Hydrologic Effects of the 2020 Drought on Auckland Regional Waterbodies

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Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Cover image: Cascades Stream, Waiheke Island. Photograph taken by RIMU science team during State of the Environment sampling.

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Executive summary

This report describes the inventory and analysis of rainfall, soil moisture, river flow, lake water level, and groundwater level data for 2020, specifically to characterise the effects of the 2020 drought on the region's rivers, lakes, and aquifers. Data spanning the 2020 drought were compared against long-term records to analyse the magnitude and duration of impacts on regional waterbodies.

The data indicate the summer of 2020 had one of the most severe droughts in the Auckland hydrological record. Multiple hydrometric datasets clearly show significant impacts from the 2020 drought. Regional average rainfall over the summer was 52% below the mean for the period 1980-2020. Record low soil moisture was recorded at most monitoring sites and low soil moisture conditions persisted from November to April for most sites. Thirteen of 23 river flow sites had the greatest number of days below MALF and nine sites had the lowest seven-day mean flow on record. Regional average low flows during the 2020 calendar year had 97 days below the mean annual low flow, the highest number of low flow days over the period of analysis from 1980 to 2020. The 2020 summer water level in Lake Rototoa was the lowest on record for all data since 1984. Lake water level at Pupuke was the third lowest on record for the period 2006-2020, but generally exhibited a hydrograph similar to 2014, which was not a drought year. Nine groundwater level monitoring sites recorded the lowest groundwater level on record and 20 other sites recorded the lowest groundwater level on record for that time of the year.

Groundwater pumping from the Parakai geothermal aquifer was stopped twice during Covid-19 lockdowns, which led to sharp increases in groundwater levels. These data demonstrate how groundwater levels are significantly affected by water use and that rules on groundwater allocation and operation have observable impacts on groundwater systems. The dynamic nature of Auckland's groundwater systems is highlighted by these observations, which show that environmental outcomes can be affected by water management policies like allocation limits and temporary restrictions. This is evidence that a balance of competing values can be achieved through feedback between policy development, implementation, and monitoring.

Water use was not analysed for this report. Water use is a critical component of a complete analysis of hydrological data in the context of resource management, so the best application of these results will be alongside a subsequent analysis of water use data. This is particularly relevant to waterbodies that have a high proportion of water takes to the total availability. These water bodies are the most likely to be affected by water use and therefore the most likely to suffer ecological consequences from droughts, exacerbated by water use. This draws attention to the importance of communication of flow data to water users and the proactive management of water take activities during low flow conditions.

Table of contents

1 Introduction

This report is a retrospective of hydrology data from 2020, inventoried, analysed, and compared against past years to assess the severity of the 2020 drought as it affected rivers, lakes, and aquifers in the region. Rainfall and soil moisture are also analysed here as they are integral components of the water cycle and are important for a complete understanding of hydrological phenomena. However, the impacts of both natural and anthropogenic activities are realised in rivers, lakes, and aquifers and thus the insights gained from this report are focused on surface water and groundwater systems.

1.1 What is drought?

The term drought has varying definitions and is used in many different contexts. In essence, a drought occurs when there is less water in the environment than normal. The International Glossary of Hydrology (2012) provides two definitions of drought:

- Meteorological Drought: Prolonged absence or marked deficiency of precipitation
- Hydrological Drought: Period of abnormally dry weather sufficiently prolonged to give rise to a shortage of water as evidenced by below normal streamflow and lake levels and/or the depletion of soil moisture and a lowering of groundwater levels.

The degree or quantity by which a deficit of water constitutes a drought is variable depending on the stakeholders involved and the values and norms associated with water resources. In most cases, drought has an anthropogenic component that incorporates uses or demands for water in addition to meteorological or hydrological measurements. It has been argued that a universal definition of drought is impractical because of the difficulty in quantifying those norms into an agreed and workable objective definition of drought (Lloyd-Hughes, 2013).

This report does not attempt to define drought beyond that of marked dry years relative to the long-term record. The term drought is pragmatically applied here to describe the years in which notably low hydrological measurements occurred.

1.2 Consequences of drought

Drought has obvious consequences on human water needs for those communities which rely on rain capture for drinking water supply. The 2020 summer affected rural communities across Auckland and urban communities which are not connected to reticulated drinking water supply. Water tanker businesses experienced an unprecedented surge in demand with wait times over two months. Auckland Council initiated welfare water filling stations across the region to assist those relying on rain tank supplies. Water use restrictions were set in place by Watercare Services, with bans on outdoor watering and other restrictions alongside a water use reduction campaign.

Direct environmental consequences include reductions in the quantify of water in rivers, lakes, and a reduction in recharge to aquifers. Reductions in summer low flows have impacts on the quantity and quality of instream habitat (see more in Section 2.5.1). Terrestrial impacts of drought include changes to carbon cycling in Auckland's kauri forests through increased litterfall with a consequential increase in fire risk (Macinnis-Ng and Schwendenmann 2014) and altering the impact of plant pathogens on productive crops and significant native ecosystems (Wakelin, et al. 2018).

Economic effects are significant. The agricultural sector relies on irrigation to sustain yields, particularly for vegetable production, but production losses still occur during significant droughts. The Reserve Bank of New Zealand found that droughts have impacted primary production enough to cause reductions in national GDP, with the 2013 drought reducing annual real GPD by up to 0.6% (Kamber et al. 2013).

1.3 Auckland drought severity analyses

Auckland has one of the longest standing hydrometric monitoring datasets in New Zealand, with rainfall records in central Auckland dating back to 1853. Several notable droughts have been recorded and detailed analyses have been presented. A water supply crisis was declared in mid-1994 along with estimates of the drought being a 100-year event. Subsequent analysis of long-term rainfall records at Albert Park found that the drought of 1913-1915 was more severe and the most reasonable estimate was that the 1994 drought was the worst in 85 years, with a return interval of approximately 30 years (Fowler 1994).

The drought of 2012/13 was widespread throughout the country, particularly in the North Island, and was found to be one of the most extreme on record at the time for New Zealand (NIWA 2013). Drought conditions during 2012/13 led to a 14.2% increase in overall water use (by volume) in the Auckland region, with 17% of consent holders exceeding their consented allocation (Stansfield and Holwerda 2015). The assessment by NIWA of the 2012/13 drought also found that a drought of similar severity occurred in the 1945/46 season (NIWA 2013).

During the summer of 2020, hydrological monitoring conducted by the Research and Evaluation Unit (RIMU) measured some of the lowest values on record for rainfall, soil moisture, river flow, lake water level, and groundwater level. Historic lows in these datasets were detected through routine monitoring, however targeted gaugings were undertaken to capture low flows in rivers throughout the region. This included rivers which are not currently monitored. Initial reviews of the data indicated that 2020 had a more severe drought than the summer of 2012/13.

A homogenised central Auckland rainfall dataset was produced for the period 1853 to 2020 and the drought of 2020 was found to be the most severe on record for the six-month duration analysis (Fowler 2021).

This report uses data collected at sites across the region to develop regional average datasets to characterise hydrological conditions across the whole of the region. These datasets provide a single metric by which to compare the 2020 drought to previous years and generate a regional picture of drought severity.

2 Methods

2.1 New Zealand Drought Index

A high-level starting point for discussion of climatic conditions is the New Zealand Drought Index (NZDI). The NZDI is a unitless numerical indicator based on four climatological drought indicators: the Standardised Precipitation Index, the Soil Moisture Deficit, the Soil Moisture Deficit Anomaly, and the Potential Evapotranspiration Deficit (NIWA, 2021). The four indicators are calculated using measured data.

NZDI data are provided on the NIWA website, as a map with interpolated values and as a summarised time series for each region, starting 1 January 2007. The full NZDI dataset for the Auckland Region was downloaded from the NIWA website for the years 2007-2020.

2.2 Envelope plots and text descriptions

This report compares 2020 hydrographs alongside the full statistical range of observations for all soil moisture and groundwater level sites. This is done visually using an envelope plot. An envelope plot shows a combination of five hydrographs; four of these are based on summary statistics taken from the flow record (maximum, 75th percentile, 25th percentile, and minimum) and the final one being the measured hydrograph for the 2020 year. This allows the reader to easily identify when the current year's values rise or fall outside the min-max envelope or the 25th-75th percentile. All data are presented at a daily time step (e.g. the maximum hydrograph shows the maximum observation for 1 January for all years on record, then the maximum for 2 January and so on). This allows rapid comparison of the year of interest against a range of statistics for the full record[1].

The statistical analysis that underpins envelope plots informs the basis for text descriptions of soil moisture and groundwater level. The descriptions are based on five categories:

- Very high >historical max
- High <historical max, >75th percentile
- Normal <75th percentile, >25th percentile (the interquartile range, or IQR)
- Low <25th percentile, >historical minimum
- Very low <historical minimum

Example: *Groundwater level at Site X was low during February, March and April of 2020*. In this example, the groundwater level at Site X was below the 25th percentile, but above the historical minimum of groundwater levels for the entire three-month period (Feb-Apr). This format is used in describing both soil moisture and groundwater levels in this report.

[1] The entire record at each site was used to generate envelope plots. Sites have variable start dates, however all sites in this analysis have records from at least 2007, so all span the drought of 2013. Commencement dates provided in Appendix 1.

2.3 Rainfall

Auckland Council operates 80 rainfall sites in the region. Of these, 46 sites have records exceeding 20 years and were used for analysis in this report (Figure 2-1).

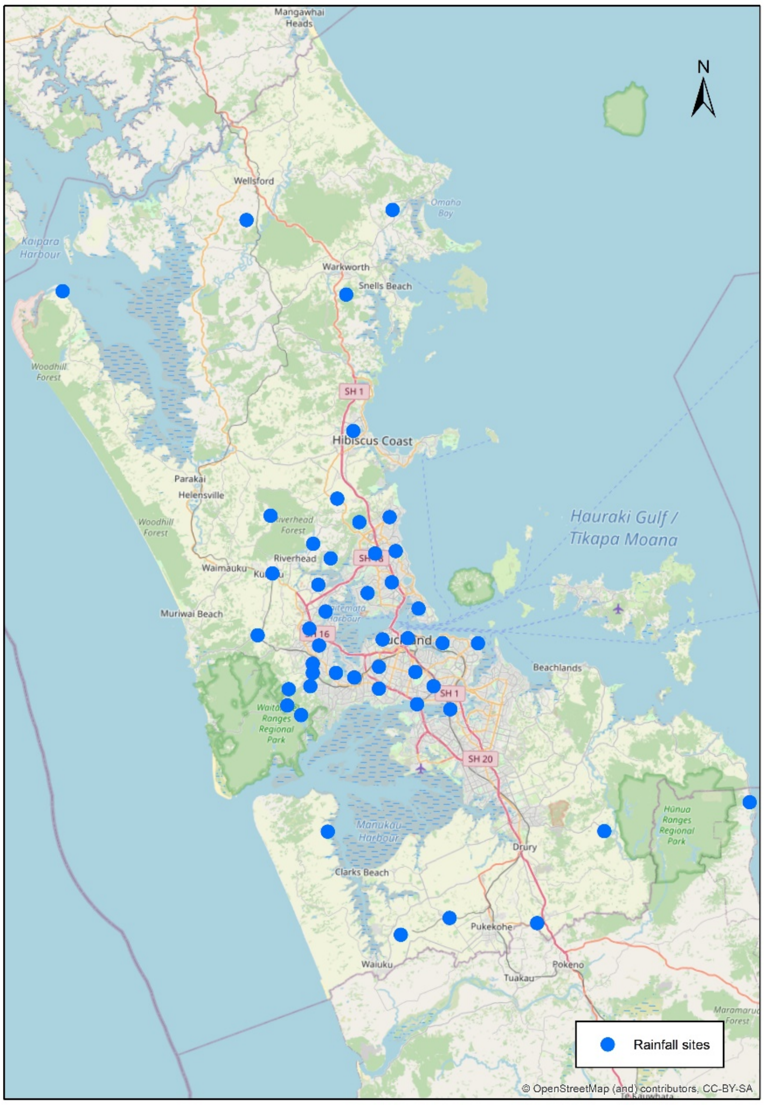

Figure 2-1: Location of rainfall sites used for this analysis.

The analysis of rainfall data was conducted using three datasets, based on time periods:

1. Calendar years from 1 January to 31 December
2. The "dry season" as 1 November to 30 April
3. The "wet season" as 1 May to 31 October

This was done to identify the temporal differences in rainfall that might best explain other hydrological phenomena like low soil moisture or river flows. For example, a "dry" summer followed by a "wet" winter can have an annual total rainfall that is close to the long-term average. However, the hydrological conditions through that year will be considerably different than a year with average summer and winter rainfall.

Rainfall analysis focused on producing regional average rainfall values. Sites were divided into two groups: all 46 sites with data for the period 2000-2020 and five sites with data for the period 1980-2020. Site details are included in Appendix 1. The five sites with data from 1980-2020 were:

1. Hoteo at Oldfields 643510
2. Ararimu at Zanders 647510
3. Whenuapai at Airbase 647601
4. Wairau at Testing Station 647722
5. Wairoa at Hunua Nursery 750010

These five sites also provide good spatial coverage of the region. The *annual total rainfall* was tabulated for all sites in the two groups (1980-2020 and 2000-2020). An average total rainfall across all sites was calculated for each year to produce an average rainfall record for the region. The rainfall network was assumed to be representative of the region. No weighting was applied to the averaging calculations, i.e. density of sites or sub-regional representativeness was not factored into the averaging process. The same process as applied above was completed for the *dry season* and *wet season* rainfall totals.

2.4 Soil moisture

Auckland Council operates 10 sites with soil moisture monitoring, 9 of which had sufficient data for analysis in this report (Figure 2-2).

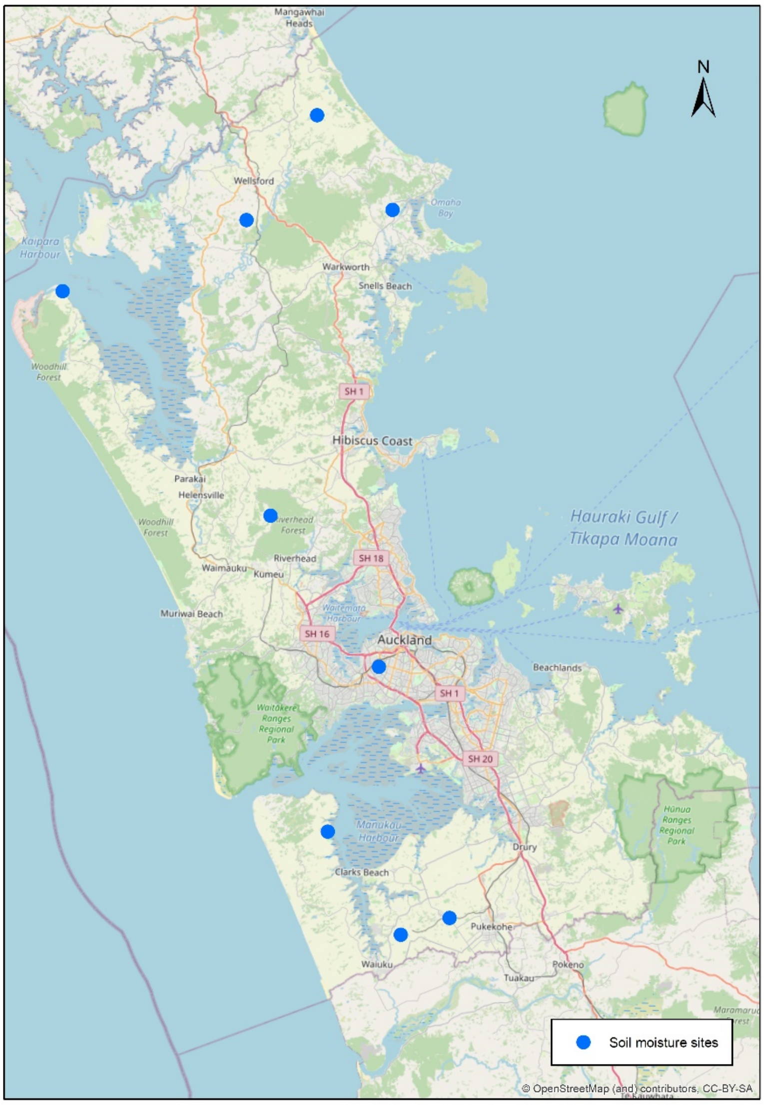

Figure 2-2: Location of soil moisture sites used for this analysis.

Soil moisture monitoring started in 2014, so records are shorter than other hydrological parameters in council's monitoring network. Comparative analysis of soil moisture to previous years can only be done for the period 2014-2020, thus potentially missing significant historical droughts. However, the soil moisture data provide valuable information to show the impact of the 2020 drought at a daily timestep and for context when assessing other analyses like rainfall or river flow.

To assess soil moisture over a longer period of time, NIWA's NZDI dataset for the Auckland Region was used. One component of the NZDI is soil moisture deficit, or SMD (NIWA 2021). This is the amount of water it would take for the soil to reach field capacity. The SMD is standardised to a field capacity of 150mm, representative of a typical loam soil. The SMD ranges from 0-150mm. A soil that is fully saturated would have an SMD of 0mm and a completely dry soil an SMD of 150mm. The SMD scale is transformed using a logarithmic function along with the three other components to calculate the NZDI on a scale of 0-3 (NIWA 2021). The transformed SMD data were used here, as it is the relative value of SMD, not the absolute, that is of interest when comparing across years.

Envelope plots for each site were used to show how the soil moisture of 2020 compared to the previous six years. These were based on a period of analysis for envelopes from the beginning of records to 30 June 2019. The trace commenced 1 July 2019 and finished 30 June 2020. This allows for easy visualisation of soil moisture over the November to April dry season as analysed for rainfall. The daily timestep presented in envelope plots provides information about both magnitude and duration of low soil moisture levels.

Soil moisture at all nine sites was assessed independently. Soil moisture levels at different sites cannot be compared directly due to variability between soil types, i.e. 40% soil moisture in soil type A does not equal 40% soil moisture in soil type B.

2.5 Rivers

Auckland Council operates 41 river flow monitoring sites. These sites provide data for multiple council programmes including State of the Environment reporting and flood management. This report uses data from 23 sites that have mean annual low flows (MALF) greater than 10 l/s, shown in Figure 2-3.

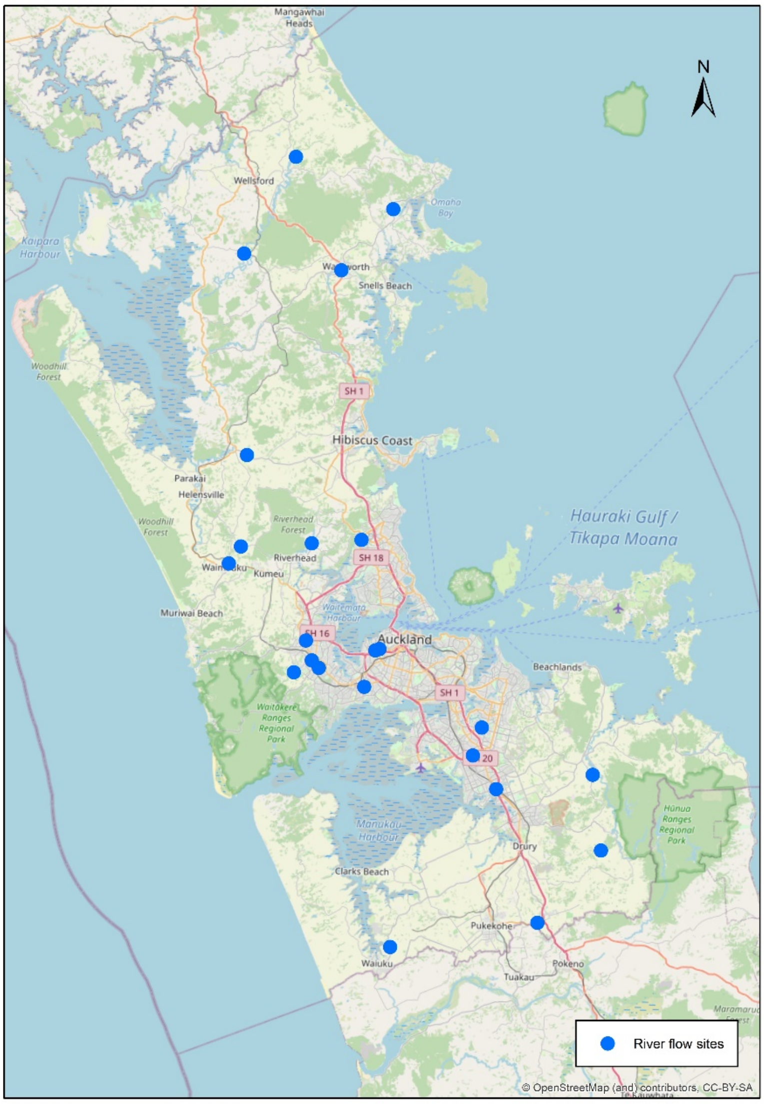

Figure 2-3: Location of river flow monitoring sites used for this analysis.

Sites with MALF less than 10 l/s were excluded due to difficulty in maintaining accurate ratings at such low flows as were present during much of 2020[2]. Manual flow gaugings were conducted throughout the summer of 2020 and several historical low flows were captured.

The analysis of flow data focused on magnitude and duration of low flows. Annual low flows were calculated for the seven-day average flow series. The lowest seven-day average flow for all years was

[2] Based on a review of rated flow data for the assessment of state and trends (Johnson 2021) which showed that flow ratings for small streams frequently exceeded 20% error against gauged flows when flows were less than 10 l/s. Zero flow conditions are also more common in these small streams.

compiled. The low flow data set was ranked by year to identify severe low flow periods in the flow record.

The seven-day annual low flows were used to calculate the seven-day mean annual low flow (MALF) for each river. An event threshold analysis was then run to determine the total number of days below the MALF for all years on record.

A regional low flow dataset was compiled based on the average of all low flow days across all 41 sites for the period 1980-2020. No weighting was applied to individual sites. This regional low flow dataset was used to compare years, with the regional average number of days below MALF serving as a proxy for drought severity.

2.5.1 MALF as a benchmark for flow analysis

The MALF is an important benchmark for river management. This statistic is generated by calculating a seven-day rolling mean of flows, then averaging the lowest seven-day flow of all years. It is often described as the lowest flow one might expect in any given year. Statistically, the MALF has a return period of approximately two years.

Most native freshwater fish species in New Zealand live for several years and reproduce annually, so flows at the MALF are likely to impact fish populations at some point in their lifespan (McDowall 2000). The MALF is thus a limiting factor on the instream life that a stream can sustain (Jowett, 1990; Clausen and Biggs, 1997; Jowett et al. 2005; Booker & Graynoth 2008 1 & 2). This includes primary production in streams where productivity can be affected by a reduction in habitat area, increases in temperature, and decreases in dissolved oxygen (Shearer and James 2020).

The natural flow of a river can be significantly affected by water takes, particularly during the dry months of the year when flows are typically at their lowest. Water takes have been found to cause significant reductions in key statistics like the MALF (Wilding 2018). Auckland Council allocates and manages water takes from streams based on the MALF. This metric is useful because it has ecological significance and is easy to apply in a water allocation framework (Franklin et al. 2012).

2.6 Lakes

Lake water level monitoring in the Auckland Region has occurred in several lakes over several different time periods. Only two lakes, Rototoa and Pupuke, have been monitored continuously at the same site since late 2005 and include water level over the 2020 summer period (Figure 2-4). Monitoring earlier than 2005 occurred at both lakes (Pupuke 1977-1989, Rototoa 1984-1999), but the original sites were disestablished, then new sites established in late 2005. As such, each lake has two independent records at unique sites.

Twelve new lake water level sites were added in early to mid-2021 as part of an expansion of Auckland Council's lake monitoring programme. These sites are not included in this report as none were in operation in 2020.

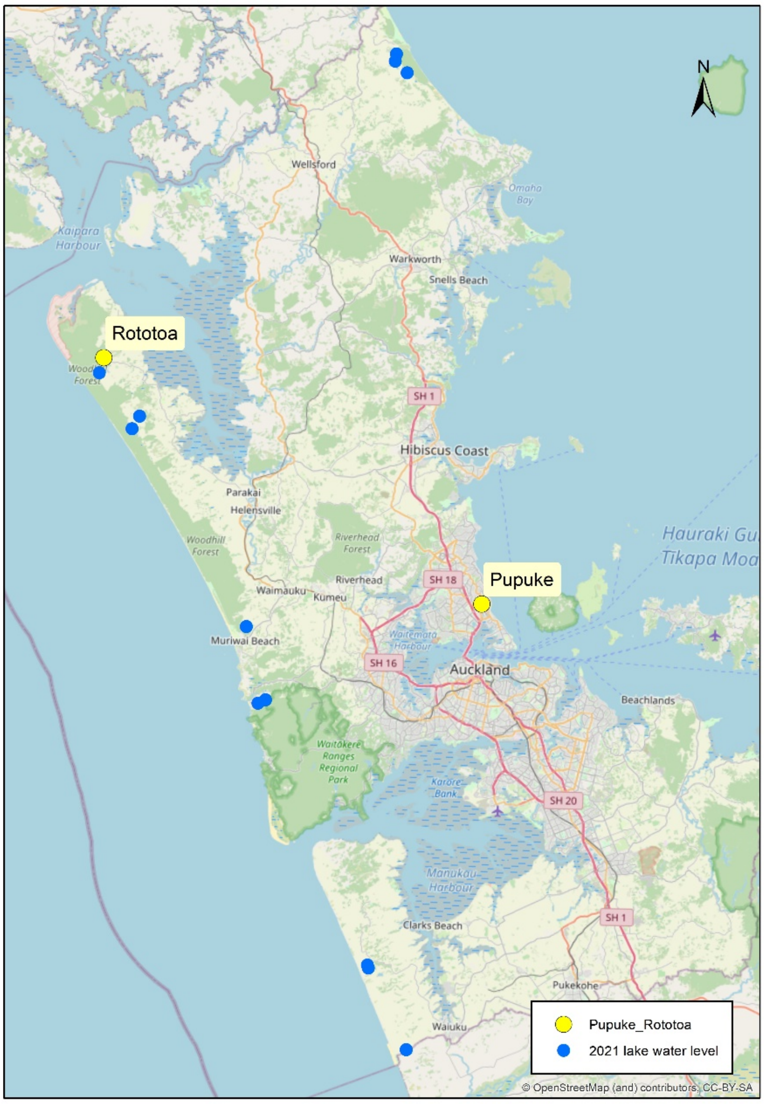

Figure 2-4: Location of lake water level monitoring sites; Rototoa and Pupuke and all other lakes added in 2021.

2.7 Groundwater

Auckland Council monitors 50 groundwater level sites (Figure 2-5), 14 of which have automatic water level recording with the data telemetered to council. The remainder are inspected manually for water level measurement each month.

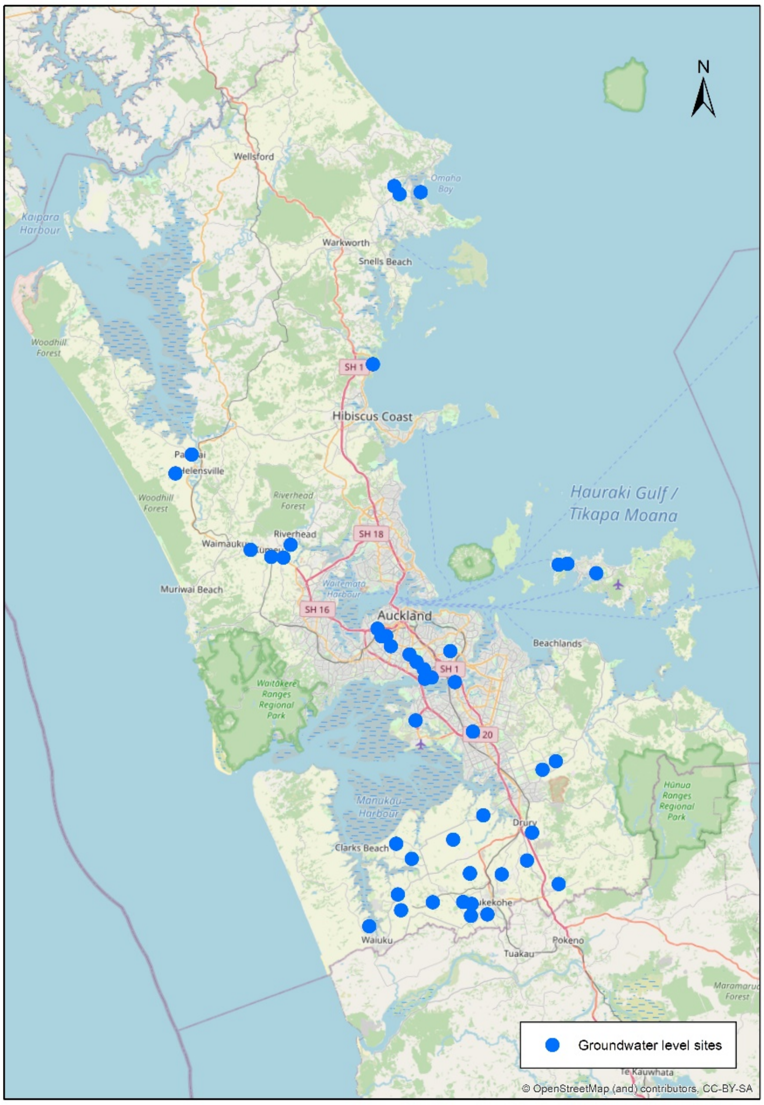

Figure 2-5: Location of groundwater level monitoring sites used for this analysis. Some sites are very close, so not all sites are visible at this map scale.

Groundwater levels were assessed against the historical record using envelope plots, as described in Section 2.2. These show groundwater levels from 1 July 2019 to 30 June 2020 against the entire 12-month statistical range. The full envelope plots for the entire year are provided in in Appendix 4.This allows for visualisation of groundwater levels over the November to April dry season as analysed for rainfall.

A summary table was compiled to simplify the envelope plots data for 50 sites data in a single table. The summary table was compiled using monthly averages of groundwater levels for each month from January to May (these four months contained the lowest groundwater levels of 2020 for all monitoring sites). Similarly, the statistics from the envelope plots were also averaged over each month; minimum, 25th percentile, 75th percentile, and maximum. Cells were highlighted where the observed 2020 groundwater levels were below the 25th percentile or the minimum.

