaired.

Land damage mapping

There are three steps of land damage mapping and assessment depending on the degree of damage arising from an earthquake:

1. Step 1 - preliminary regional broad scale mapping to give a quick assessment of the extent and severity of damage.
2. Step 2 - rapid property-by-property mapping of liquefaction, lateral spread and land movement observations to give an indication of area-wide issues.
3. Step 3 - detailed individual EQC Land Damage Assessment Team (LDAT) process for individual land claim settlement.

Following regional reconnaissance and broad mapping assessments (Step 1), individual property-by-property rapid mapping of liquefaction, lateral spread and land movement observations (Step 2) in the areas worst affected by liquefaction on the Plains and land movement in the hills was undertaken by geotechnical professionals for EQC.

Mapping of the severity of land damage determined the areas that needed more detailed individual property inspections by assessment teams (Step 3).

Land survey

High-resolution aerial photographs of the most-affected areas of Christchurch city, and Waimakariri and Selwyn districts were taken in the days following each of the main earthquakes. Aerial photography was used as a tool to assess the nature and extent of liquefaction which occurred. This was an important supplement to ground inspections where evidence of liquefaction (sand and water ejection) was either removed or reduced before the inspections could take place.

Aerial LiDAR (Light Detection and Ranging) technology surveys that measure the height of the ground from the air (accurate to +/- 100mm) were, in contrast, delayed until the sand and silt (and snow) had been removed so that the actual ground surface level was correctly identified.

Cut slope failure, Port Hills. Photo: Tonkin & Taylor

Subsurface ground investigations

This section of the report outlines the investigations and reporting undertaken across 50 Canterbury suburbs. This information is technical and mainly for use by professionals engaged in insurance assessment or repair and rebuilding work.

EQC commissioned geotechnical ground investigations for the suburbs on the Plains most affected by land damage, following the Christchurch earthquake series that began on 4 September 2010. T&T did broad scale investigations on behalf of EQC within suburbs in Christchurch city, and Waimakariri and Selwyn districts. This included subsurface (below ground) site investigations and factual reporting for the suburbs most affected by liquefaction-induced land damage.

These investigations included:

a) Cone penetration testing (CPT) - gives a profile of soil strength
b) Machine boreholes - gives a profile of soil types
c) Geophysical testing - looks at soil stiffness and density
d) Groundwater observations - assesses groundwater levels
e) Laboratory testing - analyses soil from the boreholes.

A total of 1344 CPTs and 162 boreholes were completed throughout the suburbs. CPTs were done in 50 suburbs and boreholes in 34 of those suburbs. Geophysical testing of 12 kilometres (km) in length was undertaken in 11 suburbs and standpipe piezometers (instruments measuring groundwater level) were installed in most of the suburbs - a total of 666.

Factual geotechnical information obtained from the investigations is intended to provide a source of geotechnical data to support geotechnical advice for EQC and for future council consent applications for the suburbs profiled. Each report contains technical information for geotechnical engineers to design land repairs in those suburbs. The reports present all available geotechnical and engineering geological investigations that were commissioned by EQC during 2010-2011 and all readily available geotechnical data that Environment Canterbury (ECan) holds for the suburb as at September 2010. No interpretations of the factual investigation results have been made in the factual reports or this reporting.

These reports follow on from Stage 1 and 2 geotechnical land damage assessment reports dated October 2010 and November 2010 respectively, available on EQC website at: http://canterbury.eqc.govt.nz/news/reports

Groundwater assessment

Groundwater levels across Canterbury are important when considering the effects of liquefaction on the land. Liquefaction occurs where loose soils below the groundwater level substantially lose strength and stiffness in response to earthquake shaking, causing the soil to behave like a pressurised liquid. This can result in the sand-water mixture being forced to the surface.

As a part of the overall geotechnical ground investigations commissioned by EQC, groundwater levels have been assessed.

Generally, the shallow groundwater levels have returned to almost normal levels in most cases. Initial results suggest there has been little long-term impact on groundwater levels in the Christchurch area from the main earthquakes. This means that the absolute level of groundwater remains the same, but in some areas the land elevation has dropped so the groundwater is closer to the surface.

A network of shallow groundwater monitoring wells recorded the levels of general change of groundwater conditions the day following the Christchurch 1 Earthquake.

The data showed that most of the short-term groundwater level changes caused by the Christchurch 1 Earthquake occurred in the southern and eastern areas of Christchurch.

However, none of the recorded earthquake related groundwater table changes appear to be greater than the normal range of fluctuations recorded prior to the earthquake. Where the land surface has dropped generally, it is expected that the depth to the groundwater below the ground surface will now be less than the depth prior to the two major earthquakes (Darfield and Christchurch 1 Earthquake).

Process

Collecting this information to inform EQC has been a thorough process, which has been internationally peer-reviewed in June 2011 based on the information available at that stage. The mapping and assessment processes and methodology are in line with international best practice, and align with the New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines.

Pavement damage from ground oscillation, Christchurch city.

1 Introduction

For the Earthquake Commission (EQC), Tonkin & Taylor Ltd (T&T) has undertaken ongoing land damage assessments of the main urban residential land areas in Canterbury, in the South Island of New Zealand.

T&T provides land damage assessments of individual residential properties and advice to assist EQC in assessing residential insurance land claims made under the Earthquake Commission Act 1993.

Land in Canterbury - and particularly in the Christchurch and Kaiapoi urban areas - has been significantly affected by the Canterbury earthquakes which began on 4 September 2010 and continued through 2010, 2011 and 2012.

Due to the scale and extent of land changes arising from the Canterbury earthquakes T&T has undertaken, at EQC's request, a broad geotechnical land damage assessment on a community/suburb wide basis, in addition to individual residential property assessments.

This report updates and collates earthquake-related residential property land information provided to EQC, as at 29 February 2012. It explains what information has been collected, how and why. It follows on from Stage 1 and 2 geotechnical land damage assessment reports dated October 2010 (T&T 2010a) and November 2010 (T&T 2010b) respectively, available on EQC website at: http://canterbury.eqc.govt.nz/news/reports

The information in those reports will not be repeated. However, reference will be made to those reports and they should be read in conjunction with this report to get a more complete view of land changes as a result of the Canterbury earthquakes.

This report is intended for the use of people who do not have specific technical expertise in the areas covered and should not be considered to form a complete technical report on land changes in Canterbury.

In undertaking this assessment work T&T has engaged with and relied on the observations and inputs from a range of local and international experts.

These include GNS Science, the Natural Hazards Platform, New Zealand Aerial Mapping, local authority recovery teams, universities, the Earthquake Commission, Land Information New Zealand, Ministry of Civil Defence & Emergency Management, New Zealand and overseas research teams (USA, Japan and Australia), councils, the insurance industry, other New Zealand experienced consultants, the New Zealand Government and the Canterbury community. We wish to acknowledge the extraordinary efforts of these groups and the high value of all the information that has been provided by them. Collaboration is the key to information gathering and ongoing assessment of land damage in Canterbury, to facilitate the recovery efforts.

The September 2010 earthquake Greendale Fault trace. The fault trace is the intersection of a fault with the ground surface; also, the line commonly plotted on geologic maps to represent a fault. Photo: Environment Canterbury.

Ejected sand and silt covering land, and lateral spreading adjacent to the estuary, Christchurch city. Photo: Tonkin & Taylor

This report does not include information on how EQC land claim settlement will be processed or the specifics of solutions for repairing land. This report was prepared and/or compiled for EQC to communicate information associated with assessing insurance claims made under the Earthquake Commission Act 1993. It was not intended for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of these maps and data or for the consequences of any person relying on them in any way. Information presented as land damage in the context of this report does not constitute land damage for individual claim settlement purposes.

Key points:

- **This report details what information has been collected by T&T, how and why.**
- **This report was prepared for EQC to communicate information on residential insurance land claims made under the Earthquake Commission Act 1993. It brings together information from a number of sources but readers should note that this information is intended for the use of people who do not have specific technical expertise in the areas covered and neither it nor data presented should be considered to form a complete technical report on land changes in Canterbury.**
- **This report does not include information on how EQC land claim settlement will be processed or the specifics of solutions for repairing land.**
- **Some of the information contained in this report will belong to organisations other than EQC. Wherever possible the owner of the information is identified. More detail on such information should be sought from the organisation that holds it.**

2 The Canterbury earthquake series

2.1 The four main earthquakes

The magnitude M7.1 **Darfield Earthquake** occurred at 4:36am local time on 4 September 2010. The hypocentre was about 40 kilometres (km) west of Christchurch city,

The September 2010 earthquake Greendale Fault trace. Photo: GNS Science

at a depth of 10km. The epicentre was close to the town of Darfield. An east-west trending fault rupture on the Canterbury Plains extends to within 18km of Christchurch city. Analysis of the seismogram records in New Zealand indicate the main shock had primarily strike-slip (sideways) motion, which agrees with the observed 29km long surface fault rupture. However, the main shock has been observed to be complex, and an important reverse (compressional) component is seen in strong ground motion and land survey data. The duration of strong ground motions on firm soil sites was about 15 seconds.

At 12:51pm local time on 22 February 2011, the M6.2 **Christchurch 1 Earthquake** jolted the city. The hypocentre was about 10km southeast of Christchurch city, at a depth of about 5km. The epicentre was close to Lyttelton Port.

This earthquake was one of New Zealand's worst natural disasters and 185 people died, mainly in the central business district (CBD) of Christchurch city where commercial buildings collapsed. A declared state of national emergency stayed in force from 23 February 2011 until 30 April 2011. This was the first time in New Zealand's history that a state of national emergency had been declared as a result of a civil defence emergency event.

The initial fault plane dips to the south at about 65 degrees from beneath the New Brighton estuary to the Port Hills, and it slipped by up to 2.5 metres (m) during the earthquake, raising the Port Hills by up to 400 millimetres (mm). Conversely, the New Brighton area subsided by up to 100mm on the north side of the fault. The earthquake did not rupture the ground surface, unlike the much larger magnitude M7.1 Darfield Earthquake.

The Christchurch 1 Earthquake produced very strong shaking for its size. Strong shaking lasted 8-10 seconds close to the epicentre (e.g. Heathcote Valley), 15-20 seconds on the soft sediments underlying Christchurch city, and more than 20 seconds out on the Plains (e.g. Darfield area). The earthquake was centred on a complex set of small faults collectively and informally called the Port Hills fault that extends in a general way from near New Brighton Beach in a south south west direction, across the northern side of the Heathcote estuary and toward Cashmere.

The Christchurch 1 Earthquake produced the highest vertical and horizontal ground accelerations (how hard the earth shakes) ever recorded in New Zealand. These ground accelerations were more than two times the force of gravity (g) in parts of the Port Hills and well over 0.5 g in areas of the plains.

The Port Hills sustained extensive land damage in this earthquake including rock fall, large-scale landslides, small-scale landslides and retaining wall failures.

A M6.0 earthquake, the **Christchurch 2 Earthquake**, struck at 2.20pm on 13 June 2011 producing ground accelerations of more than two times the force of gravity (g) in parts of the Port Hills and 0.4 g in the CBD. There was renewed liquefaction and further damage, including partial collapse of already weakened buildings in the CBD red exclusion zone. The earthquake was centred 10km southeast of the city within the aftershock zone of the Christchurch 1 Earthquake. It was on an approximately north to north-west to south to south-east oriented fault at right angles to the Port Hills fault. The aftershock pattern associated with this earthquake extended south across Banks Peninsula toward Akaroa.

Ground motions in both the 22 February 2011 M6.2 and the 13 June 2011 M6.0 were significantly stronger in Christchurch city compared with the 4 September 2010 Darfield Earthquake because of its shallow depth and close proximity, even though the Darfield Earthquake was of greater magnitude.

A M5.8 earthquake struck east of Christchurch at 1:58pm on 23 December 2011 approximately 8km off the coast of New Brighton (**Christchurch 3 Earthquake**). This was followed by a M5.9 earthquake shortly afterwards at 3:18pm. This series of earthquakes was further eastward than the 13 June 2011 aftershocks. Being further from built up areas, with slightly lower magnitudes and somewhat greater depth than the biggest shakes, the effects were generally less damaging across most of the region than the previous main earthquakes. However, the location and direction of the fault meant that significant effects were observed in the northeastern suburbs of Christchurch. Following the Christchurch 3 earthquake, aftershocks continued throughout the afternoon and overnight, with several above M5.0.

The M5.8 and M5.9 earthquakes were not characterised by the very high ground motions in the Christchurch urban area of earlier earthquakes, except for an isolated high recording at New Brighton Beach in the M5.8 earthquake that may reflect the close proximity to the epicentre.

On 2 January 2012 an intense burst of aftershock activity comprising more than 30 earthquakes above M3.0, with two earthquakes above M5.0, occurred about 20km north-east of the city.

An aerial view of cliff collapse in the Port Hills after the 22 February 2011 Christchurch 1 Earthquake. Photo: Tonkin & Taylor.

2.2 Significant aftershocks

Since 4 September 2010 there have been many significant aftershocks. The table below shows the list of significant aftershocks since the 4 September 2010 earthquake (as at 15 January 2012) as sourced from GeoNet.

Aftershocks are expected to continue with no warning. However, over time they will decline in intensity and frequency. Their location cannot be predicted. The damage an aftershock may cause depends on the location and depth of the earthquake.

Key points:

- **In the Canterbury earthquake series that began on 4 September 2010 there have been four main earthquakes (Darfield, Christchurch 1, 2 and 3 Earthquakes) that have likely resulted in measurable land damage.**
- **The 22 February 2011 earthquake was one of New Zealand's worst natural disasters. 185 people died as a result of the earthquake. A declared state of national emergency stayed in force from 23 February 2011 until 30 April 2011.**
- **This was the first time in New Zealand's history that a state of national emergency had been declared as a result of a civil defence emergency event.**
- **The unusual aspect of the Christchurch earthquakes was their very strong shaking relative to the size of the earthquake.**
- **The 22 February 2011 Christchurch 1 Earthquake produced the highest vertical and horizontal ground accelerations (how hard the earth shakes) ever recorded in New Zealand.**
- **More information about the earthquakes can be found at www.geonet.org.nz or www.gns.cri.nz**

Table 2.1 - The four main earthquakes and significant aftershocks

Event	Date	Magnitude	Depth	Location
Darfield earthquake*	**4 September 2010**	**M7.1**	**10km**	**10km SE of Darfield**
Aftershock	19 October 2010	M5.0	9km	10km SW of Christchurch
Aftershock	14 November 2010	M4.9	9km	20km SW of Christchurch
Aftershock	26 December 2010	M4.4	3km	≤5km of Christchurch
Aftershock	20 January 2011	M4.1	7km	10km SW of Christchurch
Aftershock	4 February 2011	M4.6	9km	20km SW of Christchurch
Christchurch 1 earthquake (Lyttelton)*	**22 February 2011**	**M6.2**	**5km**	**10km SE of Christchurch**
Aftershock	16 April 2011	M5.3	11km	20km SE of Christchurch
Aftershock	30 April 2011	M5.2	9km	60km NW of Christchurch
Aftershock	10 May 2011	M5.3	15km	20km W of Christchurch
Aftershock	6 June 2011	M5.5	15km	20km SW of Christchurch
Foreshock	13 June 2011	M5.6	9km	10km SE of Christchurch
Christchurch 2 earthquake (Sumner)*	**13 June 2011**	**M6.0**	**6km**	**10km SE of Christchurch**
Aftershock	15 June 2011	M5.0	6km	20km SE of Christchurch
Aftershock	21 June 2011	M5.4	8km	10km SW Christchurch
Aftershock	9 October 2011	M5.5	12km	10km NE of Diamond Harbour
Foreshock (Christchurch 3 earthquake)	23 December 2011	M5.8	8km	20km E of Christchurch
Christchurch 3 earthquake (New Brighton)*	**23 December 2011**	**M5.9**	**6km**	**10km E of Christchurch**
Aftershock	24 December 2011	M5.1	8km	22km SE of Christchurch
Aftershock	2 January 2012	M5.1	13km	19km E of Christchurch
Aftershock	2 January 2012	M5.5	14km	20km E of Christchurch
Aftershock	6 January 2012	M5.0	7km	14km E of Christchurch
Aftershock	7 January 2012	M5.3	8km	15km SE of Christchurch
Aftershock	15 January 2012	M5.1	6km	10km E of Christchurch

*Note: *Events shown in bold have likely resulted in measurable land damage for EQC insurance claim processes. Other smaller events may have triggered localised liquefaction but are unlikely to have resulted in measureable land damage.*

3 Land damage assessment

3.1 General land damage

The susceptibility of ground to liquefaction as a result of earthquake shaking has been a recognised natural hazard for Canterbury for some time. This is shown on Environment Canterbury (ECan) liquefaction hazard maps (ECan, 2004), and various preceding hazard maps for Canterbury.

The Darfield Earthquake of 4 September 2010 resulted in surface expression of liquefaction, albeit localised to particular areas across the Canterbury region. The liquefaction resulted in ground settlement and lateral spreading and, to a lesser extent, bearing capacity failure, with consequential building damage.

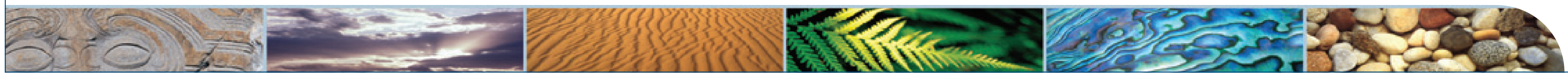
The Christchurch 1 Earthquake of 22 February 2011, although of smaller magnitude than the Darfield Earthquake, caused even greater urban land damage both from liquefaction and displaced land. Damage was over a much wider area, because of the earthquakes shallow depth and close proximity to central Christchurch. The observed surface expression of liquefaction has been noted by international experts as perhaps the greatest ever extent of observed liquefaction in an urban area.

The ground accelerations recorded from the Christchurch 1 Earthquake are among some of the highest recorded anywhere in the world.

The great extent of ground liquefaction was 10 times that caused by the September 2010 earthquake, affecting mainly the eastern side of the city.

The Christchurch 2 Earthquake of 13 June 2011 caused further land damage both from liquefaction on the Plains and land displaced in the Port Hills. However, this was generally to a lesser extent in most suburbs compared with 22 February 2011. The Christchurch 3 Earthquake of 23 December 2011 caused land damage as a result of liquefaction particularly to the eastern suburbs on the Plains and some relatively minor land movements in the hill suburbs.

An aerial view of liquefaction and flooding after the 22 February 2011 earthquake. Photo: Tonkin & Taylor.



Lateral spread alongside the Avon River. Photo: Tonkin & Taylor

In areas adjacent to the rivers, a mix of lateral spreading, ground oscillation (backwards and forwards ground movement during earthquake shaking) and liquefaction-related settlement resulted in very severe damage to pipelines; cracking, deformation and differential settlement of buildings; and inundation of land and buildings with sand and water.

In the areas away from the rivers, underlain by loose alluvial deposits, damage occurred due to ground oscillation, the ejection of sand, and liquefaction-related settlement. This resulted in generally minor to moderate damage to buildings and localised inundation of land and buildings with sand.

A short time (generally hours to days) after earthquake shaking stops, the liquefied soil regains the strength that it had before the earthquake and returns to its pre-earthquake state.

On steep coastal cliffs and throughout the Port Hills area the Christchurch 1 Earthquake triggered a relatively large number of rock falls and earthquake induced slope failures (Hancox and Perrin, 2011). Severe localised damage was caused by cliff top seismic amplification (increased earthquake shaking because of the makeup of the ground). The most damage occurred in areas that had a high susceptibility to earthquake induced slope failures such as steep to near vertical natural cliffs, ridges and unsupported cuts, and excavations for buildings and quarries. Rock fall occurred as single to multiple boulder roll, as well as relatively large debris inundations from cliff collapse from approximately 30 to 70 metre (m) high cliff faces on to roads, reserves and areas behind buildings and residential properties. The Christchurch 2 Earthquake caused similar damage due to very high horizontal ground accelerations.

Much of the ground movement only occurs during severe shaking, and is termed seismically displaced land. When the shaking stops the ground also stops moving.

Ongoing minor aftershocks throughout 2010 and 2011 did not cause significant measurable land damage for insurance claim purposes.

Land damage assessments for EQC have been split into two regions:

A. **The Plains** - this is land that is typically flat and is underlain by materials that can be broadly described as susceptible to liquefaction during earthquake shaking where the groundwater table is shallow. These are fine grained alluvial, aeolian, estuarine and marine sediment deposits comprising silts, sands and gravels.

B. **The Port Hills** - this is considered to be sloping land located on the Port Hills and wider Banks Peninsula area, composed primarily of volcanic rock (basalt) overlain by loess. Where the basaltic lava flows outcrop as bluffs or pinnacles, the jointed blocks of rock are susceptible to breaking free of the face or the ground and rolling down slopes when subjected to strong ground shaking. Earthquake induced land movement in the form of landslides can also occur on steep slopes and adjacent to retaining walls when subjected to strong ground shaking.

3.2 Land damage types - the Plains

Earthquake land damage identified on residential properties on the Canterbury Plains is explained below (Table 3.1). Appendix A has diagrammatic and photographic representations of the damage types.

Detailed identification of land damage is mapped during individual engineering land damage assessments (see section 4.4) undertaken at each residential property for the purpose of EQC claim settlement.

The physical land damage on this table is often interrelated with the land settling i.e. future land damage can worsen in subsequent events if land dropped as a result of the earthquakes.

In addition to these seven types of land damage, some land on the plains may have undergone physical changes that are not obvious from a visual assessment. In some cases, land has become more vulnerable to future natural disaster events because of physical changes that have occurred to the land, in particular, a drop in the height of the land. This change in height has occurred as a consequence of regional tectonic movements, or the ejection of sands when liquefaction has occurred. As a result, some land is more susceptible to change from:

1. future flooding events. In the case of land closer to the sea, predominantly through tidal events, and in the case of land further to the west, through rainfall events;
2. future liquefaction events. In the case of some land, the reduction in height has reduced the thickness of the crust, that is the thickness of the non-liquefiable layer below the ground surface.

Not all changes in land height will be considered to be "land damage" by EQC under the EQC Act, whether they are will depend on the significance of the change.

The natural hazards of flooding and liquefaction susceptibility have been recognised for Canterbury for some time, as shown on Christchurch City Council and ECan maps.

Table 3.1 - The Plains land damage types as assessed for EQC land claims purposes

Type	Description
Cracks fron lateral spreading	Lateral spreading is the sideways movement of land typically toward watercourses or other unconfined land faces. Blocks of the earth crust move sideways over liquefied soils toward an area of lower elevation. Surface damage can include minor to major cracks in the land, tilting of crust blocks and associated distortions to structures.
Land cracking (oscillation movements)	Cracks to land resulting from both lateral spreading (see above) and also oscillation induced cracking. This category of land damage refers to oscillation induced cracking only. The cracks produced from oscillation (backwards and forwards ground movement during earthquake shaking) are typically minor.
Undulating land	Undulating land is caused by the uneven settlement of the ground surface as a result of the ejection of sand and silt, and to a lesser extent the uneven settlement of liquefied soils.
Localised ponding	Local settlement or lowering of the ground resulting in water forming ponds on the ground surface in locations where it did not pond before the earthquakes.
Local settlement	In some areas residential land has settled more than the adjacent land beneath which public services are located (and vice-versa). In some situations this results in drains that previously flowed toward public services now flowing back toward the house.
Groundwater springs	New groundwater springs are now emitted at the ground surface where this was not happening before the earthquake. This usually occurs at a specific location on residential land.
Inundation by ejected sand and silt	This includes the ejection of sand and silt to the ground surface from the zone below the water table through cracks in the crust. The ejected sand and silt may be deposited in isolated mounds, under dwellings, or over large areas.

3.3 Land damage types - Port Hills

The following types of land damage (Table 3.2) have been identified as occurring on residential properties on the hill suburbs of Christchurch. Appendix A has diagrammatic and photographic representations of the damage types.

The EQC Act provides statutory insurance for residential insured property against natural disaster damage where any physical loss or damage to the property has occurred and also covers physical loss or damage that has not yet occurred but is considered (by EQC) to be 'imminent' as a direct result of the natural disaster which has occurred.

Table 3.2 - The Port Hills land damage types as assessed for EQC land claim purposes

Type	Description
Rock fall	Rocks already impacting structures, land and other assets. Rocks that have been dislodged and moved down slope, and have now stopped moving, but have the potential to move in the future. Bedrock outcrop that has been loosened or undermined by the ground shaking, resulting in additional 'source' rock potential ie. could fall some time in the future.
Large scale land movement	Land movement near the base of the Port Hills caused by strong earthquake shaking and possible loss of toe support (liquefaction of alluvial material), resulting in down slope movement. Seismic displacement of land on ridge crests and near the edge of cliffs resultings in cracking and deformation of land, and may result in some down slope/lateral movement. Large scale 'collapse' of bedrock cliffs resulting in loss of land at the top of the cliff face and inundation (burial) of land/structures/assets at the base of the cliff.
Small scale land movement and retaining wall failures	Failure of existing unretained fill slopes. Failure of existing unretained cut slopes. Failure of existing retaining walls supporting cut slopes. Failure of existing retaining walls supporting fill slopes.

Below is a diagram (Figure 3.1) showing how cut and fill slopes work.

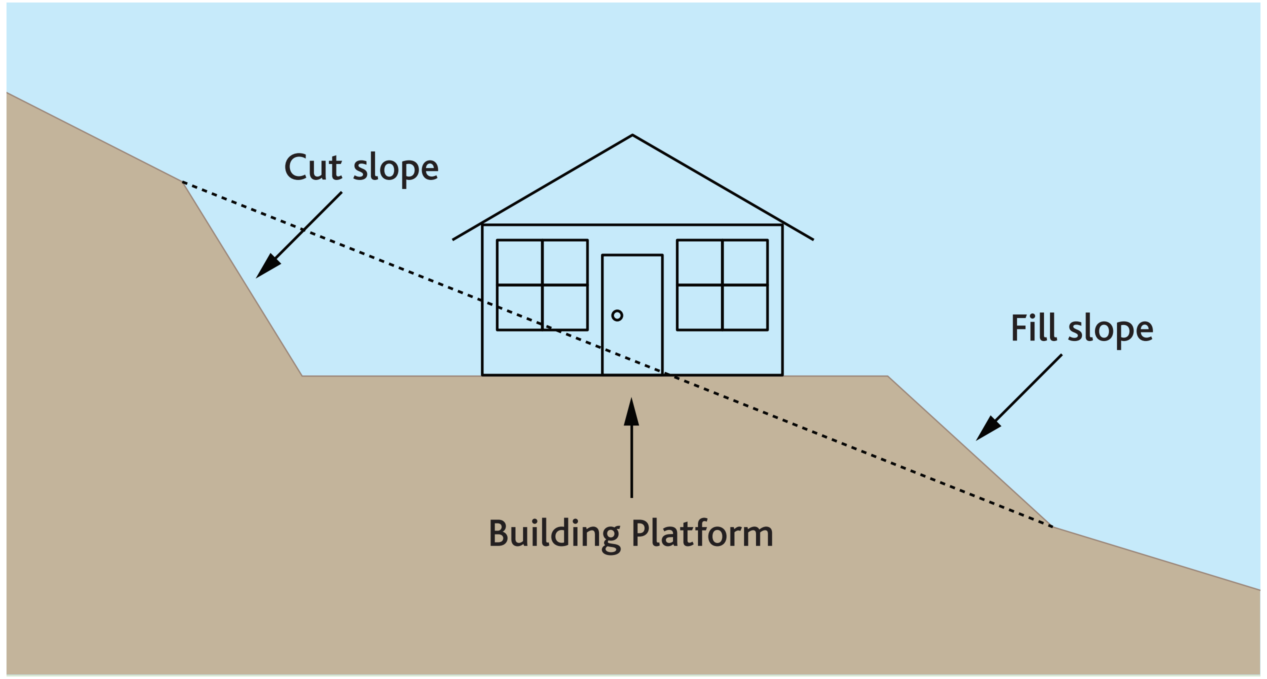


Figure 3.1 shows how a slope is cut into the hill on the upslope side of a hillside house and filled out to make a level platform on the down slope side.

Key points:

- **There are two areas in Canterbury that were differently affected by the main earthquakes of 2010 and 2011 - the flat land of the Plains and the slopes of the Port Hills and Banks Peninsula area.**
- **For EQC, T&T has mapped and assessed land damage to assist in EQC's claim settlement. This has been the most complex and resource intensive land investigation ever undertaken on EQC's behalf with the scale of the investigation more than ten times greater than any other EQC investigation and many times larger than that seen for major infrastructure projects in this country.**
- **Canterbury's susceptibility to the types of land damage seen on the Plains and in the hills was well known in advance of the earthquakes. The susceptibility is typical to many parts of New Zealand prone to earthquakes.**
- **In most of the urban areas with known susceptibility, while the land has changed as a result of the earthquakes, it is no less safe to live or build on than it was before the earthquakes. However, as a result of the earthquakes, building requirements may have changed, including foundation types and building materials.**
- **The 22 February 2011 earthquake, although of smaller magnitude than the 4 September 2010 earthquake, caused even greater urban land damage both from liquefaction and land movement, and over a much wider area, because of its shallow depth and close proximity to central Christchurch.**
- **On the Plains there are seven types of land damage identified and mapped for EQC during the individual property land damage assessments. There may be more than one type of land damage observed on a property. (Appendix A has diagrammatic and photographic representations of the damage types.)**
- **On the hills, there are three forms of land damage mapped for EQC during individual property land damage assessments. There may be more than one type of land damage on a property. (Appendix A has diagrammatic and photographic representations of the damage types.)**
- **On some properties there is no land damage, but there may still be building damage due to earthquake shaking.**

4 Mapping process and methodology

There are three steps in land damage mapping and assessment, depending on the degree of land damage arising from an earthquake.

These are:

1. Step 1 - preliminary regional broad scale mapping, to give a quick assessment of the extent and severity of damage.
2. Step 2 - rapid property-by-property mapping of land damage patterns, to give an indication of area-wide issues.
3. Step 3 - detailed individual EQC Land Damage Assessment Team (LDAT) process for individual land claim settlement.

The following points relating to land damage mapping should be noted.

- Mapped liquefaction and lateral spread observations have been gathered using a variety of methods and have varying precision and reliability. Canterbury's susceptibility to the types of land damage seen on the Plains and in the hills was well known in advance of the earthquakes. Areas where liquefaction was not apparent in this earthquake series may still be prone to liquefaction in future. The pattern of liquefaction in future earthquakes may be different to previous observations. Published liquefaction hazard maps for Canterbury are still a better indicator of potential liquefaction and land damage hazards in future earthquakes. ECan holds such hazard maps.
- The maps provided in this report identify areas where land damage and evidence of liquefaction were visible at the surface at the time of inspection. It is possible that liquefaction may have occurred at depth without obvious evidence being visible at the surface, or that evidence of liquefaction may have been removed before an area was inspected.
- It is noted that liquefaction and related land damage is not only related to the ground and groundwater conditions, but also the specific characteristics of a particular earthquake (frequency, directionality, duration etc).

4.1 Step 1: Regional mapping - all areas

Land damage assessment processes completed following the 22 February 2011 Christchurch 1 Earthquake, and subsequent aftershocks, were similar to what was done following the 4 September 2010 Darfield Earthquake (T&T, 2010a). The report prepared following this assessment process is available on EQC website at: http://canterbury.eqc.govt.nz/news/reports

Preliminary regional (broad scale) mapping included:

1. Initial general observations from teams in the field during and immediately following the earthquakes - 22 February 2011, 13 June 2011 and 23 December 2011.
2. Rapid reconnaissance flyover mapping of affected areas including Waimakariri district, Christchurch city, Port Hills and Lyttelton Harbour - 23 February 2011, 14 June 2011 and 24 December 2011.
3. Preliminary liquefaction observation mapping on the Plains conducted by road drive-over survey - 24 to 25 February 2011, 15 to 16 June 2011 and 23 to 24 December 2011.
4. Aerial photograph mapping of liquefaction observations on the plains
   i. The aerial photography was undertaken on 23 - 24 February 2011 by NZ Aerial Mapping.
   ii. The aerial photography was undertaken on 15 - 17 June 2011 by NZ Aerial Mapping.
   iii. The aerial photography was undertaken on 24 and 26 December 2011 by NZ Aerial Mapping.

4.2 Step 2: Property-by-property mapping - the Plains

Following regional reconnaissance and broad mapping assessments, geotechnical professionals undertook rapid property-by-property mapping of liquefaction and lateral spread observations in the areas worst affected by liquefaction. This was for EQC's rapid reconnaissance triaging.

Mapping of liquefaction and lateral spread observations was based on rapid property inspections to grade the severity of the liquefaction and lateral spread after the earthquakes. This was done after the 4 September 2010 and 22 February 2011 earthquakes. It provided an overview of the pattern of land damage across Canterbury. It was not repeated after the 13 June 2011 or 23 December 2011 earthquakes. This was because the severity and extent of liquefaction was less than what happened on 22 February 2011, and generally caused an incremental increase only of the same types of damage on each property as observed after 22 February 2011. Mapping of liquefaction and lateral spread observations was used to determine areas the land damage assessment team should go to for more detailed individual property inspections (Step 3) (see section 4.4).

4.2.1 Methodology for severity mapping - post 22 February 2011

Mapping liquefaction and lateral spread severity property-by-property after the Darfield earthquake was undertaken from 5 September 2010 to early November 2010. In-fill mapping in additional areas continued until early December 2010. Further mapping was required from 28 February to 25 March 2011 following the Christchurch 1 Earthquake. Assessments were completed based on observations of liquefaction and lateral spread visible from public roads and reserves, and by entering private properties and talking to homeowners where appropriate. Information collected on more than 100,000 properties throughout the urban residential areas of Christchurch city, Waimakariri and Selwyn districts was then digitised to produce maps of the pattern on liquefaction and lateral spread observations for residential properties.

A member of T&T's field team, recording cracks on a residential property.

Local maps, using aerial photo imagery and property boundaries sourced from Terraview (2010) at a 1:3000 scale, were used to record the observations. To simplify assessment and field-based mapping, descriptions of the severity of liquefaction and lateral spread observed were colour coded. Each land parcel assessed was assigned a land observation colour code classification, according to the following observation categories shown in Table 4.1. These categories were developed and refined further from the property-by-property rapid mapping undertaken following the 4 September 2010 earthquake, as reported on in the T&T Stage 1 Report (T&T, 2010a). These categories are aligned with international practice and the New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines (NZGS, 2010).

These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (CERA) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

It is possible that more than one land observation category will apply across a property.

The table also provides a comparison of the observation categories developed for the local mapping with the performance levels given in the New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines (NZGS, 2010).

Table 4.1 - The Plains liquefaction and lateral spread observations - local property-by-property mapping categories

Observation category	Colour code*	Observation	Description	Performance level**
Lateral spreading	Dark Red	Very severe lateral spreading	Extensive lateral spreading (≥1m cumulative); large open cracks extending through the ground surface, with very severe horizontal and/or vertical displacements (≥200mm). May also include liquefaction observations as below.	L5
	Red	Moderate to major lateral spreading	Moderate to major lateral spreading (<1m cumulative), large cracks extending across the ground surface, with horizontal and/or vertical displacement (>50mm, but generally <200 mm). May also include liquefaction observations as below.	L4
Liquefaction	Dark Orange	Severe liquefaction	Visible signs of severe liquefaction (major amounts of ejected sand on ground surface), and/or severe settlement, site is substantially (≥ 25 percent) covered in sand; small cracks from ground oscillations (<50mm) may be present, but little to no vertical displacement across cracks; limited evidence of lateral movement.	L3 to L4
	Light Orange	Moderate liquefaction	Visible signs of liquefaction (minor to moderate ejected sand on surface), site is covered by up to as much as 25 percent in sand, small cracks from ground oscillations (<50mm) may be present, but no vertical displacement of cracks; no apparent lateral movement.	L2 to L3
Shaking	Green	Minor land effects	Shaking-induced ground cracking resulting from cyclic deformation and surface waves. Effects generally limited to minor cracking (tension) and buckling (compression). No signs of liquefaction or lateral/vertical displacements obviously visible at the surface.	L0 to L1
	Blue	No observed land effects	No apparent liquefaction or land effects obviously visible at the surface.	L0

** For mapping following the September Darfield Earthquake the dark orange and red categories were combined in the Red category*
*** Performance Level based on general interpretation (NZGS, 2010). This table focuses on observed land effects as assessed in the field compared with effects from liquefaction as discussed in the NZGS Guideline.*

The following (Figure 4.1) looks at typical distribution of categories of liquefaction and lateral spread observations for the Plains.

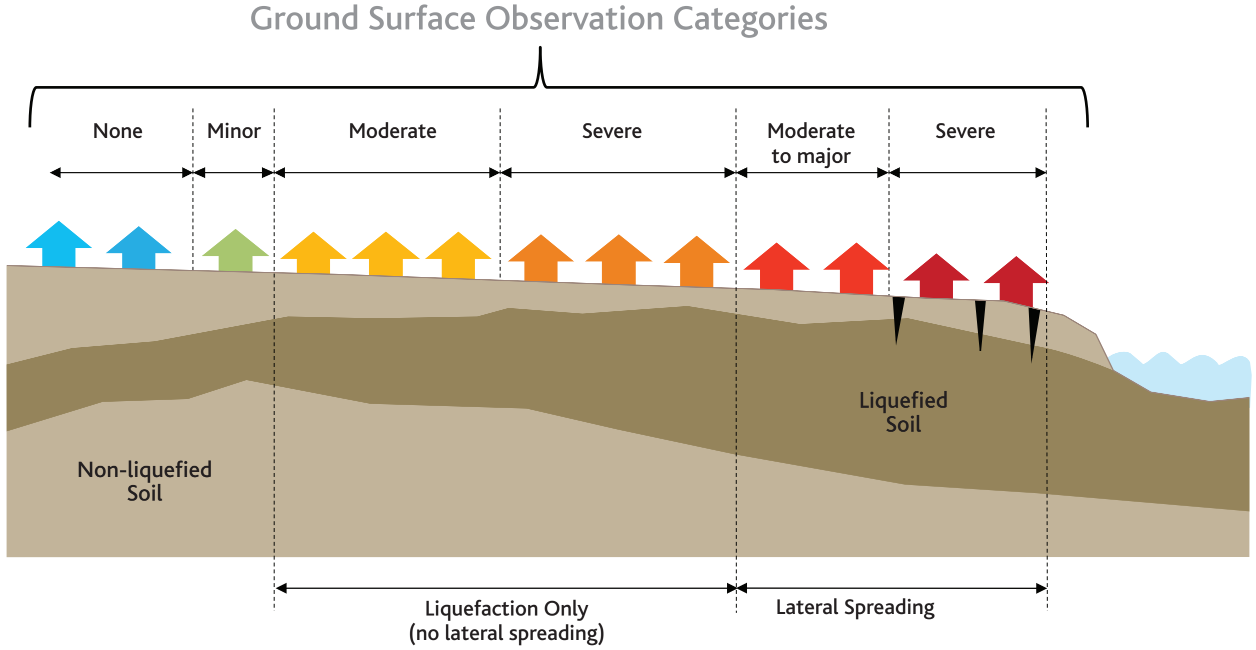


Figure 4.1 Schematic section of spatial distribution of categories of the Plains liquefaction and lateral spread observations

The figure represents general conditions observed in the field. In lateral spreading areas, both lateral spreading and ejection of liquefied material were often observed, however the most significant effects on residential buildings in these areas were usually caused by the lateral spreading. In liquefaction only areas, minor lateral ground movements occurred in some places due to ground oscillation or relaxation, however the most significant effects on buildings were usually related to liquefaction settlement or strength loss.

General liquefaction and lateral spread maps for the Plains are included in Appendix B for Northern, Central, Eastern and Southern suburbs (Map Series 2 to 5).

4.3 Step 2: Property-by-property mapping - Port Hills

Generally, the 4 September 2010 Darfield Earthquake produced only building shaking damage in the hill suburbs of Christchurch. There was damage to a small number of houses and landslip debris required removal from insured residential property. The effect of the Darfield Earthquake on residential land in the Port Hills was minor. This was expected given the magnitude and location of the earthquake. No land mapping or specific land assessment was undertaken at that time.

The Christchurch 1 Earthquake on 22 February 2011 generated peak ground accelerations that were about twice the standard level previously specified for most engineering design. Topographic amplification, rock fall and cliff collapse was extensive. The extreme ground shaking (accelerations recorded on 22 February 2011 are among the highest recorded anywhere in New Zealand) caused displacement of ground on and immediately above very steep slopes, and dislodged rocks from pinnacles and bluffs.

Following initial reconnaissance in the days immediately following the 22 February 2011 earthquake, a separate team of geotechnical professionals was mandated to assess the 'risk to life and lifelines' on behalf of the Christchurch City Council (CCC) and Christchurch Civil Defence (CD). This group was called the Port Hills Geotechnical Group (PHGG).

The CCC PHGG is a consortium of geotechnical consultancies. Collectively they have worked to assess lifelines and life safety issues arising from geotechnical hazards as a result of the earthquakes. Primarily these hazards stem from rock falls, boulder roll and cliff collapse. This group has worked on a macro, global scale in areas of significant land effects or associated life risk hazards.

EQC's initial reconnaissance - and the subsequent life and lifeline risk assessments by CCC - identified three main damage/potential damage situations on the Port Hills and wider Banks Peninsula. These are presented previously in the table (Table 3.2).

Through the state of national emergency, Urban Search and Rescue (USAR) teams and members of the PHGG were responsible for the application of 'red-stickers' (and the subsequent Section 124 notices), to houses/properties that were considered unsafe for occupation. This was as a result of immediate earthquake damage making the building unsafe, or identified potential risk for geotechnical reasons. A red sticker meant that the building was not to be entered because it was considered unsafe. Sites/areas of concern were visited on the basis of information provided to the various consultancies by emergency services, members of the public and from specific observations of damage or damage potential noted from the rapid aerial reconnaissance or during fieldwork.

There may still be notices on homes/properties in the Port Hills prohibiting entry for safety reasons. The CCC is responsible for these. The issuing and removal of red stickers is not the responsibility of EQC and is not associated in any way with the process of claim settlement by EQC.

The specialist EQC Land Damage Assessment Team (LDAT - Step 3 - see section 4.4) has undertaken individual site assessments of properties on the hill suburbs, including the Port Hills and Lyttelton, as part of the normal EQC insurance process. These assessments are being completed for the purposes of insurance claim settlement, not to facilitate placement/removal of red placard/Section 124 notices, nor for design of remedial/repair works. This work has been ongoing since 14 March 2011.

Additional preliminary assessments of some areas of significant area-wide ground changes have been undertaken by T&T on behalf of EQC. Collaboration with geotechnical consultants working for the CCC ensured that any investigations in areas where CCC assets were also damaged/threatened allowed for appropriate data capture to address both EQC and CCC requirements.

Following the 22 February 2011 earthquake, EQC building assessors undertook rapid building assessments of the entire Christchurch area including the Port Hills. This information contained a land observation component that was used as an initial triage of the worst affected hill suburb areas for the specialist teams to assess later.

4.3.1 Methodology for severity mapping - post 13 June 2011

Further land changes occurred as a result of the similar magnitude Christchurch 2 Earthquake on 13 June 2011. Overall, the effect of this earthquake on residential land in the Port Hills was less than from the 22 February 2011 earthquake.

Aerial view of liquefaction effects around QEII park. Photo: Tonkin & Taylor

Following the 13 June 2011 earthquake a specific land observation rapid mapping categorisation was designed (Table 4.3) to categorise the severity of the effects of the earthquakes on residential land in the hill suburbs. This was similar to what was used on the Plains. This provided a broad assessment and understanding of the nature, extent and patterns of the land observations on the sloping suburbs of Christchurch, in particular the Port Hills suburbs between Westmorland and Whitewash Head, including Lyttelton.

This information was collected on behalf of EQC. It complements the work undertaken by the PHGG but does not in any way provide an assessment of life safety hazards. That is beyond the scope of work required by EQC Act 1993.

Teams of engineering field personnel mapped general land observations on a residential property-by-property micro scale for the purpose of collecting early information for individual insurance claims. The teams visited each property, briefly mapped land observations and created plans of the wider affected areas. The objective was to determine the distribution and patterns of land effects, and to identify areas of significant land damage which would likely require more intensive investigation and assessment later.

Areas where the earthquakes had significant effects on residential land were identified. The individual residential properties within these areas, which are referred to as locations of 'area-wide' assessment, have had a combined geotechnical land assessment. This may include additional specific mapping, subsurface ground investigations, ongoing monitoring and/or modelling before any EQC insurance claim settlement is made.

Table 4.3 - The Port Hills land observations categories

Observation category	Colour code	Observation description	Description
Rock fall Boulders and blocks of basalt detach and roll from a bedrock outcrop during the ground shaking, or have the potential to roll down slopes, impacting structures, land and other public/private assets. Major cliff collapse. Failure of postglacial to recent sea cliffs and quarry faces.		Rock fall 1 - potential (RF1)	Rocks with the potential to impact properties have been dislodged and moved down slopes, and have now stopped moving, but have the potential to move in the future. Bedrock outcrop that has been affected by the ground shaking, resulting in additional 'source' rock potential.
		Rock fall 2 - minor inundation (RF2)	Rocks that have already impacted properties (structures, land and other assets).
	Dark Orange	Rock fall 3 - major inundation (RF3	Large scale 'collapse' of rock cliffs resulting in inundation of properties (land/structures/assets) at the base of the cliff.
Land movement (seismically displaced land) Identified where land has been damaged (cracked/displaced/deformed) due to the strong shaking/accelerations experienced during the earthquake. Includes ridge cracking and loss of toe support (liquefaction of alluvial material) etc.	Red	Small scale - minor (LM1)	Cracking and deformation of land resulting in lateral and/or vertical displacement. Individual cracks less than 50mm wide, or less than 100mm cumulative crack widths over a typical 30m section.
	Dark Red	Large scale - major to severe (LM2)	Cracking and deformation of land with down slope component and/or vertical displacement (includes cliff collapse land at top of a slope). Individual cracks greater than 50mm wide, or more than 100mm cumulative crack widths over a typical 30m section.
	Purple	Land inundation (LM3)	Inundation from failed slopes (unretained and/ or retained).
Retaining wall failures Deformation of existing retaining walls, fill slopes or cut faces.	Green	Retaining walls 1 - minor (RW1)	Retaining walls <1.5m high.
	Pink	Retaining walls 2 - major (RW2)	Retaining walls >1.5m high and retaining walls <1.5m high supporting the building or access way.
No observed land effects	Blue		No apparent land cracking or other land effects obviously visible at the surface. However strong shaking may have had an effect on buildings.

Where multiple combinations of land observations for a property existed mapping was undertaken with the base colour from 'land movement' and an abbreviated annotation of rock fall or retaining wall category overtop (i.e. RF or RW).

A general land observation map based on EQC building assessor rapid assessment damage data from pre 13 June 2011 for the Port Hills and Lyttelton area is included in Appendix B (Map 6a). The post 13 June 2011 land observations are presented as a series of maps (6b to 6f) included in Appendix B.

4.4 Step 3: Detailed individual property EQC land damage assessments

To assist EQC in determining land damage claim settlements for insurance purposes, an EQC Land Damage Assessment Team (LDAT) of specialist engineers and technicians was established to assess individual properties following the 4 September 2010 earthquake.

T&T managed, trained and supervised a team of up to 400 engineers from approximately 40 engineering consultant companies from throughout New Zealand. This was the largest and most complex land damage assessment exercise ever undertaken for EQC. A land damage template form of each property was created, to map and assess individual land damage insurance claims for observed physical land damage.

Initially EQC LDAT inspections and forms were completed for 16,000 out of the estimated 25,000 properties where the land was affected by the 4 September 2010 earthquake (prior to 22 February 2011). Approximately 65,000 properties have since been assessed in detail on an individual basis since 22 February 2011 (generally inspections have not been repeated for those properties assessed before the 13 June 2011 earthquake. No inspections had been repeated since the 23 December 2011 earthquake at the time this report was finalised). To date 60,000 property owners have informed EQC of land damage with lodgement of their EQC claim.

Land and limited building damage information was collected. Template forms included the types of land damage identified for the Plains and for the Port Hills. In addition a site plan containing a recent aerial photograph was used to sketch the location of any observed land effects for each individual property.

EQC LDAT did property assessments in the affected areas based on physical address, regardless of whether there was an EQC claim lodged. This was done because more than 90 percent of the properties in the worst affected suburbs had lodged an EQC claim for at least one of the main earthquakes. It was, therefore more efficient to assess properties by going house-to-house, rather than only inspecting properties around Christchurch once a claim for land damage was received by EQC. As a result there are likely to be more LDAT assessments than there are properties with EQC land claims.

The data from the land effects inspections will be used by EQC claims teams for work on the claims settlement process. When individual properties go through the claim settlement process an EQC cost estimator will either visit the site again (with the engineering land damage assessment information on hand) or will use the recorded information including the aerial site plan for each site (EQC LDAT form) and undertake a detailed remedial cost estimate.

Key points:

- **Extensive mapping and assessment of land after the main earthquakes in Canterbury in 2010 and 2011 has given EQC a picture of the area-wide land changes and individual property land damage.**
- **Mapping and assessment has ranged from gathering and categorising information in the worst affected suburbs for triaging purposes (Step 1 and 2 mapping), to more detailed mapping and assessments of individual residential properties (Step 3) for individual EQC claim settlements.**
- **EQC has never had to map and assess land damage on such a large scale before. Industry experts believe that this may be the largest exercise of its type undertaken in the world.**
- **The mapping and assessment processes and methodology are in line with international best practice and aligned with the New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines.**

- **Categories of land observations have been mapped with specific colours (some of the maps in Appendix B). These observation mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (CERA) for residential land zoning and the Department of Building and Housing (DBH) for technical categories. In most cases their use pre-dates the CERA zoning decisions.**
- **Some homes/properties in the Port Hills may still have Section 124 notices prohibiting entry for safety reasons. The Christchurch City Council is responsible for issuing and for removing these and they have nothing to do with EQC's property assessments for insurance purposes.**
- **Land information collected for EQC does not in any way provide an assessment of life safety hazards. That is beyond the scope of work required by EQC Act 1993.**
- **EQC has been sharing technical data it has collected with other agencies such as territorial authorities, CERA, and engineering and construction professionals, to facilitate rebuilding in Canterbury.**

5 Land survey data and assessment

High-resolution aerial photographs of the most affected areas of Christchurch city and Waimakariri and Selwyn districts were taken in the days following each of the main earthquakes. Aerial photography was used (see Section 4) as a general tool to assess the nature and extent of land affected by liquefaction. This was an important supplement to ground inspections where evidence of liquefaction (sand and water ejection) had been either removed or reduced before the inspections could take place.

