Tonkin & Taylor

Appendix C: Groundwater modelling methodology

ENVIRONMENTAL AND ENGINEERING CONSULTANTS

C1. Introduction

For the purpose of this study, the objective has been to generate a water table surface for the earthquakes listed below. The earthquake-specific water table surfaces are used for the purpose of liquefaction vulnerability modelling. The four earthquake specific water table surfaces are:

1. The water table surface immediately prior to the 04 September 2010 earthquake;
2. The groundwater surface immediately prior to the 22 February 2011 earthquake;
3. The groundwater surface immediately prior to the 13 June 2011 earthquake;
4. The groundwater surface immediately prior to the 23 December 2011 earthquake.

C2. Report on development of median water table surface

The four earthquake-specific GW surfaces have been developed based on the median water table surface which was created for Christchurch, as summarised in the following report:

van Ballegooy, S., Cox, S. C., Agnihotri, R., Reynolds, T., Thurlow, C., Rutter, H. K., Scott, D.M. Begg, J. G., McCahon, I. (2013) *Median water table elevation in Christchurch and surrounding area after the 4 September 2010 Darfield Earthquake*. GNS Science Report 2013/01 (in final draft at time of issue)

The report presented contour maps of the water table elevation and depth below ground across Christchurch City and the surrounding area for the period following the M_w7.1 Darfield Earthquake of 04 September 2010. It also assessed the historic long-term (pre-Darfield Earthquake) fluctuations in the water table and compared them to the developed post-earthquake median water table surface, commenting on direct effects caused by the earthquake series.

The median water table surface was generated using monitoring well data, as well as river monitoring and coastline data. The data was taken from the 'post-Darfield Earthquake' period (04 September 2010 to 31 December 2012).

Monitoring well data from the following sources contributed to the development of the median water table surface:

1. Christchurch City Council (CCC) – 22 wells, long term (>10 year) monitoring duration, typically measured at weekly or fortnightly intervals;
2. Environment Canterbury (ECan) – 22 wells, long term (>10 year) monitoring duration, typically measured at weekly or fortnightly intervals;
3. Earthquake Commission (EQC) – 762 wells, all installed after 22 February 2011, typically measured at monthly intervals.

The total 806 monitoring wells selected for the development of the median water table surface are assumed to provide data on the unconfined water table (as opposed to confined aquifers). To qualify as being representative of the surface water table, all monitoring wells were required to be either:

1. a shallow depth (<10 m) in the Eastern/Coastal or Transitional zones, with groundwater levels that are not locally anomalous; or
2. an intermediate depth (from <10 to 35 m) in the Inland Zone, west of Christchurch City where the groundwater is unconfined and Weeber (2008) demonstrated connection between the shallow aquifers.

Any monitoring well records that appeared to be measuring confined groundwater levels, indicating either artesian or sub-artesian pressure, were not included in the dataset used to generate the median water table surface.

In addition to monitoring well data, monitored river level data for the Avon, Heathcote and Styx Rivers (provided by CCC), and river level data for the Waimakariri River (provided by ECan) contributed to the development of the median water table surface. Duration of monitoring data for the rivers varied from 15-minute to 6-hourly intervals. A mean sea level along sections of coastline on the study area's eastern extent was also assumed for the generation of the median water table surface.

Two key resulting contour plots, which appear in the median water table report (van Ballegooy et al., 2013), are presented in this Appendix. The final contour plot of the median water table surface (m RL) is presented in Figure C.1. The contour plot showing the median depth to the water table surface (m bgl) is presented in Figure C.2.

C3. Methodology for calculation of earthquake-specific water table surfaces

The earthquake-specific contours were produced using data from the same sources as used in the median water table surface report (Section C2 above), except only those sources were used which had recorded water table levels immediately prior to the specific earthquake.

The number of applicable monitoring wells with readings prior to each earthquake are summarised in the table below.

Table C1: Monitoring data sources used for earthquake-specific water table surfaces

	04 September 2010	**22 February 2011**	**13 June 2011**	**23 December 2011**
EQC monitoring wells	0	0	211	159
ECan monitoring wells	12	22	22	22
CCC monitoring wells	10	13	22	22
CCC river levels (Avon, Heathcote & Styx Rivers)	14	14	0	0

Note 1: It has been assumed that there is less than minor difference between groundwater levels for July 2011 and June 2011, therefore the water table levels recorded within the EQC monitored wells for July 2011 have assumed to be the likely water table levels just prior to the 13 June 2011 earthquake.

The majority of the first phase of EQC monitoring wells were installed by the end of July 2011, after three of the four main earthquakes had occurred. While this means that by 23 December 2011 there were the most monitoring wells in place (which would theoretically result in the groundwater model with the highest level of confidence), due to the Christmas holiday period only around half of the monitoring wells were measured. As a result the 13 June 2011 groundwater surface has the highest level of confidence followed by the December 2011 surface. The surface with the lowest confidence is the 04 September 2011.

Where groundwater levels were available just prior to a specific earthquake the difference between the monthly groundwater reordering and the known median groundwater level (van Ballegooy et al., 2013) for that particular monitoring well was calculated. These differences were then used to create an earthquake-specific offset surface using Surfer kriging software. The offset contour represents a prediction of how water table levels at a particular month differ from the median groundwater levels (calculated over a 1-year or 2-year period) based on their location within the Christchurch area. Table C1 above provides details on the number of monitoring well points which contribute to each earthquake offset surface.

Once the offset surface was produced it was visually inspected to identify any features which appear as anomalies relative to the other data points due to potential incorrect water table measurements, unusual seasonally high or low readings or other errors in the data. Where anomalies were identified the particular well was inspected and removed from the dataset (if required).

Typically the initial offset plots produced for 13 June 2011 and 23 December 2011 had a good spread of data over the subject area and required little refinement before they could be used to create earthquake-specific water table levels. However the initial offset surfaces produced for 04 September 2010 and 22 February 2011 had a far less intensive spread of data over the subject area requiring further refinement before it could be used to create earthquake specific water table levels.

Therefore, r river level monitoring stations were included to provide some control in the Avon River/CBD area. Using the same approach as for the monitoring wells, the difference between the median water level at a river station and the water level at the river station a day before the earthquake was used in creating the offset plot.