Monthly average groundwater levels were compared against long-term monthly groundwater level statistics using envelope plots[3]. For ease of display in the report, a summary of the envelope plot results was tabulated, using the months of January to May. The range from January to May was chosen because the lowest groundwater level of the year fell within this range for all sites.

2.8 Water use data

This report does not include a comprehensive assessment of water use. River flow and groundwater level records are influenced by water abstraction, so incongruencies between datasets (e.g. rainfall and river flow) can potentially be a result of abstractive water use. Water use records are not able to be analysed in a comprehensive way at this time, i.e. at a level commensurate with the hydrological analysis, due to issues with data upload for consent holders, inability of databases to house compliance data, database connections between consents, and non-compliance in data submission.

[3] Note that envelope plots used the entire groundwater level record, so the number of years represented varies between sites. 28 sites have records commencing before 1993, and all commenced before 2013. Commencement dates for groundwater sites are in Appendix 1.

3 Results

3.1 New Zealand Drought Index

The New Zealand Drought Index (NZDI) provides a high-level starting point for assessing the severity of impacts on waterbodies. The NZDI has five drought severity categories:

- Dry NZDI 0.75-1.00
- Very Dry NZDI 1.00-1.25
- Extremely Dry NZDI 1.25-1.50
- Drought NZDI 1.50-1.75
- Severe Drought NZDI 1.75-2.50

The plot of NZDI for Auckland (Figure 3-1) clearly shows that the summer of 2020 had the highest drought index value since 2007 (note the NZDI is only available from 2007 onwards). Other *severe* category droughts (NZDI >1.75) occurred in in 2011, 2013, 2018, and 2010, in decreasing order of maximum NZDI severity. Given the historic peak in NZDI, significant impacts on waterbodies are to be expected.

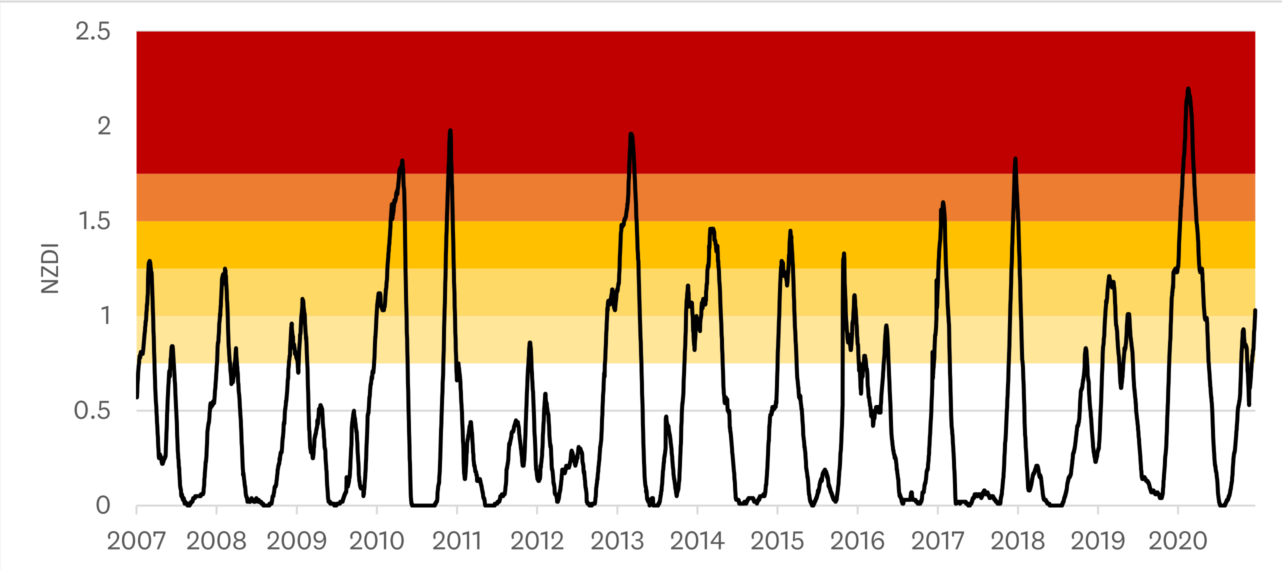

Figure 3-1: Plot of NZDI for the Auckland region for the years 2007-2020 with shading by severity category.

3.2 Rainfall

3.2.1 Regional average rainfall totals

The regional rainfall total for 2020 (12-month calendar year) was approximately 24% below the regional mean, the lowest rainfall year in the period 1980-2020 (Figure 3-2). Other years which were 10% or more below the regional mean were 2005, 2015, 2019. The longer rainfall record based on fewer sites showed two significant drought periods of 1981-82 and 1993. Both the short record and long record agree well between the regional average total rainfall, demonstrating the near representativeness of the five sites with long-term record for the entire region.

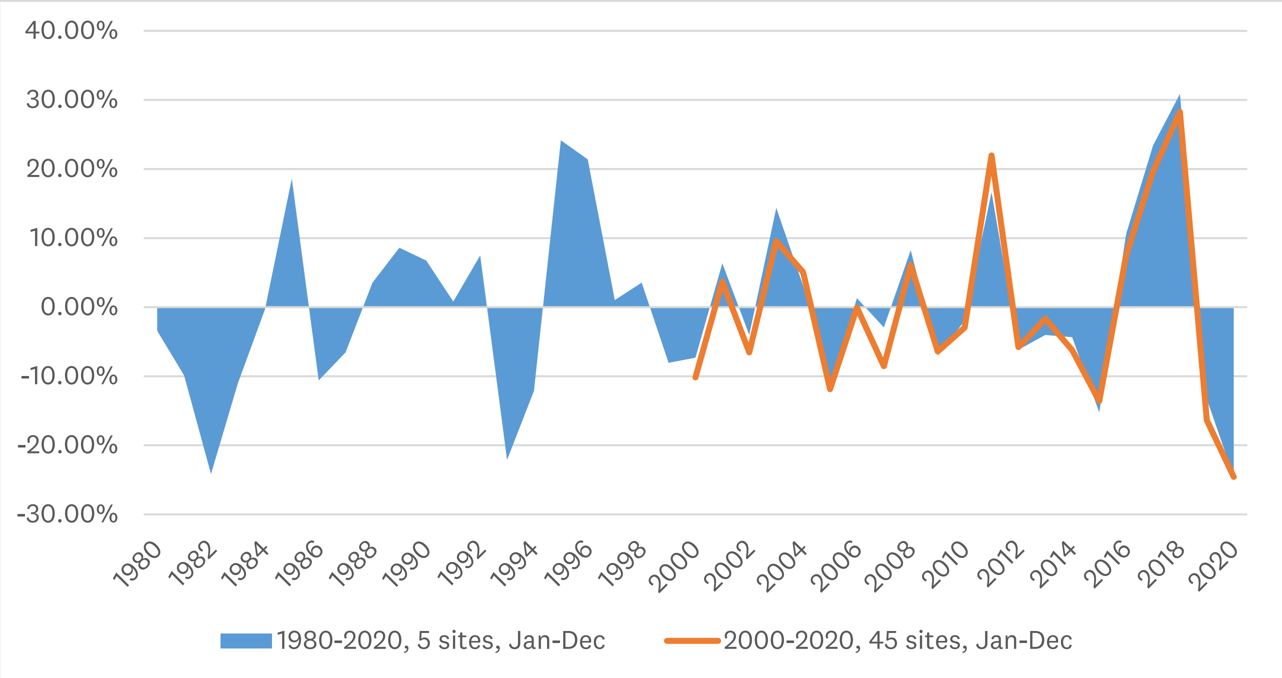

Figure 3-2: Deviation from the long-term mean of the annual regional total rainfall for the calendar year period 1980-2020.

The regional rainfall total for the dry season period 1 November 2019-31 April 2020 was approximately 52% below the regional mean, the lowest rainfall year in the period 1980 to 2020 (Figure 3-3). The results of isolating the dry season were similar to the 12-month calendar year in the direction of deviation, but the magnitude of the deviation was nearly twice as high (approx. ±60% for the dry season analysis vs ± 30% for the calendar year analysis). Although relatively consistent, some changes in the direction of deviation occurred for some years.

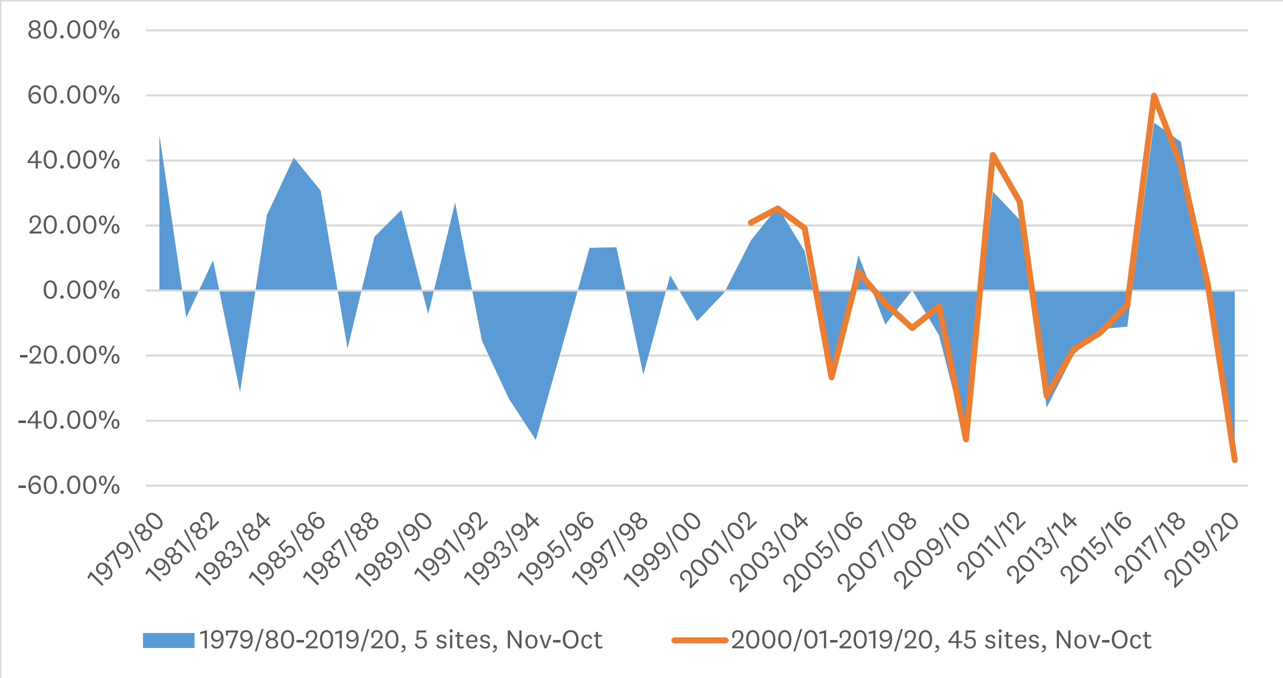

Figure 3-3: Deviation from the long-term mean of the annual regional Dry Season rainfall (Nov-Apr) for the period 1979/80-2019/20.

The regional rainfall totals for the wet season analysis did not exhibit the same patterns as previous analyses. The negative deviations at the start of the period of analysis were larger and more frequent than the 12-month or dry season analyses (Figure 3-4). The wet season analysis did not show the large variations between positive and negative deviations in the period 2016-2020 that were seen in the dry season analysis.

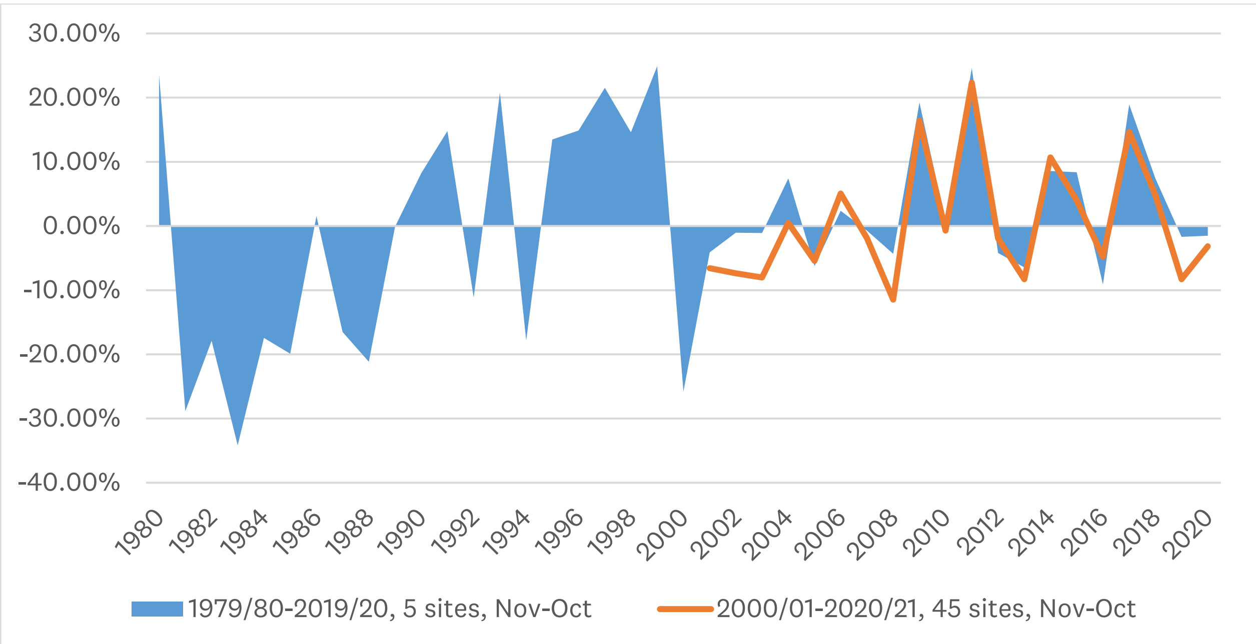

Figure 3-4: Deviation from the long-term mean of the annual regional Wet Season (May-Oct) for the period 1980-2020.

3.3 Soil moisture

Soil moisture levels reflected the low rainfall observed for 2020. Sharp drops in soil moisture occurred throughout the region in late October to early November. As expected, a comparison with the modelled regional soil moisture deficit (SMD) showed a strong inverse relationship between observed soil moisture and SMD (Figure 3-5).

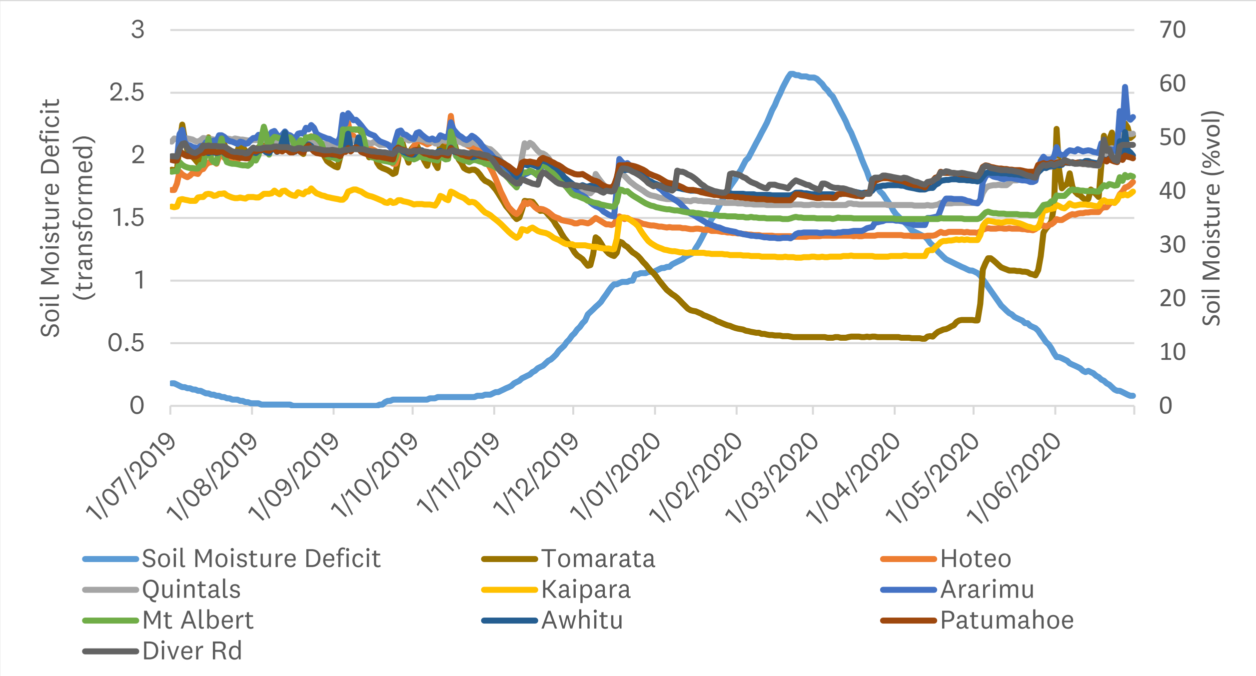

Figure 3-5: Observed soil moisture vs regional soil moisture deficit (SMD source: NIWA).

The full SMD dataset from NIWA from 2007-2020 shows that 2020 had the highest SMD, with the next highest SMDs in 2013 and 2010, respectively (Figure 3-6).

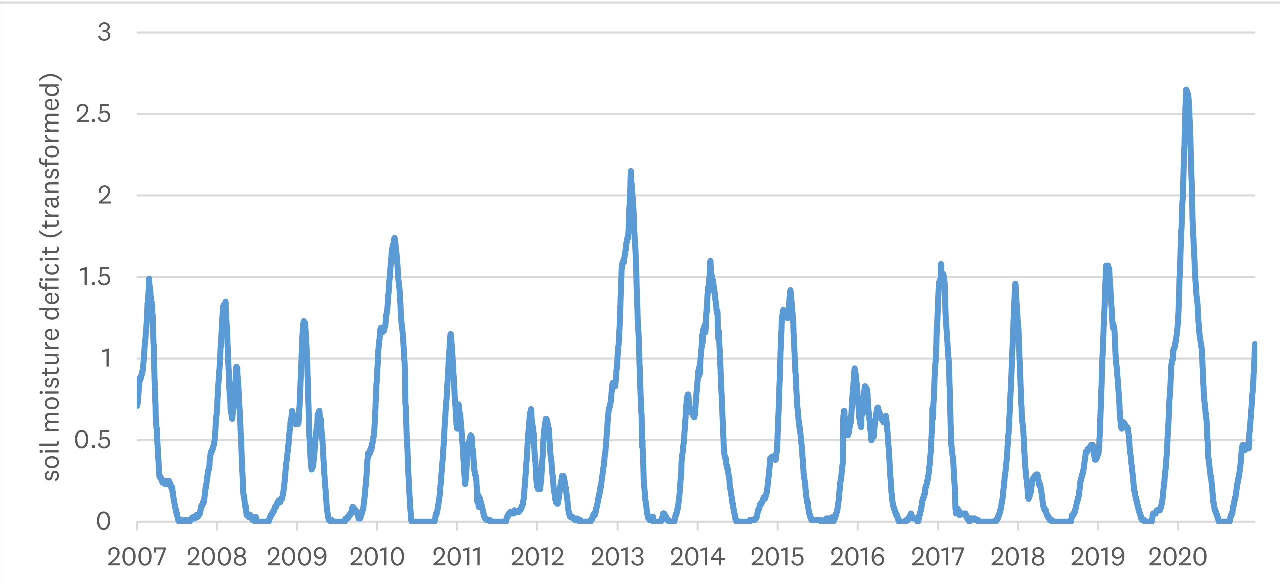

Figure 3-6: Auckland regional soil moisture deficit (Source: NIWA).

In the envelope plots, all sites showed moisture percentages below the interquartile range (IQR) for contiguous periods of multiple months, many of which also showed multiple months below the historical minimum[4]. Tomarata at Brien's Farm (north-east part of the region) had the most marked drop in soil moisture. Soil moisture levels were below the IQR for the entire period from 17/11/2019 to 1/06/2020, a total of 197 days (Figure 3-7). Soil moisture envelope plots for all sites are provided in Appendix 2.

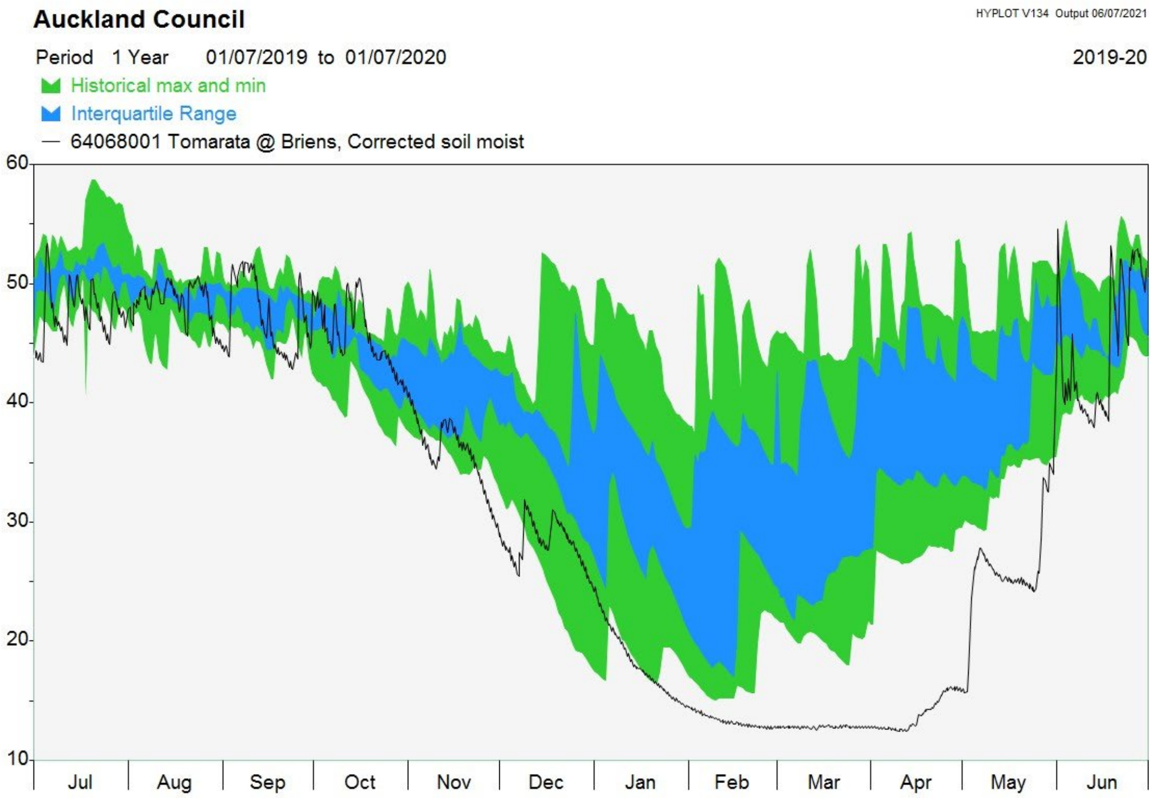

Figure 3-7: Example soil moisture envelope plot for Tomarata at Briens Farm for the period 1 July 2019 to 30 June 2020.

[4] Soil moisture monitoring commenced in 2014, so observations below the IQR or historical minimum are only indicative of the previous six years.

3.4 River flows

Flows were analysed for both the magnitude and duration of low flows. The magnitude of low flows was assessed based on the lowest seven-day mean flow. Nine sites had the lowest seven-day mean on record (or tied with the lowest on record). The locations of the sites were widespread across the region (Figure 3-8).

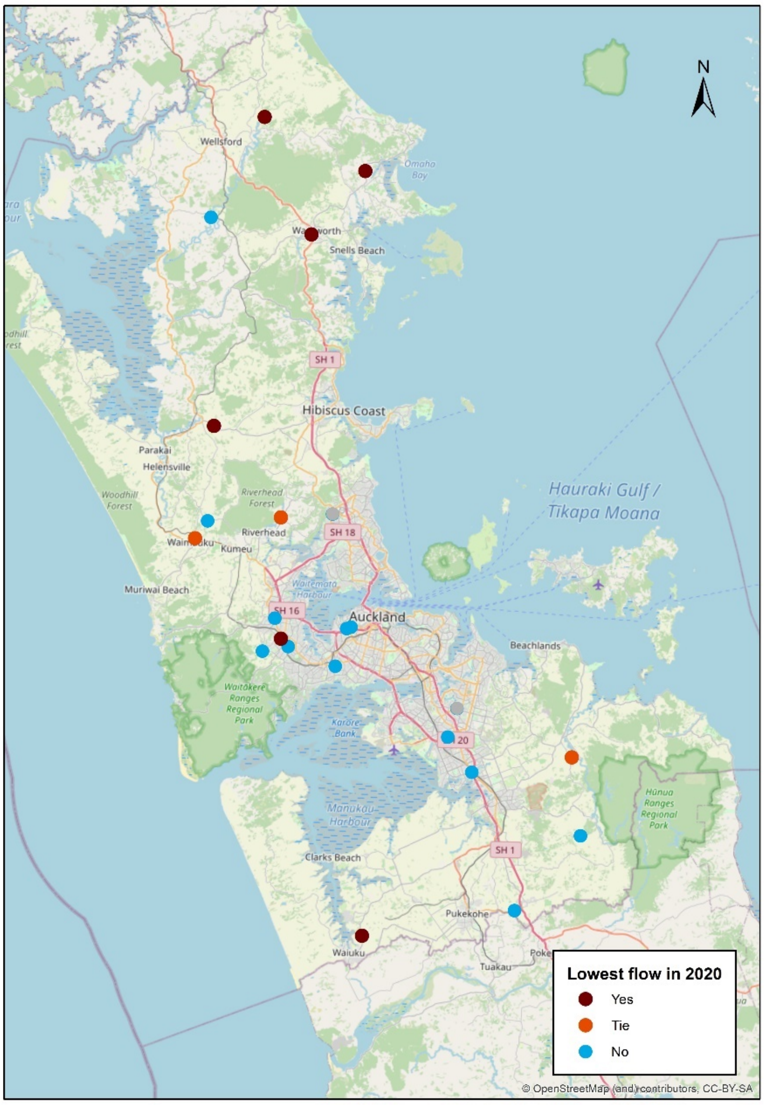

Figure 3-8: Location of flow sites with lowest seven-day mean flow on record during 2020.

The duration of low flows was assessed based on the number of days below the seven-day mean annual low flow (MALF). The greatest number of days below the MALF occurred in 2020 for 13 of the 23 streams analysed (Figure 3-9). Fourteen sites had greater than 90 days below MALF in 2020. Annual days below MALF for all sites are provided in Appendix 3.

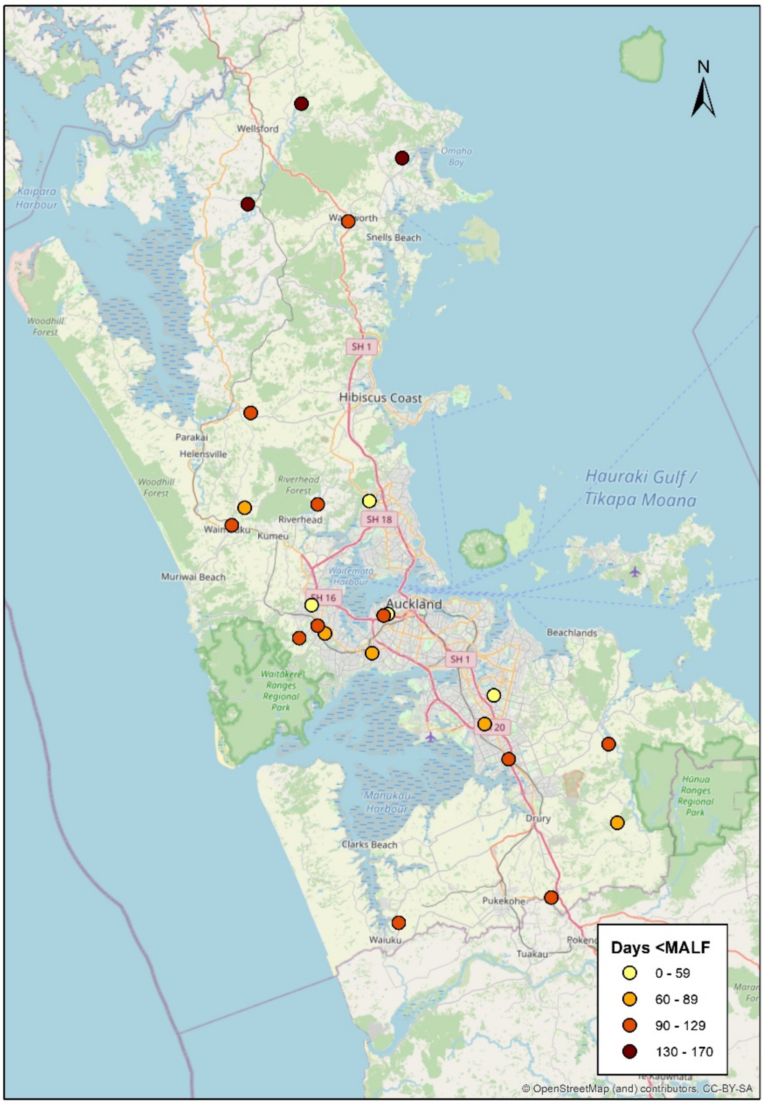

Figure 3-9: Days below MALF during 2020.

The regional average total number of days below the MALF was used as a relative indicator of drought severity at the regional scale, i.e. more days below MALF indicates more severe drought. 2020 had the greatest number of low flow days over the period of analysis from 1980 to 2020 (Figure 3-10).