Aerial LiDAR (Light Detection and Ranging) technology surveys that measure the height of the ground from the air (accurate to +/- 100mm) were, in contrast, delayed until the sand and silt (and snow) had been removed so that the actual ground surface level was identified correctly. LiDAR surveys were undertaken in September 2010, March 2011, May 2011, September 2011 and February 2012. This LiDAR imagery was processed overseas to develop a bare earth model, free of buildings, trees and other obstructions with height greater than half a metre.

The LiDAR surveys were commissioned by various organisations (including Ministry of Civil Defence & Emergency Management, Christchurch City Council and EQC).

The LiDAR data was acquired by New Zealand Aerial Mapping (NZAM) and AAM Brisbane.

With the assistance of NZAM, Land Information New Zealand (LINZ) and GNS Science, T&T has produced maps showing changes in level of the ground after the Canterbury Earthquakes. Key results from this work are included in the maps at the back of this report.

Key points:

- **Land survey data (LiDAR) acquired following the main earthquakes has provided a comparison of the level of the ground before and after the Canterbury earthquakes. Along with the new survey benchmark information across Canterbury, this data has enabled ground level surface models to be developed.**

6 Ground investigations

6.1 General background - the Plains

EQC commissioned geotechnical ground investigations for residential areas where the land was most affected by the Darfield and Christchurch 1 earthquakes. T&T did broad scale investigations on behalf of EQC within the affected areas of the Waimakariri district, Christchurch city and Selwyn district suburbs. On the Plains this included subsurface site investigations and factual reporting at a suburb-wide level of detail.

This section outlines the investigations and reporting undertaken across 50 Canterbury suburbs.

The factual reports collate geotechnical investigation data from boreholes, soil tests and geophysical testing in each suburb. Factual geotechnical information obtained from the investigations is intended to provide a source of geotechnical data to support geotechnical advice for EQC and for future Council consent applications for the suburb. The reports present all available geotechnical and engineering geological investigations that were commissioned by EQC during 2010-2011 and all readily available geotechnical data that Environment Canterbury (ECan) held for the suburb as at September 2010. No interpretation of the factual investigation results has been made in the factual reports or this reporting.

The factual reports provide general technical information that will assist repair and rebuild decisions for areas affected by the earthquakes. The factual technical information details the subsurface state (including strength, soil types, etc) and condition of the land for those selected suburbs. This information can be compared with pre-earthquake data to tell if subsurface geology and geotechnical properties have changed. Typically the state of the subsurface land conditions has not changed materially due to the process of liquefaction on the Plains as a result of the Canterbury earthquakes.

Some individual properties may require individual geotechnical investigations and reports for dwelling repair purposes to be undertaken as determined by the normal insurance and consenting processes.

6.2 Information available - the Plains

Factual reported information collected following the 4 September 2010 and 22 February 2011 earthquakes can be obtained on EQC website: http://canterbury.eqc.govt.nz/news/reports

The information found on the website consists of area-wide geotechnical investigations in residential areas where significant widespread liquefaction was observed.

These investigations included:

a) Cone penetration testing
b) Machine boreholes
c) Geophysical testing
d) Groundwater observations
e) Laboratory testing.

6.2.1 Cone penetration testing (CPT)

CPT identifies continuous subsurface ground strength properties and characterises the typical soil profile.

6.2.2 Machine boreholes

Machine borehole information provides intermittent ground strength parameters of the subsurface conditions and a clear indication of the soil types from the actual core recovered. This information along with CPT results is used to produce a geological profile for the area.

EQC has stored material retrieved from the boreholes.

A machine drilling a borehole to assist in geological profiling of land in Canterbury affected by the earthquakes. Photo: Tonkin & Taylor.

6.2.3 Geophysical testing

Geophysical testing comprised Multichannel Analysis of Surface Waves (MASW) which is a technique to calculate the subsurface ground profile based on geophone measurements (vibration) recorded at the surface. Typically the geophones used were spaced at 1 metre(m) centres, to produce a vertical profile extending about 13m below ground level. This technique was carried out at approximately five metre intervals along a horizontal alignment to provide a two dimensional profile of the strength and density of the soil.

This was compared to the CPT data and borehole information to further determine and confirm information about the geological profile (densities of materials) to approximately 13m below the existing ground surface. The geophysical survey line may also identify loose deposits from old river channels that could be present in the subsurface strata in some locations.

6.2.4 Groundwater observations

Initial groundwater observations were made based on results of CPT testing, field observations of waterways (river and stream levels) and standpipe piezometers (instruments that measure the ground water level) that were installed during CPT testing and borehole drilling. Additional piezometers for ongoing groundwater monitoring were installed where appropriate and as detailed in the factual reports.

Ongoing monitoring of established piezometers is undertaken on a monthly basis, as well as after any significant aftershocks (Section 7). This monitoring data is used in conjunction with historic groundwater data to produce groundwater contour models for the affected regions.

6.2.5 Laboratory testing

Soil classification tests have been undertaken to provide quantitative analysis of the recovered sample materials from the boreholes.

6.2.6 Summary of area-wide suburb testing locations - the Plains

Table 6.1 indicates the general suburb locations where geotechnical subsurface ground investigations have been done. Investigations and reporting were nearly complete after the 4 September 2010 earthquake when the 22 February 2011 earthquake happened. Additional testing in previously investigated suburbs was added (see asterisk in table) and newly affected areas of land were also included in the testing.

A total of 1344 CPTs and 162 boreholes were completed throughout the suburbs. CPTs were done in 50 suburbs and boreholes in 34 of those suburbs. Geophysical testing (MASW) of 12km in length was undertaken in 11 suburbs and a total of 666 piezometers were installed.

EQC did no further suburb wide geotechnical subsurface investigations following the 13 June 2011 and 23 December 2011 earthquakes, because no new areas significantly affected by liquefaction were observed. The data collected before these earthquakes is still applicable.

The suburb names used in this table and the geotechnical factual reports are indicative of the general area covered by each report, not necessarily the official suburb boundaries defined by the local councils (however the factsheet data tables in Appendix C are broken down using the official suburb definitions).

6.3 General background - Port Hills

Geotechnical mapping and subsurface investigations were commissioned by EQC around selected hill suburbs (Table 6.2 over page) of Christchurch following the Christchurch 1 Earthquake on 22 February 2011. The extreme ground shaking in this earthquake caused extensive land movements in the Port Hills and Lyttelton. Investigations were undertaken for insurance claim purposes to understand the mechanisms and triggers of the land changes and to determine if there was any ongoing movement.

Locations of area-wide land movement were assessed together, as shown in Table 6.2.

Some individual properties may require individual geotechnical investigations and reports to be undertaken as determined by the normal insurance and consenting processes.

Table 6.1: Suburb investigation testing locations and numbers

Suburb	CPTs post Sept 2010	CPTs post Feb 2011	BHs post Sept 2010	BHs post Feb 2011	Total length (m) of MASW
Waimakariri district					
Kaiapoi North	43	-	6	-	730
Kaiapoi South	55	-	9	-	750
Kairaki Beach	3	-	1	-	-
Pines Beach	11	-	1	-	-
Waikuku Beach	2	-	-	-	-
Christchurch city					
Aranui*	5	29	-	2	-
Avon Loop	5	-	-	-	-
Avondale*	19	36	2	1	1540
Avonside*	31	17	7	3	1575
Beckenham	-	28	-	4	-
Bromley	-	20	-	1	-
Bryndwr	-	12	-	2	-
Belfast	13	-	-	-	-
Bexley	35	-	5	-	1200
Bishopdale	12	-	-	-	-
Brooklands	22	-	-	-	-
Burwood*	60	36	9	10	490
Casebrook	8	-	-	-	-
Cashmere	-	11	-	2	-
Central city	4	-	-	-	-
Dallington	62	-	9	-	2460
Fendalton*	12	13	-	7	-
Halswell	49	-	2	-	-
Hillsborough	-	14	-	-	-
Hoon Hay*	4	29	-	3	-
Kaianga	2	-	-	-	-
Linwood	-	37	-	-	-
Merivale*	7	14	-	6	-
New Brighton*	9	28	-	4	480
North New Brighton	-	6	-	-	-
Opawa	-	22	-	3	-
Papanui	-	14	-	1	-
Parklands	9	-	-	-	-
Redcliffs	3	-	-	-	-
Redwood	16	-	-	-	-
Richmond*	32	39	3	6	1245
Saint Albans*	13	60	-	7	-
Saint Martins*	1	27	-	8	-
Shirley	-	25	-	3	-
Somerfield	-	31	-	4	-
South New Brighton*	1	8	-	3	-
Southshore*	10	-	-	1	-
Spencerville	20	-	2	-	320
Spreydon	-	22	-	4	-
Sydenham	-	14	-	-	-
Waimairi Beach/Queenspark	-	23	-	3	-
Wainoni*	28	40	5	2	1220
Waltham*	1	21	-	3	-
Woolston	-	54	-	8	-
Selwyn district					
Tai Tapu	7	-	-	-	-
Total	**614**	**730**	**61**	**101**	**12,010**

*Note: * Suburbs where additional testing was added following the 22 February 2011 earthquake.*

As with the Plains, geotechnical ground investigations have been undertaken and this general technical information will assist in repair and rebuild decisions for areas damaged by the earthquakes.

Machine boreholes (BHs) have been drilled to provide intermittent ground strength parameters of the subsurface conditions and a clear indication of the soil types from the core material recovered. This information along with results from piezometers (instruments that measure fluid pressure) and inclinometers (instruments used to monitor land movement) is used to produce a geological profile for the area.

No further area wide investigations were undertaken by EQC following the 13 June 2011 and 23 December 2011 earthquakes because the data already collected is still applicable. However, ongoing monitoring has been undertaken following further significant earthquake shaking.

Key points:

- **EQC has collected a lot of technical data, on both the Plains and the Port Hills, to understand how the earthquakes have changed the land. This is important for settling individual claims and the information has been collected expressly for this purpose.**
- **EQC is sharing area-wide data it has collected with other agencies such as territorial local authorities, CERA, and engineering and construction professionals, to facilitate rebuilding in Canterbury.**
- **Technical data collected by EQC on the Plains is available in technical reports on its website: http://canterbury.eqc.govt.nz/news/reports**
- **T&T's technical mapping and analysis work for EQC is internationally peer reviewed by geotechnical experts in the United States and New Zealand.**

Table 6.2: Ground investigations in area wide land movement locations

Area name	Mechanism of failure/damage*	BHs	Inclinometers** installed	Piezometers installed
Defender	Seismic displacement, localised rock fall and inundation.	3	1	3
Glendevere/ Balmoral	Cliff collapse with tension cracking above, inundation, seismic displacement, retaining wall failure, fill settlement/slumping.	3	1	1
Huntlywood Dalgarven	Seismically displaced land at base of slope, localised retaining wall failure.	3	-	3
Kinsey/Clifton	Cliff collapse, seismically displaced land, landslip (extension/ translation/compression).	30	7	9
Maffeys	Seismic displacement with tension cracking above headscarp.	4	2	4
Ramahana/ Aotea/Glenview	Seismically displaced land at base of slope, continuous cracks through adjacent properties, localised retaining wall failure.	5	1	5
Richmond Hill	Cliff collapse, inundation, retaining wall failure, fill settlement/slumping, tension cracking.	4	-	1
Vernon	Seismically displaced land, landslip (extension/ translation/compression). Generation of springs at toe of slope.	15	5	10

*Notes: * land that has moved down slope during/immediately following earthquake shaking **land movement monitoring instrument*

7 Groundwater data and assessment

Groundwater levels across Canterbury are important when considering the effects of liquefaction on the land. Liquefaction occurs where loose soils below the groundwater level lose substantial strength and stiffness in response to earthquake shaking. This causes the soil to behave like a pressurised liquid where the sand and water mixture is ejected to the ground surface.

ECan published a report "Earthquake impacts on groundwater - Update #1" dated 13 April 2011 (ECan, 2011) following the earthquake of 22 February 2011. This report presents groundwater levels monitored in deep well boreholes from around Christchurch following the earthquake.

An initial analysis of the reported data shows there were significant groundwater level changes in eastern parts of Christchurch following the 22 February 2011 earthquake compared with what was recorded in the 4 September 2010 earthquake. Relatively short-term spikes in groundwater levels in the eastern suburbs were recorded, with increases of about 4m in some places. This was generally expected considering the proximity of the earthquake and the strong ground shaking recorded. The September 2010 earthquake had a greater impact in the west of Christchurch.

Generally groundwater levels have returned to almost normal levels in most cases and there is no clear evidence of significant change in aquifer pressures or properties. Initial test results suggest there has been little long term impact on groundwater levels in the Christchurch area from both earthquakes (i.e. the absolute level of groundwater remains the same, but in some areas the land elevation has dropped so the groundwater is closer to the surface).

ECan is undertaking ongoing monitoring to check for damage and blockages to the monitoring wells.

As part of the overall geotechnical ground investigations commissioned by EQC around selected suburbs of Canterbury, a series of standpipe piezometers (instruments measuring fluid pressure) were installed in completed boreholes to a depth of approximately 6m below ground surface. Standpipe piezometers were also installed in completed CPT locations to approximately 4m below ground surface between February and December 2011.

Standpipes were installed across the city to monitor groundwater to be used in groundwater surface modelling. A total of 666 standpipes were installed across various suburbs (Table 7.1 over page). These have been monitored on a monthly basis since installation. A number of standpipes have electronic level loggers installed and data is downloaded periodically from them.

After each earthquake the groundwater levels generally returned to their original elevation, because the groundwater surface elevation is strongly influenced by the mean sea level. Information collected from the widely spaced geotechnical site investigations and measurements of groundwater levels was combined with ECan water level data to develop a groundwater model.

Groundwater level (Lyttleton datum 1937) contouring across the city was completed using the Surfer (version 10) contouring and presentation package.

The groundwater levels were calculated using the median for sites with short periods of record (generally less than five monthly records during winter 2011), and mean plus one standard deviation for sites where the length of record was more than a year.

Maps showing the general groundwater contour model across the various suburbs (the Plains) are provided in Appendix B.

Key points:

- **While there were changes immediately after the main earthquakes, initial test results suggest there has been little long term impact on groundwater levels in Canterbury. That means, the absolute level of ground water remains the same, but in some areas the land has dropped so the groundwater is closer to the surface.**
- **Groundwater levels are important when considering the effects of liquefaction on the land in any future events.**

8 Information data acquisition

Various forms of data have been collected for the purpose of assisting EQC land claims settlement process and include:

1. Rapid mapping of land observations
2. Land damage assessment team (EQC LDAT) individual property inspections
3. Subsurface ground investigations
4. Groundwater levels
5. LiDAR airborne surveys of land levels
6. Ground surveys of land levels.

As outlined in Section 1, T&T has engaged with a range of local and international experts. The data has been received and input into a database that can be interrogated to produce maps and information to assist in the Canterbury recovery process.

All land damage information collected and collated by T&T on behalf of EQC is made available for EQC insurance claim settlement processes.

The map series (Table 8.1 over page) generated for this land report are detailed below and included in Appendix B.

Table 7.1: Standpipe piezometers installed throughout various suburbs			
Suburb	Post 22 February 2011		Post 4 September 2010
	CPT (Approx 4m depth)	BH (Approx 6m depth)	BH (Approx 6m depth)
Waimakariri district			
Kaiapoi North	23	-	1
Kaiapoi South	20	-	1
Kairaki Beach	3	-	1
Pines Beach	8	-	1
Christchurch city			
Aranui	23	-	-
Avon Loop	4	-	-
Avondale	28	-	-
Avonside	21	2	-
Beckenham	21	1	-
Belfast	4	-	-
Bexely	16	-	1
Bishopdale	8	-	-
Bromley	10	1	-
Brooklands	11	-	-
Bryndwr	6	1	-
Burwood	44	6	-
Casebrook	2	-	-
Cashmere	1	-	-
Central city	2	-	-
Dallington	34	-	-
Fendalton	12	2	-
Halswell	14	-	1
Hillsborough	9	-	-
Hoon Hay	11	1	-
Kaianga	2	-	-
Linwood	17	-	-
Merivale	5	-	-
New Brighton	21	-	-
North New Brighton	4	-	-
Opawa	10	2	-
Papanui	5	-	-
Parklands	9	-	-
Redcliffs	3	-	-
Redwood	14	-	-
Richmond	36	-	-
Saint Albans	23	-	-
Saint Martins	8	-	-
Shirley	15	1	-
Somerfield	16	-	-
South New Brighton	9	-	-
Southshore	10	-	-
Spencerville	5	-	-
Spreydon	7	1	-
Sydenham	5	-	-
Waimairi Beach-Queenspark	21	3	-
Wainoni	20	-	-
Waltham	8	-	-
Woolston	31	-	-
Total	639	21	6

Table 8.1 - Map series			
Map series 1- Overview maps			
Map 1.1	General overview map		
Map 1.2	Overview map - Northern suburbs		
Map 1.3	Overview map - Central suburbs		
Map 1.4	Overview map - Eastern suburbs		
Map 1.5	Overview map - Southern suburbs		
Map 1.6	Overview map - Port Hills and Lyttelton suburbs		
Map series 2 - Northern suburbs			
Map 2a	General land observation map	Total area of liquefaction observations to 13 June 2011	
Map 2b	Detailed land observation map	Recorded observations from 4 September 2010	
Map 2c	Detailed land observation map	Recorded observations from 22 February 2011	
Map 2d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	
Map 2e	Groundwater elevation contours		
Map 2f	LiDAR survey	Bare earth digital elevation model pre September 2010	
Map 2g	LiDAR survey	Bare earth digital elevation model post June 2011	
Map 2h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	
Map series 3 - Central suburbs			
Map 3a	General land observation map	Total area of liquefaction observations to 13 June 2011	
Map 3b	Detailed land observation map	Recorded observations from 4 September 2010	
Map 3c	Detailed land observation map	Recorded observations from 22 February 2011	
Map 3d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	
Map 3e	Groundwater elevation contours		
Map 3f	LiDAR survey	Bare earth digital elevation model pre September 2010	
Map 3g	LiDAR survey	Bare earth digital elevation model post June 2011	
Map 3h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	
Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	
Map 4d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	
Map 4e	Groundwater elevation contours		
Map 4f	LiDAR survey	Bare earth digital elevation model pre September 2010	
Map 4g	LiDAR survey	Bare earth digital elevation model post June 2011	
Map 4h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	
Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	
Map 5b	Detailed land observation map	Recorded observations from 4 September 2010	
Map 5e	Groundwater elevation contours		
Map series 6 - Port Hills and Lyttelton suburbs			
Map 6a	General land observation map	Aggregated land observations to 13 June 2011	Port Hills to Diamond Harbour
Map 6b	Detailed land observation map	Land observations after 13 June 2011	Port Hills to Diamond Harbour
Map 6b-1	Detailed land observation map	Land observations after 13 June 2011	Westmoreland to Hillsborough
Map 6b-2	Detailed land observation map	Land observations after 13 June 2011	Heathcote to Scarborough
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	Lyttelton
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	Diamond Harbour

9 Suburb technical land information - the Plains

A series of factsheets have been prepared to summarise the area-wide technical land information collected by EQC for the residential areas on the Plains most affected by liquefaction and lateral spread. This includes subsurface investigation information, typical groundwater levels and changes in ground elevation.

Each main earthquake has resulted in differing extents and patterns of liquefaction and lateral spread occurring across the Canterbury region. The variation is the result of the varying proximity of the epicentres of the earthquakes, the magnitudes, depths, shaking duration and geological conditions. The liquefaction which has occurred throughout many parts of Christchurch city and Waimakariri and Selwyn districts was extensive, and in some areas the effects accumulated from the ongoing series of earthquakes.

Technical information fact sheets have been prepared for the following suburbs on the Plains (Table 9.1) and are included in Appendix C.

Table 9.1 - Summary of suburbs with technical information factsheets

Sheet number	Region	Suburbs included
1	Kaiapoi	Kaiapoi Lakes, North Kaiapoi and South Kaiapoi
2	Kairaki Beach to Pines Beach	Kairaki Beach and Pines Beach
3	Spencerville to Brooklands	Brooklands and Spencerville
4	Casebrook to Belfast	Belfast, Casebrook, Northcote, Redwood and Styx
5	Parklands to Waimairi Beach	Parklands, Queenspark and Waimairi Beach
6	Ilam to Bishopdale	Bishopdale, Bryndwr, Burnside, Fendalton and Ilam
7	Merivale to Mairehau	Central city, Mairehau, Merivale, Papanui and St Albans
8	Richmond to Burwood	Avondale, Avonside, Burwood, Dallington, Richmond, Shirley, Travis, Wainoni and Westhaven
9	Aranui to North New Brighton	Aranui, Bexley, New Brighton and North New Brighton
10	Hillmorton to Riccarton	Hillmorton, Hoon Hay, Riccarton and Upper Riccarton
11	Cashmere to Sydenham	Addington, Beckenham, Cashmere, Somerfield, Spreydon and Sydenham
12	St Martins to North Linwood	Bromley, Linwood, North Linwood, Opawa, Phillipstown, St Martins, Waltham and Woolston
13	Redcliffs to South New Brighton	Redcliffs, South New Brighton and Southshore
14	Halswell	Halswell, Oaklands, Wentworth Park and Westlake
15	Tai Tapu to Halswell	Halswell River, Lincoln and Tai Tapu

10 Conclusions

Since 4 September 2010, Canterbury has experienced an unprecedented level of seismic activity known as the Canterbury earthquake series. This series has included main earthquakes on 4 September 2010, and 22 February, 13 June and 23 December 2011. This series is expected to be on-going for some time. GNS Science predicts that Canterbury will experience increased seismic activity for about 30 years.

The earthquakes have caused widespread liquefaction of the loose, saturated soils that lie beneath the Plains. This liquefaction has often resulted in physical damage to the land in the form of lateral spreading, land cracking, undulations, ponding, local settlement, groundwater springs and inundation by ejected sand and silt.

It was recognised at an early stage that in places land had undergone changes over wide areas due to tectonic movements, as well as more localised movements because of liquefaction. Over much of the wider Christchurch area land is now higher, or lower, and/or in a different place than it was prior to the earthquakes. This does not necessarily imply that the land has been damaged, rather that the land has changed.

The main source informing the vertical and lateral changes to the land has been the LiDAR surveys. Benchmark resurveys by GNS and Land Information New Zealand (LINZ) have confirmed the LiDAR information at point locations.

As a result of land lowering, some areas may now be more susceptible to liquefaction and flooding effects.

In the Port Hills, strong shaking has resulted in rock fall, large-scale cliff collapse and consequential inundation, as well as smaller land movement, ground cracking and retaining wall failures.

This physical land damage has been assessed from regional mapping using aerial photographs and rapid ground reconnaissance, as well as property-by-property mapping, and lastly though detailed individual land damage assessments.

11 References

Environment Canterbury (ECan, 2004) The solid facts on Christchurch Liquefaction. Environment Canterbury, Christchurch, New Zealand.

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New Zealand Geotechnical Society (NZGS, 2010) Guidelines for Geotechnical Earthquake Engineering Practice in New Zealand. Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards. July 2010.

Terraview (2010) Aerial photo sourced from Terralink International (Copyright 2002-2005 Terralink International Limited and its Licensors).

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Tonkin & Taylor Ltd (T&T, 2010b) Report prepared for the Earthquake Commission. Darfield Earthquake 4 September 2010 Geotechnical Land Damage Assessment & Reinstatement Report STAGE 2 REPORT, dated November 2010.

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12 Glossary

Alluvial deposits

These are formed over very long periods of time as fine particles of silt and clay, and larger particles of sand and gravel, are deposited and reshaped by water. Alluvial deposits underlie large areas of the Canterbury Plains.

Bearing capacity failure

The ground's ability to support foundations, and the buildings above, is termed its "bearing capacity". This capacity can vary. As an example some soil types when flooded or exposed to earthquake may behave quite differently and have dramatically reduced ability to support foundations, leading to bearing capacity failure.

Building

Where the word "building" is used in this document it shall be taken to mean residential dwelling unless it explicitly states otherwise.

Deposition

Deposition is the geological process by which material is added to a landform or land mass. Wind and water can carry eroded materials and deposit these over extended geologic periods building up layers of sediment.

Differential settlement

When designing foundations for buildings the primary design concerns are settlement and the ability of the ground to support the weight (referred to as bearing capacity). All structures settle to some degree as the ground below takes the added weight. Differential settlement is when one part of a foundation settles more than another part and can cause problems to the building above.

Epicentre

The epicentre is the point on the earth's surface directly above the point where an earthquake rupture starts (the hypocentre).

Ground oscillation

In areas where liquefaction occurs away from the unconstrained edge of a channel or dip, large horizontal movement and cracks are unable to occur. However, due to the underlying liquefied material, the ground surface is able to move backwards and forwards (oscillate) during earthquake shaking. This may cause minor ground cracking and damage to underground infrastructure.

Hypocentre

The hypocentre is the point within the earth where an earthquake rupture starts.

Lateral spreading

The most severely affected areas are where land has been able to move horizontally due to its proximity to open channels or dips. The land is unconstrained and moves towards these channels. In moving, cracks parallel to the channel can open up and the surface of the land can drop.

Liquefaction

Liquefaction describes a process where loose soils below the groundwater level substantially lose strength and stiffness in response to an applied cyclic force, such as earthquake shaking, causing the soil to behave like a pressurised liquid. For example, in some areas in Canterbury the pressurised soil/ water mixture has squeezed to the surface through cracks, creating sand boils, colloquially called "sand volcanoes".

Liquefaction related settlement

After land has liquefied, the pressurised groundwater flows out of the soil and this allows the soil to reconsolidate. Also, in many areas, some of the liquefied soil was ejected to the surface. Both of these processes result in ground settlement. Most of this settlement will have occurred shortly after the earthquake, but in some areas gradual settlements occurred for several weeks or months after the earthquake.

Magnitude (M)

Magnitude is a measure of the energy at the source. There are several different measures of magnitude but the one now and almost exclusively used in New Zealand is termed Moment Magnitude. All the different magnitude measures are related to a log-based scale proposed by Richter and are adjusted to be almost the same in the range of magnitude 6.0 to 7.5, and so are all loosely termed the "Richter Scale".

13 Applicability

This report was prepared and/or compiled for EQC to communicate information that may be relevant to residential land claims under the Earthquake Commission Act 1993. The report was not intended for any other purpose and may not be relied upon for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of any map(s) and data in this report or for the consequences of any other person relying on them in any way. This information is not intended to form a complete technical report on land changes in all or any part of Canterbury.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Authorised for Tonkin & Taylor Ltd by:

Nick Rogers - Project Director

APPENDIX A

Generic land damage types

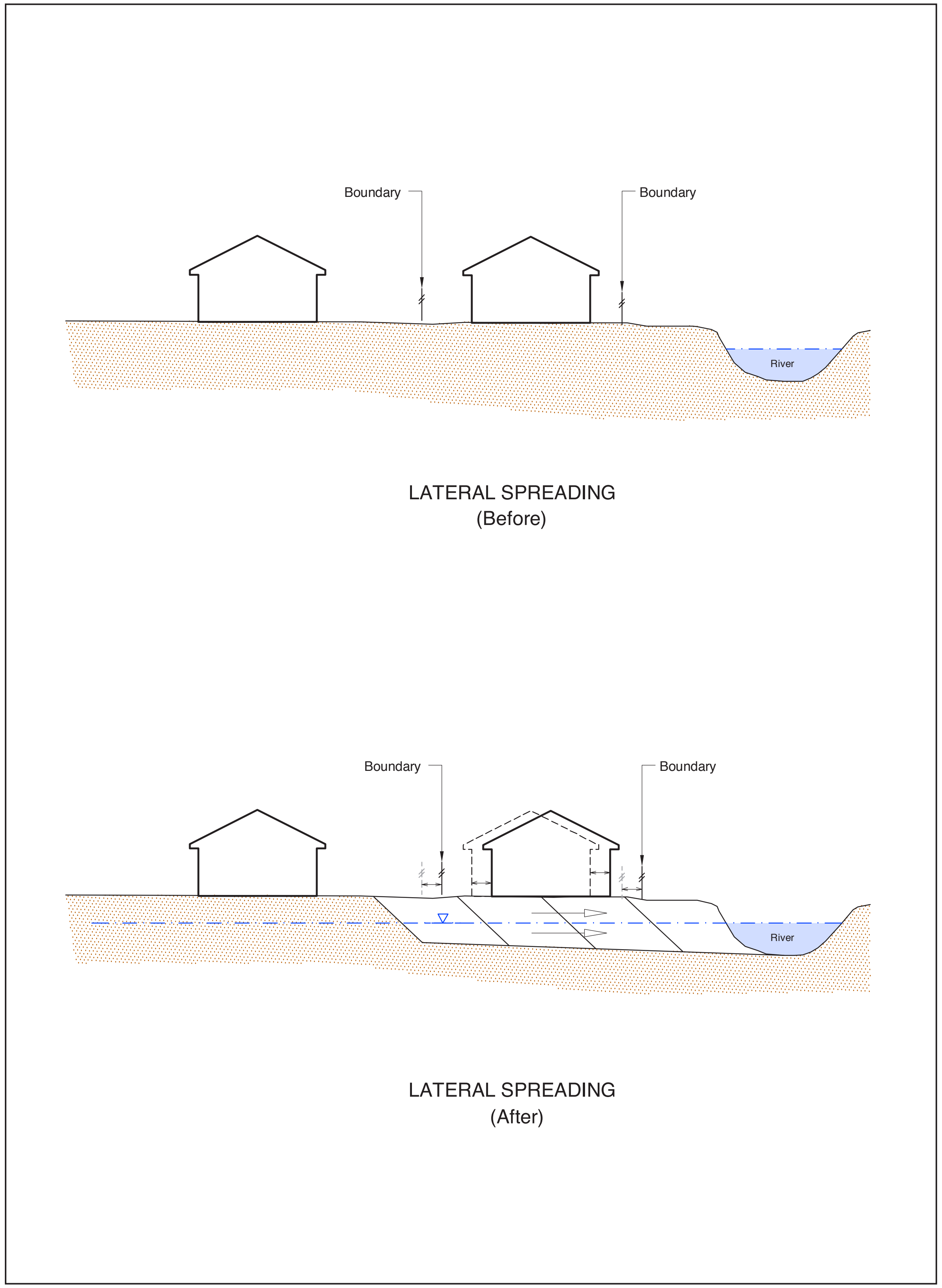
The Plains

Lateral spreading
Land cracking
Undulating land
Localised ponding
Local settlement
New groundwater springs
Inundation by ejected sand and silt

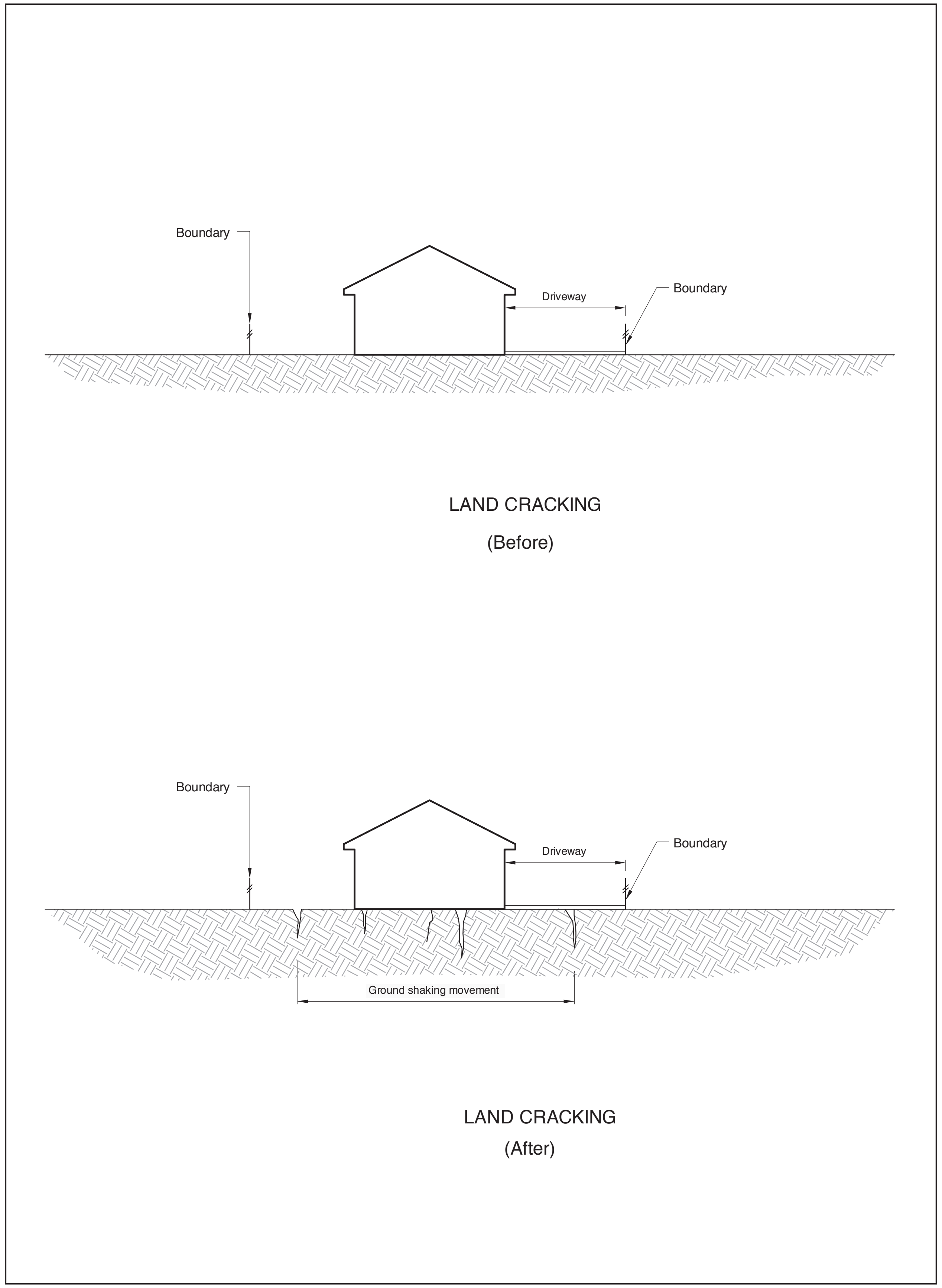
The Port Hills

Rockfall
Large scale landslides
Small scale landslides/ Retaining wall failures

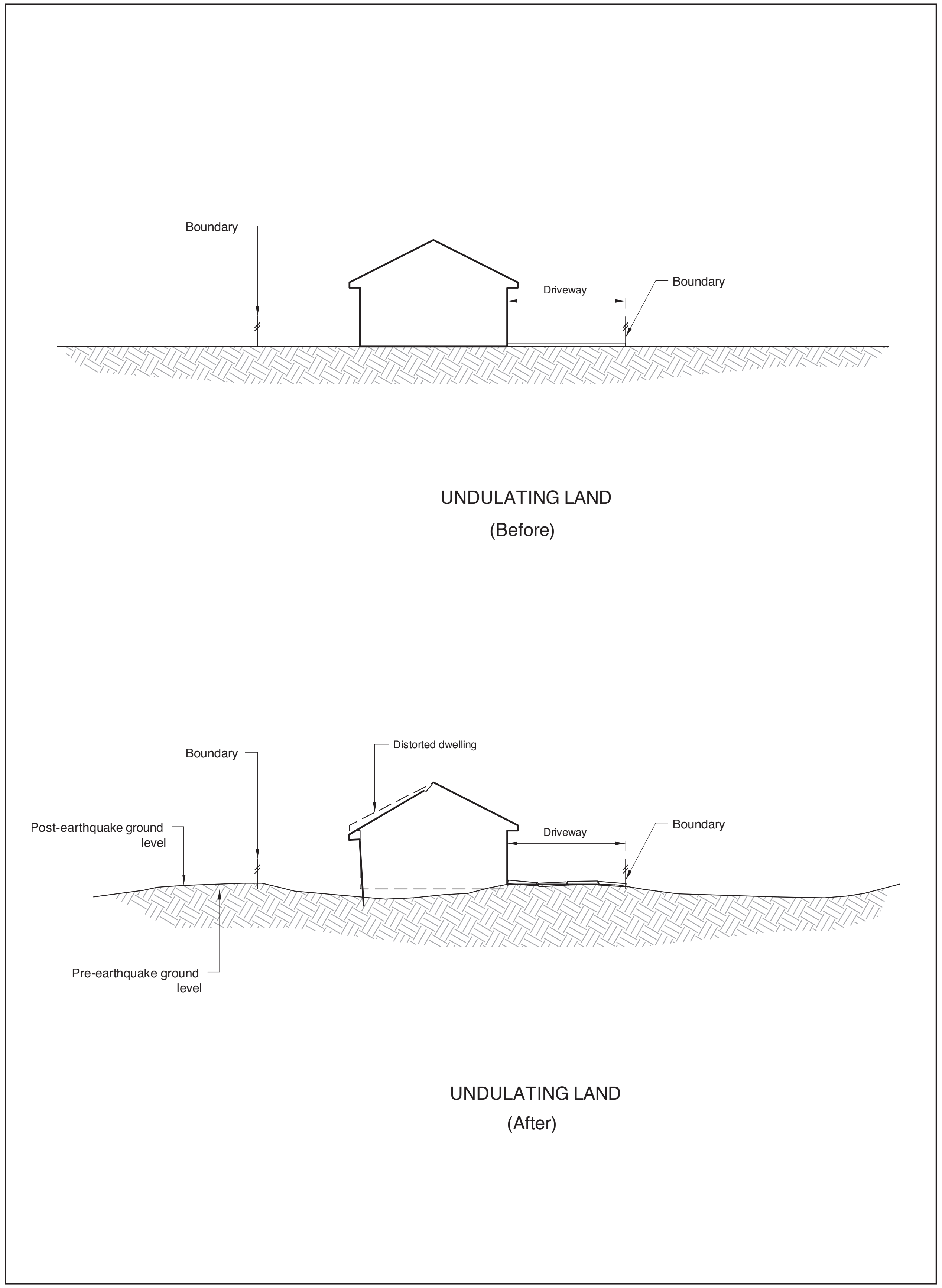
The Plains - Lateral spreading

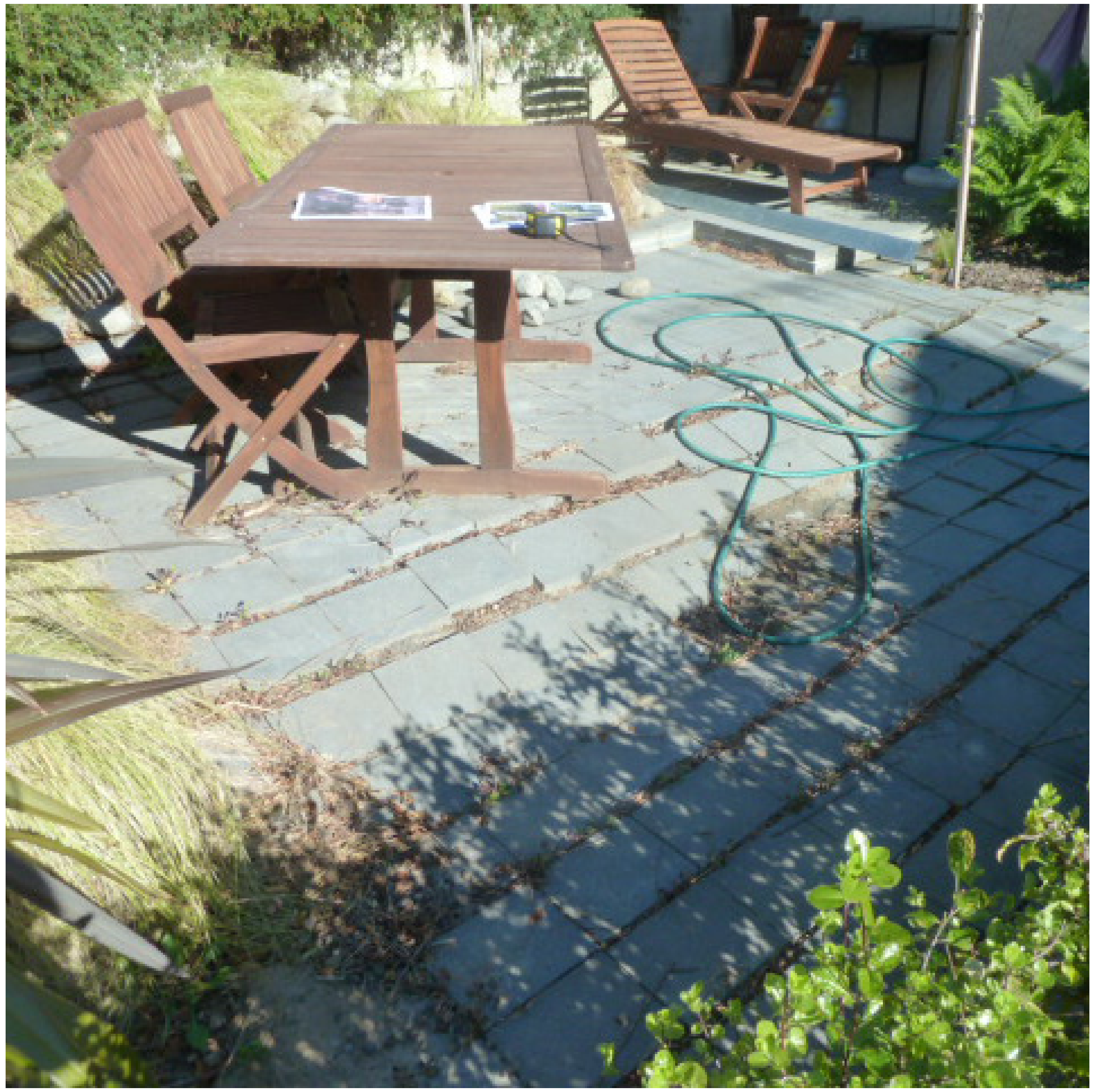


The Plains - Land cracking

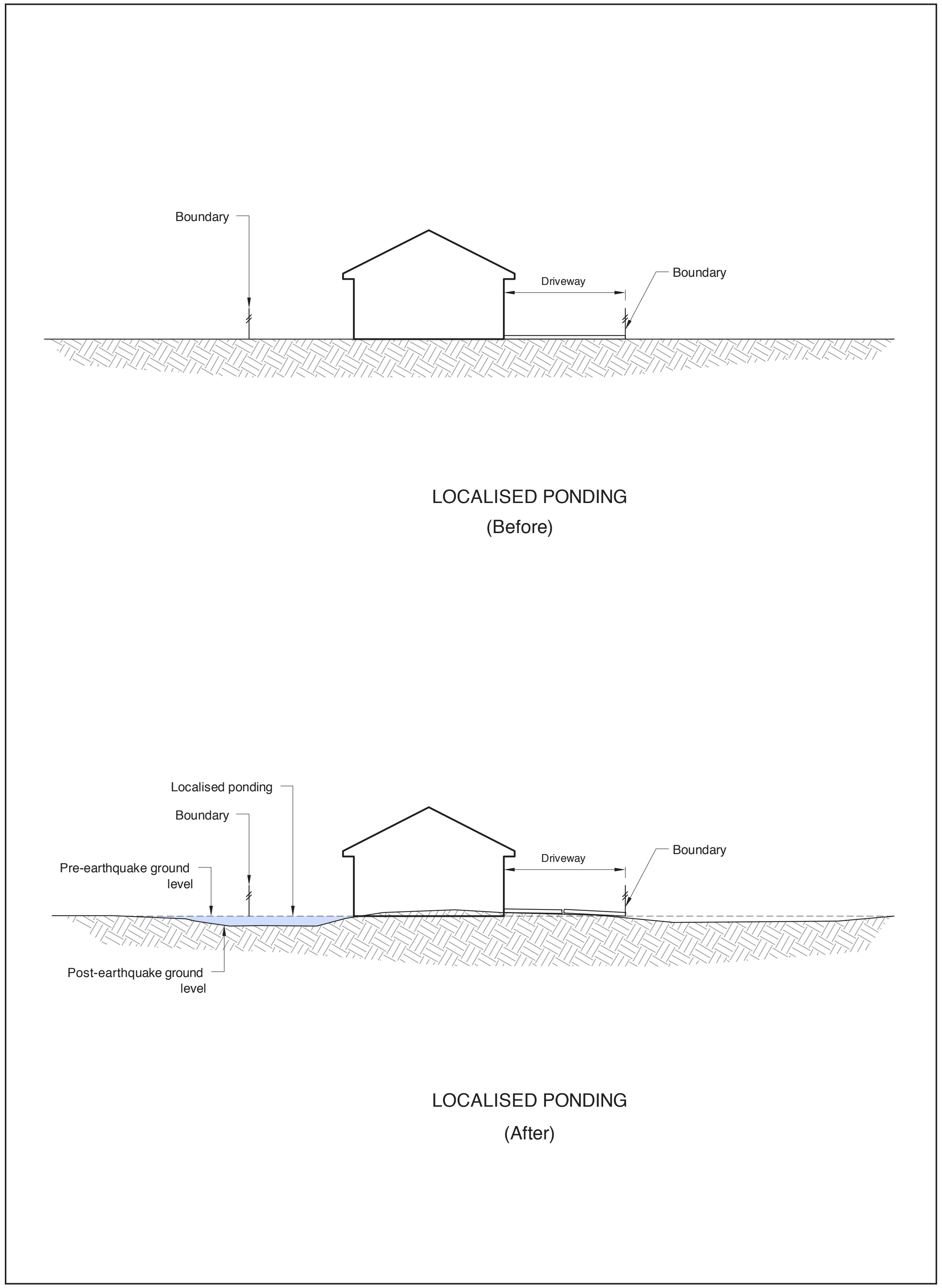


The Plains - Undulating land

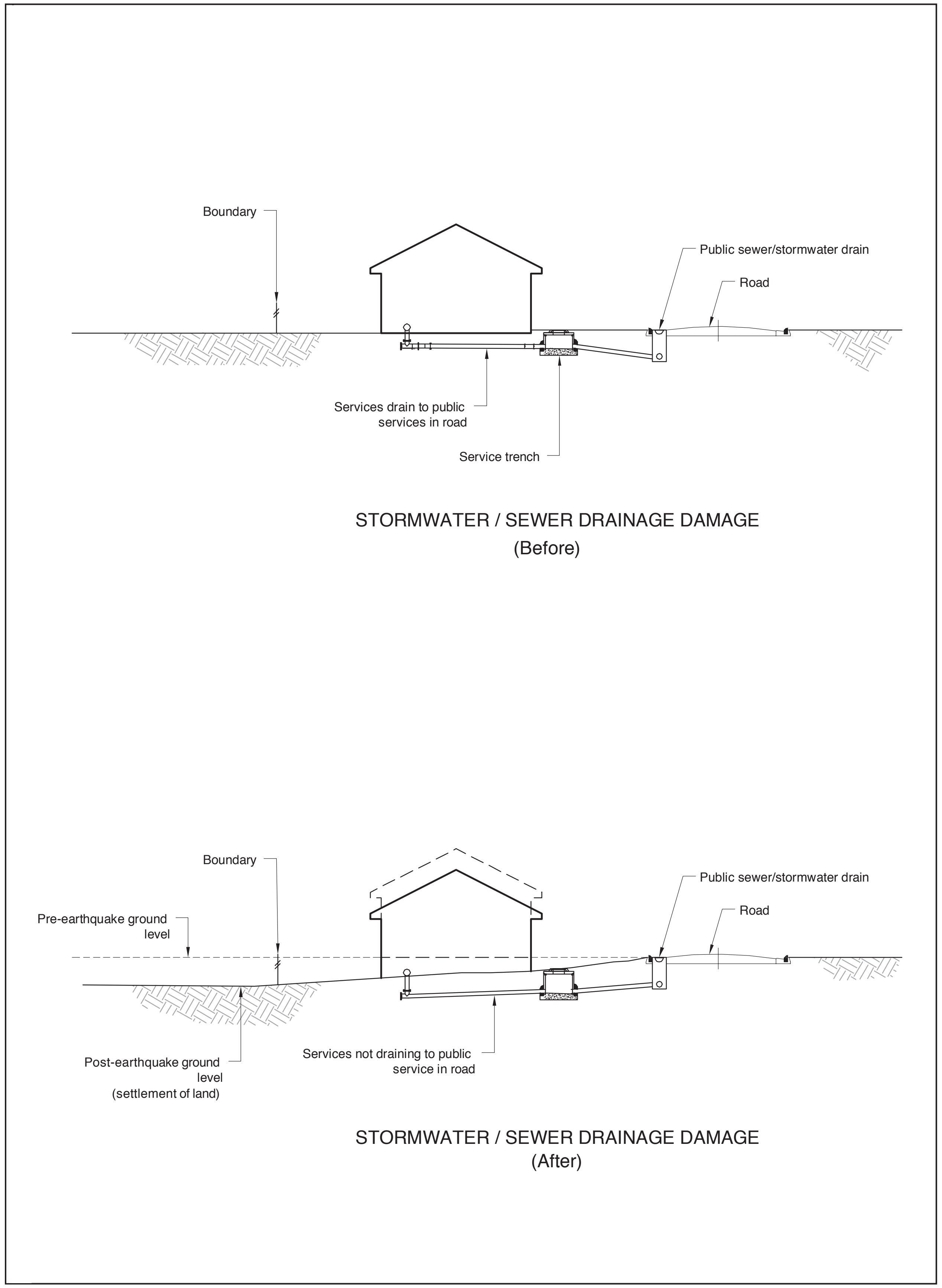




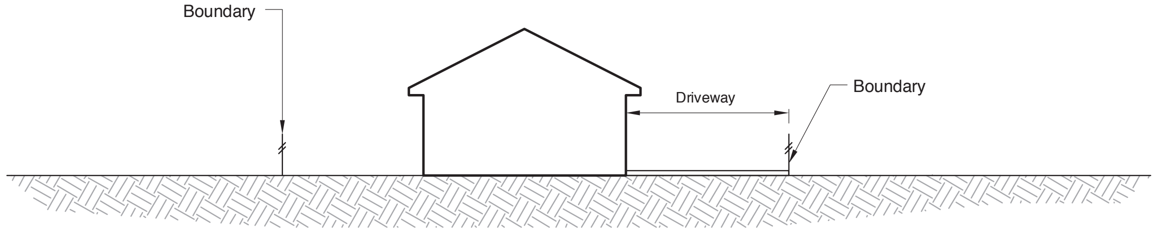
The Plains - Localised ponding



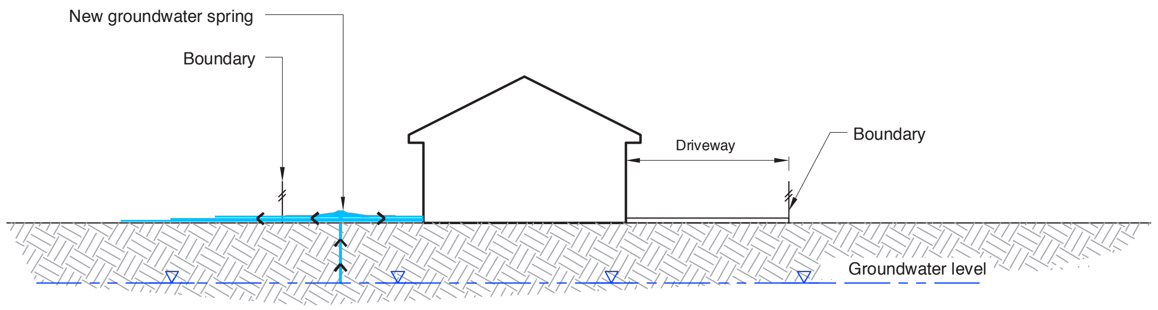
The Plains - Local settlement



The Plains - New groundwater springs

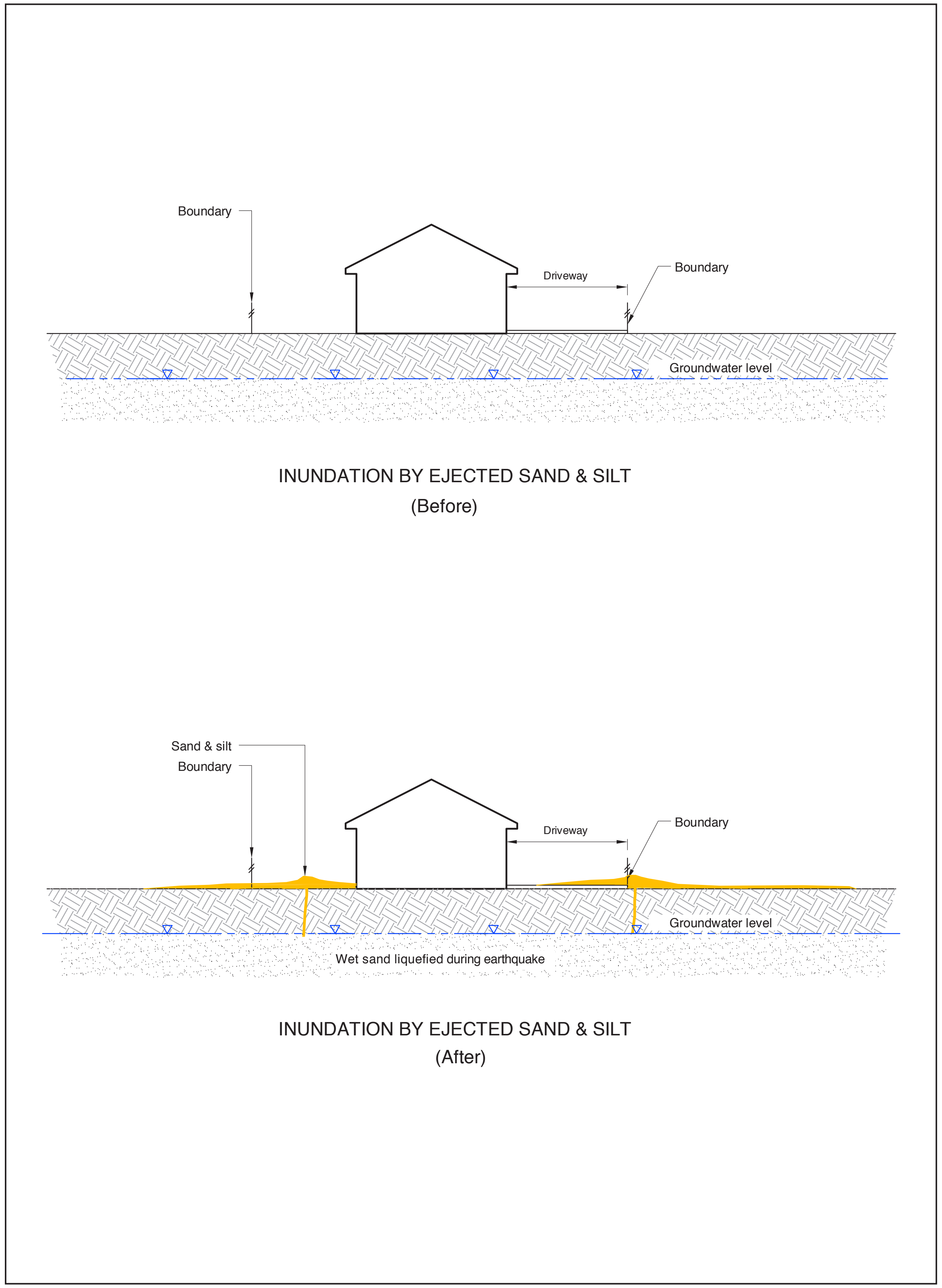


NEW GROUNDWATER SPRINGS
(Before)