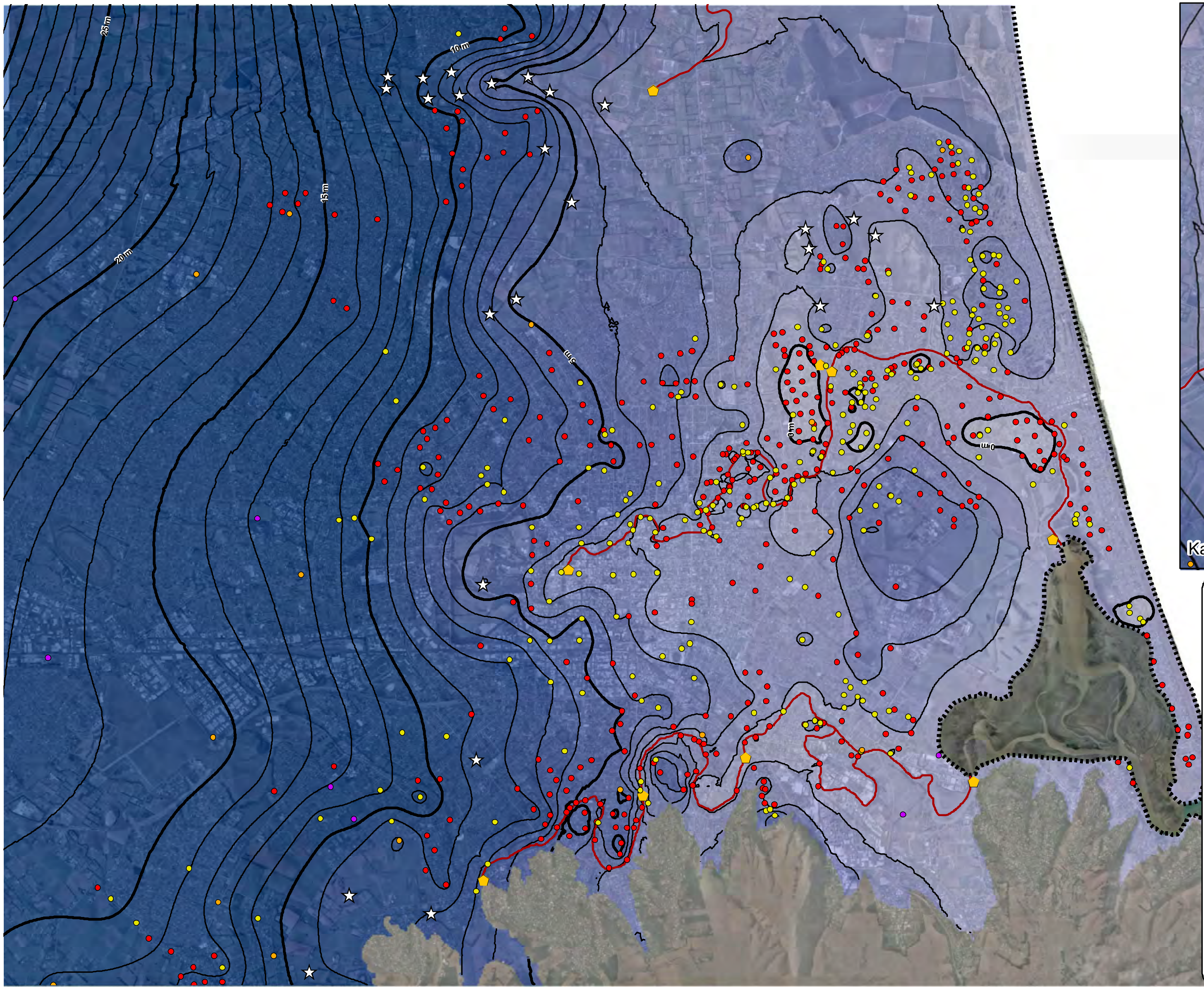
After completing the earthquake-specific offset surface , Surfer's residual function was used to obtain an offset value for the monitoring wells which do not have a water table reading directly prior to the specific earthquake. The offset values were applied to the median water table levels (van Ballegooy et al., 2013) for each monitoring well to obtain an estimate of the earthquake-specific water table levels for well locations where no data was available for that specific earthquake. For further details on using the offset plot method for predicting water table levels reference should be made to van Ballegooy et al., 2013 Section 6.

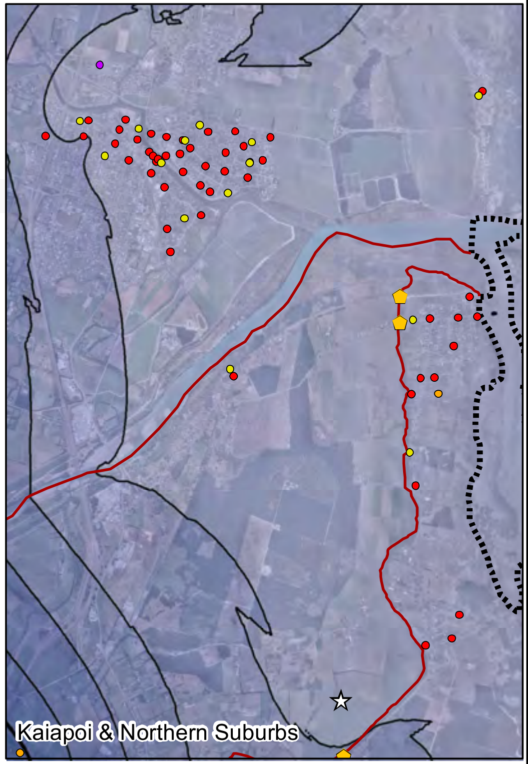
Once the earthquake-specific grid and contours were produced (as a surface in m RL) they were visually inspected to identify discrete points which caused features that did not fit with the overall surface and did not have sufficient data to justify the overall trend. Where necessary, well locations were deleted from the earthquake-specific water table surface if the particular well created features that could not be justified.

In addition, a comparison between the earthquake-specific water table surface and LiDAR survey was undertaken to identify areas where water levels were above ground level. In these areas an individual groundwater drawdown point was added, with a water level set at 100mm below ground level. Up to 23 drawdown points were used in each of the four earthquake-specific surfaces.

The following figures in this Appendix present the earthquake-specific water table surfaces which have been calculated:

- The earthquake-specific contour plots of the water table surface (as a reduce level) for 04 September 2010, 22 February 2011, 13 June 2011 and 23 December 2011 are presented in Figures C3, C5, C7 and C9 respectively.
- The earthquake-specific contour plots showing the depth to the median water table surface (as metres below ground level) for 04 September 2010, 22 February 2011, 13 June 2011 and 23 December 2011 are presented in Figures C4, C6, C8 and C10 respectively.





LEGEND

Monitoring Wells

- EQC Monitoring Well ≥ 9 Months Data
- EQC Monitoring Well < 9 Months Data
- ECan Monitoring Well
- CCC Monitoring Well

Other Analyses Data

- Coastal Strings
- Draw Down Points
- River Strings
- River Monitoring Station

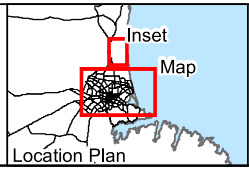
Groundwater Level (m)

< 0	5 - 6
0 - 1	6 - 7
1 - 2	7 - 8
2 - 3	8 - 9
3 - 4	9 - 10
4 - 5	> 10
No Data	

Notes: Aerial Imagery supplied by New Zealand Aerial Mapping ltd.

A3 SCALE 1:60,000

0 1 2 3 4 (km)



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APPROVED		

ARCFILE 52020-0200-GWM58

SCALE (AT A3 SIZE) 1:60,000

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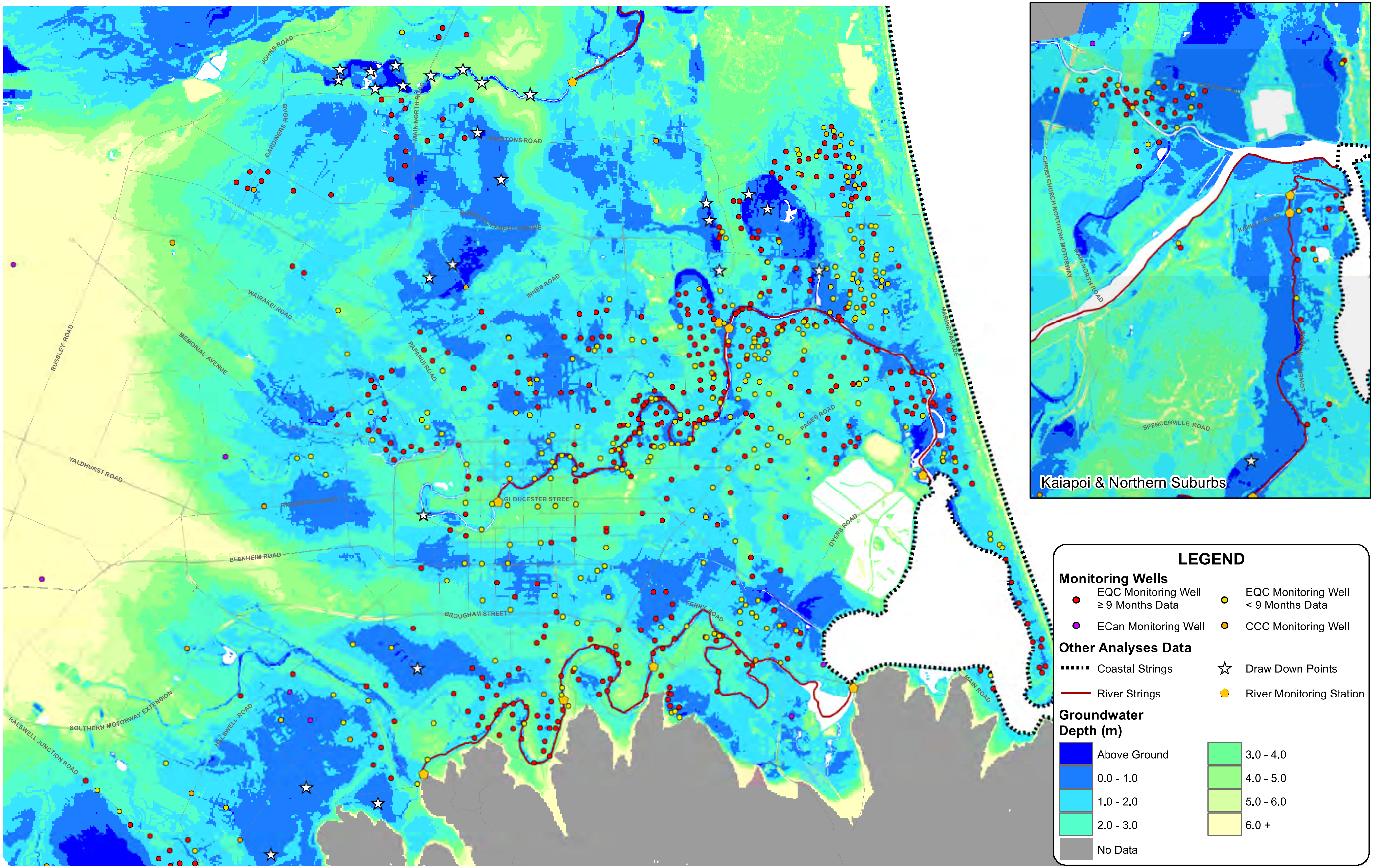
EARTHQUAKE COMMISSION
CHRISTCHURCH CITY & KAIAPOI
Groundwater Level Median Model (Lyttleton Vertical Datum 1937)