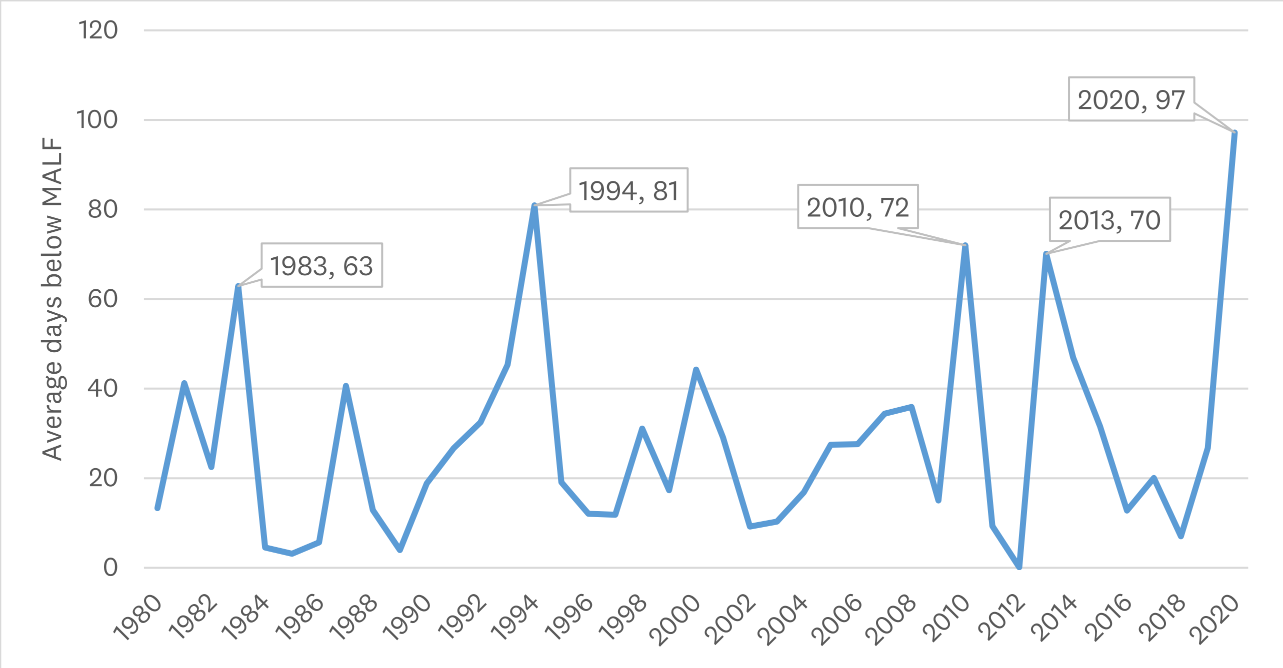

Figure 3-10: Regional average days below MALF.

3.5 Lake water levels

3.5.1 Lake Rototoa

Water level data for Lake Rototoa is available at two sites over two different time periods: 1984-1999 and 2005-present (Figure 3-11). The more recent water level record is presented here for the purpose of comparing the 2020 summer period in a similar context to other hydrographic data (rainfall, river flows, groundwater levels). All water level data are provided in Appendix 4.

The record from 2006-2020, inclusive, shows that water levels in the lake remained within a consistent range of approximately 0.6 and 1.0 mRL. Annual water level fluctuation generally ranged between 0.5 and 1 metre. The water level during the 2020 summer was an exception, dropping to a record low of 0.445 mRL (also lower than all data in the 1984-1999 record).

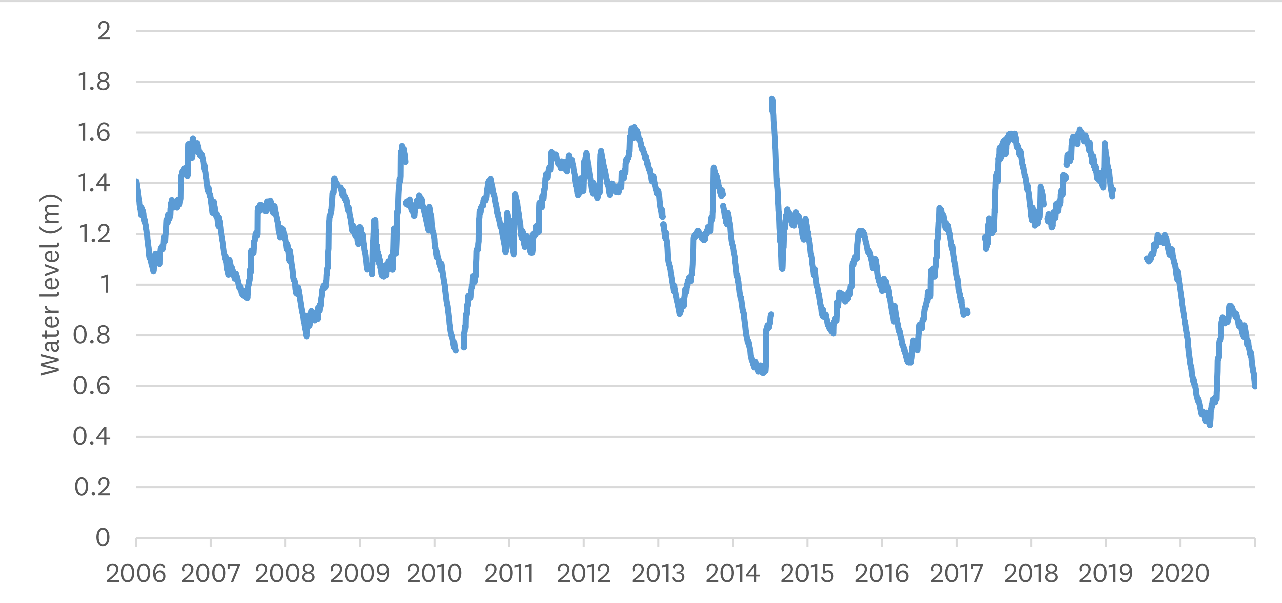

Figure 3-11: Lake Rototoa water level hydrograph.

3.5.2 Lake Pupuke

Water level data for Lake Pupuke is available at two sites over two different time periods: 1977-1989 and 2005-present. The more recent water level record is presented here for the purpose of comparing the 2020 summer period in a similar context to other hydrographic data (rainfall, river flows, groundwater levels). The full hydrograph from 1977-2020 is provided in Appendix 4.

Water levels ranged from approximately 0.5m to 2.0m, with a seasonal fluctuation of approximately 0.5m (Figure 3-12). The lowest water level in the period 2006-2020 was during the summer of 2013. This followed a greater than 2 m decline in water levels following the high in 2011. Lake levels remained relatively low from 2013 until late 2016. A similar magnitude drop in lake level occurred in 2010 (also a dry year), but was followed by a wet year in 2011, during which lake levels rose to those observed in previous years.

Water levels rose to the highest levels on record during 2017 and 2018. A water level decline of over 2 metres occurred from 2018 to 2020, but the lowest water level during 2020 was approximately 0.2m greater than the low of 2013.

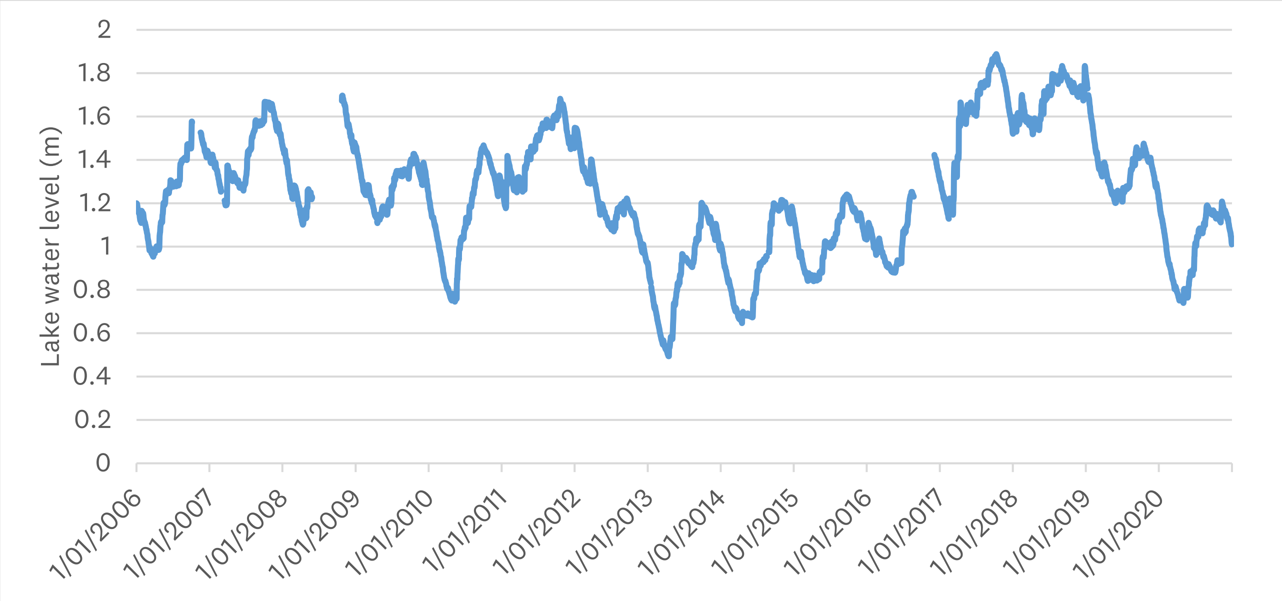

Figure 3-12: Lake Pupuke water level hydrograph.

3.6 Groundwater levels

Groundwater levels during 2020 exhibited extreme lows for many aquifers across the region. Some sites had groundwater levels were lower than the interquartile range (IQR) for the entire year of 2020, with extended periods lower than the historical minimum level on record.

Monthly average groundwater levels were compared against long-term monthly groundwater level statistics using the envelope plot method[5]. For ease of display, a summary of the envelope plot results was compiled in Table 3-1, using the months of January to May. The range from January to May was chosen because the lowest groundwater level of the year fell within this range for all sites. The full envelope plots for the entire year are provided in in Appendix 4. These show the 2020 groundwater levels against the entire 12-month statistical range.

Thirty-five sites had monthly groundwater levels in 2020 that were lower than the long-term IQR for that month. Thirty-one of those sites had at least one month that was lower than the 25th percentile groundwater level for that month. Twelve of those sites had at least one month in 2020 that was the lowest on record for that month. Note that groundwater sites in Table 3-1 are ordered by their coordinate-based site number, so the sites are arranged approximately north to south.

[5] Note that envelope plots used the entire groundwater level record, so the number of years represented varies between sites. 28 sites have records commencing before 1993, and all commenced before 2013.

Table 3-1: Comparison of 2020 monthly average groundwater levels against the long-term minimum, 25th percentile, and interquartile range for months Jan-May (values in mRL, NZVD2016).

Site	Site name	Jan-20	Feb-20	Mar-20	Apr-20	May-20
Less than long-term interquartile range						
Less than the long-term 25th percentile						
Less than the long-term minimum						
6437005	Quintals Road Omaha	5.52	4.91	4.57	4.52	5.16
6437021	Omaha Flats Bore 25	1.13	0.81	0.95	1.01	2.74
6437087	Caroline Heights	1.26	1.09	0.88	0.95	1.03
6457041	Waiwera Beachfront Deep	2.75	2.80	2.82	2.84	2.79
6457097	Waiwera Beachfront Shallow	2.76	2.83	2.82	2.81	2.80
6464007	Parakai 86	2.99	2.99	2.73	3.65	3.10
6464089	Rimmer Road	4.39	4.20	4.16	4.22	4.33
6474003	Waitākere Road #2	13.50	2.20	3.69	16.93	19.49
6475003	Selaks Bore Kumeu	22.30	19.84	18.79	19.17	20.15
6475005	Trigg Road	21.64	21.11	20.42	20.04	20.09
6475157	Short Road Riverhead	18.45	17.67	17.14	16.87	16.73
6479007	Nick Johnstone Drive	30.82	30.96	30.88	30.72	30.53
6487001	Volcanic street	37.81	37.75	37.73	37.74	37.89
6487007	Selkirk Road	18.47	18.01	17.89	17.80	18.36
6487009	Leslie Road	27.14	26.52	26.39	26.21	26.78
6487021	Chamberlain Park	10.85	10.65	10.62	10.73	10.93
6488045	PD-13S	20.14	19.87	19.70	20.05	21.17
6497007	Alfred/Grey St	2.67	2.54	2.38	2.43	2.98
6497013	Cemetery Bore	1.58	1.45	1.42	1.50	1.68
6497015	Orakau Ave	37.96	37.09	36.71	36.74	36.87
6497017	Amelia Earhart	3.11	2.86	2.79	2.84	2.87
6497019	Tiwai Road	15.41	14.55	14.53	15.07	15.24
6498003	Angle Street	2.45	2.43	2.46	2.47	2.54
6498035	Puhinui at Lambie Drive	23.33	23.03	22.73	22.53	22.46
6570013	Mako Road		5.84	5.76	5.66	5.60
6570015	Tawaipareira	1.94	1.46	1.27	1.39	1.67
6594001	Mt Richmond	-3.04	-3.30	-3.56	-3.80	-4.00
7409001	Burnside Road	25.99	23.53	22.09	22.34	24.47
7409011	Bullens Road	21.87	20.66	20.08	18.99	18.56
7417001	Glenbrook Hall	7.95	7.50	7.60	8.09	8.49
7417021	Seagrove Road Main	4.50	3.78	3.36	3.40	3.78
7418003	Waiau Pa Bore 2C	4.82	3.92	6.46	9.88	10.47
7418013	Batty Road	21.93	21.77	21.62	21.54	21.59
7418023	Ostrich Farm Road #2	20.05	19.87	19.77	19.79	19.92
7418027	Ostrich Farm Road Obs	20.28	20.11	20.01	20.03	20.15
7419003	Tuhimata Road	23.48	23.09	22.85	22.81	22.93
7419007	Fielding Road Sand	6.38	5.08	5.09	6.29	7.82
7419009	Fielding Road Volcanic	14.42	14.14	13.98	13.94	14.03
7419011	Cooper Road	14.24	13.09	13.80	15.47	16.58
7419013	Fielding Road Waitematā	11.92	11.42	11.17	11.11	11.12
7419119	Karaka #2	3.68	3.05	2.78	2.96	3.19
7427003	Divers Road	4.10	5.43	7.79	10.26	11.58
7427005	Maraeorahia	1.34	1.00	1.38	1.84	2.10
7428043	Pukekohe DSIR	49.20	49.17	49.20	49.23	49.26

Site	Site name	Jan-20	Feb-20	Mar-20	Apr-20	May-20
7428047	Mauku Main	26.19	25.62	25.72	26.29	26.58
7428103	Rifle Range Deep	47.86	47.39	47.48	48.13	48.94
7428105	Rifle Range Shallow	56.77	56.82	56.51	56.14	56.30
7429011	Revell Court	62.87	62.51	62.18	61.92	61.82
7429013	Douglas Road Volcanic	51.01	50.59	50.48	50.42	50.42
7510005	Wooten Road	157.18	156.44	155.87	155.48	155.19

3.6.1 Sands

The groundwater level at Rimmer Road (Helensville) was within the interquartile range (IQR) for all of 2020. The sand aquifer at Fielding Road (Drury) was below the IQR in early 2020 but increased to normal levels through the middle of the year before dropping below the IQR in late 2020.

3.6.2 Volcanics

Monitoring wells in the Onehunga Volcanic aquifer showed mostly low groundwater levels (below IQR) throughout 2020 except for Tiwai Road and Angle Street. Tiwai Road, in the central area of the aquifer, had groundwater levels in the normal range (inter-IQR) for most of 2020. Angle Street, at the down-gradient extent of the aquifer, had groundwater levels in the high to normal range for most of 2020.

Wells in the Three Kings volcanic aquifer had sub-IQR groundwater levels until May 2020, then were variable, ranging from high to low and frequently within the normal range (inter-IQR) for the remainder of the year.

The one monitoring well in the Mt Richmond aquifer had groundwater levels within the normal range for the entire year.

The one monitoring well in the Drury Volcanic aquifer had groundwater levels in the low to very low range (sub-IQR).

3.6.3 Kaawa shell

Glenbrook Kaawa monitoring wells (4) generally had groundwater levels below the IQR for most of 2020. Glenbrook Hall was the only site that had high groundwater levels (above the IQR), which occurred from March through December 2020. Mauku Main had normal levels from mid to late 2020.

The one site in the Awhitu Kaawa, Maraeorahia, was below the IQR for all of 2020.

The one site in the Waiuku Kaawa, Diver Road, had very low (below historical minimum) groundwater levels in early 2020, followed by sub-IQR levels for the remainder of the year.

The two deeper monitoring wells of the Pukekohe Kaawa had normal groundwater levels for much of 2020. The shallower monitoring well, Ostrich Farm #2, had low groundwater levels (sub-IQR) for all of 2020.

3.6.4 Greywacke

The only greywacke aquifer currently monitored is at Waiheke Island. Groundwater levels at Tawaipareira, in the central west aquifer area, were below the historical minimum for all of 2020 (the site was installed in 2015). The site at Nick Johnstone Road, in the western aquifer area, had groundwater levels that were above the IQR at the start of 2020, progressing to sub-IQR levels in late 2020.

3.6.5 Deep Waitematā Group

The Omaha Waitematā aquifer has three monitoring wells. Quintals Road and Omaha Flats bore 25 are located near most of the water takes in the centre of the aquifer and exhibit pumping effects. Both showed very low (below the historical minimum) groundwater levels for much of 2020. The site at Caroline Heights on the Omaha Spit had groundwater levels above the IQR for most of 2020.

The Kumeu Waitematā aquifer had high groundwater levels (above the IQR) at the far west and far eastern extents for most of 2020. Sites in the central areas of the aquifer showed low groundwater levels, particularly in the early months of 2020.

Lambie Drive, in the Manukau Waitematā aquifer, started 2020 with normal groundwater levels, but dropped below the IQR in March and remained below the IQR for the remainder of 2020.

The Clevedon Waitematā aquifer had groundwater levels below the IQR for all of 2020. This included historically low levels at Bullens Road for periods, while Burnside Road groundwater levels were below the historical minimum for almost all of 2020.

Fielding Road, in the Bombay-Drury Waitematā and Karaka #2 in the Karaka Waitematā, both had groundwater levels below the historical minimum for all of 2020. Seagrove Road, further to the west in the Waiau Pa Waitematā, had low groundwater levels (below IQR) in early 2020 and normal levels from mid to late 2020.

3.6.6 Geothermal

Groundwater levels in the Waiwera geothermal aquifer have been elevated compared to the historical record after stoppage of the largest groundwater take in 2018. This is discussed in more detail in the five-yearly State of the Environment Report (Johnson 2021).

The Parakai geothermal aquifer had normal groundwater levels (inter-IQR) for all of 2020. However, there were sharp groundwater level increases during Covid-19 travel restrictions.

3.7 Covid-19 lockdown effects

The effects of the Covid-19 travel restrictions (aka lockdowns) were clearly seen in groundwater level monitoring of the Parakai geothermal aquifer. Water use data from the Parakai Springs hot pools complex showed that pumping ceased on 24 March 2020, which coincided with the announcement that New Zealand would enter Level 4 lockdown on the 26th (Figure 3-13). The groundwater hydrograph for Parakai Bore 86 clearly shows a recovery phase of aquifer water levels immediately following the cessation of pumping. Groundwater level recovery continued until 5 May 2020 at which time levels dropped sharply, coinciding with re-commenced pumping. The aquifer resumed the typical seasonal water level conditions after both travel restriction periods.

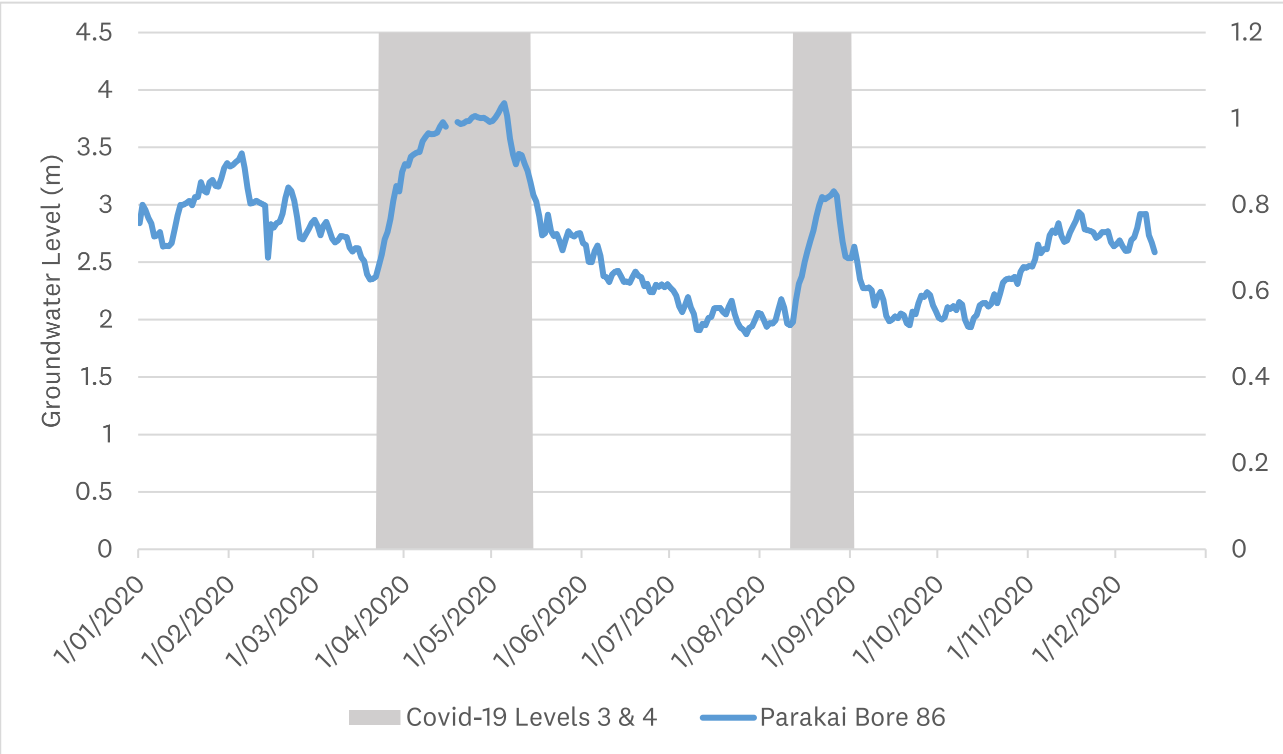

Figure 3-13: Groundwater level at Parakai Bore 86 and periods of Covid-19 alert levels 3 and 4 during 2020.

4 Discussion

4.1 Rainfall

Rainfall was analysed using three datasets:

- Calendar year – this is the most straightforward analysis and is easy to relate to other analyses which focus on the calendar year. Annual low values are consistently captured within the calendar year. There is low risk of missing the annual low rainfall, i.e. the lowest summer rainfall consistently occurs after 1 January.
- Dry Season – isolating the driest months (November-May) is of most importance to agriculture. This analysis removes high rainfall in the wet season that could mask the severity of dryness when totalled over an entire year (i.e. a significant drought followed by a wet winter can lead to a 'normal' annual total).
- Wet season – This analysis eliminates the dry season to better show the magnitude of rainfall outside the summer growing season and better characterises the potential for high river flows, lake levels, and groundwater recharge.

The calendar year analysis clearly showed the historic impact of the 2020 drought, however the dry season and wet season analyses were more revealing of extremes. The total dry season rainfall for 2020 was 52% less than the dry season mean for 1989-2020. The dry season analysis also had twice the deviation from the mean than the calendar year, which highlights the effectiveness of removing wet season data when assessing the severity of the dry season with respect to rainfall.

Wet season analysis showed that patterns observed in annual totals and dry season totals were not reflected in the wet season. This analysis is most useful in assessing the antecedent rainfall conditions prior to the onset of the dry season and for assessing the relative impact of successive annual cycles on dry season severity. For example, the wet season analysis for the period 2016-2020 showed that there was little deviation from the mean and little difference year on year. This indicates that wet season conditions were relatively consistent and that the severity of the 2020 drought on waterbodies was mostly a result of severely low rainfall in that year, not cumulative impacts of previous years.

4.2 Soil moisture

Soil moisture sites have only been in place since 2014 and so have limited value in assessing historical drought severity. However, the high-resolution datasets (15-minute interval) allow for a detailed review of the progression of soil moisture levels in 2020. These plots are complementary to other datasets when assessing statistics from longer records, i.e. a soil moisture envelope plot for 2020 is useful to provide context for 2020 rainfall, river flow, or groundwater level statistics. The NIWA soil moisture deficit data provide context for severity over the longer term, indicating that soil moisture was lower in 2020 than any time from 2007.

4.3 River flow

River flow statistics for 2020 show that the drought was historically significant, both in duration and magnitude of low flows. This report also used a regional average dataset for low flows, based on the average number of days below the MALF across all sites. This provided useful insight into the overall impacts of droughts throughout the flow record. The 2020 drought had the highest number of days below the MALF for the periods of analysis from 1980-2020.

Sites with extreme low flows were also reviewed for any spatial patterns to determine if certain rivers or catchments in the Auckland Region were more affected by the drought. Thirteen of the 23 sites analysed had greater than 90 days of flow below the MALF. These sites were located throughout the region and did not show an obvious spatial pattern to the number of low flow days, however the three sites with more than 130 days below MALF were the most northern three sites. Sites with greater than 90 days below MALF were in various geological terrains, including low-baseflow sedimentary rocks (most of the sites in the north), volcaniclastic rocks (Waitākere Ranges), greywacke basement (Hunua Ranges) and high-baseflow basalts (southern sites). This demonstrates the impact of the drought on a wide range of catchment types. The ecological significance of MALF suggests that the extended periods of extreme low flows in 2020 likely had negative consequences for instream biota.

River flow data are unnaturalised, i.e. not corrected for water abstraction. The magnitude of low flow days did not perfectly match the magnitude of low rainfall years. One possible cause is that the flow data used are unnaturalised. Therefore, water abstraction may have a variable influence on river flows depending on several factors, including antecedent climatic conditions that affect water use demand, primarily for irrigation. It is possible that low flows in 2010 and 2013 were more strongly affected by irrigation than past dry seasons like 1994 and 1983 when summer low flows were not as low. The relatively high summer flows of 2019 do not match well against the low annual rainfall total, but the dry season rainfall was near the long-term mean.

4.4 Lake water level

The lake water level hydrographs showed a distinct difference between Rototoa and Pupuke for the summer of 2020. Rototoa had the lowest lake water level on record during 2020, which is generally consistent with observations of rainfall, soil moisture, river flows, and groundwater. Pupuke, however, did not decline to historic low water levels, rather the 2020 hydrograph was similar to 2014 or 2015, which were not drought years.

Lake Pupuke had sustained low water levels from 2013-2016. This is a three-year period following a historic drought in 2013. The low water levels during this period indicate that multiple years with only average rainfall may not provide sufficient inflows to allow the lake to recover from severe droughts (noting that 2013 was a severe drought). The impact of the 2020 drought didn’t result in as low a lake level as 2013. It appears that the rise in lake levels to historic highs during the wet years of 2017 and 2018 significantly buffered the impact of the 2020 drought.

The two lake hydrographs show a very similar seasonal pattern when overlayed, in both the timing of the seasonal fluctuation and the magnitude of the fluctuation (Figure 4-1). This indicates that the overall climatic drivers of lake amplitude (winter highs and summer lows) affect the lakes in similar ways. This may only be coincidental however, given their distinctly different geology, topography, bathymetry, and volume.

Lake level data are unnaturalised, i.e. not adjusted for water abstraction. The actual or potential impact of water takes has not been investigated.

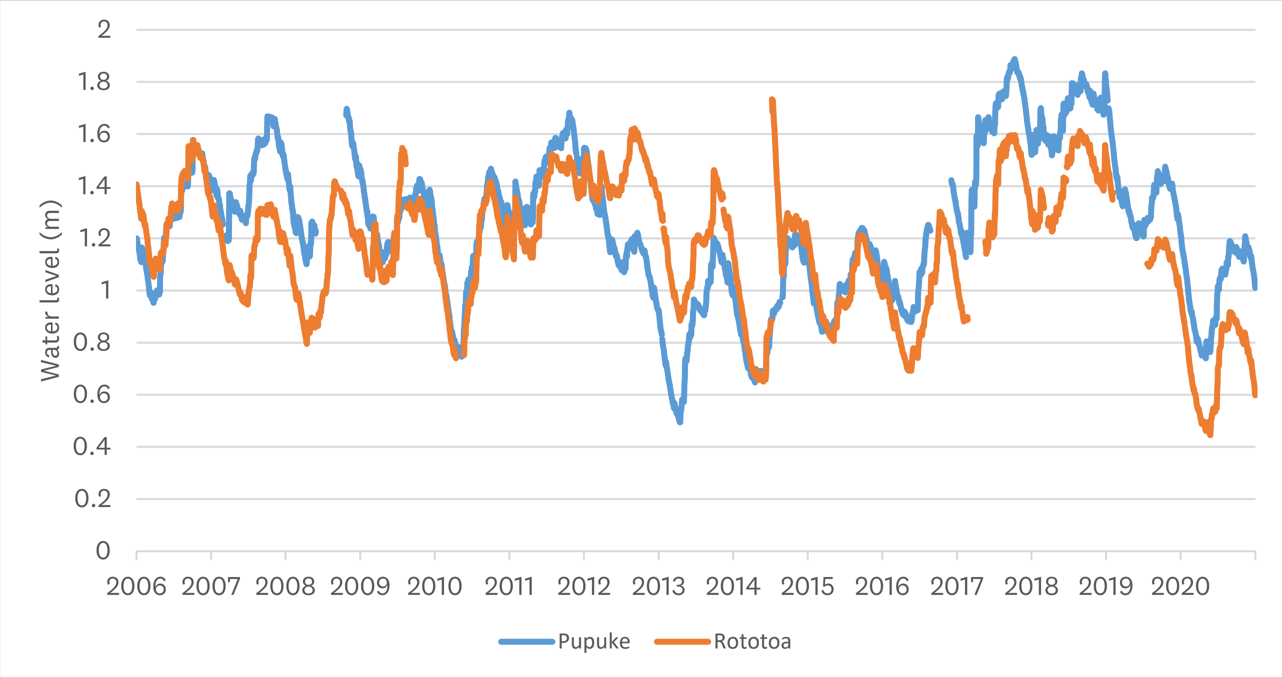

Figure 4-1: Lake Pupuke and Lake Rototoa water level hydrographs.

4.5 Groundwater levels

Groundwater levels exhibited different patterns based on location, geology type, and degree of confinement, but noticeable drought effects in 2020 appear in the majority of records. The groundwater level effects can be described as two major types: immediate declines as a result of groundwater use, and gradual declines due to reduced recharge. Many aquifers had sustained low levels beyond the summer irrigation period, most likely due to reduced recharge. The responses observed in aquifers across the region are described here by geology type.