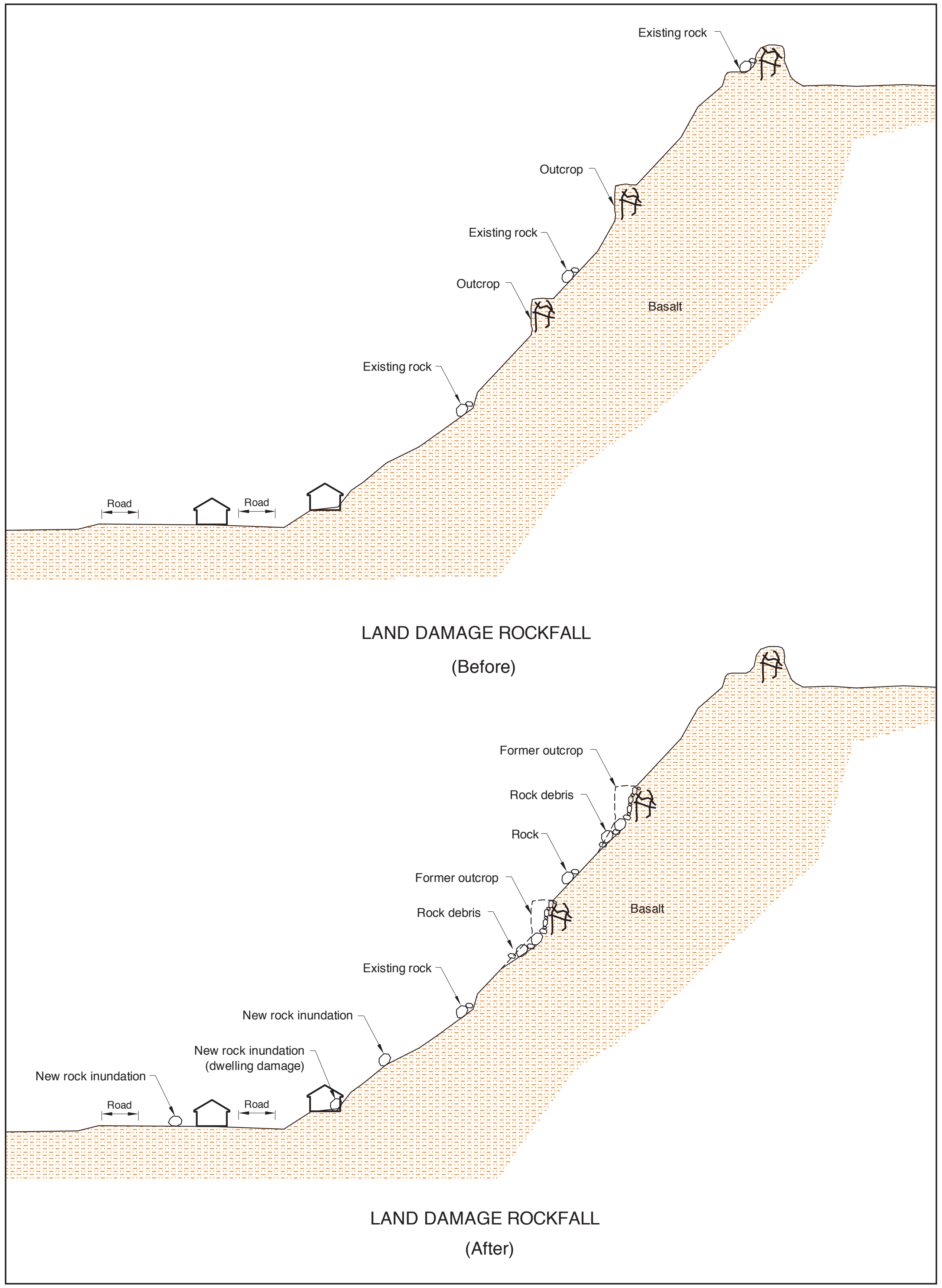


NEW GROUNDWATER SPRINGS
(After)

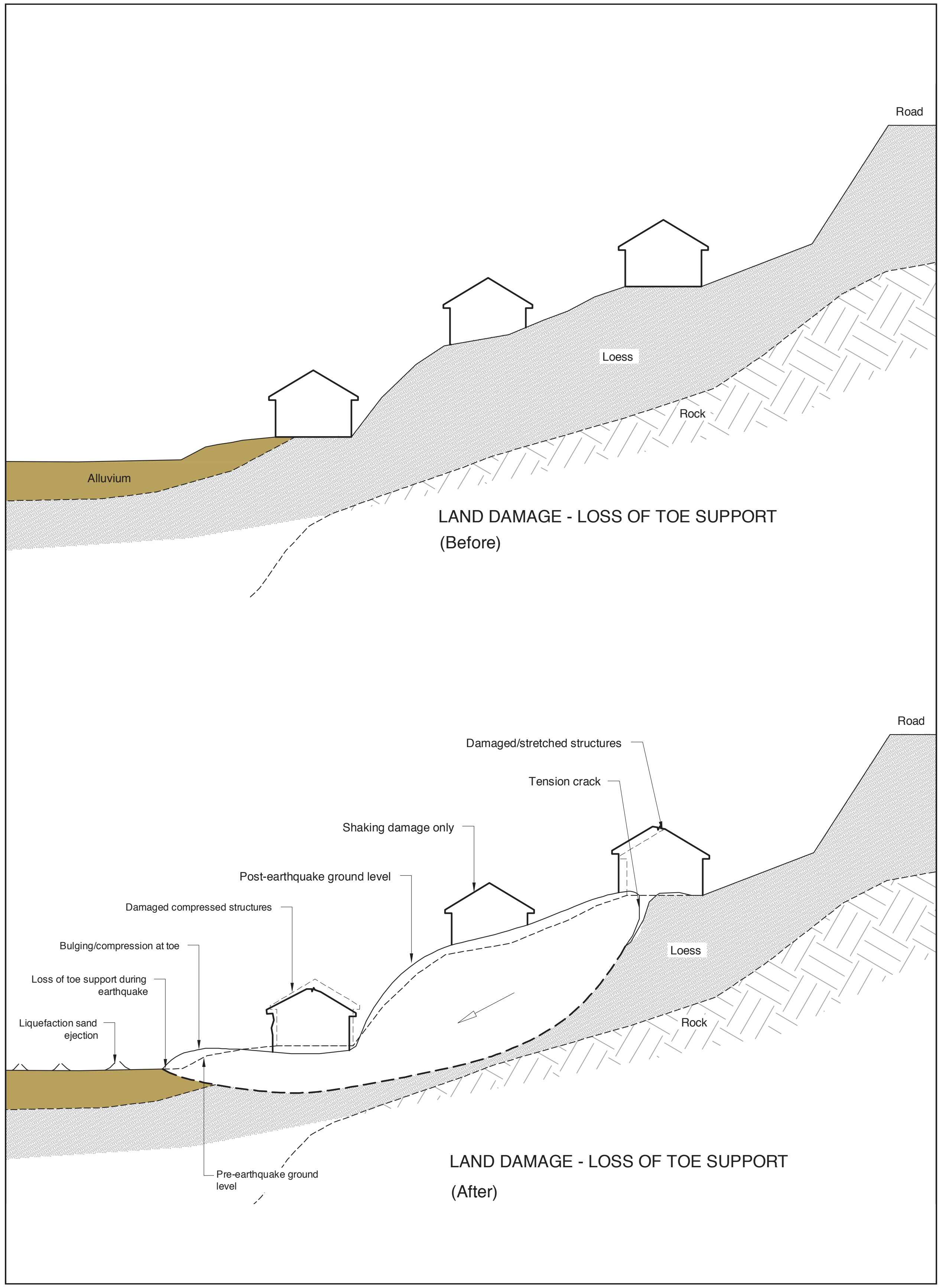
The Plains - Inundation by ejected sand and silt



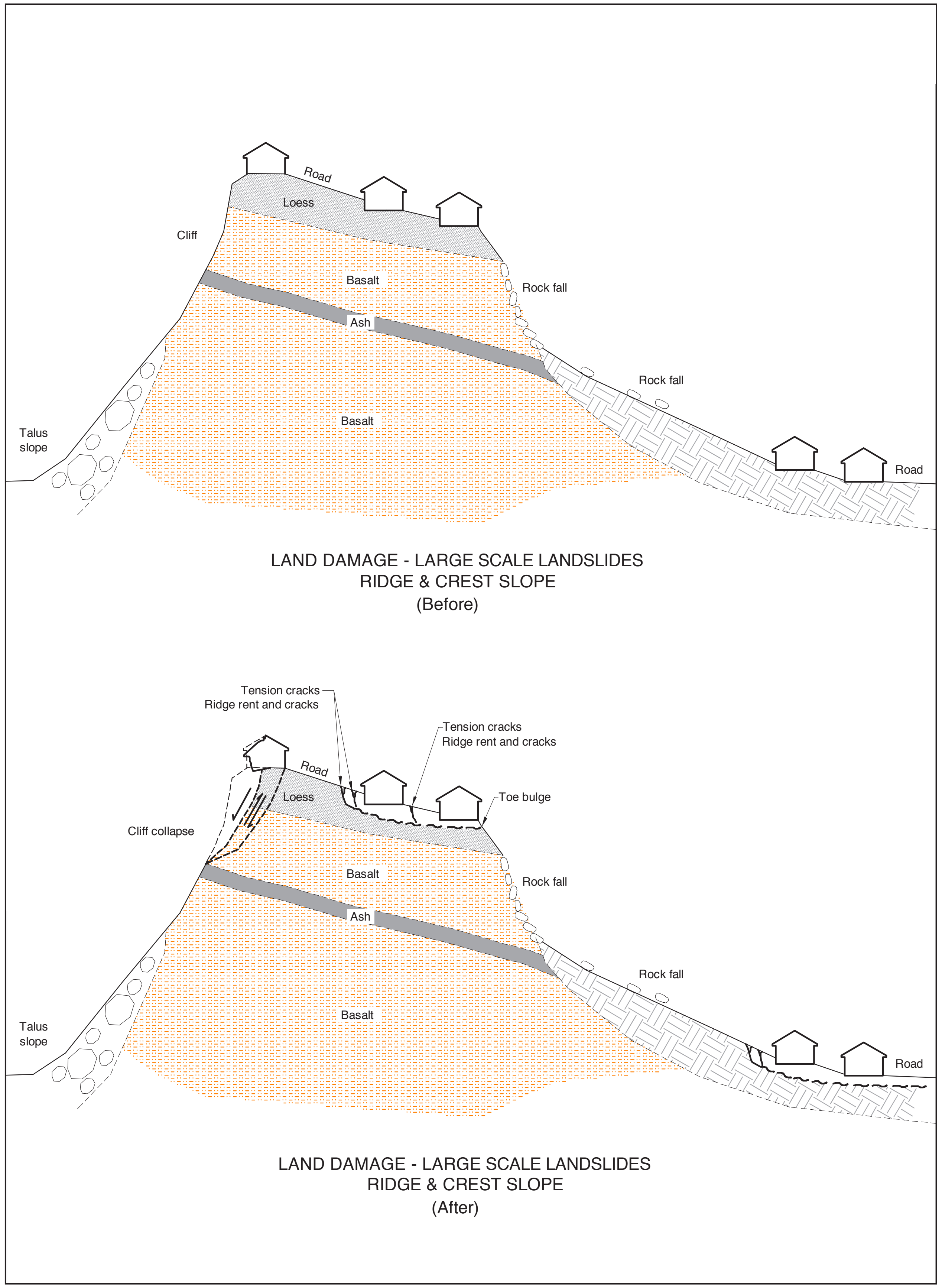
The Port Hills - Rock fall



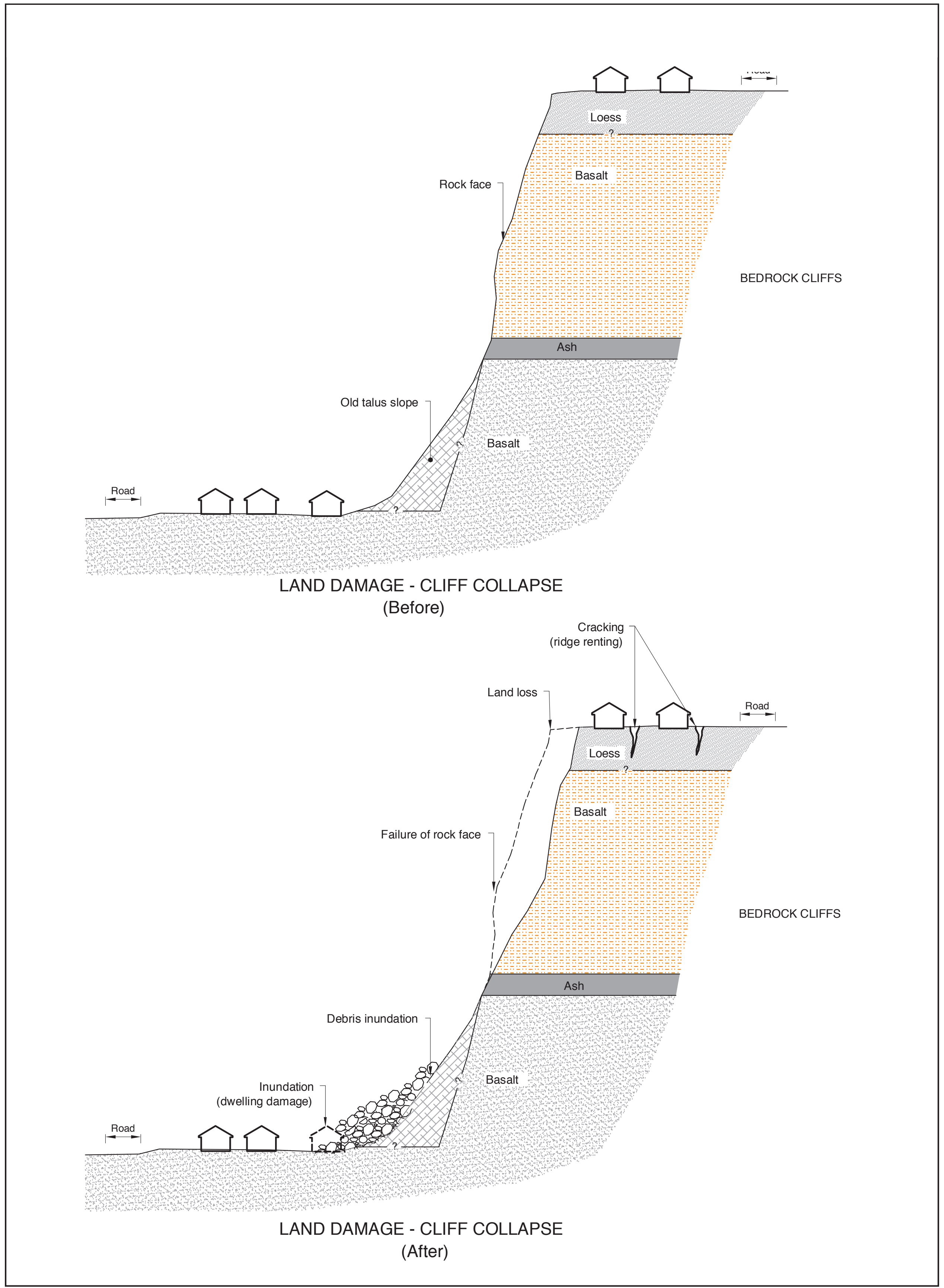
The Port Hills - Large scale landslides: Loss of toe support



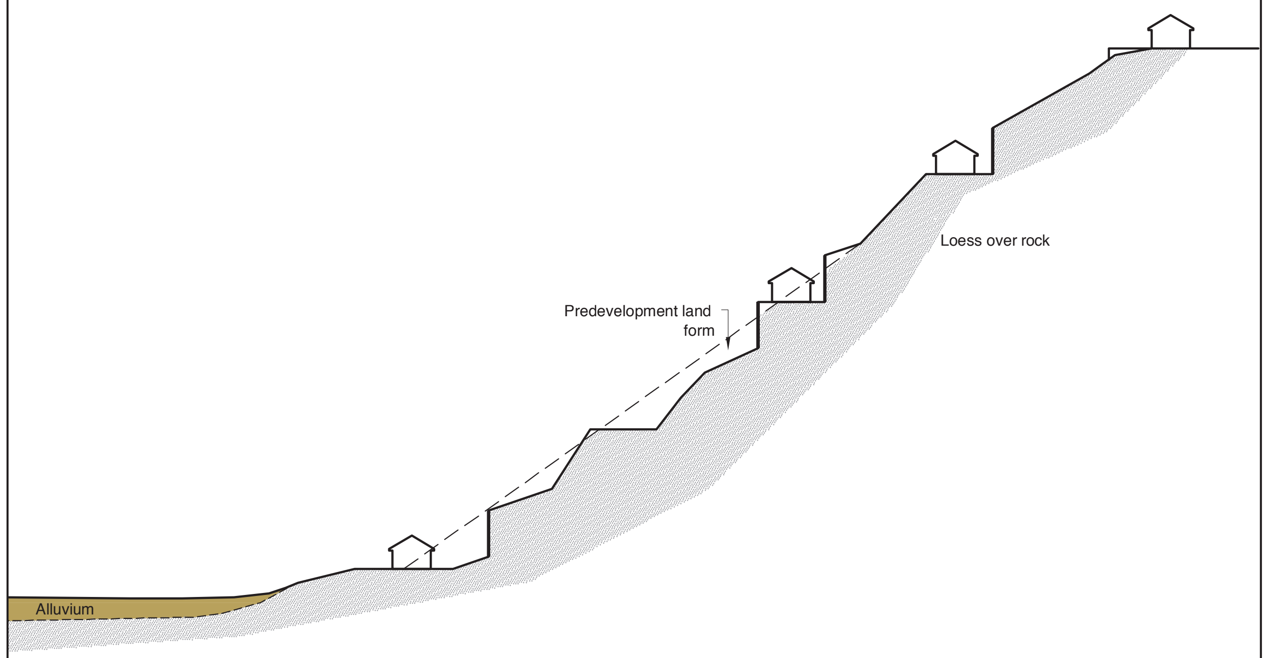
The Port Hills - Large scale landslides: Ridge and crest slope



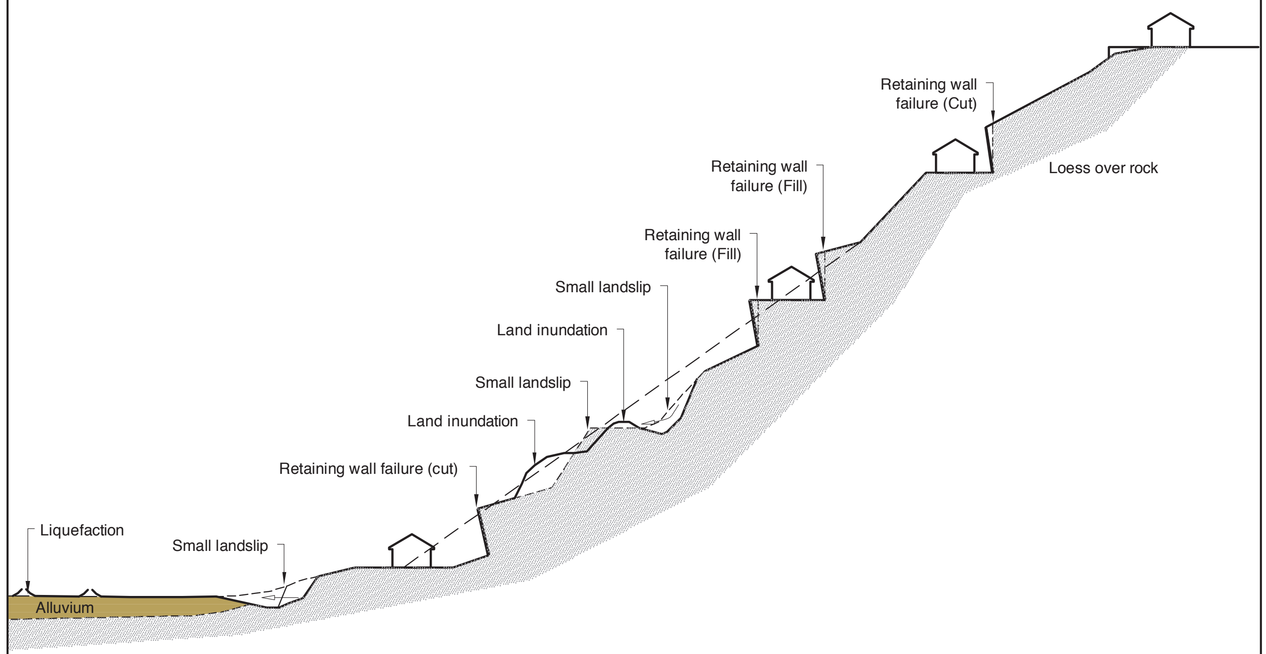
The Port Hills - Large scale landslides: Cliff collapse



The Port Hills - Small scale landslides/retaining wall failures



SMALL SCALE LANDSLIDES - RETAINING WALL FAILURES
(Before)



SMALL SCALE LANDSLIDES - RETAINING WALL FAILURES
(After)

APPENDIX B

Map series

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
Map 1.4	Overview map - Eastern suburbs		32
Map 1.5	Overview map - Southern suburbs		33
Map 1.6	Overview map - Port Hills and Lyttelton suburbs		34
Map series 2 - Northern suburbs			
Map 2a	General land observation map	Total area of liquefaction observations to 13 June 2011	35
Map 2b	Detailed land observation map	Recorded observations from 4 September 2010	36
Map 2c	Detailed land observation map	Recorded observations from 22 February 2011	37
Map 2d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	38
Map 2e	Groundwater elevation contours		39
Map 2f	LiDAR survey	Bare earth digital elevation model pre September 2010	40
Map 2g	LiDAR survey	Bare earth digital elevation model post June 2011	41
Map 2h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	42
Map series 3 - Central suburbs			
Map 3a	General land observation map	Total area of liquefaction observations to 13 June 2011	43
Map 3b	Detailed land observation map	Recorded observations from 4 September 2010	44
Map 3c	Detailed land observation map	Recorded observations from 22 February 2011	45
Map 3d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	46
Map 3e	Groundwater elevation contours		47
Map 3f	LiDAR survey	Bare earth digital elevation model pre September 2010	48
Map 3g	LiDAR survey	Bare earth digital elevation model post June 2011	49
Map 3h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	50
Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	51
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
Map 4d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	54
Map 4e	Groundwater elevation contours		55
Map 4f	LiDAR survey	Bare earth digital elevation model pre September 2010	56
Map 4g	LiDAR survey	Bare earth digital elevation model post June 2011	57
Map 4h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	58
Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	59
Map 5b	Detailed land observation map	Recorded observations from 4 September 2010	60
Map 5e	Groundwater elevation contours		61
Map series 6 - Port Hills and Lyttelton suburbs			
Map 6a	General land observation map	Aggregated land observations to 13 June 2011	62
Map 6b	Detailed land observation map	Land observations after 13 June 2011	63
Map 6b-1	Detailed land observation map	Land observations after 13 June 2011	64
Map 6b-2	Detailed land observation map	Land observations after 13 June 2011	65
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
Map 1.4	Overview map - Eastern suburbs		32
Map 1.5	Overview map - Southern suburbs		33
Map 1.6	Overview map - Port Hills and Lyttelton suburbs		34
Map series 2 - Northern suburbs			
Map 2a	General land observation map	Total area of liquefaction observations to 13 June 2011	35
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Map 2c	Detailed land observation map	Recorded observations from 22 February 2011	37
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Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
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Map series 5 - Southern suburbs			
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Map 5b	Detailed land observation map	Recorded observations from 4 September 2010	60
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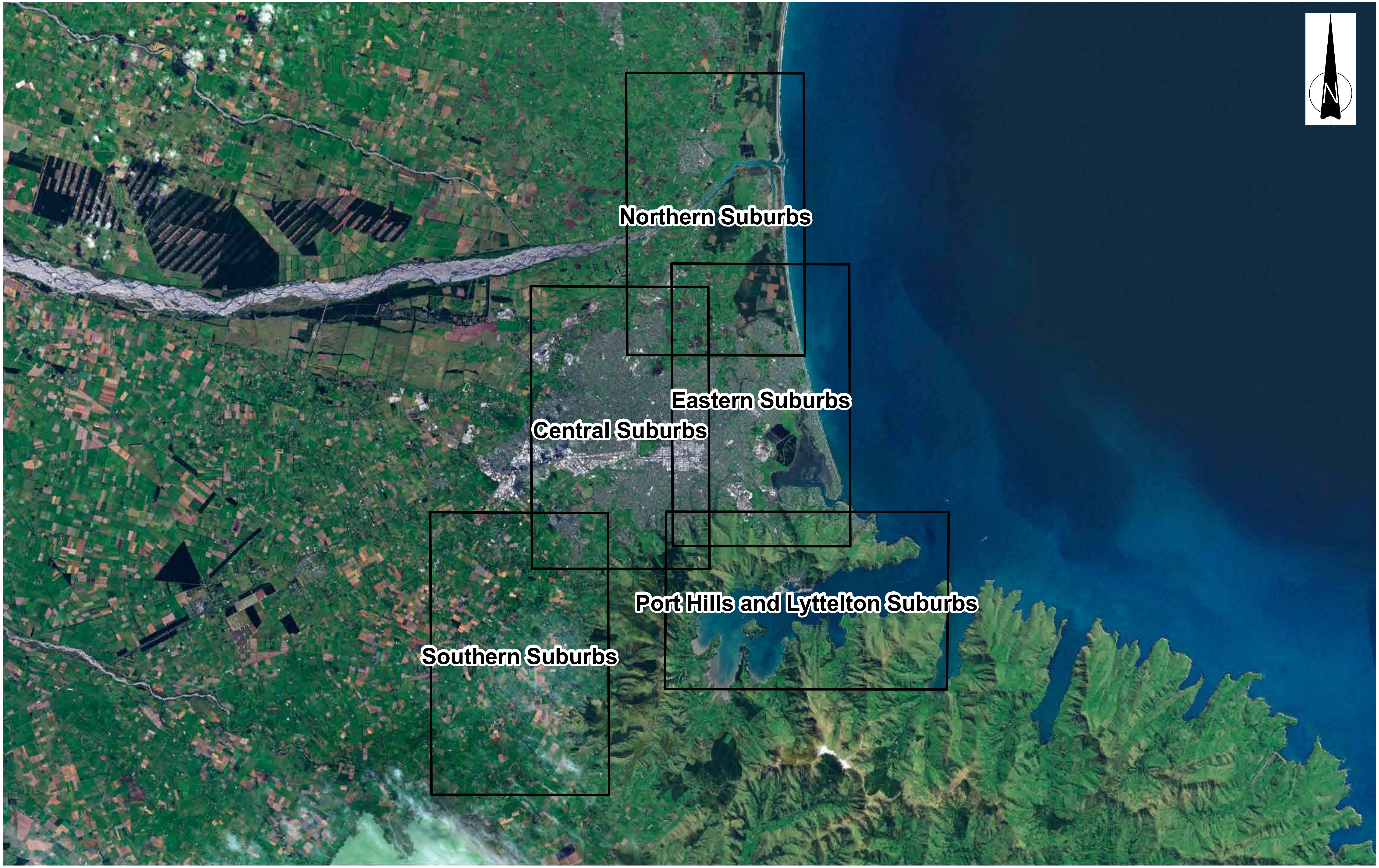
Map series 6 - Port Hills and Lyttelton suburbs			
Map 6a	General land observation map	Aggregated land observations to 13 June 2011	62
Map 6b	Detailed land observation map	Land observations after 13 June 2011	63
Map 6b-1	Detailed land observation map	Land observations after 13 June 2011	64
Map 6b-2	Detailed land observation map	Land observations after 13 June 2011	65
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67



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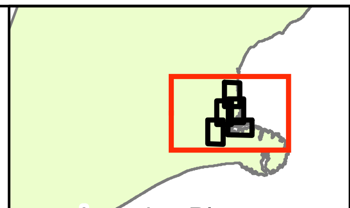
A3 SCALE 1:200,000

0 2 4 6 8 10 (km)



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ARCFILE A3L_Map1.1_GeneralOverview_08062012		
SCALE (AT A3 SIZE) 1:200,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

FIGURE No. Map 1.1

Rev. 0

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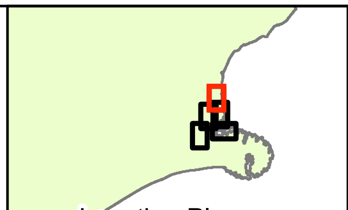
Blue lines represent suburb boundaries initially supplied by CCC, SDC and WDC. Subsequently combined and modified by T&T for Earthquake Recovery purposes.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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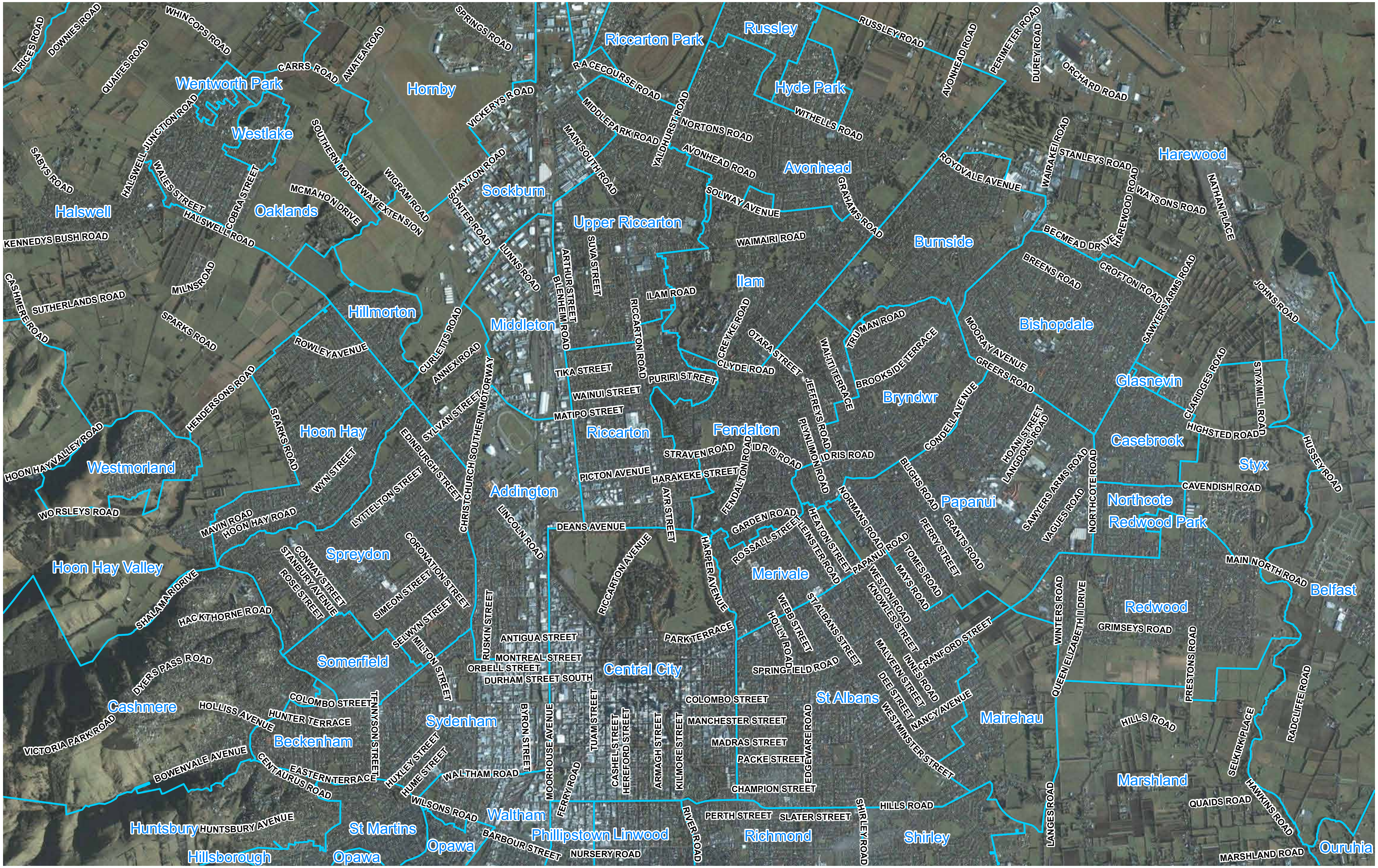
APPROVED		
ARCFILE		
A3L_Series1_OverviewMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

Northern Suburbs

FIGURE No. Map 1.2 Northern Suburbs

Rev. 0



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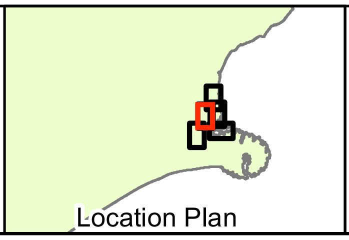
Blue lines represent suburb boundaries initially supplied by CCC, SDC and WDC. Subsequently combined and modified by T&T for Earthquake Recovery purposes.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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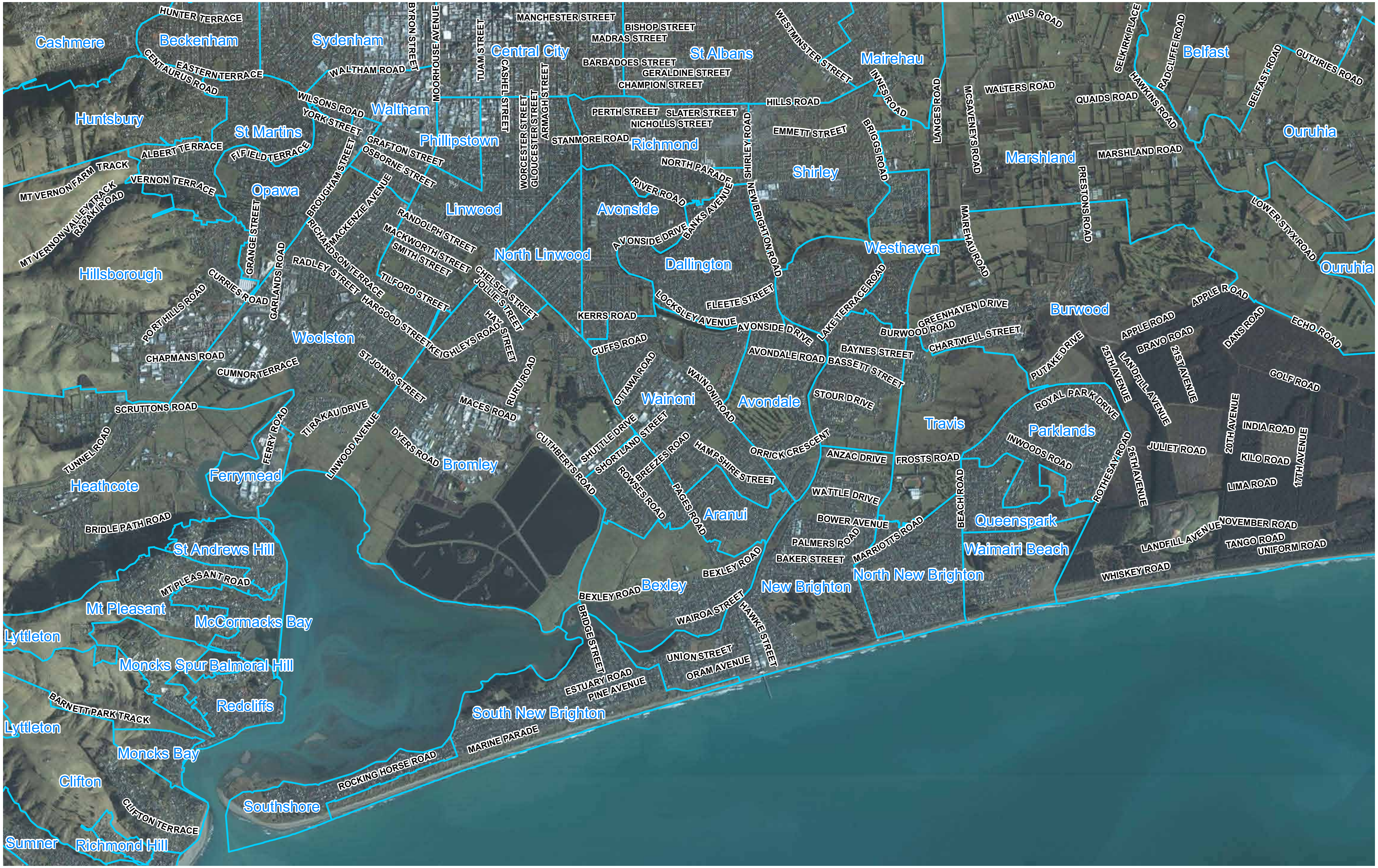
DRAWN	HKB	Jun.12
CHECKED		
APPROVED		
ARCFILE A3L_Series1_OverviewMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

Central Suburbs

FIGURE No. Map 1.3 Central Suburbs

Rev. 0



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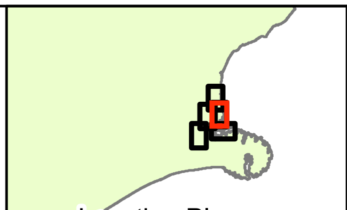
Blue lines represent suburb boundaries initially supplied by CCC, SDC and WDC. Subsequently combined and modified by T&T for Earthquake Recovery purposes.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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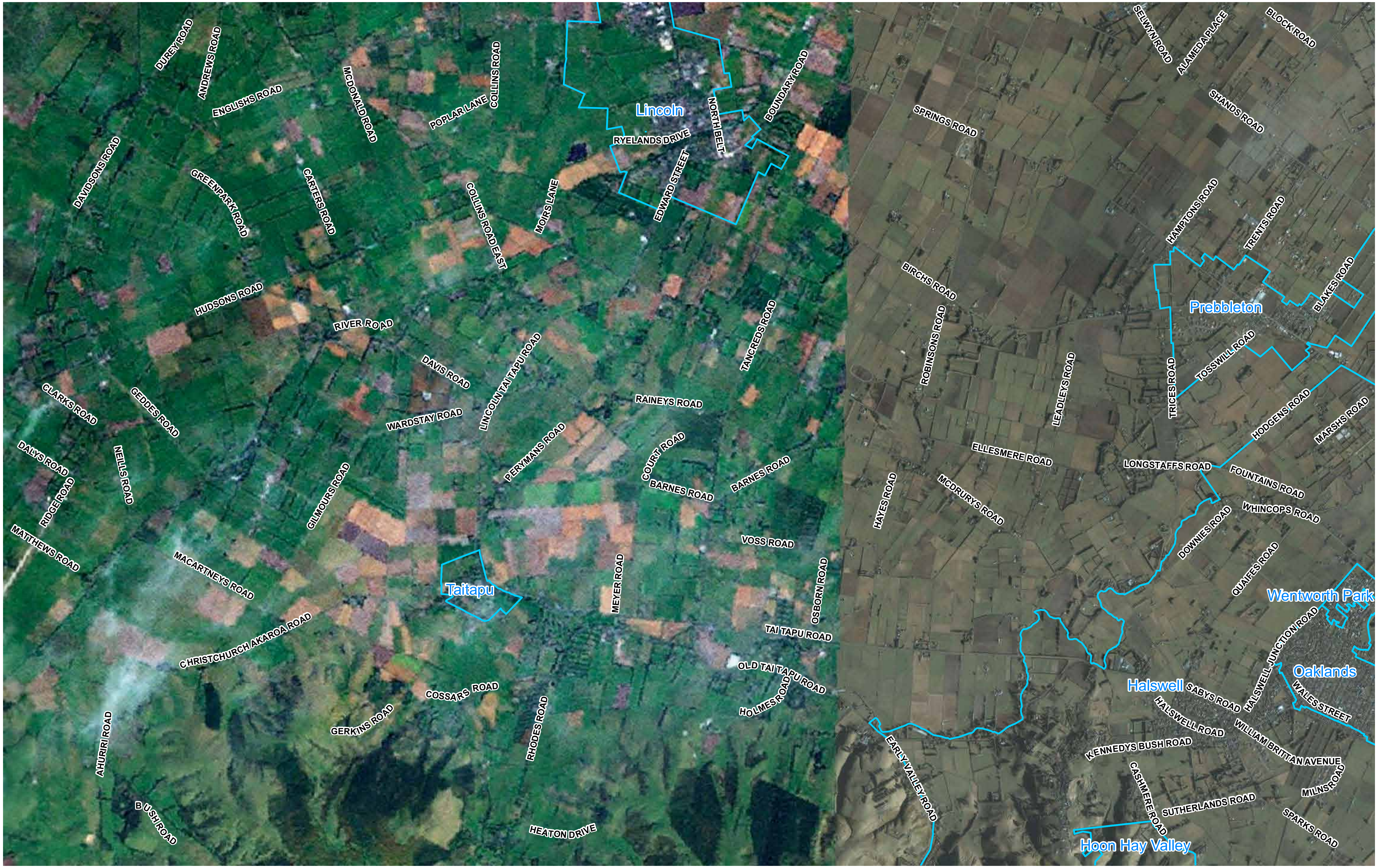
APPROVED		
ARCFILE A3L_Series1_OverviewMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

Eastern Suburbs

FIGURE No. Map 1.4 Eastern Suburbs

Rev. 0



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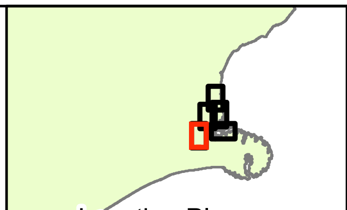
Blue lines represent suburb boundaries initially supplied by CCC, SDC and WDC. Subsequently combined and modified by T&T for Earthquake Recovery purposes.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

N



Location Plan

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APPROVED		
ARCFILE A3L_Series1_OverviewMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

Southern Suburbs

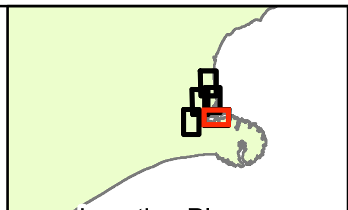
FIGURE No. Map 1.5 Southern Suburbs

Rev. 0

Notes:
Aerial photography from ArcGIS online
Blue lines represent suburb boundaries initially supplied by CCC, WDC and SDC.
Subsequently combined and modified by T&T for Earthquake Recovery purposes.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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APPROVED		
ARCFILE A3L_Series1_OverviewPortHillsOnly_23022012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 1
GENERAL OVERVIEW MAP

Port Hills and Lyttelton Suburbs

FIGURE No. Map 1.6 Port Hills and Lyttelton Suburbs

Rev. 0

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
Map 1.4	Overview map - Eastern suburbs		32
Map 1.5	Overview map - Southern suburbs		33
Map 1.6	Overview map - Port Hills and Lyttelton suburbs		34
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Map 2a	General land observation map	Total area of liquefaction observations to 13 June 2011	35
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Map series 3 - Central suburbs			
Map 3a	General land observation map	Total area of liquefaction observations to 13 June 2011	43
Map 3b	Detailed land observation map	Recorded observations from 4 September 2010	44
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Map 3d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	46
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Map 3g	LiDAR survey	Bare earth digital elevation model post June 2011	49
Map 3h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	50
Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	51
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
Map 4d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	54
Map 4e	Groundwater elevation contours		55
Map 4f	LiDAR survey	Bare earth digital elevation model pre September 2010	56
Map 4g	LiDAR survey	Bare earth digital elevation model post June 2011	57
Map 4h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	58
Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	59
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Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67

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A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

N

Location Plan

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ARCFILE A3L_LiquefactionMaps_31052012		
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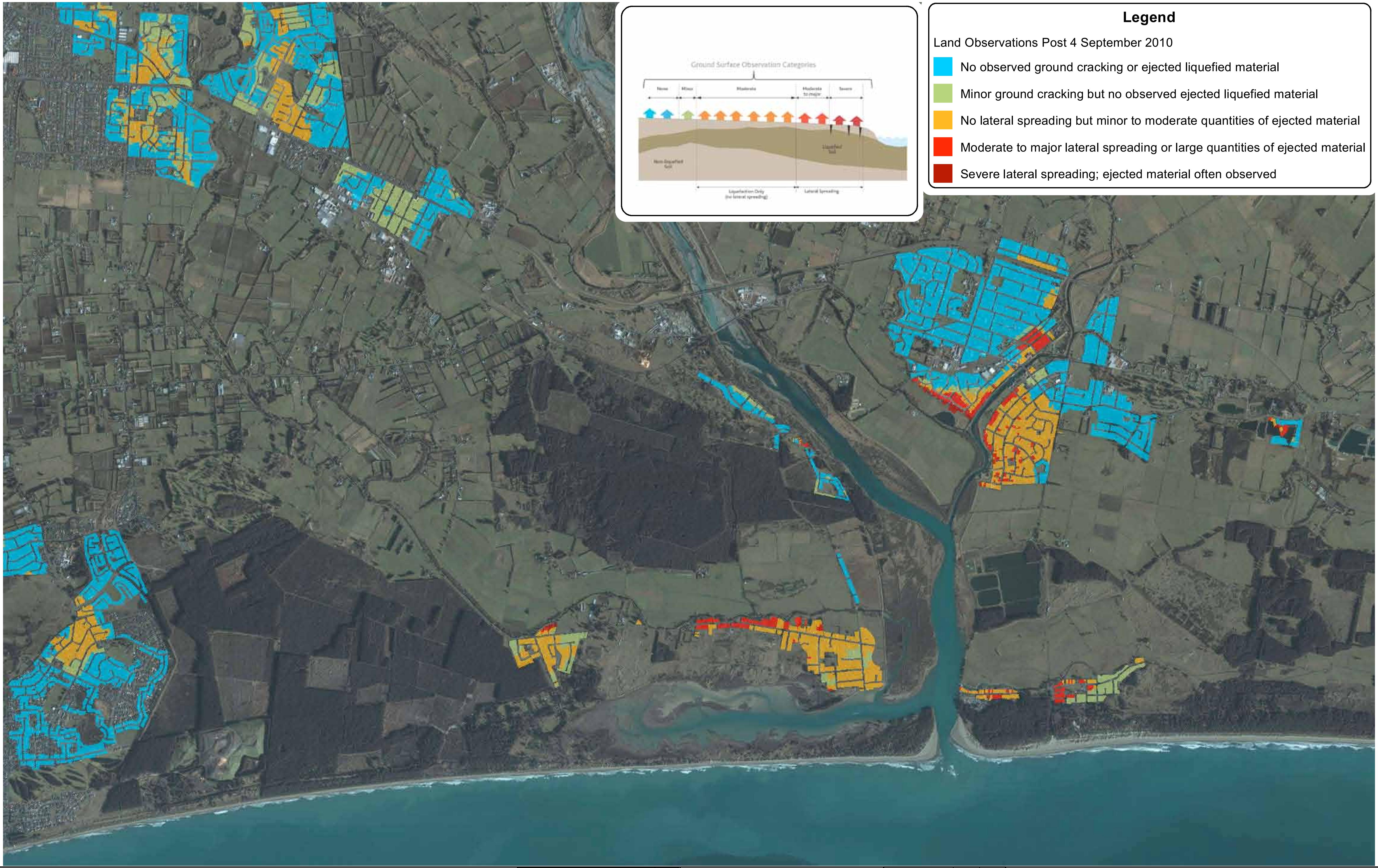
MAP SERIES 2
GENERAL LAND OBSERVATION MAP
Total Area of Liquefaction Observations from Events Between 4 September 2010 to end 13 June 2011