FIGURE No. Figure C1

Rev.

Date: 26/02/2013 Time: 4:40:51 p.m.



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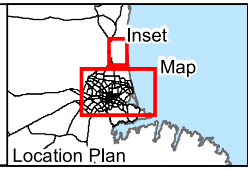
A3 SCALE 1:60,000

0 1 2 3 4 (km)

N



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ARCFILE 52020-0200-GWM57

SCALE (AT A3 SIZE) 1:60,000

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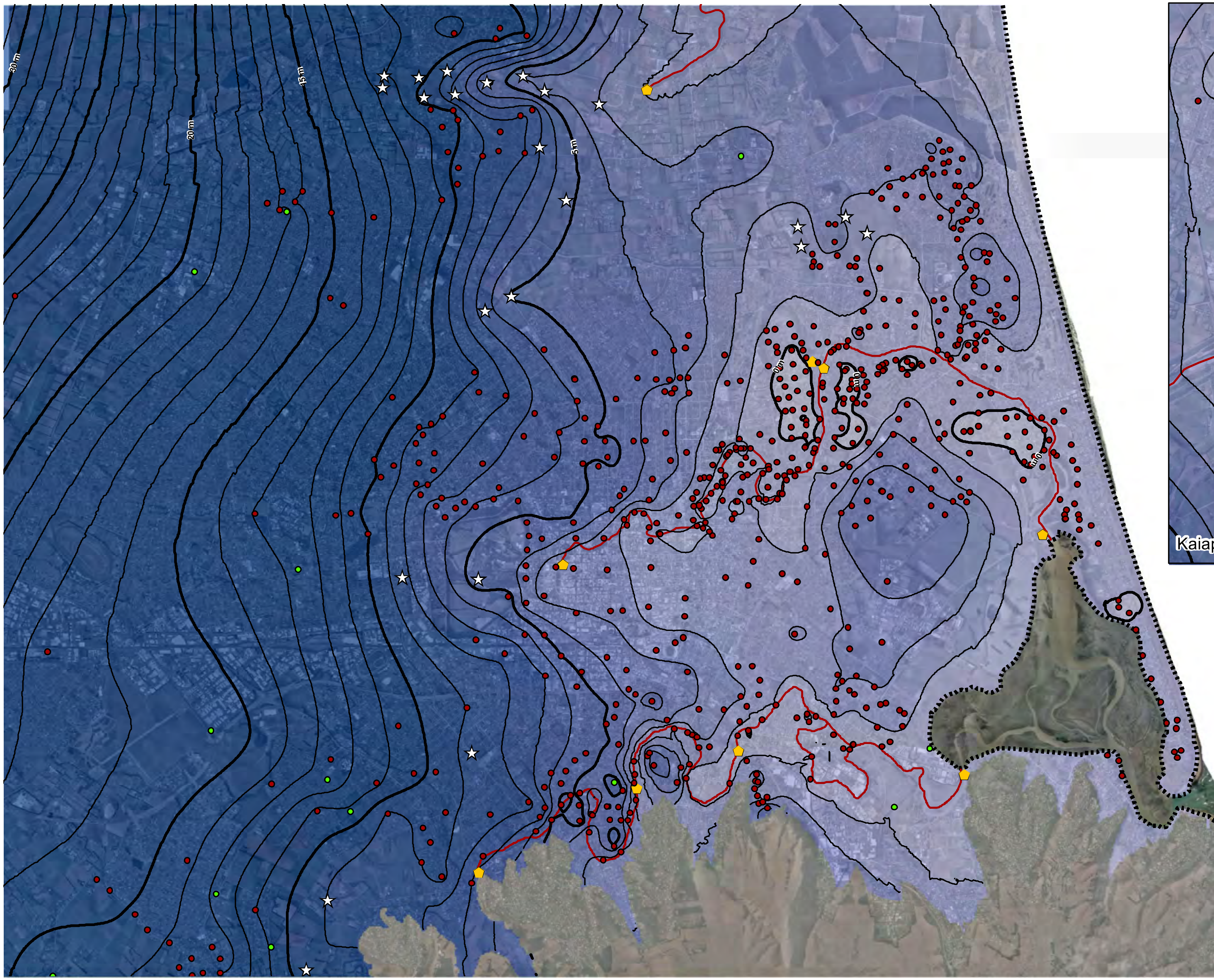
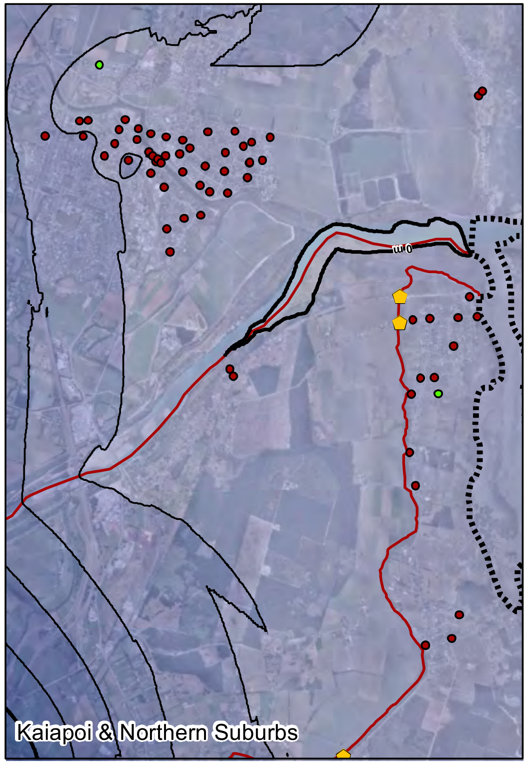
CHRISTCHURCH & KAIAPOI
Depth to Groundwater 25m Grid (Post Dec 2011 Median Model)

FIGURE No. Figure C2

Rev.

Date: 26/02/2013 Time: 4:44:14 p.m.





LEGEND

Monitoring Wells

- Measurement in September 2010
- No Measurement in September 2010

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Level (m)

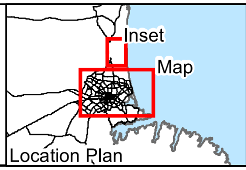
- < 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- > 10
- No Data

Notes: Aerial Imagery supplied by New Zealand Aerial Mapping ltd.