4.5.1 Sands

The groundwater level record at Rimmer Road (Helensville) showed that the entire 2020 hydrograph was within the interquartile range (IQR), indicating no noticeable effect of the drought. This result is somewhat counter-intuitive as shallow, unconfined sands would be expected to be greatly affected by climatic conditions, assuming the aquifer maintains typical throughflow and discharge to a sink (either surface water or another aquifer).

The groundwater level at Fielding Road (sand aquifer) was below the interquartile range for early 2020 and increased to within the IQR from May through September, dropping back into the low range for the remainder of the year. Overall, the impact of the drought on water levels in this aquifer was less than many other aquifers in the region.

4.5.2 Volcanics

Most sites in the Auckland isthmus (7 of 10) had groundwater levels below the IQR in the first few months of 2020. Three of the seven sites had sub-IQR groundwater levels for the entire year. The remaining three sites had groundwater levels in the normal or high range.

Generally, the effects of the drought were more pronounced in the summer months and eased as the year progressed and rainfall increased. This follows a conceptual model of shallow unconfined volcanic aquifers that respond relatively directly with rainfall, where increased groundwater levels occurred as rainfall increased in mid-late 2020.

4.5.3 Kaawa

Groundwater levels at several sites in the Kaawa were very low or low at the start of 2020, which indicates a more rapid drop in water levels than would be expected for a confined aquifer, most likely driven by water takes. Climatic pressures may have been less of a driver for low groundwater levels than irrigation demand in the case of the Kaawa aquifer. A line of reasoning to support this idea is that low rainfall starting in November 2019 was unlikely to have affected groundwater levels by early 2020, but high irrigation demand would have begun right away, leading to increased groundwater withdrawals, thus affecting groundwater levels in step with low rainfall.

4.5.4 Waitematā

Waitematā aquifers all exhibited low to very low groundwater levels. Wells in Omaha and Kumeu at the marginal extent of the aquifers showed little or no affect in groundwater levels (levels were in the normal range) while wells closer to the main abstractive centres showed large declines in groundwater levels at the onset of dry conditions in late 2019. This indicates that irrigation demand may have been a major factor in declining water levels during the drought, in addition to (or despite) reduced rainfall recharge. Other parts of the region have fewer monitoring wells, so a similar observation (marginal edge vs central) cannot be made for other aquifers.

Waitematā aquifers in Clevedon and those along the southern Manukau Harbour (Karaka to Waiau Pa) had very low groundwater levels through much of 2020. These aquifers were among the most affected in the region, most having record low groundwater levels for much of the year. These are also important aquifers for irrigation, stock drinking, and domestic supply. Water levels declined sharply in early 2020 and remained low or very low throughout the year. It is likely that low groundwater levels at the start of the year were mostly affected by abstraction, while persisting low groundwater levels late in the year were reflecting low rainfall recharge.

4.5.5 Geothermal

Auckland's geothermal aquifers, two of which are monitored, have poorly understood recharge mechanisms. Clear links between rainfall recharge and groundwater level have not been established. Management of geothermal aquifers has historically focused on maintaining groundwater levels and temperature. Changes to abstraction limits have led to direct changes in water level and temperature regimes (such that abstraction limits have led to the desired water level and temperature outcomes), suggesting that abstraction, not climatic factors, is the primary driver of groundwater level, not annual rainfall recharge cycles (Crane 1999). As such, the impacts of the 2020 drought are unlikely to be observed in the geothermal groundwater level record, when factored for abstraction effects.

However, the impacts of Covid-19 provided a clear link between groundwater abstraction and groundwater level response. This gives valuable context as to the importance and effectiveness of groundwater allocation and operational management on affecting groundwater levels.

4.6 Water use

This report does not include an analysis of water use. River flows are not naturalised, i.e. water takes are not added back into the flow record to estimate the flow if no abstraction occurred. Days below MALF as assessed for this report are likely affected by abstraction. Without accurate data on water use, it is not possible to isolate the relative effects of natural vs artificial controls on river flow. However, the cumulative effects of the drought as-measured present valuable data for comparison to previous years.

5 Summary

Rainfall records had historic lows for many sites. The use of the regional average datasets for the full calendar year, dry season (November-April), and wet season (May-October) provided useful insights into drought severity. These included assessing antecedent rainfall conditions prior to the onset of droughts and the magnitude of low rainfall totals during drought periods. Regional average rainfall records indicated that the rainfall during the 2020 drought was the lowest on record at 52% below the long-term mean. Soil moisture data, despite short records starting in 2015, complemented rainfall data by showing the pattern of soil moisture through the year and the magnitude of soil moisture declines.

Several rivers had the lowest ever gauged flows during the summer of 2020. Nine rivers had the lowest seven-day low flow on record (or tied with the lowest). Many rivers had the highest number of days below MALF on record (13 of 23). The regional average number of days below MALF provided an insightful way to characterise annual river flows through time, with 2020 having the greatest number of days below MALF over the period of analysis from 1980-2020.

Drought effects were observed in most groundwater level records. Many wells had the lowest groundwater level on record during 2020. The data suggest that the effects of the 2020 drought were brought on initially by irrigation demand given the relatively rapid declines observed in some wells, particularly those in Waitematā geology, where inter-annual climate effects are somewhat subdued. The impacts continued late into 2020 suggesting a delayed impact of the drought through reduced recharge.

Water use is a key component to any hydrological analysis that includes water bodies which are a source for water abstraction. This analysis did not include water use data due to database issues. Demand for irrigation would have been at or near an all-time high during 2020. Water use is likely to have had significant effects on river flows and groundwater levels, which robust analysis and reporting of water use data may elucidate.

The analysis of all hydrometric datasets indicates the hydrological drought of 2020 was likely the most severe on record.

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Appendix 1: Site details

Rainfall Sites	Sub-region	Site	Easting	Northing	Start date
Hoteo at Oldfields	North	643510	1735747	5976946	25/10/1977
Tamahunga at Quintals Road	North	643713	1755540	5978303	18/05/1977
Kaipara Heads	North	644211	1710813	5967291	3/11/1971
Mahurangi at Satellite Dish	North	644616	1749240	5966835	3/07/1982
Orewa at Treatment Ponds	North	646619	1750205	5948366	30/11/1979
Ararimu at Zanders	Central	647510	1738983	5936876	9/11/1978
Kumeu at Maddrens	Central	647513	1739266	5929066	31/07/1977
Whenuapai at Airbase	Central	647601	1745482	5927516	1/09/1945
Rangitopuni at Walkers	Central	647614	1744793	5933070	13/09/1978
Albany at Heights Road	Central	647618	1751033	5935988	21/12/1998
School at Paremoremo	Central	647619	1747144	5931081	1/09/1997
Wairau at Testing Station	Central	647722	1755440	5927857	13/05/1973
Oteha at Rosedale Ponds	Central	647727	1753163	5931755	1/06/1984
School at Mairangi Bay	Central	647737	1755968	5932097	18/05/1997
Inwards Reserve	Central	647738	1752153	5926391	18/05/1997
Torbay at Glamorgan School	Central	647739	1755131	5936696	4/07/1997
Opanuku at Candia Road	Central	648517	1744707	5915567	17/12/1999
Keeling Road	Central	648612	1744707	5916831	12/12/1990
Lincoln Park Avenue	Central	648613	1744264	5921576	12/12/1990
Harmel Road Pump Station	Central	648614	1747875	5915584	23/01/1991
Avondale Racecourse	Central	648615	1750345	5914938	24/08/1992
Constable Lane	Central	648625	1746459	5923880	20/12/1999
Te Pai Park	Central	648626	1745568	5919279	20/12/1999
Mt Albert Grammar	Central	648717	1753704	5916402	11/10/1991
Alexandra Park Runway	Central	648718	1758617	5915704	23/04/1992
Albert Park	Central	648719	1757591	5920276	3/09/1962
Plymouth Reserve	Central	648732	1759057	5924306	18/05/1997

Rainfall Sites	Sub-region	Site	Easting	Northing	Start date
Cox's Bay Park	Central	648733	1754176	5920115	26/08/1999
Churchill Park	Central	648816	1767115	5919583	24/03/1993
Okahu Bay Bowling Club	Central	648817	1762302	5919634	31/12/1993
Cutler Park	Central	649637	1748027	5939181	21/12/1999
Mt Roskill Substation	Central	649713	1753684	5913432	11/09/1991
Colin Maiden Park	Central	648851	1764753	5916809	3/03/1995
Harbour Road Reserve	Central	649714	1758856	5911346	21/12/1992
Waitākere Filter Station	Central	648513	1738676	5915966	20/07/1993
Park Village	Central	649842	1769089	5914636	24/09/1995
Anns Creek	Central	649818	1763345	5910654	21/05/1992
Rowe Street	Central	649723	1759380	5911995	7/10/1988
Bassant Reserve	Central	649836	1761088	5913759	6/03/2001
Mangemangeroa	Central	649941	1772195	5912158	8/10/2001
Botanical Gardens	Central	740945	1769930	5902091	27/03/1983
Waitākere Domain	West	648516	1737267	5920662	16/12/1999
Oratia Cemetery Oratia	West	649636	1744379	5913777	10/12/1999
Forrest Hill Road	West	649517	1741480	5913372	14/12/1999
Reservoir Bush Road	West	649516	1741261	5911171	10/12/1999
Huia Filter Station	West	649641	1746104	5910847	14/12/1990
Arataki Visitors Centre	West	649514	1743146	5909847	22/01/1975
Waharau Regional Park	East	750213	1803921	5898062	9/04/1983
Wairoa at Hunua Nursery	East	750010	1784237	5894142	6/12/1979
Awhitu at Brook Road	South	741611	1746752	5894063	31/12/1989
Whangamaire	South	741813	1763274	5882381	22/06/1992
Ngakoroa at Donovans	South	742914	1775123	5881674	22/10/1980
Waitangi at Diver Road	South	742736	1756667	5880110	30/11/1993

River Flow Sites	Site number	Easting	Northing	Stahler stream order	Upstream catchment area (km^2)	Commenced
Tamahunga Stream	6501	1755631	5978391	3	8.31	23/02/1978

River Flow Sites	Site number	Easting	Northing	Stahler stream order	Upstream catchment area (km^2)	Commenced
Mahurangi River	6863	1748589	5970087	4	47.20	21/04/2009
Rangitopuni River	7805	1744587	5933077	5	81.50	16/05/1975
Oteha Stream	7811	1751328	5933522	3	12.31	13/12/1979
Opanuku Stream at Candia Road	7904	1742162	5915566	3	16.13	8/08/2006
Swanson Stream	7907	1743783	5919897	4	23.20	3/02/1994
Oratia Stream	7911	1745527	5916175	4	28.80	22/06/1999
Opanuku Stream at Vintage Reserve	7912	1744587	5917203	3	24.60	23/06/1999
Whau Stream	8006	1751679	5913591	2	4.36	9/09/2005
Motions Stream	8104	1753745	5918720	3	3.55	27/03/1990
Meola Stream	8106	1753197	5918529	3	14.89	3/04/1998
Otara Stream	8208	1767628	5908076	3	18.94	28/04/1992
Wairoa River	8516	1782663	5901676	5	150.60	13/02/1979
Mangawheau Stream	8529	1783781	5891411	4	30.93	15/06/1988
Waitangi Stream	43602	1755195	5878315	3	18.48	1/04/1966
Papakura Stream	43803	1769579	5899729	4	41.40	16/06/1969
Puhinui Stream	43807	1766420	5904316	3	12.86	6/12/1978
Ngakaroa Stream	43829	1775153	5881619	3	4.95	28/03/1980
Kaipara River	45311	1733345	5930348	5	155.30	6/10/1978
Ararimu River	45326	1734999	5932630	5	66.80	14/12/1983
Kaukapakapa Stream	45415	1735809	5945031	5	62.30	4/07/1994
Hoteo River	45703	1735424	5972357	5	276.56	10/06/1977
Waiteitei River	45705	1742460	5985481	4	80.86	21/02/1996

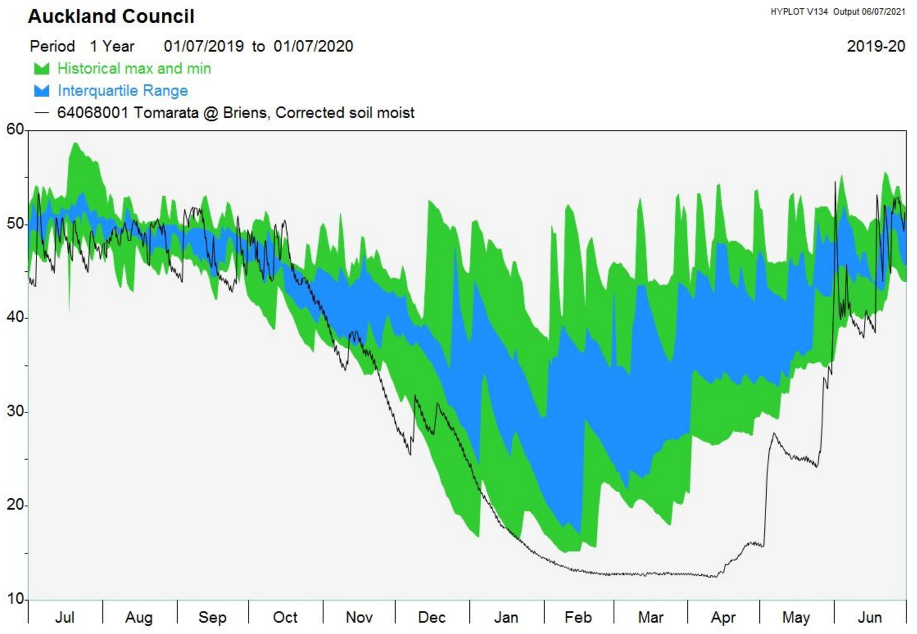
Groundwater Sites	Site number	Easting	Northing	Aquifer	Total depth (m)	Casing depth (m)	Casing Ø (mm)	Record start	Confinement	Recording	Freq.
Quintals Road Omaha	6437005	1755760	5978227	Omaha Waitematā	129.6	94	200	3/02/1977	confined	manual	monthly

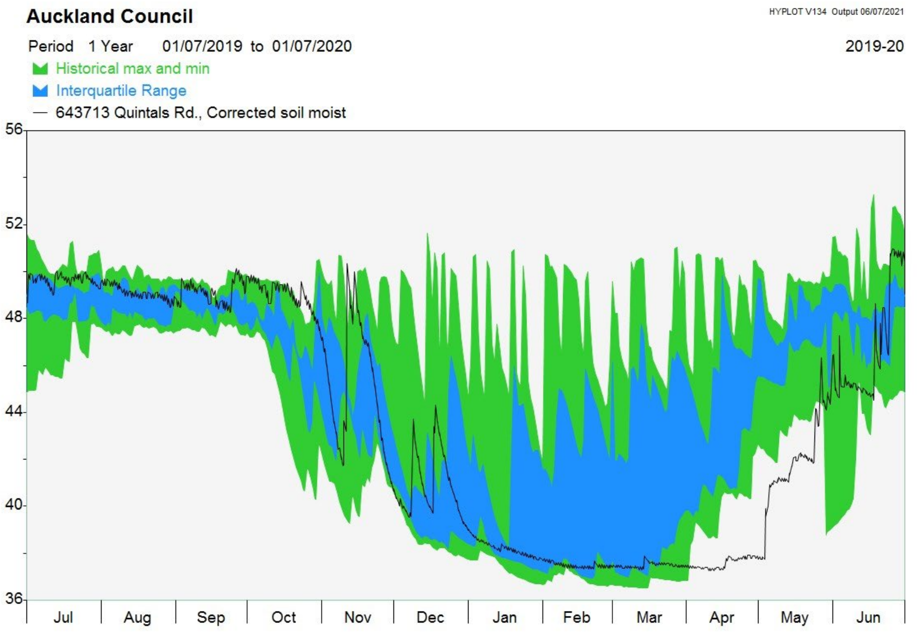
Groundwater Sites	Site number	Easting	Northing	Aquifer	Total depth (m)	Casing depth (m)	Casing Ø (mm)	Record start	Confinement	Recording	Freq.
Omaha Flats Bore 25	6437021	1756485	5977154	Omaha Waitematā	90	34	100	7/12/1977	confined	automatic	15-minute
Caroline Heights	6437087	1759338	5977414	Omaha Waitematā	188	131	100	31/05/1993	confined	manual	monthly
Waiwera Beachfront Deep	6457041	1752868	5954102	Waiwera geothermal	407		100	30/11/1976	confined	automatic	15-minute
Waiwera Beachfront Shallow	6457097	1752873	5954101	Waiwera geothermal	52	30	100	10/12/1997	Semi/unconfined	automatic	15-minute
Parakai Bore 86	6464007	1728297	5941883	Parakai geothermal	249	100	200	13/06/1984	confined	automatic	15-minute
Rimmer Road	6464089	1726124	5939301	Kaipara sand	63.5	49.5	100	15/04/1997	unconfined	manual	monthly
Waitākere Road #2	6474003	1739082	5927989	Kumeu West Waitematā	150	78	100	5/08/1998	confined	automatic	15-minute
Selaks Bore	6475003	1740754	5927896	Kumeu East Waitematā	299	101	100	12/02/1986	confined	manual	monthly
Trigg Road	6475005	1736310	5928959	Kumeu West Waitematā	248	71	100	11/01/1989	confined	manual	monthly
Short Road	6475157	1741716	5929638	Kumeu East Waitematā	242	91.5	100	10/09/1996	confined	manual	monthly
Nick Johnstone Drive	6479007	1778056	5926955	Waiheke West greywacke	88.5	42	100	11/03/2006	confined	manual	monthly
Volcanic Street	6487001	1755313	5915915	Onehunga volcanic	10.5	7	50	14/11/1996	unconfined	manual	monthly
Selkirk Road	6487007	1754021	5917236	Western Springs volcanic	25.5			13/11/1996	unconfined	automatic	15-minute
Leslie Road	6487009	1754685	5917291	Western Springs volcanic	24.3	18.3	50	13/11/1996	unconfined	automatic	15-minute
Chamberlain Park	6487021	1753511	5918278	Western Springs volcanic				15/06/1998		manual	monthly
PD-13S	6488045	1763376	5915230	Mt Wellington volcanic	23.5	22.5	50	11/12/1991	unconfined	manual	monthly
Alfred Street	6497007	1759789	5912783	Onehunga volcanic	40	24	50	6/06/1989	unconfined	manual	monthly
Waikaraka Cemetery	6497013	1759920	5911507	Onehunga volcanic	15.9	9.9	50	21/06/1993	unconfined	manual	monthly
Orakau Avenue	6497015	1757832	5914770	Onehunga volcanic	47.8	41.8	50	14/11/1996	Unconfined	manual	monthly
Amelia Earhart	6497017	1758649	5905851	Mangere-Manurewa Kaawa	50.6	42.6	50	25/03/1997	Semi-/confined	manual	monthly

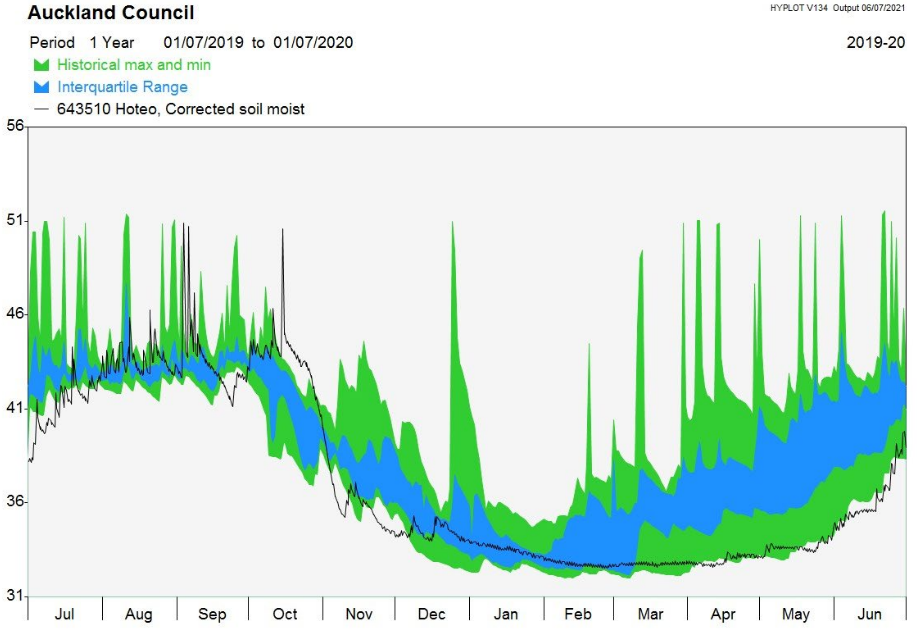
Groundwater Sites	Site number	Easting	Northing	Aquifer	Total depth (m)	Casing depth (m)	Casing Ø (mm)	Record start	Confinement	Recording	Freq.
Tiwai Road	6497019	1758791	5913752	Onehunga volcanic	58.53	46.53	50	8/04/1997	Semi-/confined	manual	monthly
Angle Street	6498003	1760820	5911670	Mt Wellington volcanic	25	9.78	100	6/06/1989	unconfined	automatic	15-minute
Mako Road	6570013	1779254	5927093	Waiheke West greywacke	117	106	25	16/03/2006	confined	manual	monthly
Puhinui at Lambie Drive	6498035	1766421	5904323	Manukau Waitematā	201	60	100	30/06/1993	confined	manual	monthly
Tawaipareira	6570015	1783160	5925794	Waiheke Central West greywacke	60	53.5	100	12/02/2007	confined	automatic	15-minute
Mt Richmond	6594001	1764001	5911038	Mt Richmond volcanic	42.6	30.27	150	9/08/2001	unconfined	manual	monthly
Burnside Road	7409001	1777680	5900303	Clevedon East Waitematā	169	154.2	100	10/07/1985	confined	manual	monthly
Bullens Road	7409011	1775849	5899165	Clevedon West Waitematā	75	38.9	100	21/06/1993	confined	manual	monthly
Glenbrook Hall	7417001	1756247	5882259	Glenbrook Kaawa	103.7		115	16/03/1970	confined	manual	monthly
Seagrove Road	7417021	1756024	5889134	Waiau Pa Waitematā	201	97.8	100	8/08/1991	confined	manual	monthly
Waiau Pa Bore 2C	7418003	1758131	5887101	Glenbrook Kaawa	43.8	34.7	200	18/04/1980	confined	manual	monthly
Batty Road	7418013	1763756	5889684	Glenbrook Kaawa	50	41.4	100	20/12/1985	confined	manual	monthly
Ostrich Farm Road #2	7418023	1766027	5885160	Pukekohe Kaawa	47.6	46	80	20/12/1985	confined	manual	monthly
Ostrich Farm Road Observation	7418027	1766016	5885089	Pukekohe Kaawa	84	68	80	20/12/1985	confined	manual	monthly
Tuhimata Road	7419003	1770320	5884982	Pukekohe Kaawa	114.2	67.6	100	3/12/1986	confined	manual	monthly
Fielding Road Sand	7419007	1774443	5890653	Bombay-Drury sand	64	57	100	4/04/1989	semi-confined	manual	monthly
Fielding Road Volcanic	7419009	1774447	5890664	Bombay-Drury volcanic	46.7	16.3	150	4/04/1989	unconfined	manual	monthly
Cooper Road	7419011	1773758	5886862	Bombay-Drury Kaawa	120.6	108.4	100	16/01/1990	confined	manual	monthly
Fielding Road Waitematā	7419013	1774438	5890637	Bombay-Drury Waitematā	273	157	100	24/04/1991	confined	manual	monthly

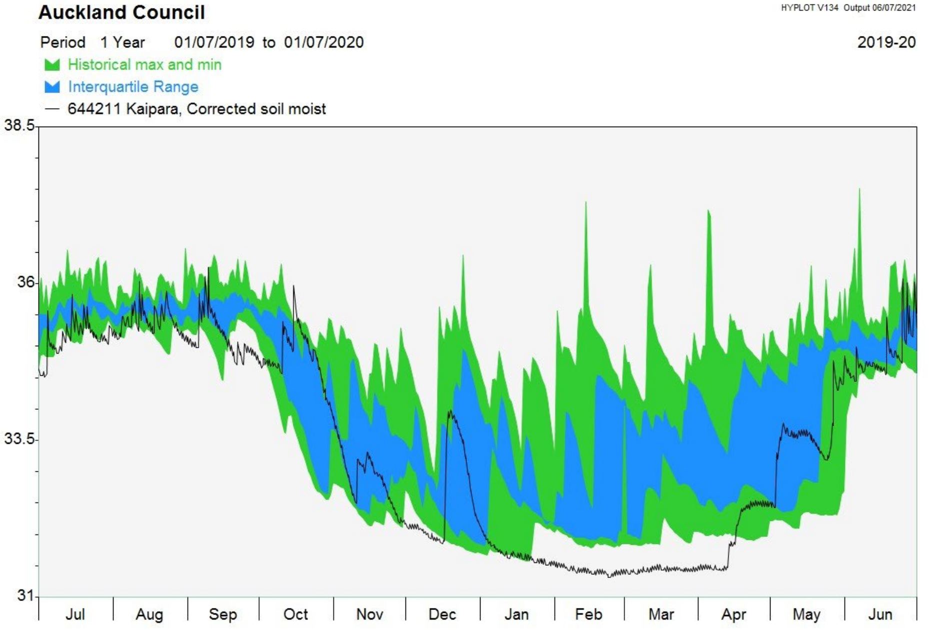
Groundwater Sites	Site number	Easting	Northing	Aquifer	Total depth (m)	Casing depth (m)	Casing Ø (mm)	Record start	Confinement	Recording	Freq.
Karaka #2	7419119	1767829	5892996	Karaka Waitematā	207	91.2	100	12/03/1992	confined	automatic	15-minute
Diver Road	7427003	1756683	5880119	Waiuku Kaawa	218	173	100	27/08/1985	confined	manual	monthly
Maraeorahia	7427005	1752381	5877971	Awhitu Kaawa	62	51.5	100	5/01/1987	confined	automatic	15-minute
Pukekohe DSIR	7428043	1765111	5881260	Pukekohe central volcanic	96.3	73	150	26/04/1979	confined	manual	monthly
Mauku Main	7428047	1760994	5881217	Glenbrook Kaawa	194.7	156	150	17/04/1985	confined	automatic	15-minute
Rifle Range Deep	7428103	1766258	5880972	Pukekohe central volcanic	90	78	50	24/04/1997	confined	manual	monthly
Rifle Range Shallow	7428105	1766250	5880967	Pukekohe central volcanic	42	30	50	24/04/1997	unconfined	manual	monthly
Revell Court	7429011	1768376	5879583	Pukekohe central volcanic	54.6	10.4	150	14/08/1979	unconfined	automatic	15-minute
Douglas Road Volcanic	7429013	1766160	5879366	Pukekohe central volcanic	108.2	71	100	6/06/1980	confined	automatic	15-minute
Wooten Road	7510005	1778058	5883662	Bombay volcanic	76.5	58.3	100	15/12/1991	confined	manual	monthly