FIGURE No. Map 2a Northern Suburbs

Rev. 0



Legend

Land Observations Post 4 September 2010

- No observed ground cracking or ejected liquefied material
- Minor ground cracking but no observed ejected liquefied material
- No lateral spreading but minor to moderate quantities of ejected material
- Moderate to major lateral spreading or large quantities of ejected material
- Severe lateral spreading; ejected material often observed

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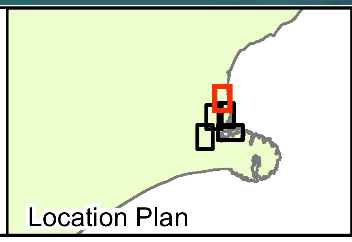
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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ARCFILE A3L_LiquefactionSept_08062012.mxd		
SCALE (AT A3 SIZE) 1:40,000		
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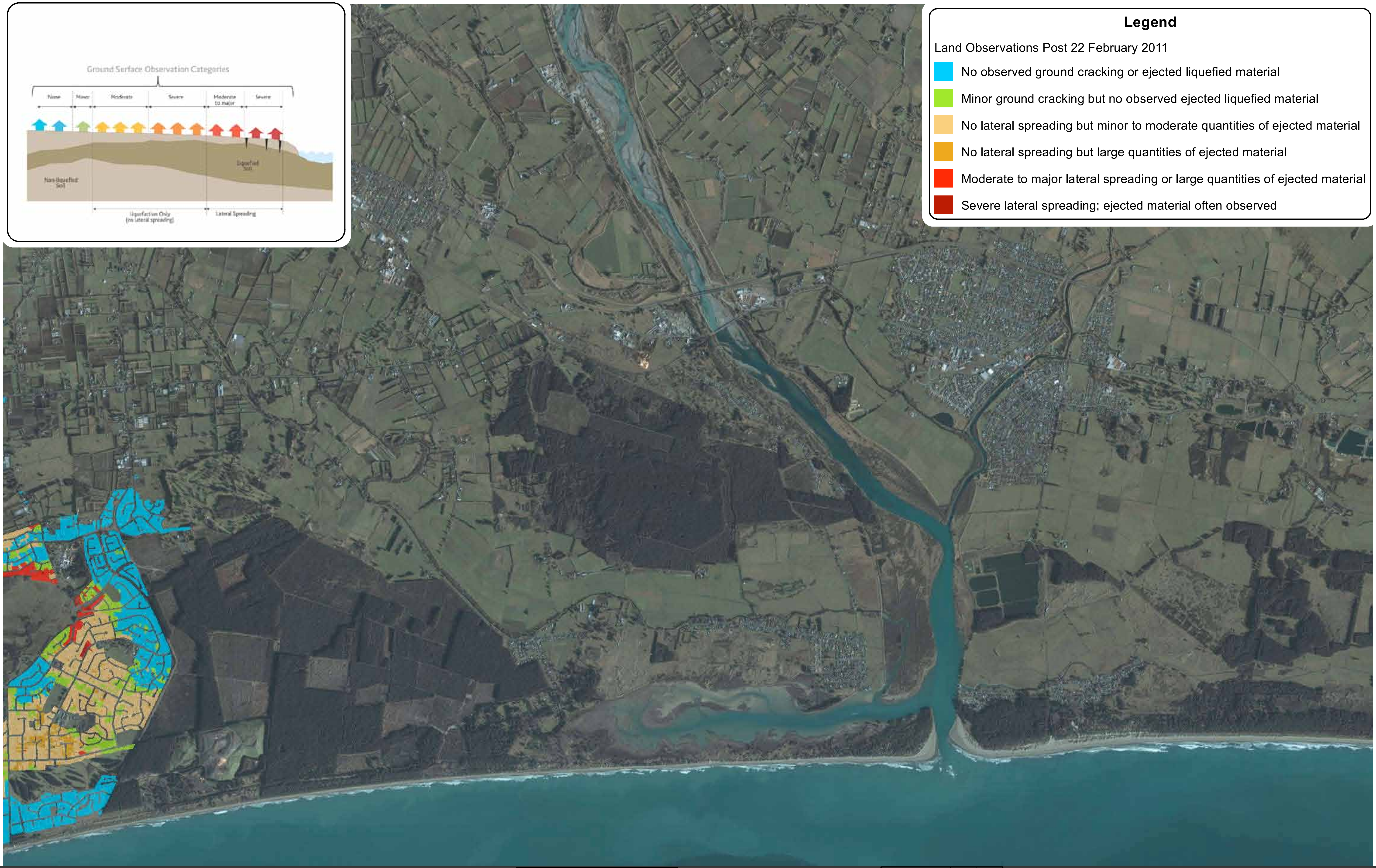
MAP SERIES 4
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading
Observations from 4 September 2010

FIGURE No. Map 2b Northern Suburbs

Rev. 0



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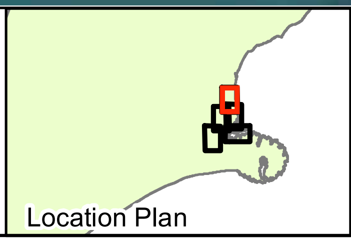
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)


Location Plan

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DRAWN	HKB	Jun.12
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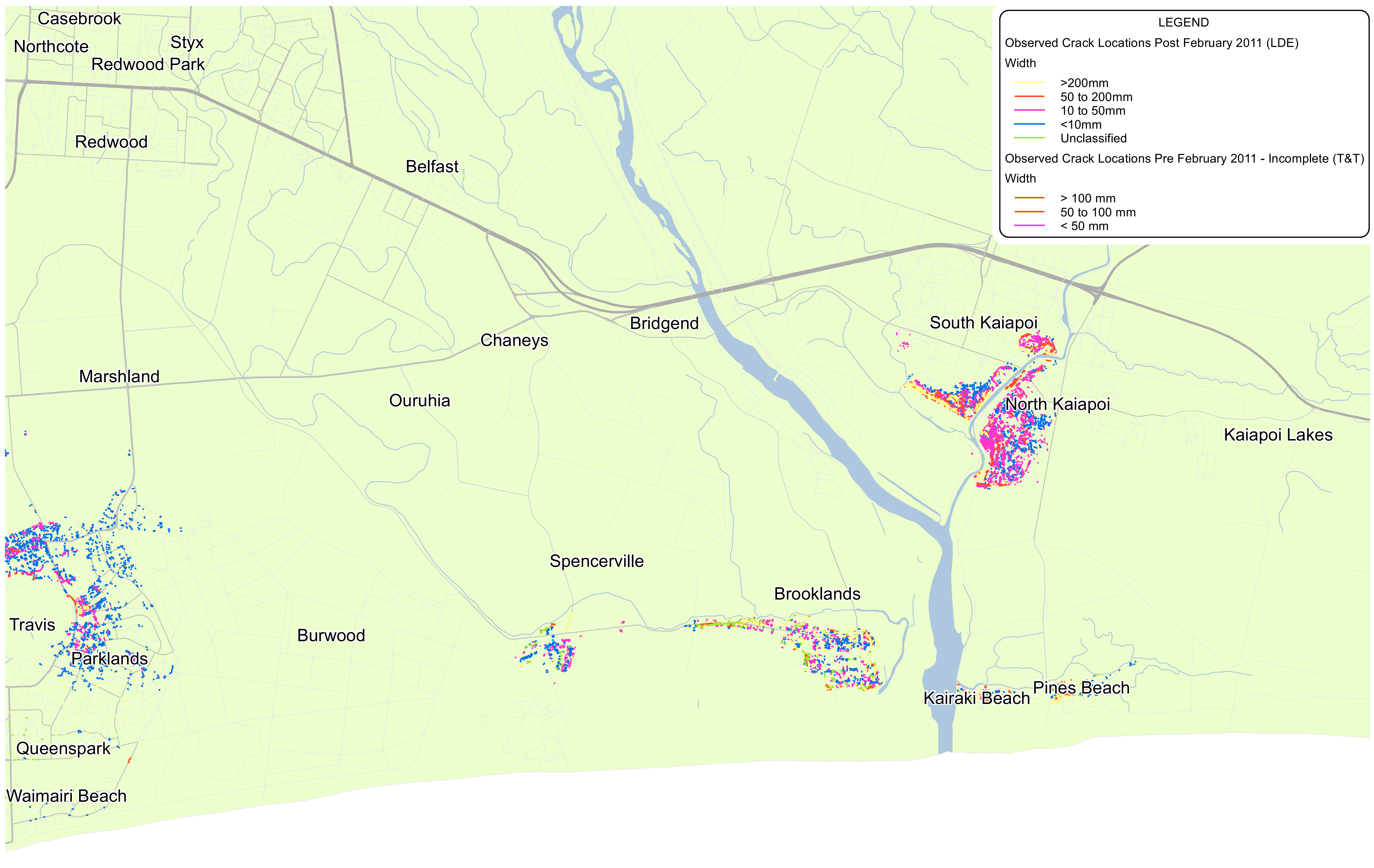
APPROVED		
ARCFILE A3L_LiquefactionFeb_08062012.mxd		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 2
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading
Observations from 22 February 2011

FIGURE No. Map 2c Northern Suburbs

Rev. 0



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ARCFILE A3L_GroundCracking_08062012
SCALE (AT A3 SIZE) 1:40,000
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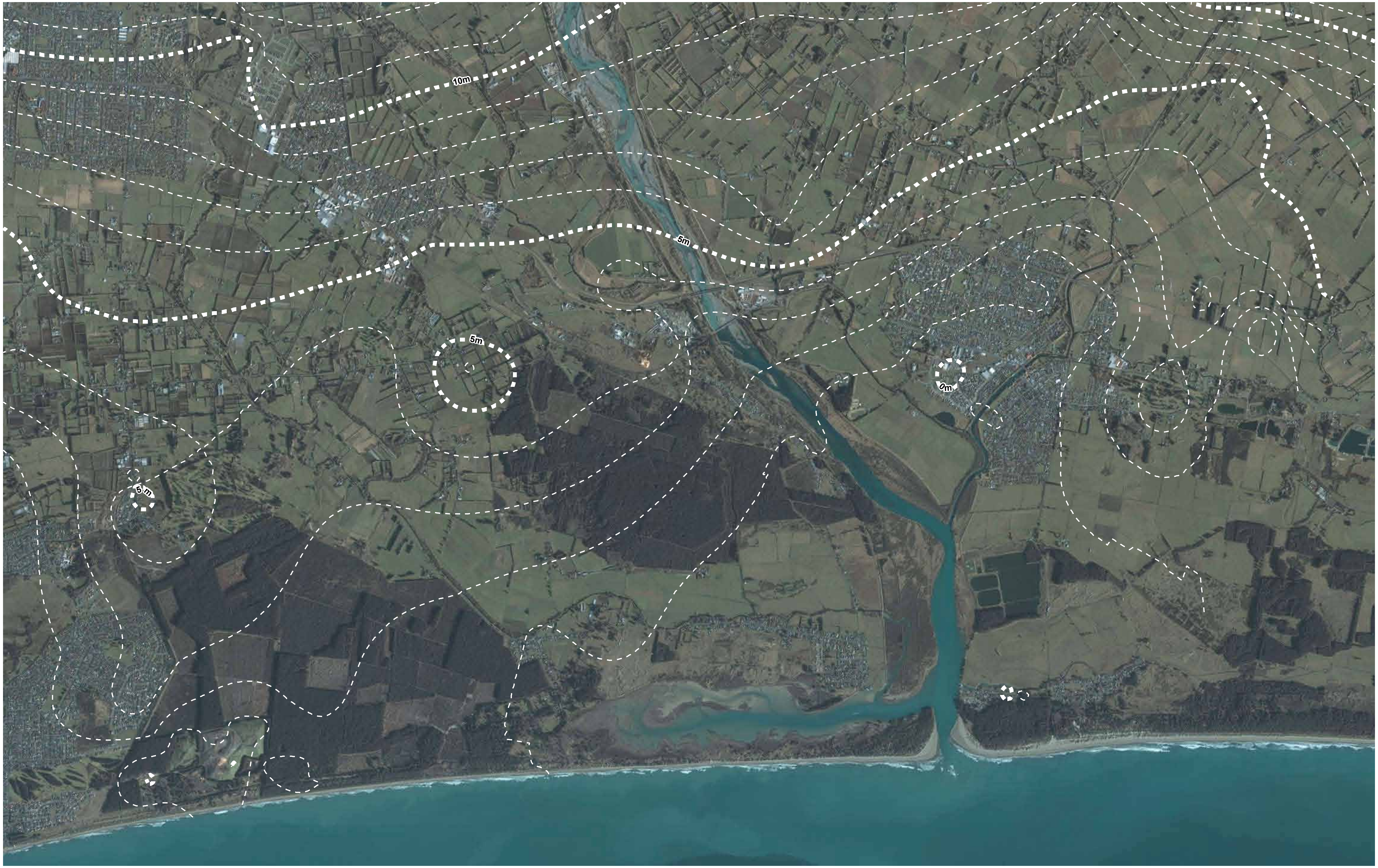
MAP SERIES 2
OBSERVED GROUND CRACKING
Observed Ground Crack Locations
Post 4th September 2010 and 22nd February 2011

FIGURE No. Map 2d Northern Suburbs
Rev. 0

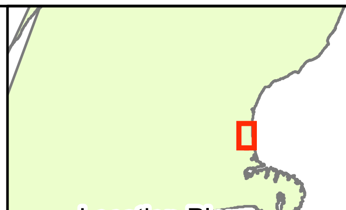


Notes: Aerial photography from ArcGIS Online
Vertical Datum: Lyttelton 1937

Groundwater Contours are indicative only and are derived from data of varying sources (including ECAN and EQC piezometers). NB Levels of accuracy vary across the dataset.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



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APPROVED		

ARCFILE A3L_GroundwaterMaps_31052012
SCALE (AT A3 SIZE) 1:40,000
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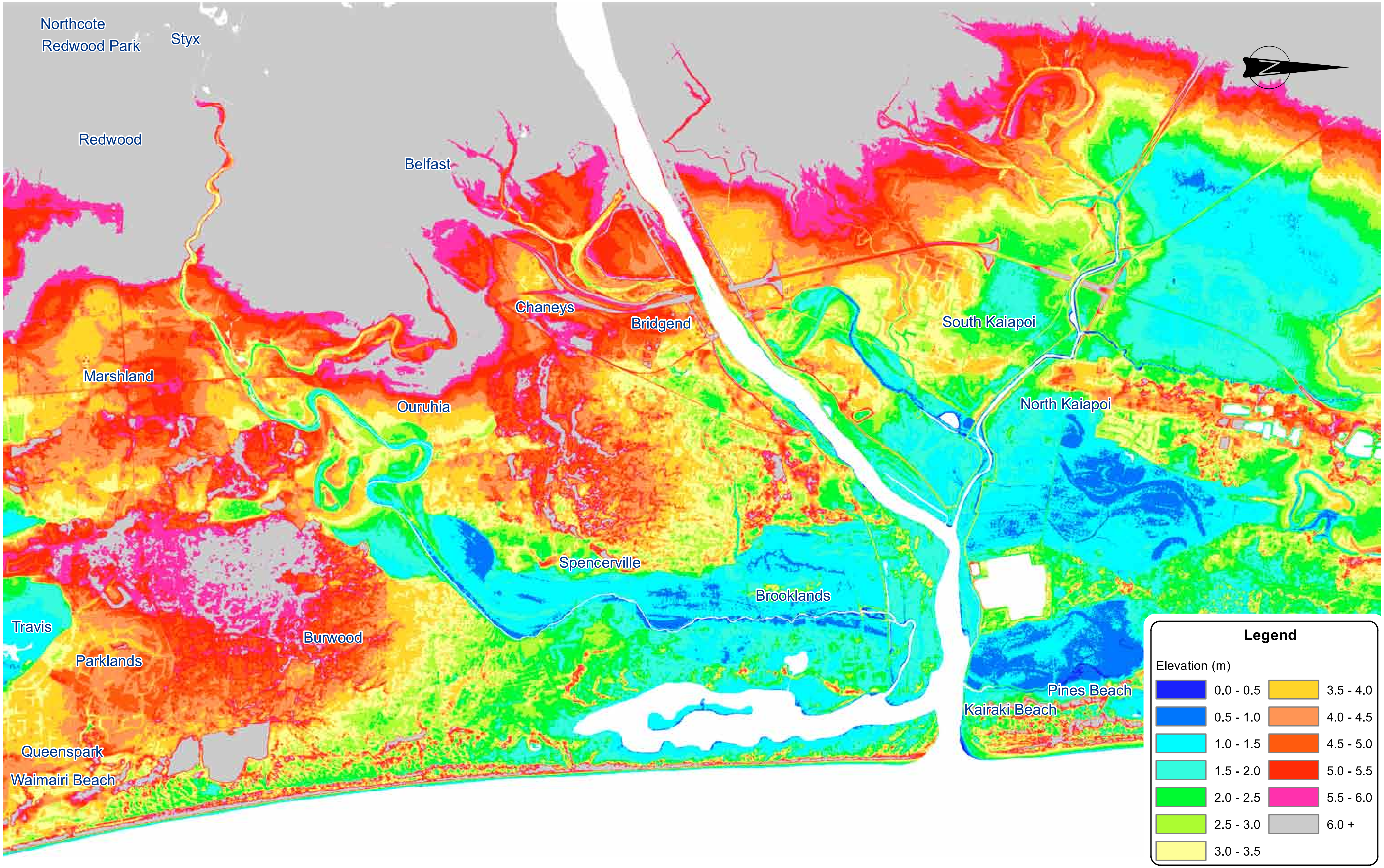
Ref. 52000.400

MAP SERIES 2
GROUNDWATER ELEVATION CONTOURS

FIGURE No. Map 2e Northern Suburbs

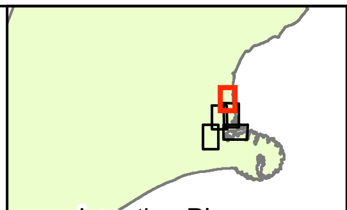
Rev. 0



Notes: LiDAR data supplied by AAM Hatch.
Vertical Datum: Lyttelton 1937

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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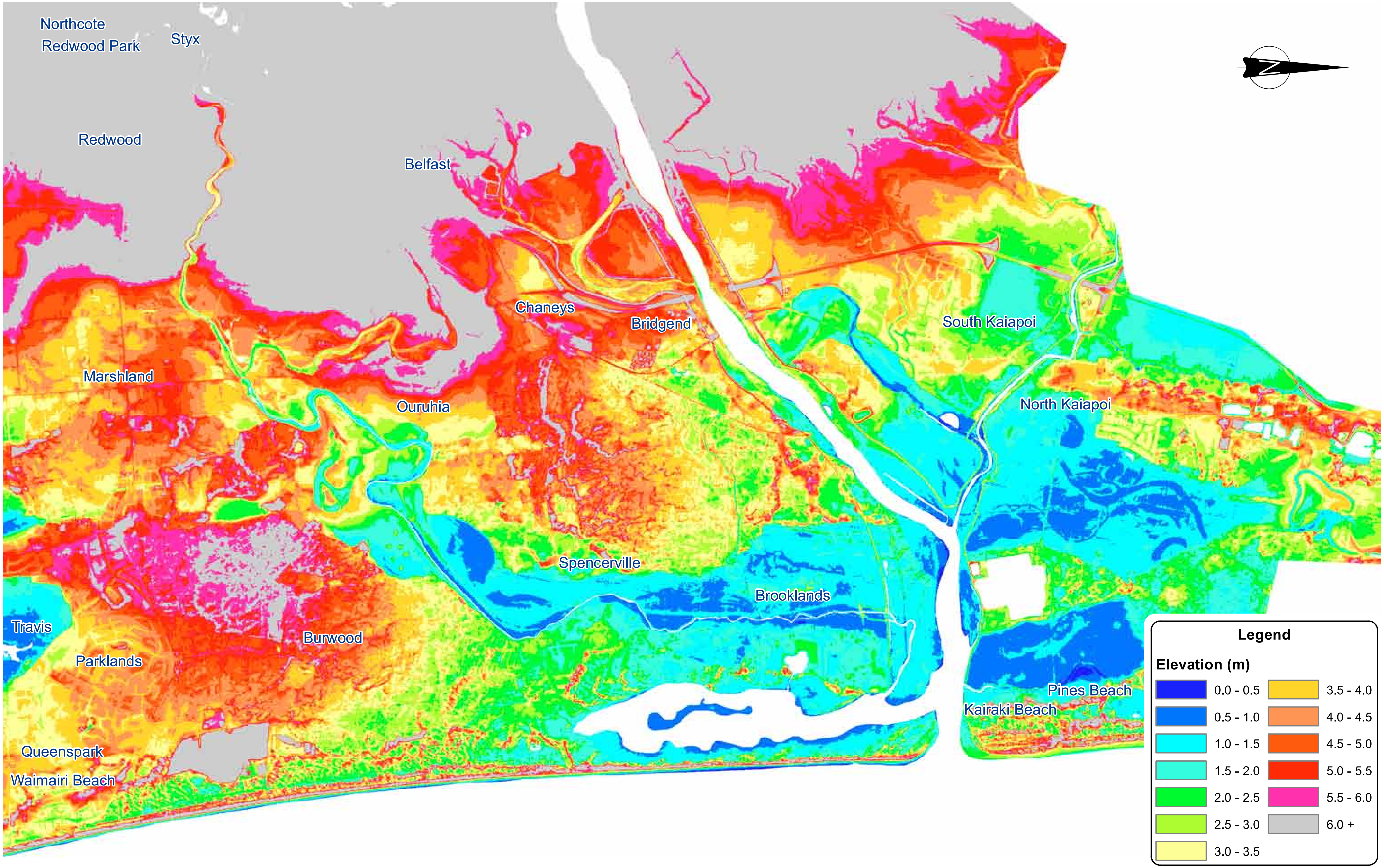
ARCFILE A3L_LidarPre2010_ElevationRL_01062012
SCALE (AT A3 SIZE) 1:40,000
Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400

MAP SERIES 2
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Pre September 2010

FIGURE No. Map 2f Northern Suburbs

Rev. 0



Notes: LiDAR data supplied by NZAM.
Vertical Datum: Lyttelton 1937

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

Location Plan

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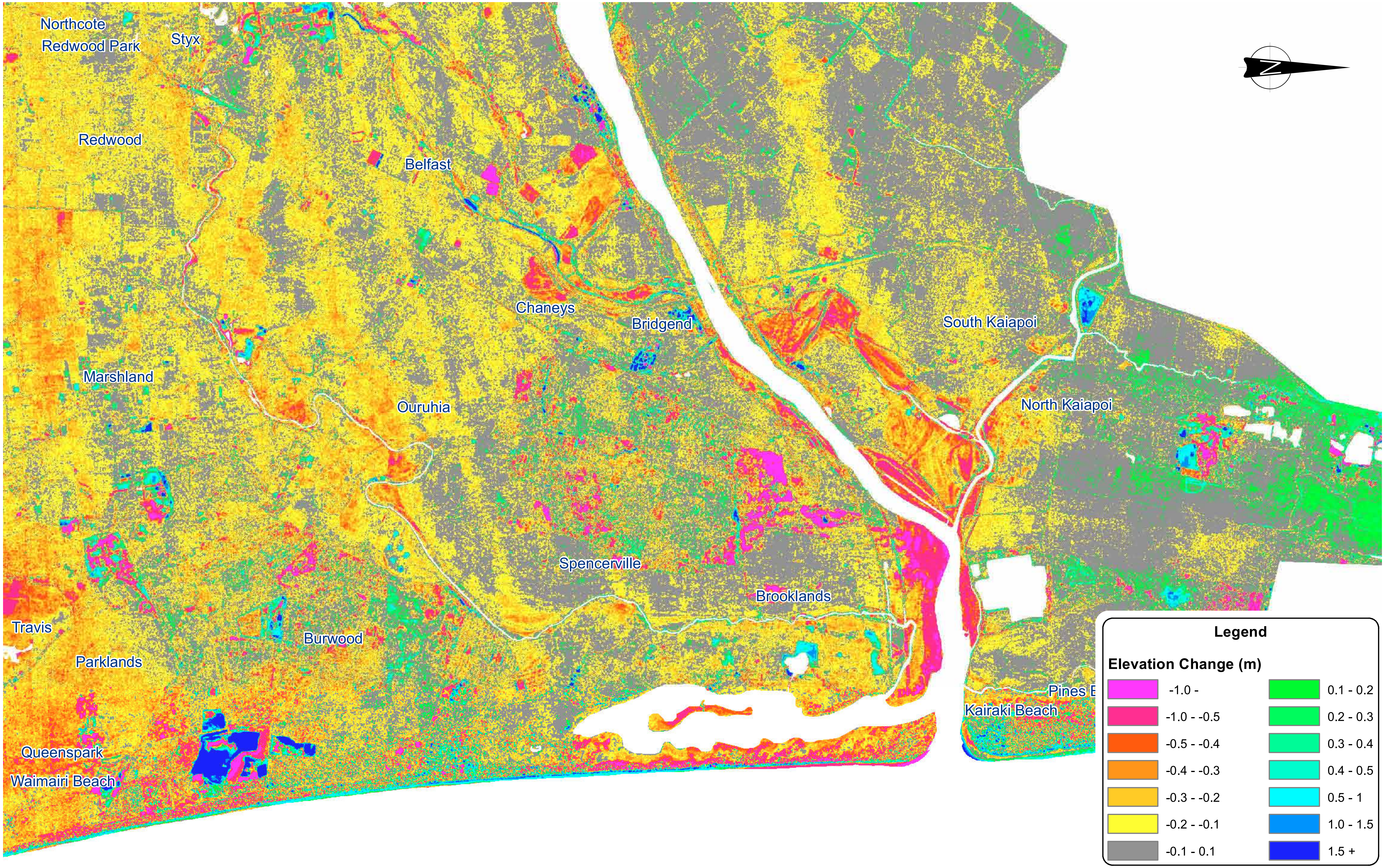
DRAWN	HKB	Jun.12
CHECKED		
APPROVED		
ARCFILE A3L_LidarPostJuneElevationRL_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 2
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Post June 2011

FIGURE No. Map 2g Northern Suburbs

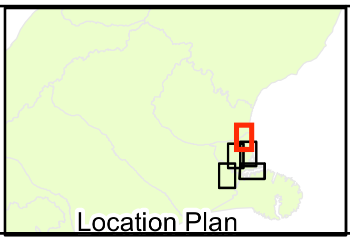
Rev. 0



Notes: Pre 2010 LiDAR supplied by AAM Hatch, Post June 2011 LiDAR supplied by NZAM. LiDAR Difference Model Produced by T&T. Negative values represent a decrease in ground elevation & positive values represent an increase in ground elevation.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



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APPROVED		
ARCFILE A3L_LidarPre2010toJun2011_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 2
GROUND SURFACE ELEVATION CHANGE
LiDAR Difference
Pre 2010 to Post June 2011

FIGURE No. Map 2h Northern Suburbs

Rev. 0

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
Map 1.4	Overview map - Eastern suburbs		32
Map 1.5	Overview map - Southern suburbs		33
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Map 3d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	46
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Map 3f	LiDAR survey	Bare earth digital elevation model pre September 2010	48
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Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	51
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
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Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	59
Map 5b	Detailed land observation map	Recorded observations from 4 September 2010	60
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Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
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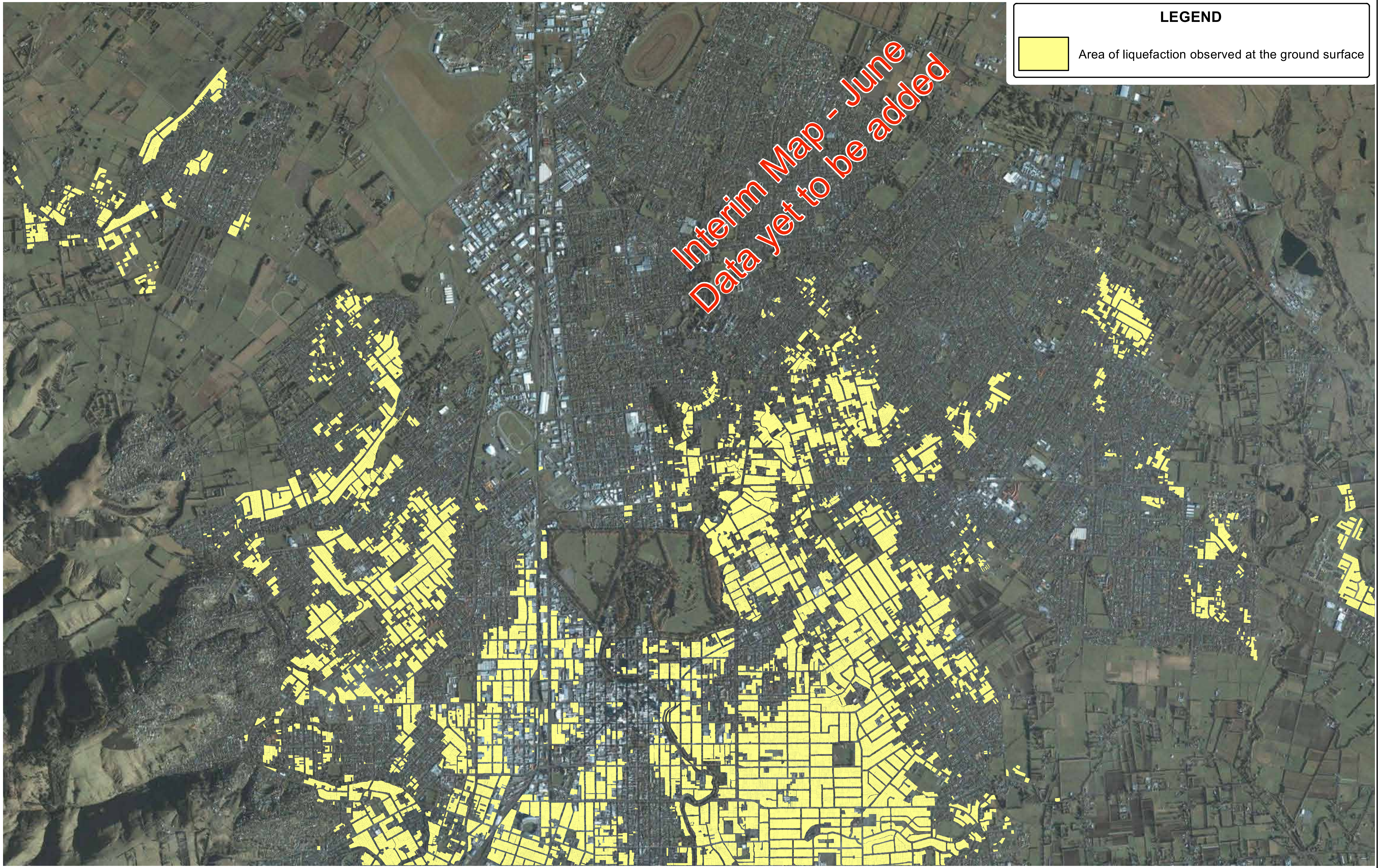

Notes: Road Database supplied by Terralink International Ltd. Rivers, lakes, lagoons, coastline and roads licensed under Creative Commons Attribution 3.0 New Zealand and sourced from LINZ Aerial Photography from ArcGIS Online

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

N

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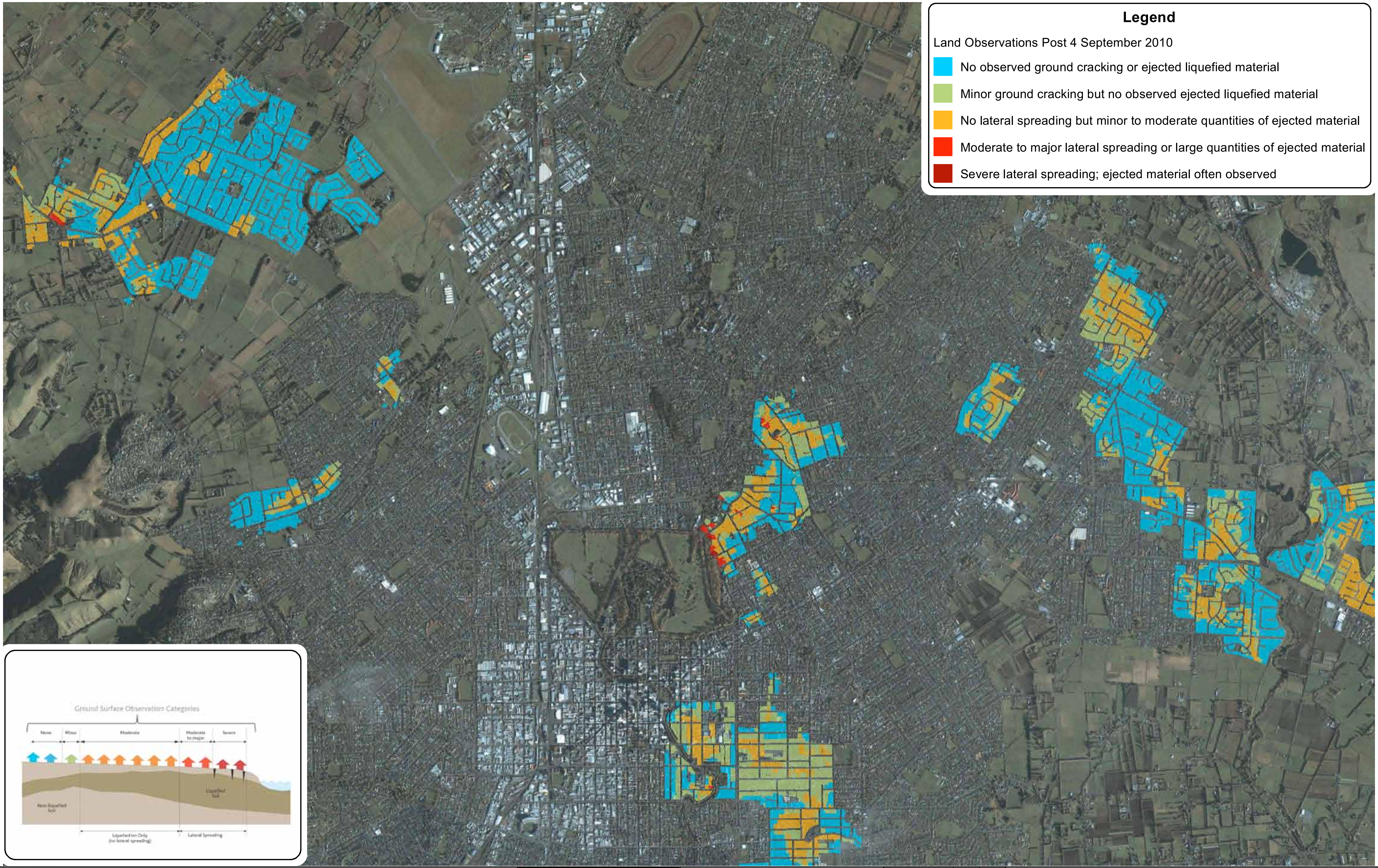
ARCFILE A3L_LiquefactionMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 3
GENERAL LAND OBSERVATION MAP
Total Area of Liquefaction Observations from Events Between 4 September 2010 to end 13 June 2011

FIGURE No. Map 3a Central Suburbs

Rev. 0



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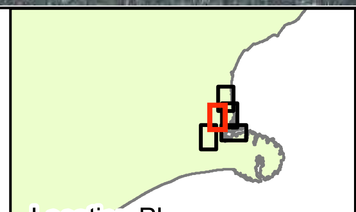
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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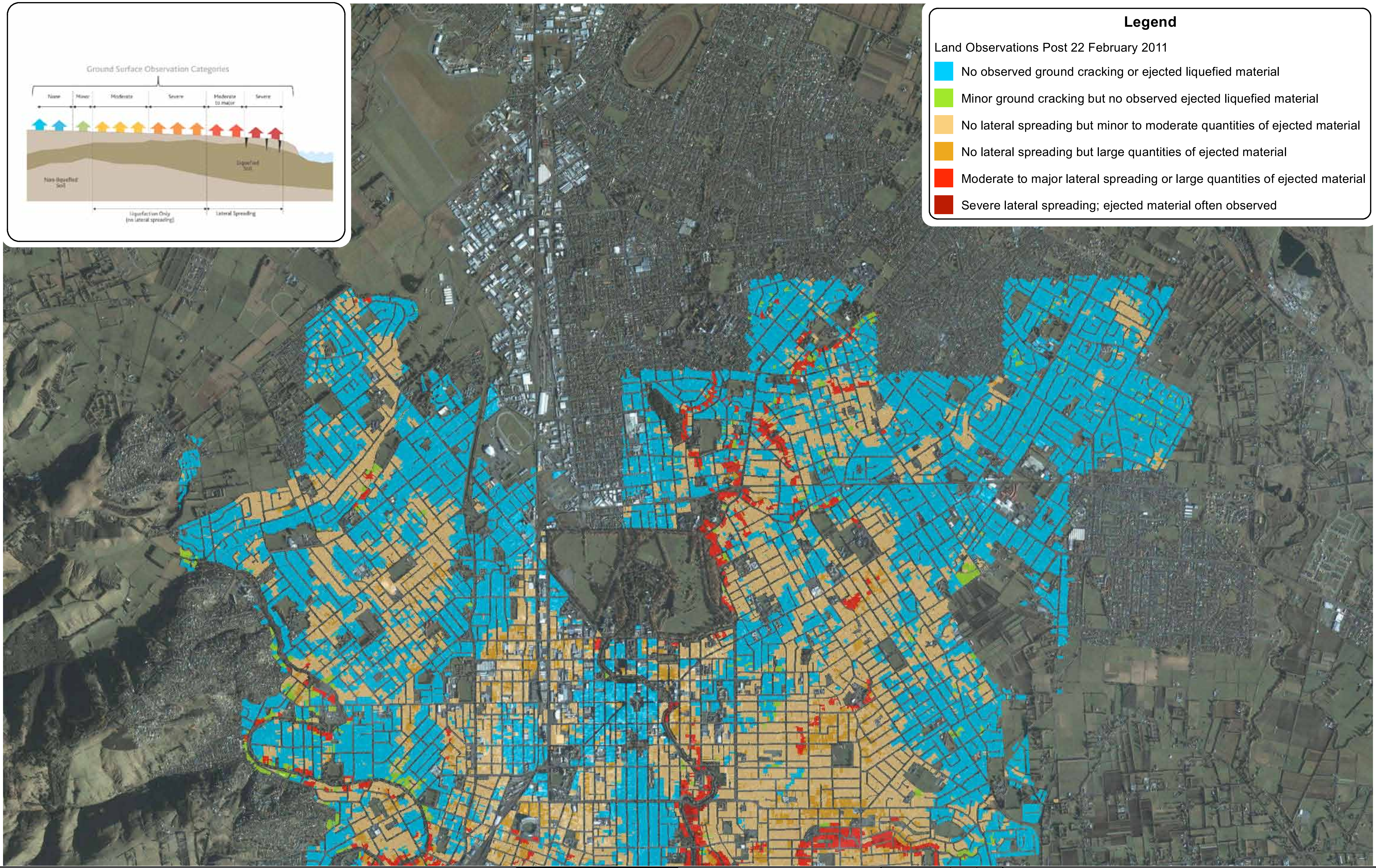
APPROVED		
ARCFILE A3L_LiquefactionSept_08062012.mxd		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 4
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading
Observations from 4 September 2010

FIGURE No. Map 3b Central Suburbs

Rev. 0



Legend

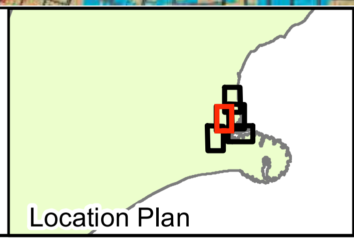
Land Observations Post 22 February 2011

- No observed ground cracking or ejected liquefied material
- Minor ground cracking but no observed ejected liquefied material
- No lateral spreading but minor to moderate quantities of ejected material
- No lateral spreading but large quantities of ejected material
- Moderate to major lateral spreading or large quantities of ejected material
- Severe lateral spreading; ejected material often observed

Notes: Road Database supplied by Terralink International Ltd. Rivers, lakes, lagoons, coastline and roads licensed under Creative Commons Attribution 3.0 New Zealand and sourced from LINZ. Aerial Photography from ArcGIS Online

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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DRAWN	HKB	Jun.12
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APPROVED		

ARCFILE A3L_LiquefactionFeb_08062012.mxd

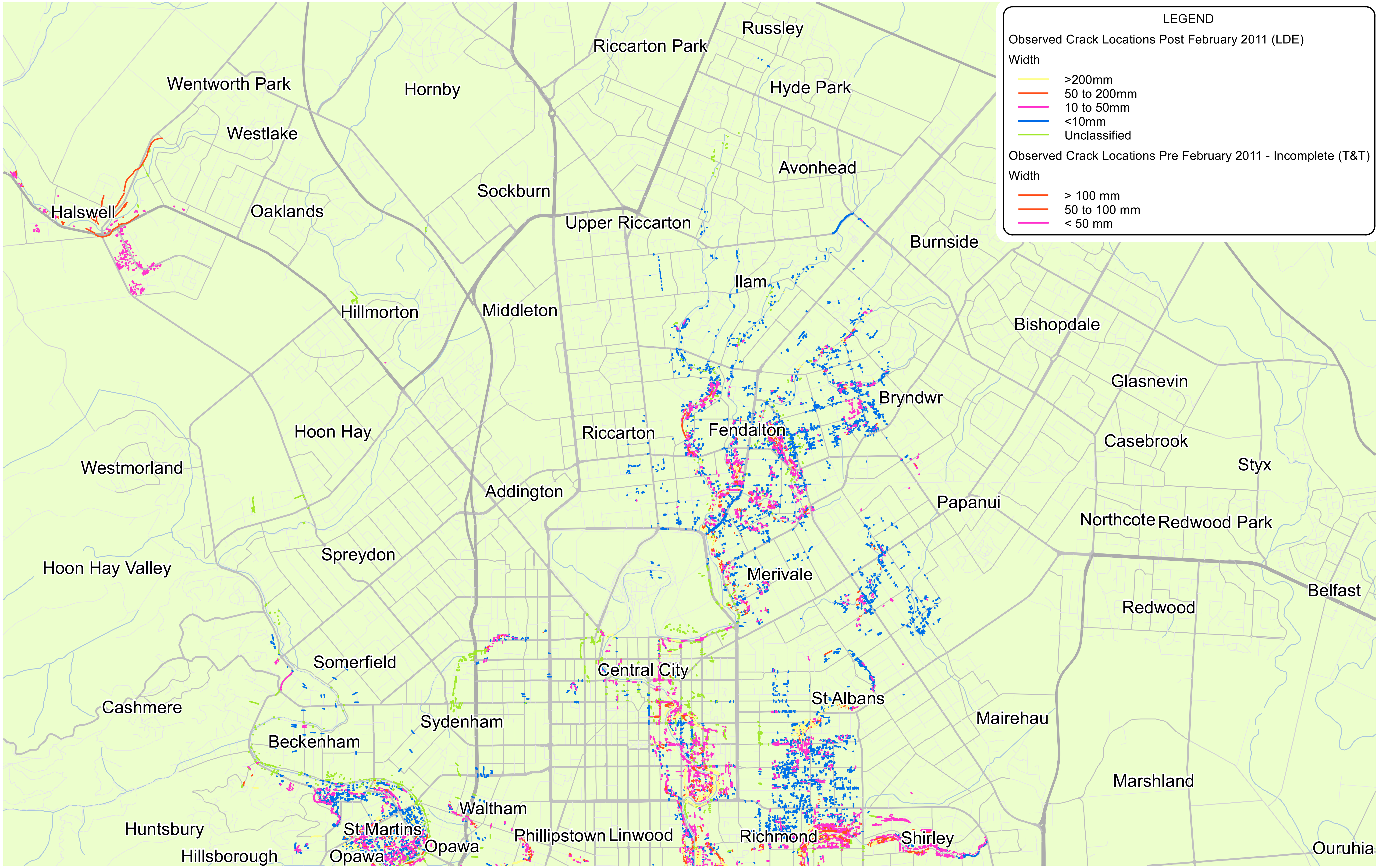
SCALE (AT A3 SIZE) 1:40,000

Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400

MAP SERIES 3
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading Observations from 22 February 2011

FIGURE No. Map 3c Central Suburbs

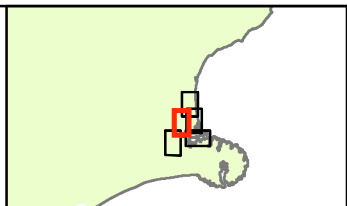
Rev. 0



Notes: Road Database supplied by Terralink International Ltd. Rivers, lakes, lagoons,coastline and roads licensed under Creative Commons Attribution 3.0 New Zealand and sourced from LINZ

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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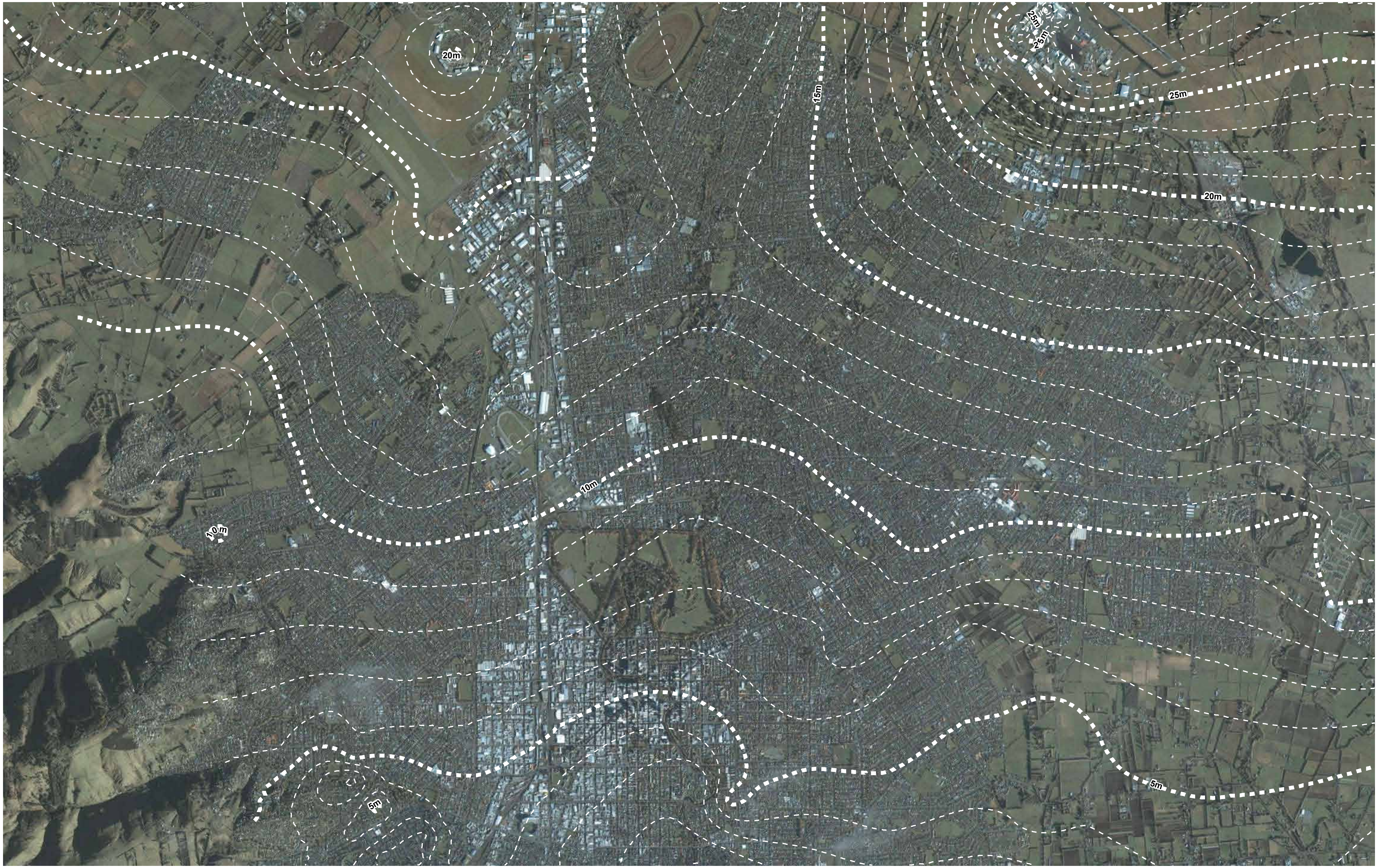
APPROVED		
ARCFILE A3L_GroundCracking_08062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 3
OBSERVED GROUND CRACKING
Observed Ground Crack Locations
Post 4th September 2010 and 22nd February 2011

FIGURE No. Map 3d Central Suburbs

Rev. 0



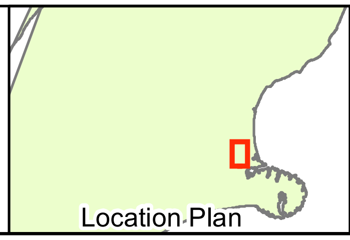
Notes: Aerial photography from ArcGIS Online
Vertical Datum: Lyttelton 1937

Groundwater Contours are indicative only and are derived from data of varying sources (including ECAN and EQC piezometers). NB Levels of accuracy vary across the dataset.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

