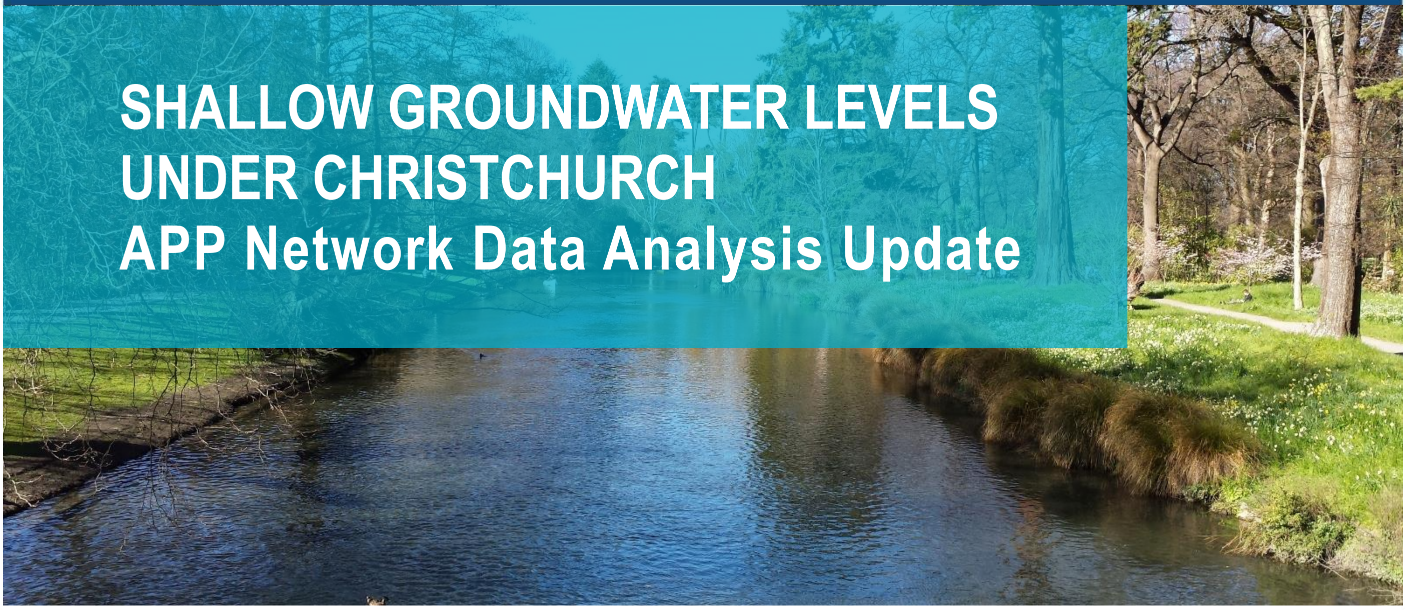
Groundwater REPORT

SHALLOW GROUNDWATER LEVELS UNDER CHRISTCHURCH
APP Network Data Analysis Update



PREPARED FOR
Christchurch City Council

WL23047

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This APP Network Data Analysis Update is intended to help Council understand the approximate locations where high groundwater levels may occur at times. The findings presented herein are a high-level assessment based on the available data and methodologies as of the date of publication, including a coarse prediction of groundwater levels under a projected future sea level scenario.

The purpose of this study is not to accurately define the shallow groundwater hazard at a local scale (there is insufficient data to do this), but rather to provide a high-level assessment at the city-wide scale. Variability and precision of the available land surface levels and local-scale hydrogeological conditions influence the reliability of the presented findings. Future changes in land use and drainage patterns, and unforeseen events will also influence the depth and frequency of occurrence of shallow groundwater levels. Consequently, the predictions at any specific location should therefore be treated as approximate and it is important to acknowledge the inherent uncertainties and associated limitations. The study findings do not reflect current or future Council policy, but are used to provide a guide to areas that are most likely to be affected by shallow groundwater.

The information on groundwater levels is general and applies to broad areas, not to a specific property. Any person acquiring a property must verify the groundwater conditions applicable to that property by conducting site specific investigations and verification. Christchurch City Council and Aqualinc Research Limited accept no responsibility or liability for any reliance placed on the general information or for any error, deficiency or omission in the information provided to users. Any person using this information does so at their own risk.

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1 INTRODUCTION AND BACKGROUND

Following the Christchurch earthquake sequence, a network of piezometers was installed across Christchurch to monitor shallow groundwater levels. This is referred to as the Automated Piezometer Programme (APP) network. Over the period 2011-2016, monthly groundwater level measurements were manually collected from these piezometers. Given the large number of piezometers (~800), measurements could not all be collected within a short timeframe (e.g. over a day or two), meaning externalities (such as rainfall or infrastructure works) across the collection periods impacted the relationship between data points.

From 2016 Aqualinc Research Ltd (Aqualinc) undertook analysis of this data as part of CCC's LDRP45 programme, and this is documented in Rutter (2020)[1]. This study derived site-specific statistics for each piezometer, but the analysis showed that there was little spatial correlation between sites, and confidence in any subsequent calculated groundwater level surface declined rapidly with distance from measurement points.

In 2017, 247 piezometers were fitted with data loggers, logging temperature and groundwater levels at 10-15 minute intervals. This is referred to as the Automated Piezometer Programme (APP) network. Ownership of the APP network was passed to Christchurch City Council (CCC) from EQC in 2019.

Many of the piezometers were existing Earthquake Commission (EQC) sites, but others were newly installed piezometers, some installed in areas that previously had no monitoring. This resulted in a significant data set that is valuable for understanding the dynamics and rapid responses of shallow groundwater levels to rainfall and other drivers. The automated logging also addressed the issue with the earlier data regarding the long length of time taken to collect measurements during each monitoring round. The data sets now extend for an additional six years from the start of automated logging, during which time some extreme rainfall events have occurred (for example July 2017, February 2018, May 2021 and July 2022) as well as the very dry periods over the summers of 2015/16 and 2016/17. These events have the potential to change the statistics that were derived for the LDRP45 project. The additional piezometers in areas where there was no previous monitoring may also change the surface that is derived. Therefore, this work aims to assess whether or not the new high-resolution data has changed the statistics, and whether or not the additional monitoring points adequately fills gaps for areas with no previous monitoring.

CCC asked Aqualinc to undertake further data analysis to support the preparation of notices to be placed on Land Information Memoranda (LIMs) across the city that identify potential risk from shallow groundwater. Such notices may take the form "*Groundwater levels in your area may be periodically less than 350 mm below ground level. See XXX report for further information*". In areas with an additional risk of sea level rise (SLR), the LIM comments could be "*Groundwater levels in your area may be periodically less than 350 mm below ground level. Future sea level rise may further raise groundwater levels in your area. See XXX report for further information*".

The analysis update has the dual benefit of identifying opportunities to rationalise the monitoring network, an outcome sought by CCC.

Newly collected temporal high-resolution data has been analysed to determine how this additional data alters the findings compared to the original (2020) study for informing city-wide risk management for shallow groundwater. The new data has been used to generate a "depth to groundwater" surface which is compared against the equivalent generated for the LDRP45 project. Areas of significant differences are highlighted. This report documents this work.

[1] Rutter (2020): *LDRP45: Impacts of Earthquakes and Sea Level Rise on Shallow Groundwater Levels.* Aqualinc Report C17054. Prepared for Christchurch City Council. 14 August 2020.

2 DATA OVERVIEW AND PROCESSING

There are four groups of groundwater level data that have been considered as part of this study:

1. Long term data collected manually by both CCC and Environment Canterbury (ECan) at fortnightly or monthly intervals comprising:
   - 55 bores regularly monitored; and
   - A further 23 bores monitored by CCC as part of their Eastman Te Kura site study (with data available from 2016 to present).
2. Old data from 782 bores collected manually by EQC at monthly intervals from 2011/12 to late 2016;
3. New data collected from 160 original EQC bores instrumented with transducers that record data automatically from late 2016 to present (these bores have both manual data prior to late 2016 and new high-resolution data thereafter); and
4. New data collected from 84 new monitoring bores with transducers that record high-resolution data automatically from late 2016 to present (these have no manual data prior to 2016).

The locations of these bores are shown in Figure 1. There are some overlaps between the above datasets.

The focus of this this updated analysis is on the influence of the new high-resolution data on the interpolated surface. Therefore, where this new high-resolution data does not exist, the same original data has been re-used in generating both the pre- and post-2016 surfaces (unchanged). In this way, any differences between pre- and post-2016 surfaces are due largely to the use of the newer high-resolution data and not heavily influenced by differing spatial coverages of data sets (except where new bores have been installed or old bores have been removed).

The measured data does not adequately cover the entire study area. However, shallow groundwater is hydraulically connected to the coast, the estuary and the rivers. Therefore, these surface water boundaries are additional fixed levels (as derived by Rutter, 2020) to further control groundwater levels. The locations of these boundary controls are also shown in Figure 1.

A key focus of the Rutter (2020) study was on the occurrence of high groundwater levels. This was defined as the 85th (high) percentile groundwater levels (i.e. the 15th percentile value of depth-below-ground measurements), with a 0.35 m depth assigned as the criteria above which it becomes potentially problematic (i.e. for considering risk). For consistency, these same statistics have been the key focus of the updated study discussed herein.

As part of their wider water management strategy, CCC are engaging with other consultants to develop surface water flood models for specific catchments around the city. These flood models require surfaces of depth to shallow groundwater with which to calibrate the models. The models span areas beyond the study area previously considered by Rutter (2020) and therefore the study area of the updated analysis has been enlarged, as is indicated in Figure 1. Furthermore, the flood models require groundwater surfaces (of depths to shallow groundwater) for specific dates. Therefore, surfaces for specific dates (discussed later) have been derived along with the 85th (high) percentile surface.

As the study area is now larger, the pre-2016 surface has been regenerated. Due to differing interpolation settings and the enlarged study area, this surface is different to the equivalent surface presented in Rutter (2016). For specifying notices on LIMs, the outputs from this more recent study should be used in preference to the older study.

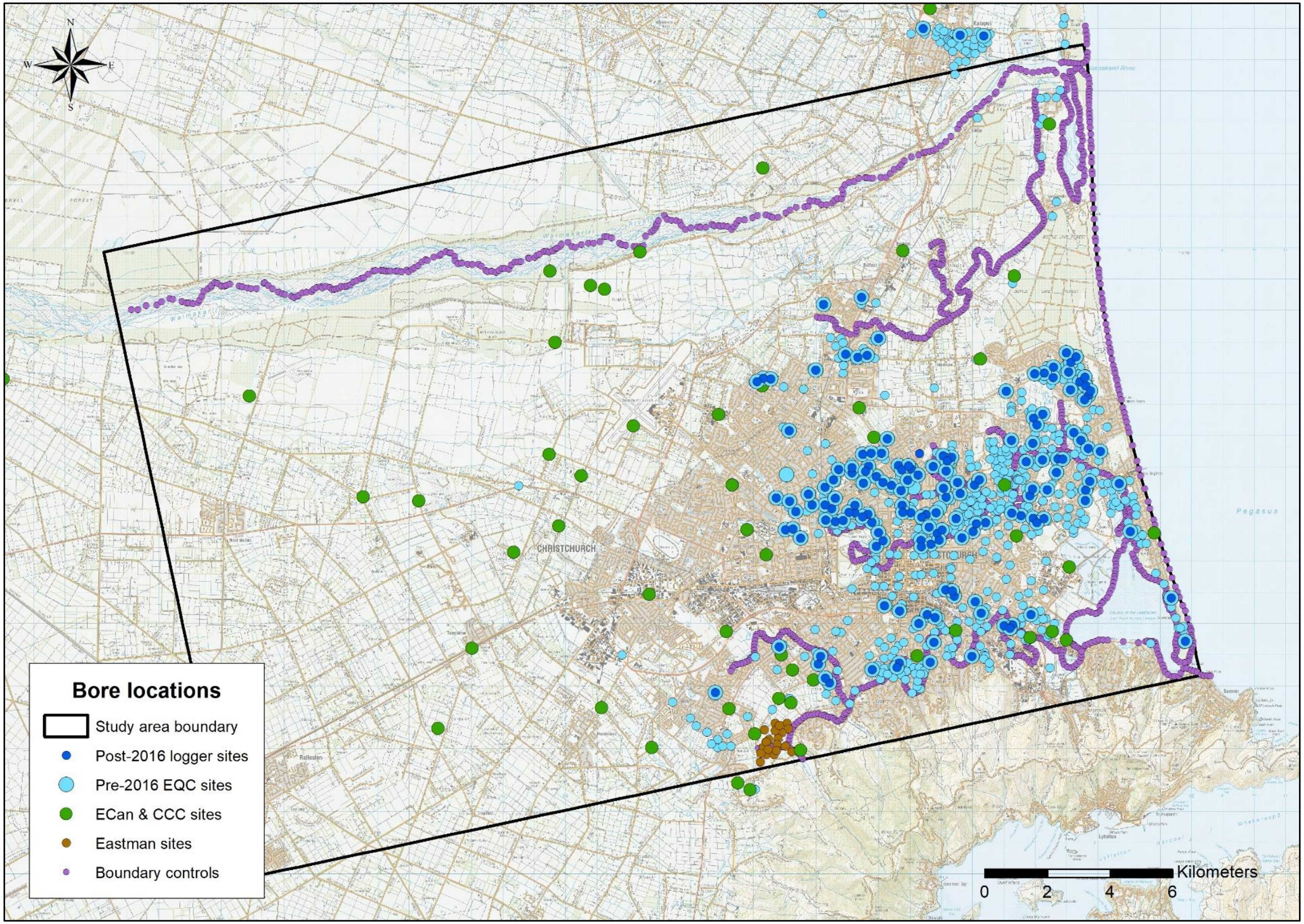


Figure 1: Locations from which data has been collated for analysis

2.1 Data Processing and Analysis

The first task of the study was to compare groundwater records collected pre- and post-2016 for the 160 bores where data sets span both periods. Then, the 85th percentile groundwater levels were derived separately from each period to use in generation of surfaces of depth to shallow groundwater. These surfaces were then compared. Finally, the 1.0 m sea level rise prediction presented by Rutter (2020) were added to the newly-generated surfaces to provide an indication of the future risk from shallow groundwater under future se level rise. A brief discussion is also provided on the surfaces generated for specific dates to inform flood modelling. These are each discussed below.