Appendix 2: Soil moisture envelope plots


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
64068001 Tomarata @ Briens, Corrected soil moist
60
50
40
30
20
10
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
643713 Quintals Rd., Corrected soil moist
56
52
48
44
40
36
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
643510 Hoteo, Corrected soil moist
56
51
46
41
36
31
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun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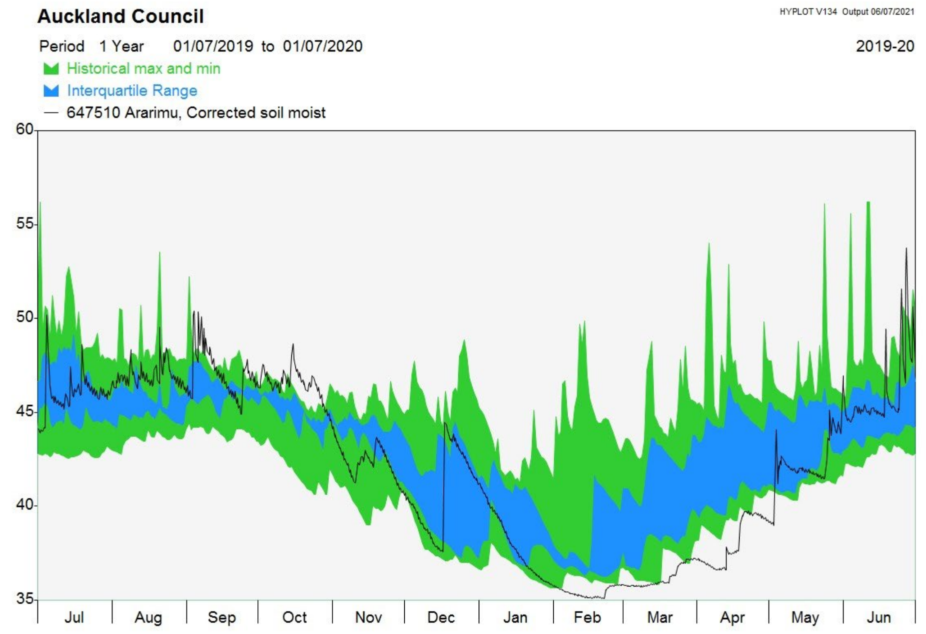
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
644211 Kaipara, Corrected soil moist
38.5
36
33.5
31
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun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Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
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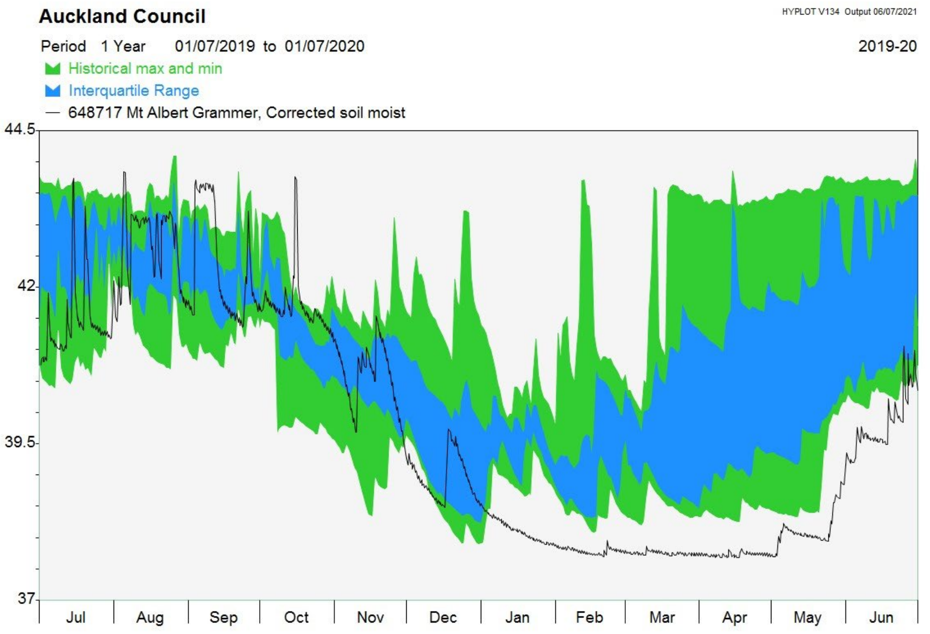
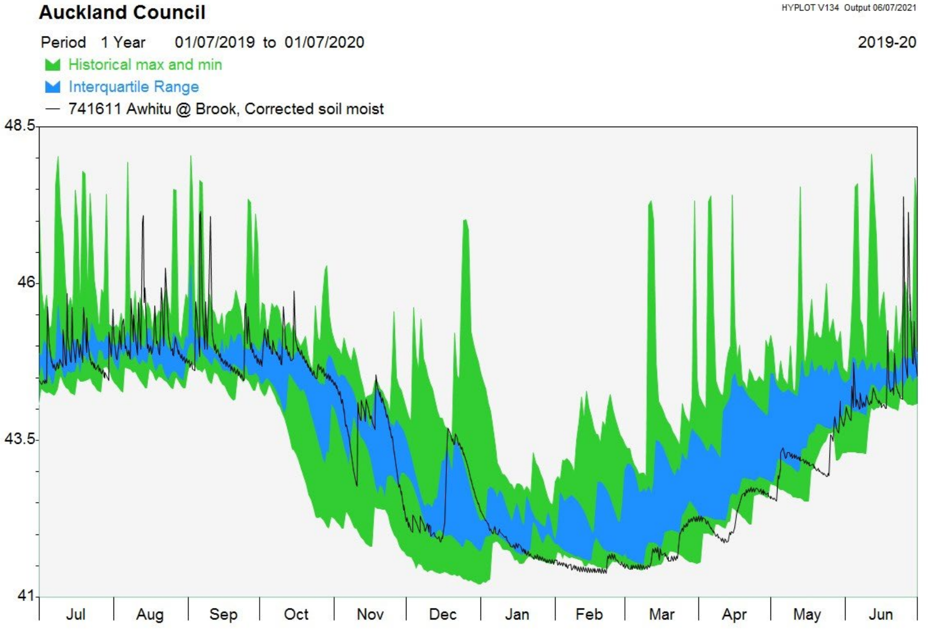
60
55
50
45
40
35
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
648717 Mt Albert Grammer, Corrected soil moist
44.5
42
39.5
37
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun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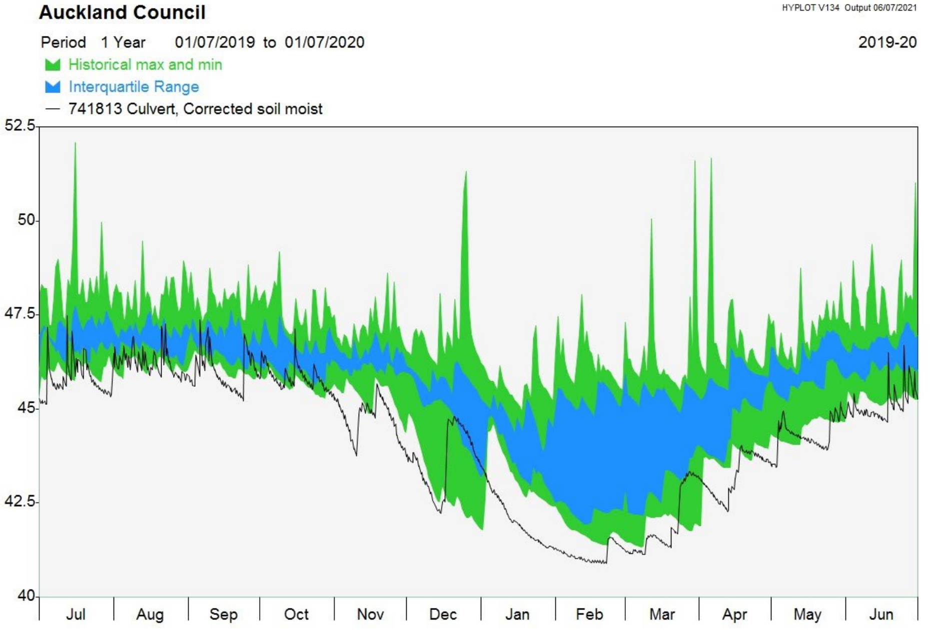
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
741611 Awhitu @ Brook, Corrected soil moist
48.5
46
43.5
41
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
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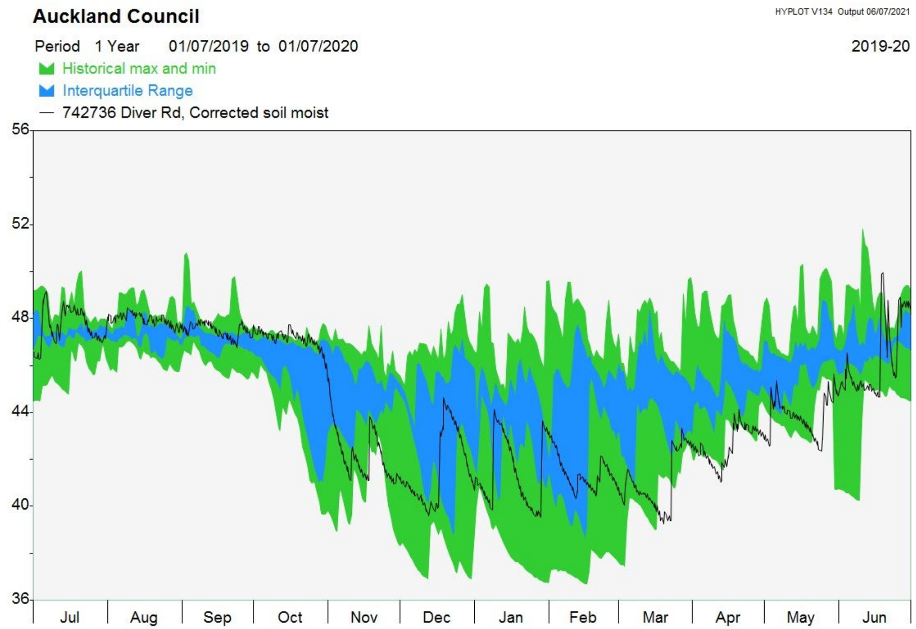
52.5
50
47.5
45
42.5
40
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 06/07/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
742736 Diver Rd, Corrected soil moist
56
52
48
44
40
36
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

Appendix 3: River flow: days below seven-day MALF by site

	Tamahunga	Mahurangi	Rangitopuni	Oteha	Opanuku	Swanson	Oratia	Opanuku vintage	Whau	Motions	Meola	Otara	Wairoa
1970													
1971													
1972													
1973													
1974													
1975													
1976													
1977			25.405										
1978	49.837		27.415										
1979	36.939		24.352										6.583
1980				10.52									
1981			12.403	55.566									25.663
1982	8.357		19.107	56.41									
1983	54.563		6.821	91.171									49.803
1984				0.405									
1985				0.434									
1986	8.227			15.84									
1987	56.963		35.057	70.877									49.73
1988	1.173		1.227	41.639									14.917
1989				7.335									
1990	9.679		16.69	19.995									48.001
1991	31.501		8.109	41.499									
1992	1.912		10.415	53.621									1.38
1993	33.204		61.4	58.598								123.06	69.016
1994	45.302		66.406	69.01		72.073						114.958	101.309
1995	14.717		24.976	20.544		40.066				12.931		44.423	
1996						2.477				14.829		51.958	

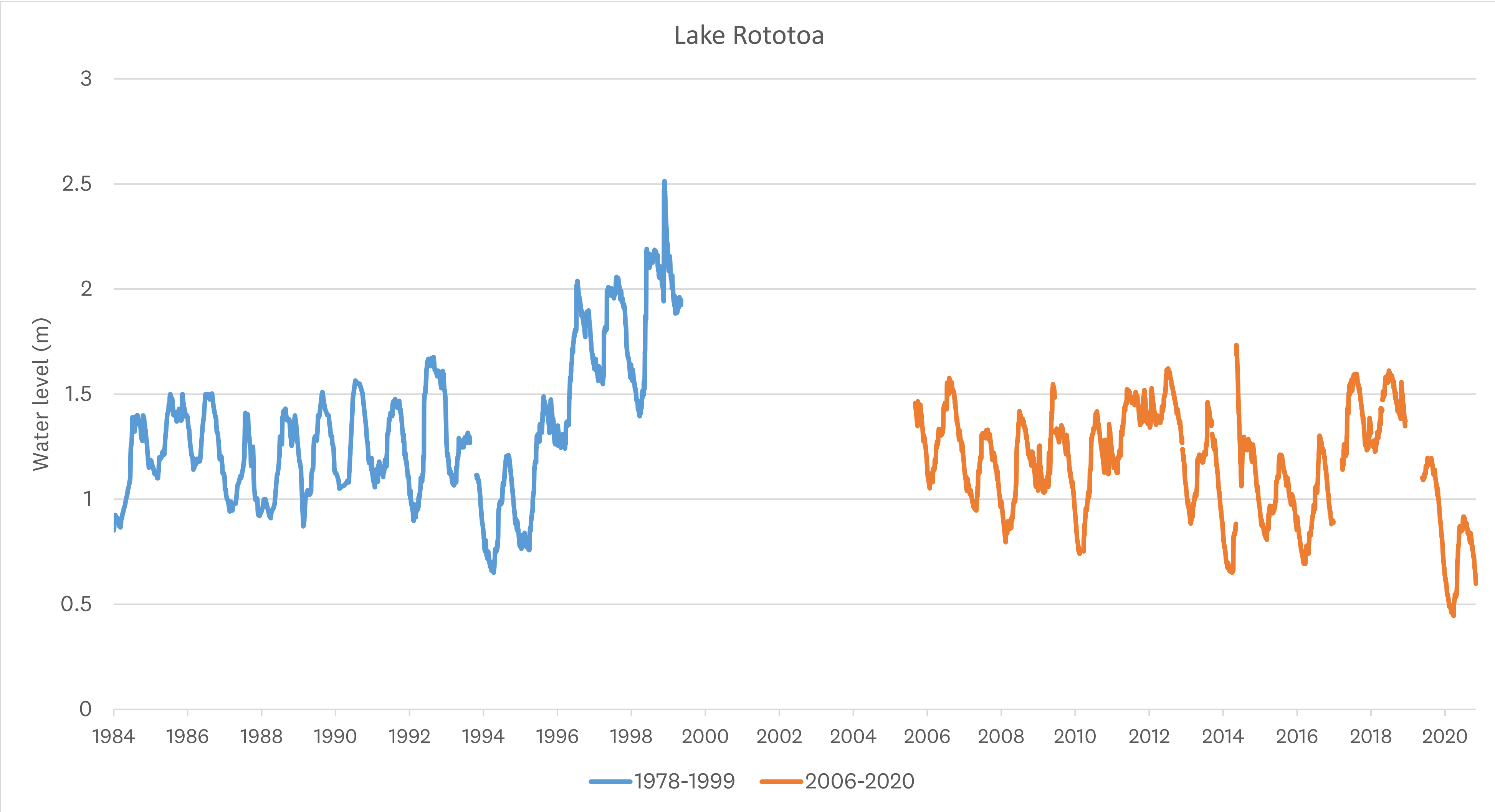
	Tamahunga	Mahurangi	Rangitopuni	Oteha	Opanuku	Swanson	Oratia	Opanuku vintage	Whau	Motions	Meola	Otara	Wairoa
1997						19.44				0.629		32.577	21.194
1998	42.331			7.199		24.741				1.548		71.614	32.422
1999	6.923		2.454	5.992		34.581				32.319	9.559	53.74	11.447
2000	24.485		28.711	16.299		51.964	62.46	51.895		64.661	55.4	46.446	57.784
2001				5.671		31.326	22.195	47.13		35.839	10.698	49.325	42.725
2002	2.275							8.765		44.124	2.256	4.972	
2003	22.665					6.987		0.054		53.766		6.44	3.293
2004								2.796		47.521		14.798	
2005	22.209		41.493	11.59		50.82	16.685	19.98	2.41	77.353	59.618	30.485	1.714
2006	25.495		29.291	12.91		19.893	34.801		64.044	60.182	8.521	60.785	11.419
2007	40.89		35.268	11.097	14.693	35.155	30.788		23.674	80.058	13.201	47.242	17.349
2008	4.84		20.827	20.332	8.256	58.369	0.231	7.353	3.939	74.715	20.986	43.739	88.34
2009	9.93		12.73	9.755		21.51	5.567	1.124		20.522		12.334	12.498
2010	65.169	92.44	81.677	48.366	26.847	73.346	78.511	22.622	49.931	128.758	87.172	52.32	66.194
2011					8.275								13.632
2012					0.113								
2013	70.655	93.037	74.366	46.502	73.949	56.858	57.697	53.88		78.85	75.217	58.321	88.093
2014	0.53	70.527	54.377	19.91	104.827	46.742	58.891	51.936		58.953	49.134	2.305	70.964
2015	5.038	27.33	38.256	0.193		10.267	65.301	7.658	81.803	4.24	23.046	14.619	66.807
2016		3.502	17.636						3.025	20.065	9.012		32.804
2017	14.438	19.05	34.22			12.211	1.968	26.472	29.481	19.789	18.395		17.018
2018	0.31		0.005				5.551	6.648	6.792				
2019	14.095	27.774	24.287	0.686	76.312	18.97	2.35	17.27	20.832				63.8
2020	135.327	125.193	117.454	N/A	89.794	42.571	84.68	100.504	87.342	56.579	90.1	N/A	124.999

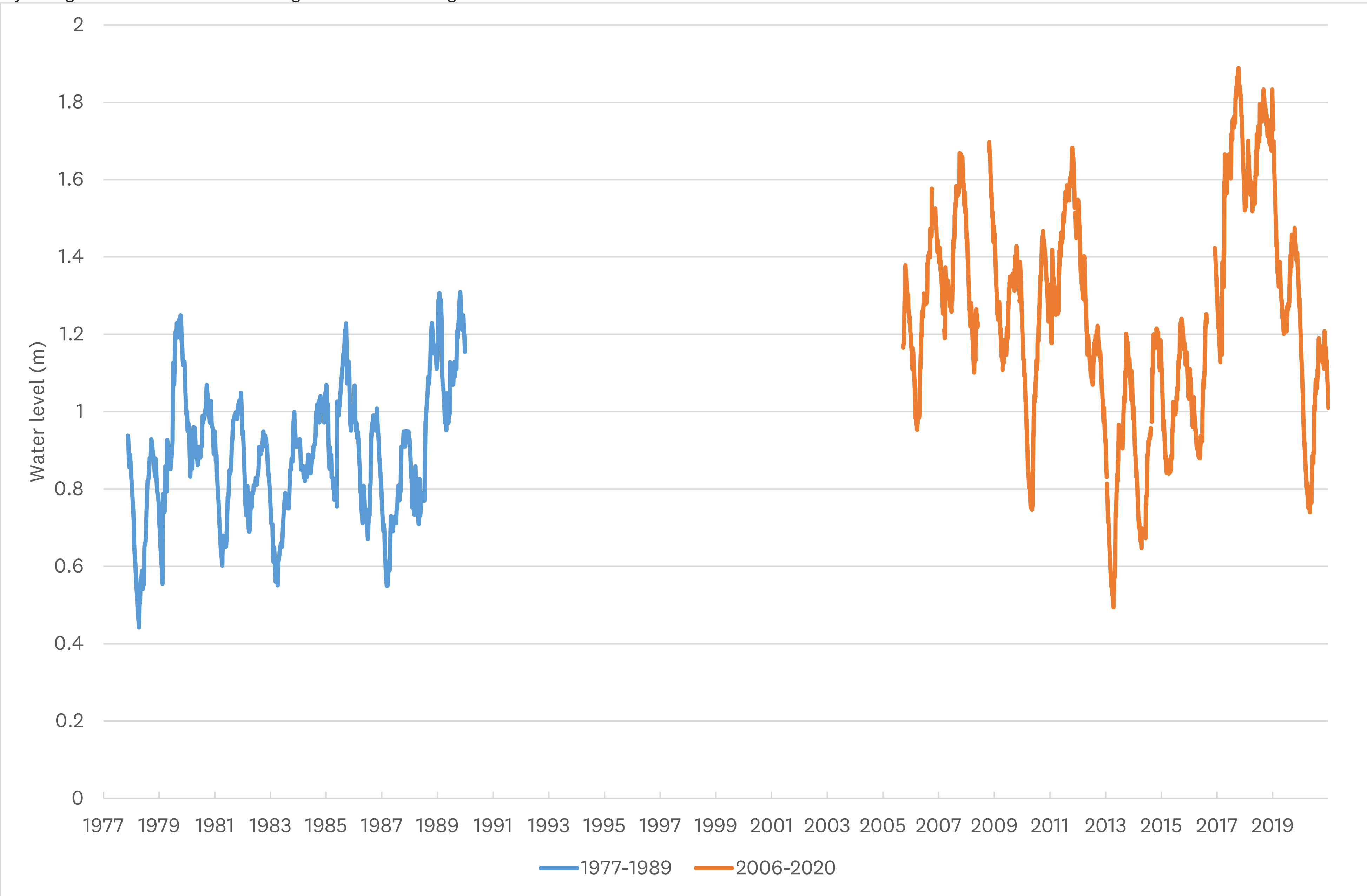
	Mangawheau	Waitangi	Papakura	Puhinui	Ngakoroa	Kaipara	Ararimu	Kaukapakapa	Hoteo	Waiteitei	All sites Average
1970		105.77	58.28								
1971		2.65	2.46								
1972			0.01								

	Mangawheau	Waitangi	Papakura	Puhinui	Ngakoroa	Kaipara	Ararimu	Kaukapakapa	Hoteo	Waiteitei	All sites Average
1973		65.99	46.99								
1974		98.42	115.35								
1975		64.43	70.31								
1976		5.18	15.58								
1977		22.70	0.05								
1978		63.25	52.91	0.11					66.66		
1979		8.35	35.94	6.99		3.54			13.04		
1980				20.64							15.58
1981		20.24	48.58	76.63	20.58	14.11					34.22
1982		24.24	9.39	28.36	11.98	21.24			6.81		20.66
1983		89.66		69.36	62.39	78.49			52.48		60.82
1984				0.36	0.11				16.63		4.38
1985				1.27	0.66	9.62					3.00
1986			1.62		2.79	0.50	2.20				5.19
1987		34.97	36.17	4.42	51.84	55.35			60.74		44.92
1988		32.02	8.27	10.01	10.54	2.89			6.81		12.95
1989		0.60									3.97
1990	19.21	2.04	17.21	19.67	27.28				15.24		19.53
1991			5.44	22.18	21.95	16.62	2.12		62.94		26.67
1992				54.23			8.42		52.54		29.77
1993	18.67	0.11	5.18	72.71	21.55	2.96	24.50		43.02		42.88
1994	80.65	97.63	74.55	103.82	96.06	41.92	77.27		78.86		80.93
1995	2.71	0.11		27.18	14.99	5.08		21.73	14.56		18.24
1996				9.49		1.38		4.78			14.15
1997		0.15		13.61		1.40		4.21			11.65
1998	16.94	21.81	37.09	52.01	10.31	27.82	66.89	4.89	49.24	19.71	29.82
1999	5.55	30.41	18.28	21.98	10.75		3.16		2.72		16.59
2000	51.69	48.64	32.27	29.76	9.08	90.30	39.82		42.09	40.70	43.24
2001	19.02	30.89	17.38	9.71	2.92	79.51	35.43			18.99	28.67
2002				6.06	4.41						10.41
2003	0.19		4.73	10.37			0.64				10.35

	Mangawheau	Waitangi	Papakura	Puhinui	Ngakoroa	Kaipara	Ararimu	Kaukapakapa	Hoteo	Waiteitei	All sites Average
2004			2.25								16.84
2005	7.57	69.64	3.18	5.57	13.87	15.55	39.48	22.22			27.90
2006	25.02	36.87	25.22	20.52	19.31	24.69	0.33	16.05			27.52
2007		23.82	16.32	27.97	30.78	63.79	49.46	45.85	25.51	45.43	35.01
2008	64.25	88.93	40.64	45.25	89.54	58.50	46.97	22.93		21.56	37.93
2009	4.31	38.94	24.74	16.43	16.98	7.82	23.63	14.04	1.38	37.80	15.05
2010	65.75	85.16	83.75	25.42	87.17	88.88	73.03	82.03	80.76	163.73	75.00
2011	1.89				7.77	8.21	2.12	10.87		20.17	9.12
2012					0.20						0.16
2013	77.89	72.97	71.09	63.38	72.36	74.45	82.61	72.09	82.19	41.69	70.93
2014	57.68	68.91	28.63	24.72	57.03	79.34	18.16	29.16	45.39	39.79	48.30
2015	49.72	49.14	31.43	40.74	39.33	55.08	29.46	26.31	7.31		32.18
2016	2.71	6.14	0.76	0.35	0.56	30.77	38.43	19.40			12.79
2017	4.16	1.39	14.39	5.55	1.83	34.46	35.43	27.15	37.78	42.07	19.89
2018						4.46			1.28	31.05	7.01
2019	14.05	6.94			2.57	23.00		32.03	36.05	49.61	25.33
2020	84.17	103.37	94.12	65.88	92.06	108.47	62.62	122.57	136.82	169.68	99.73

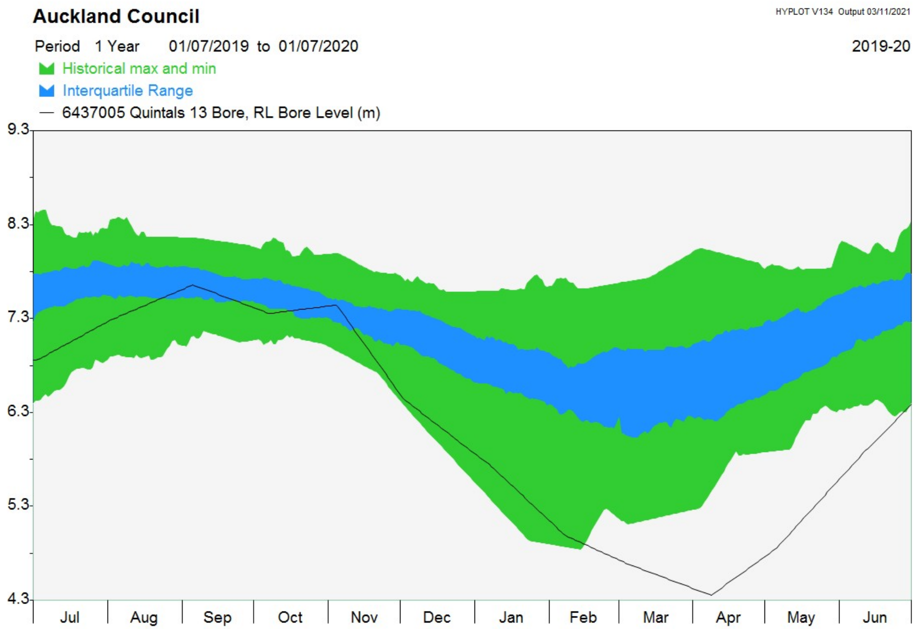
Appendix 4: Lake water level hydrographs

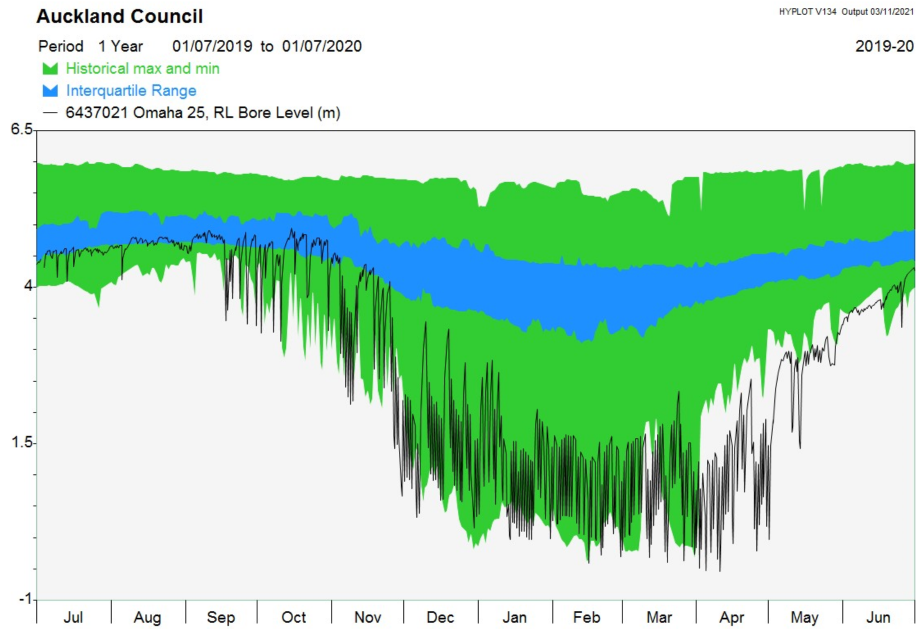


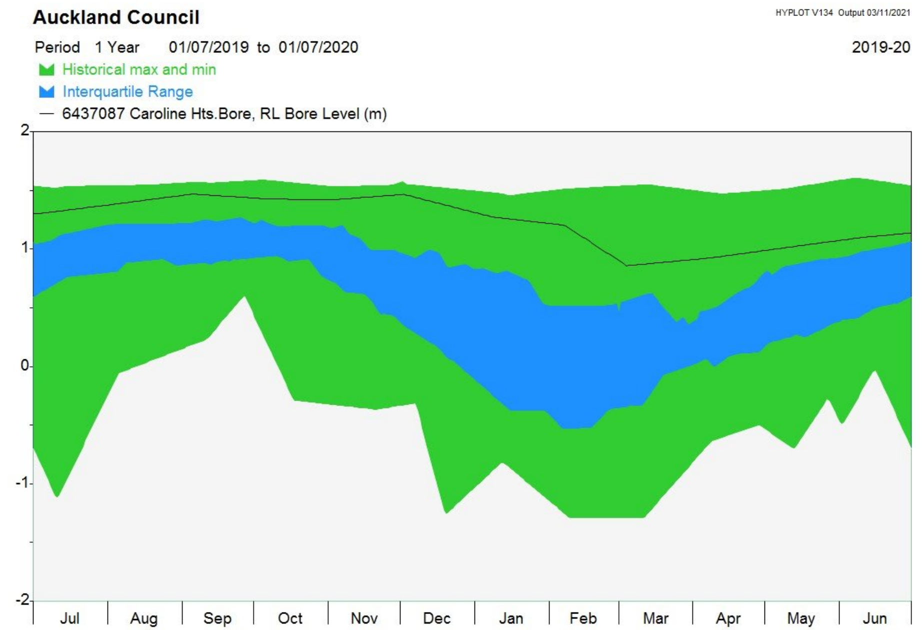


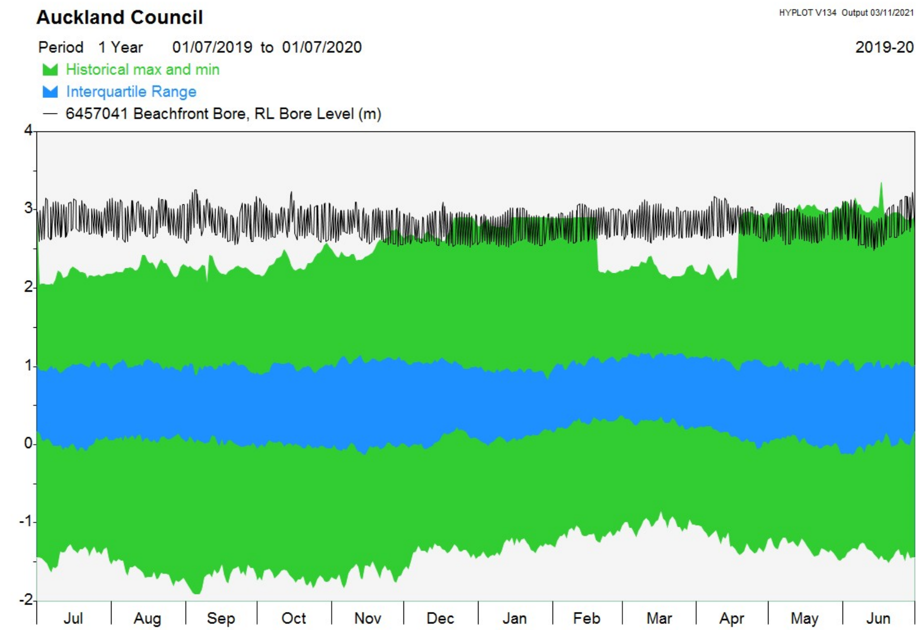
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Water level (m)
1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
1977-1989
2006-2020

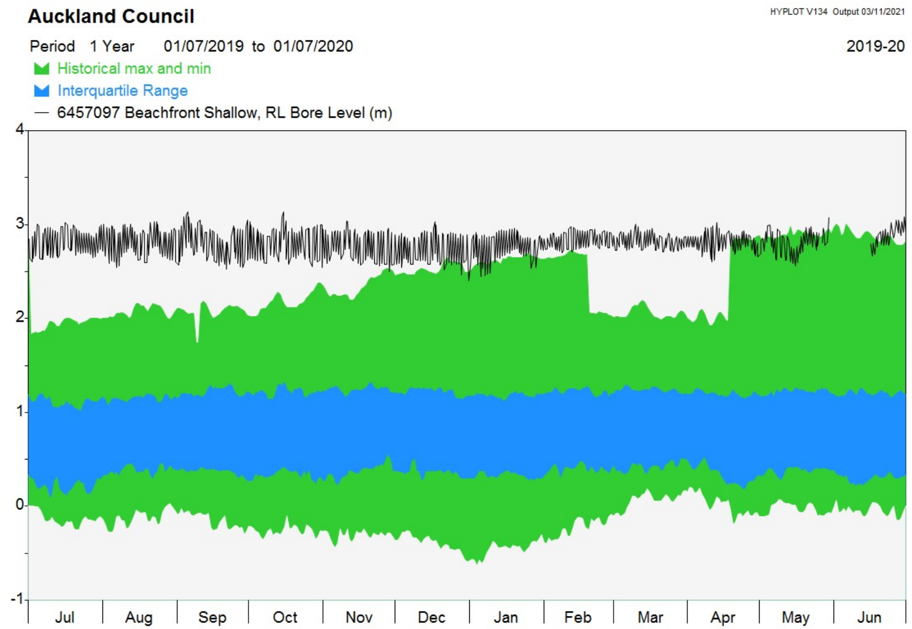
Appendix 5: 2020 groundwater level envelope plots