N



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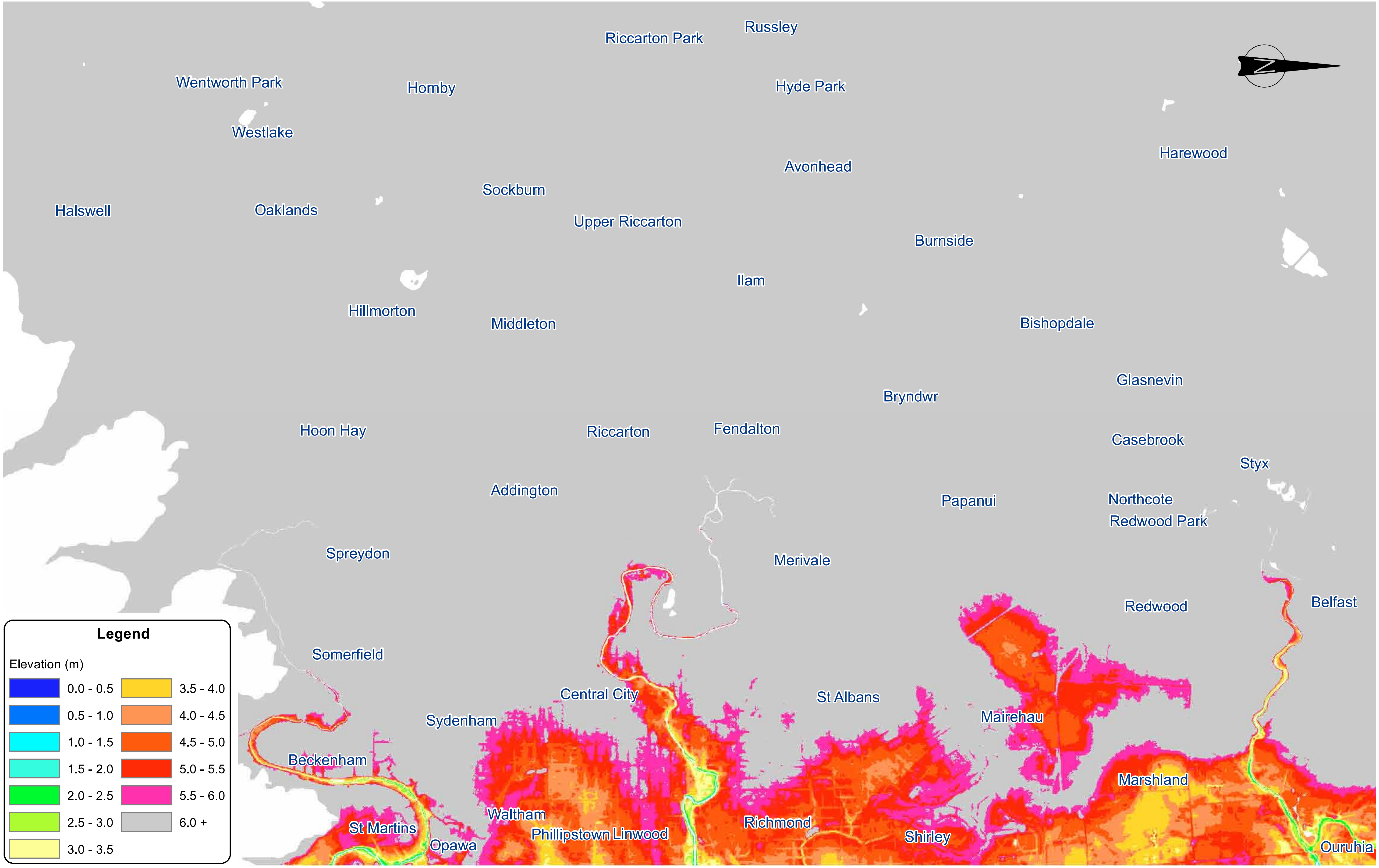
ARCFILE A3L_GroundwaterMaps_31052012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 3
GROUNDWATER ELEVATION CONTOURS

FIGURE No. Map 3e Central Suburbs

Rev. 0

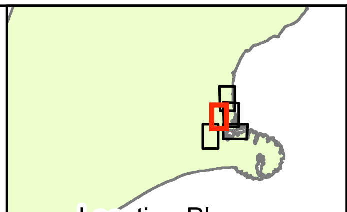


Notes: For map presentation purposes, only levels below 6m are colour differentiated. The actual height differences in these areas between Maps 3g and 3f are, however, shown on Map 3h.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

LiDAR data supplied by AAM Hatch.
Vertical Datum: Lyttelton 1937



Location Plan

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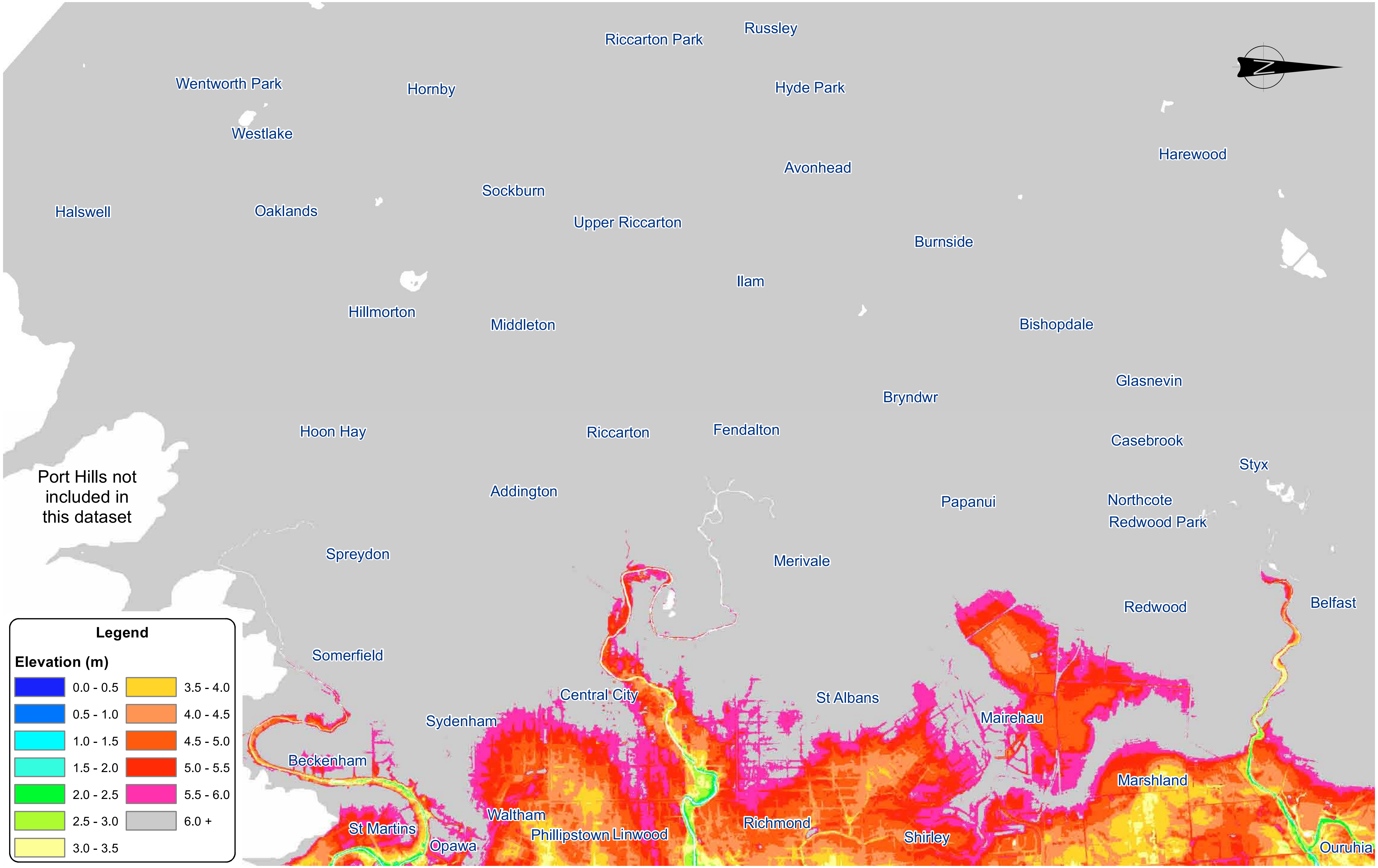
ARCFILE A3L_LidarPre2010_ElevationRL_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 3
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Pre September 2010

FIGURE No. Map 3f Central Suburbs

Rev. 0

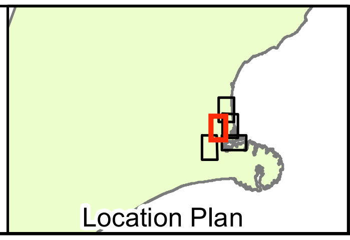


Notes: For map presentation purposes, only levels below 6m are colour differentiated. The actual height differences in these areas between Maps 3g and 3f are, however, shown on Map 3h.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

LiDAR data supplied by NZAM.
Vertical Datum: Lyttelton 1937



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ARCFILE A3L_LidarPostJuneElevationRL_01062012

SCALE (AT A3 SIZE) 1:40,000

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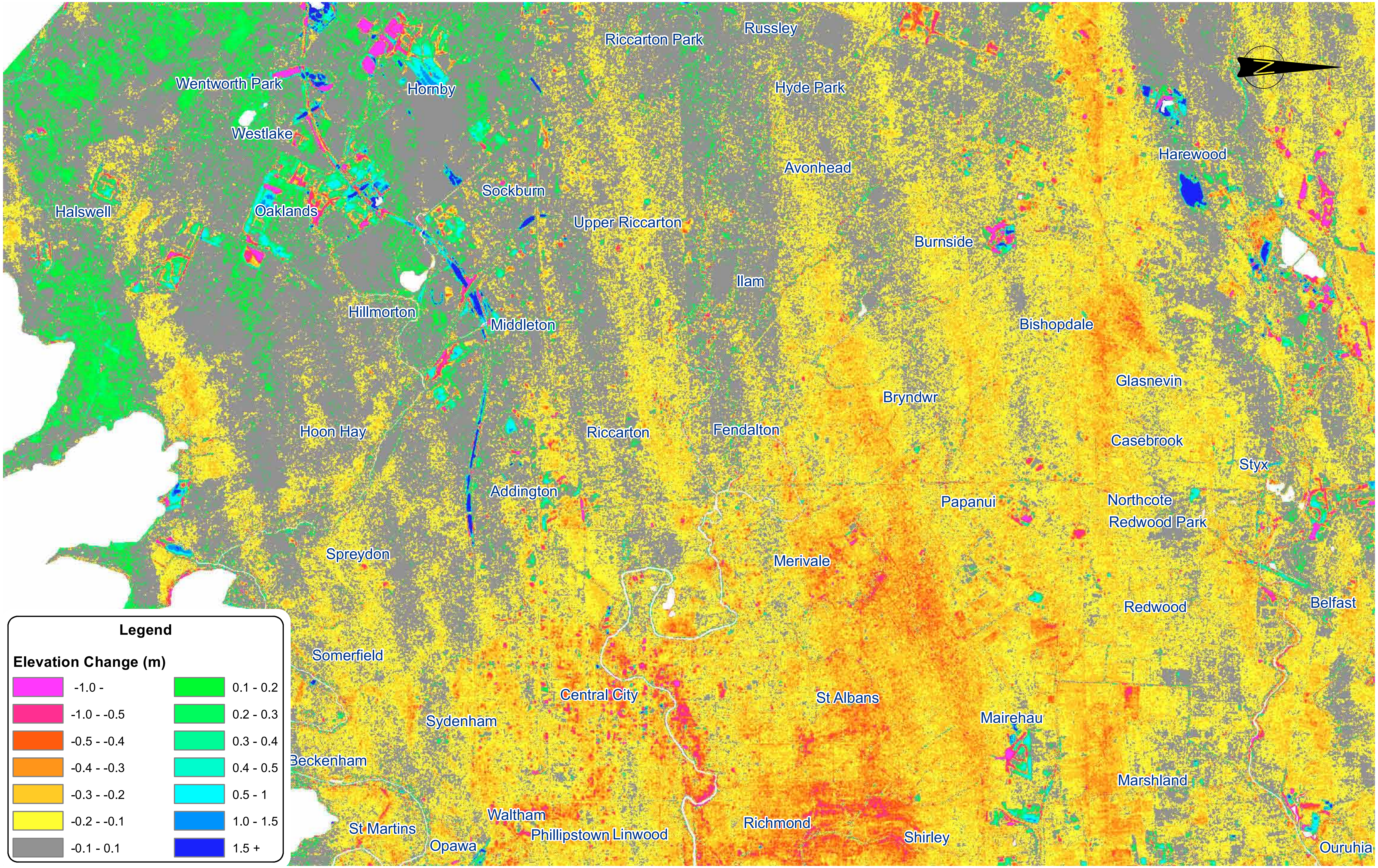
MAP SERIES 3
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Post June 2011

FIGURE No. Map 3g Central Suburbs

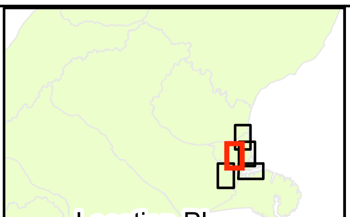
Rev. 0



Notes: Pre 2010 LiDAR supplied by AAM Hatch, Post June 2011 LiDAR supplied by NZAM. LiDAR Difference Model Produced by T&T. Negative values represent a decrease in ground elevation & positive values represent an increase in ground elevation.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)


Location Plan

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EARTHQUAKE COMMISSION
KŌMIHANA RŪWHENUA

DRAWN	HKB	Jun.12
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APPROVED		
ARCFILE A3L_LidarPre2010toJun2011_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 3
GROUND SURFACE ELEVATION CHANGE
LiDAR Difference
Pre 2010 to Post June 2011

FIGURE No. Map 3h Central Suburbs

Rev. 0

Map series

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Map series 2 - Northern suburbs			
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Map 3g	LiDAR survey	Bare earth digital elevation model post June 2011	49
Map 3h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	50
Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	51
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
Map 4d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	54
Map 4e	Groundwater elevation contours		55
Map 4f	LiDAR survey	Bare earth digital elevation model pre September 2010	56
Map 4g	LiDAR survey	Bare earth digital elevation model post June 2011	57
Map 4h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	58
Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	59
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Map series 6 - Port Hills and Lyttelton suburbs			
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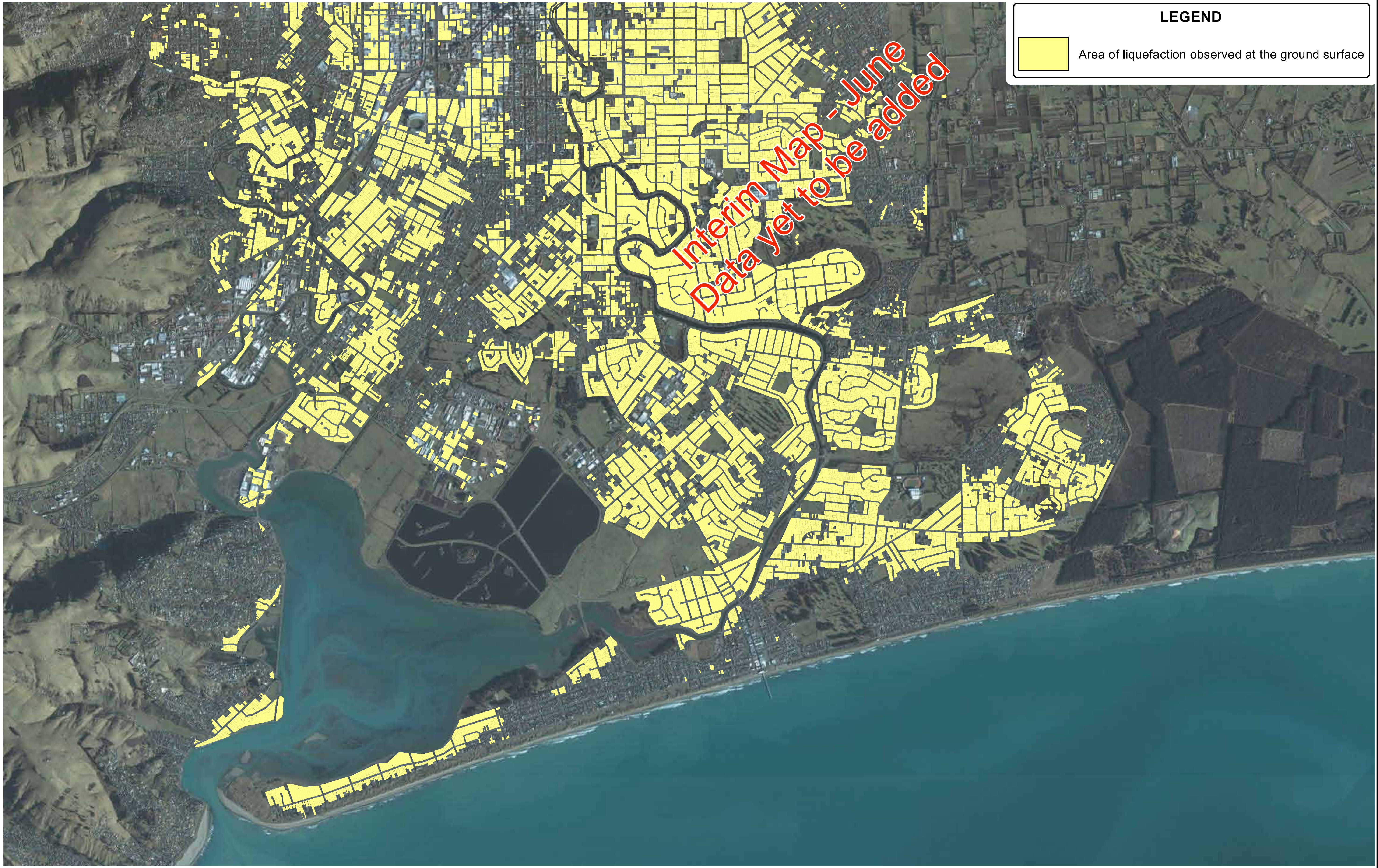
Map 6b-2	Detailed land observation map	Land observations after 13 June 2011	65
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67



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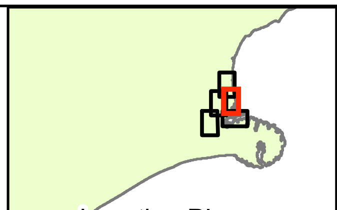
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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ARCFILE A3L_LiquefactionMaps_31052012

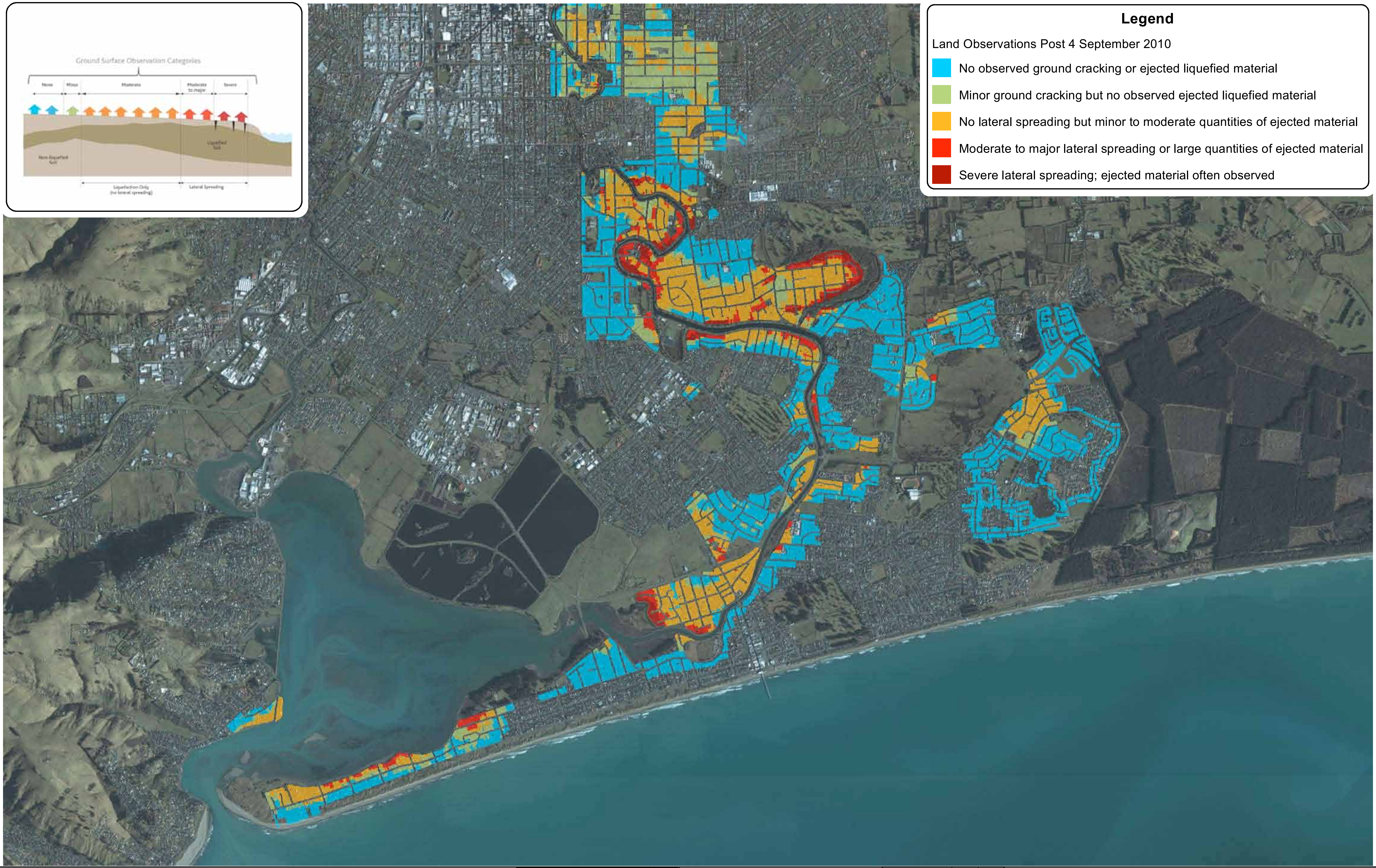
SCALE (AT A3 SIZE) 1:40,000

Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400

MAP SERIES 4
GENERAL LAND OBSERVATION MAP
Total Area of Liquefaction Observations from Events
Between 4 September 2010 to end 13 June 2011

FIGURE No. Map 4a Eastern Suburbs

Rev. 0



Legend

Land Observations Post 4 September 2010

- No observed ground cracking or ejected liquefied material
- Minor ground cracking but no observed ejected liquefied material
- No lateral spreading but minor to moderate quantities of ejected material
- Moderate to major lateral spreading or large quantities of ejected material
- Severe lateral spreading; ejected material often observed

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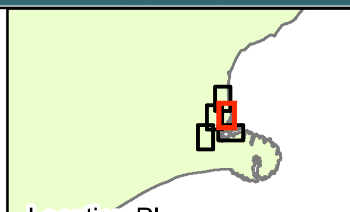
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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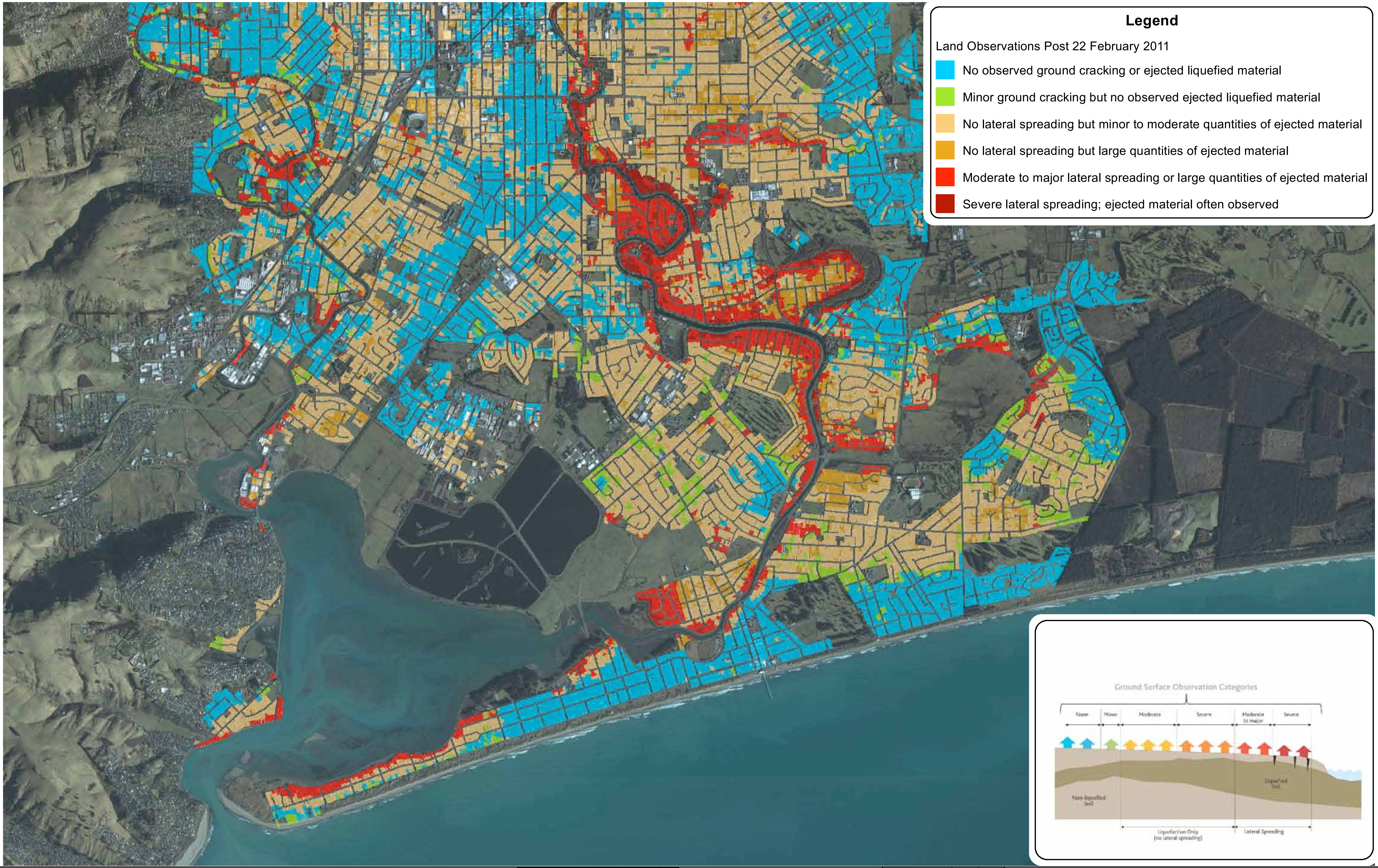
ARCFILE	A3L_LiquefactionSept_08062012.mxd	
SCALE (AT A3 SIZE)	1:40,000	
Prepared By Tonkin & Taylor Ltd. Ref.	52000.400	

MAP SERIES 4
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading
Observations from 4 September 2010

FIGURE No. Map 4b Eastern Suburbs

Rev. 0



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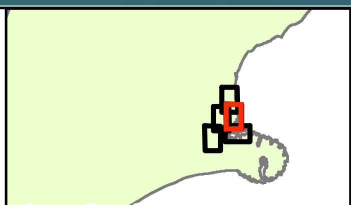
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



Location Plan

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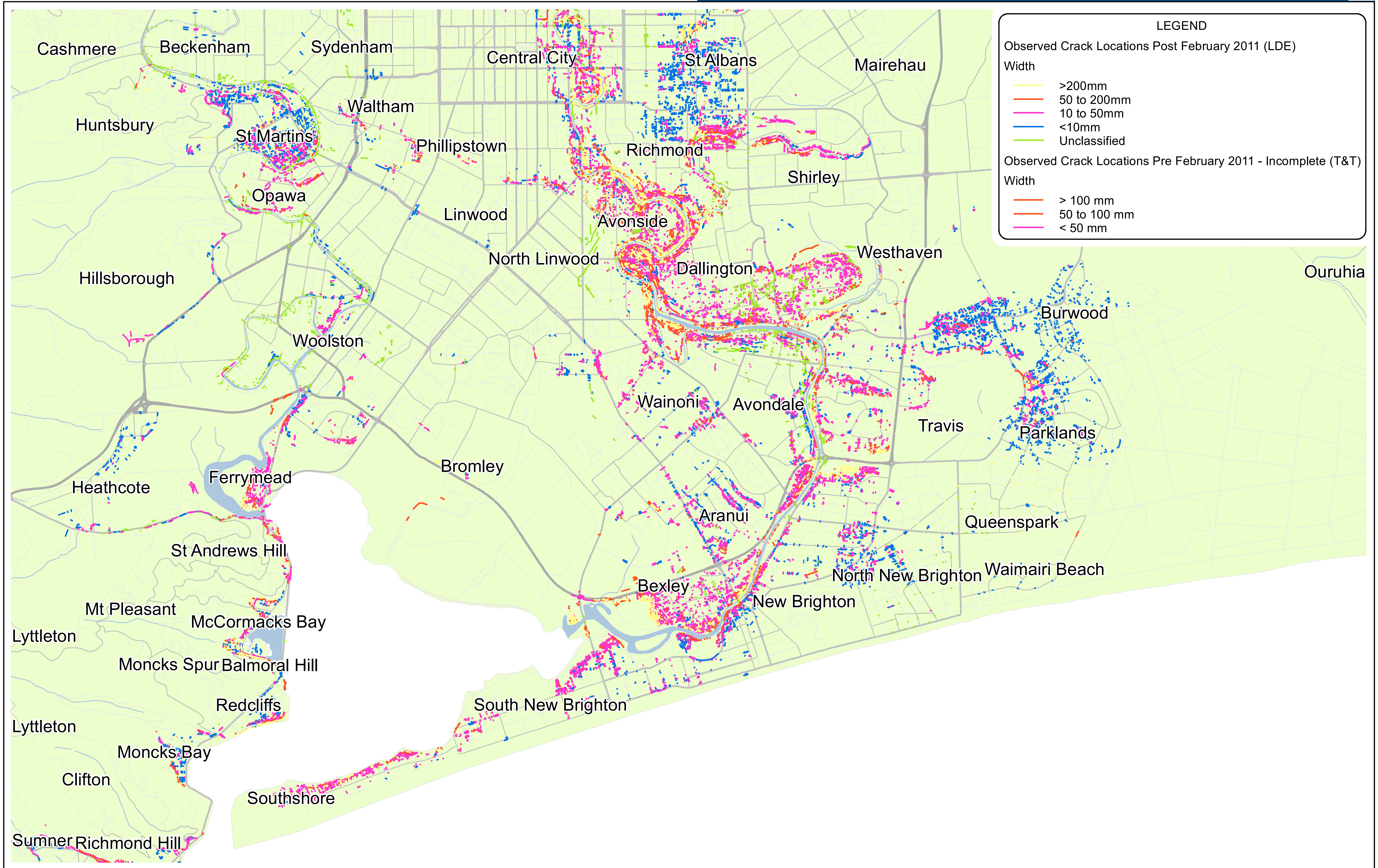
APPROVED		
ARCFILE A3L_LiquefactionFeb_08062012.mxd		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 4
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading Observations from 22 February 2011

FIGURE No. Map 4c Eastern Suburbs

Rev. 0



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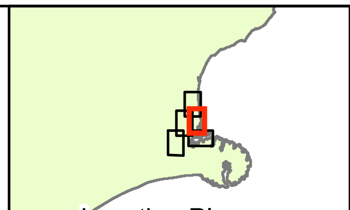
A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)


Location Plan

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APPROVED		

ARCFILE A3L_GroundCracking_08062012

SCALE (AT A3 SIZE) 1:40,000

Prepared By Tonkin & Taylor Ltd. Ref. 52000.400

MAP SERIES 4
OBSERVED GROUND CRACKING
Observed Ground Crack Locations
Post 4th September 2010 and 22nd February 2011

FIGURE No. Map 4d Eastern Suburbs

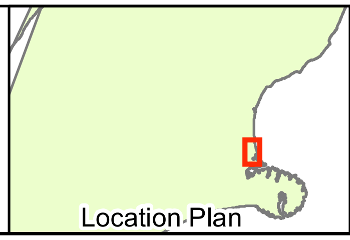
Rev. 0

Notes: Aerial photography from ArcGIS Online
Vertical Datum: Lyttelton 1937

Groundwater Contours are indicative only and are derived from data of varying sources (including ECAN and EQC piezometers). NB Levels of accuracy vary across the dataset.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)



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ARCFILE A3L_GroundwaterMaps_31052012
SCALE (AT A3 SIZE) 1:40,000
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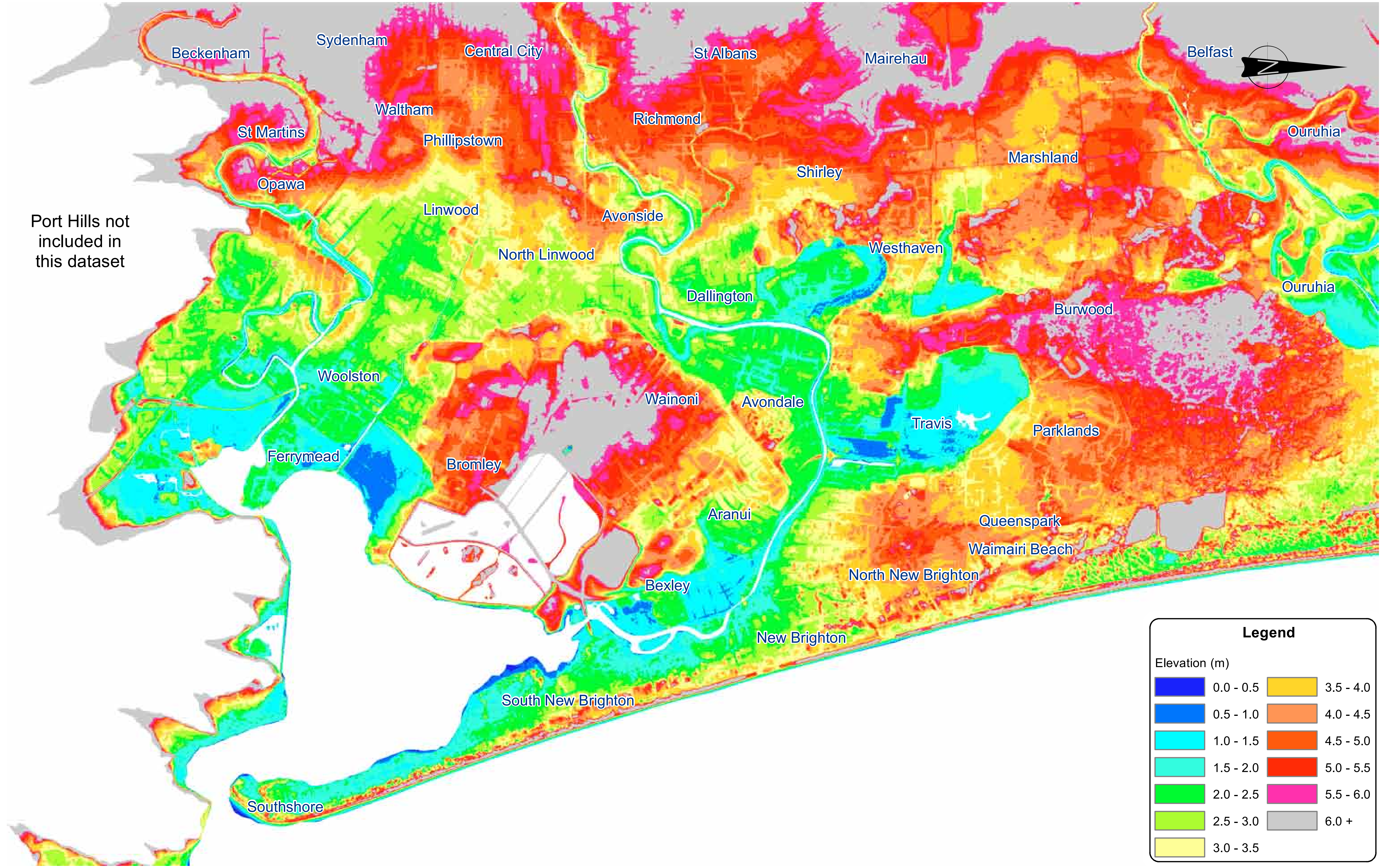
Ref. 52000.400

MAP SERIES 4
GROUNDWATER ELEVATION CONTOURS

FIGURE No. Map 4e Eastern Suburbs
Rev. 0



Notes: LiDAR data supplied by AAM Hatch.
Vertical Datum: Lyttelton 1937

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

Location Plan

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APPROVED		

ARCFILE A3L_LidarPre2010_ElevationRL_01062012

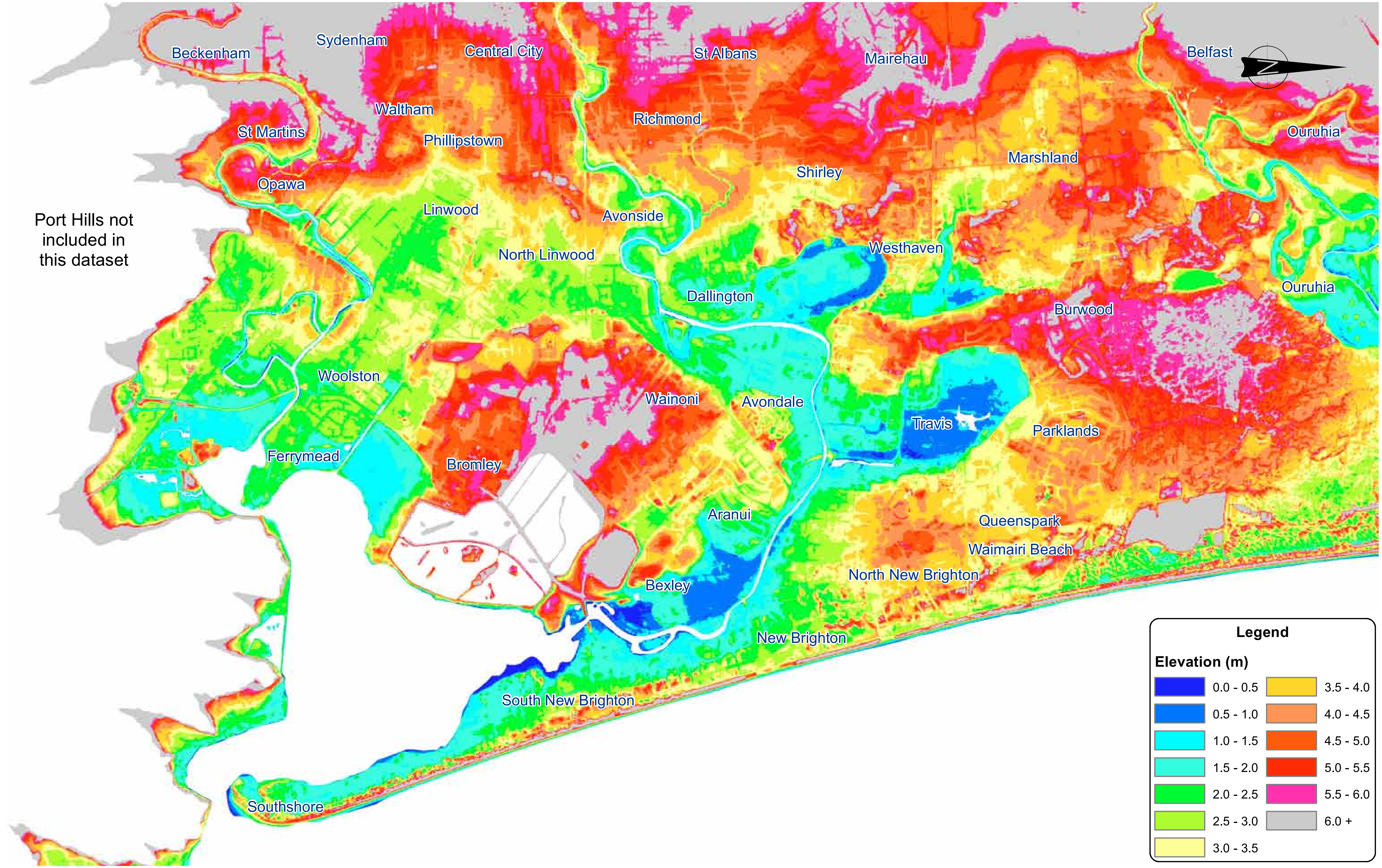
SCALE (AT A3 SIZE) 1:40,000

Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400

MAP SERIES 4
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Pre September 2010

FIGURE No. Map 4f Eastern Suburbs

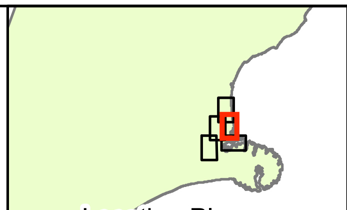
Rev. 0



Notes: LiDAR data supplied by NZAM.
Vertical Datum: Lyttelton 1937

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)


Location Plan

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DRAWN	HKB	Jun.12
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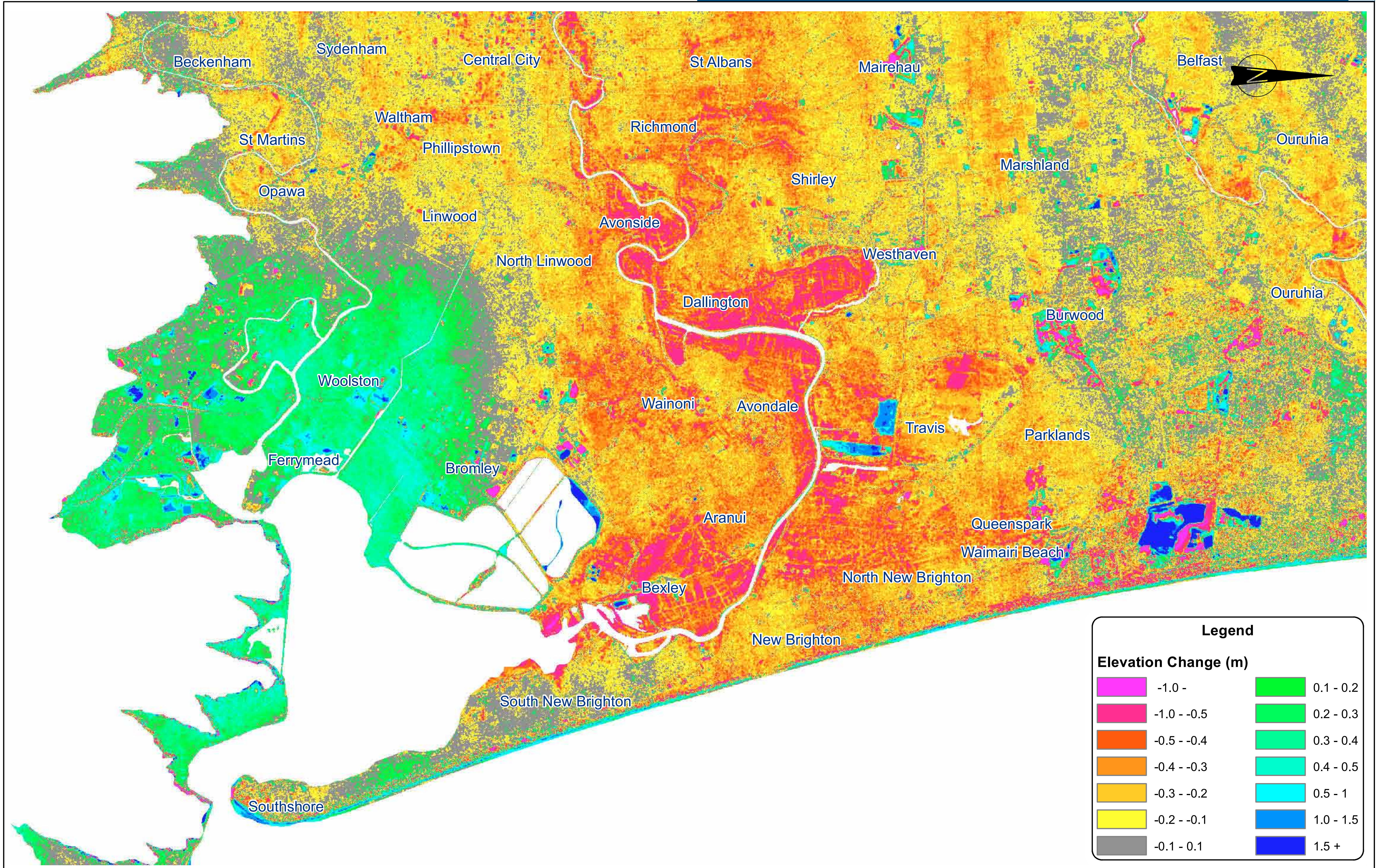
APPROVED		
ARCFILE A3L_LidarPostJuneElevationRL_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

MAP SERIES 4
LIDAR SURVEY
BARE EARTH DIGITAL ELEVATION MODEL
Post June 2011

FIGURE No. Map 4g Eastern Suburbs

Rev. 0



Notes: Pre 2010 LiDAR supplied by AAM Hatch, Post June 2011 LiDAR supplied by NZAM. LiDAR Difference Model Produced by T&T. Negative values represent a decrease in ground elevation & positive values represent an increase in ground elevation.