2.1.1 Comparison of Pre- and Post-2016 Data

Data from APP bores that contain both pre- and post-2016 records were processed as follows:

1. Combining the data

   Over the years, the APP records have been collected by multiple parties, and each party has used different formats for storing and referencing the data. Therefore, the first step in processing the data was to align and combine all records for each site. Initially, the different records of each bore were combined as much as possible by using the bore reference numbers (there are multiple names for each bore) and/or the instrument number. Where this was not successful, datasets were combined based on location with a 10 m distance threshold (to allow for small changes in logged location). Where this was uncertain, the locations were manually checked on site (there were only a few sites matched in this way).

2. Generating summary statistics

   Summary statistics for pre-2016 and post-2016 data sets were generated separately. Statistics included median, mean, standard deviation, minimum, maximum, 15th percentile, 50th percentile, and 85th percentile. The 15th percentile depth to groundwater statistic (equivalent to the 85%ile high groundwater level) has been used in subsequent analyses.

Examples from three APP bores are shown in Figure 2. Here, one bore shows a noticeable rise in groundwater levels post-2016, one bore shows little change, and one shows a noticeable reduction. Appendix A lists the change (between pre- and post-2016 data sets) in the 85%ile (high) statistics for each bore. Table 1 summarises the changes in bores which are mapped in Figure 3.

Table 1: Count of changes in 85th percentile depths to groundwater level pre- and post-2016

Change (m)	Count of bores
< -0.1 m (lowered)	31
-0.1 - +0.1 (balanced)	83
> 0.1 m (raised)	101

From Table 1 and Figure 3, the majority of the bores show a rise in the 85th percentile high groundwater level statistic. As shown in Figure 4, it was unusually wet over 2017, 2018 and 2022 (with several high-intensity rainfall events), and this has resulted in higher-than-expected groundwater levels over much of Christchurch. Therefore, groundwater rises are largely due to the wet climate (over the past few years). Bores that show a decline are primarily located west of Christchurch city (further out on the plains)

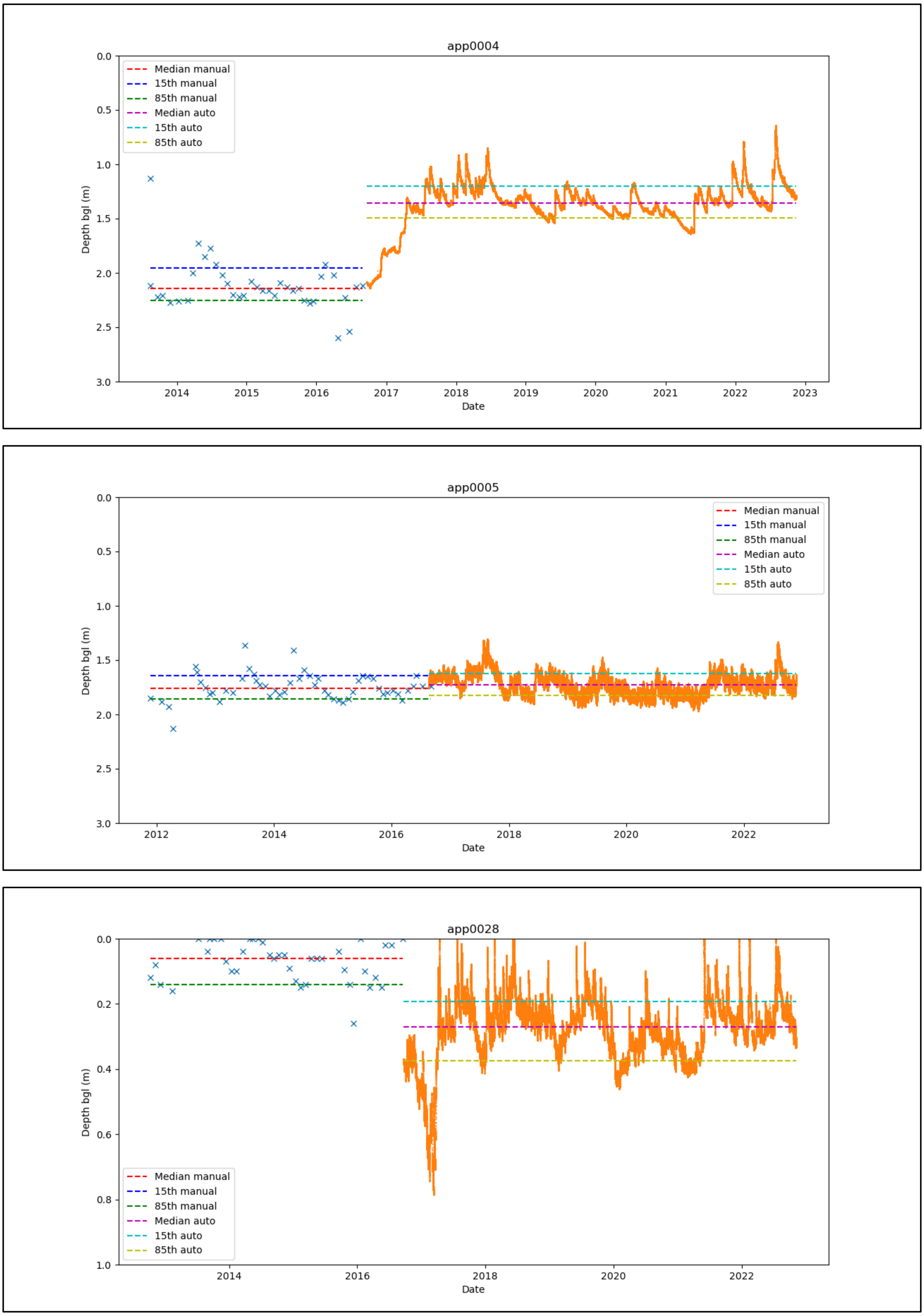


Figure 2: Example APP time series data

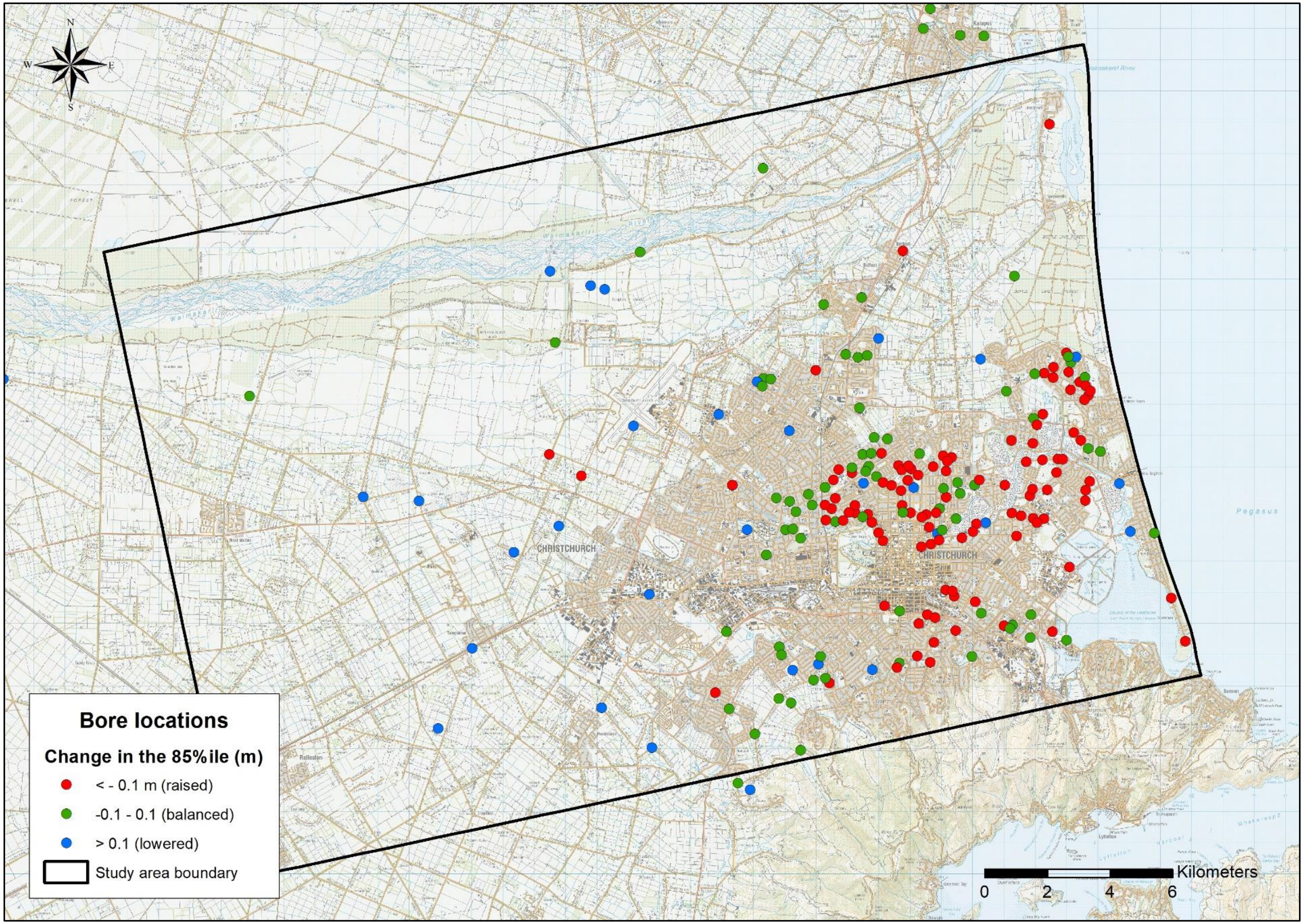


Figure 3: Change in the 85th percentile groundwater level pre- to post-2016

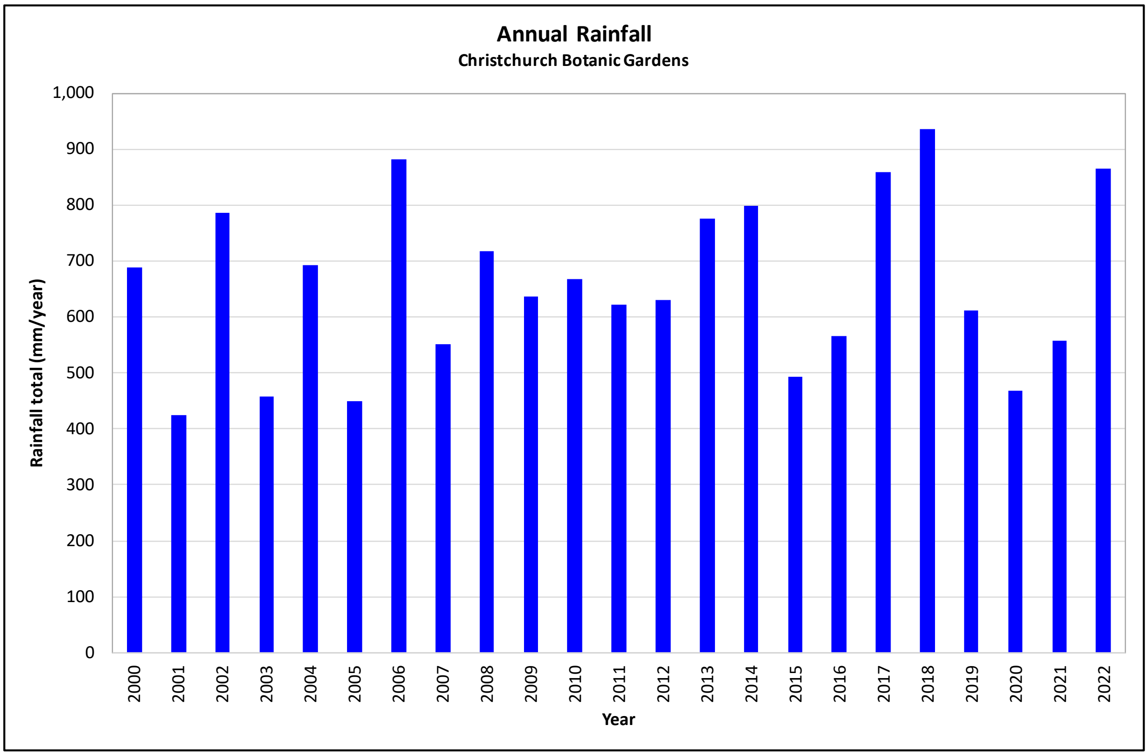


Figure 4: Annual rainfall total for Christchurch Botanic Gardens: 2000-2022

2.1.2 Shallow Groundwater Level Surfaces

Surfaces of shallow groundwater levels have been generated using the full suite of data available (as discussed in Section 2) for both pre- and post-2016 periods (separately). To generate the depth-to-groundwater surfaces, the measured data was first converted to elevation above sea level (using each bore's measuring point datum). This was important as the ground surface can be highly variable within short distances (resulting in sharp differences in depth to groundwater), whereas groundwater levels (above mean sea level) are spatially smoother. Therefore, interpolating groundwater level elevations (rather than depth to groundwater) provides a better interpolation between measurement locations. The depth-to-groundwater level surfaces have therefore been derived using the following work flow:

1. The depth-to-groundwater statistic (or for specific dates) for each bore was extracted from the measured data.
2. This depth was then converted to an elevation above sea level using each bore's measuring point datum.
3. These groundwater level elevations were then interpolated using a natural-neighbour interpolation method in the software package GMS (2023)[2]. Multiple interpolation methods were trialled (including linear, inverse-distance-weighted, natural-neighbour and kriging) and it was found that natural-neighbour provided the smoothest interpolation (without unreal artefacts) while still matching the measured data.
4. This surface was then subtracted from a 4 m gridded digital elevation model (DEM) of the land surface (supplied by ECan) to calculate a surface of depth to groundwater.

Maps of depths to shallow groundwater are presented in Appendix B, and digital versions of these surfaces have been supplied separately to CCC. At the scale of the maps in Appendix B, it is difficult to see differences between pre- and post-2016 datasets, and particularly whether there are changes to the 0.35 m depth to groundwater limit that was used for the previous study. The changes between old and new surfaces are

[2] GMS (2023): *Groundwater Modelling System (version 10.7.5).* Software developed and supported by Aquaveo LLC, USA.

positive: that is, the new data has expanded (slightly) the areas that exceed the 0.35 m depth to water trigger, and no areas have dropped out of the areas considered to be at risk from shallow groundwater.

Figure 5 presents histograms of 85th percentile (upper 15th percentile) groundwater levels for both the older manual data and the newer automatic data, demonstrating an overall rise in shallow groundwater levels. This rise is also clear from the cumulative probability function in the right plot which shows that the incidence of very shallow water levels has increased slightly.

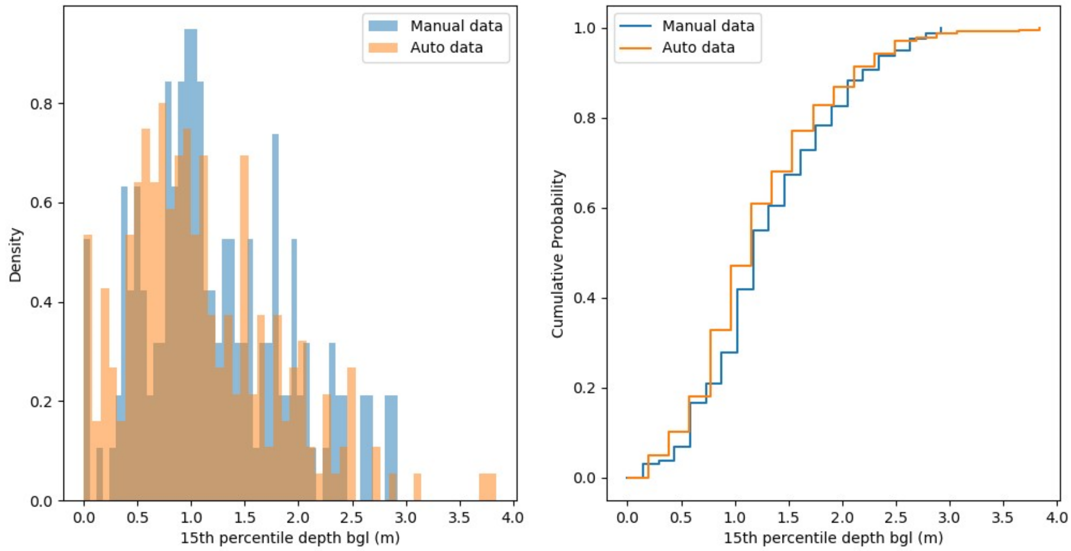


Figure 5: Histograms (left plot) and cumulative probability distribution (right plot) of shallow groundwater levels

It is also interesting to look at the differences between the manual and automatic data for wells where this data exists. Figure 6 shows histograms of the differences of the medians (left plot) and 85th percentiles (upper 15th percentile) (right plot) groundwater levels. Positive values indicate an increase in the water level while negative values indicate a decrease in water level. In both cases the mean change is greater than zero, indicating that (on average) water levels have risen slightly.

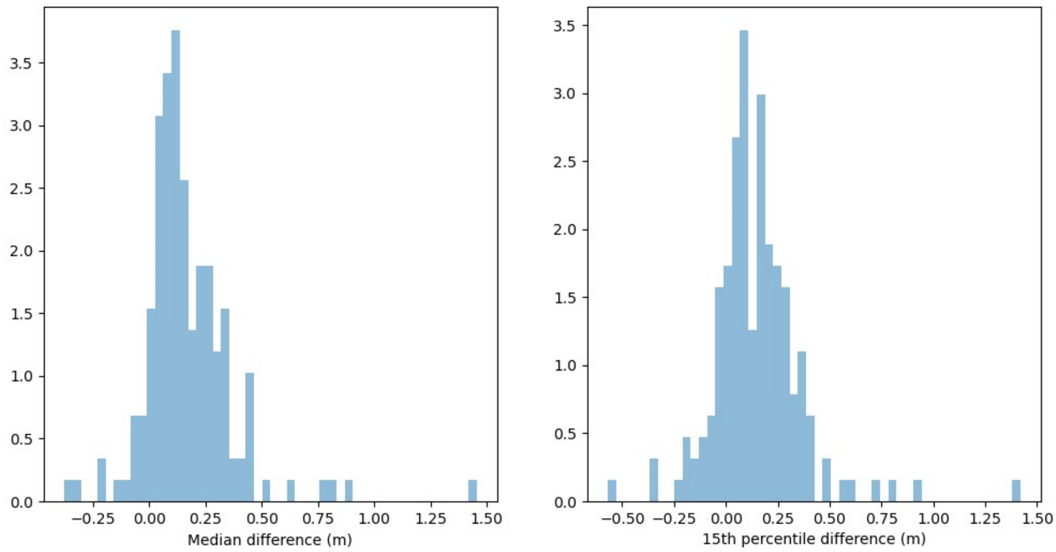


Figure 6: Histograms of differences in shallow 85th percentile (upper 15th percentile) (left plot) and median (right plot) groundwater levels between older manual data and newer automatic data
(a positive value indicates that the water level has increased)

Figure 7 presents a comparison of the study area where the interpolated depth-to-groundwater is shallower than 0.35 m with new surfaces derived from both pre- and post-2016 data overlaid. Similarly, a zoomed-in example area is provided in Figure 8. For reference, the locations of existing active monitoring bores are shown on these figures. From Figure 7 and Figure 8:

- Differences between pre- and post-2016 data sets are small at a city scale.
- Compared to the new pre-2016 surface, the post-2016 data has resulted in higher shallow groundwater levels in small areas scattered mainly over areas north and east of the CBD (i.e. in the areas from St Albans through to Papanui, and Woolston/Bromley though to North New Brighton).
- The additional areas of shallow groundwater levels are located adjacent to areas that already experience shallow levels (i.e. a small enlargement of the pre-2016 areas), apart from a small new area near North New Brighton.

Figure 9 compares the new post-2016 surface with the surface originally defined by Rutter (2020) for the 0.35 m limit. Differences between these surfaces are due to both different data sets (e.g. the inclusion of new data) and different interpolation techniques. Overall, the new post-2016 surface covers a larger area where groundwater is 0.35 m or shallower compared to the original surface. New areas tend to be located more towards the centre of the study area. In the Marshlands-Belfast and Hilmorton areas, the new post-2016 surface covers a smaller area than the Rutter (2020) surface. However, there is little data in these areas to verify this. Greatest confidence is placed in the areas with nearby measured data compared to areas further away from measurement sites.

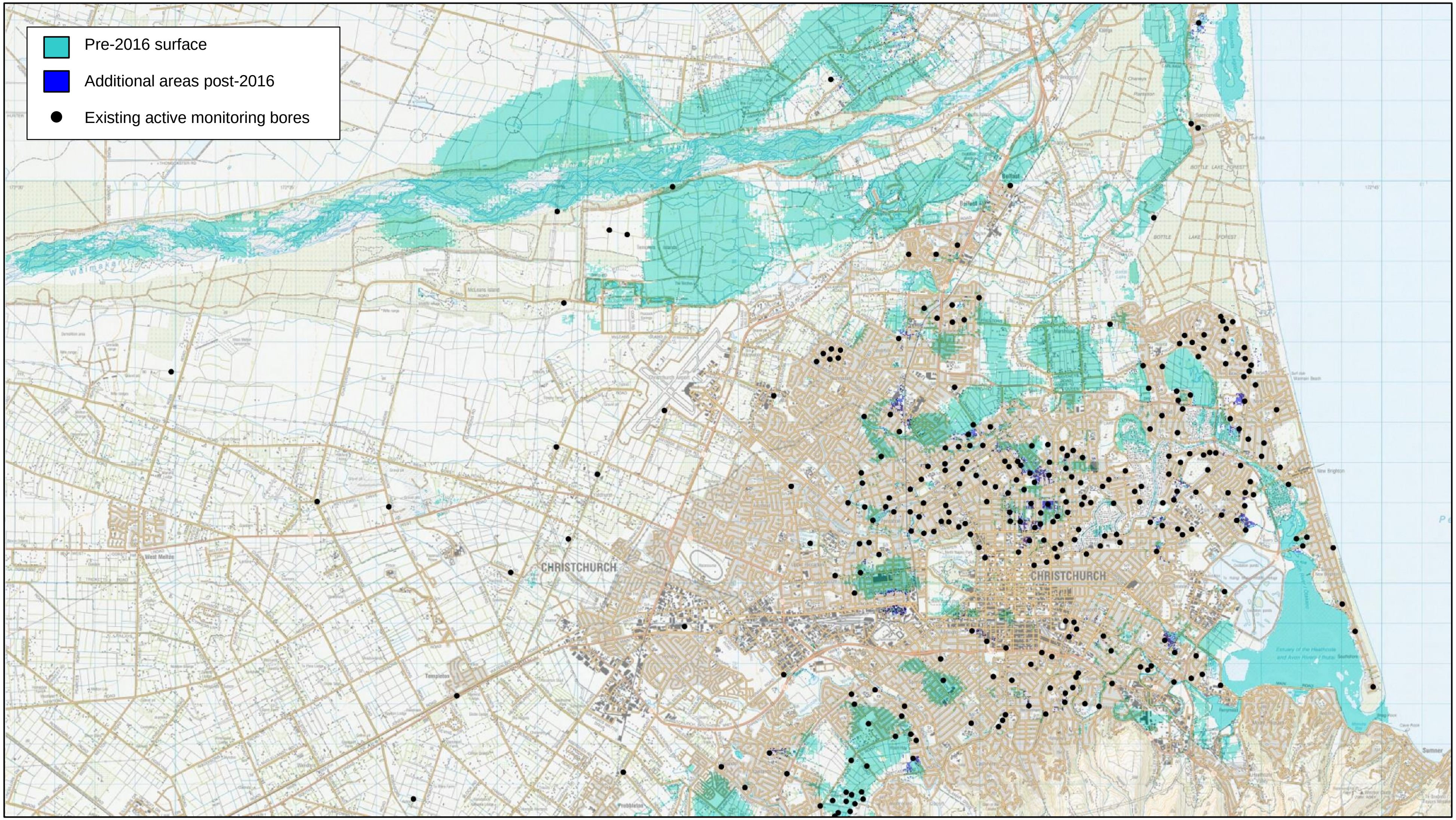


Figure 7: Areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl

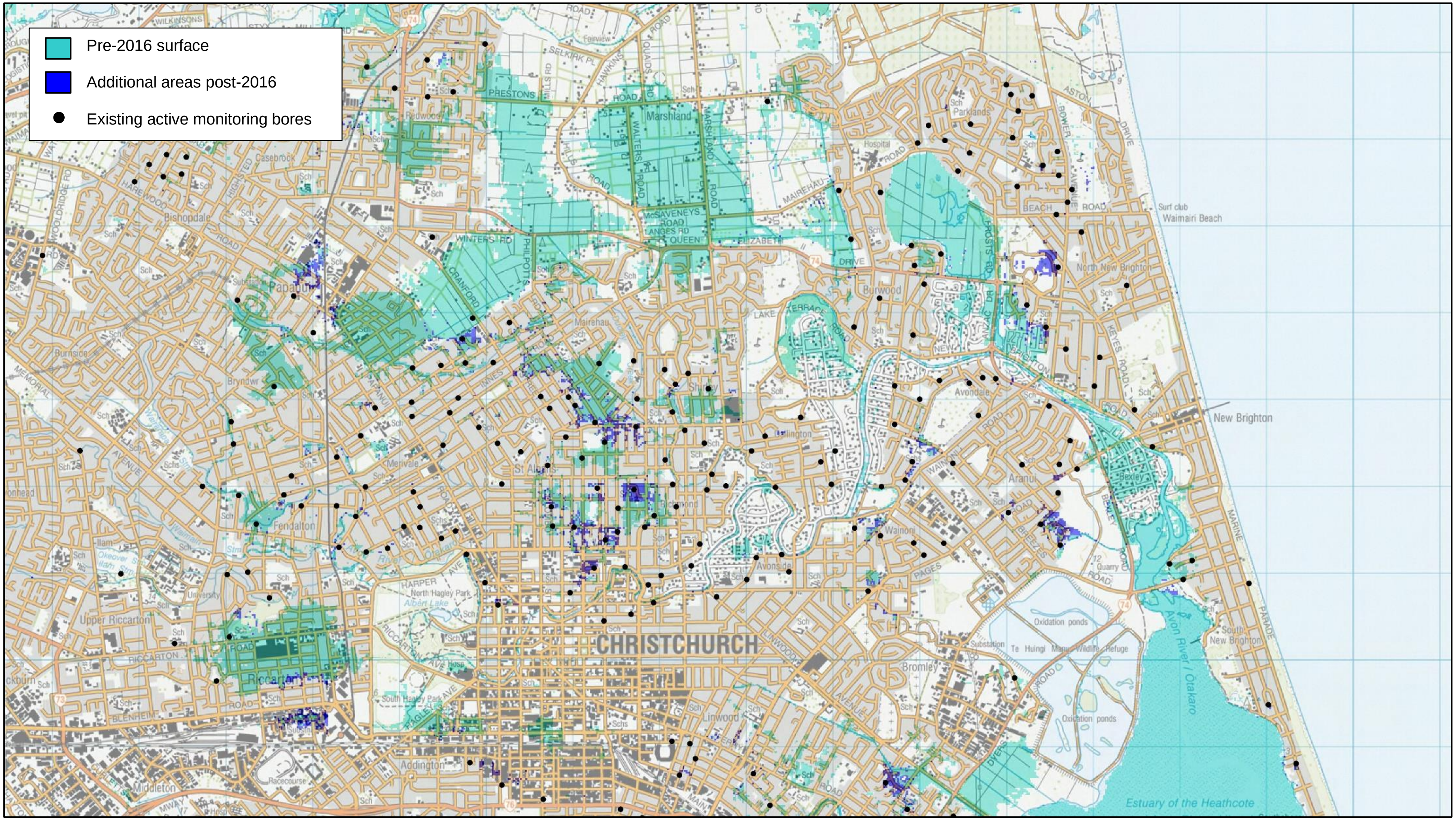


Figure 8: Example zoomed-in areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl

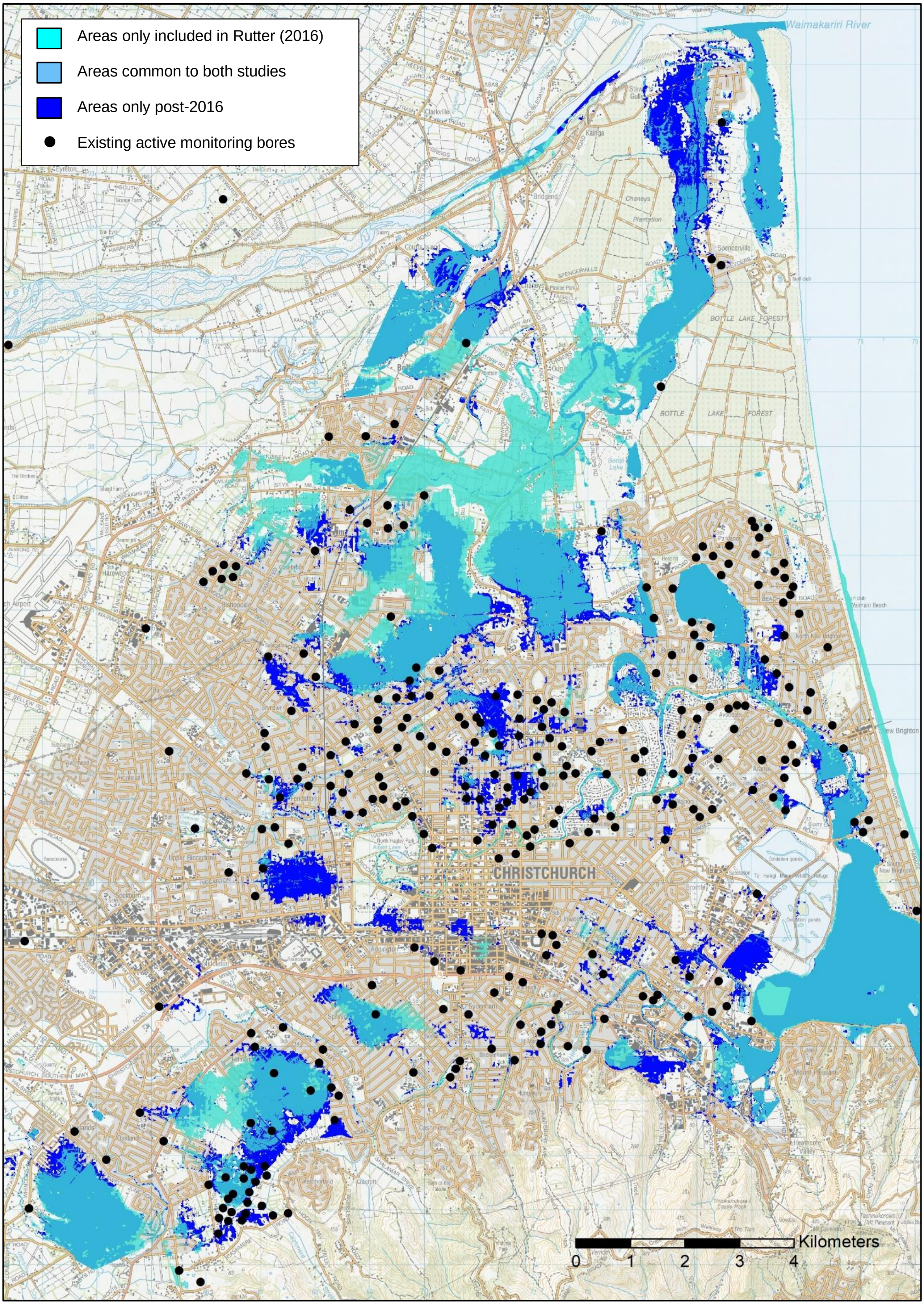


Figure 9: Areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl: original versus new post-2016 surfaces

2.1.3 Sea Level Rise

A key outcome for CCC is to identify areas where modelled sea level rise might add to the shallow groundwater risk. For the purposes of this study, the 1.0 m sea level rise scenario provided by Rutter (2020) has been added to the depth to groundwater surfaces discussed in Section 2.1.2. The resulting surface of shallow groundwater levels including this scenario of sea level rise is provided in Appendix C, and digital versions of these surfaces have been supplied separately to CCC. As before, the scale of these maps makes it difficult to see changes between pre- and post-2016 datasets. Therefore, Figure 10 presents a comparison of the study area where the newly interpolated depth-to-groundwater is shallower than 0.35 m with both pre- and post-2016 overlaid. Similarly, a zoomed-in example area is provide in Figure 11.

From Figure 10 and Figure 11, key points of differences are again small, and are similar to the no-sea-level-rise scenarios discussed in Section 2.1.2.

Figure 12 compares the new post-2016 surface with sea level rise against the equivalent surface derived by Rutter (2020) for the 0.35 m limit. Again, then new post-2016 surface (with 1.0 m sea level rise) generally spans a larger area where groundwater is 0.35 m or shallower compared to the original surface. As before, new areas tend to be located more towards the centre of the study area, with reductions in the Marshlands-Belfast and Hilmorton areas. Greatest confidence is placed in the areas with nearby measured data.

As the response of sea level rise is predicted to occur primarily on the coastal side of the CBD, the coverage of land where depth to groundwater is less than 0.35 m is larger in these areas compared to further inland.

2.1.4 Surfaces of Specific Dates to Inform Flood Modelling

CCC have engaged with other consultants to prepare flood models for specific surface water catchments over the city. Depth to shallow groundwater is one of the datasets used to calibrate (or constrain) these models. Therefore, CCC have requested that surfaces to shallow groundwater levels be generated for specific dates that overlap the surface water flood model simulation periods. These dates are:

- 15/06/2013
- 15/12/2021
- 25/07/2022

Although specific dates are requested, some of the bores that are measured manually do not have measurements on those specific dates, but rather within a week or two either side. Therefore, where this occurs, groundwater levels have been interpolated between measurements at adjacent times. This maximises the coverage of data used in generating the shallow groundwater level surfaces.

The resulting surface of shallow groundwater levels for specific dates are provided in Appendix D and digital versions of these surfaces have been supplied separately to CCC.

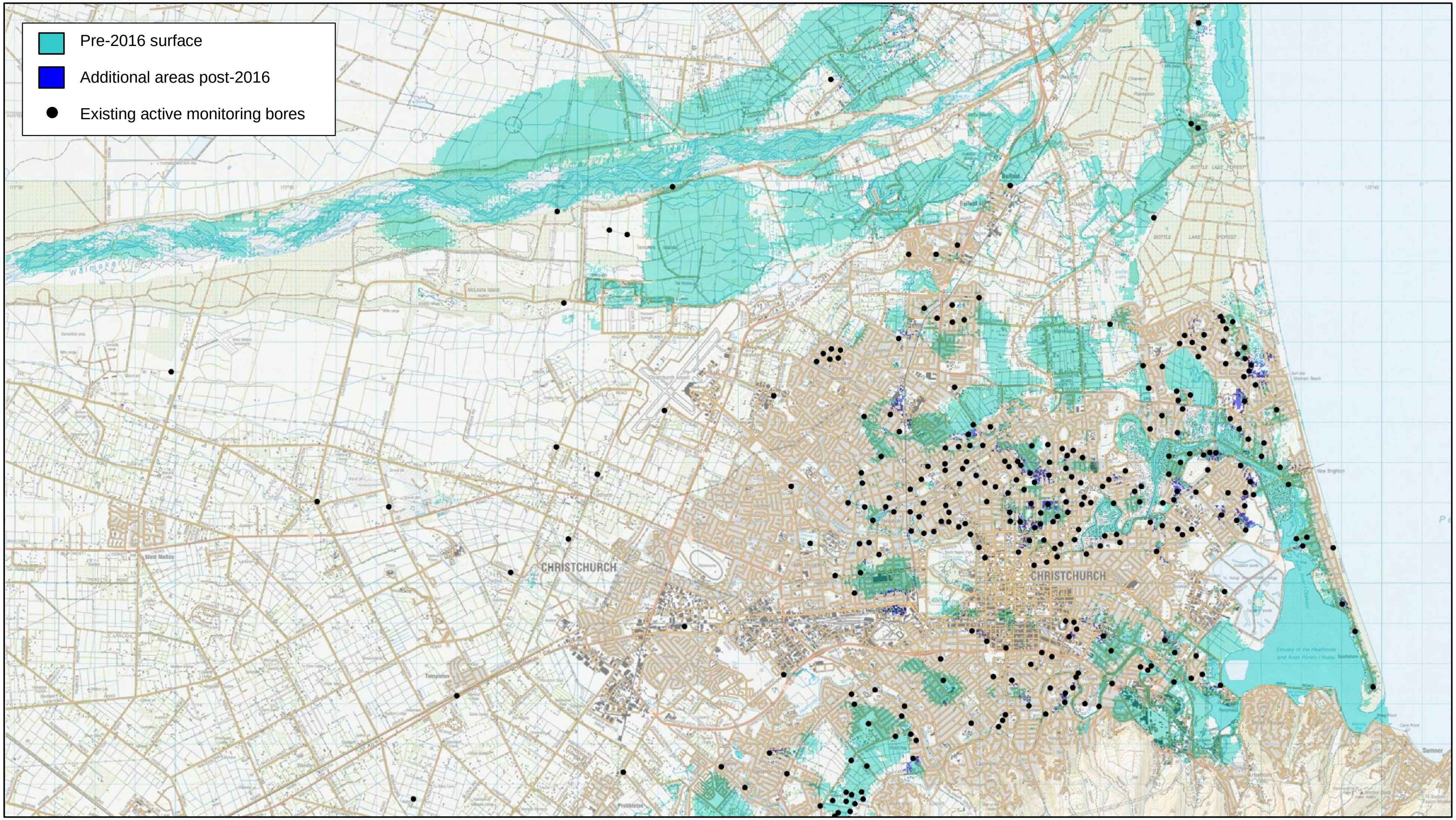


Figure 10: Areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl with 1.0 m sea level rise

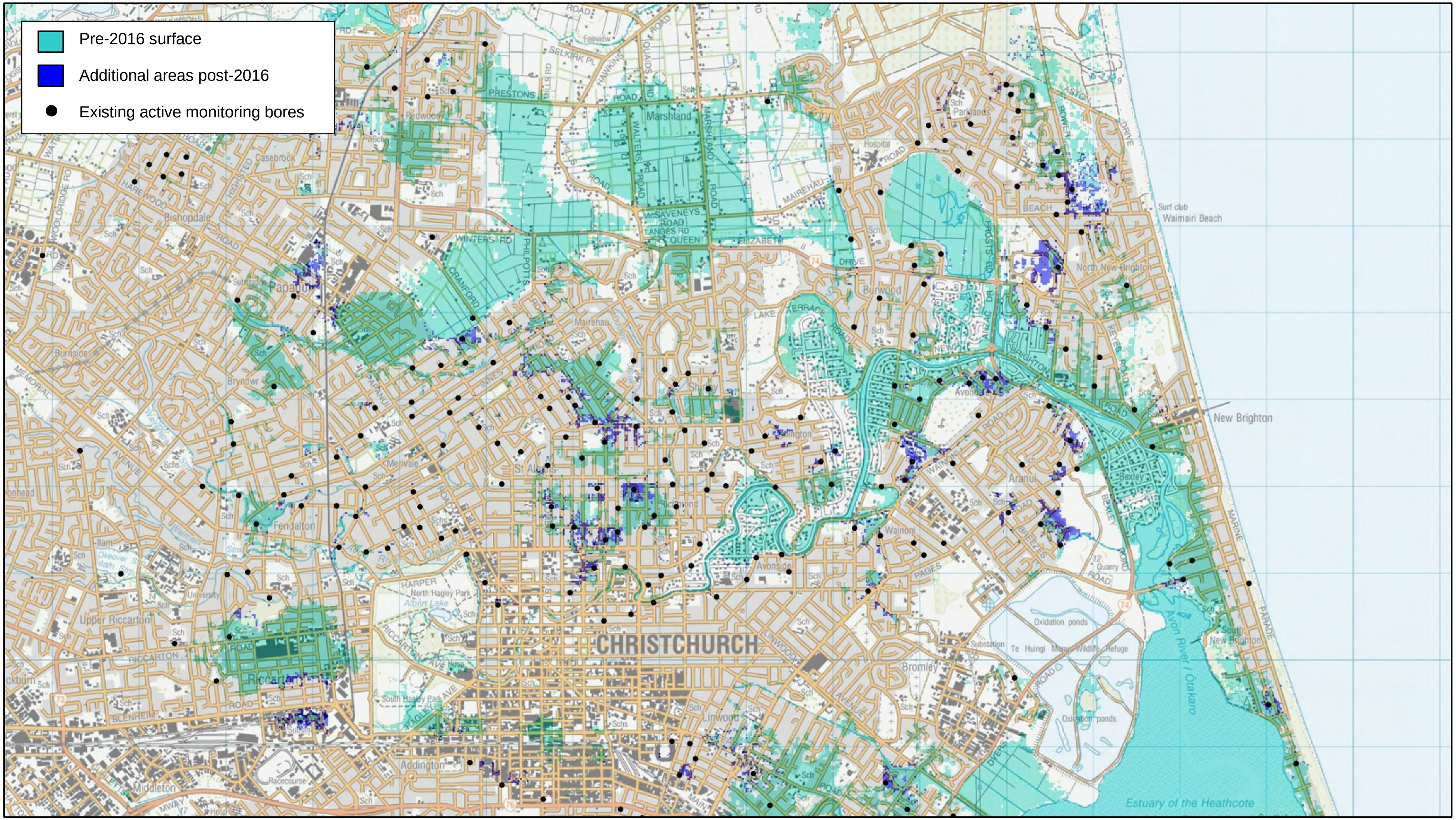


Figure 11: Example zoomed-in areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl with 1.0 m sea level rise

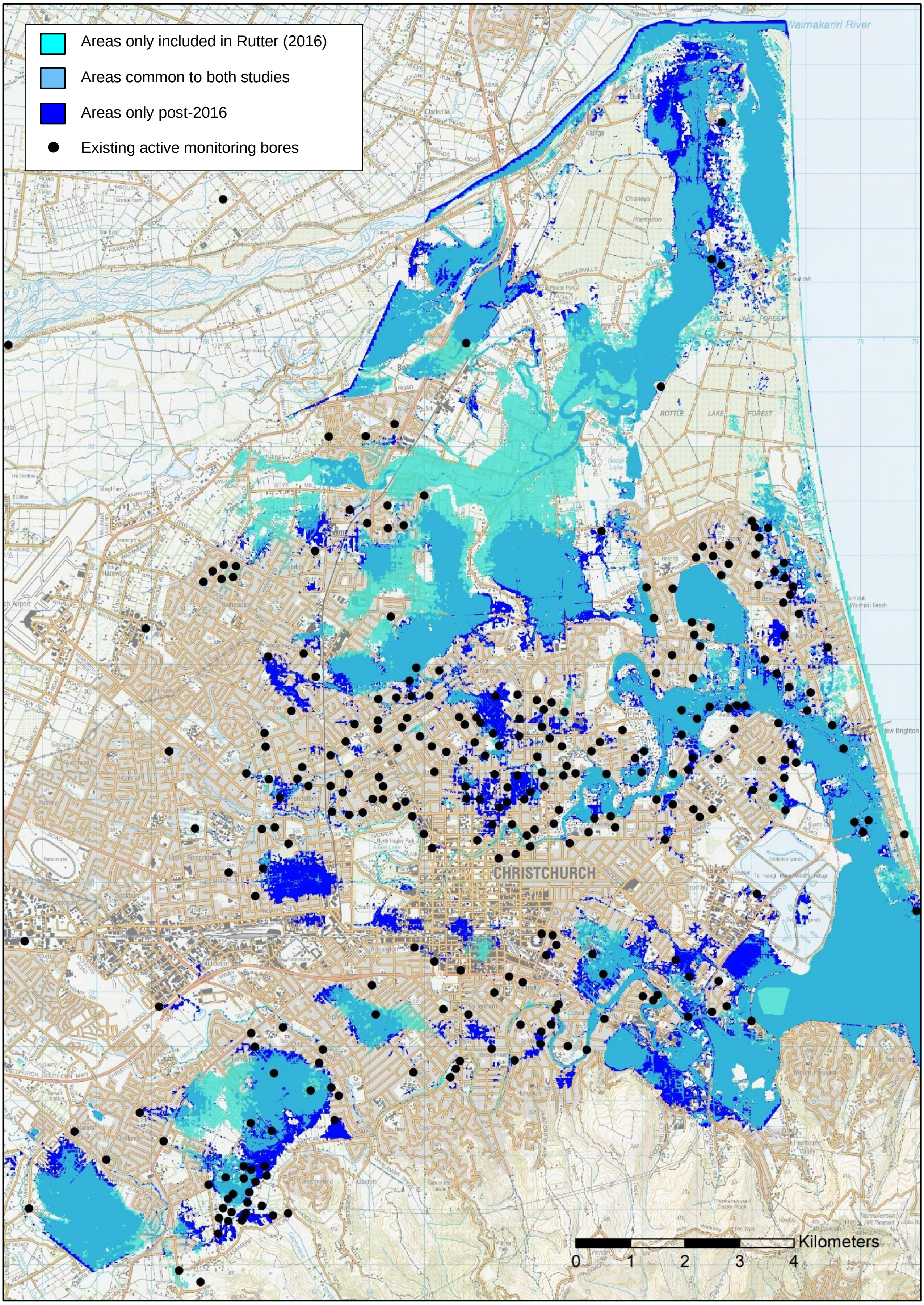


Figure 12: Areas where the 85th percentile depth to groundwater is predicted to be less than 0.35 m bgl with 1.0 m sea level rise: original versus new post-2016 surfaces

2.2 Discussion and Next Steps

The high-resolution data collected since 2016 provides a unique insight into the behaviour of shallow groundwater over this period. This has been a period with some extreme rainfall events, as well as two years of low groundwater recharge. The response of the APP network has been variable: the majority of bores show raised groundwater levels relative to the preceding 2011 to 2016 period, some show little change, and some have lowered. Overall, the changes are generally relatively small (< ~0.3 m) though even this small change may cause some issues in areas with very shallow groundwater.

The inclusion of the new (post-2016) data (while using the old data in areas with no post-2016 data) has enabled the generation of new surfaces. The changes from the original 2016 surface to the new one have resulted in some areas that have expanded and other areas that have reduced. However, the value of the additional spatial data has been limited as many of the new piezometers are located close to existing bores. The addition of the Eastman Te Kura data has provided more confidence in the interpolation in this area, where there previously had been little information. Greatest confidence is provided in the areas that are close to measurement sites and also areas where the original and new surfaces are close in terms of groundwater level for each.

The additional temporal data has resulted in an interpolated surface with differences in the depth to shallow groundwater that is noticeable in some areas, but with little difference in other areas.

Spatially, the new data provides some additional control, but not substantially. The network was originally installed for land damage assessment post-earthquakes. It was not designed for defining depth to shallow groundwater across the city, and the spatial distribution of bores is not ideal for this purpose. Regardless, the data sets are far more advanced than what is typical in across other cities in New Zealand and are a valuable source of information for informing shallow groundwater risk.

Further observations are as follows:

- CCC should be commended for maintaining the operation of the APP network over the last few years when record-high groundwater levels have been experienced in some areas. There is now greater confidence in the measured high groundwater levels which are likely to be good predictors of future highs (including potential sea level rise which has been accommodated in the sea level rise scenario).
- The high-resolution temporal data captures the dynamic response of groundwater levels to high-intensity, short duration, rainfall events. This cannot be captured by individual manual measurements. As manual field measurements usually occur during fair weather, the response from wet weather events is usually missed.
- Visual inspection of the time series indicates that, by and large, very high groundwater levels occur for short durations (from hours to a day or two) before receding, but near-high groundwater levels remain for longer. Short duration peaks typically occur when there is heavy rain, so from a landowner's perspective, it is not obvious that groundwater might be contributing to surface flooding. Groundwater flooding would then only come to the forefront when flooding remains, well after the event has passed and conditions would be expected to be dry. This has occurred in some areas such as Flockton Basin, Woolston, parts of Halswell, and Brighton (which is exacerbated by tidal effects). Sustained high groundwater levels are of concern for property owners (for example due to damage to vegetation and the effects of rising damp).
- There is greater confidence in the likelihood of shallow groundwater in areas with nearby measurements compared to areas further away from measurement sites. Given this, LIM notices could be grouped into two categories, such as:
  - Shallow groundwater is <u>likely</u> at times (for shallow areas near measurement points); and
  - Shallow groundwater is <u>possible</u> at times (for shallow areas away from measurement points).
- The larger spatial changes in the interpolated surfaces tend to occur where a measurement point 'came online' (i.e. a new bore was monitored) or 'went offline' (i.e. a bore ceased to be measured). The cessation of monitoring has mainly occurred due to the conversion from manually dipped bores in many bores to the use of transducers on fewer bores. There will also be some cases where there has been damage to the bore (say from roading, infrastructure or land development works), but also occasionally due to failure of the down-hole logger. This is expected to continue into the future (as the loggers age), and so it is recommended that the monitoring of as many bores as possible is maintained to reduce the future influence of these valuable data sources disappearing.

- However, if CCC wish to rationalise the network (to reduce ongoing costs and/or redistribute the available transducers), then removing bores from areas where multiple bores are clustered together and where hydraulic responses are similar is recommended. Such locations may include:
  - Bishopdale (between Harewood and Sawyers Arms roads): currently 5 bores in close proximity (APP bores 101, 114, 116, 211 and 212), all of which have similar hydraulic responses – could remove two or three bores.
  - Avondale (between Orrick Crescent and Anzac Drive): currently 3 bores in close proximity (APP bores 35, 47, 78), two of which have similar hydraulic responses (47 and 78) – could remove one bore.
  - North New Brighton (near corner of Beach Road and Bower Avenue): currently 3 bores in close proximity (APP bores 4, 54 and 172), two of which have similar hydraulic responses (4 and 54) – could remove one bore.
  - Woolston (Riley Crescent): currently 3 bores in close proximity (APP bores 5, 55 and 80), two of which have similar hydraulic responses (5 and 80) – could remove one bore.
  - Beckenham (southern end of Colombo Street): currently 3 bores in close proximity (APP bores 109, 130 and 226), two of which have similar hydraulic responses (130 and 226) – could remove one bore.

  In addition, a similarity assessment has identified pairs of bores (located in close proximity to each other) that have similar hydrographs where one bore could be dropped. These are listed in Appendix E.

- The interval that groundwater levels are logged could be reduced from 15 minutes to 1 hour. This will extend the length of time before loggers become full, thereby reducing the frequency (and therefore costs) of colleting this data from approximately once every 9 months to once every 3 years. However, this needs to be balanced with the knowledge that the loggers are starting to age, and therefore there is a higher chance of logger failure (and therefore lost data) between data collection rounds. Annual collection rounds is recommended.

- There will be areas where CCC might strategically want to place transducers (for example in areas prone to groundwater flooding or in long term manually-monitored bores). Many of the original EQC bores are still in existence and may be usable. If groundwater level data is to be used operationally, then it will be necessary to telemeter the data. Options have been explored to assess the viability of doing this, and purchase/subscription options have been identified (and previously provide to CCC). If the purpose of monitoring is to obtain background information in areas that have no current monitoring, then downhole transducers and periodic downloads are a viable option. Areas with no current monitoring include:
  - The CBD area (which in particular has historically reported issues with shallow groundwater) and a wider area from west to east across the middle of the city;
  - North of Papanui;
  - Marshlands; and
  - Coastal areas in general.

  The locations of these general areas are depicted in Figure 13.

- Point measurements of groundwater levels are limited in their ability to fully capture the *spatial* variability of high groundwater level risk, but the automated network provides excellent *temporal* resolution. Conversely, geophysical methods have the ability to capture the state of the groundwater system over large areas, but only at the time of measurement. Therefore, the combination of the APP network with strategic geophysical testing could provide CCC with a sound spatial and temporal coverage of responses to further reduce the uncertainty associated with the assessment of shallow groundwater risk. Aqualinc would be happy to discuss the possibilities of geophysical testing with CCC if this was of interest, though the science is still being developed.

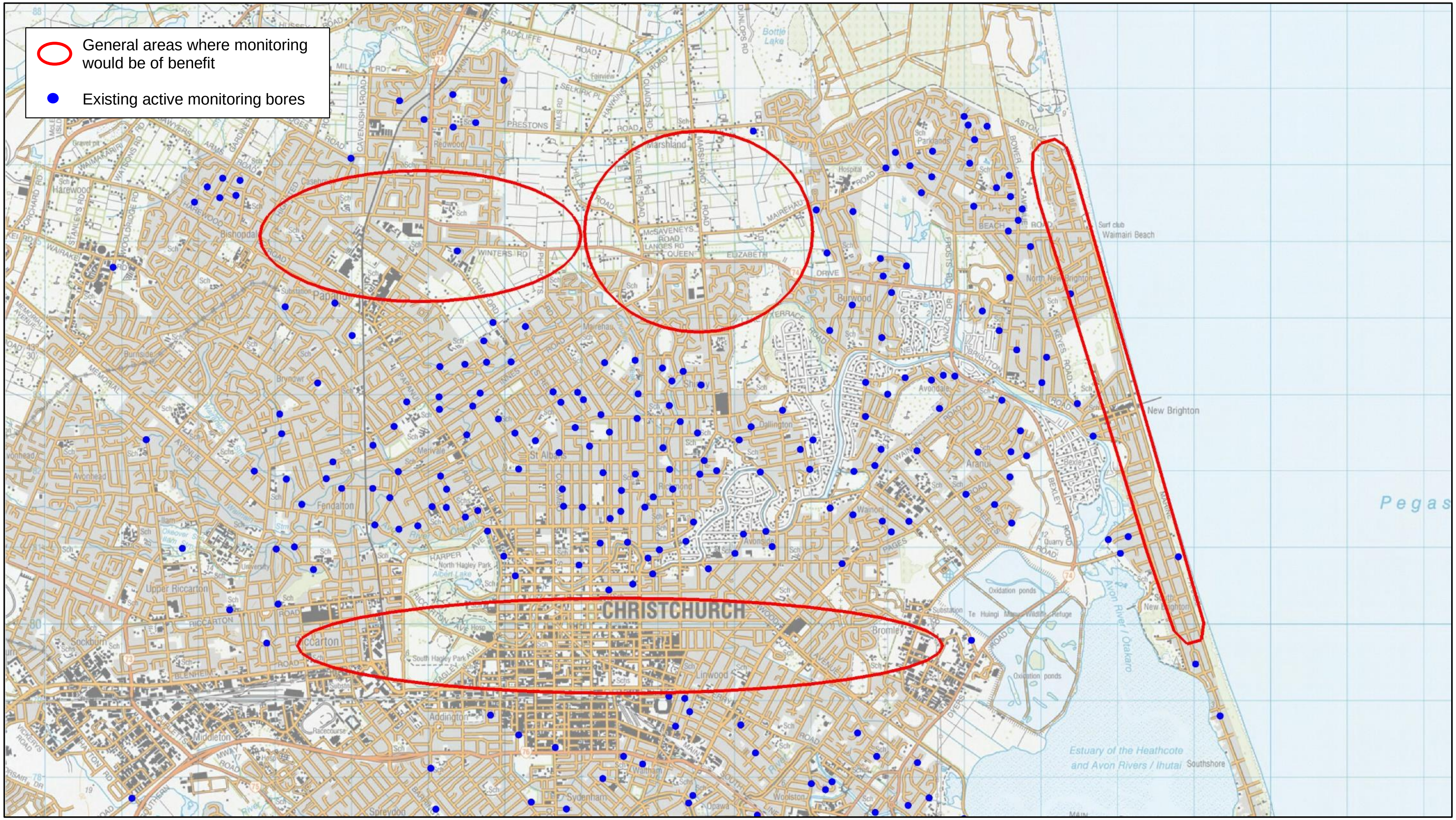


Figure 13: General areas where future monitoring would of benefit

Appendix A: Change in the 85th percentile shallow groundwater levels between pre- and post-2016 data sets

Negative values denote raised groundwater levels; positive values denote lowered groundwater levels.

Bore name	Change in 85th percentile (m)
1	-0.01
2	0.17
3	-0.38
4	-0.73
5	-0.02
6	-0.05
7	-0.19
8	-0.39
9	-0.27
10	0.21
11	-0.09
12	-0.26
13	0.57
14	-0.39
17	-0.37
18	0.05
19	-0.04
21	-0.38
22	-0.30
23	-0.01
24	-0.08
25	-0.36
26	-0.21
27	-0.48
28	0.19
29	-0.19
30	-0.26
31	-0.24
32	-0.22
33	-0.27
34	-0.30
36	-0.24
37	0.06
38	-0.09
39	-0.15

Bore name	Change in 85th percentile (m)
40	-0.22
41	-0.17
42	-0.10
43	-0.01
44	-0.11
45	-0.30
46	-0.81
47	-0.57
48	-0.19
49	-0.18
50	0.04
51	-0.07
52	-0.10
53	0.12
54	-0.92
55	-0.11
56	-0.10
57	-0.09
58	-0.26
59	-0.15
60	-0.13
61	0.02
62	-0.05
63	-0.10
64	-0.09
65	-0.26
66	-0.25
67	-0.17
68	0.02
69	-0.20
70	-0.19
71	-0.05
72	0.05
73	-0.07
74	-0.19

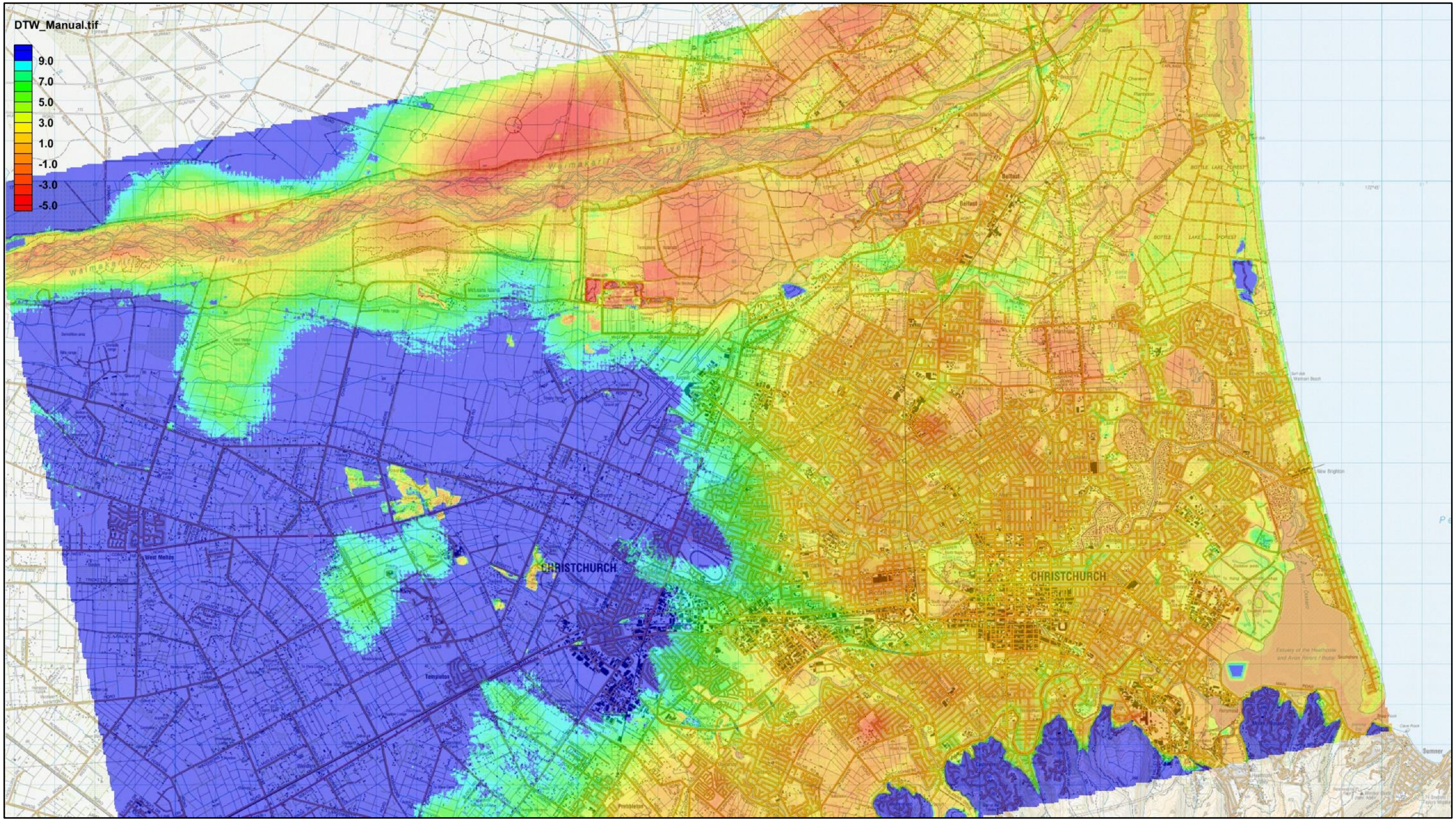
Bore name	Change in 85th percentile (m)
75	-0.32
76	-0.13
77	-0.28
78	-0.50
79	-0.13
80	-0.06
81	-0.15
82	-0.07
83	-0.18
84	-0.19
85	-0.15
87	-0.03
88	0.02
89	-0.21
90	-0.22
91	-0.30
92	-0.13
93	-0.28
94	-0.16
95	-0.31
96	-0.20
97	-0.20
98	-0.19
99	-0.16
100	-0.10
101	-0.01
102	-0.14
103	-0.16
104	-0.07
105	-0.24
106	0.05
107	-0.39
108	-0.04
109	0.08
110	0.02

Bore name	Change in 85th percentile (m)
111	-0.09
112	0.11
113	-0.15
114	0.17
115	-0.16
116	0.08
117	-0.37
118	0.06
119	-0.12
120	-0.13
121	-0.23
122	-0.09
123	-0.11
124	-0.11
125	-0.33
126	-0.05
127	-0.08
128	-0.33
129	-0.32
130	-0.14
131	-0.06
132	0.01
133	-0.08
134	-0.01
135	-0.04
136	-0.08
137	-0.06
138	0.01
139	-0.18
140	0.15
141	-0.04
142	-0.10
143	-0.28
144	0.00
145	-0.16
146	0.00
147	-0.07

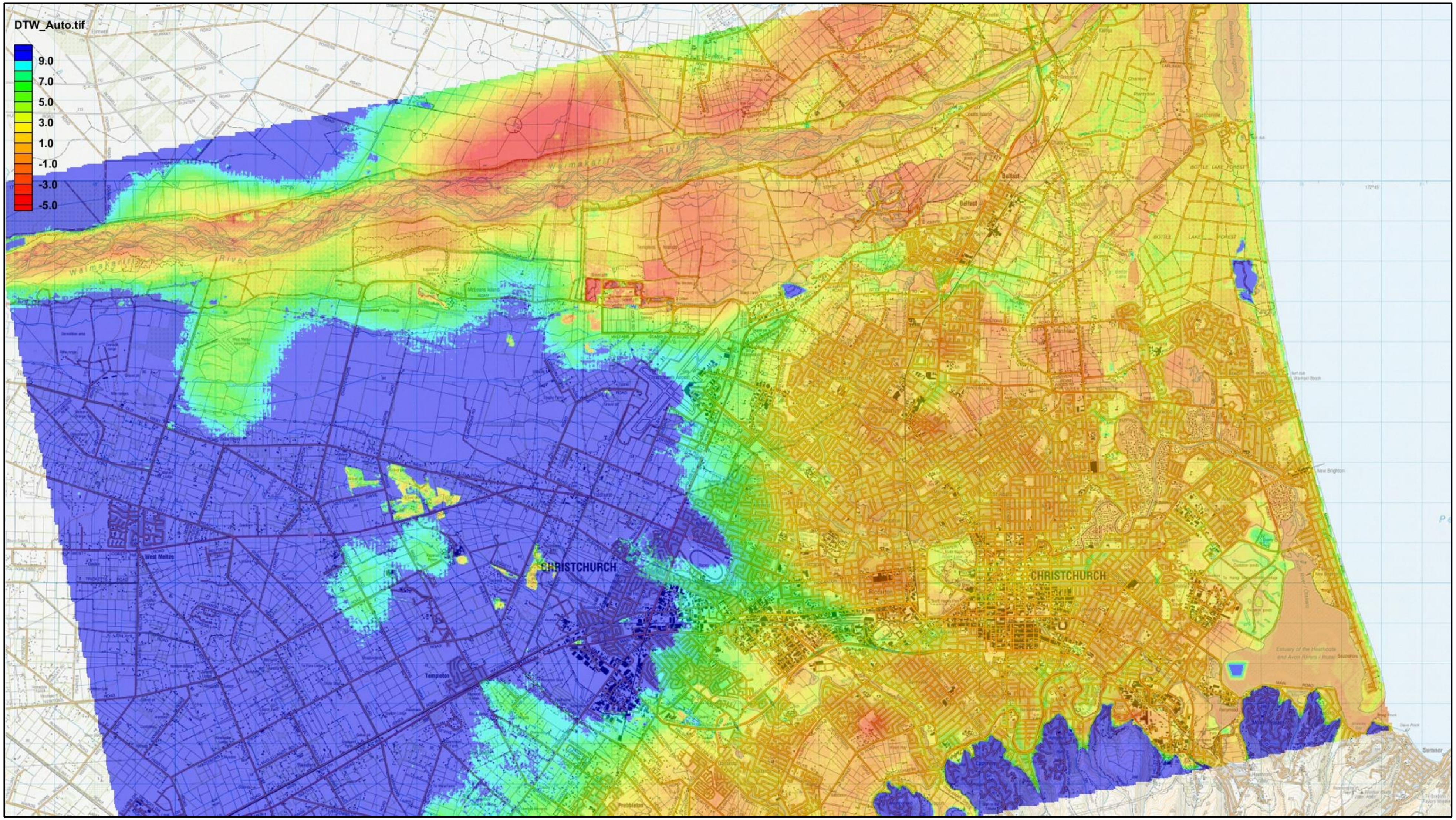
Bore name	Change in 85th percentile (m)
159	-0.41
160	0.13
162	-0.05
164	0.25
167	-0.17
169	0.35
170	-0.29
172	-0.62
173	-0.25
177	0.01
178	0.05
182	-0.07
184	-0.01
192	0.37
193	-1.42
199	-0.41
205	-0.32
244	-0.36
M35_0601	0.01
M35_0724	0.00
M35_0931	0.07
M35_0948	0.08
M35_1079	0.87
M35_1080	0.58
M35_1110	0.55
M35_1111	-0.25
M35_1156	-0.40
M35_1380	0.01
M35_1691	1.21
M35_1878	0.57
M35_3614	0.90
M35_3739	-0.10
M35_3740	0.17
M35_5407	-0.88
M35_5412	-0.25
M35_5413	0.39
M35_5417	-0.06

Bore name	Change in 85th percentile (m)
M35_5420	0.03
M35_5422	0.00
M35_5425	-0.39
M35_5436	-0.08
M35_5526	-0.54
M35_5560	0.17
M35_6936	-0.60
M35_7169	-0.74
M35_7896	-0.09
M35_8236	0.02
M35_8256	-0.01
M35_8370	0.14
M35_8371	0.15
M35_8372	3.42
M35_8968	0.22
M35_8969	0.10
M36_0142	1.10
M36_0202	0.75
M36_2452	0.08
M36_3166	-0.24
M36_3167	0.02
M36_3168	-0.08
M36_3175	-0.08
M36_4741	0.13
M36_5385	-0.09
M36_5709	0.01
M36_5711	0.72
M36_5715	0.13
M36_5716	0.54
M36_5719	-0.05
M36_5720	-0.29
M36_7089	-0.03
M36_7090	-0.02
M36_7091	-0.02
M36_7092	-0.04
M36_7535	-0.13

Appendix B: Depths to shallow groundwater

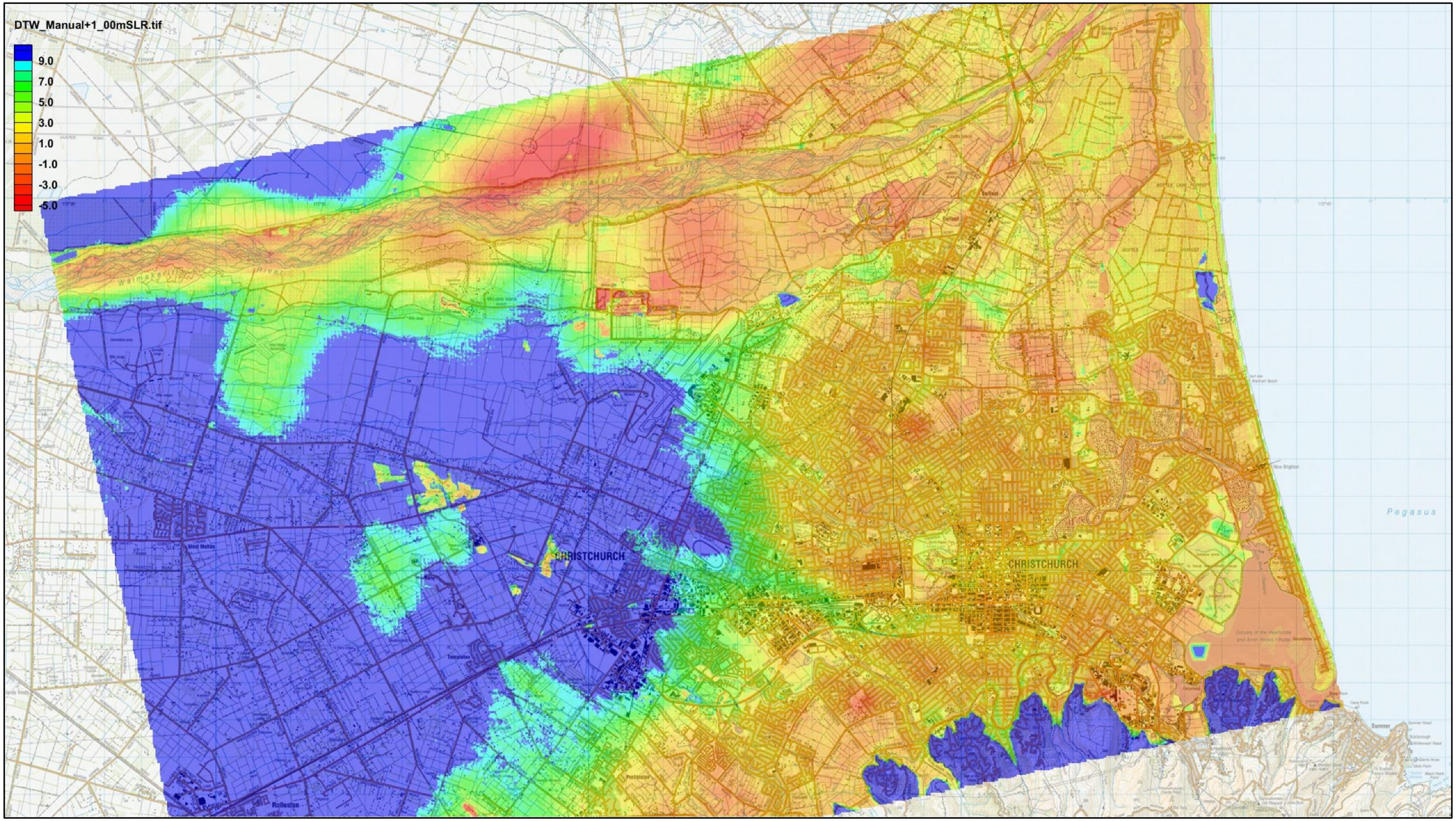


Depth to shallow groundwater: Pre-2016 data

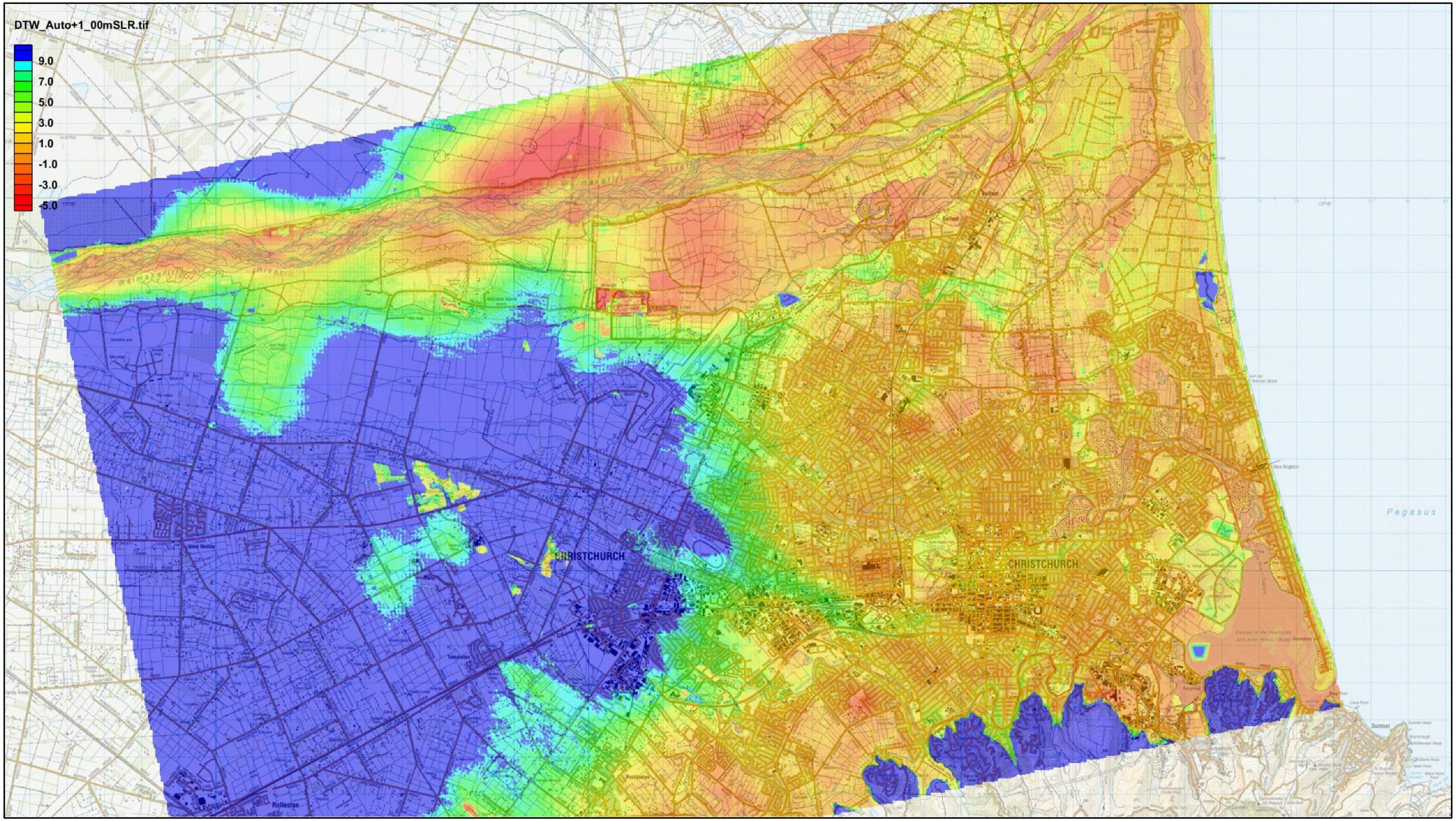


Depth to shallow groundwater: Post-2016 data

Appendix C: Depths to shallow groundwater with 1.0 m sea level rise

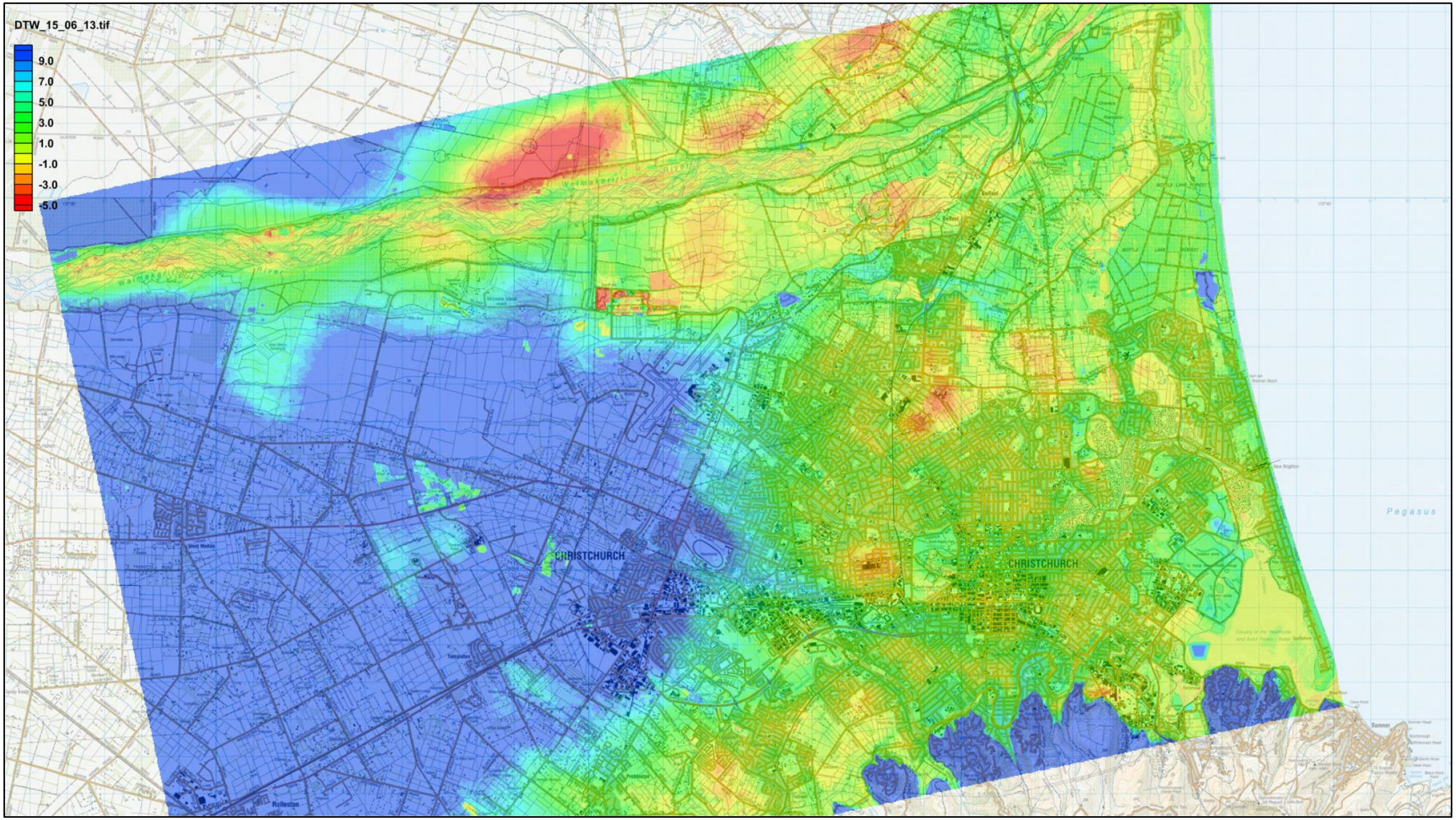


Depth to shallow groundwater with 1.0 m sea level rise: Pre-2016 data

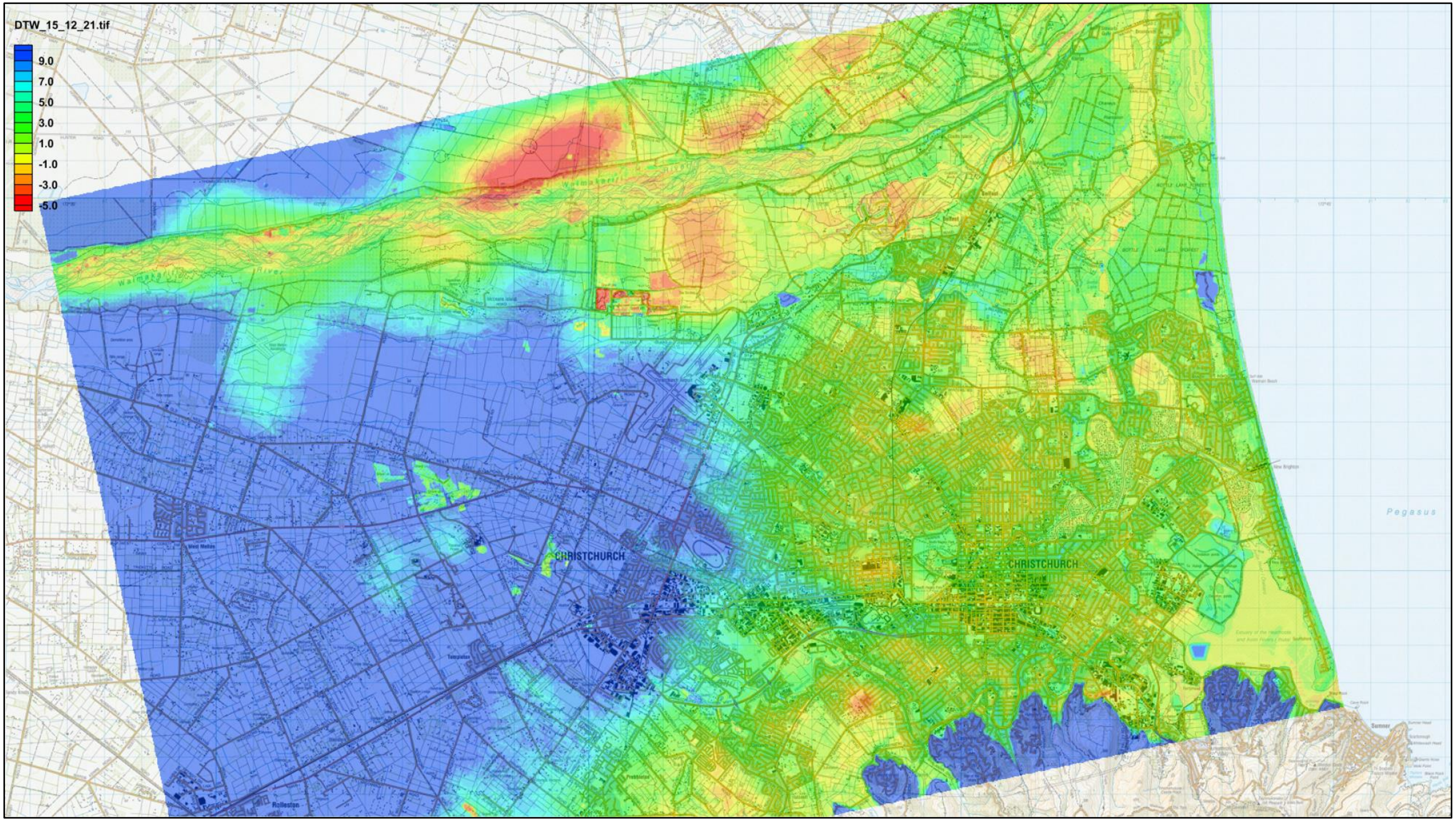


Depth to shallow groundwater with 1.0 m sea level rise: Post-2016 data

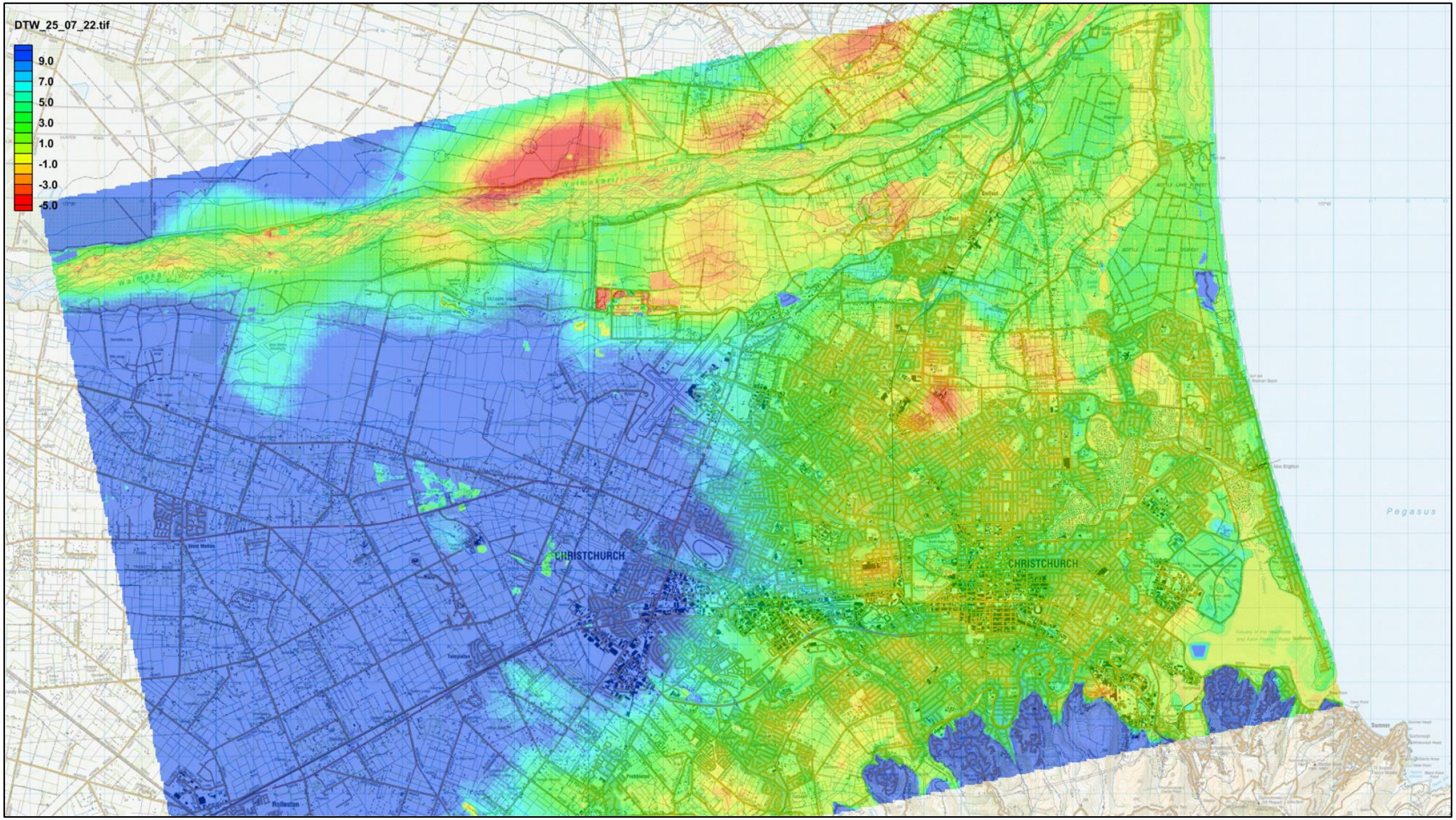
Appendix D: Depths to shallow groundwater for specified dates



Depth to shallow groundwater for 15/06/2013



Depth to shallow groundwater for 15/12/2021



Depth to shallow groundwater for 25/07/2022

Appendix E: Pairs of APP bores with similar hydrographs

Bore 1	Bore 2
50	68
69	99
33	203
69	94
75	143
42	206
113	201
30	48
178	179
231	240
93	143
84	131
34	102
33	34
42	217
231	241

Some of these APP pairs double up. For example, bore 33 pairs with both bores 203 and 34. So in this case, two bores could be dropped.