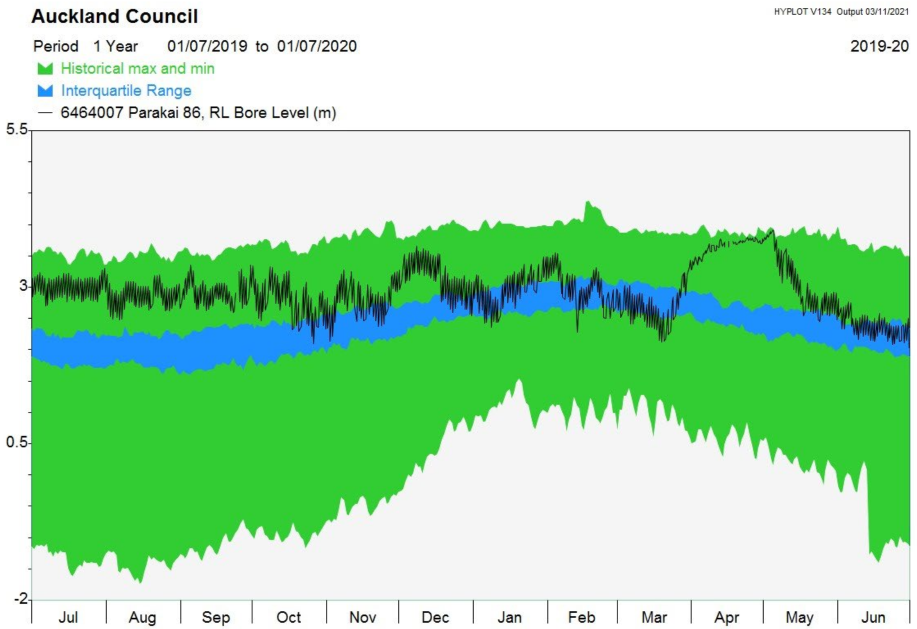

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6437005 Quintals 13 Bore, RL Bore Level (m)
9.3
8.3
7.3
6.3
5.3
4.3
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

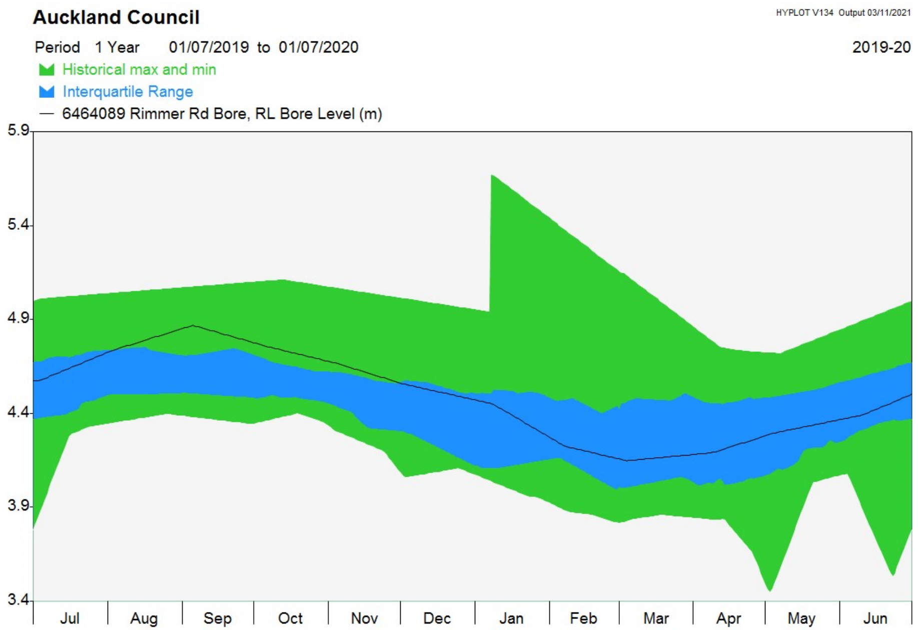

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6437021 Omaha 25, RL Bore Level (m)
6.5
4
1.5
-1
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

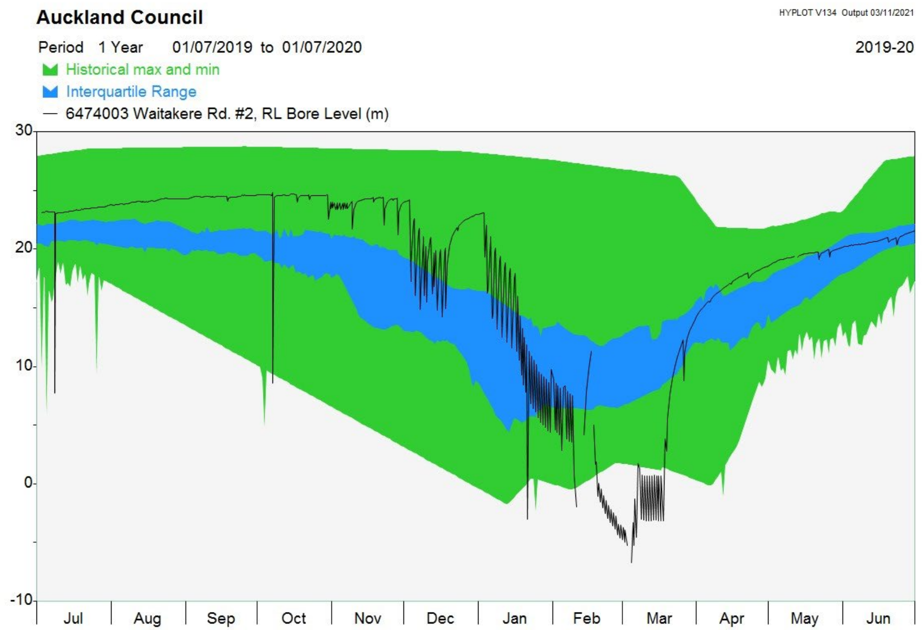

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6437087 Caroline Hts.Bore, RL Bore Level (m)
2
1
0
-1
-2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

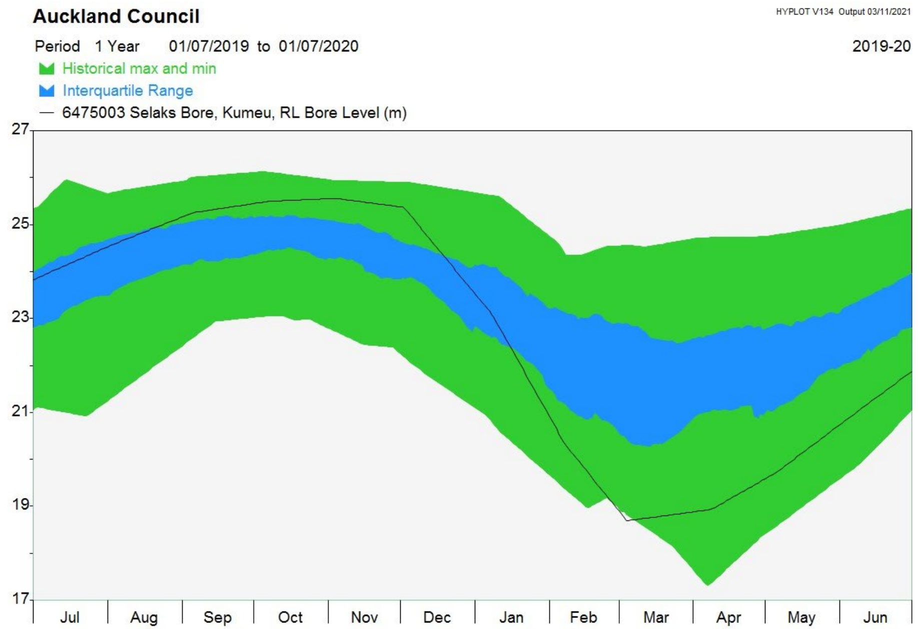

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6457041 Beachfront Bore, RL Bore Level (m)
4
3
2
1
0
-1
-2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

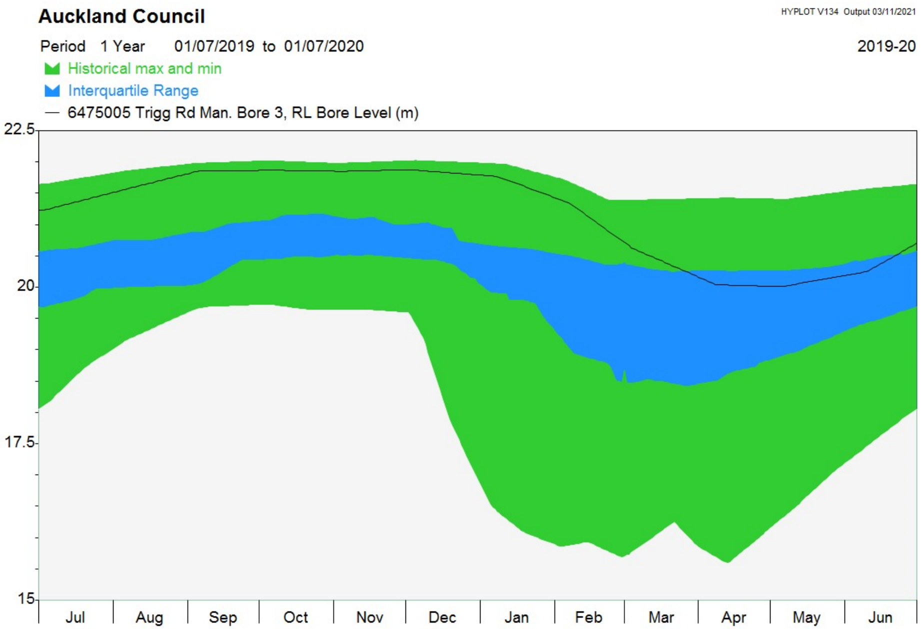

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6457097 Beachfront Shallow, RL Bore Level (m)
4
3
2
1
0
-1
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

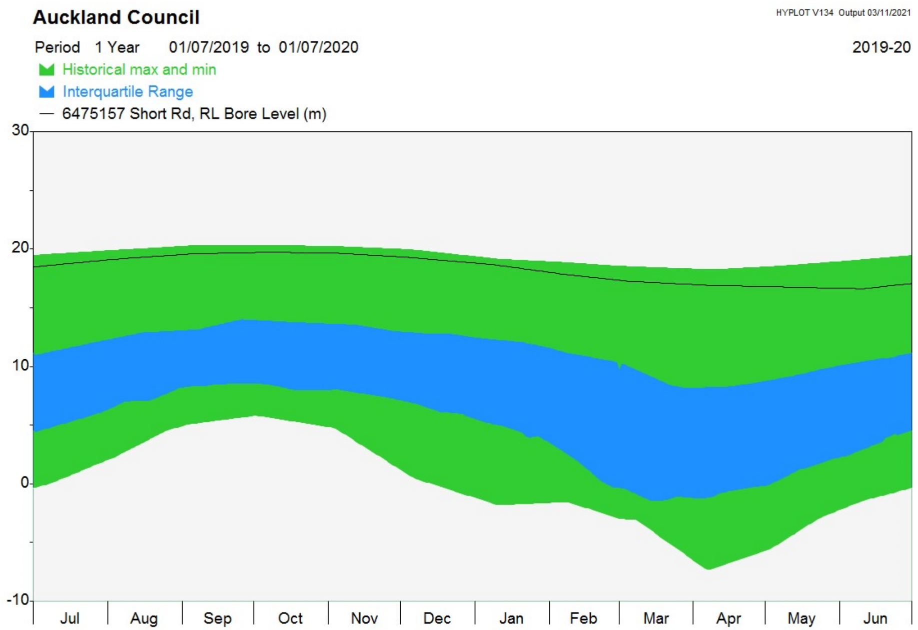

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6464007 Parakai 86, RL Bore Level (m)
5.5
3
0.5
-2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

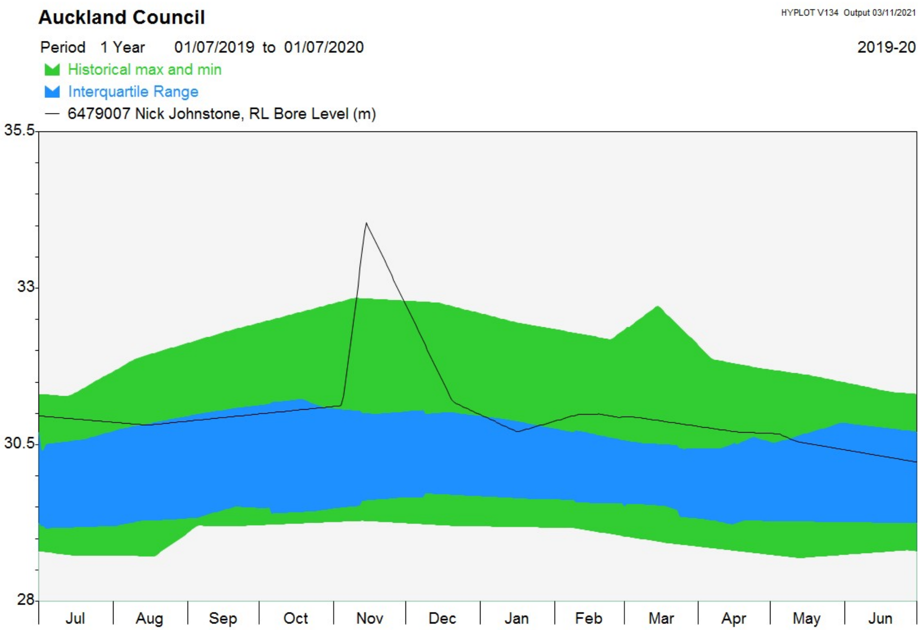

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6464089 Rimmer Rd Bore, RL Bore Level (m)
5.9
5.4
4.9
4.4
3.9
3.4
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

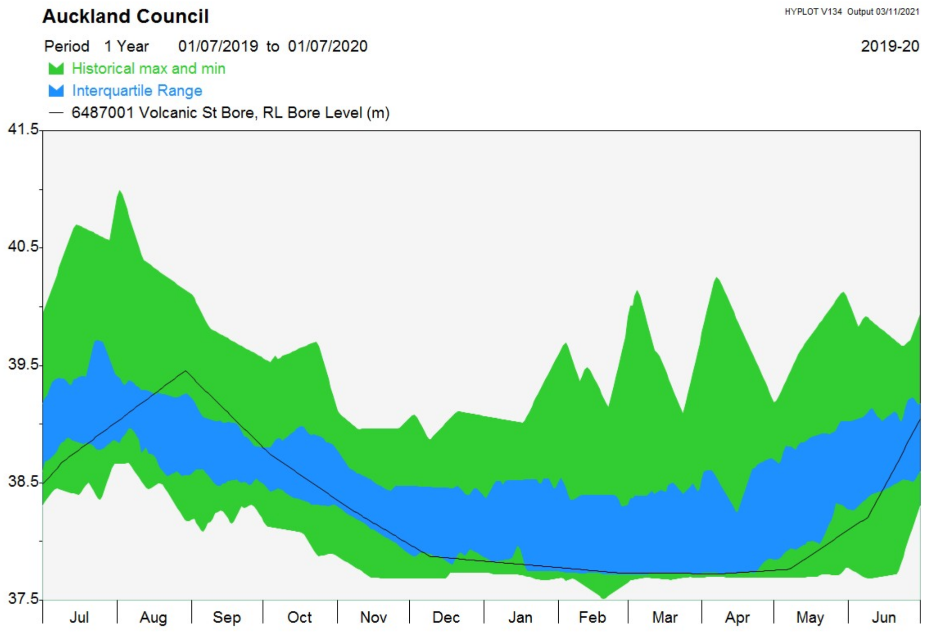

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6474003 Waitakere Rd. #2, RL Bore Level (m)
30
20
10
0
-10
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

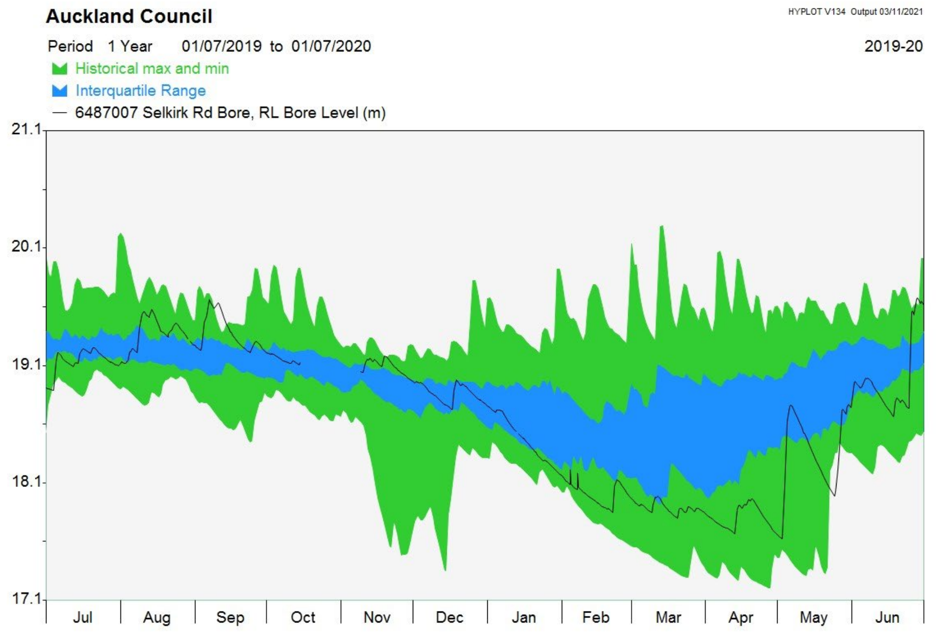

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6475003 Selaks Bore, Kumeu, RL Bore Level (m)
27
25
23
21
19
17
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

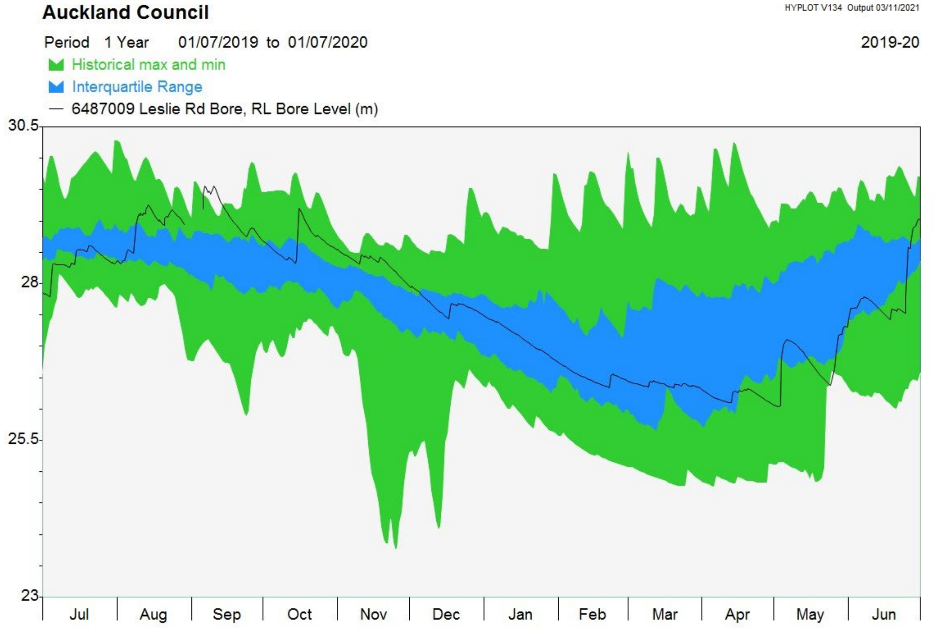

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6475005 Trigg Rd Man. Bore 3, RL Bore Level (m)
22.5
20
17.5
15
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

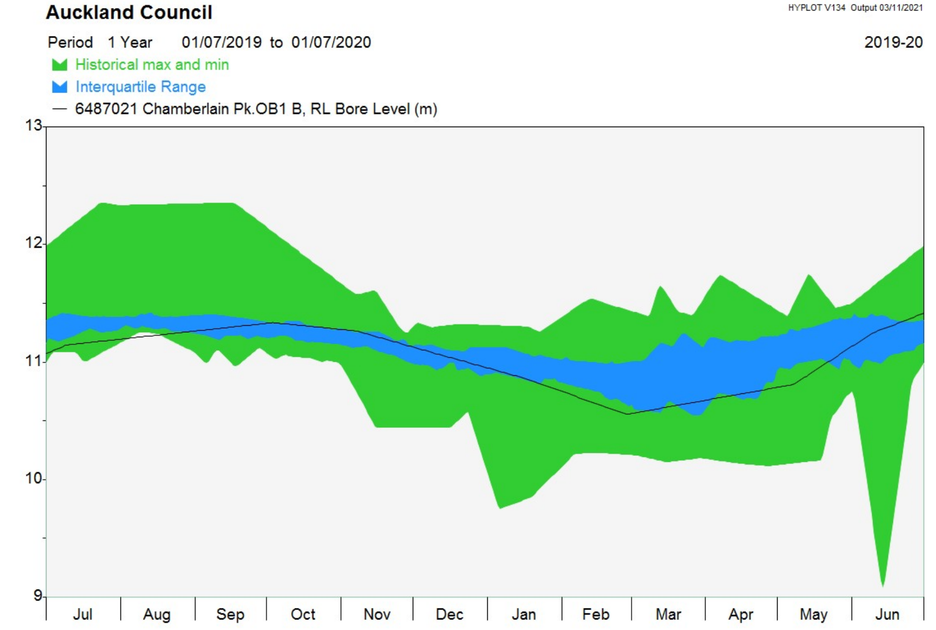

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6475157 Short Rd, RL Bore Level (m)
30
20
10
0
-10
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

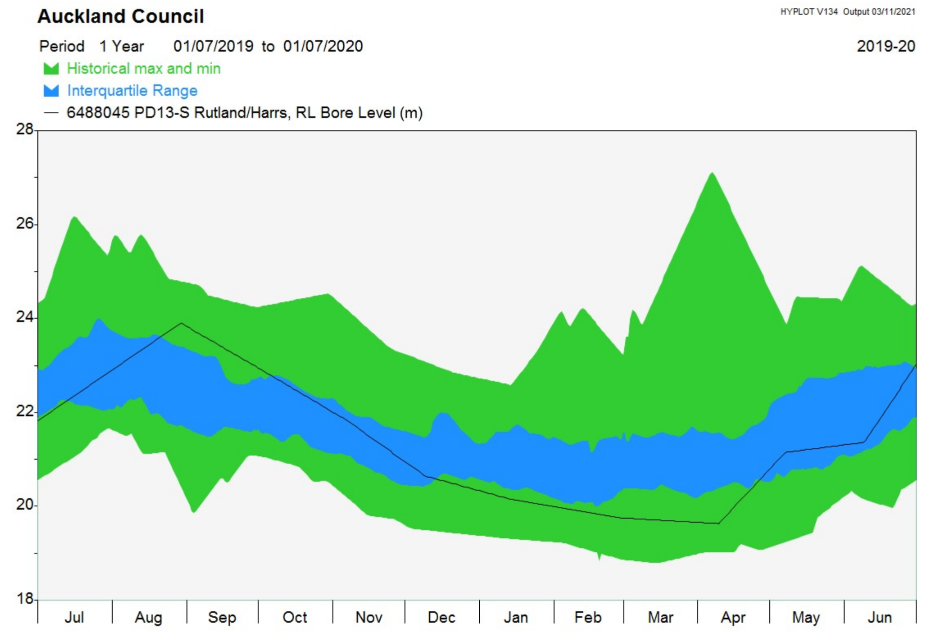

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6479007 Nick Johnstone, RL Bore Level (m)
35.5
33
30.5
28
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

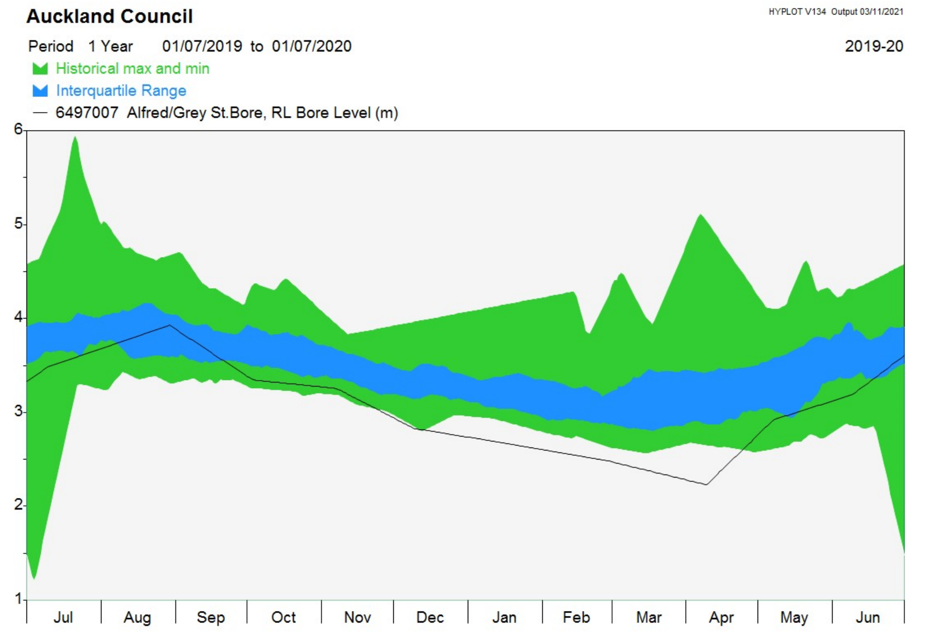

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6487001 Volcanic St Bore, RL Bore Level (m)
41.5
40.5
39.5
38.5
37.5
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

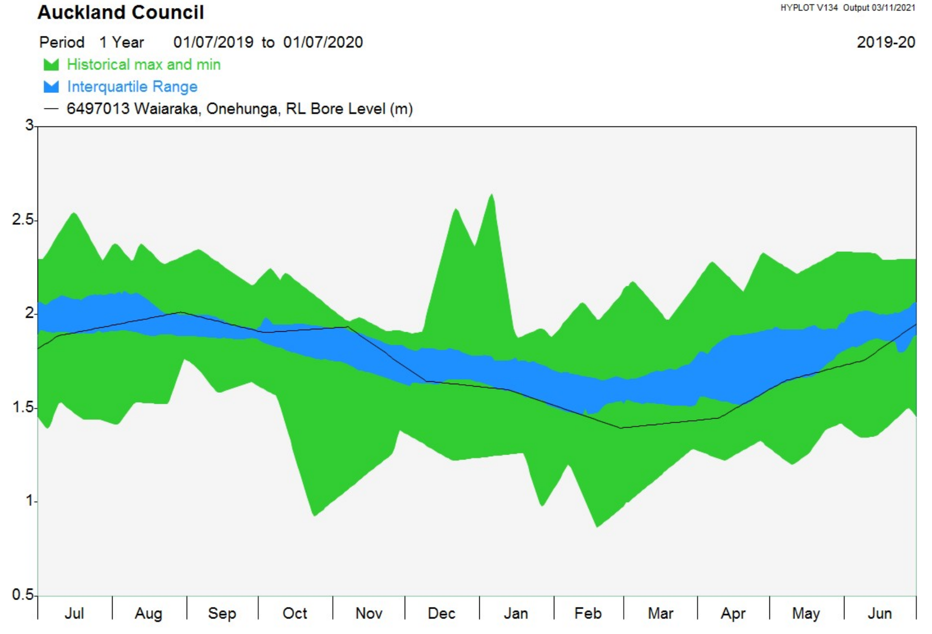

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6487007 Selkirk Rd Bore, RL Bore Level (m)
21.1
20.1
19.1
18.1
17.1
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

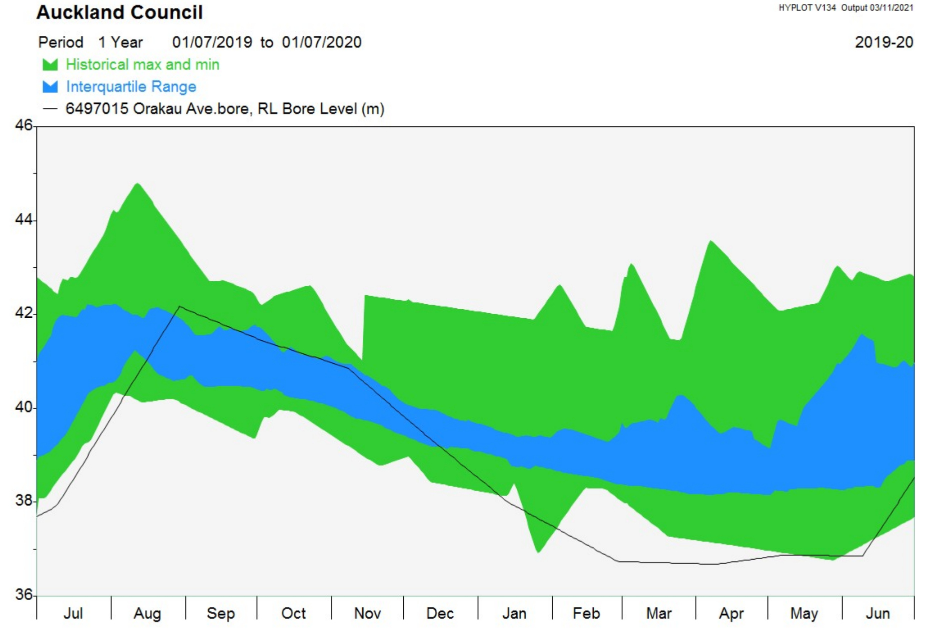

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6487009 Leslie Rd Bore, RL Bore Level (m)
30.5
28
25.5
23
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