A3 SCALE 1:40,000

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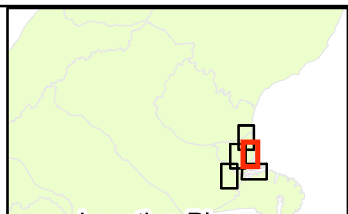
Location Plan

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KŌMIHANA RŪWHENUA

DRAWN	HKB	Jun.12
CHECKED		
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ARCFILE A3L_LidarPre2010toJun2011_01062012		
SCALE (AT A3 SIZE) 1:40,000		
Prepared By Tonkin & Taylor Ltd. Ref. 52000.400		

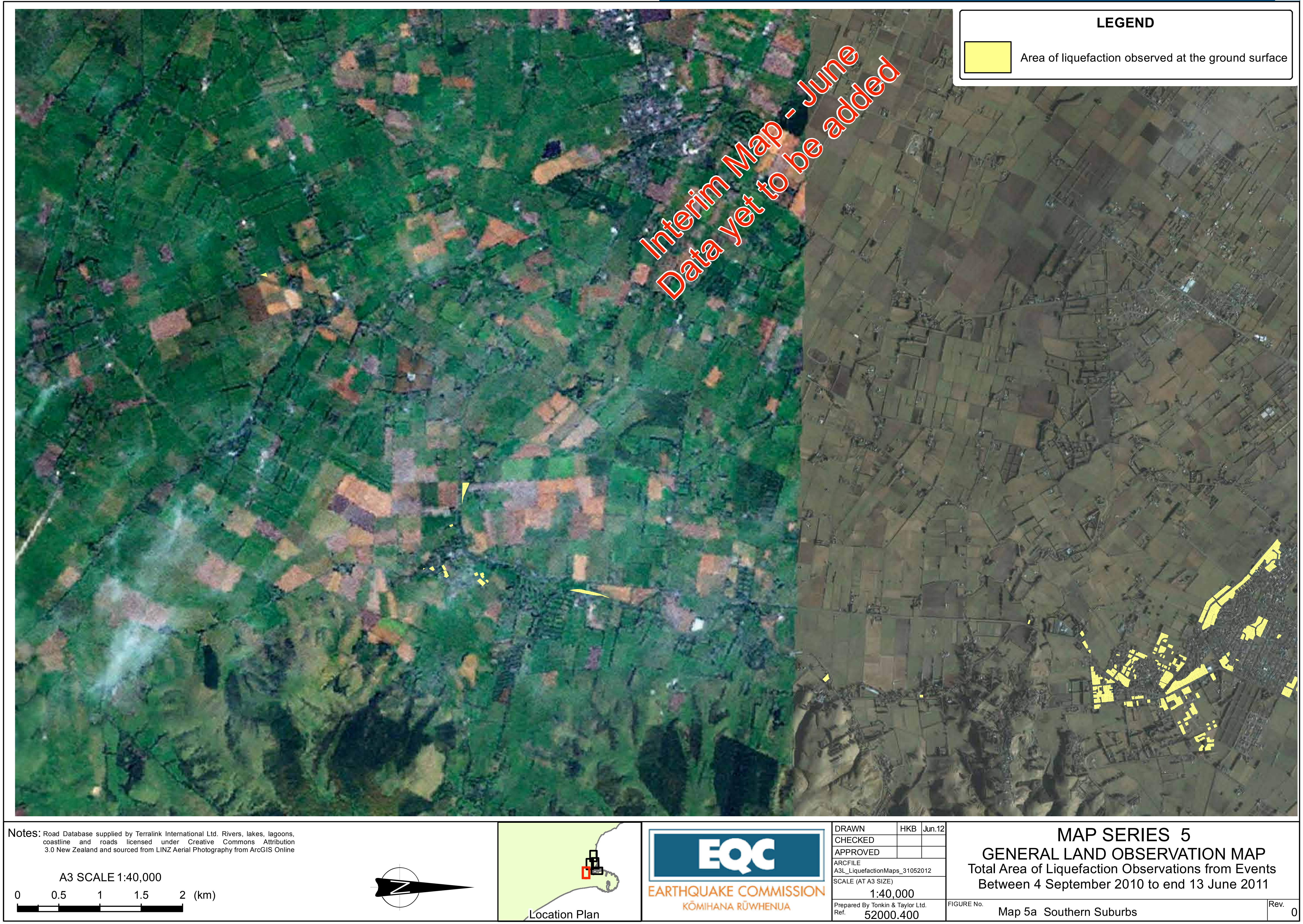
MAP SERIES 4
GROUND SURFACE ELEVATION CHANGE
LiDAR Difference
Pre 2010 to Post June 2011

FIGURE No. Map 4h Eastern Suburbs

Rev. 0

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
Map 1.4	Overview map - Eastern suburbs		32
Map 1.5	Overview map - Southern suburbs		33
Map 1.6	Overview map - Port Hills and Lyttelton suburbs		34
Map series 2 - Northern suburbs			
Map 2a	General land observation map	Total area of liquefaction observations to 13 June 2011	35
Map 2b	Detailed land observation map	Recorded observations from 4 September 2010	36
Map 2c	Detailed land observation map	Recorded observations from 22 February 2011	37
Map 2d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	38
Map 2e	Groundwater elevation contours		39
Map 2f	LiDAR survey	Bare earth digital elevation model pre September 2010	40
Map 2g	LiDAR survey	Bare earth digital elevation model post June 2011	41
Map 2h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	42
Map series 3 - Central suburbs			
Map 3a	General land observation map	Total area of liquefaction observations to 13 June 2011	43
Map 3b	Detailed land observation map	Recorded observations from 4 September 2010	44
Map 3c	Detailed land observation map	Recorded observations from 22 February 2011	45
Map 3d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	46
Map 3e	Groundwater elevation contours		47
Map 3f	LiDAR survey	Bare earth digital elevation model pre September 2010	48
Map 3g	LiDAR survey	Bare earth digital elevation model post June 2011	49
Map 3h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	50
Map series 4 - Eastern suburbs			
Map 4a	General land observation map	Total area of liquefaction observations to 13 June 2011	51
Map 4b	Detailed land observation map	Recorded observations from 4 September 2010	52
Map 4c	Detailed land observation map	Recorded observations from 22 February 2011	53
Map 4d	Observed ground cracking	Crack locations post 4 September 2010 and 22 February 2011	54
Map 4e	Groundwater elevation contours		55
Map 4f	LiDAR survey	Bare earth digital elevation model pre September 2010	56
Map 4g	LiDAR survey	Bare earth digital elevation model post June 2011	57
Map 4h	Ground surface elevation change	LiDAR difference pre 2010 to post June 2011	58
Map series 5 - Southern suburbs			
Map 5a	General land observation map	Total area of liquefaction observations to 13 June 2011	59
Map 5b	Detailed land observation map	Recorded observations from 4 September 2010	60
Map 5e	Groundwater elevation contours		61
Map series 6 - Port Hills and Lyttelton suburbs			
Map 6a	General land observation map	Aggregated land observations to 13 June 2011	62
Map 6b	Detailed land observation map	Land observations after 13 June 2011	63
Map 6b-1	Detailed land observation map	Land observations after 13 June 2011	64
Map 6b-2	Detailed land observation map	Land observations after 13 June 2011	65
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67


LEGEND
Area of liquefaction observed at the ground surface
Interim Map - June
Data yet to be added
Notes: Road Database supplied by Terralink International Ltd. Rivers, lakes, lagoons, coastline and roads licensed under Creative Commons Attribution 3.0 New Zealand and sourced from LINZ Aerial Photography from ArcGIS Online
A3 SCALE 1:40,000
0 0.5 1 1.5 2 (km)
N
Location Plan
EQC
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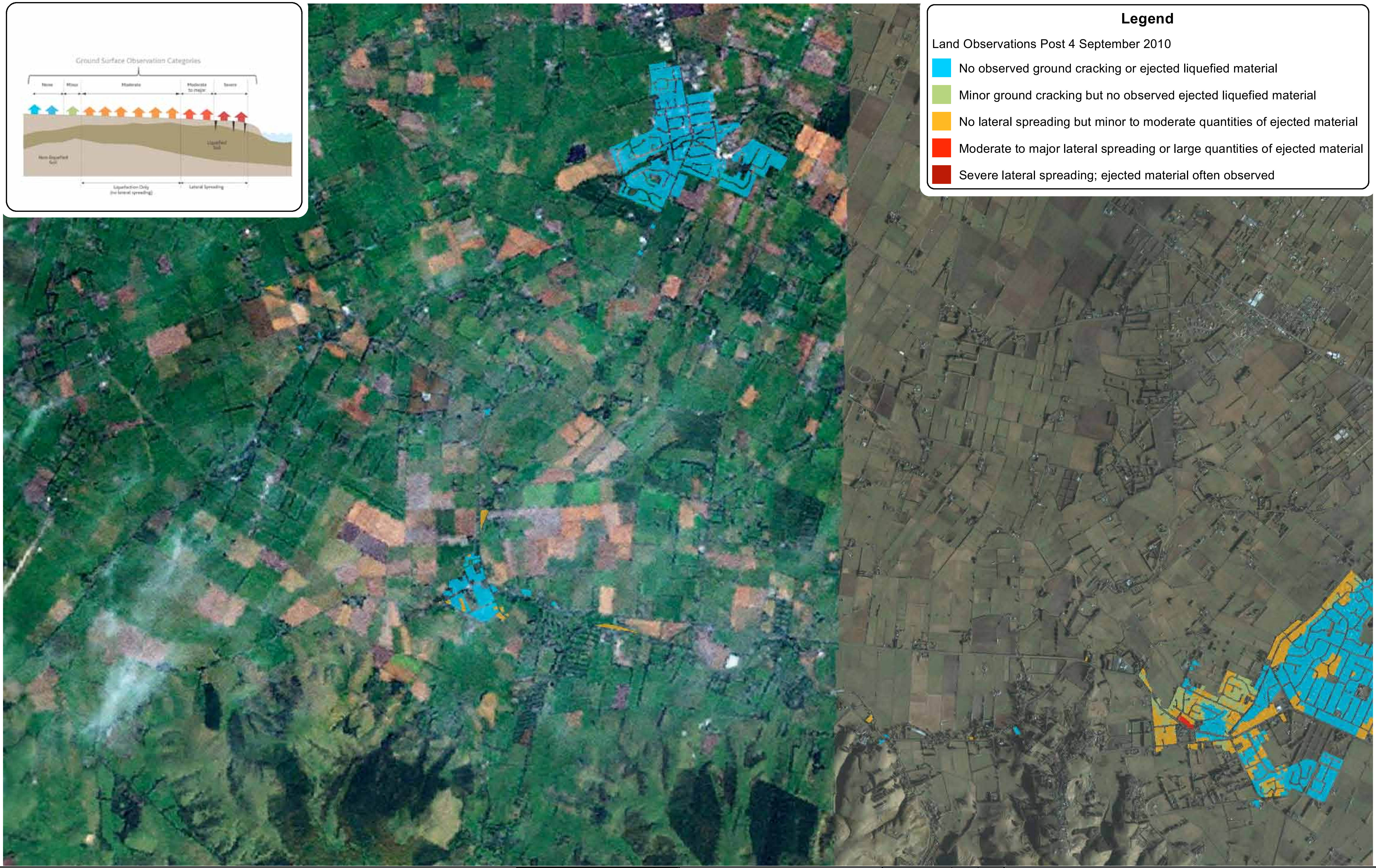
DRAWN HKB Jun.12
CHECKED
APPROVED
ARCFILE A3L_LiquefactionMaps_31052012
SCALE (AT A3 SIZE) 1:40,000
Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400
MAP SERIES 5
GENERAL LAND OBSERVATION MAP
Total Area of Liquefaction Observations from Events
Between 4 September 2010 to end 13 June 2011
FIGURE No. Map 5a Southern Suburbs
Rev. 0



Legend

Land Observations Post 4 September 2010

- No observed ground cracking or ejected liquefied material
- Minor ground cracking but no observed ejected liquefied material
- No lateral spreading but minor to moderate quantities of ejected material
- Moderate to major lateral spreading or large quantities of ejected material
- Severe lateral spreading; ejected material often observed

Notes: Road Database supplied by Terralink International Ltd. Rivers, lakes, lagoons, coastline and roads licensed under Creative Commons Attribution 3.0 New Zealand and sourced from LINZ. Aerial Photography from ArcGIS Online

A3 SCALE 1:40,000

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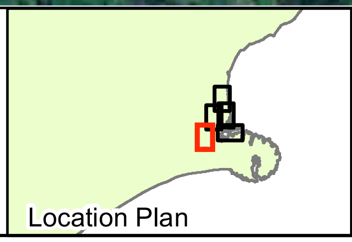

Location Plan

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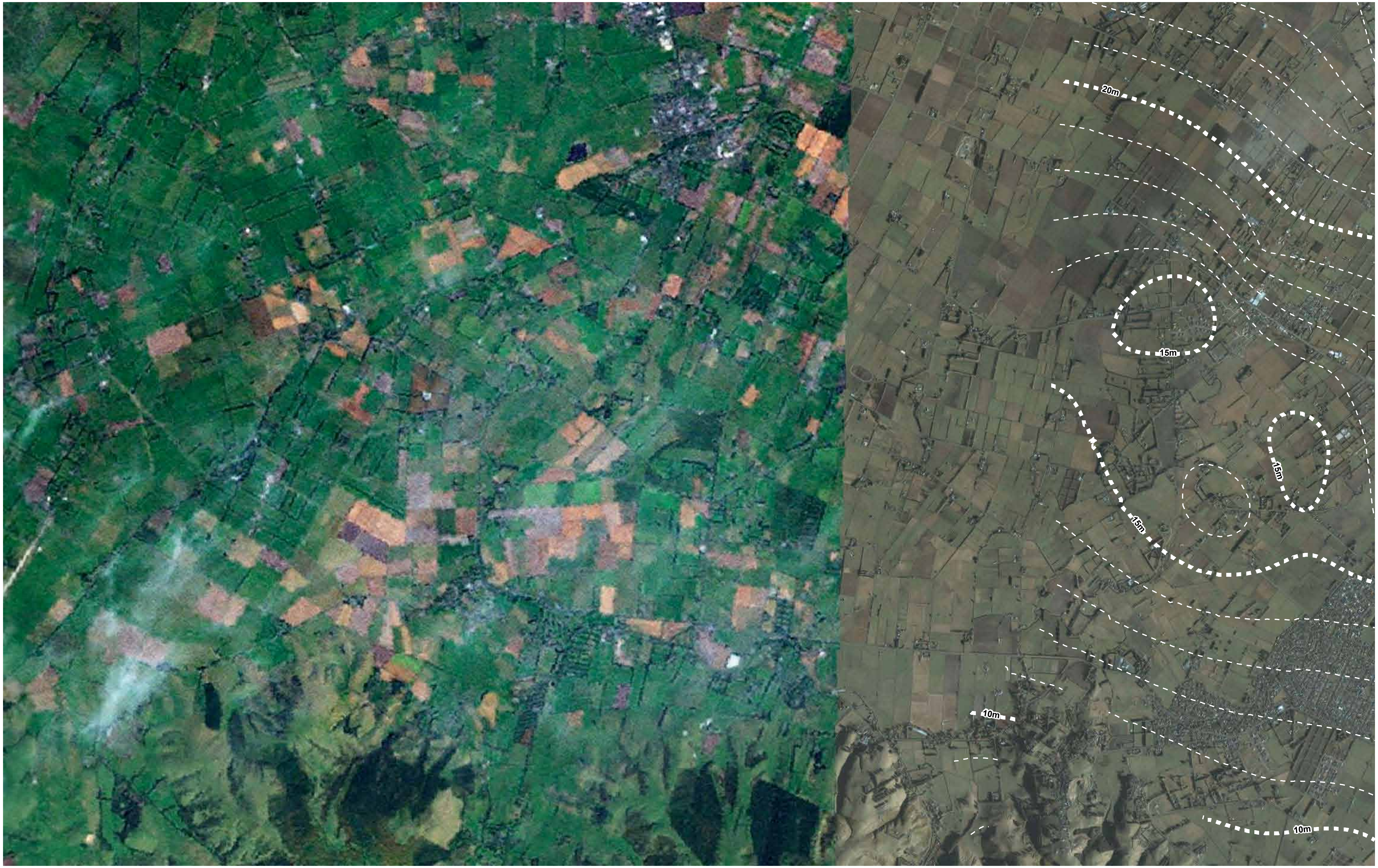
ARCFILE	A3L_LiquefactionSept_08062012.mxd	
SCALE (AT A3 SIZE)	1:40,000	
Prepared By Tonkin & Taylor Ltd. Ref.	52000.400	

MAP SERIES 5
DETAILED LAND OBSERVATION MAP
Recorded Liquefaction and Lateral Spreading
Observations from 4 September 2010

FIGURE No. Map 5b Southern Suburbs

Rev. 0



Notes: Aerial photography from ArcGIS Online
Vertical Datum: Lyttelton 1937

Groundwater Contours are indicative only and are derived from data of varying sources (including ECAN and EQC piezometers). NB Levels of accuracy vary across the dataset.

A3 SCALE 1:40,000

0 0.5 1 1.5 2 (km)

Location Plan

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ARCFILE
A3L_GroundwaterMaps_31052012

SCALE (AT A3 SIZE)
1:40,000

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Ref. 52000.400

MAP SERIES 5
GROUNDWATER ELEVATION CONTOURS

FIGURE No. Map 5e Southern Suburbs

Rev. 0

Map series

Map series 1 - Overview maps			
Map 1.1	General overview map		29
Map 1.2	Overview map - Northern suburbs		30
Map 1.3	Overview map - Central suburbs		31
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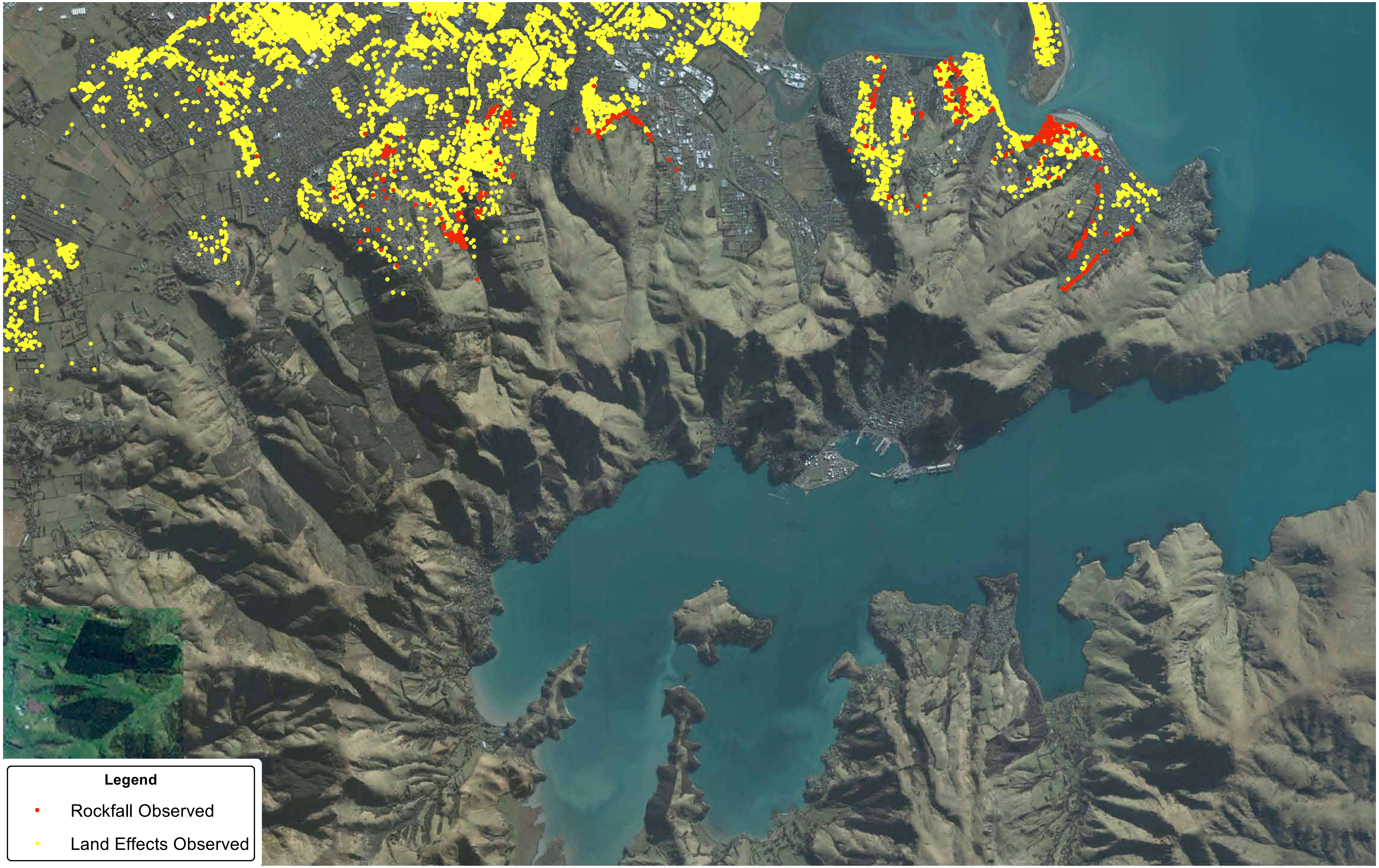
Map 6b-3	Detailed land observation map	Land observations after 13 June 2011	66
Map 6b-4	Detailed land observation map	Land observations after 13 June 2011	67



Notes: Aerial Photography from ArcGIS Online.

A3 SCALE 1:50,000

0 1 2 3 4 (km)

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ARCFILE A3L_PortHillsPHGGLandObservations_09062012		
SCALE (AT A3 SIZE) 1:50,000		
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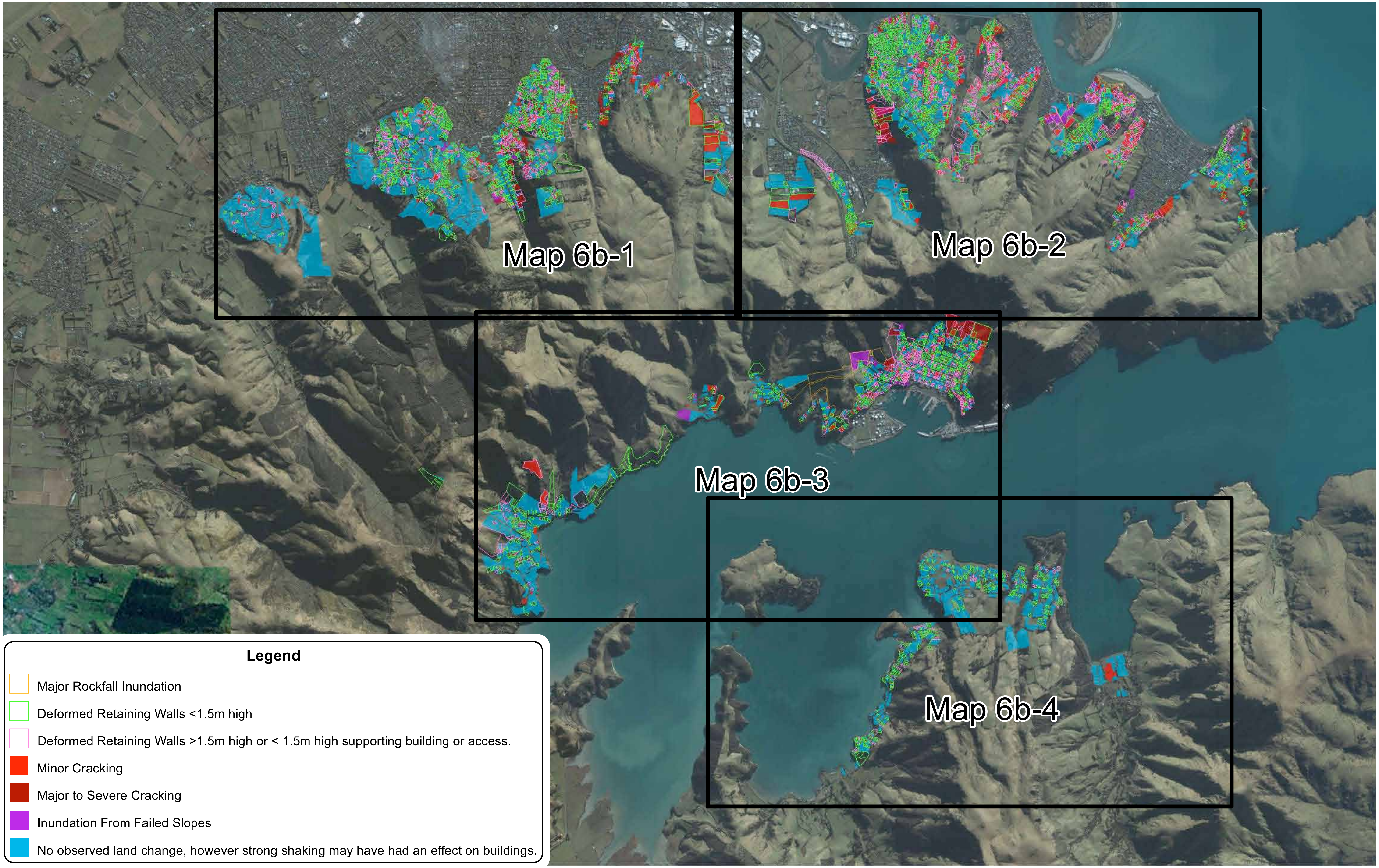
MAP SERIES 6
GENERAL LAND OBSERVATION MAP
Aggregated Land Observations
Prior to 13 June 2011

FIGURE No. Map 6a Port Hills to Diamond Harbour

Rev. 0



Notes: Aerial photography from ArcGIS Online

A3 SCALE 1:50,000

0 1 2 3 4 (km)

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Location Plan

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ARCFILE A3L_PH_LDAT_Observ_09062012

SCALE (AT A3 SIZE) 1:50,000

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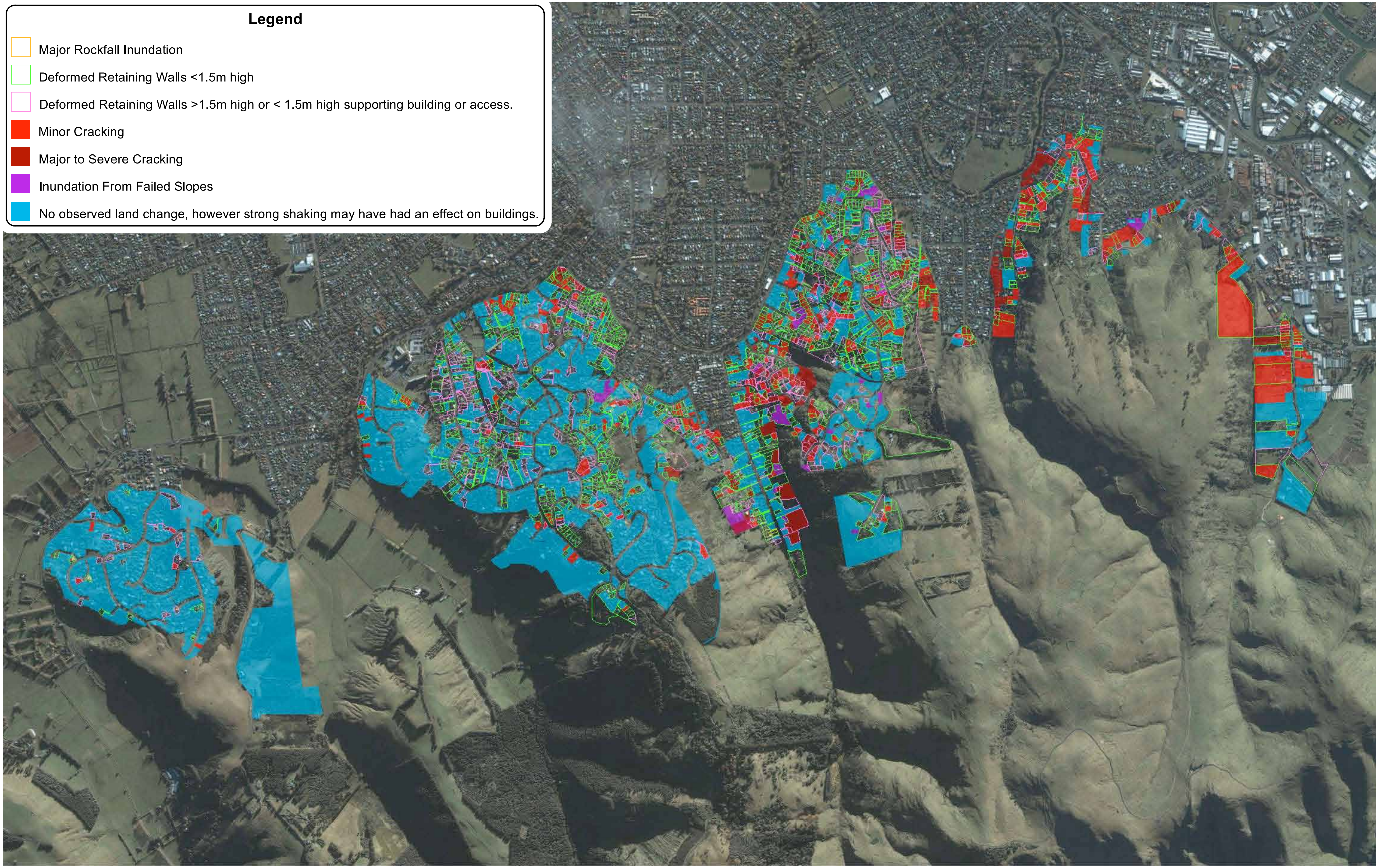
MAP SERIES 6
DETAILED LAND OBSERVATION MAP
Land Observations After 13 June 2011

FIGURE No. Map 6b Port Hills to Diamond Harbour Rev. 0



Notes: Aerial photography from ArcGIS Online

A3 SCALE 1:20,000

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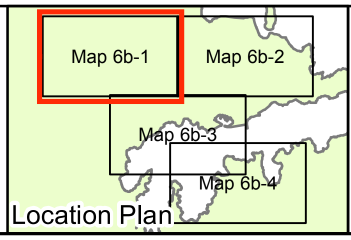

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ARCFILE A3L_PH_LDAT_ObsMulti_0906201		
SCALE (AT A3 SIZE) 1:20,000		
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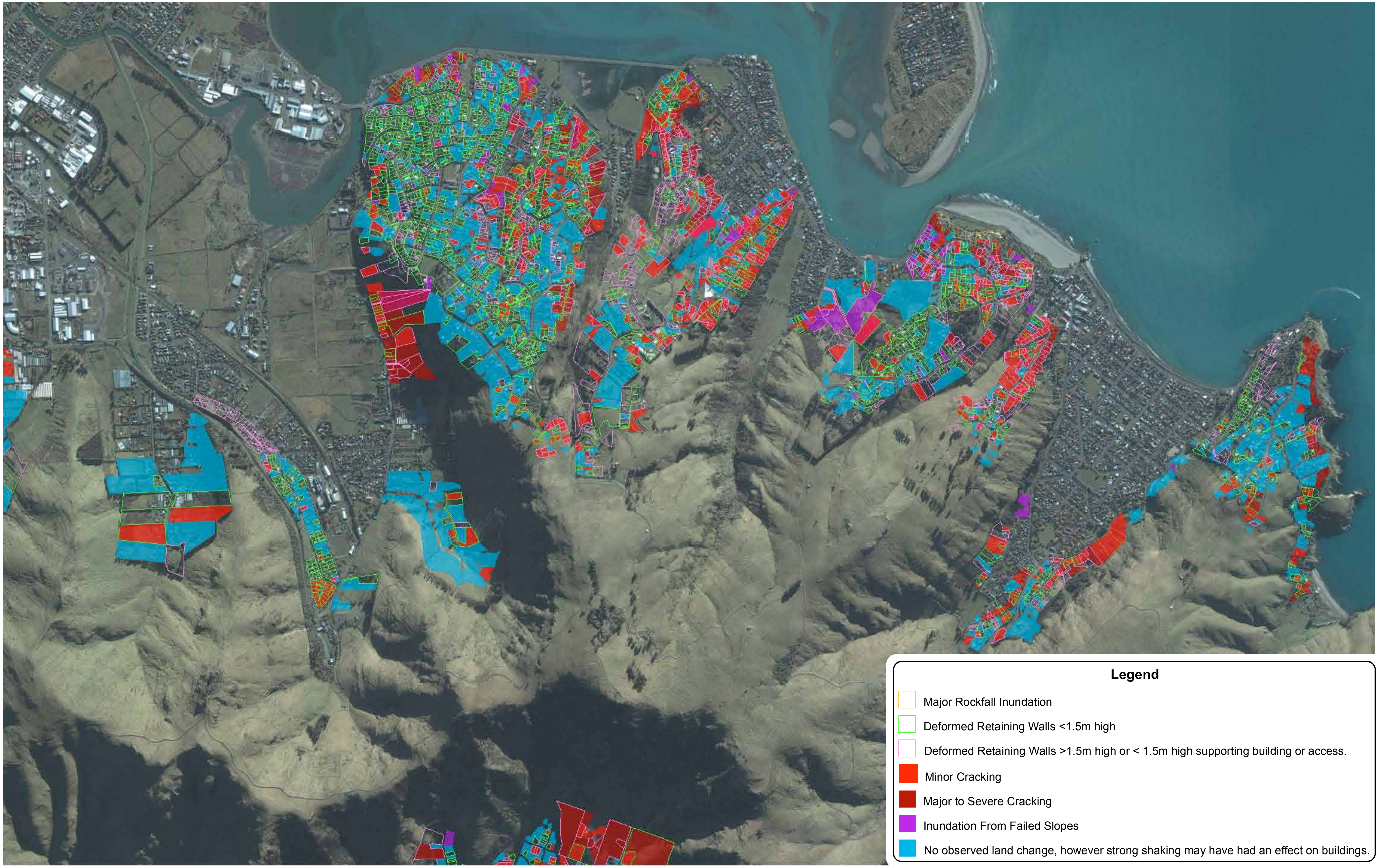
MAP SERIES 6
DETAILED LAND OBSERVATION MAP
Land Observations After 13 June 2011

FIGURE No. Map 6b-1 Westmorland to Hillsborough

Rev. 0



Notes: Aerial photography from ArcGIS Online

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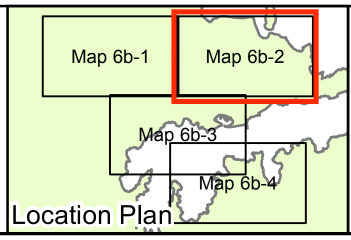

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ARCFILE A3L_PH_LDAT_ObsMulti_09062011		
SCALE (AT A3 SIZE) 1:20,000		
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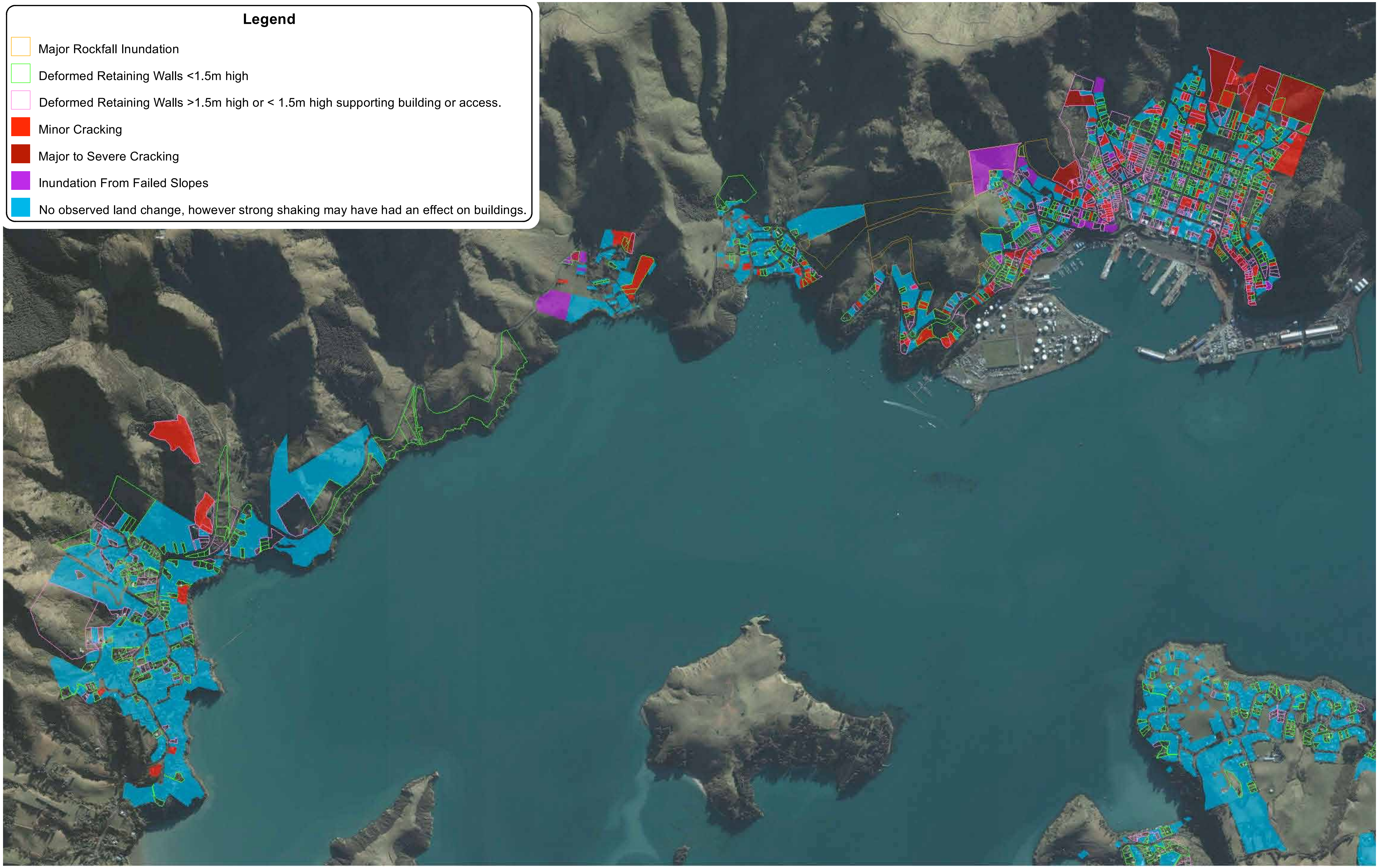
MAP SERIES 6
DETAILED LAND OBSERVATION MAP
Land Observations After 13 June 2011

FIGURE No. Map 6b-2 Heathcote to Scarborough

Rev. 0



Notes: Aerial photography from ArcGIS Online

A3 SCALE 1:20,000

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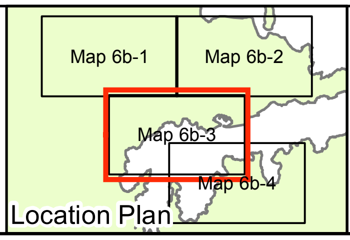

Location Plan

EQC
EARTHQUAKE COMMISSION
KŌMIHANA RŪWHENUA

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ARCFILE A3L_PH_LDAT_ObsMulti_09062011

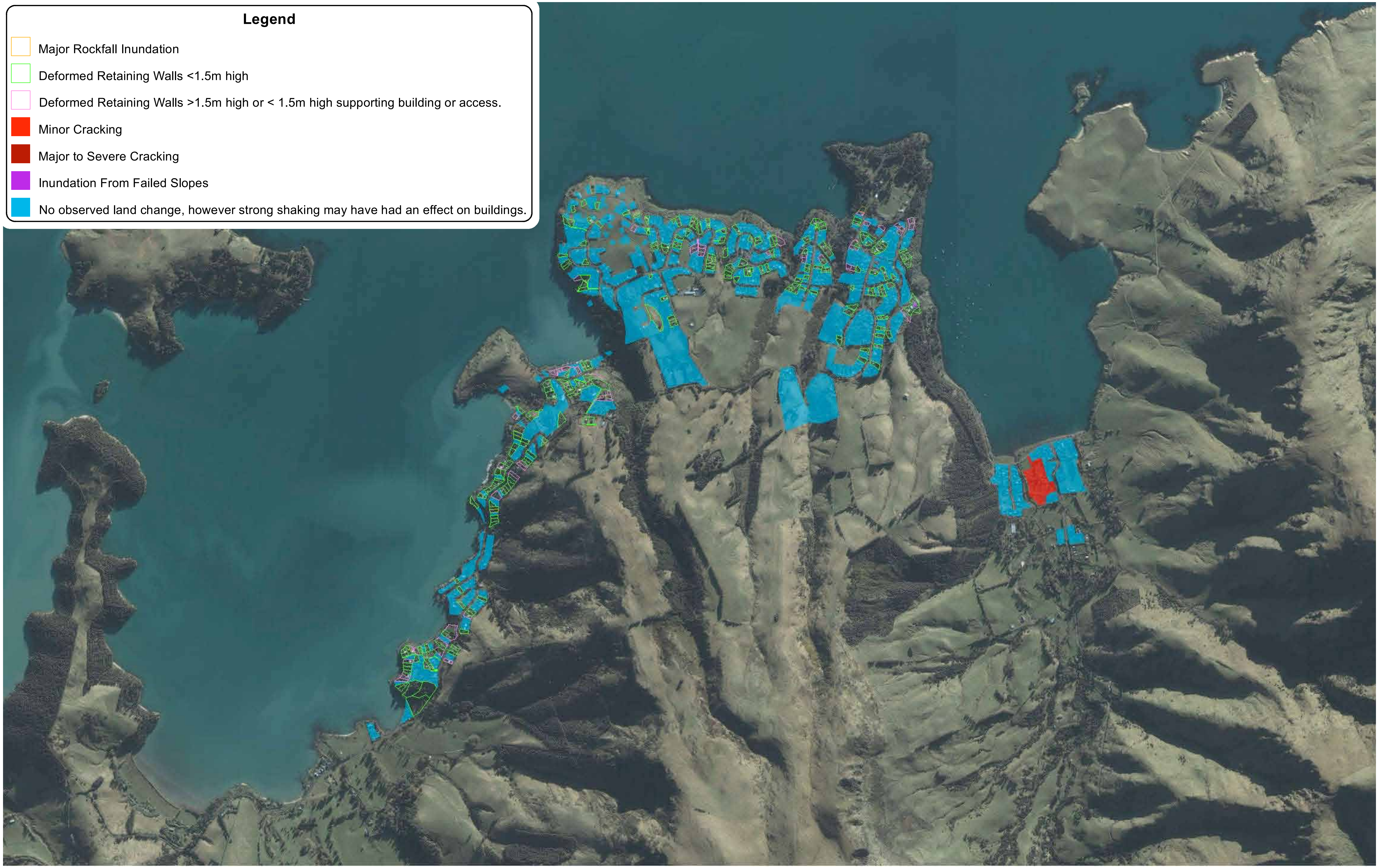
SCALE (AT A3 SIZE) 1:20,000

Prepared By Tonkin & Taylor Ltd.
Ref. 52000.400

MAP SERIES 6
DETAILED LAND OBSERVATION MAP
Land Observations After 13 June 2011

FIGURE No. Map 6b-3 Lyttelton

Rev. 0



Notes: Aerial photography from ArcGIS Online

A3 SCALE 1:20,000

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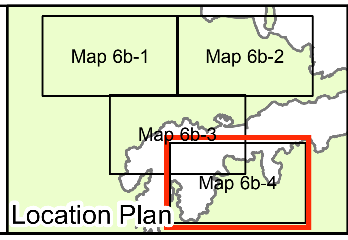

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EARTHQUAKE COMMISSION
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ARCFILE A3L_PH_LDAT_ObsMulti_0906201		
SCALE (AT A3 SIZE) 1:20,000		
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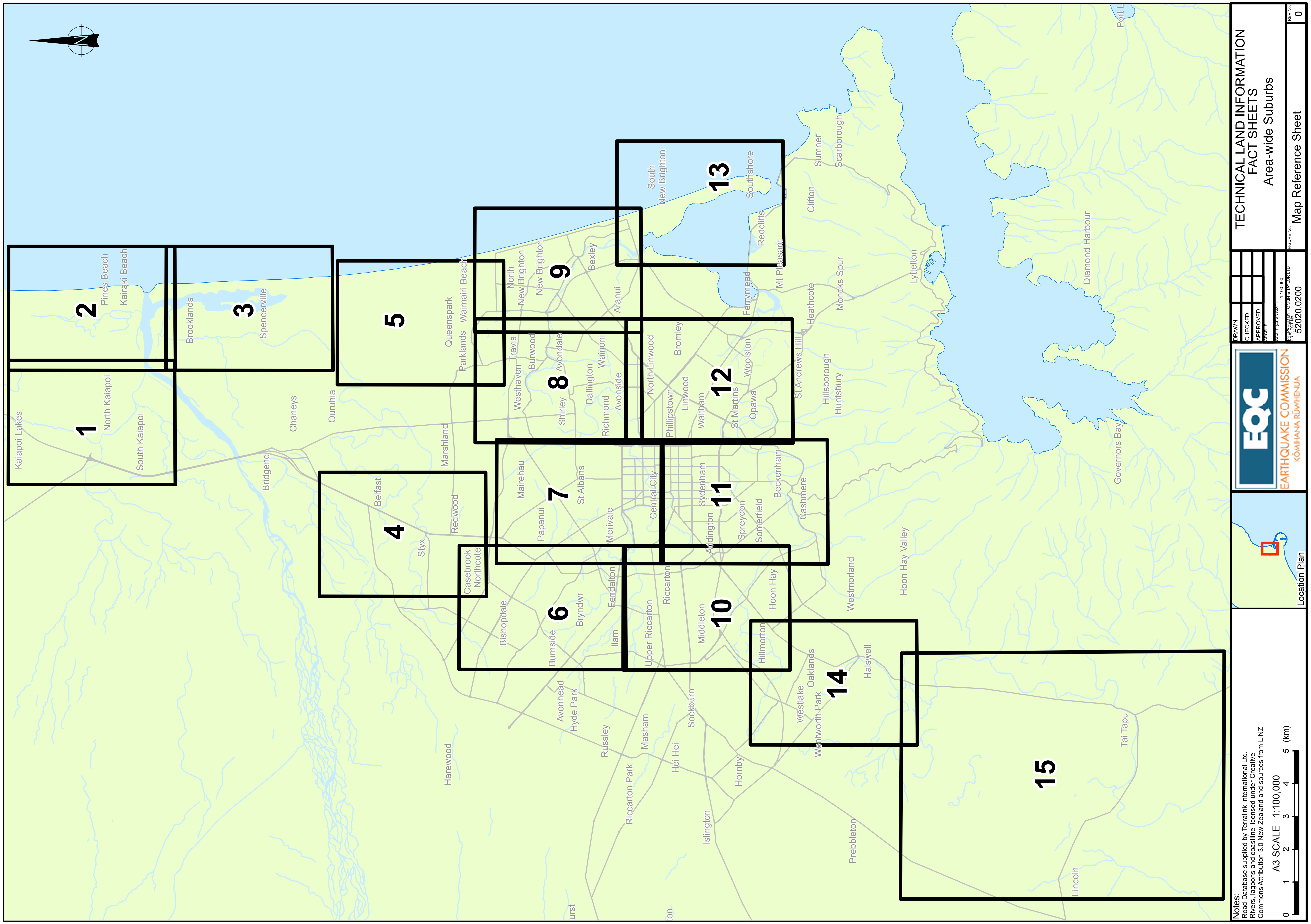
MAP SERIES 6
DETAILED LAND OBSERVATION MAP
Land Observations After 13 June 2011

FIGURE No. Map 6b-4 Diamond Harbour

Rev. 0

APPENDIX C

The Plains - area-wide suburb technical land information


TECHNICAL LAND INFORMATION
FACT SHEETS
Area-wide Suburbs
Map Reference Sheet
52020.0200
0
DRAWN
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EARTHQUAKE COMMISSION
KŌMIHANA RŪWHENUA
EQC
Location Plan
Notes:
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Commons Attribution 3.0 New Zealand and sources from LINZ
A3 SCALE 1:100,000
0 1 2 3 4 5 (km)
N
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12
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14
15
Kaiapoi Lakes
North Kaiapoi
South Kaiapoi
Pines Beach
Kairaki Beach
Brooklands
Spencerville
Chaneys
Ouruhia
Bridgend
Belfast
Redwood
Styx
Marshland
Queenspark
Parklands
Waimairi Beach
North New Brighton
New Brighton
Bexley
Aranui
South New Brighton
Southshore
Redcliffs
Mt Pleasant
Ferrymead
Travis
Burwood
Avondale
Westhaven
Wainoni
Dallington
Shirley
Richmond
Avonside
North Linwood
Bromley
Linwood
Phillipstown
Waltham
Woolston
St Martins
Opawa
Mairehau
St Albans
Papanui
Merivale
Central City
Sydenham
Addington
Spreydon
Somerfield
Beckenham
Cashmere
Casebrook
Northcote
Bishopdale
Bryndwr
Fendalton
Burnside
Ilam
Upper Riccarton
Riccarton
Middleton
Hoon Hay
Hillmorton
Oaklands
Westlake
Wentworth Park
Halswell
Avonhead
Hyde Park
Russley
Masham
Sockburn
Hei Hei
Hornby
Riccarton Park
Islington
Harewood
Prebbleton
Westmorland
Hoon Hay Valley
Tai Tapu
Lincoln
Sumner
Scarborough
Clifton
Heathcote
St Andrews Hill
Hillsborough
Huntsbury
Moncks Spur
Lyttelton
Diamond Harbour
Governors Bay
Port L

Factsheet 1 - Kaiapoi

1.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by river alluvium, and located on plains or low level terraces. Fixed beach sand dunes, river sand and back dune deposits of Holocene age are present in the northwest and southeast.

Table C1.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands and silts.

Table C1.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately low-lying with shallow groundwater.

The ground conditions and groundwater in this area are generally similar to most of the eastern suburbs of Christchurch and Waimakariri District.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

1.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 earthquake, first on a regional and street-by-street level in the days immediately after the earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by additional air-photo, regional or street-level mapping for the subsequent main earthquakes. This additional mapping indicated that the pattern of liquefaction and lateral spreading in this area for the subsequent earthquakes was generally similar to that observed in the first main earthquake, but usually less extensive and severe.

Figure C1.1 and Table C1.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C1.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C1.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C1.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Kaiapoi Lakes	2	-	1	-
North Kaiapoi	39	6	23	730
South Kaiapoi	52	9	21	750

Kaiapoi Lakes, North Kaiapoi and South Kaiapoi

Table C1.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Kaiapoi Lakes	Typically 3.9m to 4.5m (Avg 4.2m)	Typically 1.0m to 1.5m (Avg 1.2m)
North Kaiapoi	Typically 1.1m to 1.8m (Avg 1.3m)	Typically 0.3m to 1.4m (Avg 0.6m)
South Kaiapoi	Typically 1.8m to 3.8m (Avg 2.4m)	Typically 0.8m to 1.9m (Avg 1.4m)

Table C1.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken by EQC following earthquake of 4 September 2010

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	Moderate to major lateral spreading or large quantities of ejected material	Severe lateral spreading, ejected material often observed
Kaiapoi Lakes	13	0%	0%	0%	39%	46%	15%
North Kaiapoi	1682	<1%	50%	1%	42%	6%	<1%
South Kaiapoi	2364	<1%	83%	3%	6%	6%	1%

Table C1.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2005 to February 2012 (positive values are uplift, negative values are subsidence)
Kaiapoi Lakes	No data (outside range of LiDAR coverage)
North Kaiapoi	Typically -400mm to -50mm (Average -250mm)
South Kaiapoi	Typically -300mm to +0mm (Average -150mm)

Factsheet 1 - Kaiapoi

Table C1.5 - Liquefaction and lateral spread observations

Suburb	Observations
Kaiapoi Lakes	Moderate to major localised lateral spreading caused by slumping of material around the perimeter of the lakes. Further away from the lake, no surface evidence of liquefaction or related land damage was observed.
North Kaiapoi	Widespread moderate to severe liquefaction, sand ejection and settlement. Moderate to major lateral spreading towards Kaiapoi River, however majority of spreading confined to reserve area alongside the river. In the west and north of the suburb, away from the river or on higher ground, no surface evidence of liquefaction or related land damage was observed.
South Kaiapoi	Moderate liquefaction in the eastern and riverside areas, causing sand ejection and settlement. Widespread major to very severe lateral spreading in the east, towards the terrace edge and Courtenay Stream. Moderate to major lateral spreading towards Kaiapoi River and small watercourses in some areas, although generally localised to the immediately adjacent properties. Settlement and minor ground cracking has occurred in several areas without any obvious surface evidence of liquefaction, likely due to relaxation of the ground caused by lateral spreading of adjacent areas, or to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of the suburb, away from the river and streams or on higher ground, no surface evidence of liquefaction or related land damage was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Kaiapoi Lakes, North Kaiapoi and South Kaiapoi

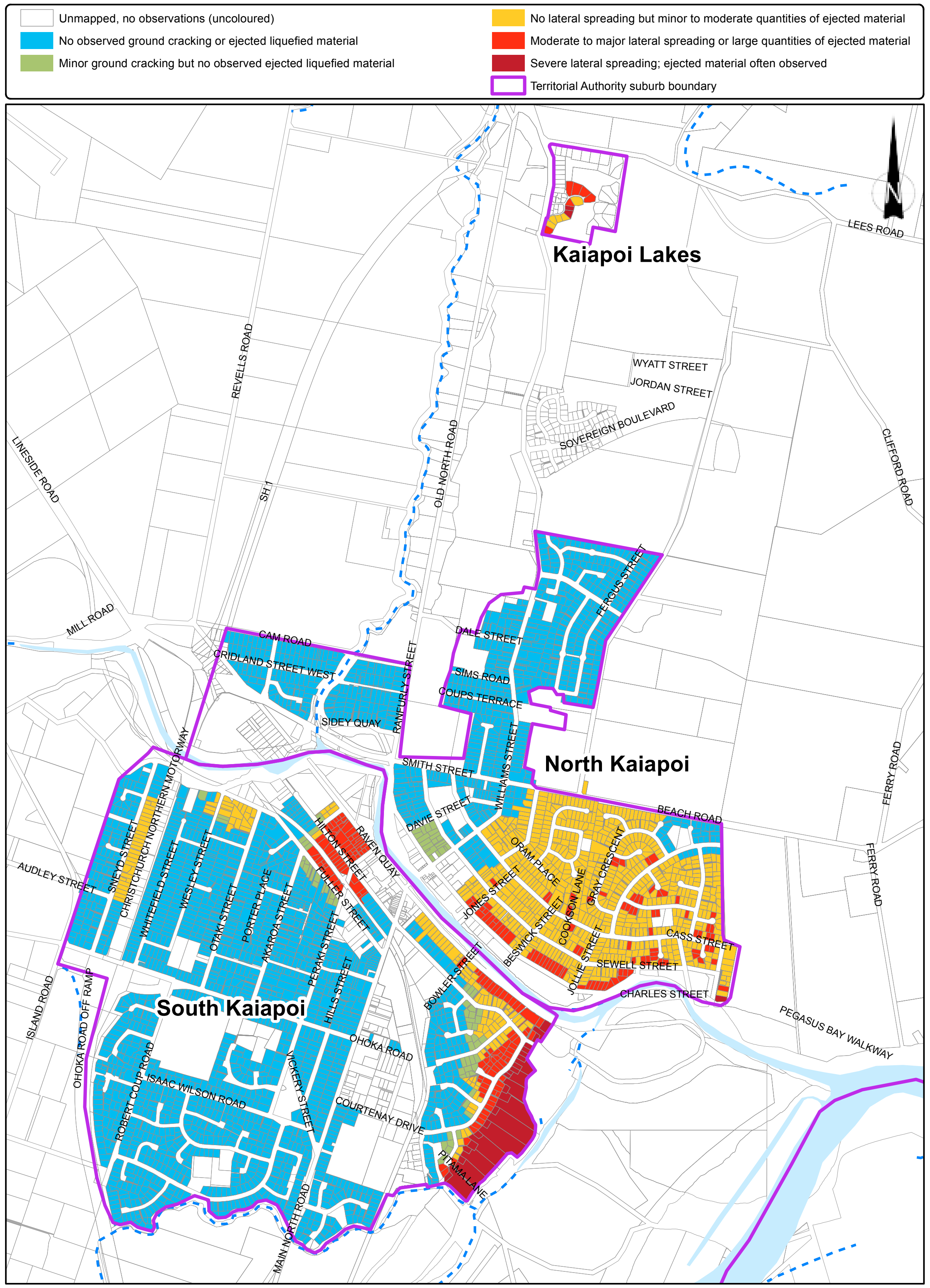

Figure C1.1 - Overview of liquefaction and lateral spreading observations, from mapping undertaken following the earthquake of 4 September 2010

Factsheet 2 - Kairaki Beach to Pines Beach

2.1 Ground conditions and groundwater

Regional geology maps show this area is underlain by stabilised beach sand dunes or river sand (and back dune deposits) of Holocene age.

Table C2.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sand and silts.

Table C2.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately low-lying with shallow groundwater.

The ground conditions and groundwater in this area are generally similar to most of the eastern suburbs of Christchurch and Waimakariri District.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

2.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 earthquake, first on a regional and street-by-street level in the days immediately after the earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by additional air-photo, regional or street-level mapping for the subsequent main earthquakes. This additional mapping indicated that the pattern of liquefaction and lateral spreading in this area for the subsequent earthquakes was generally similar to that observed in the first main earthquake, but usually less extensive and severe.