A3 SCALE 1:60,000

0 1 2 3 4 (km)

N



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ARCFILE 52020-0200-GWM10

SCALE (AT A3 SIZE) 1:60,000

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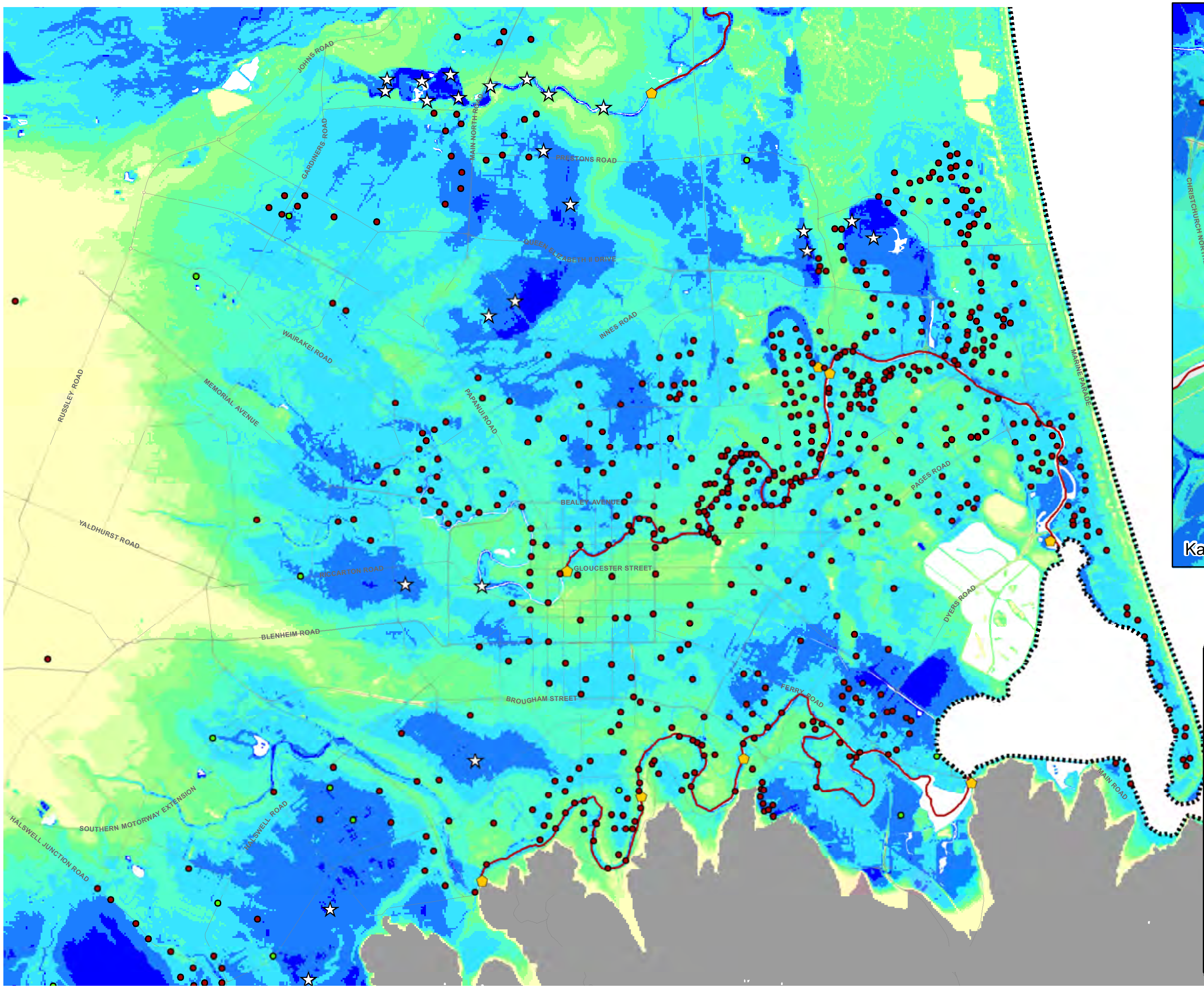
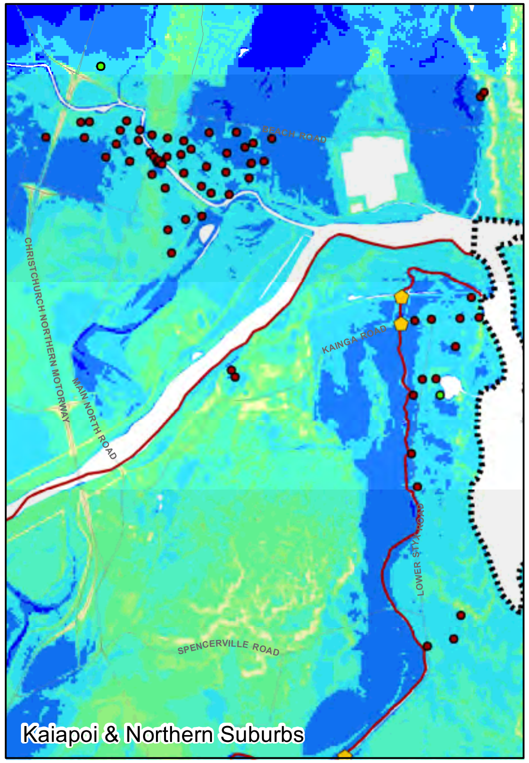
CHRISTCHURCH CITY & KAIAPOI
Groundwater Levels and Monitoring Well Locations September 2010 (Lyttleton Vertical Datum 1937)

FIGURE No. Figure C3

Rev.

Date: 26/02/2013 Time: 4:37:47 p.m.





LEGEND

Monitoring Wells

- Measurement in September 2010
- No Measurement in September 2010

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Depth (m)

- Above Ground
- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 +
- No Data

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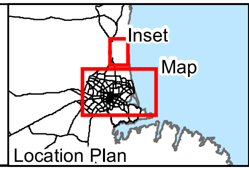
A3 SCALE 1:60,000

0 1 2 3 4 (km)



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SCALE (AT A3 SIZE) 1:60,000		
PROJECT No. 52020-0200		

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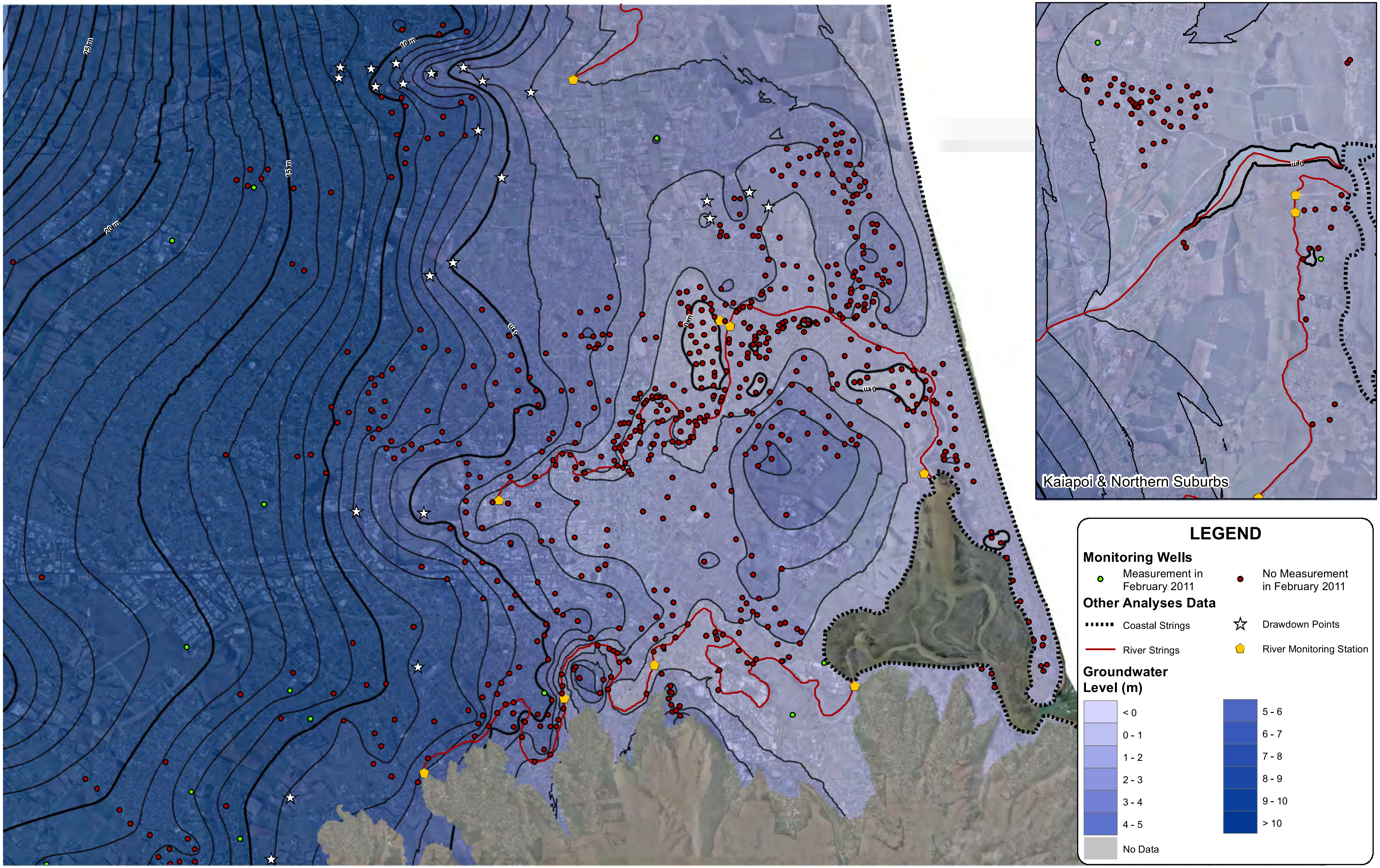
CHRISTCHURCH CITY & KAIAPOI
Depth to Groundwater 25m Grid (September 2010)

FIGURE No. Figure C4

Rev.

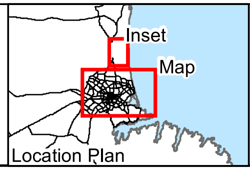
Date: 26/02/2013 Time: 4:34:53 p.m.



Notes: Aerial Imagery supplied by New Zealand Aerial Mapping ltd.

A3 SCALE 1:60,000

0 1 2 3 4 (km)



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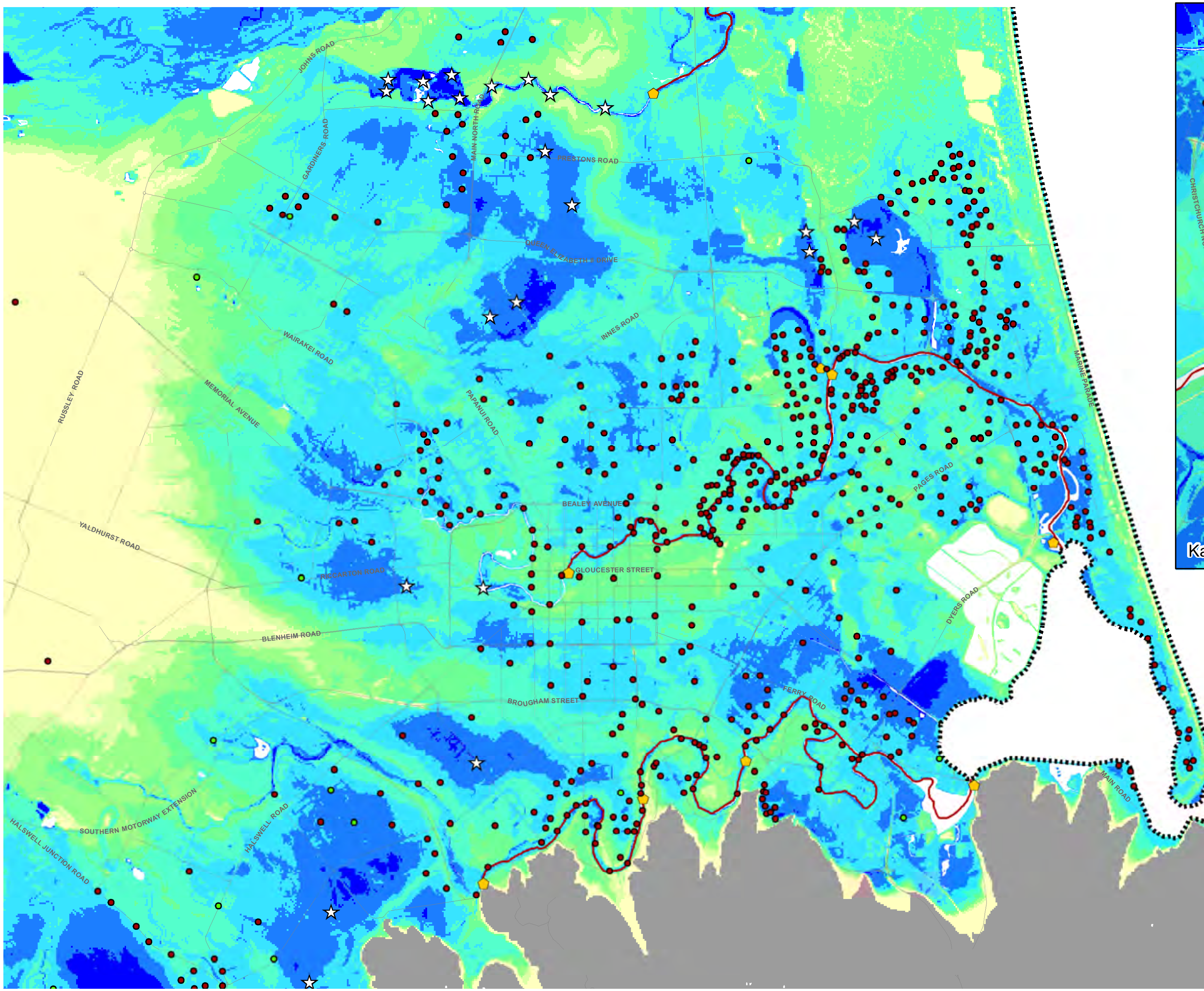
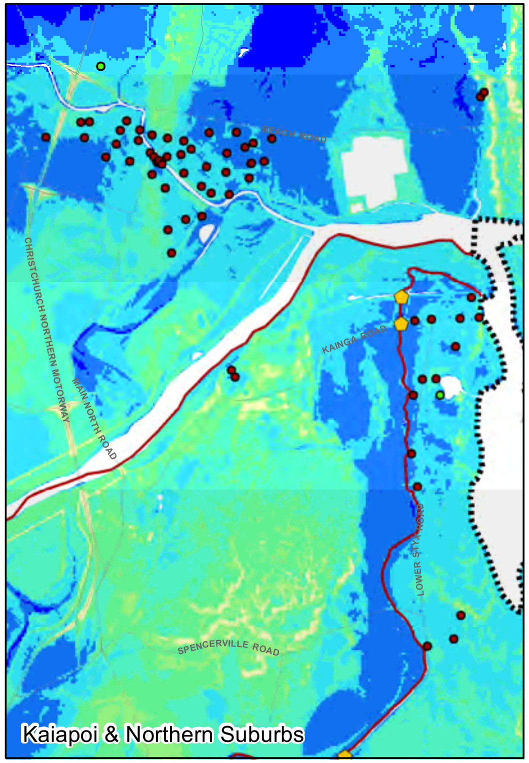
Groundwater Levels and Monitoring Well Locations February 2011 (Lyttleton Vertical Datum 1937)

FIGURE No. Figure C5

Rev.

Date: 26/02/2013 Time: 4:38:00 p.m.





LEGEND

Monitoring Wells

- Measurement in February 2011
- No Measurement in February 2011

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Depth (m)

- Above Ground
- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 +
- No Data

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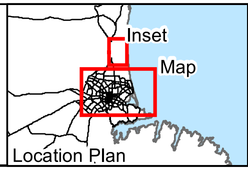
A3 SCALE 1:60,000

0 1 2 3 4 (km)



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PROJECT No.	52020-0200	

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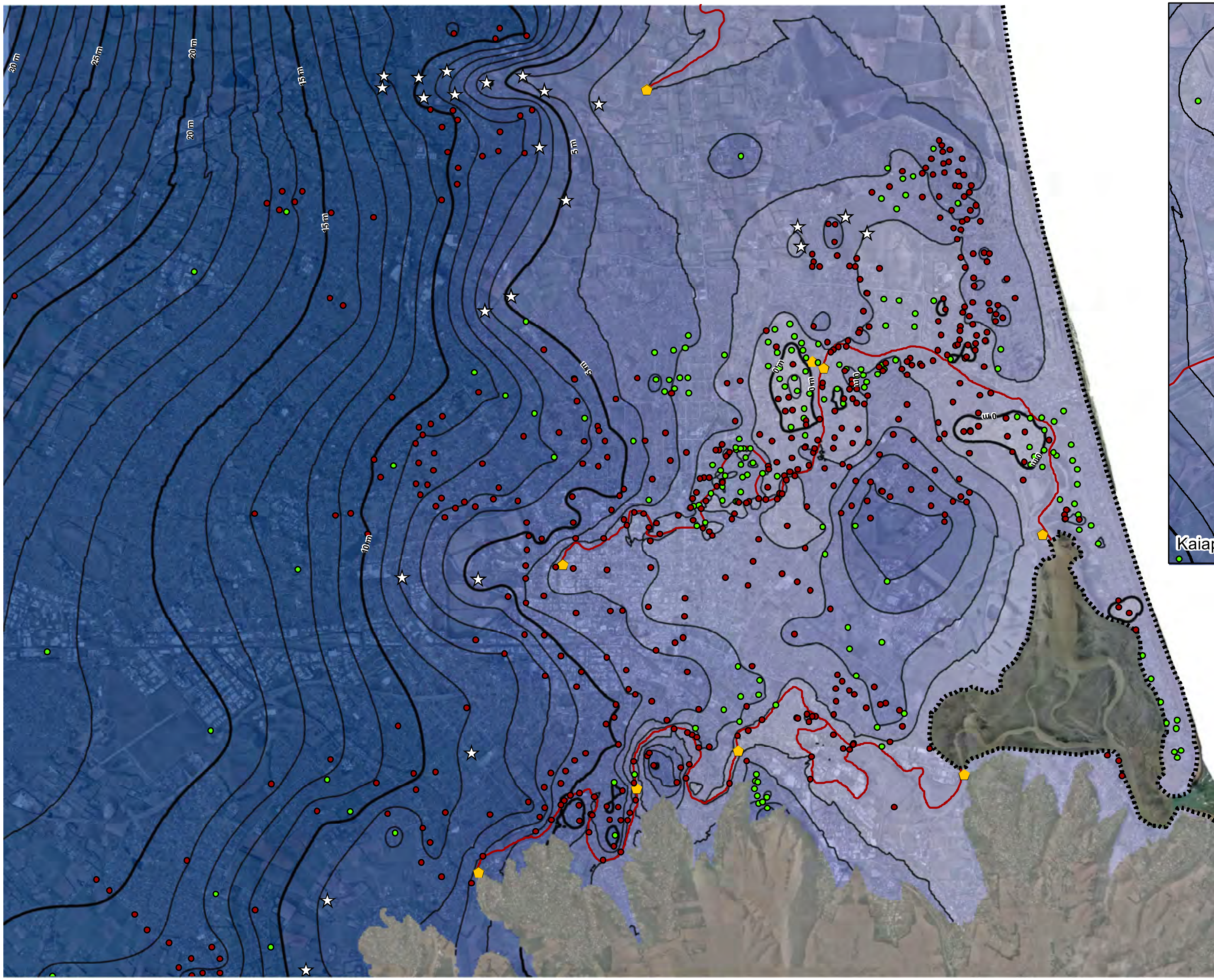
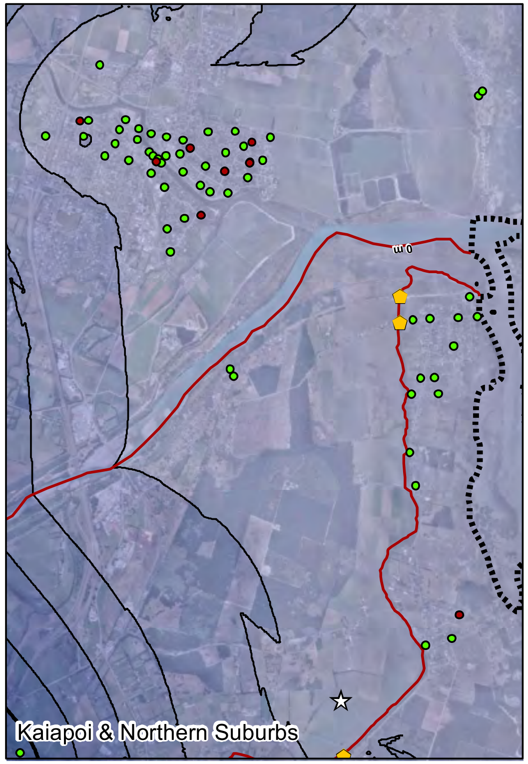
CHRISTCHURCH CITY & KAIAPOI
Depth to Groundwater 25m Grid (February 2011)

FIGURE No. Figure C6

Rev.

Date: 26/02/2013 Time: 4:35:52 p.m.





LEGEND

Monitoring Wells

- Measurement in June 2011
- No Measurement in June 2011

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Level (m)

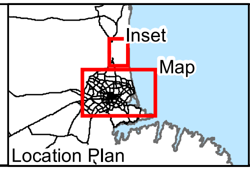
< 0	5 - 6
0 - 1	6 - 7
1 - 2	7 - 8
2 - 3	8 - 9
3 - 4	9 - 10
4 - 5	> 10
No Data	

Notes: Aerial Imagery supplied by New Zealand Aerial Mapping ltd.

A3 SCALE 1:60,000

0 1 2 3 4 (km)

N



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SCALE (AT A3 SIZE) 1:60,000		
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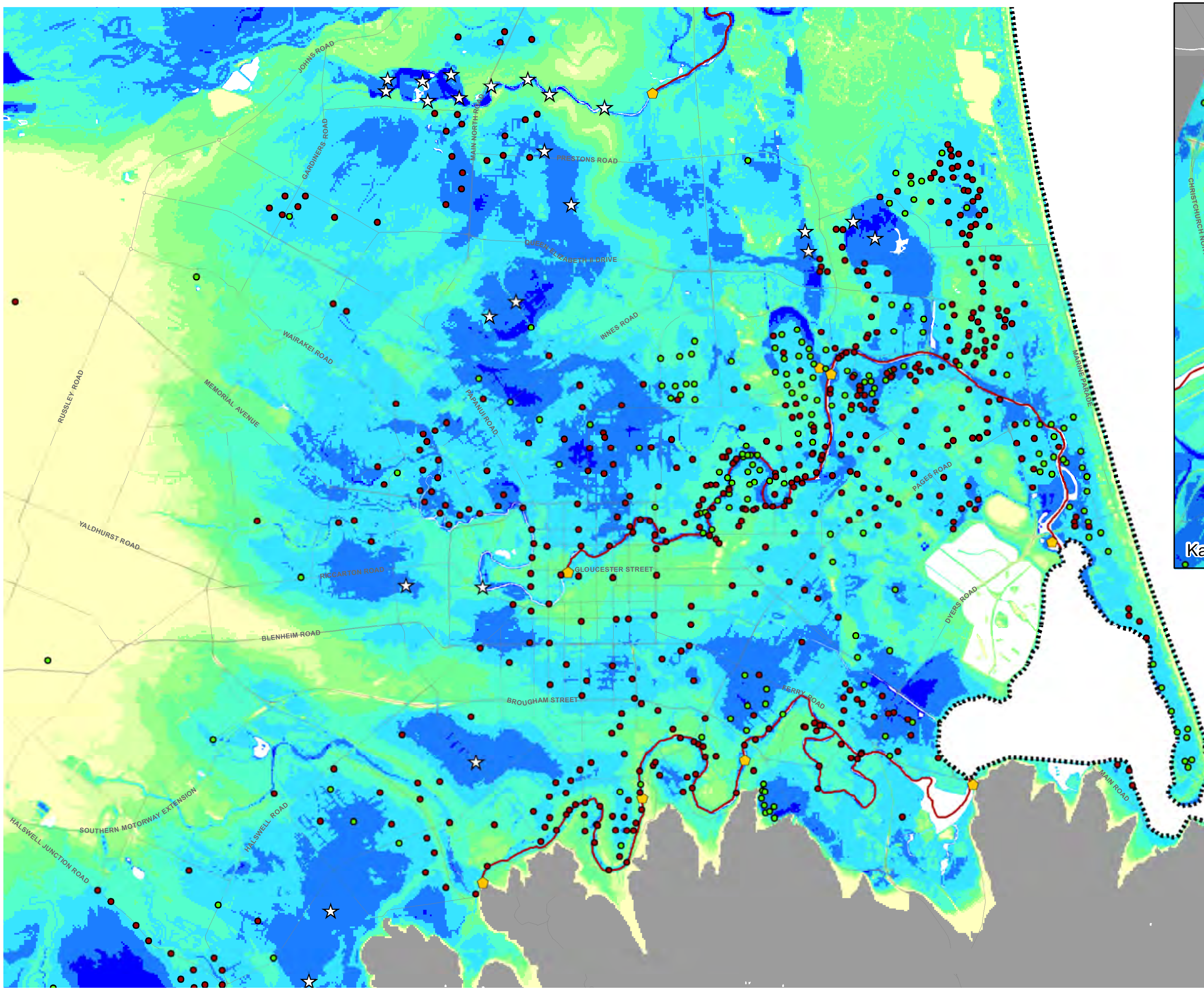
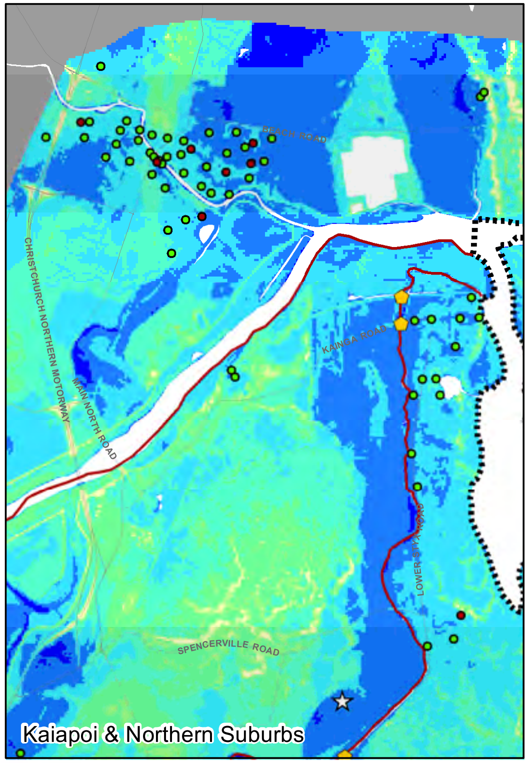
Groundwater Levels and Monitoring Well Locations June 2011 (Lyttleton Vertical Datum 1937)

FIGURE No. Figure C7

Rev.

Date: 26/02/2013 Time: 4:39:20 p.m.





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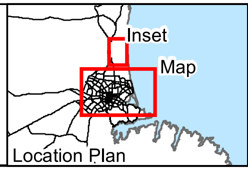
A3 SCALE 1:60,000

0 1 2 3 4 (km)



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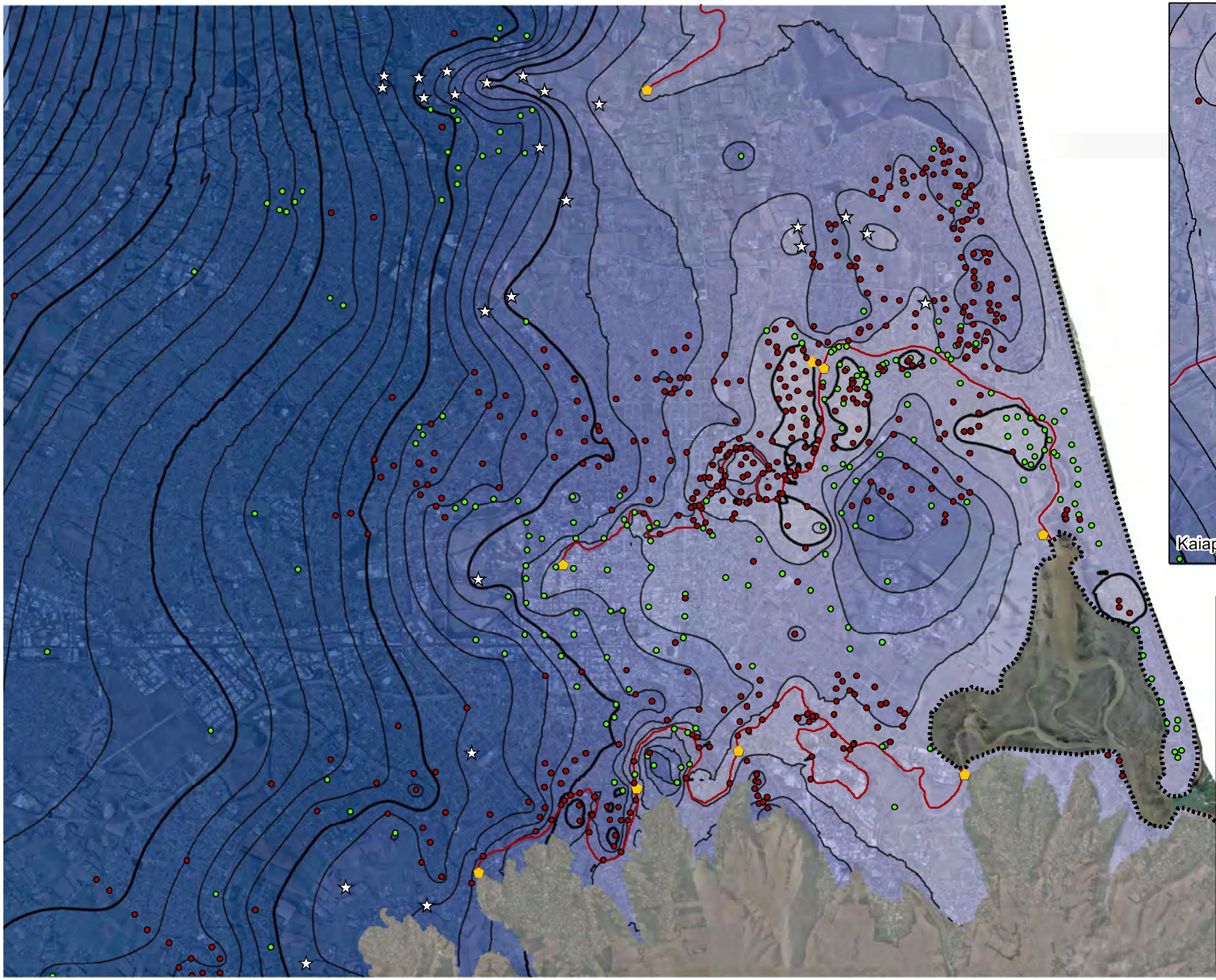
ARCFILE 52020-0200-GWM09		
SCALE (AT A3 SIZE) 1:60,000		
PROJECT No. 52020-0200		

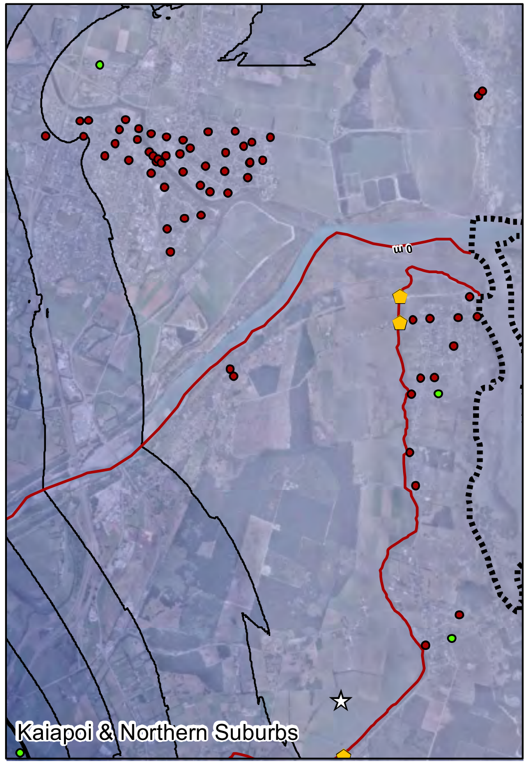
EARTHQUAKE COMMISSION
CHRISTCHURCH CITY & KAIAPOI
Depth to Groundwater 25m Grid
(June 2011)

FIGURE No. Figure C8

Rev.

Date: 26/02/2013 Time: 4:36:55 p.m.





LEGEND

Monitoring Wells

- Measurement in December 2011
- No Measurement in December 2011

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Level (m)

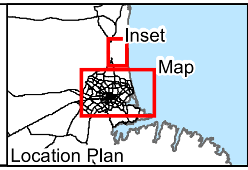
< 0	5 - 6
0 - 1	6 - 7
1 - 2	7 - 8
2 - 3	8 - 9
3 - 4	9 - 10
4 - 5	> 10
No Data	

Notes: Aerial Imagery supplied by New Zealand Aerial Mapping ltd.

A3 SCALE 1:60,000

0 1 2 3 4 (km)

N



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ARCFILE 52020-0200-GWM13		
SCALE (AT A3 SIZE) 1:60,000		
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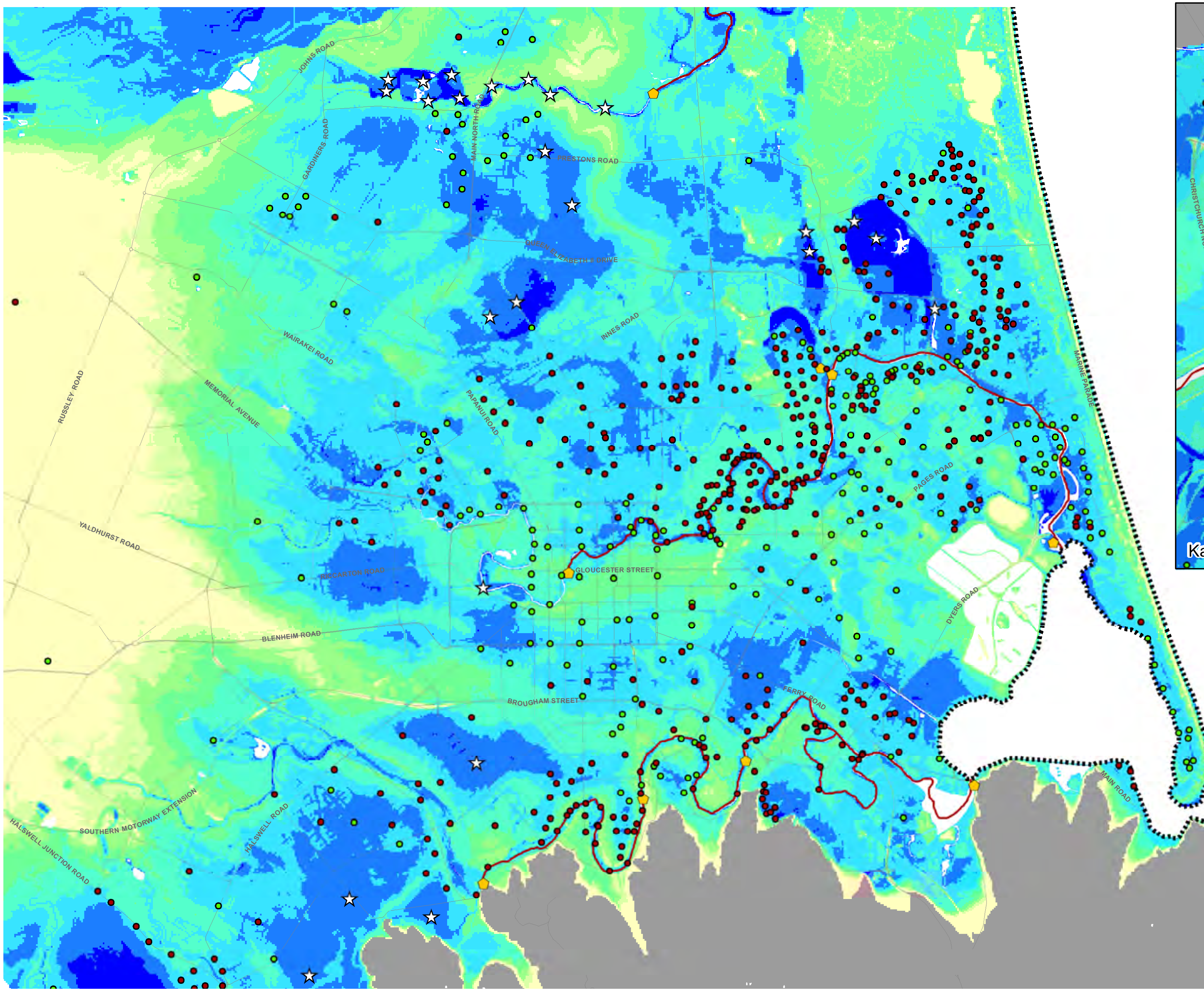
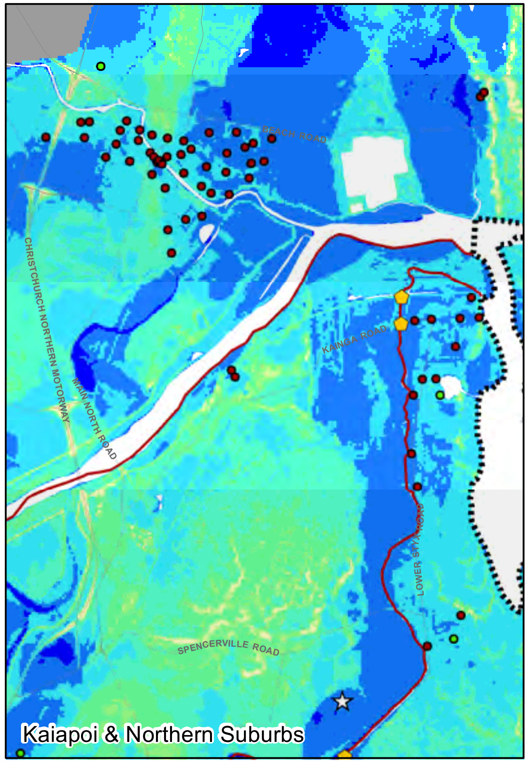
CHRISTCHURCH CITY & KAIAPOI
Groundwater Levels and Monitoring Well Locations December 2011 (Lyttleton Vertical Datum 1937)

FIGURE No. Figure C9

Rev.

Date: 26/02/2013 Time: 4:39:50 p.m.





LEGEND

Monitoring Wells

- Measurement in December 2011
- No Measurement in December 2011

Other Analyses Data

- Coastal Strings
- Drawdown Points
- River Strings
- River Monitoring Station

Groundwater Depth (m)

- Above Ground
- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 +
- No Data

Date: 26/02/2013 Time: 4:40:07 p.m.

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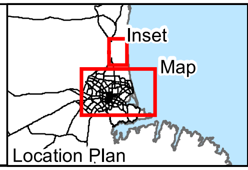
A3 SCALE 1:60,000

0 1 2 3 4 (km)

N



EQC
EARTHQUAKE COMMISSION
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DRAWN	JEL	Feb.13
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APPROVED		

ARCFILE 52020-0200-GWM14

SCALE (AT A3 SIZE) 1:60,000

PROJECT No. 52020-0200

EARTHQUAKE COMMISSION
CHRISTCHURCH CITY & KAIAPOI
Depth to Groundwater 25m Grid (December 2011)

FIGURE No. Figure C10

Rev.