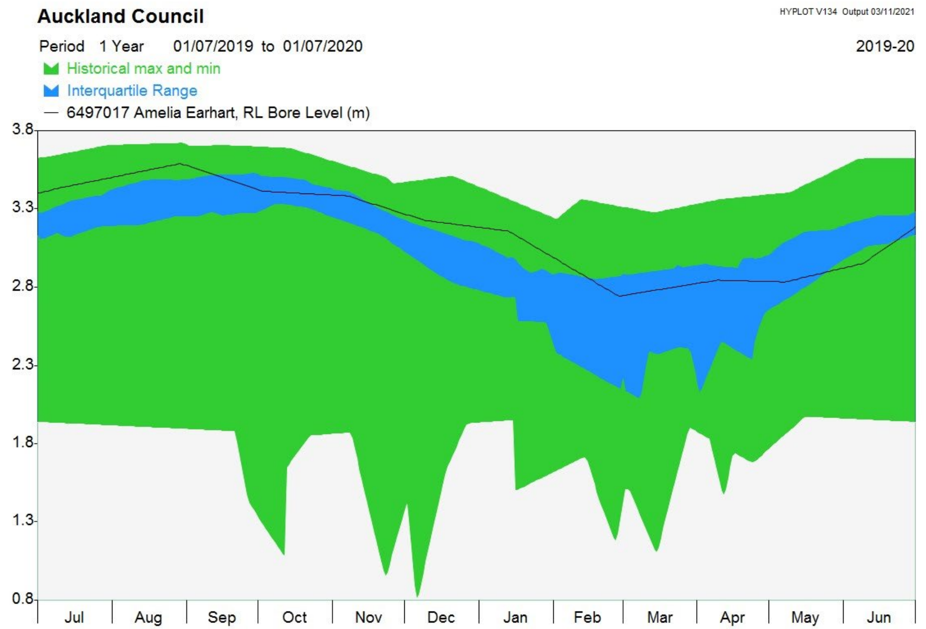

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6487021 Chamberlain Pk.OB1 B, RL Bore Level (m)
13
12
11
10
9
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

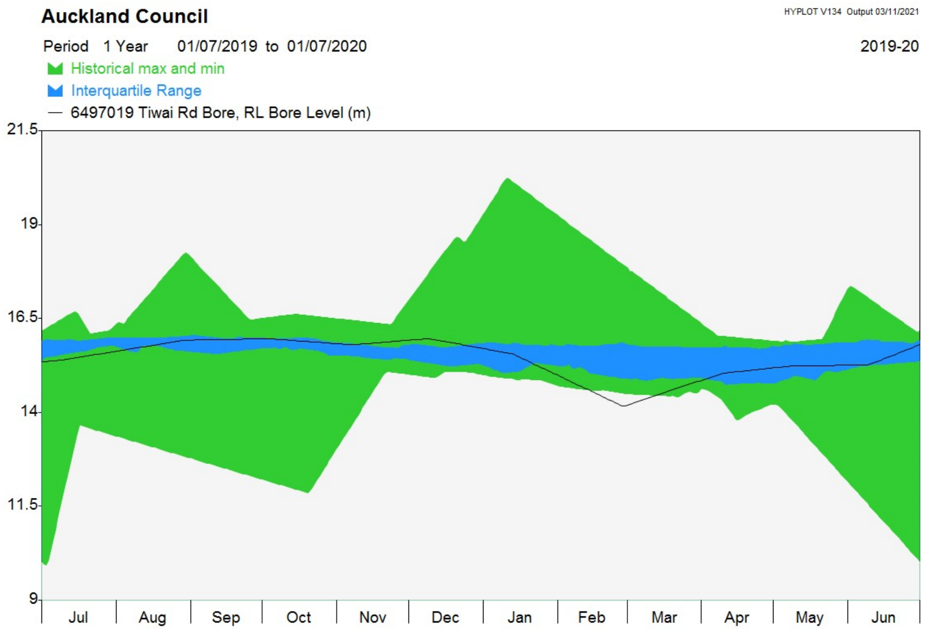

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6488045 PD13-S Rutland/Harrs, RL Bore Level (m)
28
26
24
22
20
18
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

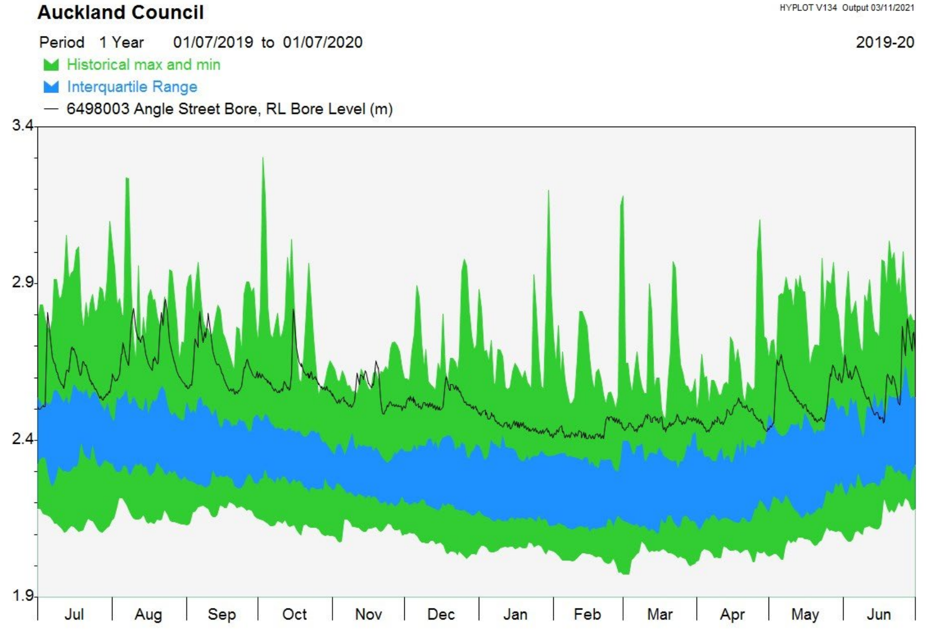

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6497007 Alfred/Grey St.Bore, RL Bore Level (m)
6
5
4
3
2
1
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

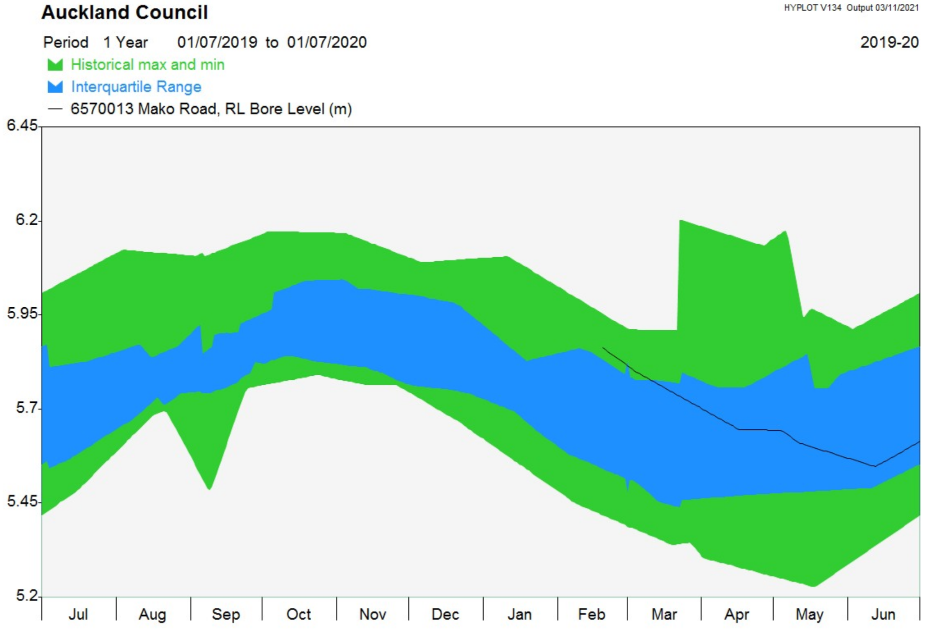

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6497013 Waiaraka, Onehunga, RL Bore Level (m)
3
2.5
2
1.5
1
0.5
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

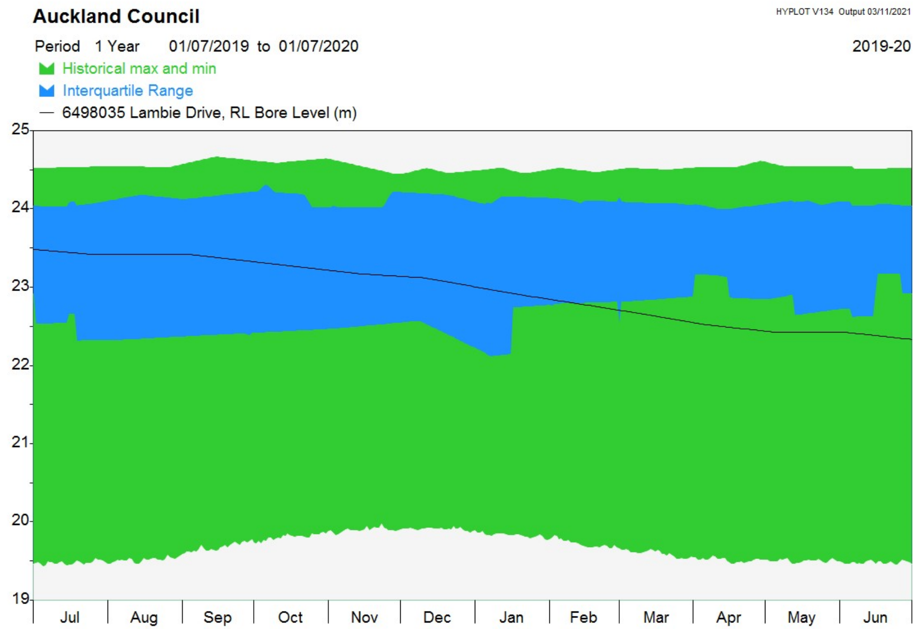

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6497015 Orakau Ave.bore, RL Bore Level (m)
46
44
42
40
38
36
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

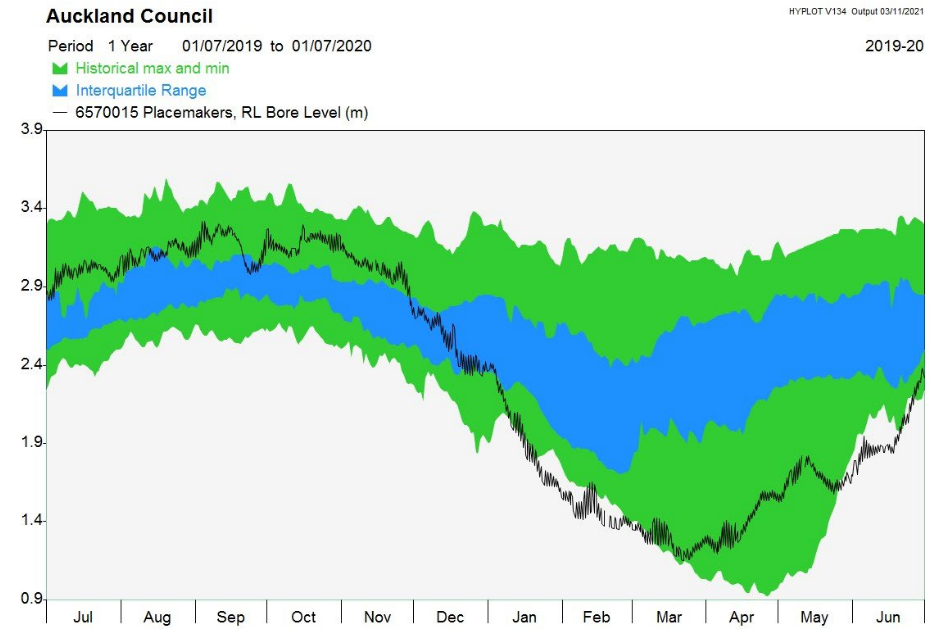

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6497017 Amelia Earhart, RL Bore Level (m)
3.8
3.3
2.8
2.3
1.8
1.3
0.8
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

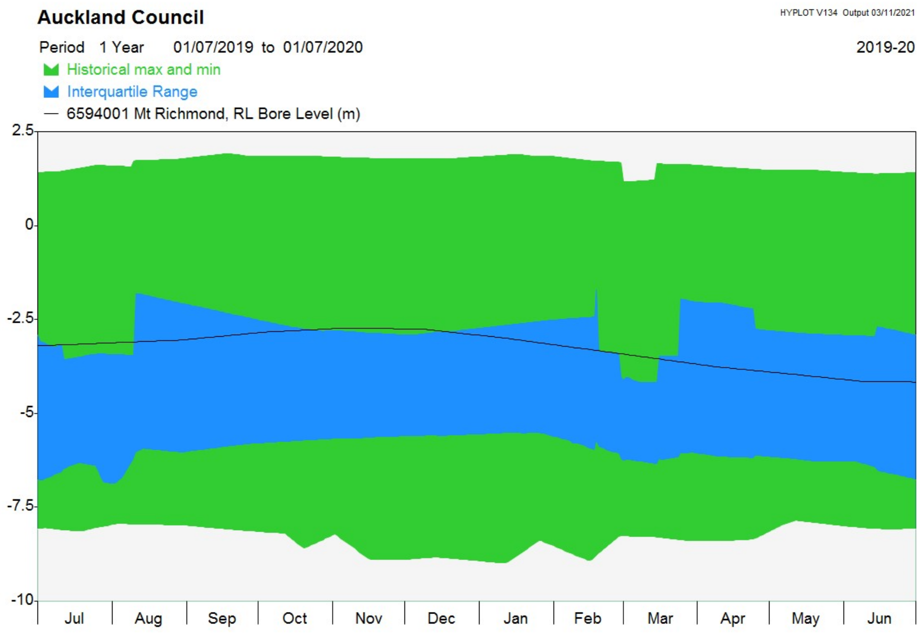

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6497019 Tiwai Rd Bore, RL Bore Level (m)
21.5
19
16.5
14
11.5
9
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

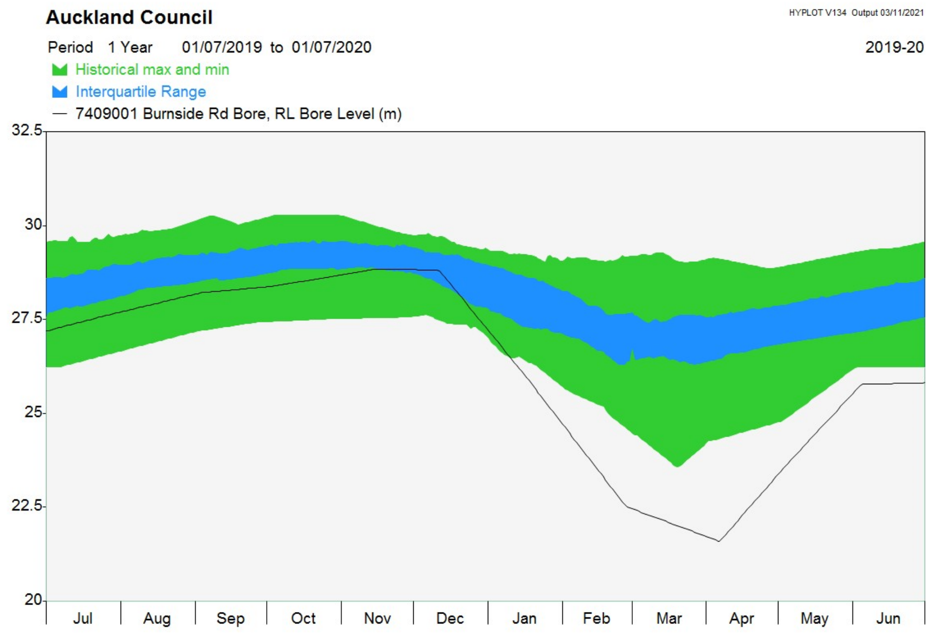

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6498003 Angle Street Bore, RL Bore Level (m)
3.4
2.9
2.4
1.9
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

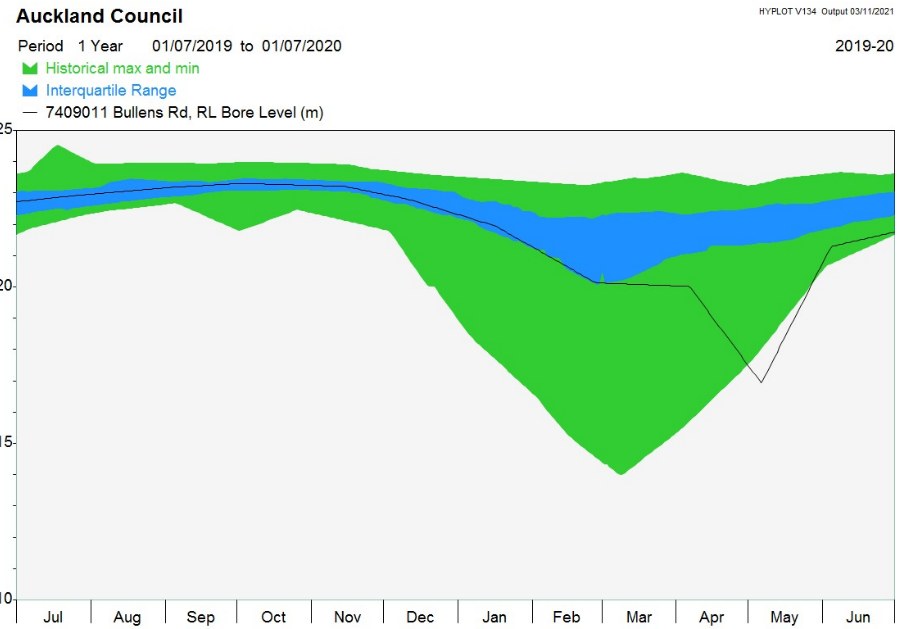

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6570013 Mako Road, RL Bore Level (m)
6.45
6.2
5.95
5.7
5.45
5.2
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

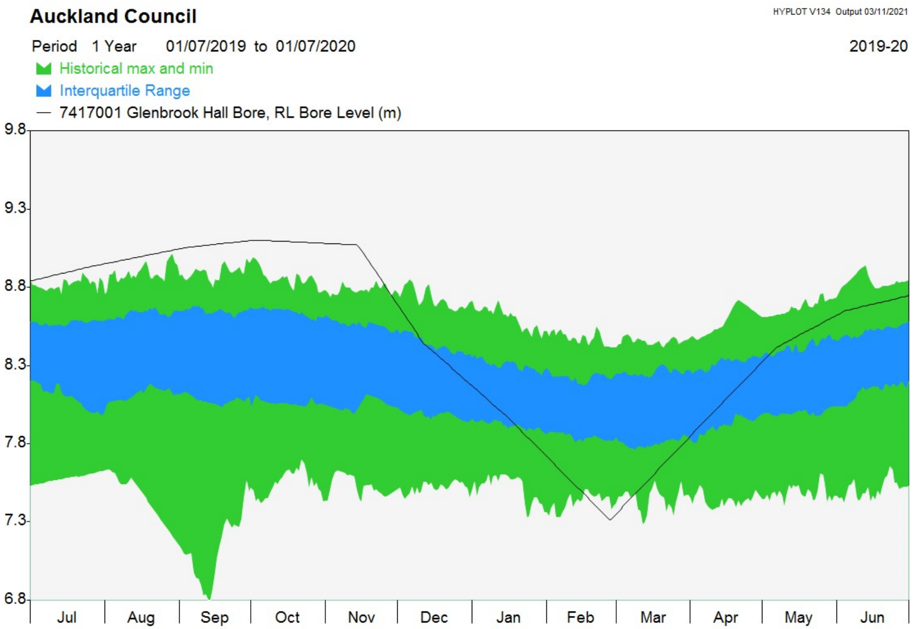

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6498035 Lambie Drive, RL Bore Level (m)
25
24
23
22
21
20
19
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

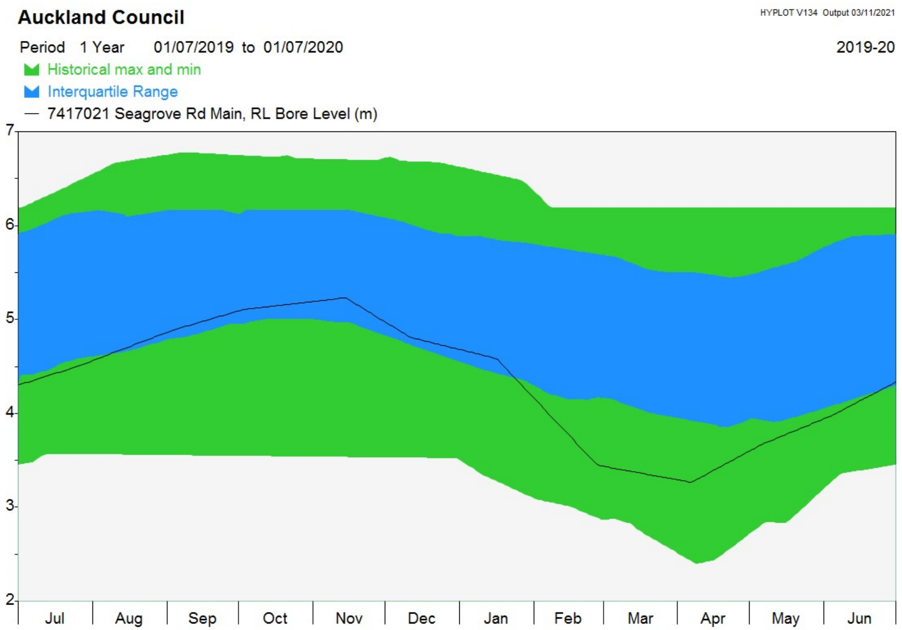

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6570015 Placemakers, RL Bore Level (m)
3.9
3.4
2.9
2.4
1.9
1.4
0.9
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

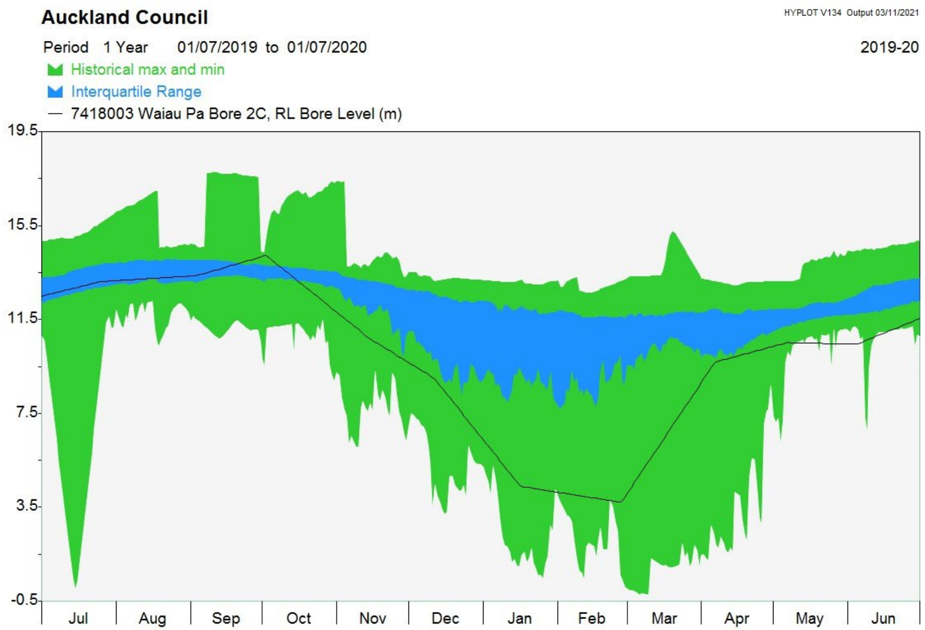

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
6594001 Mt Richmond, RL Bore Level (m)
2.5
0
-2.5
-5
-7.5
-10
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

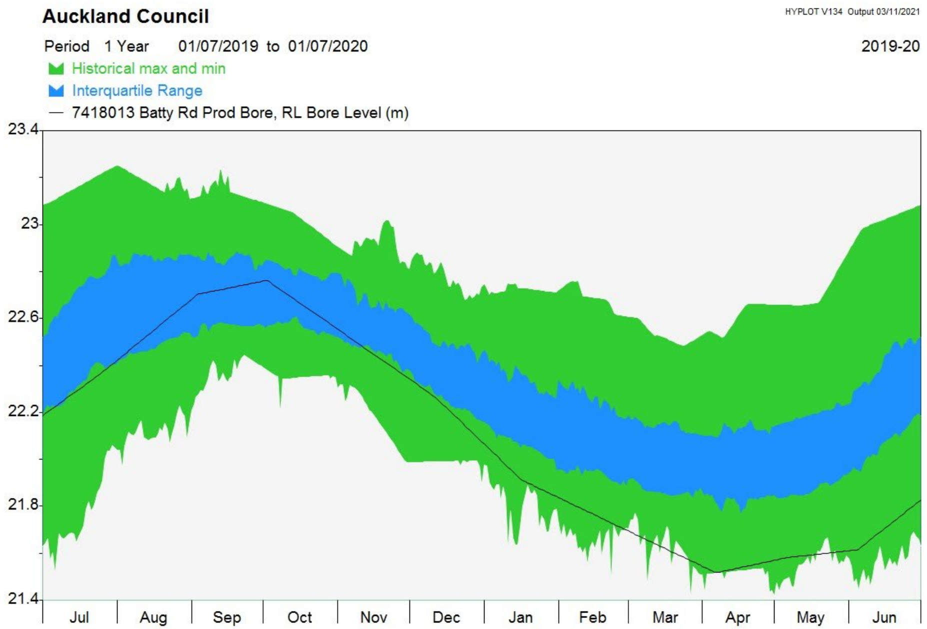

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7409001 Burnside Rd Bore, RL Bore Level (m)
32.5
30
27.5
25
22.5
20
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

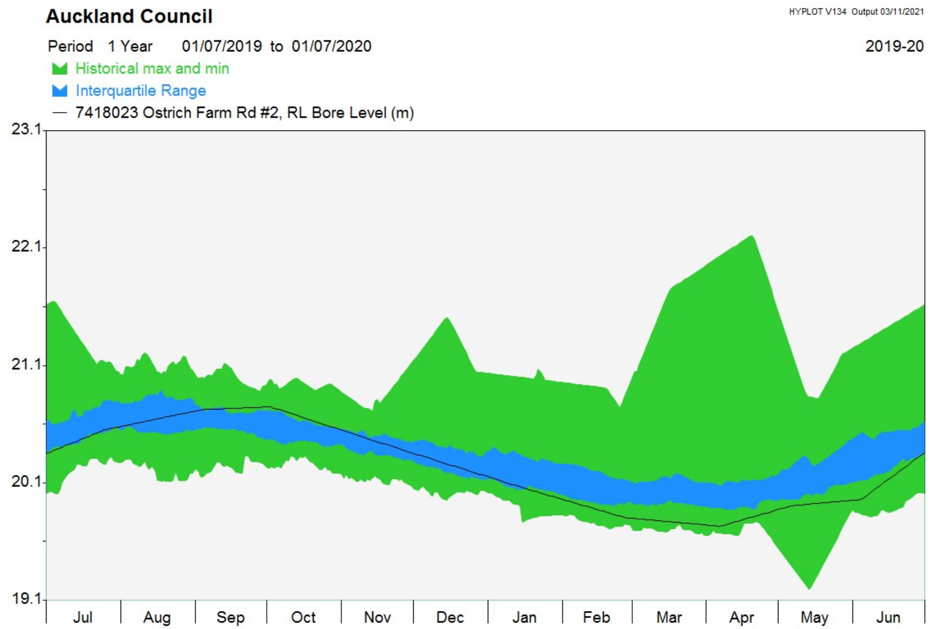

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7409011 Bullens Rd, RL Bore Level (m)
25
20
15
10
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

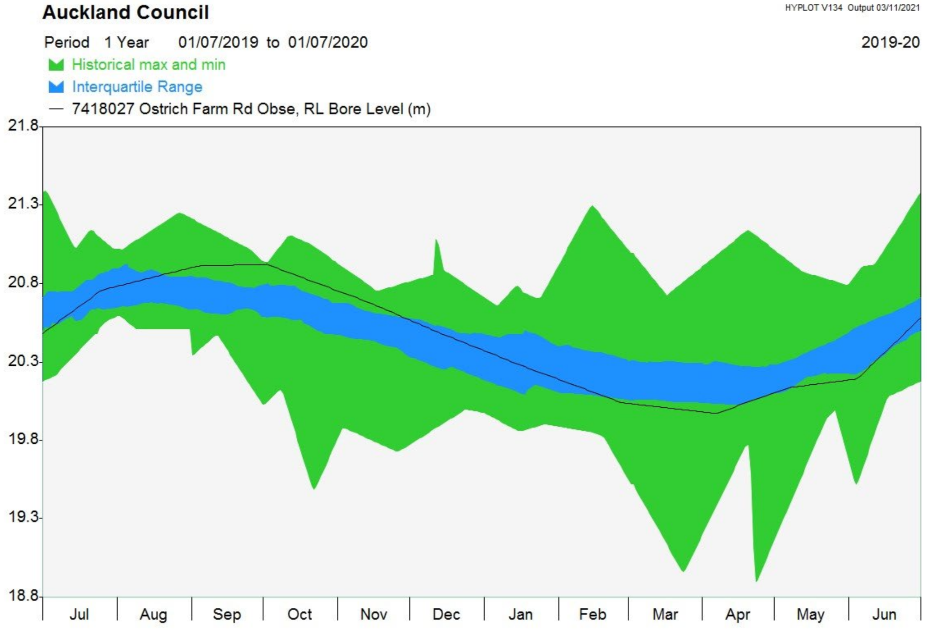

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7417001 Glenbrook Hall Bore, RL Bore Level (m)
9.8
9.3
8.8
8.3
7.8
7.3
6.8
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