Figure C2.1 and Table C2.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C2.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C2.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C2.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Kairaki Beach	3	1	4	-
Pines Beach	11	1	9	-

Table C2.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Kairaki Beach	Typically 1.2m to 1.8m (Avg 1.5m)	Typically 0.5m to 1.1m (Avg 0.7m)
Pines Beach	Typically 1.1m to 4.2m (Avg 1.4m)	Typically 0.6m to 5.4m (Avg 1.2m)

Kairaki Beach and Pines Beach

Table C2.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken by EQC following earthquake of 4 September 2010

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	Moderate to major lateral spreading or large quantities of ejected material	Severe lateral spreading, ejected material often observed
Kairaki Beach	70	0%	0%	1%	73%	26%	0%
Pines Beach	226	2%	0%	60%	11%	27%	0%

Table C2.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2005 to February 2012 (positive values are uplift, negative values are subsidence)
Kairaki Beach	Typically -500mm to -200mm (Average -300mm)
Pines Beach	Typically -450mm to +100mm (Average -150mm)

Factsheet 2 - Kairaki Beach to Pines Beach

Table C2.5 - Liquefaction and lateral spread observations

Suburb	Observations
Kairaki Beach	Widespread moderate to severe liquefaction, sand ejection and settlement. Moderate to major lateral spreading towards Kairaki Creek.
Pines Beach	In the south and west of the area (surrounding the domain), moderate to severe liquefaction, sand ejection and settlement. Seismic densification and shaking of the sand dunes to the north and east has resulted in minor settlement and ground cracking in this area. Localised moderate lateral spreading towards the creek and lower-lying ground to the west, and at the foot of the dunes towards the domain.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Kairaki Beach and Pines Beach

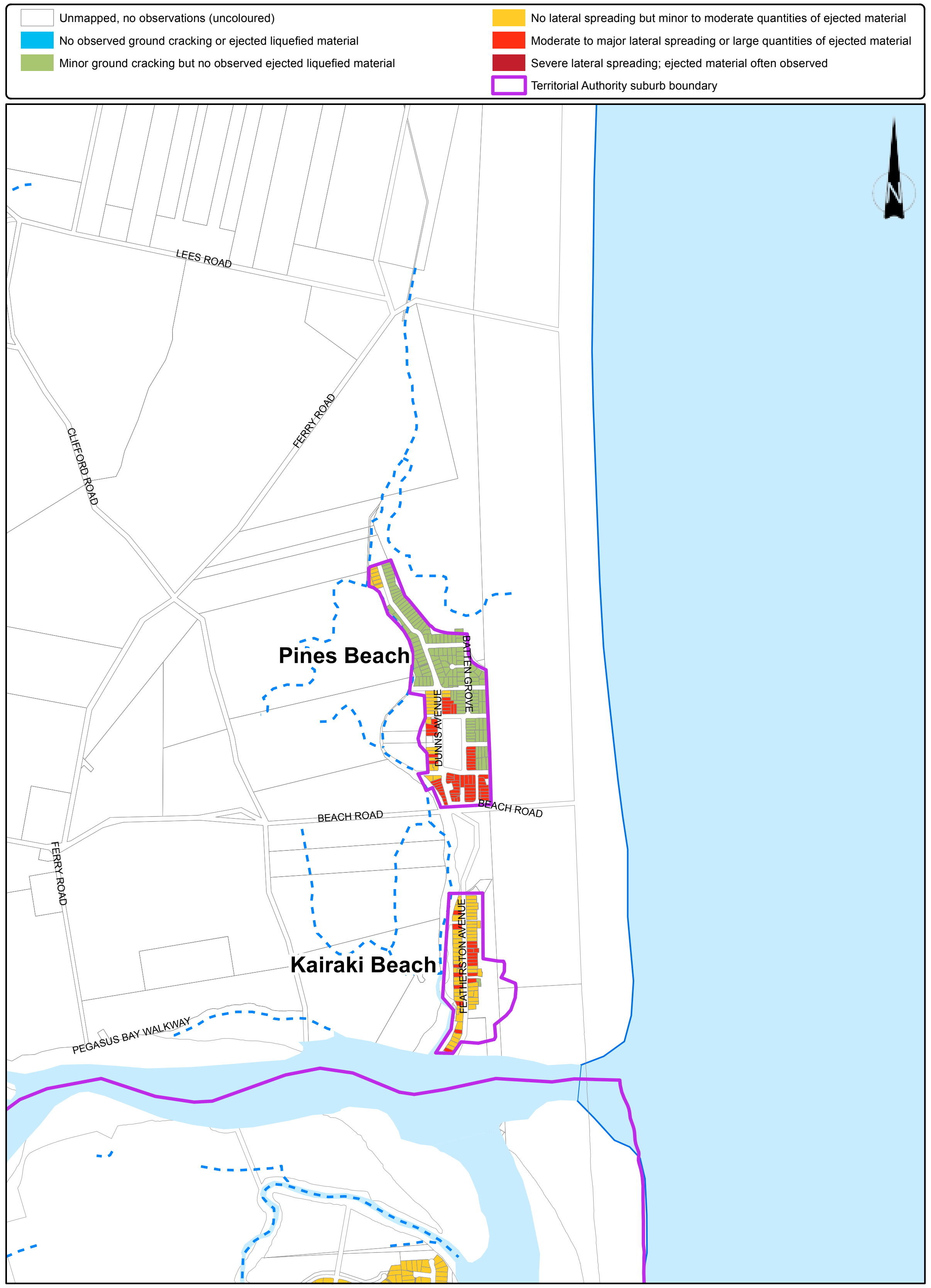

Figure C2.1 - Overview of liquefaction and lateral spreading observations, from mapping undertaken following the earthquake of 4 September 2010

Factsheet 3 - Spencerville to Brooklands

3.1 Ground conditions and groundwater

Regional geology maps show this area is underlain by stabilised beach sand dunes or river sand (and back dune deposits) of Holocene age.

Table C3.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sand and silts.

Table C3.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately low-lying with shallow groundwater.

The ground conditions and groundwater in this area are generally similar to most of the eastern suburbs of Christchurch and Waimakariri District.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

3.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 earthquake, first on a regional and street-by-street level in the days immediately after the earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by additional air-photo, regional or street-level mapping for the subsequent main earthquakes. This additional mapping indicated that the pattern of liquefaction and lateral spreading in this area for the subsequent earthquakes was generally similar to that observed in the first main earthquake, but usually less extensive and severe.

Figure C3.1 and Table C3.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area.These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C3.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C3.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C3.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Brooklands (incl. Kainga)	19	-	12	-
Spencerville	21	2	5	320

Brooklands (includes Kainga) and Spencerville

Table C3.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Brooklands (incl. Kainga)	Typically 1.2m to 2.1m (Avg 1.6m)	Typically 0.7m to 1.5m (Avg 1.0m)
Spencerville	Typically 1.8m to 2.4m (Avg 2.2m)	Typically 0.9m to 1.5m (Avg 1.2m)

Table C3.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken by EQC following earthquake of 4 September 2010

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	Moderate to major lateral spreading or large quantities of ejected material	Severe lateral spreading, ejected material often observed
Brooklands (incl. Kainga)	765	4%	25%	11%	51%	9%	0%
Spencerville	228	4%	0%	33%	60%	<1%	2%

Table C3.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Brooklands (incl. Kainga)	Typically -400mm to -100mm (Average -300mm)
Spencerville	Typically -400mm to -100mm (Average -250mm)

Factsheet 3 - Spencerville to Brooklands

Table C3.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Brooklands (incl. Kainga)	Widespread moderate liquefaction in the main residential area, causing sand ejection and settlement. Widespread major lateral spreading in the west of the main residential area, towards the Styx River. Localised moderate lateral spreading in Stewarts Gully (near Kainga) associated with movement of the stopbank towards the Waimakariri River. Settlement and minor ground cracking in several areas without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the residential properties to the west of the main Brooklands township (including most of Kainga), there was no surface evidence of liquefaction, but minor ground cracking in some areas.
Spencerville	Widespread moderate liquefaction across most of the residential area, causing sand ejection and settlement. Major to severe lateral spreading towards the Styx River, but localised to the properties immediately adjacent. Settlement and minor ground cracking in several areas without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Brooklands (includes Kainga) and Spencerville

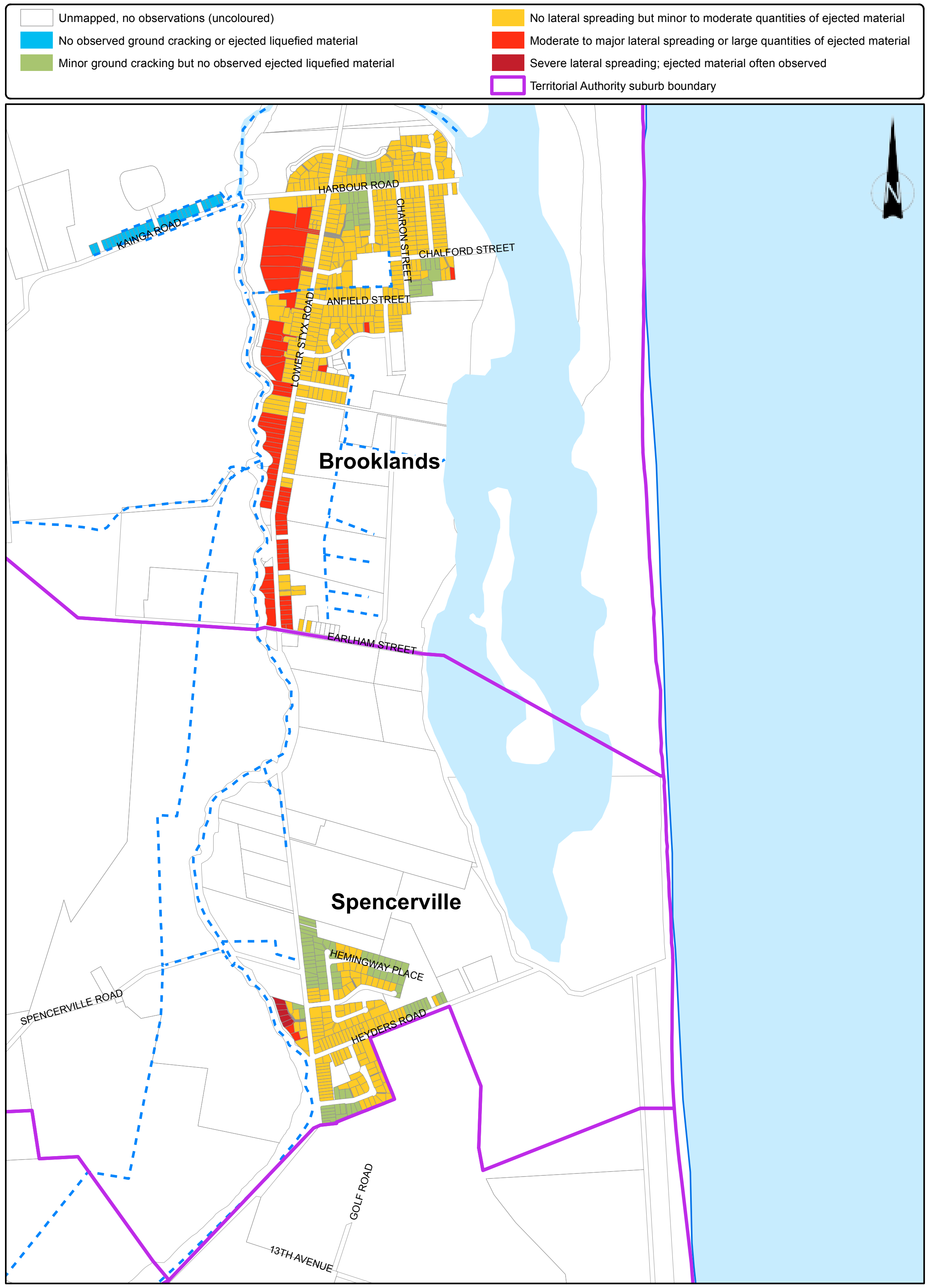

Figure C3.1 - Overview of liquefaction and lateral spreading observations, from mapping undertaken following the earthquake of 4 September 2010

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Factsheet 4 - Casebrook to Belfast

4.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by alluvial sand and silt overbank deposits. Historic river flood channels are mapped in some areas, with alluvial gravel, sand and silt. Some areas towards the north are underlain by peat, silt and sand in existing or drained swamps.

Table C4.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises clayey silt and silt overlying medium dense to dense sand. Clayey silt and silt layers typically only extend to depths of a few metres, but extend to depths in excess of 10m in some areas.

Table C4.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in September 2011, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated well above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the southern, central and northern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

4.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C4.1 and Table C4.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C4.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C4.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C4.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Belfast	12	-	4	-
Casebrook	6	-	2	-
Northcote	4	-	2	-
Redwood	10	-	8	-
Styx	5	-	4	-

Belfast, Casebrook, Northcote, Redwood and Styx

Table C4.2 - Summary of ground elevation and groundwater depth (September 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Belfast	Typically 7.3m to 14.7m (Avg 11.8m)	Typically 0.6m to 2.6m (Avg 1.8m)
Casebrook	Typically 13.9m to 15.7m (Avg 14.9m)	Typically 1.1m to 2.1m (Avg 1.6m)
Northcote	Typically 10.1m to 13.7m (Avg 12.6m)	Typically 1.7m to 2.8m (Avg 2.4m)
Redwood	Typically 7.7m to 10.7m (Avg 9.1m)	Typically 0.3m to 1.7m (Avg 1.0m)
Styx	Typically 11.4m to 12.8m (Avg 12.1m)	Typically 1.2m to 1.8m (Avg 1.5m)

Table C4.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Belfast	3145	14%	50%	25%	11%	0%	0%	0%
Casebrook	1193	6%	76%	11%	6%	<1%	0%	0%
Northcote	750	70%	21%	2%	7%	0%	0%	0%
Redwood	2995	47%	35%	10%	8%	0%	0%	0%
Styx	306	7%	43%	38%	12%	0%	0%	0%

Table C4.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to September 2011 (positive values are uplift, negative values are subsidence)
Belfast	Typically -250mm to +100mm (Average -100mm)
Casebrook	Typically -300mm to -100mm (Average -200mm)
Northcote	Typically -300mm to -100mm (Average -200mm)
Redwood	Typically -300mm to -50mm (Average -150mm)
Styx	Typically -300mm to +0mm (Average -150mm)

Factsheet 4 - Casebrook to Belfast

Table C4.5 - Liquefaction and lateral spread observations

Suburb	Observations
Belfast Casebrook Northcote Redwood Styx	Minor to moderate liquefaction in several localised areas or strips, causing sand ejection and settlement. In the surrounding areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of the suburb, no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Belfast, Casebrook, Northcote, Redwood and Styx

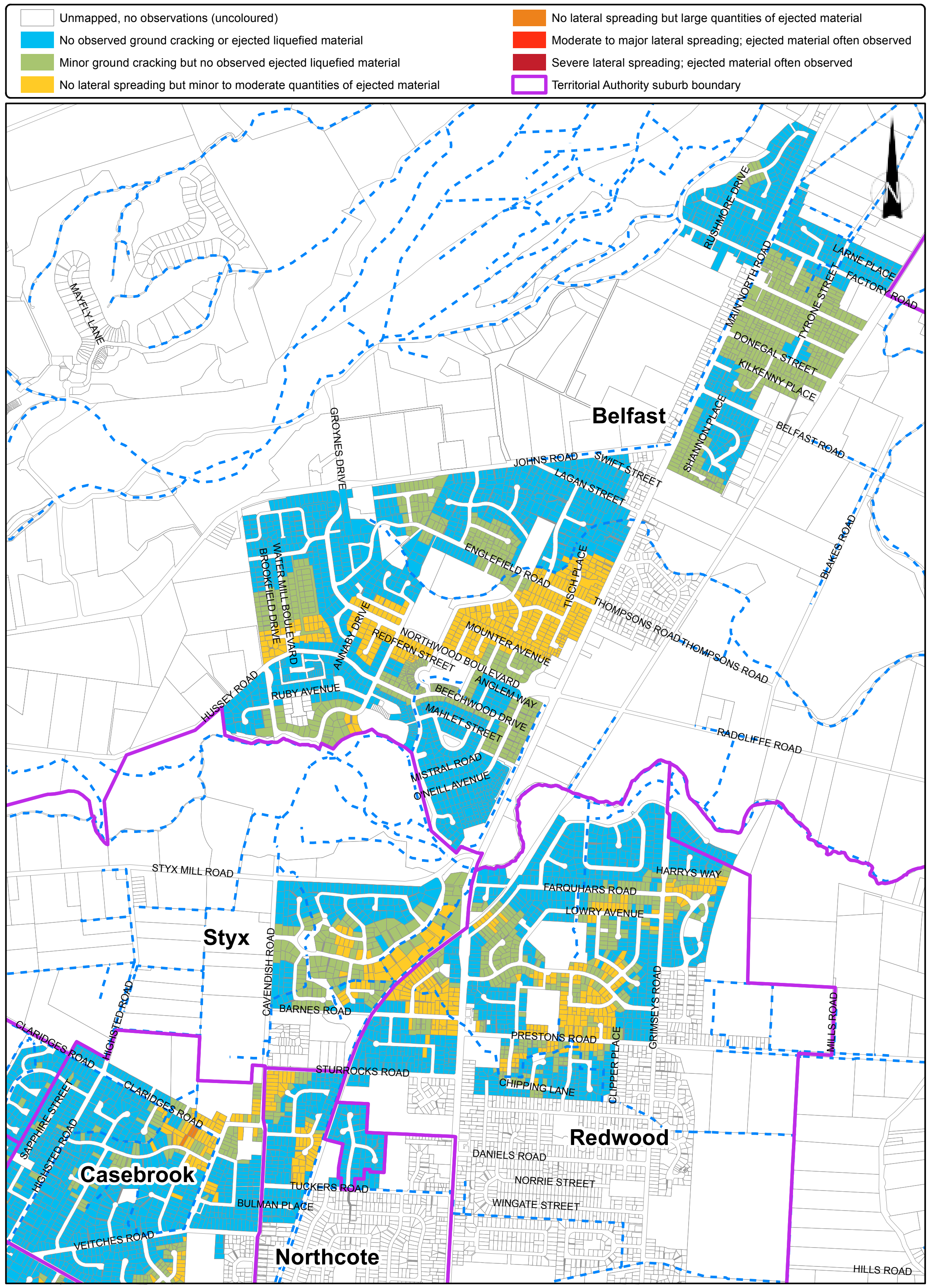

Figure C4.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

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Factsheet 5 - Parklands to Waimairi Beach

5.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by sand of fixed and semi-fixed dunes of marine origin. The southwest area of Parklands is underlain by sand, silt, and some peat of drained lagoons and estuaries, all of Holocene age deposition.

Table C5.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises loose to dense sands, silts and some clayey silt.

Table C5.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately elevated above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to, or slightly more favourable than, most of the eastern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

5.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C5.1 and Table C5.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C5.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C5.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C5.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Parklands	15	1	15	-
Queenspark	14	1	14	-
Waimairi Beach	3	1	3	-

Parklands, Queenspark and Waimairi Beach

Table C5.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Parklands	Typically 3.3m to 4.6m (Avg 4.0m)	Typically 0.8m to 1.9m (Avg 1.2m)
Queenspark	Typically 3.2m to 4.2m (Avg 3.5m)	Typically 1.3m to 2.2m (Avg 1.6m)
Waimairi Beach	Typically 3.0m to 5.5m (Avg 3.8m)	Typically 1.5m to 4.1m (Avg 2.2m)

Table C5.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Parklands	1874	1%	29%	14%	51%	2%	2%	0%
Queenspark	883	3%	5%	14%	63%	15%	<1%	0%
Waimairi Beach	626	2%	78%	5%	12%	3%	0%	0%

Table C5.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Parklands	Typically -450mm to -150mm (Average -300mm)
Queenspark	Typically -600mm to -250mm (Average -400mm)
Waimairi Beach	Typically -550mm to -100mm (Average -300mm)

Factsheet 5 - Parklands to Waimairi Beach

Table C5.5 - Liquefaction and lateral spread observations

Suburb	Observations
Parklands	Widespread minor to moderate liquefaction across much of the suburb (severe liquefaction in a small number of cases), causing sand ejection and settlement. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. Some localised areas of moderate to major lateral spreading, towards the wetland and small watercourses, or in areas of more steeply sloping ground. For the remainder of the suburb (the northwest and southeast), no surface evidence of liquefaction or related land effects was observed.
Queenspark	Widespread minor to moderate liquefaction across most of the suburb (severe liquefaction on many lower-lying roads and some residential properties), causing sand ejection and settlement. In some areas, the extent of liquefaction from the earthquake of 13 June 2011 was greater than tabulated for the first two main earthquakes in Table C5.3. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. Some localised areas of minor to moderate lateral ground movements, in areas of more steeply sloping ground.
Waimairi Beach	For the western portion of the suburb (along Bower Ave), widespread minor to moderate liquefaction (severe liquefaction in a small number of cases), causing sand ejection and settlement. Minor to moderate lateral ground movements in some localised areas of more steeply sloping ground. For the remainder of the suburb (the east), no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Parklands, Queenspark and Waimairi Beach

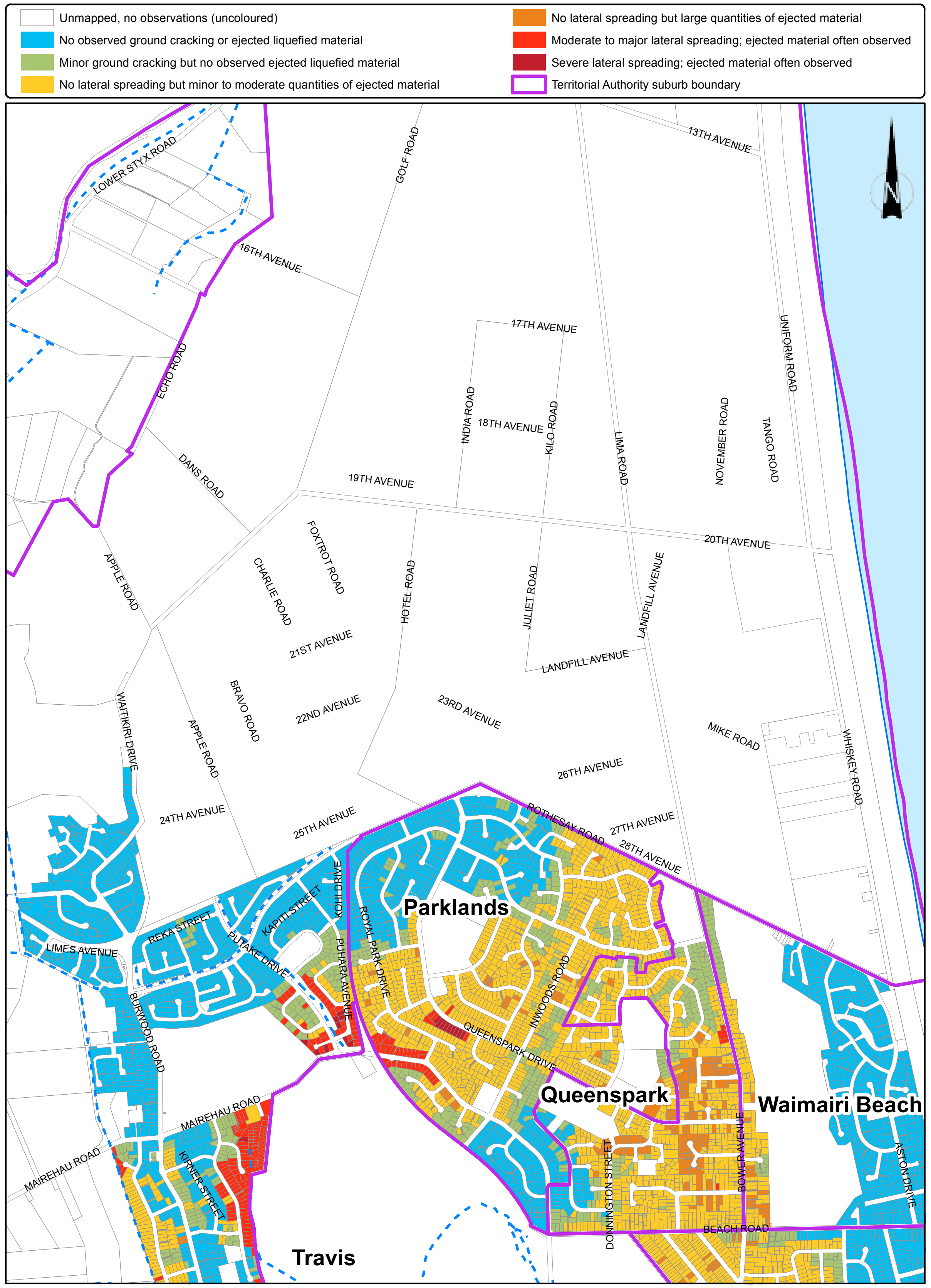

Figure C5.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

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Factsheet 6 - Ilam to Bishopdale

Bishopdale, Bryndwr, Burnside, Fendalton and Ilam

6.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by dominantly alluvial sand and silt overbank deposits.

Table C6.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands and silts.

Table C6.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in September 2011, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated well above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the southern, central and northern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

6.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C6.1 and Table C6.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C6.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C6.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C6.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Bishopdale	9	-	6	-
Bryndwr	14	2	8	-
Burnside	-	-	-	-
Fendalton	26	7	14	-
Ilam	-	-	-	-

Table C6.2 - Summary of ground elevation and groundwater depth (September 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Bishopdale	Typically 16.4m to 18.2m (Avg 17.8m)	Typically 2.1m to 2.9m (Avg 2.5m)
Bryndwr	Typically 11.3m to 16.7m (Avg 14.5m)	Typically 0.7m to 2.5m (Avg 1.8m)
Burnside	Typically 17.4m to 22.2m (Avg 19.8m)	Typically 2.0m to 3.6m (Avg 3.0m)
Fendalton	Typically 9.3m to 13.6m (Avg 11.4m)	Typically 0.4m to 1.4m (Avg 0.9m)
Ilam	Typically 13.7m to 18.2m (Avg 16.3m)	Typically 1.4m to 4.1m (Avg 2.6m)

Table C6.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Bishopdale	3680	28%	48%	13%	11%	0%	<1%	0%
Bryndwr	3010	29%	49%	2%	19%	0%	1%	0%
Burnside	2247	94%	6%	0%	<1%	0%	<1%	0%
Fendalton	2699	2%	46%	5%	36%	<1%	10%	<1%
Ilam	2335	73%	25%	<1%	1%	<1%	<1%	0%

Table C6.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to September 2011 (positive values are uplift, negative values are subsidence)
Bishopdale	Typically -400mm to -150mm (Average -250mm)
Bryndwr	Typically -350mm to -150mm (Average -250mm)
Burnside	Typically -250mm to +0mm (Average -150mm)
Fendalton	Typically -400mm to -100mm (Average -250mm)
Ilam	Typically -100mm to +50mm (Average +0mm)

Factsheet 6 - Ilam to Bishopdale

Table C6.5 - Liquefaction and lateral spread observations

Suburb	Observations
Bishopdale Bryndwr	Minor to moderate liquefaction in several areas, causing sand ejection and settlement. In the surrounding areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of the suburb, no surface evidence of liquefaction or related land effects was observed.
Burnside	Most of this suburb was not mapped at a property-by-property level, however street-level mapping and air photo analysis found no surface evidence of liquefaction or related land effects.
Fendalton	Extensive areas of minor to moderate liquefaction (severe liquefaction on a small number of properties), causing sand ejection and settlement. Moderate to major lateral spreading towards streams and watercourses in many areas, but generally localised to the immediately adjacent properties. For the remainder of the suburb, no surface evidence of liquefaction or related land effects was observed.
Ilam	Minor to moderate liquefaction in several small localised areas, causing sand ejection and settlement. Localised moderate lateral spreading on a small number of properties beside Waimairi Stream. Most of this suburb was not mapped at a property-by-property level, however street-level mapping and air photo analysis found no surface evidence of liquefaction or related land effects across the rest of the suburb.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Bishopdale, Bryndwr, Burnside, Fendalton and Ilam

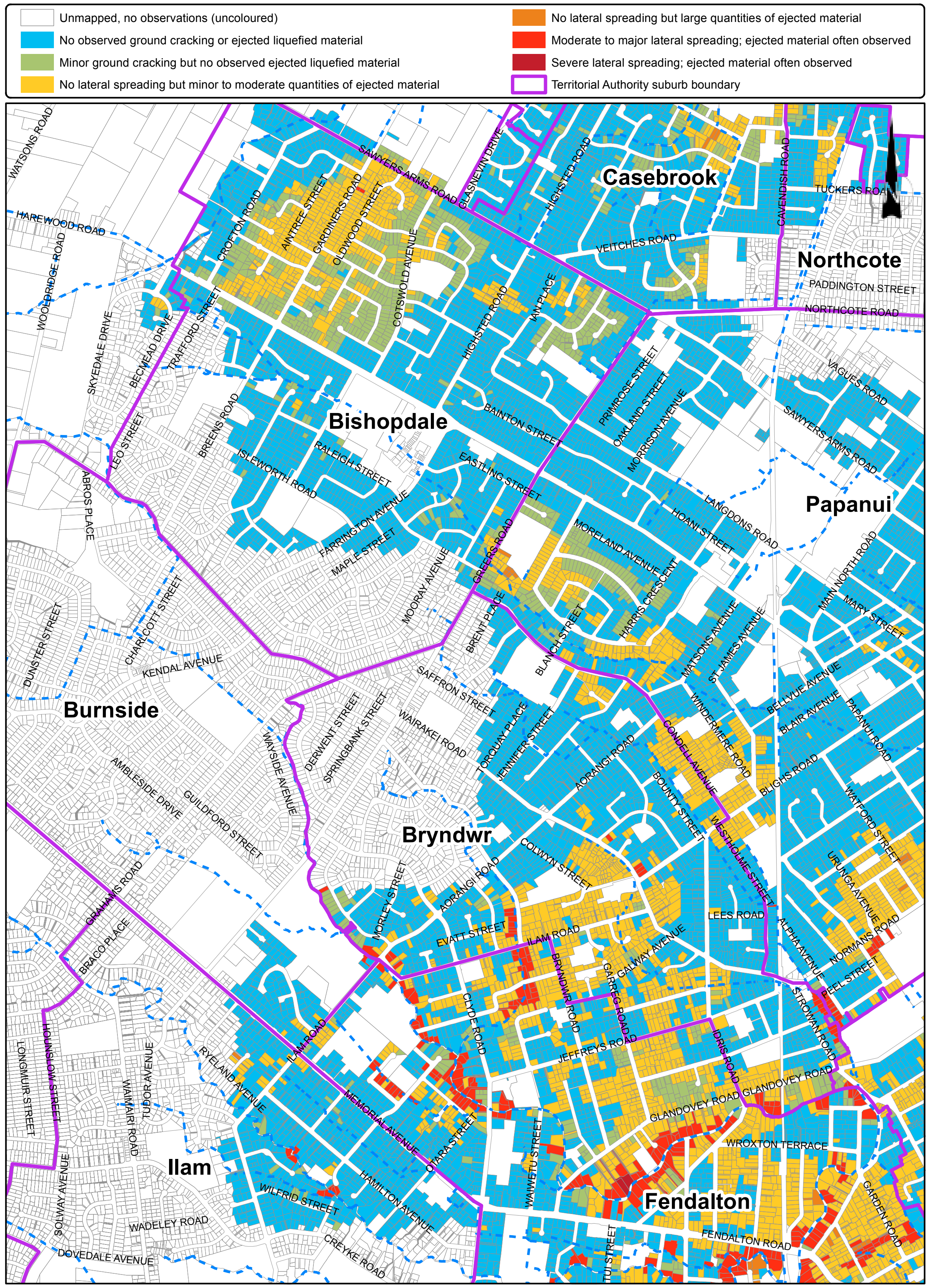

Figure C6.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Applicability - This report was prepared and/or compiled for the Earthquake Commission (EQC) to communicate information that may be relevant to residential land claims under the Earthquake Commission Act 1993. The report was not intended for any other purpose and may not be relied upon for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of any map(s) and data in this report or for the consequences of any other person relying on them in any way. This information is not intended to form a complete technical report on land changes in all or any part of Canterbury.

Factsheet 7 - Merivale to Mairehau

7.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by dominantly alluvial sand and silt overbank deposits. Towards the northwest of the area, peat, silt and sand are present in existing or drained swamps

Table C7.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands and silts.

Table C7.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated moderately to well above sea level with a shallow depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the southern, central and northern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

7.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C7.1 and Table C7.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C7.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C7.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C7.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Central City	15	-	6	-
Mairehau	-	-	-	-
Merivale	19	6	5	-
Papanui	17	1	8	-
St Albans	72	7	22	-

Central City, Mairehau, Merivale, Papanui and St Albans

Table C7.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Central City	Typically 4.2m to 7.2m (Avg 5.7m)	Typically 0.3m to 2.9m (Avg 1.2m)
Mairehau	Typically 5.7m to 6.5m (Avg 6.2m)	Typically 0.9m to 1.6m (Avg 1.2m)
Merivale	Typically 7.5m to 10.0m (Avg 9.0m)	Typically 0.4m to 1.9m (Avg 1.3m)
Papanui	Typically 9.1m to 15.5m (Avg 12.2m)	Typically 0.3m to 2.9m (Avg 1.5m)
St Albans	Typically 4.8m to 8.6m (Avg 6.4m)	Typically 0.3m to 1.7m (Avg 0.9m)

Table C7.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Central City	3081	<1%	37%	6%	47%	4%	5%	<1%%
Mairehau	946	1%	86%	1%	12%	0%	0%	0%
Merivale	1823	<1%	31%	2%	63%	<1%	3%	<1%%
Papanui	4628	4%	76%	4%	16%	<1%	<1%%	0%
St Albans	8595	<1%	24%	2%	65%	7%	2%	<1%%

Table C7.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Central City	Typically -550mm to -150mm (Average -300mm)
Mairehau	Typically -400mm to -100mm (Average -300mm)
Merivale	Typically -500mm to -200mm (Average -300mm)
Papanui	Typically -400mm to -150mm (Average -250mm)
St Albans	Typically -500mm to -250mm (Average -350mm)

Factsheet 7 - Merivale to Mairehau

Table C7.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Central City Merivale	Extensive areas of minor to moderate liquefaction (severe liquefaction on a small number of properties), causing sand ejection and settlement. Moderate to major lateral spreading towards the Avon River in many areas (severe spreading on a small number of properties) - generally localised to the immediately adjacent properties in Merivale, but becoming more extensive in Central City. For the remainder of the suburb (localised areas away from waterways), no surface evidence of liquefaction or related land effects was observed.
Mairehau Papanui	Minor to moderate liquefaction in several areas, causing sand ejection and settlement. Severe liquefaction or moderate lateral spread on a small number of properties near waterways. In the surrounding areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of the suburb, no surface evidence of liquefaction or related land effects was observed.
St Albans	Minor to moderate liquefaction across most of the suburb (severe liquefaction on some properties), causing sand ejection and settlement. Moderate to major lateral spreading towards St Albans Creek in some areas, but generally localised to the immediately adjacent properties. For the remainder of the suburb (towards the north and southwest), no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Central City, Mairehau, Merivale, Papanui and St Albans

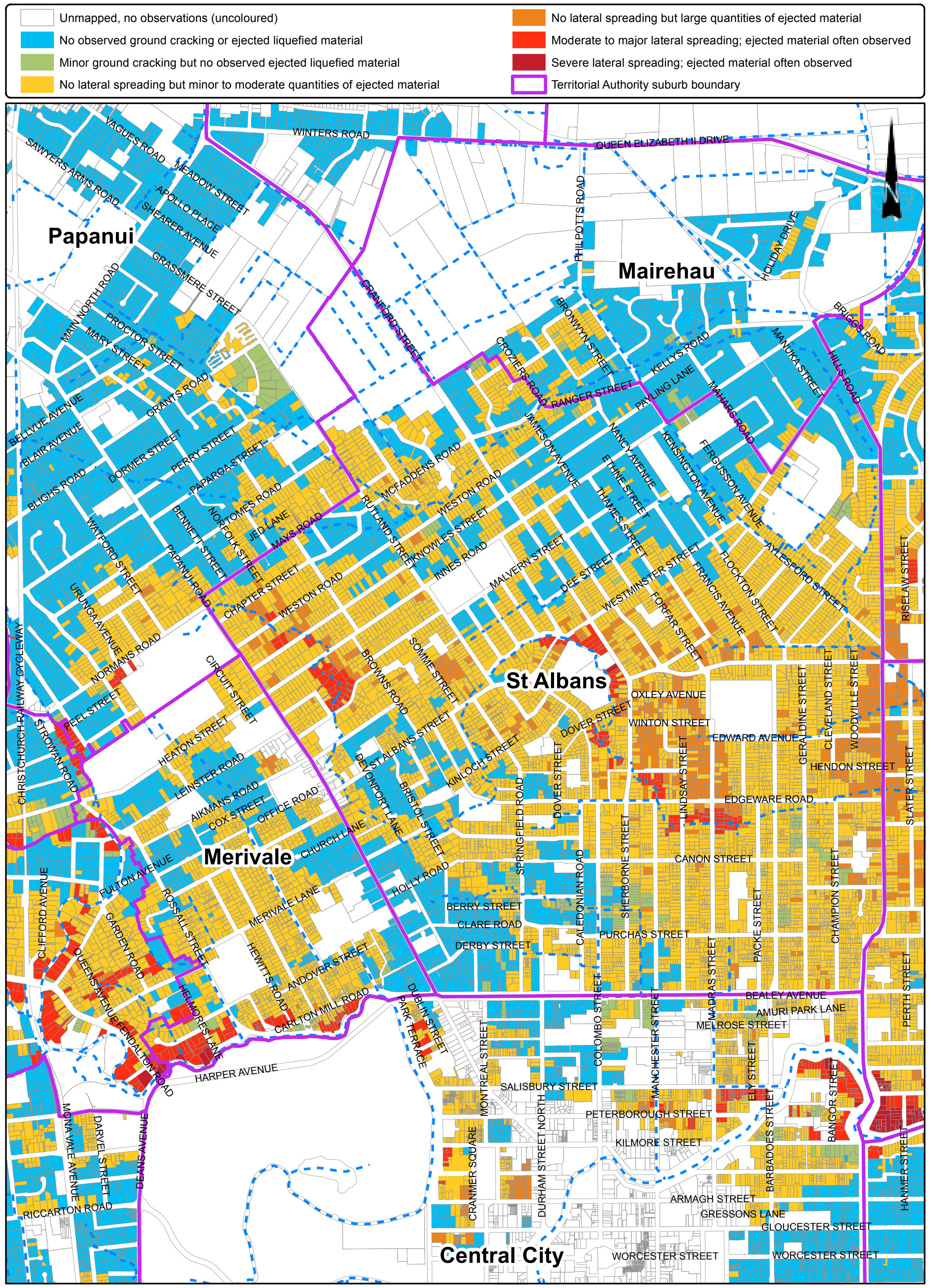

Figure C7.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

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Factsheet 8 - Richmond to Burwood

Avondale, Avonside, Burwood, Dallington, Richmond, Shirley, Travis, Wainoni and Westhaven

8.1 Ground conditions and groundwater

Regional geology maps show that the area towards the west is underlain by dominantly alluvial sand and silt overbank deposits. Sand of fixed and semi-fixed dunes and beach deposits are present in some areas in the west, and become dominant in the east. Deposits of sand, silt and peat of drained lagoons and estuaries are present in some areas in the northeast.

Table C8.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands and silts, with some clayey silt. Some gravelly material is present between Avonside and Shirley.

Table C8.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally at a moderate elevation above sea level (but is low-lying nearer the rivers), with a shallow depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the eastern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

8.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C8.1 and Table C8.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C8.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C8.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C8.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Avondale	55	3	26	1540
Avonside	66	12	29	1575
Burwood	78	19	43	490
Dallington	63	10	37	2460
Richmond	57	8	32	1245
Shirley	28	3	18	-
Travis	9	-	6	-
Wainoni	57	5	15	1220
Westhaven	-	-	-	-

Table C8.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Avondale	Typically 1.5m to 2.3m (Avg 1.7m)	Typically 0.8m to 1.8m (Avg 1.2m)
Avonside	Typically 2.2m to 4.0m (Avg 2.7m)	Typically 0.7m to 2.8m (Avg 1.4m)
Burwood	Typically 1.5m to 5.7m (Avg 3.7m)	Typically 0.7m to 3.1m (Avg 1.6m)
Dallington	Typically 1.6m to 3.6m (Avg 2.4m)	Typically 0.7m to 2.0m (Avg 1.3m)
Richmond	Typically 3.4m to 4.8m (Avg 4.4m)	Typically 0.6m to 2.3m (Avg 1.4m)
Shirley	Typically 3.3m to 5.9m (Avg 4.7m)	Typically 0.7m to 2.4m (Avg 1.6m)
Travis	Typically 1.9m to 4.9m (Avg 2.3m)	Typically 0.6m to 3.2m (Avg 0.9m)
Wainoni	Typically 2.0m to 5.6m (Avg 3.7m)	Typically 0.9m to 3.0m (Avg 2.1m)
Westhaven	Typically 2.4m to 4.6m (Avg 3.6m)	Typically 1.3m to 2.7m (Avg 2.1m)

Table C8.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Avondale	1345	2%	3%	8%	35%	15%	35%	2%
Avonside	1316	<1%	14%	<1%	37%	7%	38%	3%
Burwood	3786	<1%	36%	6%	26%	11%	15%	5%
Dallington	1928	<1%	4%	1%	46%	8%	30%	10%
Richmond	2222	<1%	1%	1%	61%	12%	15%	9%
Shirley	2093	<1%	33%	1%	52%	7%	6%	<1%
Travis	235	3%	11%	9%	58%	3%	16%	0%
Wainoni	2289	<1%	10%	8%	68%	3%	8%	2%
Westhaven	789	2%	88%	1%	8%	<1%	1%	0%

Factsheet 8 - Richmond to Burwood

Avondale, Avonside, Burwood, Dallington, Richmond, Shirley, Travis, Wainoni and Westhaven

Table C8.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Avondale	Typically -750mm to -350mm (Average -550mm)
Avonside	Typically -750mm to -250mm (Average -450mm)
Burwood	Typically -700mm to -150mm (Average -400mm)
Dallington	Typically -700mm to -300mm (Average -450mm)
Richmond	Typically -600mm to -300mm (Average -400mm)
Shirley	Typically -500mm to -150mm (Average -300mm)
Travis	Typically -500mm to -250mm (Average -350mm)
Wainoni	Typically -550mm to -250mm (Average -400mm)
Westhaven	Typically -400mm to -100mm (Average -250mm)

Table C8.5 - Liquefaction and lateral spread observations

Suburb	Observations
Avondale Avonside Burwood Dallington Richmond	Extensive areas of minor to moderate liquefaction across most of these suburbs, with severe liquefaction on about 10-15% of properties, causing sand ejection and settlement. Widespread major lateral spreading towards the Avon River, Dudley Creek, Horseshoe Lake and Travis Wetland along most of their length in these suburbs. Lateral spread displacements extend up to 50 – 250m inland, affecting about 20 – 40% of residential properties in these suburbs. Severe lateral spreading on numerous properties. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. In some localised areas, often associated with higher ground of dune deposits, no surface evidence of liquefaction or related land effects was observed.
Shirley Travis	Extensive minor to moderate liquefaction across much of the suburb (severe liquefaction on a small number of properties), causing sand ejection and settlement. Moderate lateral spreading towards Shirley Creek and Travis Wetland in some areas, but generally localised to the immediately adjacent properties. In some areas, mostly north Shirley, no surface evidence of liquefaction or related land effects was observed.
Wainoni	Extensive areas of minor to moderate liquefaction across most of the suburb (severe liquefaction on a small number of properties), causing sand ejection and settlement. Moderate to major lateral spreading towards the Avon River in some areas. Lateral spread displacements extend up to 50 – 250m inland. Severe lateral spreading on some properties. Localised major lateral ground displacements and cracking in some areas of more steeply-sloping ground at the edge of sand dune deposits. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. In some localised areas, no surface evidence of liquefaction or related land effects was observed.
Westhaven	Minor liquefaction in small localised areas of slightly lower-lying ground, causing sand ejection and settlement. Localised moderate lateral ground displacement on a small number of properties close to waterways. For most of the suburb, no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

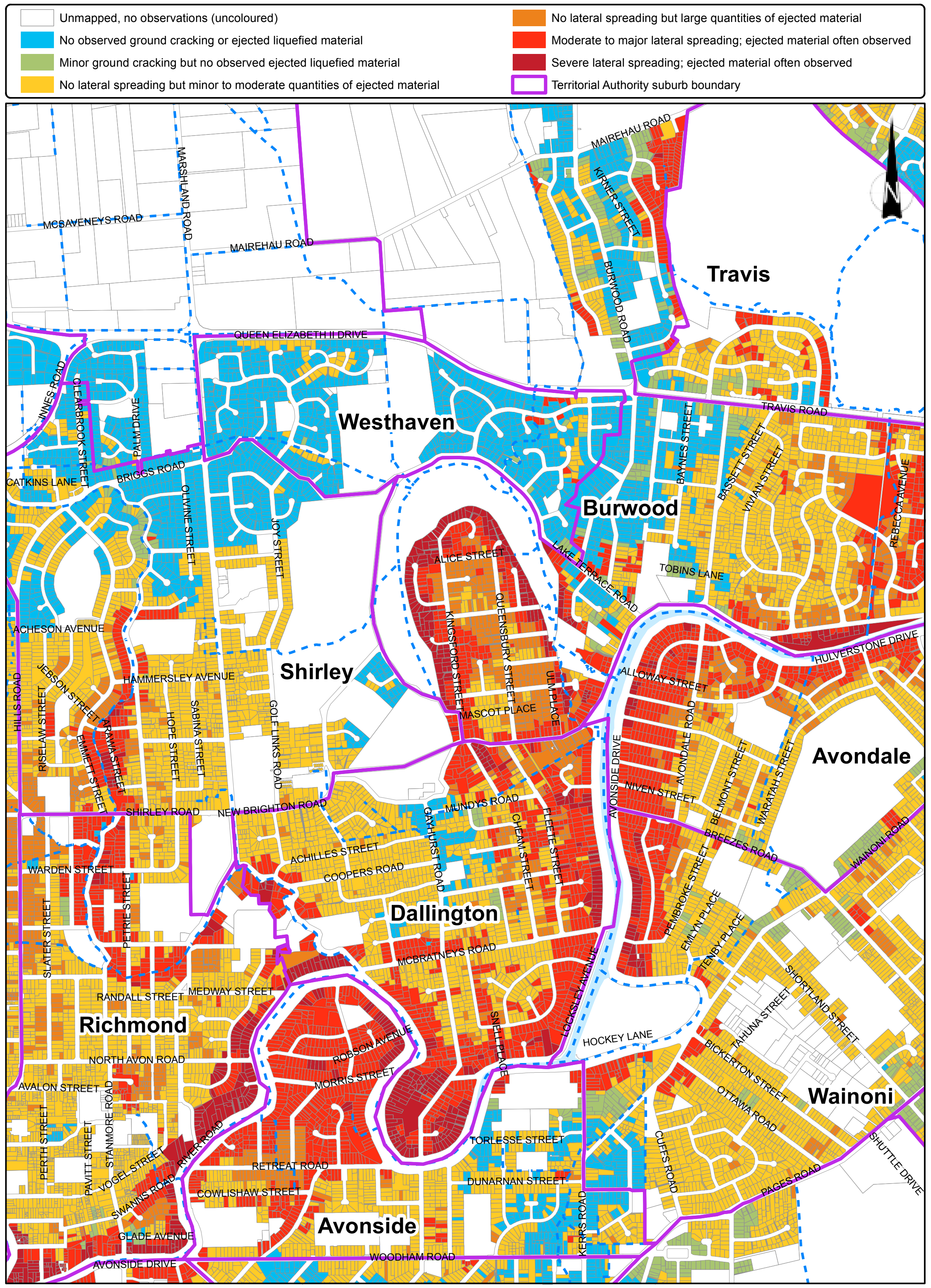

Figure C8.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 9 - Aranui to North New Brighton

9.1 Ground conditions and groundwater

Regional geology maps show that the area towards the east (near the coast), is underlain by sand of fixed and semi-fixed dunes and beach deposits. Towards the west the geology becomes a mixture of sand of fixed and semi-fixed dunes and beaches, alluvial sand and silt overbank deposits, and sand, silt, and occasional peat of drained lagoons and estuaries.

Table C9.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands and silts, with some clayey silt.

Table C9.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately low-lying (but moderately elevated in some dune areas), with a shallow depth to groundwater.

The ground conditions and groundwater in this area are generally similar to, or slightly better than (near the coast), most of the eastern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

9.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C9.1 and Table C9.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C9.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C9.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C9.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Aranui	33	2	23	-
Bexley	34	5	18	1200
New Brighton	43	4	23	480
North New Brighton	5	-	4	-

Aranui, Bexley, New Brighton and North New Brighton

Table C9.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Aranui	Typically 1.9m to 5.1m (Avg 3.5m)	Typically 0.8m to 2.3m (Avg 1.4m)
Bexley	Typically 0.7m to 1.9m (Avg 1.0m)	Typically 0.6m to 1.5m (Avg 1.1m)
New Brighton	Typically 1.6m to 3.6m (Avg 2.5m)	Typically 0.5m to 2.5m (Avg 1.8m)
North New Brighton	Typically 3.2m to 4.7m (Avg 3.9m)	Typically 1.8m to 3.3m (Avg 2.4m)

Table C9.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Aranui	1630	<1%	4%	13%	76%	1%	5%	0%
Bexley	920	1%	<1%	0%	42%	18%	30%	8%
New Brighton	2996	1%	43%	6%	32%	13%	5%	0%
North New Brighton	1790	1%	48%	8%	42%	1%	0%	0%

Table C9.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Aranui	Typically -500mm to -200mm (Average -350mm)
Bexley	Typically -800mm to -350mm (Average -500mm)
New Brighton	Typically -650mm to -150mm (Average -400mm)
North New Brighton	Typically -600mm to -200mm (Average -350mm)

Factsheet 9 - Aranui to North New Brighton

Table C9.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Aranui	In the lower-lying northeastern and southeastern areas, widespread minor to moderate liquefaction, causing sand ejection and settlement. In the higher areas to the west and north, a mixture of minor to moderate liquefaction and minor ground cracking. In many areas, sand ejection appears concentrated on the roads (which are lower-lying than the adjacent residential properties). Minor to moderate lateral spreading towards the Avon River in the north and a small watercourse in the east, but generally localised to the immediately adjacent properties.
Bexley	Widespread moderate liquefaction, with several large areas of severe liquefaction. Large volumes of ejected sand and settlement. Major to very severe lateral spreading towards the Avon River in the north and east, and of the higher land in the south towards the surrounding lower areas and wetlands. Widespread flooding of the low-lying central and northern areas – likely due to a combination of water pipeline breaks, ejected water from liquefaction, and backflow of the stormwater network from the river.
New Brighton	In the low-lying area in the west, widespread moderate to severe liquefaction, causing large volumes of ejected sand and settlement. Major lateral spreading along towards the wetland. In the low-lying area alongside the Avon River, widespread moderate liquefaction, causing sand ejection and settlement. Major lateral spreading towards the river in many locations, but generally localised to the immediately adjacent properties. In the area to the west of Keyes Rd, inland from the river, widespread moderate liquefaction (severe liquefaction on a small number of properties), causing ejected sand and settlement. Minor to moderate lateral ground movement in some areas of gently-sloping ground. In the area to the east of Keyes Rd, and to the southeast away from the river, generally no surface evidence of liquefaction or related land effects was observed.
North New Brighton	In the area to the west of Effingham St, widespread minor to moderate liquefaction (severe liquefaction on a small number of properties), causing ejected sand and settlement. Minor lateral ground movement in some areas of gently-sloping ground. In the area to the east of Effingham St, generally no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Applicability - This report was prepared and/or compiled for the Earthquake Commission (EQC) to communicate information that may be relevant to residential land claims under the Earthquake Commission Act 1993. The report was not intended for any other purpose and may not be relied upon for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of any map(s) and data in this report or for the consequences of any other person relying on them in any way. This information is not intended to form a complete technical report on land changes in all or any part of Canterbury.

Aranui, Bexley, New Brighton and North New Brighton

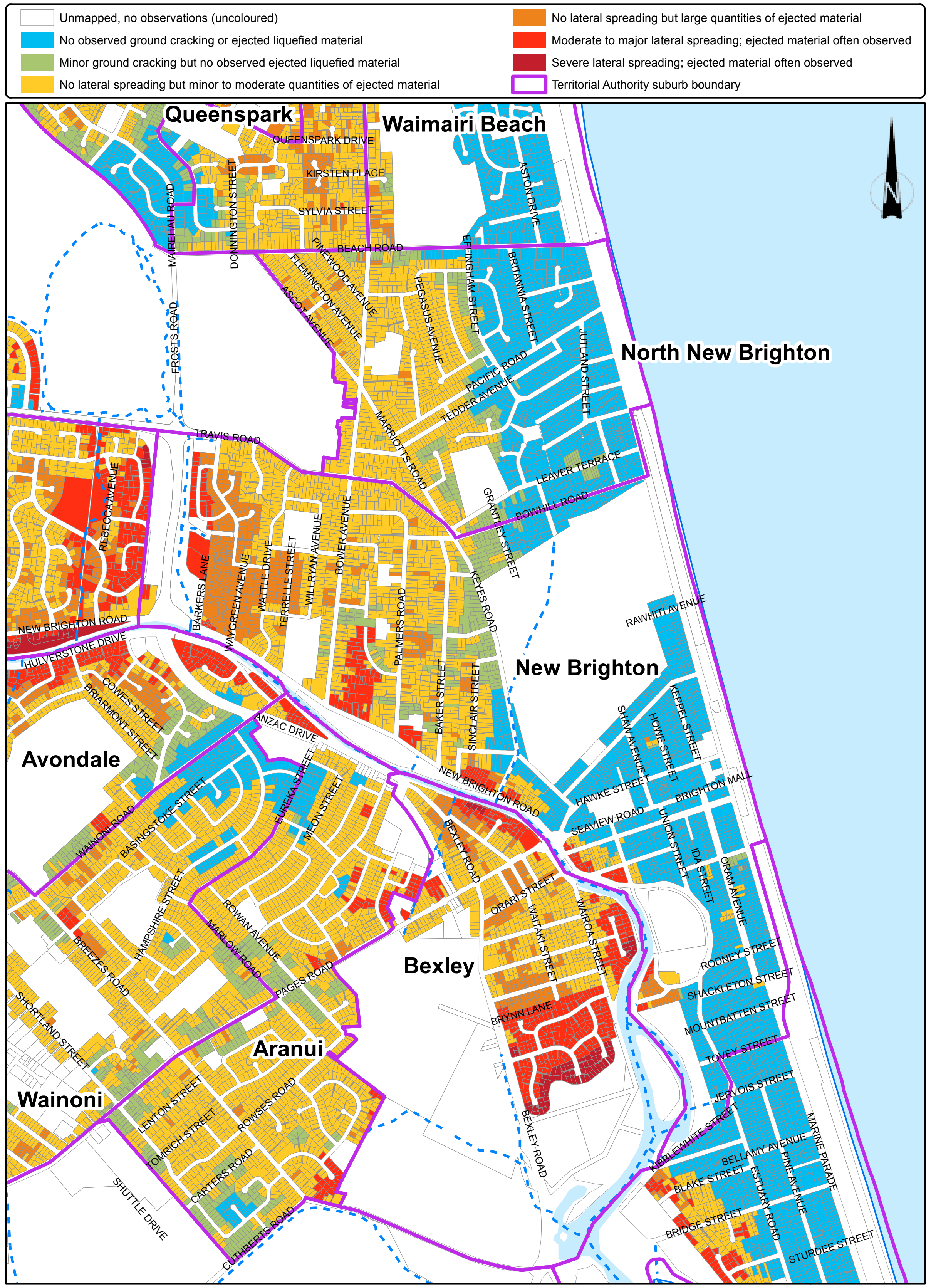

Figure C9.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 10 - Hillmorton to Riccarton

10.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by dominantly alluvial sand and silt overbank deposits, with some areas of alluvial gravel, sand and silt of historic river flood channels.

Table C10.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises loose to dense sands, silts and gravel.

Table C10.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in September 2011, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated well above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the southern, central and northern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

10.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C10.1 and Table C10.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C10.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C10.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C10.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Hillmorton	5	-	2	-
Hoon Hay	25	3	9	-
Riccarton	-	-	-	-
Upper Riccarton	-	-	-	-

Hillmorton, Hoon Hay, Riccarton and Upper Riccarton

Table C10.2 - Summary of ground elevation and groundwater depth (September 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Hillmorton	Typically 14.2m to 16.3m (Avg 15.1m)	Typically 1.7m to 3.0m (Avg 2.3m)
Hoon Hay	Typically 9.9m to 13.7m (Avg 11.6m)	Typically 0.4m to 1.7m (Avg 0.7m)
Riccarton	Typically 8.6m to 13.5m (Avg 10.9m)	Typically 0.5m to 1.8m (Avg 1.2m)
Upper Riccarton	Typically 15.3m to 23.7m (Avg 20.1m)	Typically 1.4m to 5.7m (Avg 3.0m)

Table C10.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Hillmorton	543	1%	59%	<1%	38%	<1%	1%	0%
Hoon Hay	2957	13%	55%	1%	31%	<1%	<1%	0%
Riccarton	3689	57%	36%	<1%	6%	0%	<1%	0%
Upper Riccarton	3487	100%	0%	0%	0%	0%	0%	0%

Table C10.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to September 2011 (positive values are uplift, negative values are subsidence)
Hillmorton	Typically -150mm to +50mm (Average -50mm)
Hoon Hay	Typically -200mm to +50mm (Average -50mm)
Riccarton	Typically -250mm to +0mm (Average -150mm)
Upper Riccarton	Typically -200mm to +50mm (Average -100mm)

Factsheet 10 - Hillmorton to Riccarton

Hillmorton, Hoon Hay, Riccarton and Upper Riccarton

Table C10.5 - Liquefaction and lateral spread observations

Suburb	Observations
Hillmorton Hoon Hay Riccarton	Minor to moderate liquefaction in several areas (severe liquefaction on a small number of properties), causing sand ejection and settlement. Minor to moderate lateral spreading towards the Heathcote and Avon Rivers in several small areas, but localised to the immediately adjacent properties. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed.
Upper Riccarton	This suburb was not mapped at a property-by-property level, however street-level mapping and air photo analysis found no surface evidence of liquefaction or related land effects.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

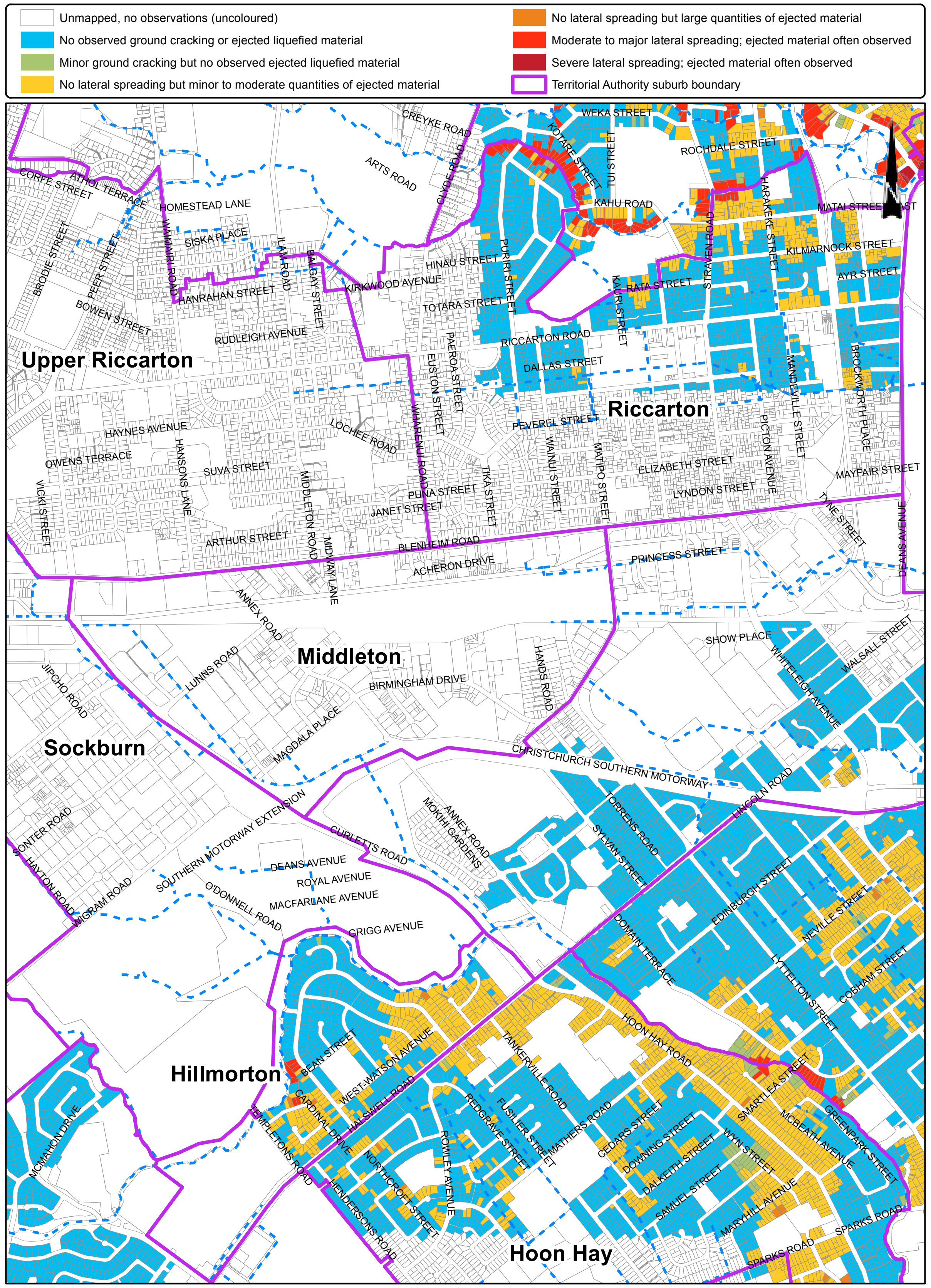

Figure C10.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 11 - Cashmere to Sydenham

11.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by dominantly alluvial sand and silt overbank deposits.

Table C11.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises loose to dense sands, silts and gravel.

Table C11.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in September 2011, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated moderately to well above sea level with a shallow depth to groundwater.

The ground conditions and groundwater in this area are generally similar to most of the southern, central and northern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

11.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C11.1 and Table C11.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C11.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C11.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C11.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Addington	-	-	-	-
Beckenham	26	3	20	-
Cashmere (on the flat)	11	2	1	-
Somerfield	27	5	14	-
Spreydon	28	4	10	-
Sydenham	15	-	6	-

Addington, Beckenham, Cashmere (on the flat), Somerfield, Spreydon and Sydenham

Table C11.2 - Summary of ground elevation and groundwater depth (September 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Addington	Typically 10.0m to 14.7m (Avg 12.0m)	Typically 1.8m to 2.7m (Avg 2.3m)
Beckenham	Typically 5.9m to 8.5m (Avg 6.8m)	Typically 0.5m to 2.8m (Avg 1.7m)
Cashmere (on the flat)	Typically 7.8m to 9.3m (Avg 8.6m)	Typically 1.2m to 2.5m (Avg 1.9m)
Somerfield	Typically 7.1m to 10.1m (Avg 8.3m)	Typically 0.3m to 2.0m (Avg 1.2m)
Spreydon	Typically 8.7m to 12.4m (Avg 10.6m)	Typically 0.5m to 1.5m (Avg 1.0m)
Sydenham	Typically 6.1m to 8.6m (Avg 7.4m)	Typically 0.6m to 2.4m (Avg 1.8m)

Table C11.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Addington	2451	6%	80%	<1%	11%	3%	0%	0%
Beckenham	1066	<1%	77%	5%	11%	<1%	6%	0%
Cashmere (on the flat)	679	49%	24%	11%	9%	3%	4%	0%
Somerfield	1186	<1%	59%	2%	35%	3%	<1%	0%
Spreydon	5004	<1%	57%	<1%	40%	2%	<1%	0%
Sydenham	2459	<1%	63%	3%	29%	4%	<1%	0%

Factsheet 11 - Cashmere to Sydenham

Addington, Beckenham, Cashmere (on the flat), Somerfield, Spreydon and Sydenham

Table C11.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to September 2011 (positive values are uplift, negative values are subsidence)
Addington	Typically -250mm to +100mm (Average -100mm)
Beckenham	Typically -300mm to +0mm (Average -150mm)
Cashmere (on the flat)	Typically -350mm to -50mm (Average -150mm)
Somerfield	Typically -300mm to -100mm (Average -200mm)
Spreydon	Typically -300mm to -100mm (Average -200mm)
Sydenham	Typically -350mm to -100mm (Average -200mm)

Table C11.5 - Liquefaction and lateral spread observations

Suburb	Observations
Addington Spreydon Somerfield	Minor to moderate liquefaction in many areas (severe liquefaction on a small number of properties), causing sand ejection and settlement. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed.
Beckenham Cashmere (on the flat) Sydenham	Minor to moderate liquefaction in many areas (severe liquefaction on a small number of properties), causing sand ejection and settlement. Minor to moderate lateral spreading towards the Heathcote River and Jacksons Creek in several areas, but localised to the immediately adjacent properties. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

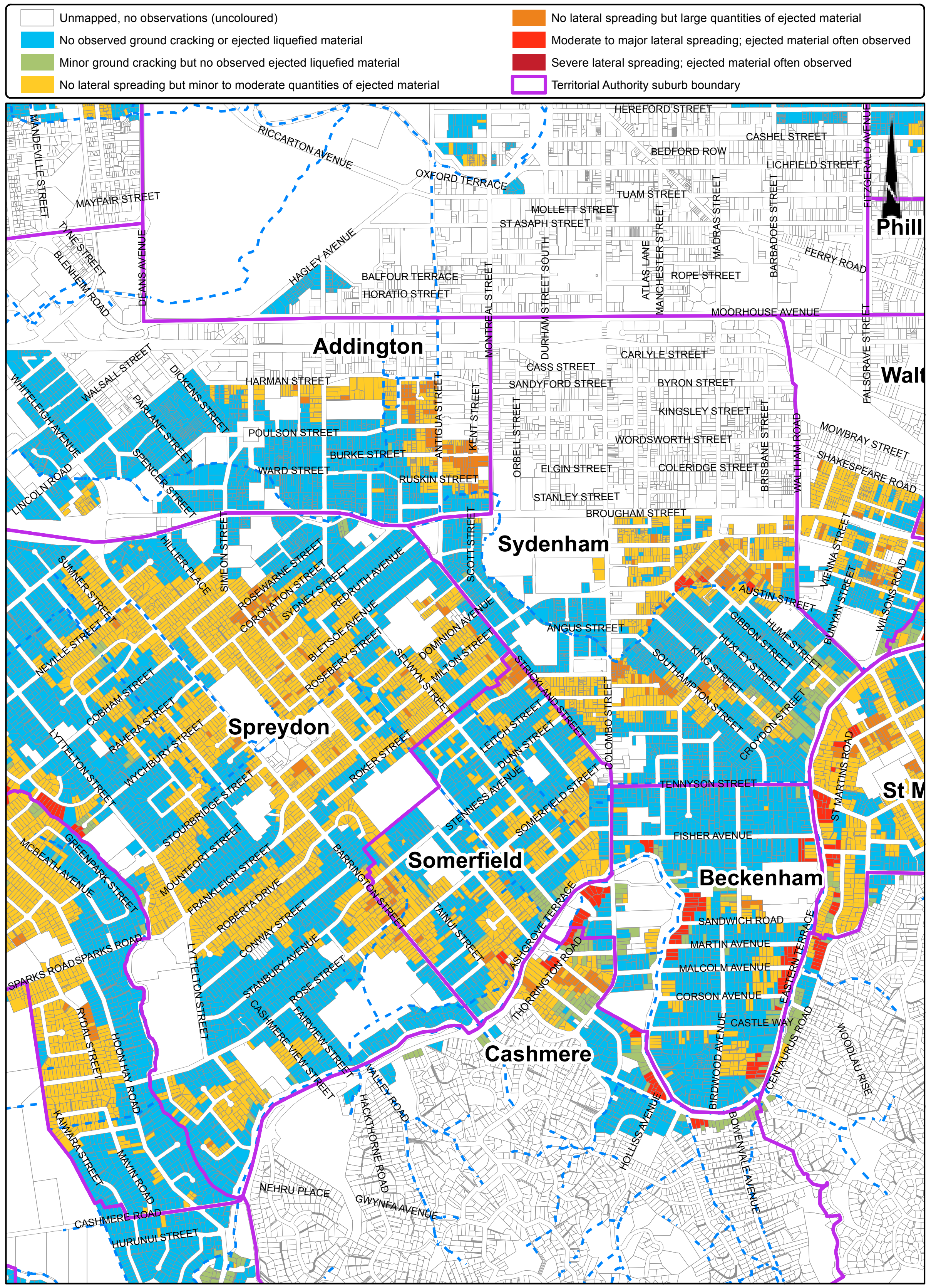

Figure C11.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 12 - St Martins to North Linwood

12.1 Ground conditions and groundwater

Regional geology maps show that the area is generally underlain by dominantly alluvial sand and silt overbank deposits. Sands of fixed and semi-fixed dunes and beach deposits are present towards the northwest. Towards the east, some areas of drained peat swamps and silt and sand of lagoon and estuary deposits are present.

Table C12.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises loose to dense sands and silts, with gravel present in some areas towards the west.

Table C12.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally at a moderate elevation above sea level (slightly lower beside the river), with shallow groundwater.

The ground conditions and groundwater in this area are generally similar to most of the eastern or southern suburbs of Christchurch. While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

12.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C12.1 and Table C12.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C12.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C12.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C12.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Bromley	24	1	11	-
Linwood	21	-	9	-
North Linwood	12	-	8	-
Opawa	23	3	11	-
Phillipstown	2	-	-	-
St Martins	30	8	10	-
Waltham	22	3	8	-
Woolston	54	8	31	-

Bromley, Linwood, North Linwood, Opawa, Phillipstown, St Martins, Waltham and Woolston

Table C12.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Bromley	Typically 2.7m to 4.4m (Avg 3.2m)	Typically 0.3m to 1.5m (Avg 0.7m)
Linwood	Typically 2.4m to 5.2m (Avg 3.6m)	Typically 0.3m to 3.3m (Avg 1.5m)
North Linwood	Typically 2.5m to 4.1m (Avg 3.1m)	Typically 0.4m to 3.0m (Avg 1.4m)
Opawa	Typically 3.1m to 6.1m (Avg 4.8m)	Typically 0.8m to 3.4m (Avg 2.2m)
Phillipstown	Typically 3.2m to 4.7m (Avg 3.7m)	Typically 0.3m to 1.9m (Avg 1.0m)
St Martins	Typically 3.8m to 6.9m (Avg 5.4m)	Typically 0.3m to 3.9m (Avg 1.7m)
Waltham	Typically 3.6m to 6.5m (Avg 5.0m)	Typically 0.3m to 2.0m (Avg 0.9m)
Woolston	Typically 2.4m to 3.8m (Avg 2.8m)	Typically 0.3m to 2.2m (Avg 0.8m)

Table C12.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Bromley	1674	1%	50%	6%	42%	<1%	<1%	0%
Linwood	4261	<1%	59%	<1%	39%	<1%	1%	0%
North Linwood	1031	<1%	44%	0%	55%	<1%	<1%	0%
Opawa	1064	2%	34%	6%	37%	4%	17%	<1%
Phillipstown	419	0%	55%	0%	42%	2%	1%	0%
St Martins	1386	13%	35%	2%	41%	4%	5%	0%
Waltham	1211	<1%	31%	<1%	54%	10%	4%	0%
Woolston	3704	1%	32%	2%	56%	6%	2%	<1%

Factsheet 12 - St Martins to North Linwood

Table C12.4 - Changes in ground elevation inferred from LiDAR survey	
Suburb	**Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)**
Bromley	Typically -400mm to +300mm (Average -50mm)
Linwood	Typically -300mm to -50mm (Average -200mm)
North Linwood	Typically -400mm to -150mm (Average -250mm)
Opawa	Typically -350mm to +0mm (Average -200mm)
Phillipstown	Typically -350mm to -100mm (Average -250mm)
St Martins	Typically -350mm to +0mm (Average -200mm)
Waltham	Typically -450mm to -150mm (Average -250mm)
Woolston	Typically -200mm to +300mm (Average +100mm)

Table C12.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Bromley Linwood North Linwood Phillipstown Waltham	Extensive areas of minor to moderate liquefaction across much of these suburbs (severe liquefaction on a small number of properties), causing sand ejection and settlement. Localised minor to moderate lateral ground displacement and cracking in some areas of sloping ground at the edge of sand dune deposits. For the remainder of these suburbs (often associated with higher ground of dune deposits), no surface evidence of liquefaction or related land effects was observed.
Opawa St Martins Woolston	Minor to moderate liquefaction in many areas, with some areas of severe liquefaction, causing sand ejection and settlement. Minor to moderate lateral spreading towards the Heathcote River and Jacksons Creek in several areas, but localised to the immediately adjacent properties. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Bromley, Linwood, North Linwood, Opawa, Phillipstown, St Martins, Waltham and Woolston

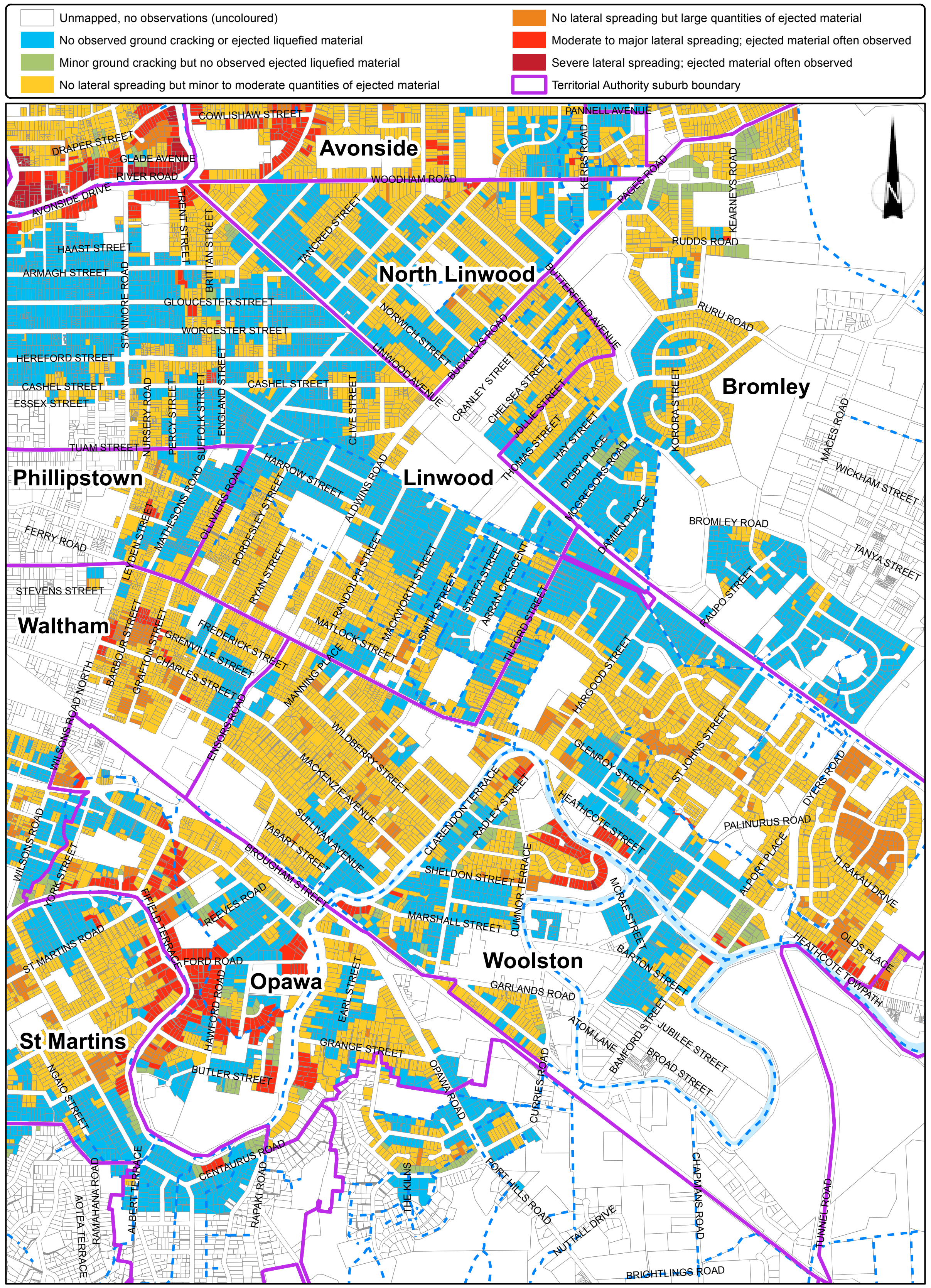

Figure C12.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 13 - Redcliffs to South New Brighton

13.1 Ground conditions and groundwater

Regional geology maps show that the area is generally underlain by dominantly beach or dune sands ranging from active or stabilised to semi-fixed and fixed. In some areas silt and sand of lagoon and estuary deposits is present.

Table C13.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises medium dense to dense sands, with layers of silt in some areas.

Table C13.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in February 2012, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally moderately low-lying, with shallow groundwater.

The ground conditions and groundwater in this area are generally similar to, or slightly more favourable than (in the northeast), most of the eastern suburbs of Christchurch.

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

13.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations were undertaken following the 4 September 2010 and 22 February 2011 earthquakes, first on a regional and street-by-street level in the days immediately after each earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by air-photo analysis for all four main earthquakes, and additional regional or street-level mapping for the earthquakes of 13 June 2011 and 23 December 2011. This additional mapping indicated that the overall pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first two main earthquakes.

Figure C13.1 and Table C13.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. The observations following the 4 September 2010 and 22 February 2011 earthquakes have been aggregated by assigning each property the most severe observation from either of these two earthquakes. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C13.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C13.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C13.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Redcliffs (on the flat)	3	-	3	-
South New Brighton	8	3	9	-
Southshore	10	1	10	-

Redcliffs (on the flat), South New Brighton and Southshore

Table C13.2 - Summary of ground elevation and groundwater depth (February 2012)

Suburb	Ground elevation above sea level	Groundwater depth
Redcliffs (on the flat)	Typically 1.8m to 4.6m (Avg 2.2m)	Typically 0.8m to 2.6m (Avg 1.0m)
South New Brighton	Typically 1.7m to 4.3m (Avg 2.2m)	Typically 1.0m to 2.0m (Avg 1.3m)
Southshore	Typically 1.6m to 2.3m (Avg 1.8m)	Typically 0.9m to 1.5m (Avg 1.2m)

Table C13.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken following earthquakes of 4 September 2010 and 22 February 2011

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	No lateral spreading, but large quantities of ejected material	Moderate to major lateral spreading, ejected material often observed	Severe lateral spreading, ejected material often observed
Redcliffs (on the flat)	490	6%	25%	2%	47%	<1%	20%	0%
South New Brighton	1430	<1%	70%	5%	16%	<1%	8%	0%
Southshore	643	<1%	10%	7%	53%	0%	30%	0%

Table C13.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to February 2012 (positive values are uplift, negative values are subsidence)
Redcliffs (on the flat)	Typically +150mm to +450mm (Average +300mm)
South New Brighton	Typically -250mm to +100mm (Average -50mm)
Southshore	Typically -250mm to +100mm (Average -50mm)

Factsheet 13 - Redcliffs to South New Brighton

Table C13.5 - Liquefaction and lateral spread observations

Suburb	Observations
Redcliffs (on the flat)	Extensive areas of minor to moderate liquefaction across most of the lower-lying part of the suburb, causing sand ejection and settlement. Moderate to major lateral spreading towards the estuary, but generally localised to the immediately adjacent properties. In the areas of higher ground further inland, no surface evidence of liquefaction or related land effects was observed.
South New Brighton Southshore	Extensive areas of minor to moderate liquefaction across most of Southshore and parts of South New Brighton, causing sand ejection and settlement. Major lateral spreading towards the estuary, varying in extent from one to several rows of houses back from the estuary edge. In some areas, settlement and minor ground cracking observed without any obvious surface evidence of liquefaction, likely due to minor liquefaction occurring at depth below the surface but not being ejected. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed, often associated with the higher ground of dunes or beach deposits.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Redcliffs (on the flat), South New Brighton and Southshore

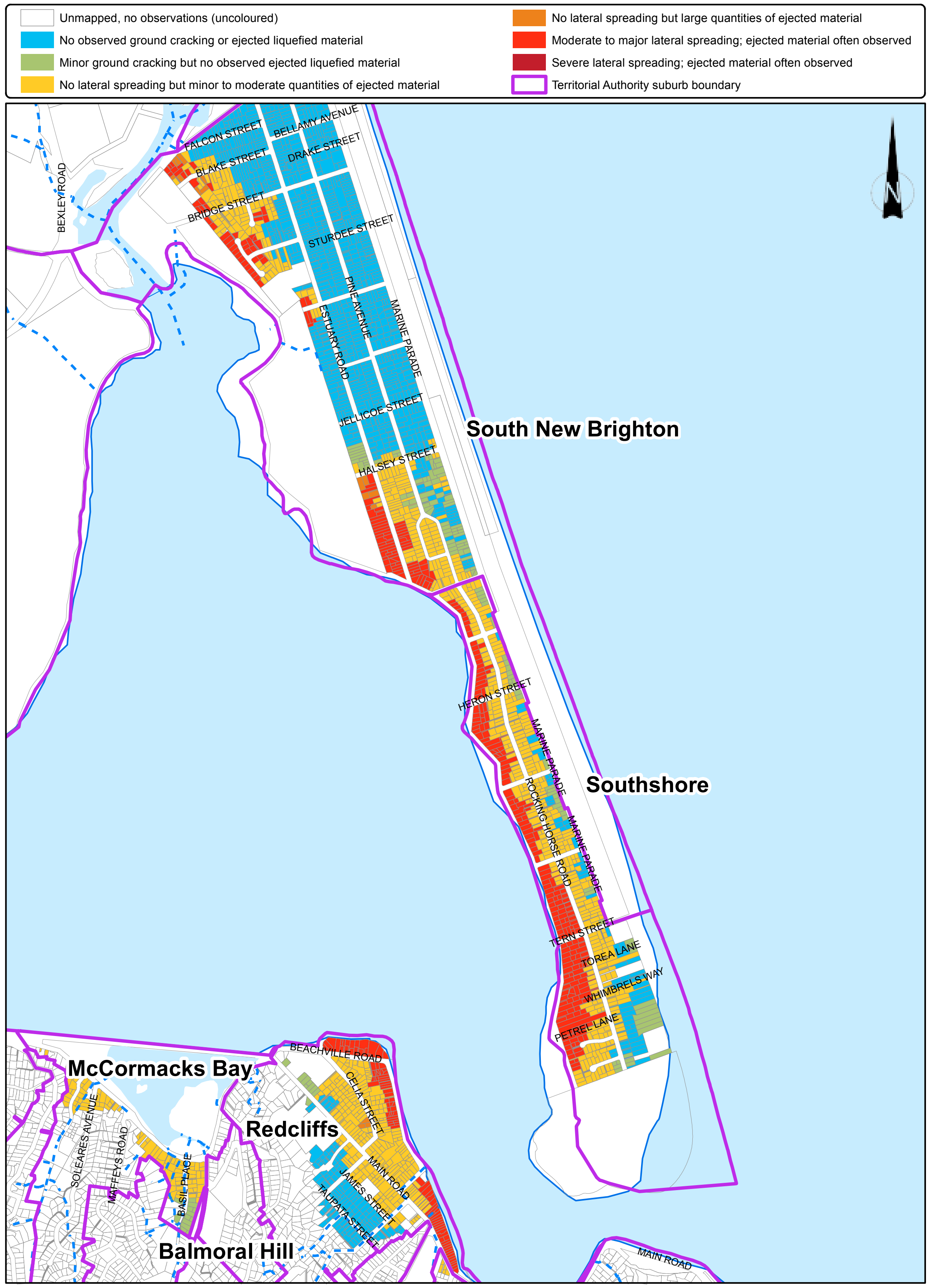

Figure C13.1 - Overview of liquefaction and lateral spreading observations, aggregated from mapping undertaken following the earthquakes of 4 September 2010 and 22 February 2011.

Factsheet 14 - Halswell

14.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by river alluvium beneath plains or low level terraces of Holocene age.

Table C14.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 and 22 February 2011 earthquakes. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands, gravels, silts and clays.

Table C14.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by EQC in September 2011, and a groundwater surface developed from recent EQC groundwater monitoring in conjunction with historic Environment Canterbury groundwater data. This area is generally elevated well above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to, or slightly more favourable than, most of the southern, central and northern suburbs of Christchurch

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

14.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 earthquake, first on a regional and street-by-street level in the days immediately after the earthquake, and then on a property-by-property level over the following weeks. This mapping was supported by additional air-photo, regional or street-level mapping for the subsequent main earthquakes. This additional mapping indicated that the pattern of liquefaction and lateral spreading in this area for the subsequent earthquakes was generally similar to that observed in the first main earthquake, but usually less extensive and severe.

Figure C14.1 and Table C14.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations in this area. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C14.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C14.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C14.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Halswell	38	2	12	-
Oaklands	8	-	1	-
Wentworth Park	2	-	2	-
Westlake	1	-	-	-

Halswell, Oaklands, Wentworth Park and Westlake

Table C14.2 - Summary of ground elevation and groundwater depth (September 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Halswell	Typically 12.3m to 15.5m (Avg 13.8m)	Typically 1.0m to 2.0m (Avg 1.5m)
Oaklands	Typically 15.0m to 18.5m (Avg 16.3m)	Typically 1.8m to 4.0m (Avg 3.0m)
Wentworth Park	Typically 17.4m to 18.1m (Avg 17.8m)	Typically 2.4m to 4.0m (Avg 3.0m)
Westlake	Typically 16.9m to 19.4m (Avg 17.8m)	Typically 2.0m to 4.0m (Avg 3.0m)

Table C14.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken by EQC following earthquake of 4 September 2010

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	Moderate to major lateral spreading or large quantities of ejected material	Severe lateral spreading, ejected material often observed
Halswell	1738	6%	45%	18%	30%	<1%	0%
Oaklands	2394	1%	90%	<1%	8%	0%	0%
Wentworth Park	260	<1%	57%	10%	32%	0%	0%
Westlake	333	0%	100%	0%	0%	0%	0%

Table C14.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from July 2003 to September 2011 (positive values are uplift, negative values are subsidence)
Halswell	Typically -200mm to +200mm (Average +0mm)
Oaklands	Typically -100mm to +300mm (Average +50mm)
Wentworth Park	Typically -100mm to +200mm (Average +50mm)
Westlake	Typically -50mm to +150mm (Average +50mm)

Factsheet 14 - Halswell

Table C14.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Halswell Oaklands Wentworth Park	Minor to moderate liquefaction in several areas, causing sand ejection and settlement. Minor to moderate lateral spreading towards streams and watercouses in several small areas, but localised to the immediately adjacent properties. For the remainder of these suburbs, no surface evidence of liquefaction or related land effects was observed.
Westlake	No surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Halswell, Oaklands, Wentworth Park and Westlake

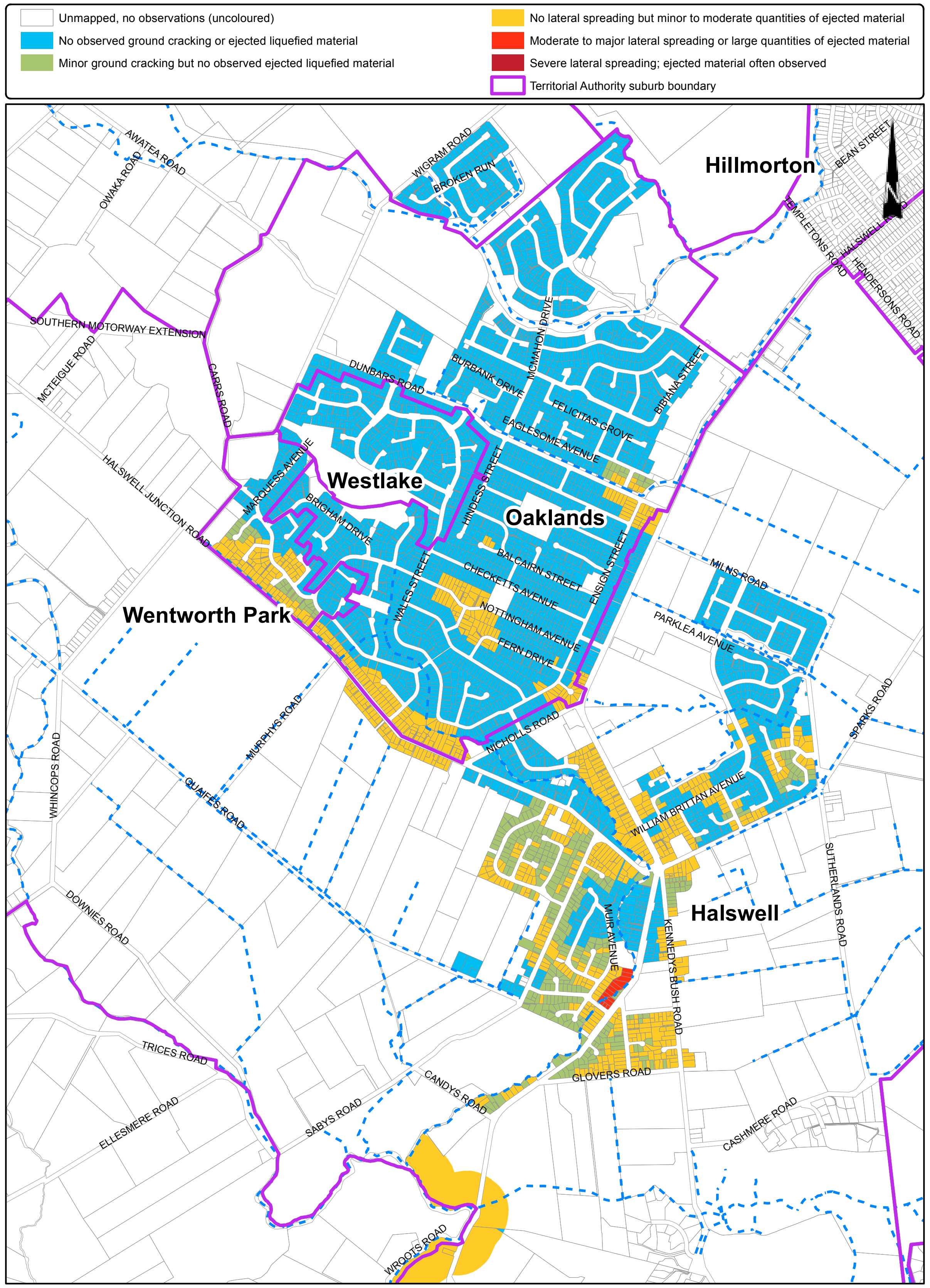

Figure C14.1 - Overview of liquefaction and lateral spreading observations, from mapping undertaken following the earthquake of 4 September 2010

Applicability - This report was prepared and/or compiled for the Earthquake Commission (EQC) to communicate information that may be relevant to residential land claims under the Earthquake Commission Act 1993. The report was not intended for any other purpose and may not be relied upon for any other purpose. EQC and its engineers, Tonkin & Taylor, have no liability to any user of any map(s) and data in this report or for the consequences of any other person relying on them in any way. This information is not intended to form a complete technical report on land changes in all or any part of Canterbury.

Factsheet 15 - Tai Tapu to Halswell

15.1 Ground conditions and groundwater

Regional geology maps show this area is generally underlain by river alluvium beneath plains or low level terraces of Holocene age.

Table C15.1 summarises the area-wide subsurface ground investigations undertaken by EQC in this area following the 4 September 2010 earthquake. These investigations indicate that the near-surface soil profile in the area generally comprises very loose to dense sands, gravels, silts and clays.

Table C15.2 summarises typical ground elevation and groundwater depths in the area (the values listed correspond to the 10th and 90th percentiles and the median). This was derived from LiDAR ground elevation survey commissioned by the Ministry of Civil Defence and Emergency Management in March 2011, and a groundwater surface developed from historic Environment Canterbury groundwater data. This area is generally elevated moderately well above sea level with a shallow to moderate depth to groundwater.

The ground conditions and groundwater in this area are generally similar to, or slightly more favourable than, most of the southern, central and northern suburbs of Christchurch

While ground surface disturbance has occurred in some areas (e.g. settlement, cracking and ejection of material), the underlying ground which liquefied appears to have now returned to its pre-earthquake strength.

15.2 Post-earthquake observations

Rapid mapping of liquefaction and lateral spreading observations was undertaken following the 4 September 2010 earthquake, first on a regional and street-by-street level in the days immediately after the earthquake, and then on a property-by-property level in urban areas over the following weeks. This mapping was supported by regional-level mapping for the subsequent main earthquakes. This additional mapping indicated that the pattern of liquefaction and lateral spreading for the subsequent earthquakes was generally similar to that observed in the first main earthquake, but less extensive and severe.

Figure C15.1 and Table C15.3 present a summary of the property-by-property rapid mapping of liquefaction and lateral spread observations undertaken by EQC in this area. The mapping undertaken by EQC was predominantly of the main urban areas of Lincoln and Tai Tapu, with less detail in the surrounding rural areas. For more extensive and detailed mapping of liquefaction observations in these rural areas, refer to the post-earthquake liquefaction report commissioned by the Selwyn District Council, available at http://www.selwyn.govt.nz/services/building/earthquake-building-recovery/liquefaction-report. These observed liquefaction and lateral spread mapping colours have completely different meaning to the colour codes used by the Canterbury Earthquake Recovery Authority (Cera) for residential land zoning and the Department of Building and Housing (DBH) for technical categories.

Table C15.4 summarises the change in ground elevation inferred from the LiDAR survey. The total change in ground elevation which has occurred is a combination of regional uplift or subsidence due to fault movements (tectonics) and local ground subsidence due to liquefaction and related effects. The LiDAR is of limited accuracy (about ±100mm). This means that the LiDAR is more suitable for measuring large changes in ground elevation (greater than about 100 to 200mm), and may not accurately represent areas where only minor changes in ground elevation have occurred.

Table C15.5 summarises the extent and severity of observed liquefaction and lateral spread.

Table C15.1 - Area-wide geotechnical investigations undertaken by EQC (December 2011)

Suburb	Number of cone penetration tests	Number of boreholes	Number of groundwater standpipes	Length of MASW geophysical testing (m)
Halswell River	-	-	-	-
Lincoln	-	-	-	-
Tai Tapu	7	-	-	-

Halswell River, Lincoln and Tai Tapu

Table C15.2 - Summary of ground elevation and groundwater depth (March 2011)

Suburb	Ground elevation above sea level	Groundwater depth
Halswell River	Typically 4.8m to 8.8m (Avg 6.5m)	Typically 0.7m to 1.3m (Avg 1.0m)
Lincoln	Typically 9.1m to 13.4m (Avg 11.3)	Typically 2.0m to 4.0m (Avg 3.0)
Tai Tapu	Typically 6.4m to 7.0m (Avg 6.7m)	Typically 0.7m to 1.3m (Avg 1.0m)

Table C15.3 - Summary of liquefaction and lateral spread observations for residential land, aggregated from mapping undertaken by EQC following earthquake of 4 September 2010

Suburb	Total residential property count	Not mapped	No observed ground cracking or ejected liquefied material	Minor ground cracking, but no observed ejected liquefied material	No lateral spreading, but minor to moderate quantities of ejected material	Moderate to major lateral spreading or large quantities of ejected material	Severe lateral spreading, ejected material often observed
Halswell River	391	61%	17%	0%	22%	0%	0%
Lincoln	1168	<1%	99%	0%	0%	0%	0%
Tai Tapu	174	3%	90%	0%	7%	0%	0%

Table C15.4 - Changes in ground elevation inferred from LiDAR survey

Suburb	Change in ground elevation from February 2008 to March 2011 (positive values are uplift, negative values are subsidence)
Halswell River	Typically -200mm to +50mm (Average -100mm)
Lincoln	No data (beyond extent of pre-earthquake LiDAR coverage)
Tai Tapu	Typically -200mm to +0mm (Average -150mm)

Factsheet 15 - Tai Tapu to Halswell

Table C15.5 - Liquefaction and lateral spread observations	
Suburb	**Observations**
Halswell River	Minor to moderate liquefaction in many rural areas alongside the Halswell River and other watercourses, causing sand ejection and settlement. Minor lateral spreading in some localised areas alongside the Halswell River. For the remainder of the area, no surface evidence of liquefaction or related land effects was observed.
Lincoln	No surface evidence of liquefaction or related land effects observed.
Tai Tapu	Minor to moderate liquefaction in several small areas, causing sand ejection and settlement. For the remainder of the urban area, no surface evidence of liquefaction or related land effects was observed.

For further area-wide geotechnical information, refer to the technical data reports on the EQC website, at http://canterbury.eqc.govt.nz/news/reports

Halswell River, Lincoln and Tai Tapu

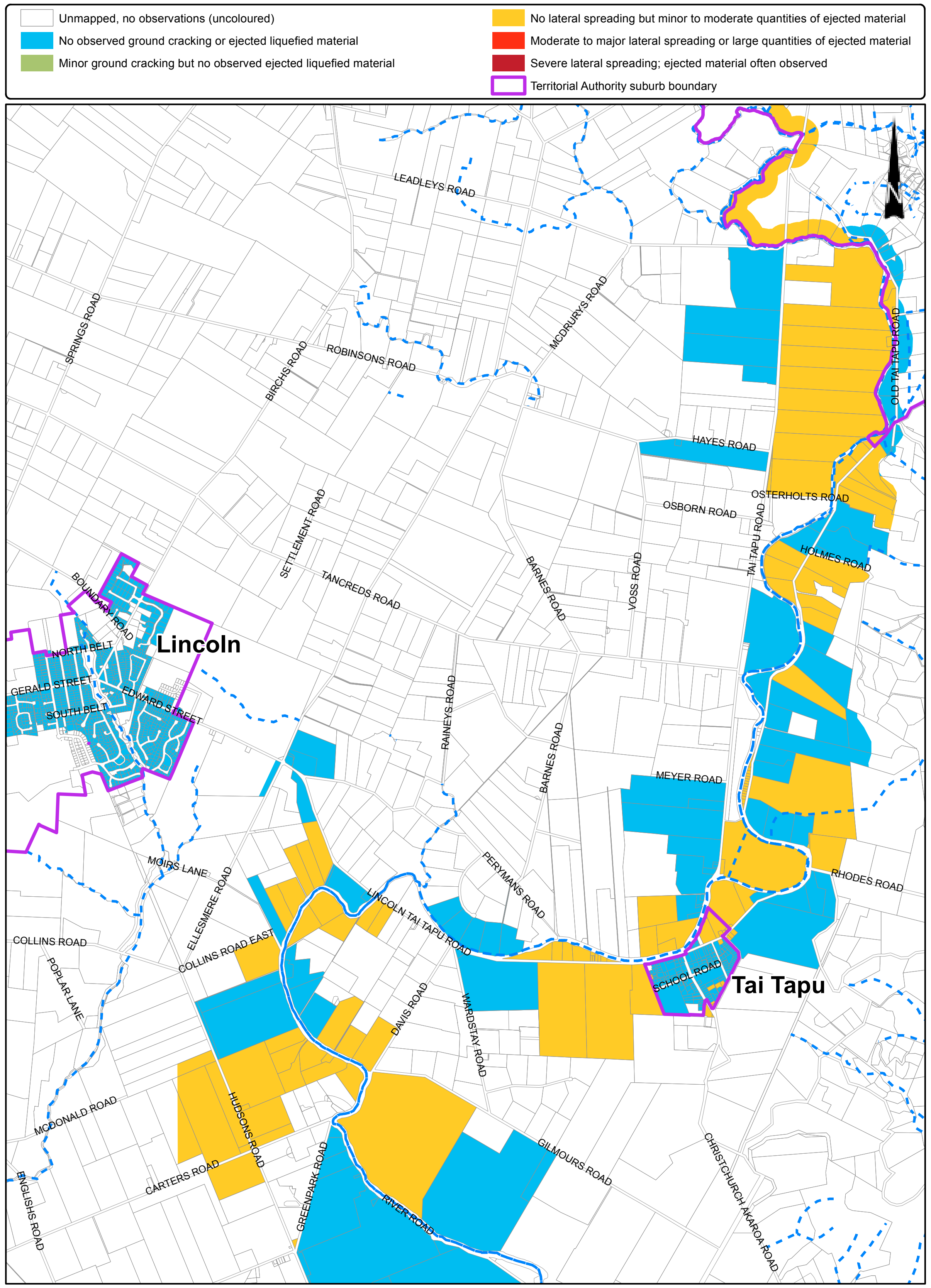

Figure C15.1 - Overview of liquefaction and lateral spreading observations, from mapping undertaken following the earthquake of 4 September 2010.