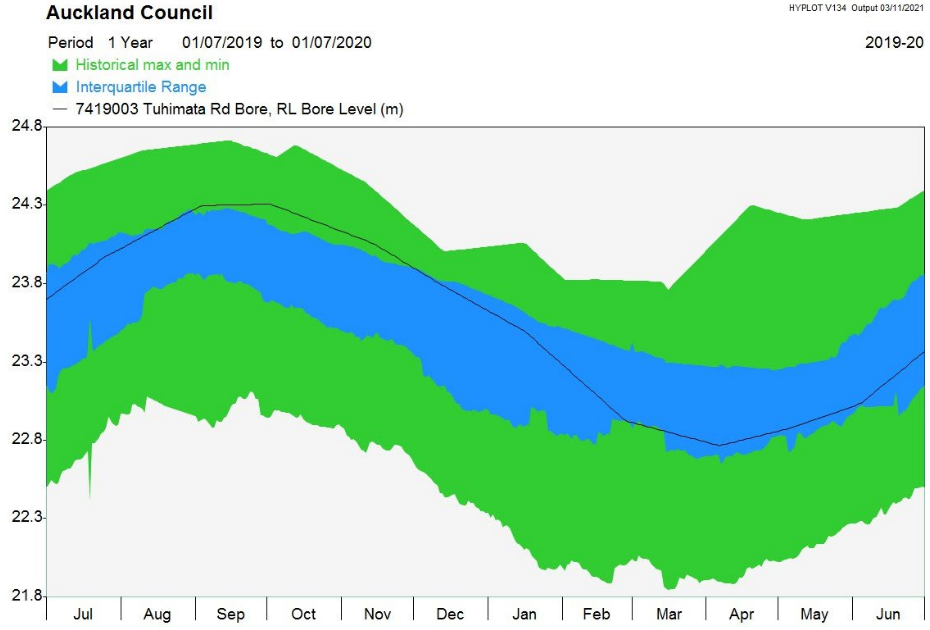

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7417021 Seagrove Rd Main, RL Bore Level (m)
7
6
5
4
3
2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

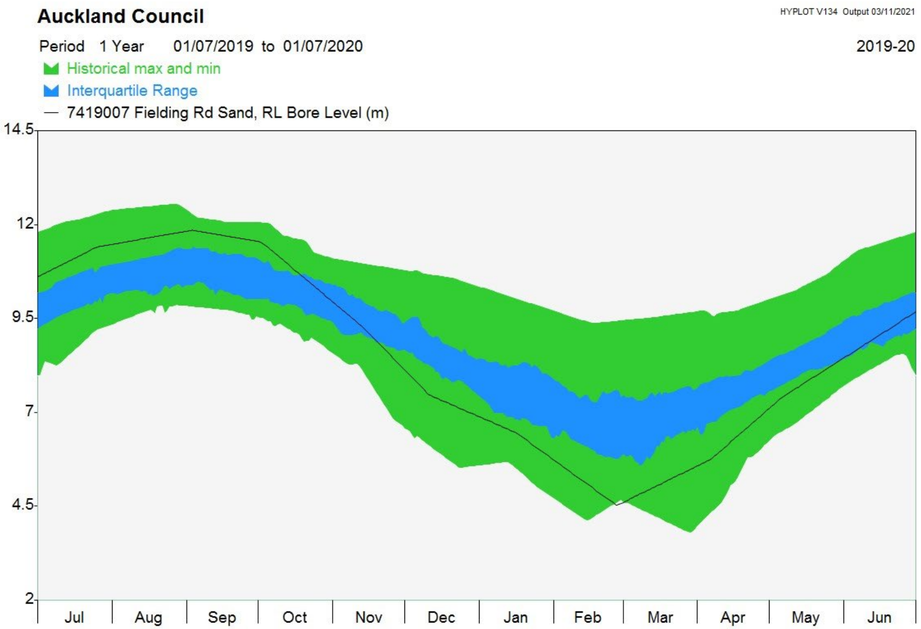

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7418003 Waiau Pa Bore 2C, RL Bore Level (m)
19.5
15.5
11.5
7.5
3.5
-0.5
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

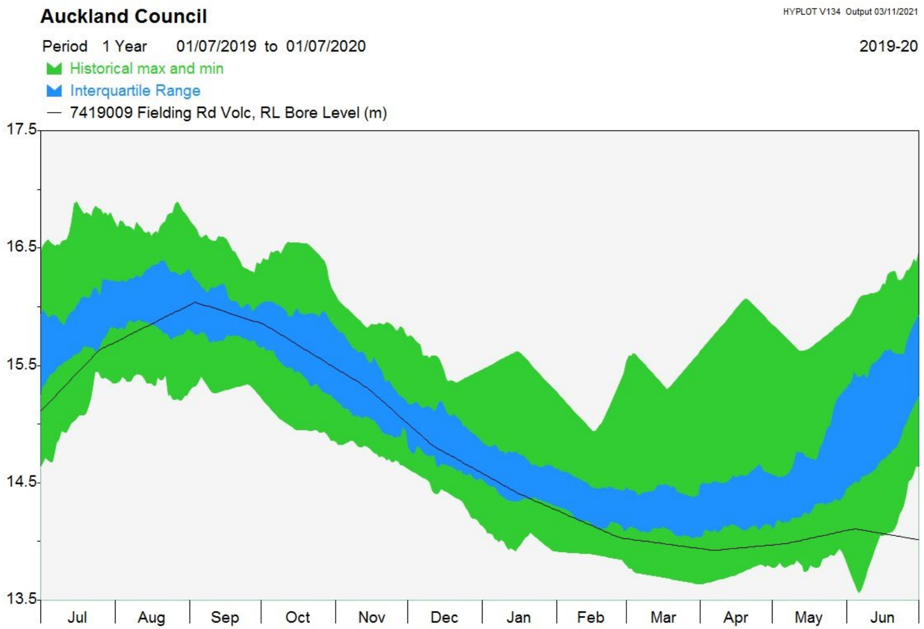

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7418013 Batty Rd Prod Bore, RL Bore Level (m)
23.4
23
22.6
22.2
21.8
21.4
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

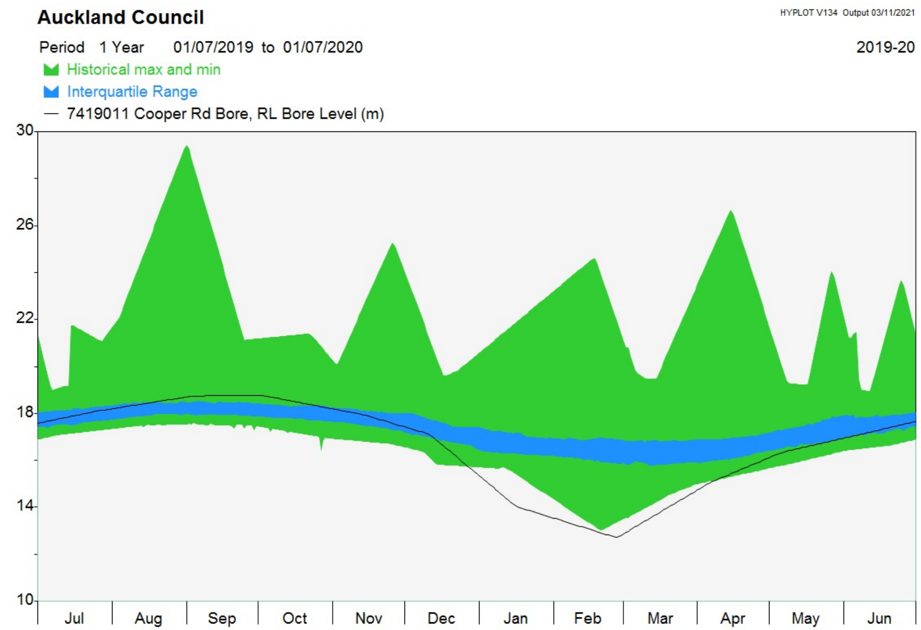

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7418023 Ostrich Farm Rd #2, RL Bore Level (m)
23.1
22.1
21.1
20.1
19.1
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

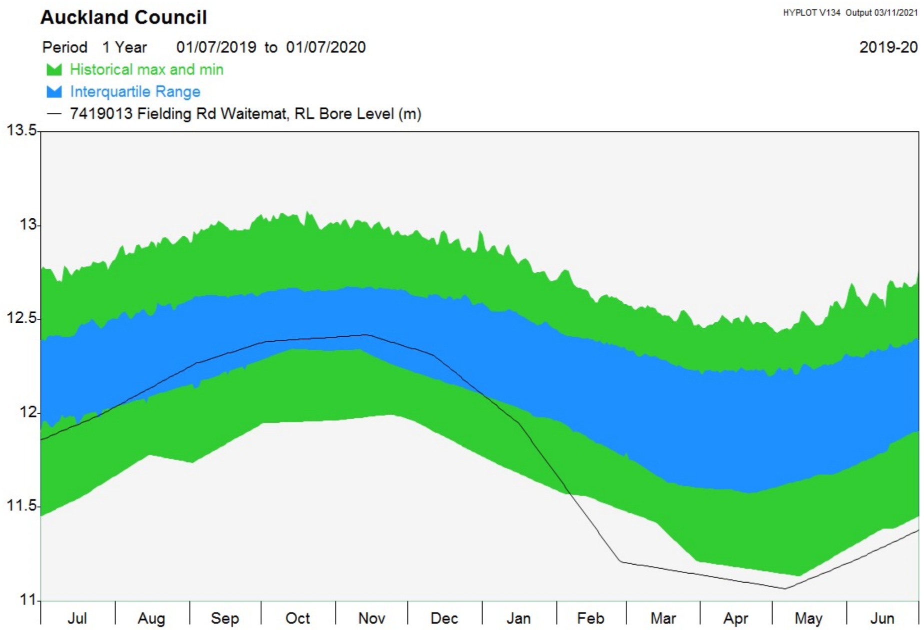

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7418027 Ostrich Farm Rd Obse, RL Bore Level (m)
21.8
21.3
20.8
20.3
19.8
19.3
18.8
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

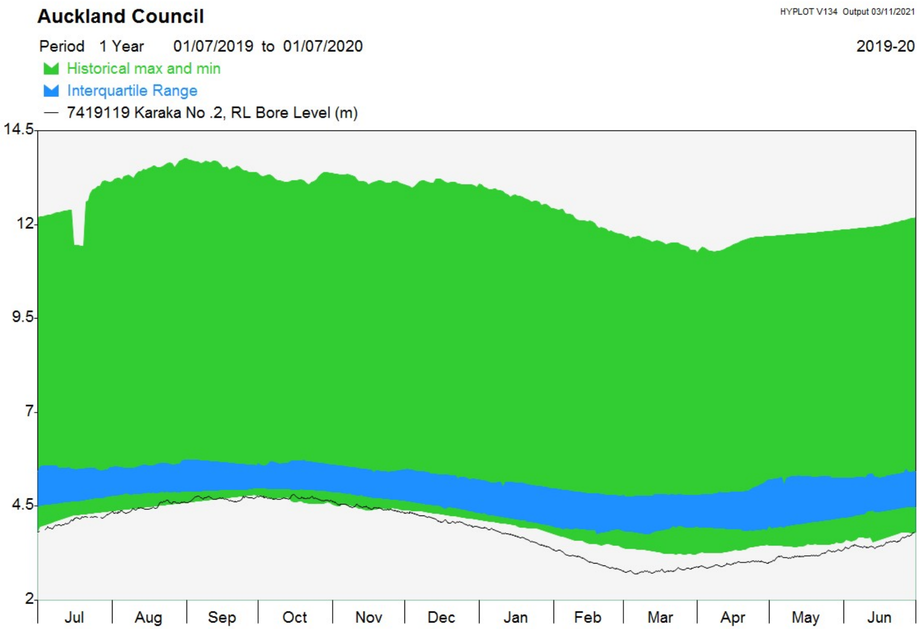

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419003 Tuhimata Rd Bore, RL Bore Level (m)
24.8
24.3
23.8
23.3
22.8
22.3
21.8
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

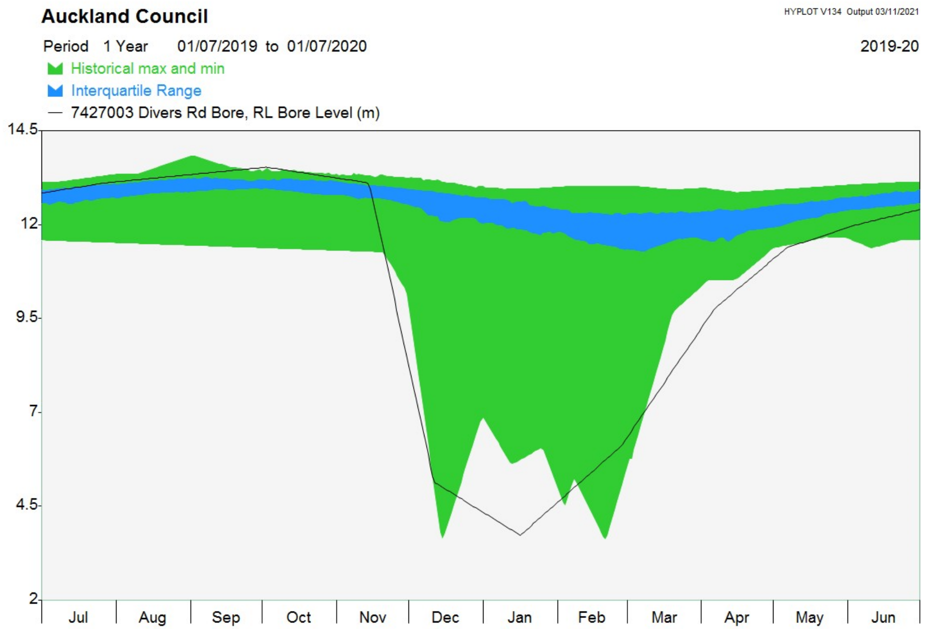

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419007 Fielding Rd Sand, RL Bore Level (m)
14.5
12
9.5
7
4.5
2
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

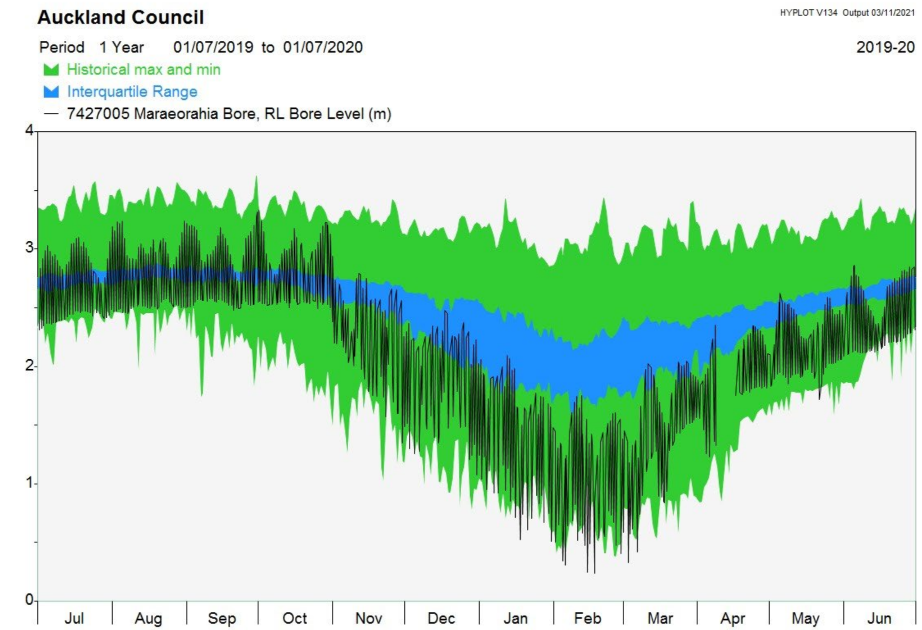

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419009 Fielding Rd Volc, RL Bore Level (m)
17.5
16.5
15.5
14.5
13.5
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

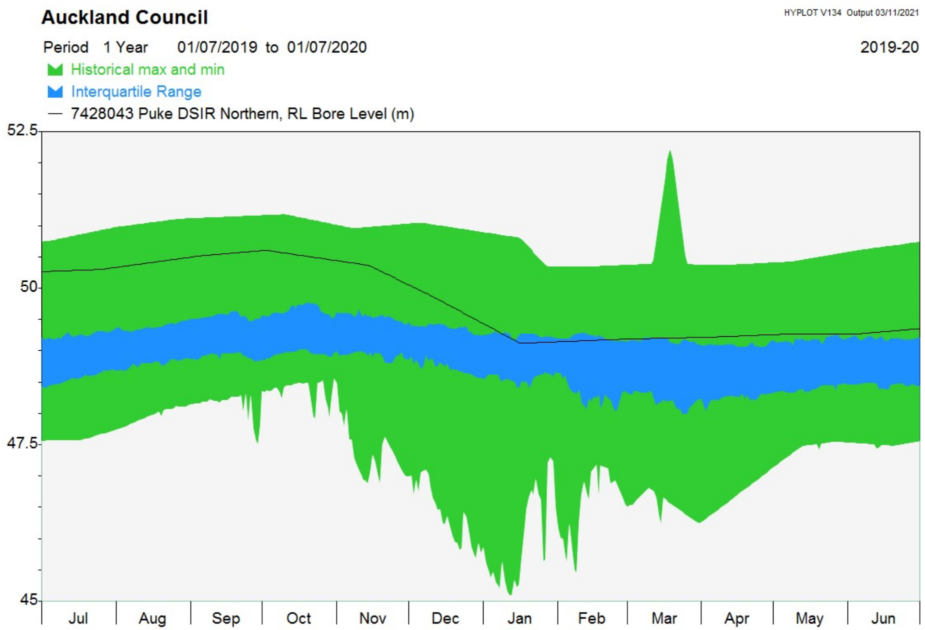

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419011 Cooper Rd Bore, RL Bore Level (m)
30
26
22
18
14
10
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

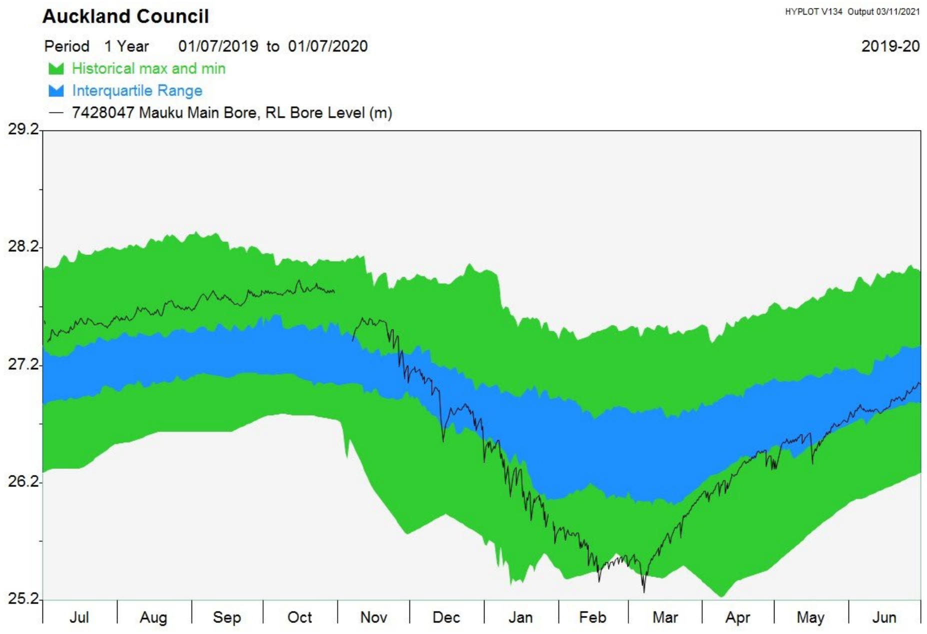

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419013 Fielding Rd Waitemat, RL Bore Level (m)
13.5
13
12.5
12
11.5
11
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

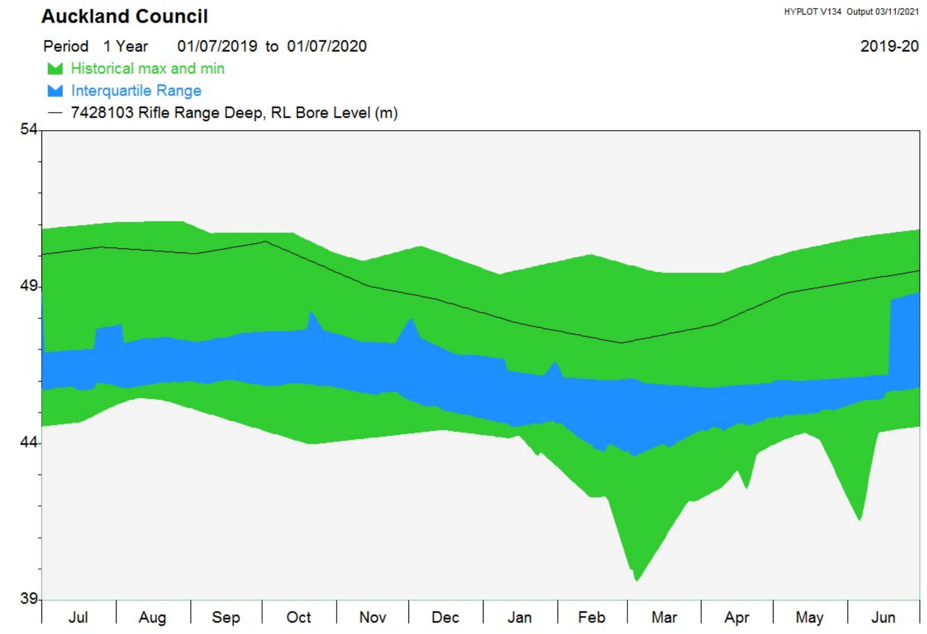

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7419119 Karaka No .2, RL Bore Level (m)
14.5
12
9.5
7
4.5
2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

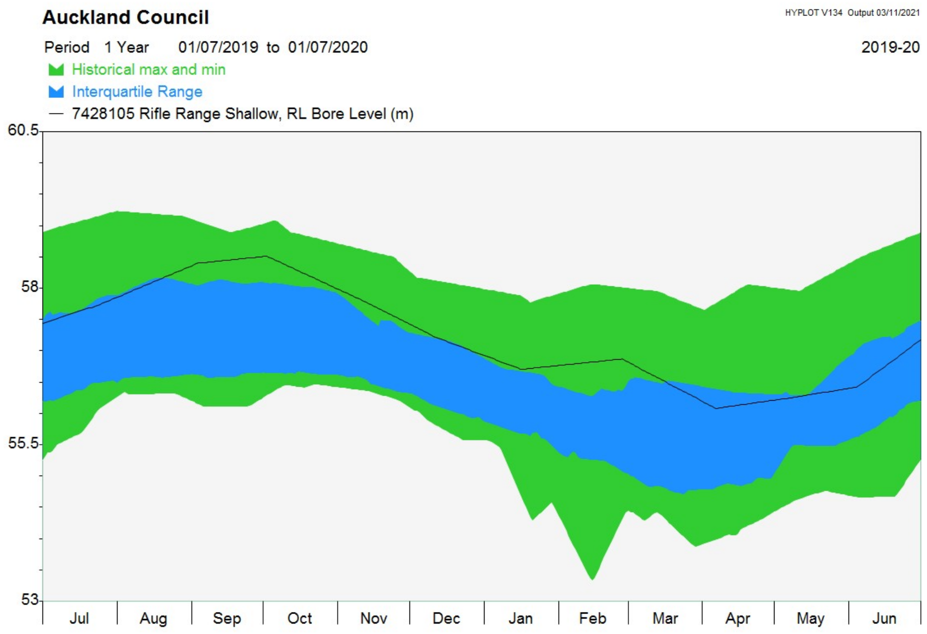

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7427003 Divers Rd Bore, RL Bore Level (m)
14.5
12
9.5
7
4.5
2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

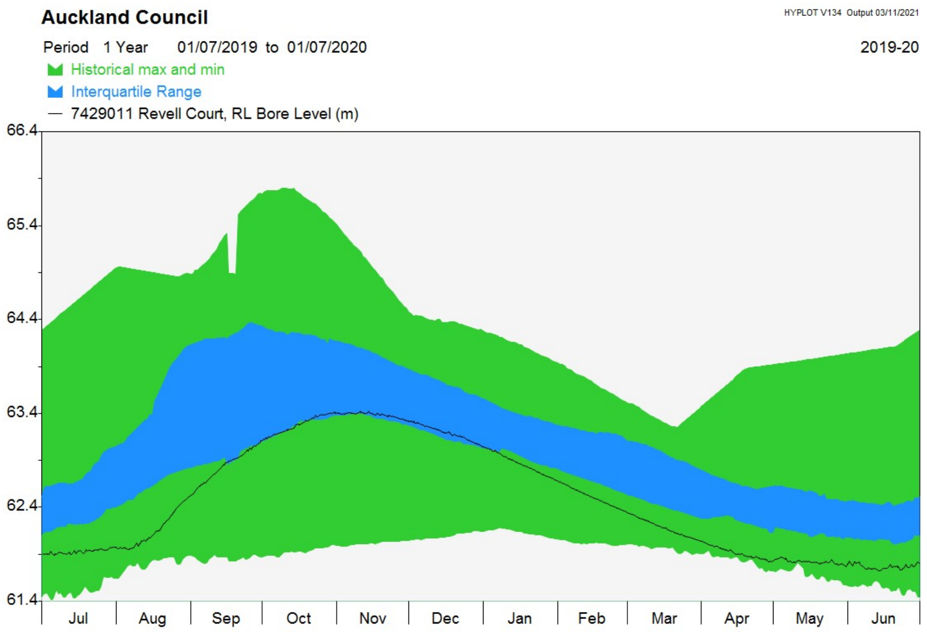

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7427005 Maraeorahia Bore, RL Bore Level (m)
4
3
2
1
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

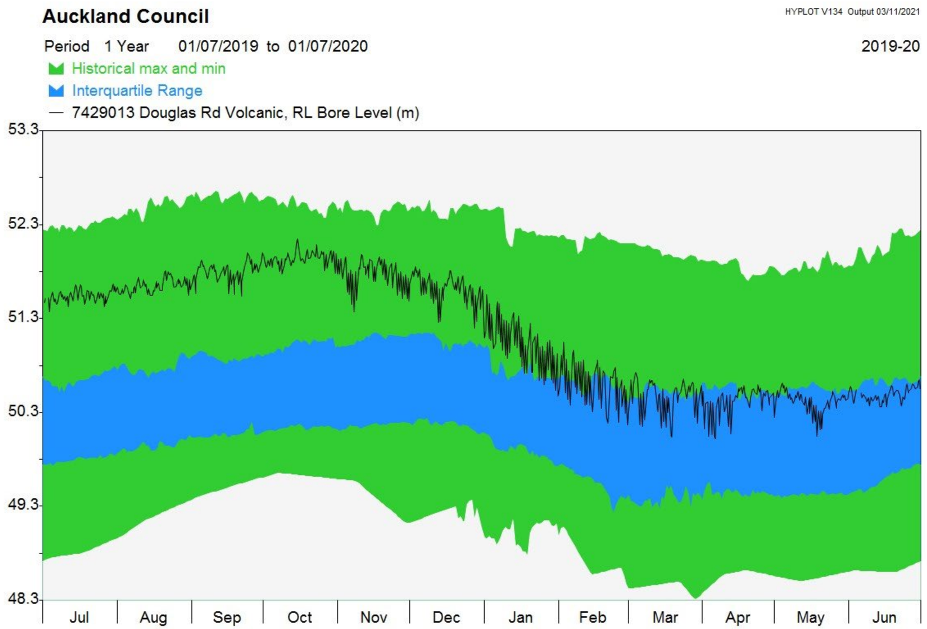

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7428043 Puke DSIR Northern, RL Bore Level (m)
52.5
50
47.5
45
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

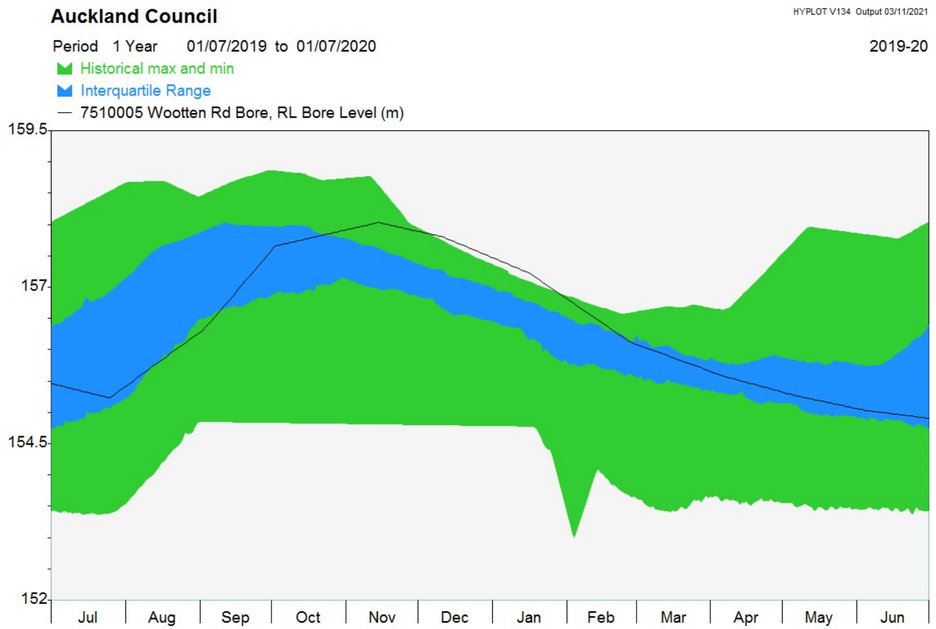

Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7428047 Mauku Main Bore, RL Bore Level (m)
29.2
28.2
27.2
26.2
25.2
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7428103 Rifle Range Deep, RL Bore Level (m)
54
49
44
39
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7428105 Rifle Range Shallow, RL Bore Level (m)
60.5
58
55.5
53
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7429011 Revell Court, RL Bore Level (m)
66.4
65.4
64.4
63.4
62.4
61.4
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7429013 Douglas Rd Volcanic, RL Bore Level (m)
53.3
52.3
51.3
50.3
49.3
48.3
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


Auckland Council
HYPLOT V134 Output 03/11/2021
Period 1 Year 01/07/2019 to 01/07/2020
2019-20
Historical max and min
Interquartile Range
7510005 Wootten Rd Bore, RL Bore Level (m)
159.5
157
154.5
152
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

Find out more: rimu@aucklandcouncil.govt.nz
or visit knowledgeauckland.org.nz and
aucklandcouncil.govt.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau