Groundwater Quantity

State of the Environment Monitoring

Triennial Report

2017-2020

Technical Report 2021-86

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Taranaki Regional Council

Taranaki Regional Council
Private Bag 713
Stratford

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Executive summary

Regional councils have responsibilities under the Resource Management Act (1991) to monitor the state of the environment within their region. The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater systems using a number of measures, including chemical and microbial water quality, groundwater levels and usage.

The focus of this report is regional groundwater quantity. The report incorporates an assessment of the volume of groundwater currently allocated for abstraction, which is compared against the estimated sustainable yields from the region's predominant aquifers. Water level data collected from a 15 site regional monitoring network were analysed to assess the range of groundwater level fluctuation across aquifers and assess possible drivers of observed fluctuations. An analysis of current state and trends in water level change over time is also presented.

The volume of groundwater allocated for abstraction across the region remains low, with only minor increases in the demand for groundwater over the last decade. As of 30 June 2020, there were only 73 current consents authorising the taking of groundwater. The highest level of allocation is currently seen in the Whenuakura and Matemateaonga aquifers (10.6% and 2.7% of sustainable yield respectively). All other aquifers have insignificant volumes of water allocated (<1 % of estimated sustainable yield).

With low demand for groundwater in Taranaki, none of the region's aquifers are presently under significant pressure. While there may be an increase in demand as people look to move away from less secure surface water sources, this is not expected to place groundwater under significant pressure in the short to medium term.

As expected, monitored groundwater sites display fluctuations in water level as a result of seasonal variations in rainfall recharge. The magnitude of these changes varies considerably by site, ranging from a few millimetres up to several metres. The magnitude of these fluctuations is influenced by rainfall patterns, bore depth, aquifer type (confined or unconfined) and hydraulic properties, the overlying land cover, and proximity to a stable surface water boundary or groundwater discharge area (e.g. river or sea).

The data collected over the last three years of monitoring at each site has also been assessed to determine the current state of groundwater levels across monitored aquifers. The assessment shows that current water levels do not differ significantly from historical long-term averages. The analysis also illustrated similarities in spatial and temporal responses to rainfall across some sites.

Water level data collected at each monitoring location has been analysed for trends. This included analysis of both long-term trends and more recent trends using data from the last five year period (2015-2020).

The results of the trend analysis show that at the vast majority of sites there has been no meaningful change in water level over time. The exceptions to this were site GND0708, near Hawera, which was found to have experienced a slightly decreasing trend over its long-term data record and GND2253, near Patea, which exhibited a slight increasing trend in recent years.

The declining trend in GND0708 was identified in the previous report and an investigation to ascertain a cause of the declining water levels was initiated. The investigation found that it was unlikely that water levels were being reduced as a result of local groundwater abstractions. A visual assessment of the data indicates the changes observed may be part of longer-term water level pattern at the site and not indicative of any widespread reduction in groundwater levels across the aquifer. Further investigation into the trend seen in GND2253 illustrates hydraulic connection with a nearby public water supply bore.

The results of the analyses undertaken show that groundwater abstraction and usage is well within current allocation limits, with little pressure on the region's groundwater systems at the present time.

This suggests that Council’s policies relating to groundwater abstraction and usage continue to support sustainable management of the region’s groundwater resource.

Table of contents

List of tables

List of figures

1 Introduction

1.1 State of the environment monitoring (SEM)

Regional councils have responsibilities under the *Resource Management Act* (*1991*) (RMA) to monitor the state of the environment within their region. The purpose of state of the environment monitoring (SEM) is to collect sufficient data to produce information on the general health of the environment.

The Taranaki Regional Council (the Council) monitors the state and trends across the region's groundwater resource using a number of measures, including chemical and microbial water quality, groundwater levels and usage. The results of the monitoring undertaken are reported in two separate SEM reports, one covering groundwater quality and the other dealing specifically with groundwater quantity, as reported in this document.

The SEM Groundwater Quantity Programme has three primary objectives:

- To assess the current state of groundwater allocation across the region's major aquifer systems;
- To provide information on the current range of groundwater levels at a selected number of sites across the region's major aquifer systems;
- Identify spatial and temporal trends in water level arising as a result of natural and/or anthropogenic influences, including allocation pressures.

This information can then be used to measure how well management practices, policies and rules are working, and whether environmental outcomes are being achieved.

1.2 Groundwater quantity management

The *Regional Policy Statement for Taranaki (2010*) (RPS) sets out the Council's approach to the sustainable management of groundwater use across the Taranaki region. Policies set out in the RPS are intended to protect against adverse effects on groundwater flows arising from over abstraction. It is intended that this be achieved by managing groundwater take volumes within the sustainable yields of specific aquifer units. Polices set out in the RPS also recognise the connection between groundwater and surface water systems and therefore the potential for reduced surface water flows as a result of groundwater abstraction. The RPS also details a range of other matters to be considered in relation to the taking and use of groundwater, while promoting its use as a potential alternative to surface water. These recognise the need for groundwater to be available for reasonable domestic, stock watering and firefighting needs, as required by section 14(3) of the RMA, subject to the taking or use not resulting in any adverse effects on the environment.

The main method of policy implementation is through the *Regional Freshwater Plan for Taranaki (2001)* (RFWP), which sets out regional rules to allow, regulate and avoid adverse effects on the environment from the taking and use of groundwater. Under Rule 48 of the RFWP, the taking of groundwater of up 50 m^3/day, at a rate not exceeding 1.5 L/s, is permitted, providing several conditions are met. Takes exceeding this volume or rate, or not meeting all associated conditions, require a resource consent. Through the consenting process, the matters set out for consideration under the RPS are assessed, as are the wider environmental effects of any proposed take.

The Council also undertakes a comprehensive programme of consent compliance monitoring. This includes the monitoring of consents authorising the taking of groundwater. The range of monitoring carried out is dependent on the risk associated with the specific take, but in most instances will include requirements to record the volumes of water taken and/or the rates of take. The recording of specific take data is also a requirement under the *Resource Management (Measuring of Water Takes) Regulations (2010)* for any take exceeding 5 L/s. In any addition to these requirements, the Council may also require monitoring of water levels in a pumping bore, or surrounding bores. The monitoring of groundwater levels is the primary means of assessing the effects of a groundwater take, be those of a specific take or the cumulative impact of multiple takes within an aquifer unit.

1.3 Groundwater quantity monitoring programme

The groundwater quantity monitoring programme is an amalgamation of two SEM groundwater monitoring programmes that were previously delivered separately by the Council, namely the pressures on groundwater resources and groundwater levels monitoring programmes. The two programmes have been amalgamated to provide a more integrated assessment of groundwater allocation pressures and the potentially observable impacts of groundwater takes (reduced groundwater levels).

The revised programme is comprised of two primary components. These include the desk based assessment of groundwater allocation volumes, based on a review of consent information and records held within the Council's water accounting system, and the operation and assessment of data from a regional groundwater level monitoring network.

This is the second report prepared under the revised programme structure. The first report covered the 2015-2016 and 2016-2017 monitoring years.

2 Regional hydrogeology

The Taranaki region hosts an extensive groundwater resource that is widely utilised for potable water supply (predominantly domestic and limited municipal), agricultural (stock water and irrigation) and industrial usage. Aquifer bearing formations can be generally characterised into those of Quaternary and Tertiary age. Figure 1 illustrates the geographical distribution of the major geological units in Taranaki. The aquifer systems in Taranaki are informally named after the geological units they occur in.

2.1 Taranaki volcanic deposits

Quaternary aged volcanic deposits cover a wide area of the Taranaki region, extending from the coastal boundary in the west, to the Tertiary deposits of the Taranaki basin in the east, and bounded to the north and south by the Quaternary marine terrace deposits.

The Taranaki volcanic deposits contain both coarse material (sands, breccia and agglomerates) and fine material (clay, tuff and ash), resulting in irregular lithologies and anisotropic hydrogeologic conditions (Taylor and Evans, 1999). These result in a complex system of unconfined, perched and semi confined aquifers within the volcanic deposits. The water table in the ring plain, which extends radially from Taranaki, Maunga is typically encountered between 1 to 10 m below ground level. Seasonal variations in water table depth of up to 5 m are common. Groundwater flow generally reflects surface topography and flows radially from Taranaki Maunga. Recharge to the Taranaki Volcanics Aquifer is mainly by local rainfall infiltration.

Shallow wells and bores drawing water from unconfined aquifers in the volcanic deposits typically yield in the range 0.5-2.5 L/s. Higher yielding confined aquifers are reported from volcanic deposits in the Kaitake Ranges (19 L/s), New Plymouth (10 L/s), Okato (20 L/s) and Kapuni (8 L/s).

Shallow, unconfined groundwater systems within the Taranaki volcanic deposits also provide baseflow to the many rivers and streams that traverse the Taranaki ring plain. A number of streams rising both within Te Papakura o Taranaki and at lower elevations across the ring plain are known to be spring fed, with the most significant contributions from groundwater occurring at elevations within Te Papakura o Taranaki.

2.2 Marine terrace deposits

The marine terrace deposits occur in coastal areas south of Hawera and, to a lesser extent, the coastal areas north of New Plymouth. Basal units are typically marine sands often with conglomerate or shell layers, grading upward to terrestrial sediments.

The marine terrace sediments range up to about 40 m in thickness and contain multiple unconfined aquifers. The water table within the marine terrace deposits generally lies between 1 to 15 m below ground level. Recharge to the Marine Terrace Aquifer is primarily by local rainfall infiltration.

Numerous shallow wells and bores draw from unconfined aquifers contained within the marine terrace deposits, with yields in the range 0.3-2.6 L/s. No confined aquifers are known to occur in the marine terrace deposits.

2.3 Tertiary sedimentary formations

Nine Tertiary sedimentary formations are recognised in the region (Figure 1). The formations as a whole are gently tilted towards the southwest. Seven formations are exposed in the eastern Taranaki hill country and continue beneath the volcanic and marine terrace deposits, while two (Otunui and Mt. Messenger) are fully exposed.

Little is known about groundwater use in the Otunui and Mt. Messenger formations. The Urenui Formation is regarded as an aquiclude/aquitard, and as such is not aquifer-bearing. In all of the other formations, shallow wells and bores draw from unconfined aquifers, and at depth the same formations host more productive confined aquifers.

Higher yielding confined aquifers are reported from the Kiore Formation at Bell Block (35 L/s), Matemateaonga Formation at Kapuni and Eltham (7-20 L/s) and the Whenuakura Formation at Patea and Waverley (8-10 L/s).

2.4 Rainfall and climate variability

The Taranaki region receives regular rainfall throughout the year as a result of its westerly position, its mid-latitude location and topography. Average annual rainfall volumes across the region range from approximately 1,000 mm along some southern coastal margins to in excess of 7,000 mm on the upper slopes of Taranaki Maunga. Rainfall volumes increase rapidly with elevation away from the coast (Figure 2). The high rainfall volumes across Taranaki generally result in rainfall surpluses being available to recharge the region’s groundwater systems, particularly where aquifer recharge zones are located in elevated areas, be it off Taranaki Maunga or the eastern hill country.

Variation in global climate patterns have the potential to affect the volume of rainfall seen in Taranaki, as it does elsewhere. The predominant processes include the El Niño-Southern Oscillation cycle (ENSO) and the Inter-decadal Pacific Oscillation (IPO). ENSO and the IPO are natural cycles that operate over timescales of years and decades, respectively.

The ENSO cycle results in interchanging El Niño and La Niña weather patterns. During El Niño New Zealand tends to experience stronger or more frequent winds from the west in summer, which can encourage dryness in eastern areas and more rain in the west. In winter, the winds tend to blow more from the south, causing colder temperatures across the country. In spring and autumn, south westerly winds are more common

During La Niña events northeasterly winds tend to become more common, bringing moist, rainy conditions to north eastern areas of the North Island and reduced rainfall to the lower and western South Island. Warmer than average air and sea temperatures can occur around New Zealand during La Niña.

In El Niño years, Taranaki tends to experience reduced rainfall volumes. In La Niña years increased rainfall volumes are generally recorded, particularly during winter and spring, and a greater occurrence of heavy rainfall events, often associated with subtropical lows coming from the north Tasman (NIWA, 2008).

The Inter-decadal Pacific Oscillation (IPO) is a Pacific-wide natural fluctuation in the climate, which causes shifts in Pacific Ocean circulation patterns. There are two IPO phases, positive and negative, with phase changes experienced every 20-30 years. In the positive phase, westerly quarter winds over the country and anticyclones in the north Tasman are more prevalent. The most recent IPO reversal occurred 1999-2000, with a shift to a negative phase. This would be expected to encourage more La Niña activity (NIWA, 2008). Thompson et al. (2006) examined rainfall figures from New Plymouth during two distinct IPO phases and concluded that rainfall producing processes at New Plymouth and in the surrounding districts in North Taranaki were not being influenced to any great extent by the phase of the IPO.

Climate change projections for the wider region suggest increasing precipitation and more extreme rainfall events in the coming decades, with longer and more frequent dry spells. NIWA reports Taranaki can expect a mixture of changes in rainfall, with an increase in rainfall of up to 8-12% in winter, with decreases in inland and northern areas in autumn and spring under different climate change scenarios. An increase in the number of dry days, particularly from spring through to autumn, can be expected with little change in winter projected by 2090. For all future climate scenarios, we anticipate seeing an increase in drought conditions, particularly by 2090. Based on the available information, it is not predicted that climate change effects will significantly alter groundwater recharge volumes over the time-scales of current climate change projections.

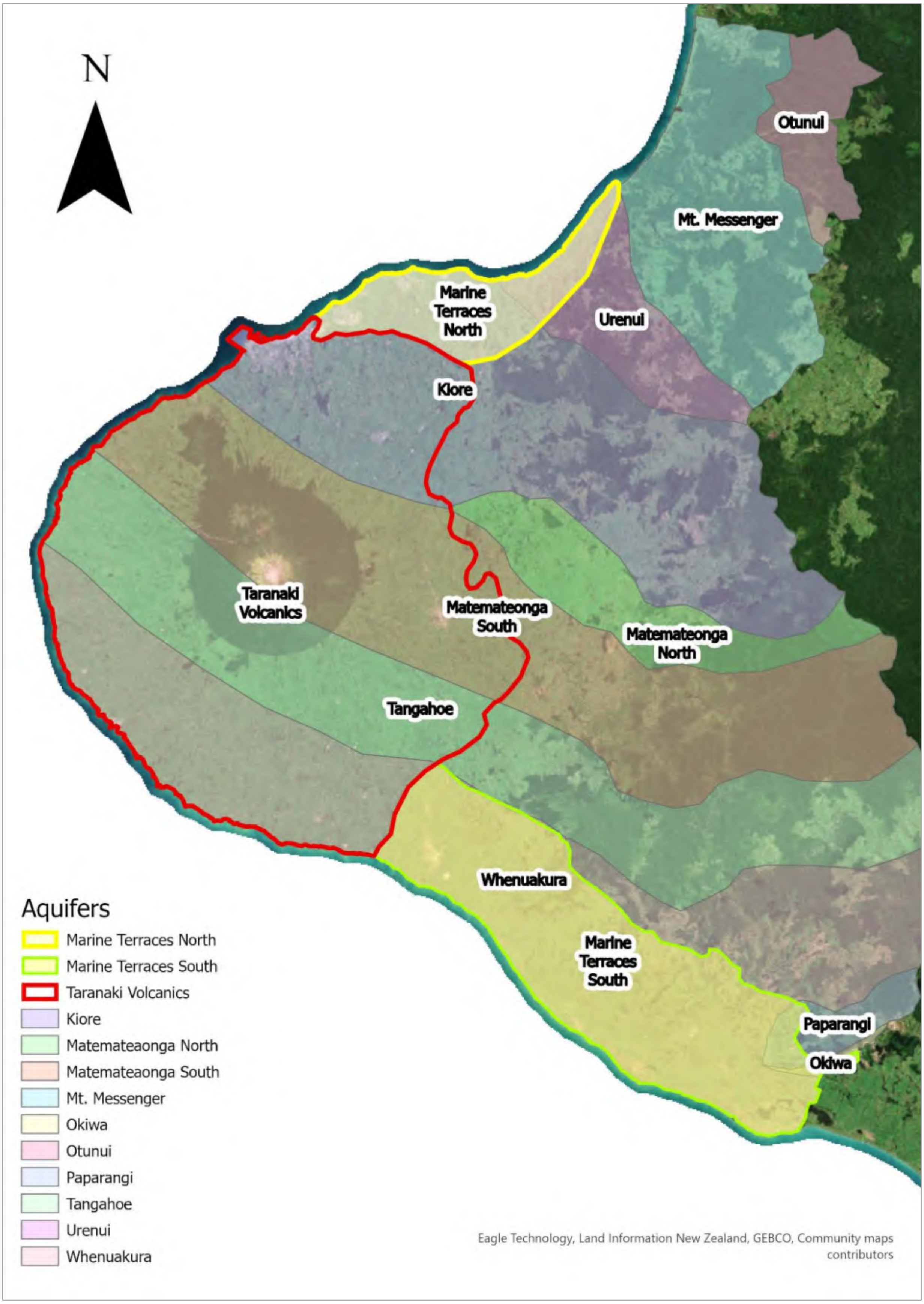


Figure 1 Distribution of the main geological units (aquifers) of the Taranaki region

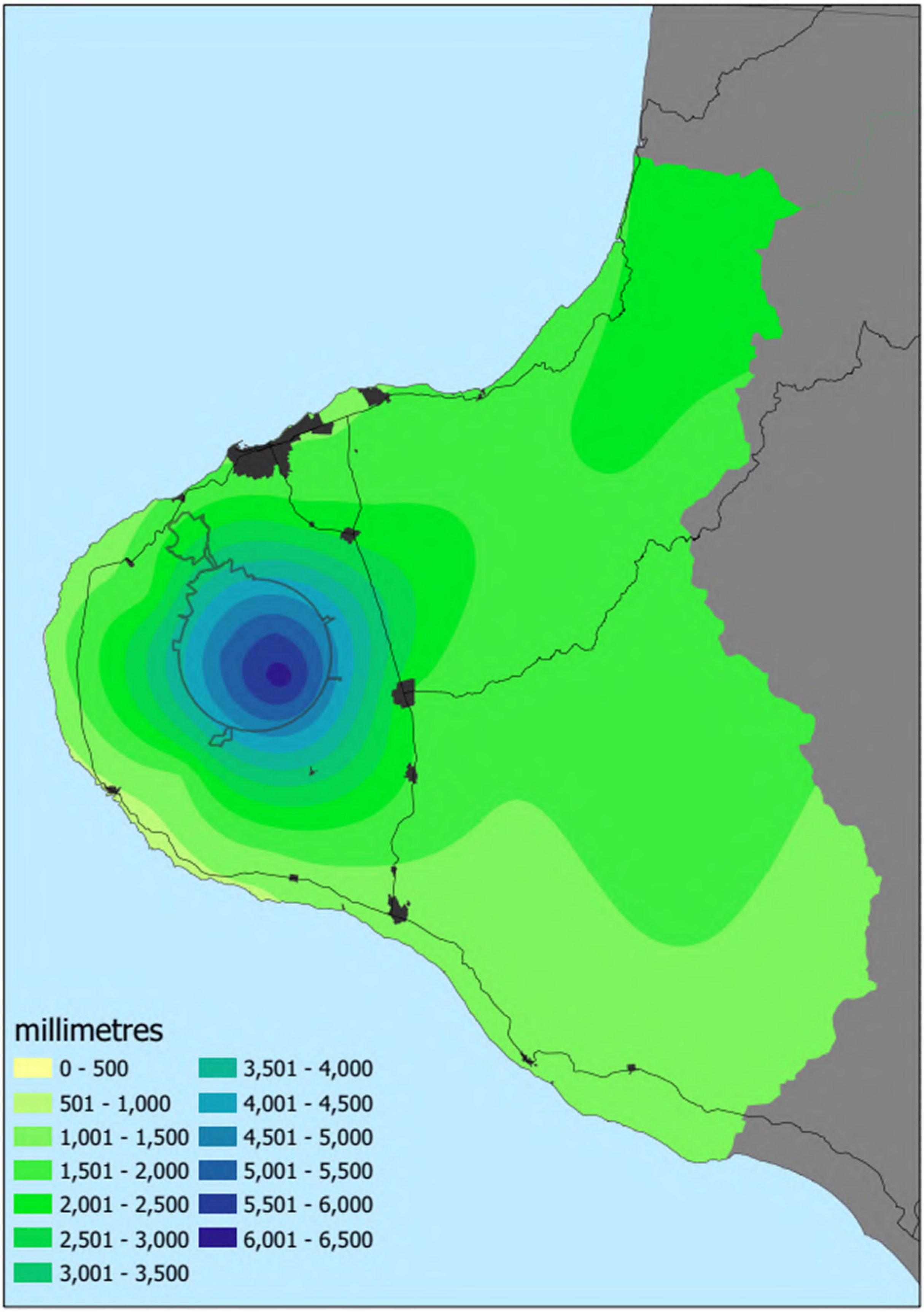


Figure 2 Patterns of rainfall distribution across Taranaki and average annual volumes (2017-2020)

2.1 Estimates of recharge and sustainable groundwater yields

For the purposes of groundwater accounting, the region has been subdivided into 12 groundwater aquifers that align with geological unit boundaries (Figure 1).

An estimate of sustainable yield has been calculated for each of the aquifers displayed in Figure 1. These have been calculated by estimating the amount of rainfall likely to recharge each aquifer on an annual basis. The calculations are therefore based on conservative estimates of 'new' water entering each aquifer each year, not on water that is already in storage.

The total volume of rainfall potentially recharging each aquifer (rainfall recharge) was calculated by multiplying 30% of the average annual rainfall by the spatial area of each aquifer receiving direct recharge from rainfall (i.e. unconfined areas of an aquifer exposed at surface). Sustainable yields have been conservatively set at 35% of rainfall recharge for all aquifers. This equates to allocable volumes that are approximately 5-10% of the total annual rainfall, so is very conservative (Table 1). In other words, it is assumed that the remaining 90-95% of rainfall either evaporates, is discharged as surface run-off or replenishes groundwater storage. Calculations are based on those proposed by Ministry for the Environment (MfE), 2008.

Table 1 Estimates of sustainable yields calculated for all groundwater aquifers

Geological age	Aquifer	Classification	(ML/yr) Sustainable yield
Quaternary	Taranaki Volcanics	Unconfined	617,670,699
	Marine Terraces North	Unconfined	40,463,833
	Marine Terraces South	Unconfined	96,732,208
Tertiary	Kiore	Confined	154,171,531
	Matemateaonga	Confined	165,961,911
	Mt. Messenger	Confined	140,017,639
	Okiwa	Confined	751,065
	Otunui	Confined	37,177,534
	Paparangi	Confined	9,928,462
	Tangahoe	Confined	96,069,770
	Urenui	Confined	45,661,458
	Whenuakura	Confined	71,384,932

3 Groundwater allocation

Groundwater abstraction primarily occurs across a small number of the region's potentially water bearing hydrogeological units, where overlying land use or development has necessitated a particular water supply need that cannot be adequately met by municipal or community supply, or a surface water abstraction.

The typically low yields associated with the region's shallow unconfined aquifers mean that abstraction of groundwater is generally only suitable for low demand uses. As a result, the majority of abstractions from these aquifers are likely to be permitted under rules set out in the RFWP, which set out limits in terms of abstraction rate and volume. The total volume of groundwater allocated across Taranaki is comprised of takes permitted by the RFWP and those authorised by a resource consent.

Estimates of potential permitted take demands were recently developed by the Council, as part of its water quantity accounting system development project. Further details of the methodology used to develop these permitted take estimates can be found in the report detailing this work (TRC, 2017). In summary though, an overall potential permitted take demand was estimated on a catchment basis, based on livestock and dairy shed water demands. The total estimated permitted take demand was proportioned between surface and groundwater sources. The permitted groundwater take estimates were also aggregated and apportioned by aquifer. This includes an estimate of the volume of permitted groundwater takes sourced from both unconfined aquifers and areas of Tertiary aquifers confined by overlying Quaternary hydrogeological units.

The volume of water allocated through resource consents was calculated using consents data stored in the Council's IRIS database. A total of 73 consents authorising the taking of groundwater, 68 for water supply and five for dewatering purposes, were current as of 30 June 2020. The locations of all consented groundwater abstractions are set out in Figure 3. The special conditions attached to each of these consents vary, as a result of standard consent conditions evolving over time. All current consents to abstract groundwater have either a take rate or volume restriction or, in some cases, a combination of both.

Where volume limits are stipulated in the conditions of a consent, this figure was used to calculate the volume of water that could potentially be taken under the consent on an annual basis. Where a take was restricted by rate, the maximum authorised rate of take has been used to calculate the volume of water that could potentially be taken under the consent over the course of a year. Both calculations assume that each take is fully utilised, that is, the maximum volume is taken on a daily or weekly basis, or abstraction occurs 24 hours a day, 365 days of the year for those consents which only specify a limit on the rate of take. Both of these scenarios are highly unlikely, and therefore the calculated usage figures likely represent an overestimation of actual water use.

Table 2 summarises the current levels of groundwater allocation against estimated sustainable yields for each aquifer.

The implications and significance of this data is discussed in Section 6.1 of this report.

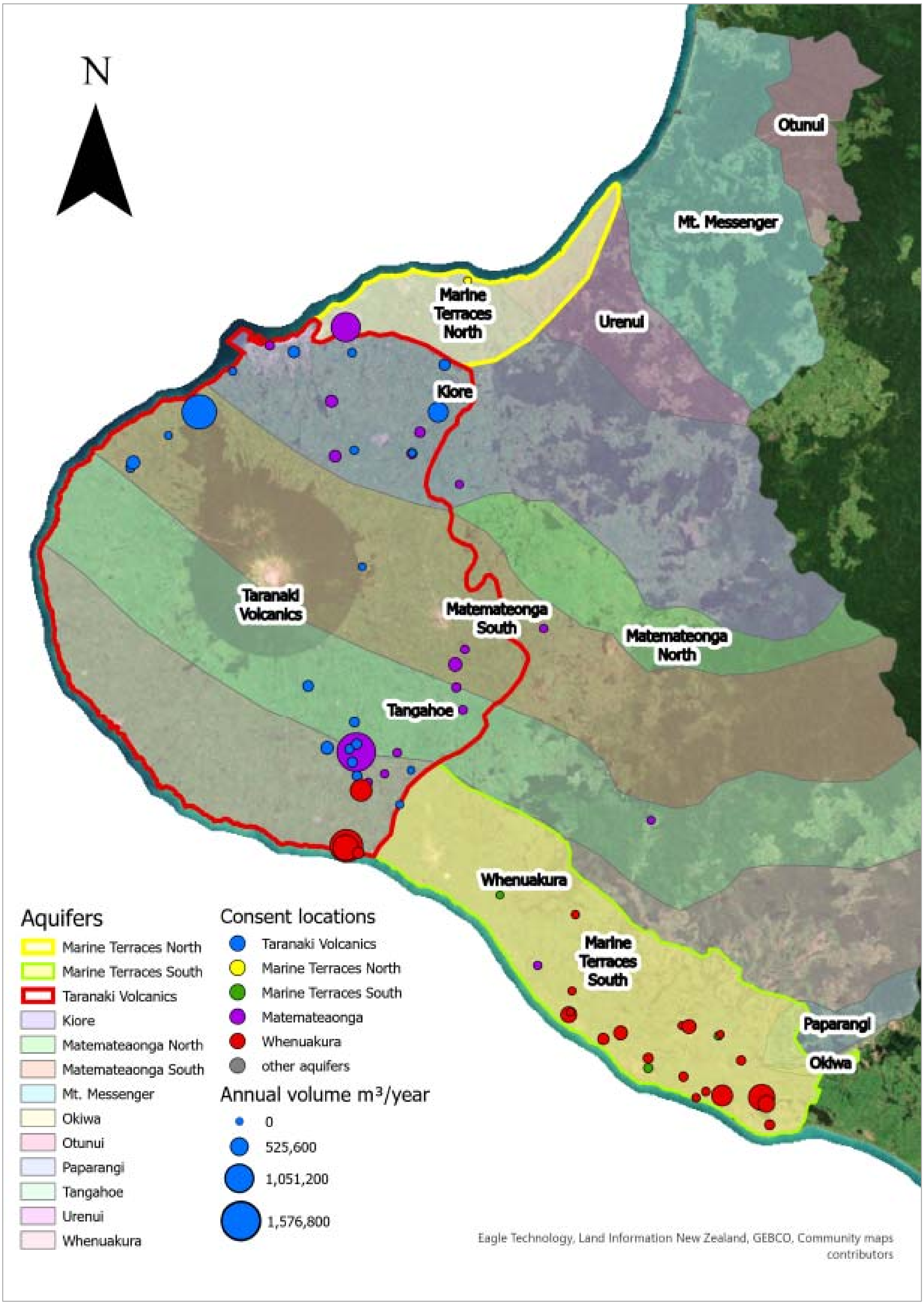


Figure 3 Locations of consented groundwater abstractions as of 30 June 2020

Table 2 Current levels of groundwater allocation across Taranaki in comparison to calculated sustainable yields for each groundwater aquifer (as at 30 June 2020)

Geological age	Aquifer	(ML/yr)		
		Sustainable yield	Allocated	% allocated
Quaternary	Taranaki Volcanics	617,670,699	5,262,205	0.9
	Marine Terraces North	40,463,833	133,433	0.3
	Marine Terraces South	96,732,208	508,800	0.5
Tertiary	Kiore	154,171,531	149,600	0.1
	Matemateaonga	165,961,911	4,425,795	2.7
	Mt. Messenger	140,017,639	70,540	<0.1
	Okiwa	751,065	3,287	0.4
	Otunui	37,177,534	18,432	<0.1
	Paparangi	9,928,462	14,708	0.2
	Tangahoe	96,069,770	134,119	0.1
	Urenui	45,661,458	0	0
	Whenuakura	71,384,932	7,553,830	10.6

4 Regional groundwater level monitoring network

The monitoring of groundwater levels enables the Council to examine the relationships between groundwater recharge and discharge within regional groundwater and surface water systems. Where recharge volumes exceed those discharged, groundwater levels rise. Conversely, if discharge volumes exceed recharge, groundwater levels fall. Fluctuations in recharge are predominantly related to climatic patterns, but can also be artificially influenced by activities such as pasture irrigation onto recharge areas. Discharge volumes are influenced by both natural processes, such as flow from springs and groundwater seepage to rivers and the coast, and the removal of groundwater by abstraction.

The Council monitors groundwater levels at 15 sites across the region. Nine of these sites are classified as long-term sites, where data has been collected for in excess of ten years. Six further sites have been added to the programme since 2012 to improve the spatial coverage of the monitoring network.

The monitoring network now includes sites in all of the region's water bearing formations that are most utilised for water supply, with site distribution targeted toward areas of greater water use pressure. The monitoring network includes sites of varying depth in order to monitor water level fluctuations in both unconfined and confined groundwater systems.

The network includes two multi-well monitoring sites, located south of Eltham (sites GND0599 and GND0600) and at Patea (sites GND2252 and GND2253). At each of these sites, two wells have been installed in close proximity to monitor vertically separated aquifer units.

Table 3 sets out the distribution of sites included in the monitoring network by aquifer. Specific details of each site are provided in Table 4 and their respective geographical locations are illustrated in Figure 4 and Figure 5 respectively.

Table 3 Distribution of groundwater level monitoring sites by aquifer across Taranaki (groundwater aquifers in bold text represent those with the greatest level of water use pressure)

Aquifer	Number of monitoring locations
Taranaki Volcanics	4
Marine Terraces North	1
Marine Terraces South	1
Kiore	0
Matemateaonga	3
Mt. Messenger	0
Okiwa	0
Otunui	0
Paparangi	0
Tangahoe	1
Urenui	0
Whenuakura	5

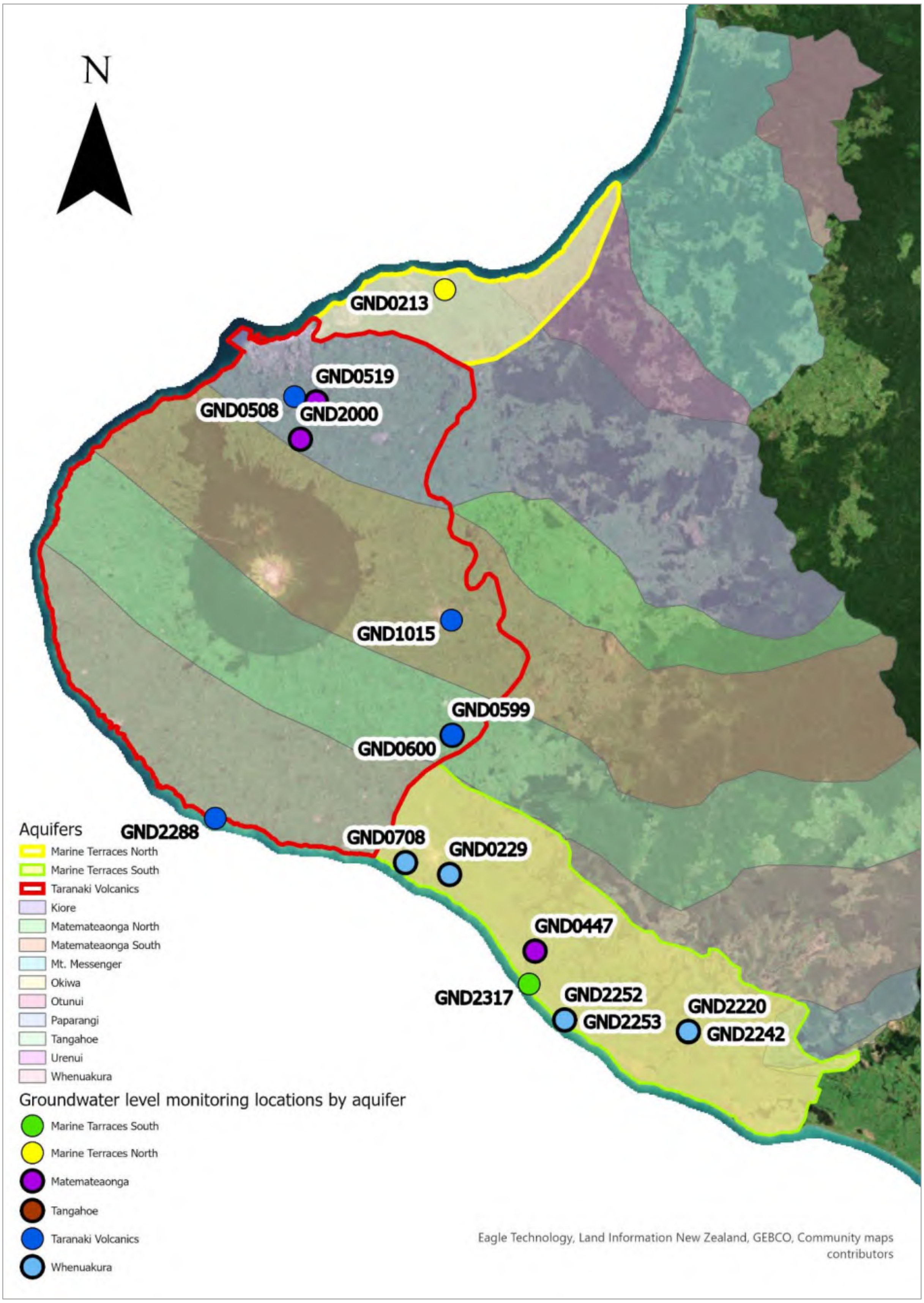


Figure 4 Monitoring site locations by aquifer

Table 4 Details of sites included in the regional groundwater monitoring network

Site code	Name	Altitude (m AMSL)	Total depth (m BGL)	Screened interval (m BGL)	Aquifer	Aquifer type	Total length of data record (Years)	Period of manual data records	Period of continuous data records*
GND0213	Motunui	54	22	18 - 21	Marine Terraces North	Unconfined	36	-	10 Jan 83 - 30 Jun 20
GND0229	Kiwi-1	95	297	68 - 297	Whenuakura	Confined	21	29 May 98 - 10 Jun 14	10 Jun 14 - 30 Jun 20
GND0447	Manutahi-1	82	1,383	542 - 562	Matemateaonga	Confined	25	28 Oct 94 - 19 Mar 13	19 Mar 13 - 30 Jun 20
GND0508	Carrington Rd.	120	14	8 - 14	Taranaki Volcanics	Unconfined	16	25 Jun 03- 12 Dec 12	12 Dec 12 - 30 Jun 20
GND0519	Mangamahoe-1	145	795	644 - 766	Matemateaonga	Confined	24	28 Oct 94 - 27 Sep 13	27 Sep 13 - 30 Jun 20
GND0599	Eltham-7	216	83	79 - 82	Tangahoe	Confined	23	17 Dec 96 - 22 Mar 13	22 Mar 13 - 30 Jun 20
GND0600	Eltham-7A	216	20	16 - 19	Taranaki Volcanics	Unconfined	23	26 Nov 96 - 22 Mar 13	22 Mar 13 - 30 Jun 20
GND0708	Nolan Rd.	70	94	82 - 94	Whenuakura	Confined	21	28 Jul 98 - 22 Mar 13	22 Mar 13 - 30 Jun 20
GND1015	Stratford Landfill BH3	300	8	2 - 8	Taranaki Volcanics	Unconfined	5	-	30 Jun 15 - 30 Jun 20
GND2000	Scout Rd.	251	464	228 - 291	Matemateaonga	Confined	10	-	11 Jun 13 - 30 Jun 20
GND2220	STDC Swinbourne St.	90	200	123 - 172	Whenuakura	Confined	7	-	28 Nov 12 - 30 Jun 20
GND2252	Patea Sentinel (Lower)	37	154	148 - 154	Whenuakura	Confined	7	-	22 Nov 12 - 30 Jun 20
GND2253	Patea Sentinel (Upper)	37	96	93 - 96	Whenuakura	Confined	7	-	22 Nov 12 - 30 Jun 20
GND2288	Oeo Landfarm	39	7	4 – 7	Taranaki Volcanics	Unconfined	4	-	27 Aug 15 - 30 Jun 20
GND2317	Vanners Landfarm	31	13	8 - 13	Marine Terraces South	Unconfined	4	-	21 Dec 15 - 30 Jun 20

*Equipment failure resulted in lost or erroneous data on the following occasions:

GND0519 - 13 January 2016 to 30 June 2017 and 10 April 2019 to 28 May 2020; **GND0508** - 03 April to 30 July 2019; **GND0600** - 31 January 2019 to 26 April 2019

GND2000 - 01 November 2017 to 18 October 2018 and 18 July 2019 to 16 October 2019; **GND0447** - 21 April 2017 to 20 April 2018; **GND0708** - 13 February 2018 to 23 April 2018

GND1015 - 14 November 2017 to 23 April 2018; **GND2253** - 19 February 2019 to 19 Nov 2019; **GND2252** - 10 May 2016 to 5 August 2016 and 25 August 2018 to 5 December 2018

GND2220 - 2 July 2019 to 8 July 2019; 16 February 2020 to 20 February 2020 and 26 March 2020 to 2 April 2020

4.1 Data collection

The method of water level data collection and frequency is variable across the network and by site. Historically, water level measurements at long-term monitoring sites (with the exception of GND0213) were obtained by manual water level measurement, at approximately monthly intervals. In some cases, collection of these manual measurements was intermittent which has resulted in gaps in the data record at some sites.

Data at site GND0213 has been recorded electronically since 1983 using a pressure transducer. Since records began, the frequency of measurement at the site has ranged from weekly to 15 minute intervals.

From 2012, pressure transducers were installed at all monitoring sites to enable the electronic measurement and recording of water level data. Data across all sites is now recorded at 15 minute intervals. Water level data is downloaded from the sites at quarterly intervals. The electronic level measurements are compensated for both barometric pressure and manual water level measurements taken at the time of the data download.

All groundwater level measurements are referenced to a standard datum of metres above mean sea level (m AMSL).

The groundwater level data is stored in the Council's time series data management system.

5 Results

5.1 Influences on observed groundwater level fluctuation

Almost all monitored sites show some fluctuation in groundwater levels as a result of seasonal variation in rainfall volumes and discharge processes. Given that the majority of groundwater recharge occurs during winter and spring, it is common to see annual peaks in groundwater levels over these periods. Conversely, when rainfall volumes reduce over summer, and soil moisture deficits are high, groundwater levels decline. As a result, minimum levels are generally recorded in late summer/early autumn. Any variation in seasonal (or annual) drivers generally result in a corresponding groundwater level response. The Taranaki region generally receives regular and plentiful rainfall however, meaning aquifers are regularly replenished.

Table 5 presents a summary of the annual ranges in water levels observed at each monitoring location across the length of their respective data records. The minimum annual water level change represents the smallest difference between the highest and lowest water level recorded over a calendar year, over the course of a site's monitoring record. Conversely, the maximum range represents the largest difference in water level observed. The average annual water level range across all sites included in the monitoring network is illustrated in Figure 5.

Table 5 Summary of observed annual variations in observed water level by site across the monitoring network (sorted by min to max average annual range)

Site code	Name	Aquifer	Aquifer type	Minimum annual water level range (m)	Maximum annual water level range (m)	Average annual water level range (m)
GND0213	Motunui	Marine Terraces North	Unconfined	2.8	6.0	4.8
GND0229	Kiwi-1	Whenuakura	Confined	0.1	0.7	0.3
GND0447	Manutahi-1	Matemateaonga	Confined	0.1	0.4	0.2
GND0508	Carrington Rd.	Taranaki Volcanics	Unconfined	1.6	5.3	3.6
GND0519	Mangamahoe-1	Matemateaonga	Confined	0.1	0.4	0.2
GND0599	Eltham-7	Tangahoe	Confined	0.4	1.6	0.9
GND0600	Eltham-7A	Taranaki Volcanics	Unconfined	0.3	3.9	1.8
GND0708	Nolan Rd.	Whenuakura	Confined	0.2	1.5	0.7
GND1015	Stratford Landfill BH3	Taranaki Volcanics	Unconfined	2.9	3.8	3.4
GND2000	Scout Rd.	Matemateaonga	Confined	0.2	1.1	0.4
GND2220	STDC Swinbourne St*	Whenuakura	Confined	7.1	19.1	11.2
GND2252	Patea Sentinel (Lower)	Whenuakura	Confined	0.4	1.8	1.2
GND2253	Patea Sentinel (Upper)	Whenuakura	Confined	0.4	1.3	0.8
GND2288	Oeo Landfarm	Taranaki Volcanics	Unconfined	0.7	1.8	1.2
GND2317	Vanners Landfarm	Marine Terraces South	Unconfined	0.2	1.5	0.9

*Note * The annual water level change seen in GND2220 is a result of pumping activity rather than a response to rainfall recharge.*

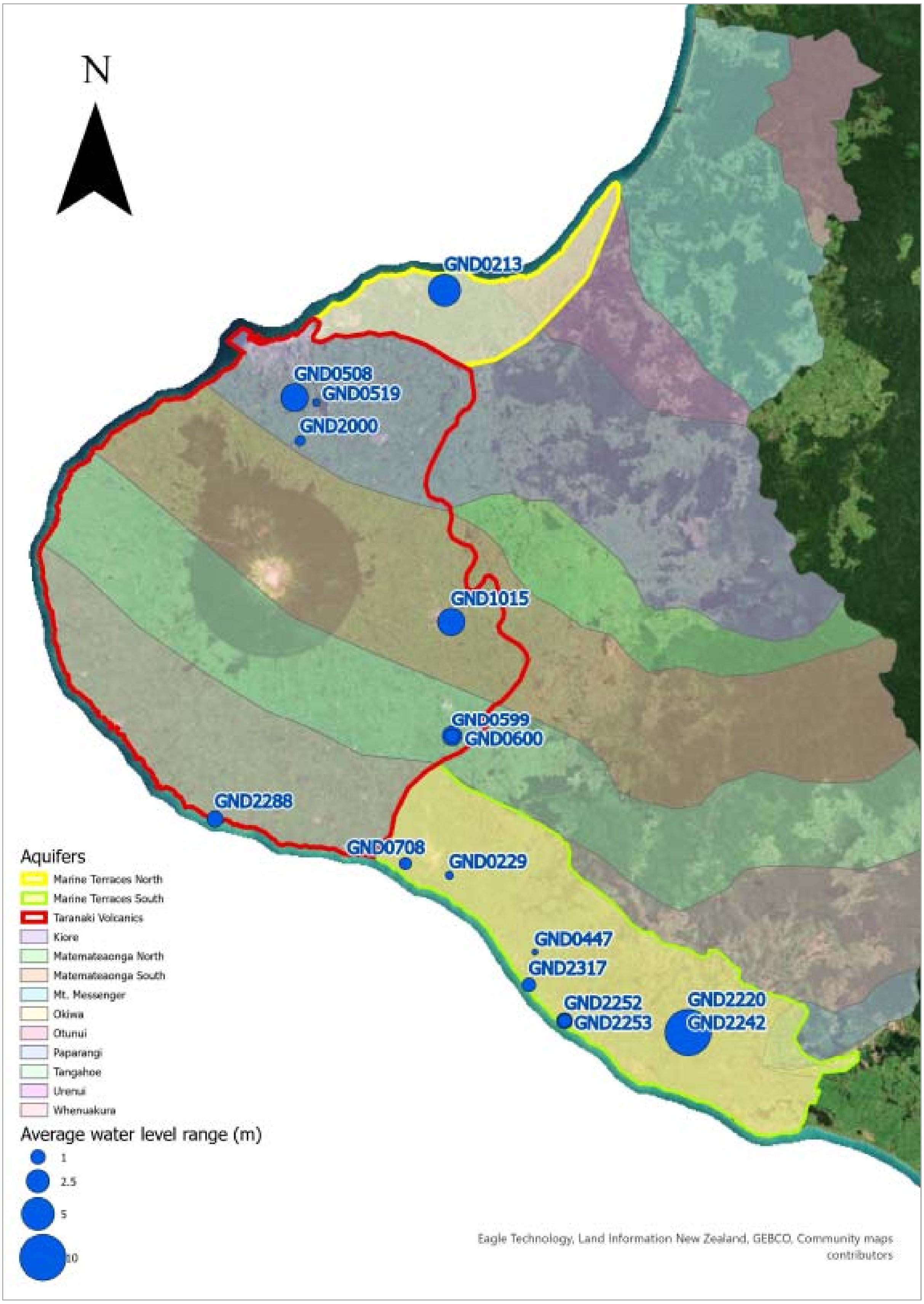


Figure 5 Plot showing observed ranges in average annual water level fluctuation by site and aquifer

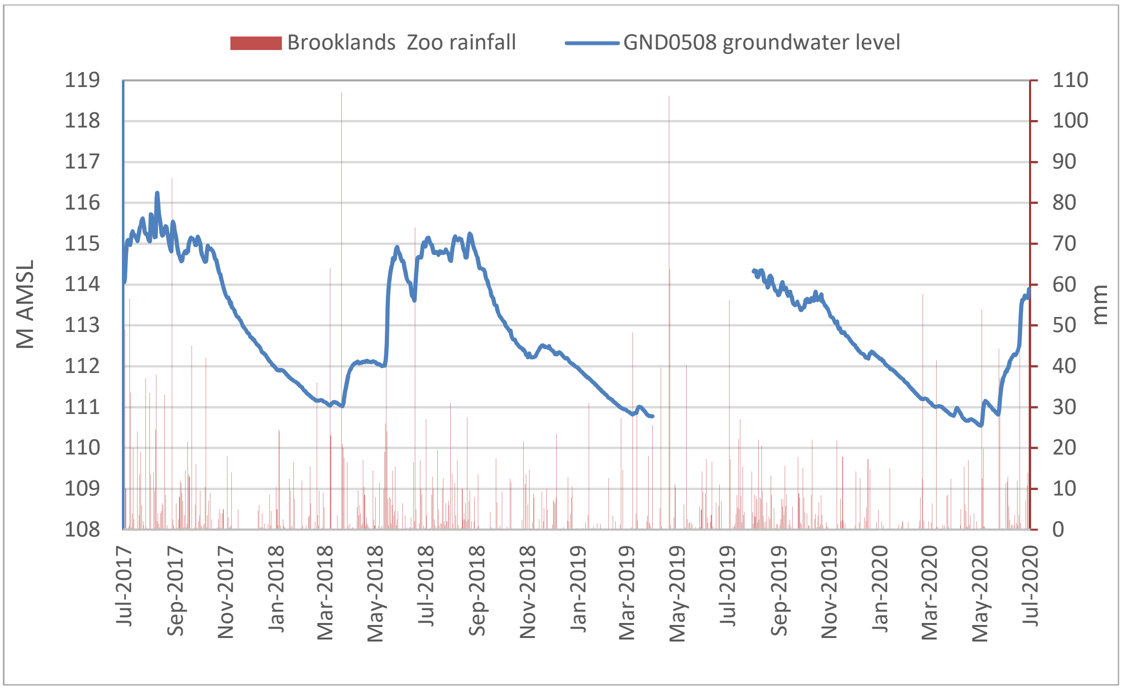
The impact of seasonal fluctuations in rainfall recharge on groundwater levels are more subdued in confined aquifers, which are disconnected from direct rainfall recharge by overlying low permeability strata. As a result, the magnitude of level fluctuations are typically much less than those seen in shallow unconfined groundwater systems, where the water table is close to the surface and receiving direct rainfall recharge. The magnitude of seasonal fluctuations and the speed of level response to rainfall is also influenced by factors other than aquifer confinement. These include the permeability and storage characteristics of strata in which the groundwater resides, its water storage capacity, the depth to the water table and the overlying land cover. Monitoring locations located close to a stable surface water boundary, such as a river or the sea, generally show less pronounced seasonal fluctuations in water level in comparison to similar sites located further away from such an influence. This is illustrated in the much smaller seasonal variations seen at shallow coastal sites in comparison to shallow sites located further inland.

Figure 6 presents a comparison of the water level response to rainfall at site GND0508, which intersects a shallow unconfined aquifer in the volcanic deposits, and site GND0708, which intersects a confined aquifer within the Whenuakura Formation. The figure illustrates the difference between these aquifers in terms of the speed and magnitude of response to rainfall events and associated recharge. Water levels at site GND0508 show a rapid response to rainfall events. There is also a pronounced seasonal pattern in the data from this site, with water level fluctuations ranging between 1.6 m and 5.3 m each year.

In comparison, the plot of water level data from site GND0708 shows very little correlation to local rainfall events. This is because the aquifer is disconnected from localised rainfall by its confining layer. While it is likely there is some leakage through the confining layer, the majority of recharge to the aquifer occurs where it is exposed at surface in the eastern hill country to the east of the site. While there is seasonality visible within the water level record, the magnitude of seasonal range in water level is much smaller, generally less than 1 m.

The factors described above can be characterised as 'natural' influences on groundwater levels. In addition to these, groundwater levels can also be significantly influenced by anthropogenic factors, most significantly the effects of groundwater abstractions. The effects of abstraction on water can occur over both the short and long-term. In simplistic terms, the short-term impact of an abstraction is the localised drawdown (lowering) of groundwater levels as water is removed from the aquifer during pumping. If the volume of groundwater abstracted from an aquifer exceeds the volume of water recharging it, a long-term decline in groundwater level is likely. Natural and anthropogenic influences on groundwater levels generally combine during summer months to exacerbate effects, as water demand is high and aquifer recharge volumes are low.

The greatest range of groundwater level fluctuations is seen in GND2220 which is an observation bore in close proximity to the South Taranaki District Council (STDC) Swinbourne Street production bore (GND2242). The groundwater level data from the site is plotted alongside total daily abstraction data from the Swinbourne Street production bore in Figure 7. Both bores intercept the same interval within the Whenuakura aquifer. The short-term effects of the abstraction on local water levels is evident in the steep and repeated drawdown of water level when abstraction is occurring. The magnitude of the water level drawdown at site GND2220 is in the range of 5 to 10 m. The water level trace from the site is typical of abstraction influence, whereby a rapid drop in water level occurs on pump start-up, followed by gradually reducing rate of drawdown over time as the pumping and aquifer recharge rates approach a steady state. The plot also illustrates the rapid initial recovery in water levels when pumping stops, with the recovery rate reducing over time. While the data from site GND2220 illustrates the short-term drawdown and recovery of water levels at the site in response to abstraction, further analysis of the data shows that water levels are declining over the longer-term, indicating a potentially unsustainable level of abstraction from the aquifer at this location. The analysis of trends in water level is discussed further in the following sections of this report.



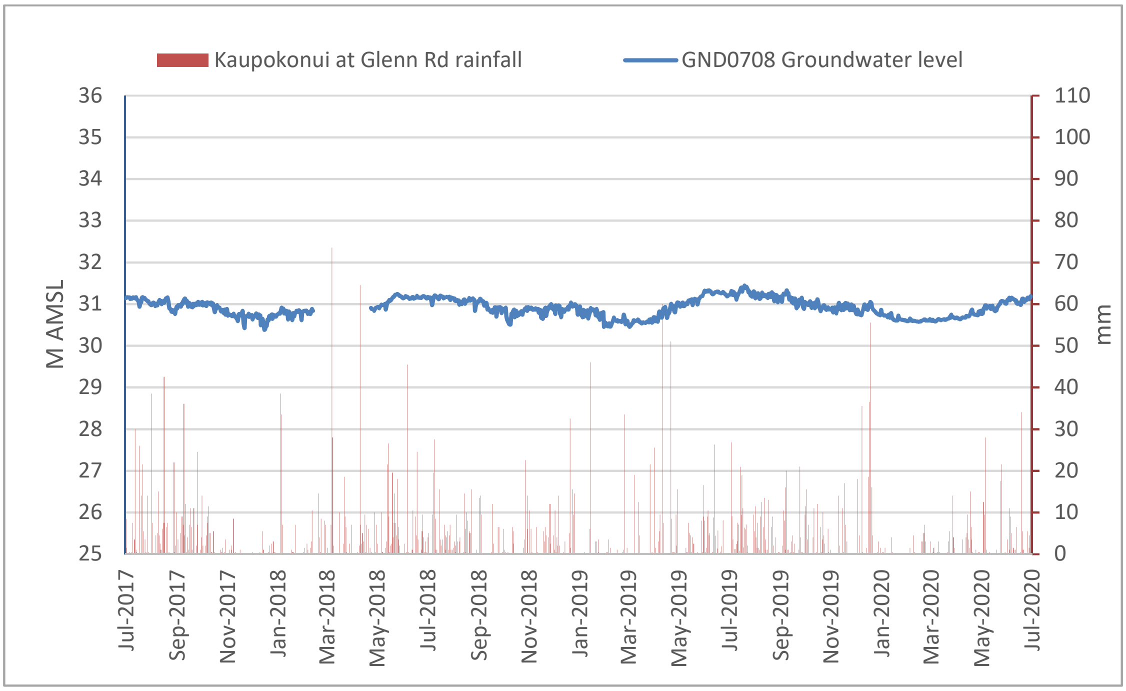


Figure 6 Comparison of hydrographs from sites GND0508 and GND0708 illustrating variation in observed water level fluctuation in response to rainfall between unconfined (GND0508) and confined aquifers (GND0708)

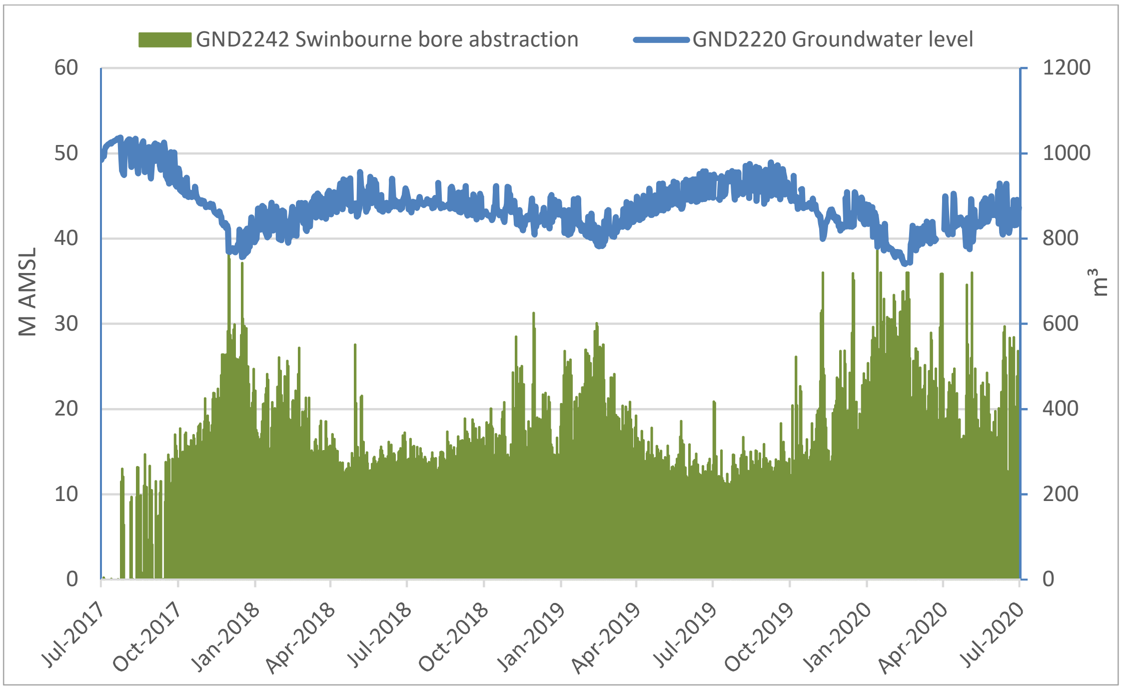


Figure 7 Groundwater level response in observation bore GND2220 during abstraction at supply bore GND2242

5.2 Current state of water levels at monitored sites (2017-2020)

The current state of groundwater levels across the region have been assessed using the most recent three years of data analysed (2017-2020). Averaging data over a three yearly time period for the assessment of state is consistent with the reporting frequency of this programme and reduces the influence of extremes experienced over any single year. The data analysed is presented in the form of envelope plots. These plots compare mean monthly groundwater levels over the 2017-2020 period with the mean monthly levels averaged over a site's entire data record. Also plotted are the historical monthly minimum and maximum levels, which provide further context when assessing recent data. Plots have been compiled for each site with a long-term data record (Figure 8). For consistency with the statistical analysis presented in the following section of this report, a long-term record is defined as being a minimum of ten years.

Across the majority of sites intersecting both unconfined and confined aquifers, current groundwater levels do not differ significantly from historical long-term averages. The variations in seasonal response that occur from year to year are generally in response to rainfall recharge with deeper aquifers exhibiting a less defined seasonal response in comparison to those at shallower depths.

5.2.1 Groundwater level response in monitored aquifers

GND0508 and GND0600 intersect the shallow Taranaki Volcanics Aquifer, albeit GND0600 in the south of the region and GND0508 in the north. GND0508 shows a general decline in average levels during drier months and a slight increase during wetter months in comparison to historical means. In contrast GND0600 indicates an increase in levels over all seasons in comparison to historical means.

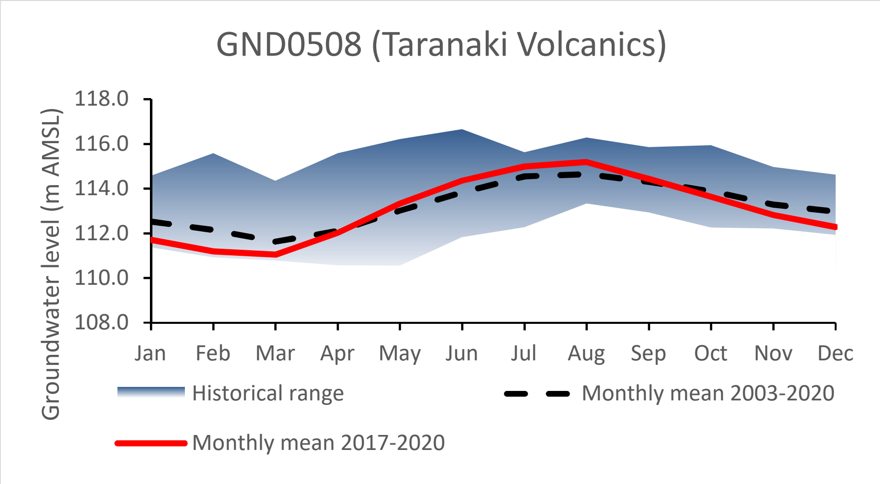
The difference in responses seen between GND0508 and GND0600 is likely solely related to their location with rainfall recharge patterns varying across the region depending on proximity to Taranaki Maunga and the Coast (Figure 2). The levels seen in GND0599 support this assumption as although GND0599 is screened across a deeper aquifer (Tangahoe) the trends and responses in the bore although more subdued closely mimic those of GND0600. These bores although separated by a confining layer are located in close proximity to each other and levels within both bores are primarily influenced by local rainfall recharge.

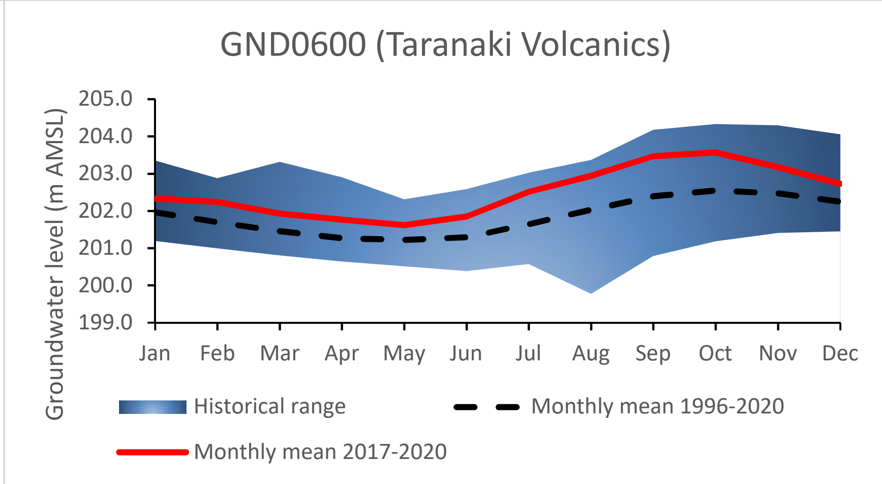
The Marine Terrace Aquifer is intersected by GND0213 in the north of the region, where it is generally unconfined and therefore heavily influenced by rainfall recharge.

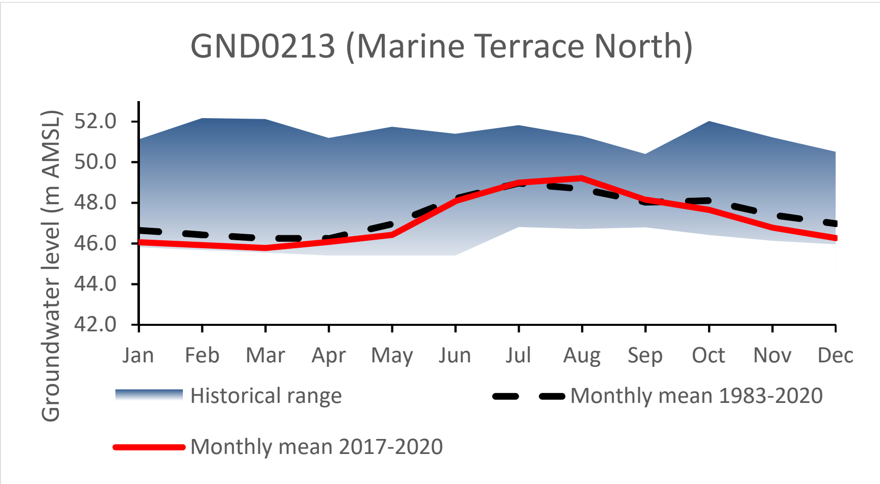
Sites within the Matemateaonga aquifer show a mixed response with water levels in GND0447 showing an increase in comparison to historical levels and GND0519 and GND2000 a slight decrease across the majority of months.

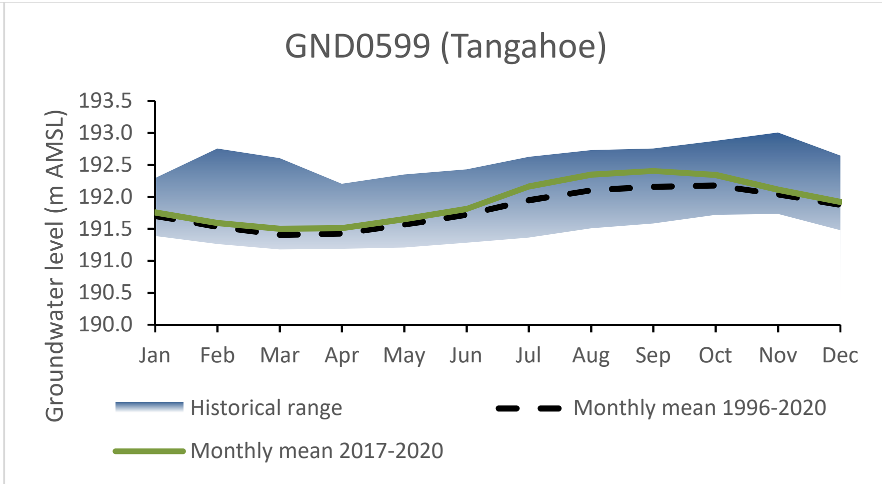
Within the Whenuakura aquifer, levels across the recent monitoring period were generally slightly lower across the majority of months in comparison to historical means with the greatest deviation from historical mean seen in GND0229. The slight declining trend seen in GND0708 is related to a longer term downward trend and is discussed further in the following section of this report.

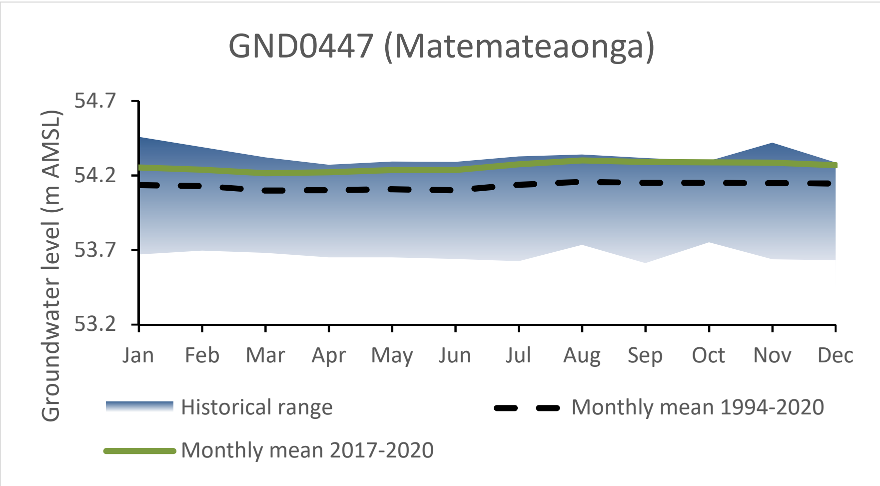
In summary, the assessment of data shows that current water levels at monitored sites do not differ significantly from historical long-term averages. The analysis of monthly mean level data has also illustrated similarities in spatial and temporal responses to rainfall across some sites. The Council's monitored rainfall sites indicate during the 2017-2018 period annual mean rainfall was higher than the annual historical mean at the majority of sites. In contrast during 2018-2019 and 2019-2020 the majority of rainfall sites indicated a lower mean rainfall resulting in a much drier years (Table 6). The annual mean rainfall for the 2017-2020 period in comparison to historical mean rainfall is provided in relation to groundwater monitoring sites in Figure 9.

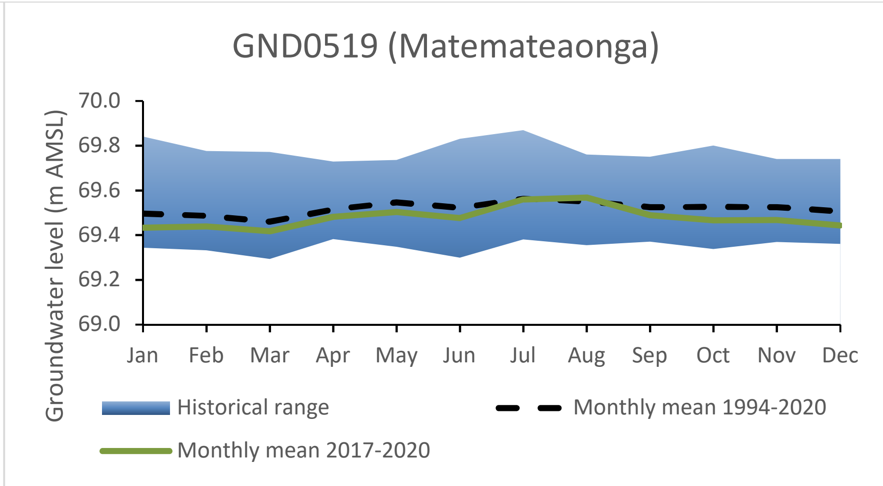

GND0508 (Taranaki Volcanics)
Groundwater level (m AMSL)
118.0
116.0
114.0
112.0
110.0
108.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Historical range
Monthly mean 2003-2020
Monthly mean 2017-2020

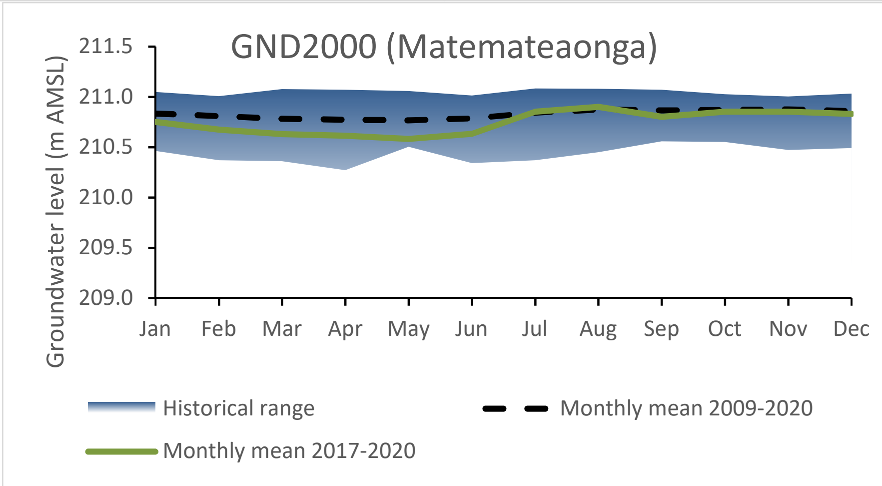

GND0600 (Taranaki Volcanics)
Groundwater level (m AMSL)
205.0
204.0
203.0
202.0
201.0
200.0
199.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Historical range
Monthly mean 1996-2020
Monthly mean 2017-2020


GND0213 (Marine Terrace North)
Groundwater level (m AMSL)
52.0
50.0
48.0
46.0
44.0
42.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Historical range
Monthly mean 1983-2020
Monthly mean 2017-2020


GND0599 (Tangahoe)
Groundwater level (m AMSL)
193.5
193.0
192.5
192.0
191.5
191.0
190.5
190.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Historical range
Monthly mean 1996-2020
Monthly mean 2017-2020


GND0447 (Matemateaonga)
Groundwater level (m AMSL)
54.7
54.2
53.7
53.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Historical range
Monthly mean 1994-2020
Monthly mean 2017-2020


GND0519 (Matemateaonga)
Groundwater level (m AMSL)
70.0
69.8
69.6
69.4
69.2
69.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Historical range
Monthly mean 1994-2020
Monthly mean 2017-2020


GND2000 (Matemateaonga)
Groundwater level (m AMSL)
211.5
211.0
210.5
210.0
209.5
209.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Historical range
Monthly mean 2009-2020
Monthly mean 2017-2020

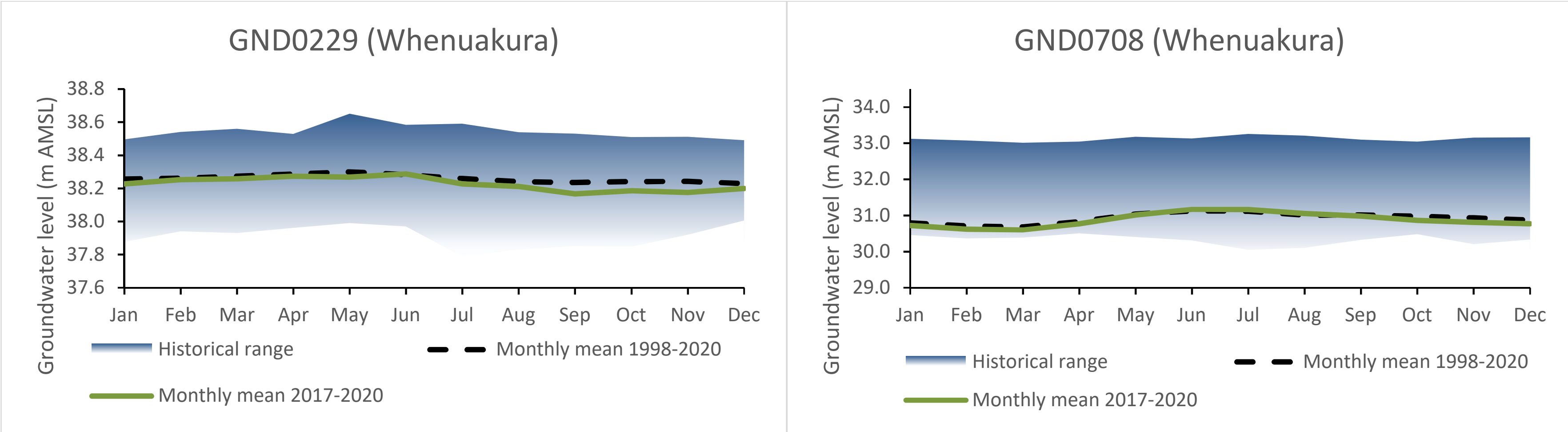


Figure 8 Envelope plots comparing monthly average water levels at each site over the period 2017-2020 with a long-term averages and extreme values. Sites with their monthly means (2017-2020) displayed as a red line are classified as intersecting unconfined aquifers and green lines representing confined aquifer sites. Each plot is titled with site code and aquifer name in brackets

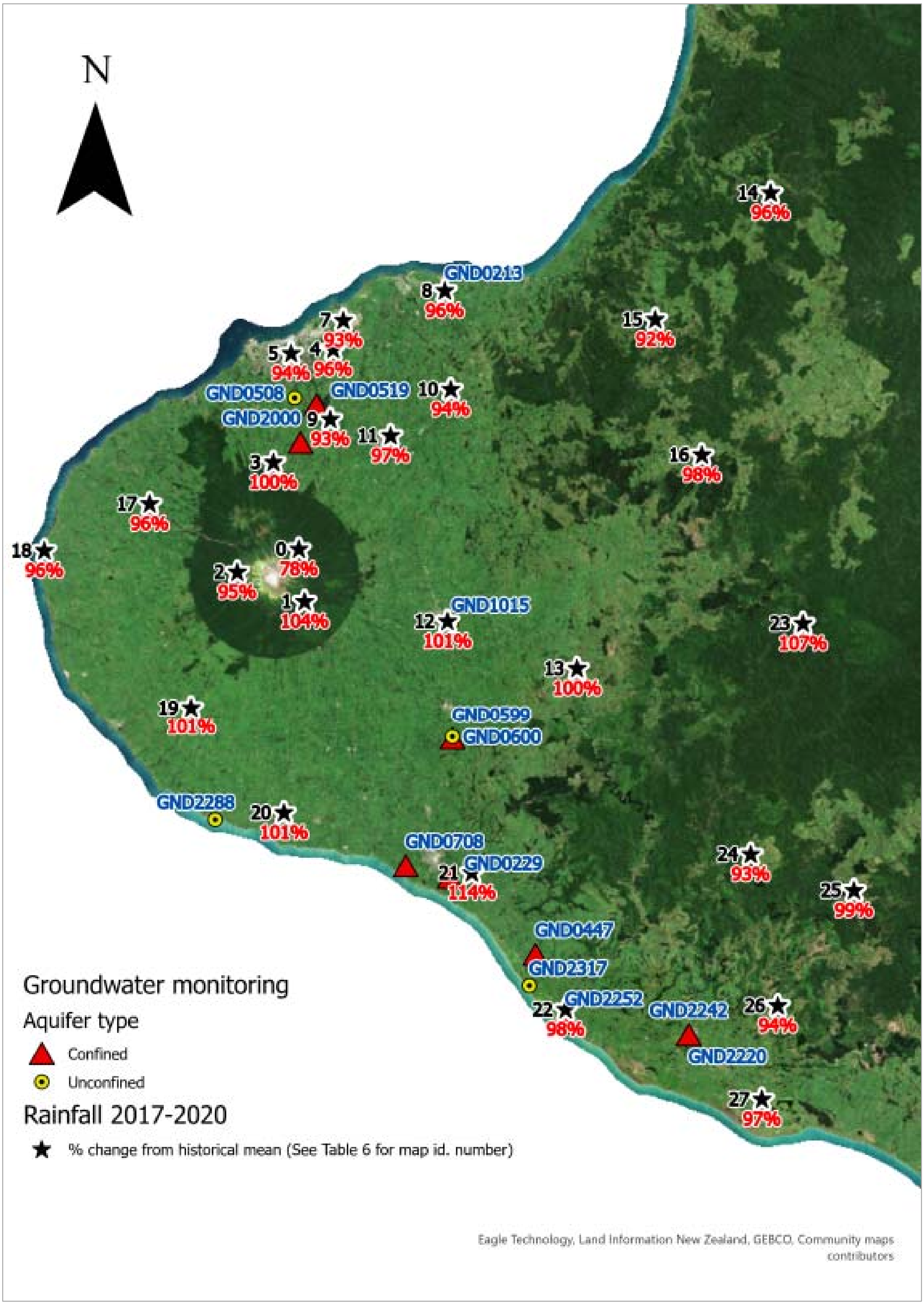


Figure 9 Groundwater monitoring sites by aquifer type and mean rainfall percent change from historical mean for the 2017-2020 monitoring period

Table 6 Rainfall percent change from historical mean during the review period

Rainfall monitoring site	Map id	2017-2018	2018-2019	2019-2020	2017-2020
North Egmont at Visitor's Centre	0	92%	73%	70%	78%
Dawson Falls	1	120%	91%	101%	104%
Kahui Hut	2	108%	86%	91%	95%
Mangorei Upper	3	116%	86%	98%	100%
Hillsborough	4	115%	84%	88%	96%
Brooklands Zoo at New Plymouth	5	121%	79%	83%	94%
Mangati at SH3	7	109%	80%	89%	93%
Motunui M39 at Weston W3	8	122%	79%	89%	96%
Waiwhakaiho at Egmont Village	9	110%	76%	93%	93%
Manganui at Everett Park	10	114%	80%	89%	94%
Inglewood at Oxidation Ponds	11	115%	83%	94%	97%
Patea at Stratford	12	125%	84%	95%	101%
Mangaehu at Bridge	13	124%	82%	95%	100%
Kotare at O'Sullivans	14	111%	82%	94%	96%
Uriti at Kaka Rd	15	105%	80%	92%	92%
Pohokura Saddle	16	119%	80%	95%	98%
Stony at Mangatete Bridge	17	109%	83%	96%	96%
Kapoaiaia at Lighthouse	18	112%	81%	95%	96%
Taungatara at Eltham Rd	19	110%	98%	94%	101%
Kaupokonui at Glenn Rd	20	116%	94%	91%	101%
Tawhiti at Duffy's	21	123%	112%	106%	114%
Patea at Bore 3	22	111%	95%	88%	98%
Omaru at Charlies	23	135%	82%	102%	107%
Omahine at Moana Trig	24	110%	80%	89%	93%
Waitotara at Rimunui Station	25	119%	83%	94%	99%
Waitotara at Ngutuwera	26	108%	90%	84%	94%
Waitotara at Hawken Rd	27	121%	86%	82%	97%

5.3 Statistical trend analysis

The groundwater level data collected has been analysed to identify trends in groundwater level change at each monitored site. The statistical analysis was conducted using R (R core team 2020). The analysis was carried out using the non-parametric Seasonal Mann-Kendall (SMK) test and Sen slope estimator (SSe) (Helsel and Hirsch, 1992). SSe is also referred to as the Mann-Kendall Slope Estimator (SKSE) and is used to represent the magnitude and direction of trends in water level without the influence of seasonal variations. SSe (slope) is expressed as cm per year of water level change.

A key purpose of the analysis is to evaluate the long-term availability and sustainability of groundwater resources in the Taranaki Region, the focus of the data analysis is to examine persistent decadal or longer trends that have occurred in bores since the onset of widespread irrigation and groundwater pumping.

To remove daily and seasonal variation in groundwater levels induced by irrigation pumping, the median groundwater level measured in winter between January and March of each year was used in the analysis (as no irrigation takes place).

The data used comprises manual monthly samples during the early phase of monitoring, and continuously recorded data for the later parts of the record. For the trend analyses, continuous data are aggregated to monthly mean values to be consistent with earlier records. A comparison with random monthly re-sampled values from the continuous data, found that the trends were almost invariable for each random re-sampling. A short-term groundwater level analysis was undertaken on monitoring bores that have a minimum of five years continuous data available as of 30 June 2020. Results are included in Table 7. Analysis on all the available data was undertaken on all sites that have a minimum of ten years continuous data. Results are included in Table 8. A comparison of statistical significance between short-term (5 year) and long-term (10 or more years) is included as Table 9. The full statistical reports are included as Appendix I and Appendix II respectively.

The confidence level gives an indication of how strong the trend is with confidence levels of 90% and over determined as very likely, those between 67% and 90% determined as likely and below 67% as indeterminate.

The analysis indicates that of the 14 sites were sufficient data was available over the five year period the majority of sites show a declining trend. The exceptions are GND2253 which indicated an increasing trend, and GND0447, GND0708 and GND1015 which all showed no discernible trend over the short-term data record.

The analysis undertaken on the nine sites where sufficient data was available to ascertain a long-term trend shows five sites exhibit an increasing trend and four a declining trend.

Where a short-term trend was identified a statistical analysis of local rainfall trends was also undertaken to ascertain if any of the short-term trends were meaningful and not a direct result of climatic variation (Table 9). Of the nine sites a trend was identified only one site GND2253 did not exhibit a similar trend to local rainfall patterns.

Where a long-term statistical trend was identified a visual comparison between daily groundwater levels and any available long-term local rainfall volumes was undertaken. The results of the analysis are discussed in the following section.

Table 7 Results of short-term trend analysis (2015 to 2020)

Site	Number of monthly mean values	Year range	Slope (cm/yr)	Trend Direction	Confidence in Trend	Confidence (%)
GND0213	60	2015-2020	-3.346	Decreasing	Likely Falling	69.0
GND0229	60	2015-2020	-2.418	Decreasing	Very Likely Falling	100.0
GND0447	49	2015-2020	-0.080	Indeterminate	Indeterminate	50.0
GND0508	58	2015-2020	-12.502	Decreasing	Very Likely Falling	93.9
GND0519	-	2015-2020	Insufficient data available during the period*			
GND0599	60	2015-2020	-4.069	Decreasing	Likely Falling	82.1
GND0600	58	2015-2020	-7.026	Decreasing	Very Likely Falling	91.9
GND0708	59	2015-2020	-0.122	Decreasing	Indeterminate	52.9
GND1015	56	2015-2020	1.569	Increasing	Indeterminate	53.1
GND2000	48	2015-2020	-3.988	Decreasing	Very Likely Falling	99.7
GND2220	60	2015-2020	-100.970	Decreasing	Very Likely Falling	100.0
GND2242	59	2015-2020	-209.808	Decreasing	Very Likely Falling	100.0
GND2252	56	2015-2020	-4.221	Decreasing	Very Likely Falling	99.2
GND2253	53	2015-2020	6.472	Increasing	Very Likely Rising	100.0

These bores were not analysed for five yearly trends due to significant data gaps.

Table 8 Results of long-term trend analysis to 30 June 2020 (minimum 10 years)

Site	Number of monthly mean values	Year range	Slope (cm/yr)	Trend Direction	Confidence in Trend	Confidence (%)
GND0213	448	1983-2020	-0.444	Decreasing	Very Likely Falling	96.3
GND0229	197	1998-2020	0.374	Increasing	Very Likely Rising	99.9
GND0447	235	1995-2020	1.997	Increasing	Very Likely Rising	100.0
GND0508	165	2004-2020	1.398	Increasing	Likely Rising	83.2
GND0519	146	1995-2020	-1.185	Decreasing	Very Likely Falling	100.0
GND0599	241	1997-2020	-0.265	Decreasing	Likely Falling	83.9
GND0600	243	1997-2020	1.297	Increasing	Very Likely Rising	99.1
GND0708	225	1999-2020	-11.465	Decreasing	Very Likely Falling	100.0
GND2000	106	2009-2020	2.490	Increasing	Very Likely Rising	99.9

Table 9 Comparison of short-term statistical trends in groundwater level and local rainfall

Site	Trend Direction	Short-Term Trend	Rainfall Station	Trend Direction	Short-Term Trend
GND0213	Decreasing	Likely Falling	Motunui	Decreasing	Very Likely Falling
GND0229	Decreasing	Very Likely Falling	Tawhiti	Indeterminate	Indeterminate
GND0508	Decreasing	Very Likely Falling	Brooklands Zoo	Decreasing	Very Likely Falling
GND0599	Decreasing	Likely Falling	Mangaehu/Patea	Decreasing	Likely Falling
GND0600	Decreasing	Very Likely Falling	Mangaehu/Patea	Decreasing	Likely Falling
GND2000	Decreasing	Very Likely Falling	Waiwhakaiho	Decreasing	Likely Falling
GND2220	Decreasing	Very Likely Falling	Patea	Decreasing	Likely Falling
GND2242	Decreasing	Very Likely Falling	Patea	Decreasing	Likely Falling
GND2252	Decreasing	Very Likely Falling	Patea	Decreasing	Likely Falling
GND2253	Increasing	Very Likely Rising	Patea	Decreasing	Likely Falling

5.4 Meaningful trend analysis

It is recognised that the statistical significance of a trend does not necessarily imply a 'meaningful' trend i.e. one that is likely to be relevant in a natural resources management sense.

To ascertain whether the statistical trend seen within an aquifer is meaningful the following needs to be considered:

- In a confined aquifer which is generally very slow to recharge and may have a significant volume of water held in storage any unexpected water level change that exceeds the range of water levels previously seen within the aquifer is likely to be meaningful.
- In semi confined and unconfined aquifers which are generally strongly influenced by rainfall recharge any unexpected water level change that significantly exceeds the range of water levels previously seen within the aquifer which does not mimic local climatic patterns is likely to be meaningful.

In addition to the type of aquifer the magnitude of any change also has to be considered in context. For example: a one metre decline in water levels within a confined aquifer that generally exhibits little change from year to year would be considered significant. Whereas a one metre change within an unconfined aquifer that fluctuates in response to rainfall recharge would likely be considered insignificant.

5.4.1 Short-term meaningful trends

To ascertain whether a short-term statistical trend is meaningful the groundwater level trend in each bore have been compared to rainfall trends over the same period in Table 9. The comparison showed that the majority of short-term groundwater level trends are a response to climatic variations.

The only bores that exhibited a trend not relatable to rainfall were GND2253 which showed a slight increase in water levels in contrast to a decreasing trend in local rainfall and GND2220 which appears to be declining in response to abstraction at the nearby municipal supply bore GND2242.

5.4.1.1 GND2253 short-term rising trend

An increasing statistically significant trend was identified in GND2253 over the short-term. The water level response in GND2253 clearly shows the influence of rainfall in the bore with high rainfall events and sustained periods of rainfall corresponding with higher water levels (Figure 10). GND2252 which monitors a deeper aquifer at the same location shows a similar but slightly subdued response.

Figure 11 compares water level in both bores to abstraction and shows that the deeper bore GND2252 exhibits a significant response to abstraction with water levels declining during periods of greater abstraction. A more subdued response to abstraction, although not as easily discernible in the graph below, would also be expected in GND2253 due to the proximity of the two bores and the connectivity between the two aquifer intervals.

During the previous monitoring period (2015-2017) GND2252 exhibited a slight declining water level trend linked to localised abstraction via GND2197. The water levels in GND2252 now appear to have stabilised in response to a reduction in abstraction volumes. The slight increasing trend identified in GND2253 is therefore likely also a response to the reduced abstraction and is not an indication of any meaningful change within the aquifer itself.

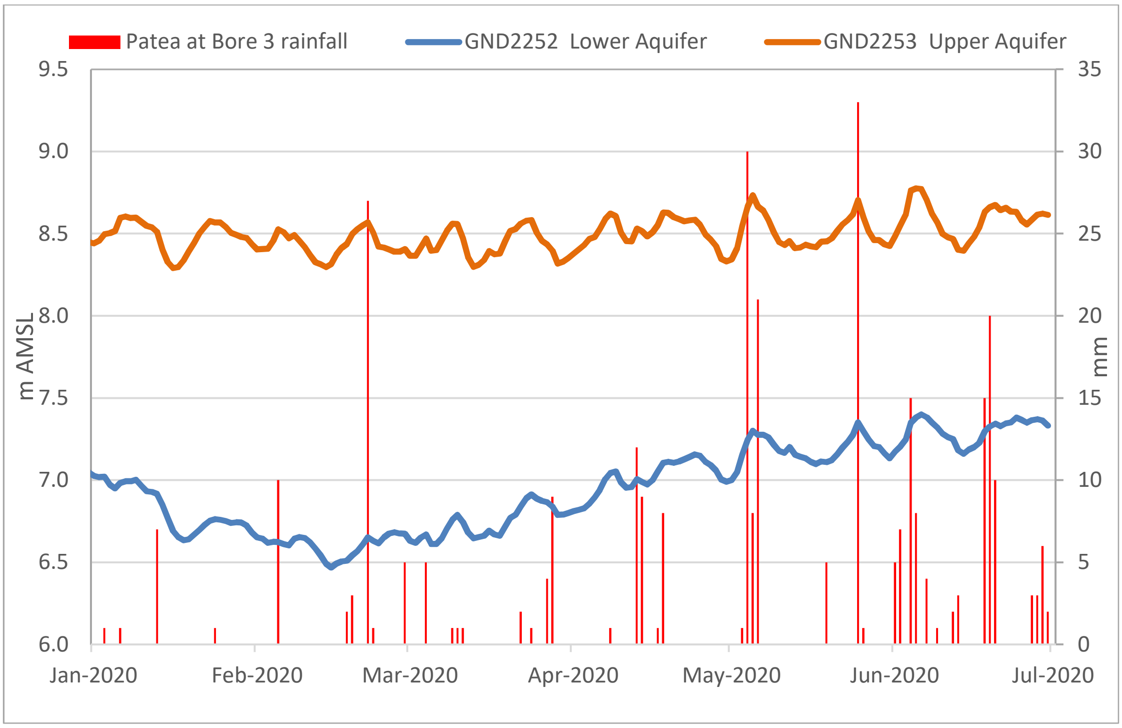


Figure 10 Groundwater levels in GND2252 and GND2253 compared to rainfall

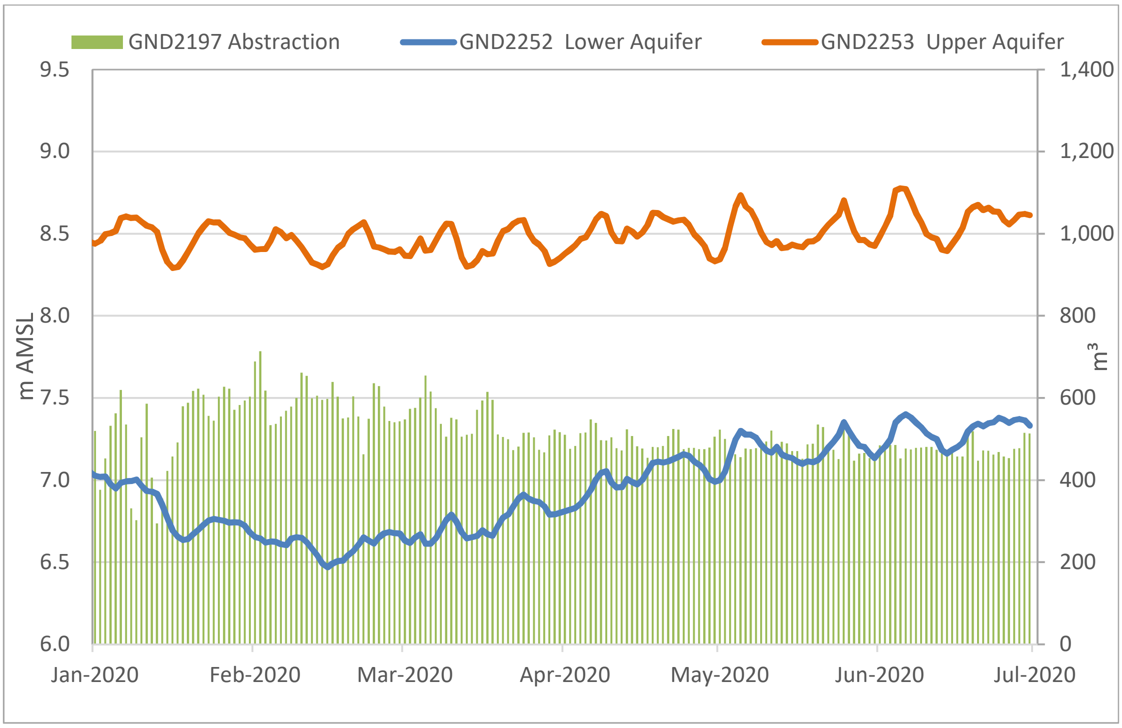


Figure 11 Groundwater levels in GND2252 and GND2253 compared to abstraction

5.4.1.2 GND2220 short-term declining trend

GND2220 was installed to monitor the response within the deep Whenuakura aquifer due to abstraction in the Municipal supply bore GND2242. The monitoring bore provides a more discernable groundwater level trace as it is not directly influenced by the fluctuations resulting from operation of the pump. A comparison between abstraction and water level indicate the declining levels may be partially or solely related to an increase in abstraction at the site (Figure 7). To date the decline is minimal and therefore not environmentally significant. Due to the relatively short-term data set available for assessment and the effects of pumping it is not possible at this time to determine if the decline is unsustainable. Groundwater levels will continue to be monitored closely.

5.4.2 Long-term meaningful trends

Where a long-term statistical trend was identified a visual comparison against rainfall records over the same period, if available, was undertaken. Where a site did not have adequate rainfall data to make a direct comparison, the scale of any changes in conjunction with available rainfall data has been utilised to determine the significance of any trend. All nine of the long-term monitoring sites exhibited either a falling or rising statistical trend and are discussed below.

5.4.2.1 GND0213 long-term falling trend

GND0213 is located in the north of the region and intercepts the marine terrace deposits. The Motunui rainfall gauge is located at the same site and has recorded rainfall since 1998. A comparison between daily water levels and rainfall shows a similar increasing trend in both data sets. Due to the significant fluctuations in water level exhibited in the bore each year (average range of 4.8 m) and the strong seasonal response the slight statistical trend seen in the data since 1983 of <1 cm per year is not considered significant.

5.4.2.2 GND0229 long-term rising trend

GND0229 intercepts a deep confined aquifer in the south of the region. A comparison of daily water levels in the bore and local rainfall volumes since 1998 indicate the bore exhibits a subdued response to long-term climatic variations. The slight increase in water levels seen over time is therefore likely a response to a slight increase in rainfall in the vicinity of the site and is not indicative of any meaningful trend in the aquifer.

5.4.2.3 GND0447 long-term rising trend

GND0447 is screened within a deep confined aquifer in the south of the region. A comparison between daily water levels and local rainfall since 1997 indicate that although water levels do not exhibit a strong seasonal response they do respond to high intensity rainfall events. As the statistical trend in water levels at this site appears linked to climatic variations it is not considered indicative of any meaningful trend in the aquifer.

5.4.2.4 GND0508 long term rising trend

GND0508 intercepts the shallow unconfined Taranaki Volcanics Aquifer in the north of the region. The water level at the site shows a significant response (averaging 3.6 m per year) to local rainfall. The long-term data set indicates that the slight increasing trend in water levels is related to a slight increase in rainfall volumes over time and is therefore not considered indicative of any meaningful trend in the aquifer.

5.4.2.5 GND0519 long-term falling trend

GND0519 is screened within a confined aquifer in the north of the region. Water levels in the bore exhibit a small range of change annually (average range 20 cm per year). As there is a large gap in the water level data between 2018 and 2019 due to failure of the logger the data between 1994 and 2018 has been compared against local rainfall volumes. The comparison indicates that the slight falling trend seen in water level of 1.1 cm per year is linked to a reduction in local rainfall volume over the same period and therefore is not considered meaningful.

5.4.2.6 GND0599 long-term falling trend and GND0600 long-term rising trend

GND0599 and GND0600 are located in the central part of the region. The bores intercept separate aquifer intervals and are installed side by side. Rainfall at Stratford has been used for comparison and indicates that both bores mimic rainfall with GND0599, the deeper of the two bores, showing a more subdued response. The statistical trend analysis indicated a slight increase in GND600 and slight decrease in GND0599 overtime. However as both bores exhibit a substantial respond to rainfall and the trend seen in each bore is small (equates to <1% per year of annual water level range) these trends are not considered significant.

5.4.2.7 GND0708 long-term falling trend

GND0708 intersects a confined aquifer near Hawera in the south of the region. While the long-term trend identified at GND0708 has statistical significance, the change in water level over the trend period is relatively minor. Statistical analysis of the short-term data also indicated a slight decline in groundwater level over the most recent five year period although this was at a reduced rate and not deemed statistically significant. The trends do not appear directly related to local rainfall recharge. Following the discovery of the long-term falling trend in GND0708 a recommendation to undertake a further investigation in to the cause of the decline was included in the 2015-2017 monitoring report. The outcome of the investigation are discussed below in Section 5.4.3.

5.4.2.8 GND2000 long-term rising trend

Site GND2000 intersects the Matemateaonga aquifer at Scout Road in North Taranaki. The well is screened in a confined aquifer between 228 and 291 m BGL. A statistically significant increasing long-term trend was identified in the data recorded at GND2000. Although at this stage the increase is relatively minor a more detailed analysis of the data in comparison to local rainfall was undertaken. The analysis confirms there is a slight subdued response to rainfall in the bore (Figure 12) and therefore the slight increase in water level is not considered symptomatic of a meaningful change within the wider aquifer.

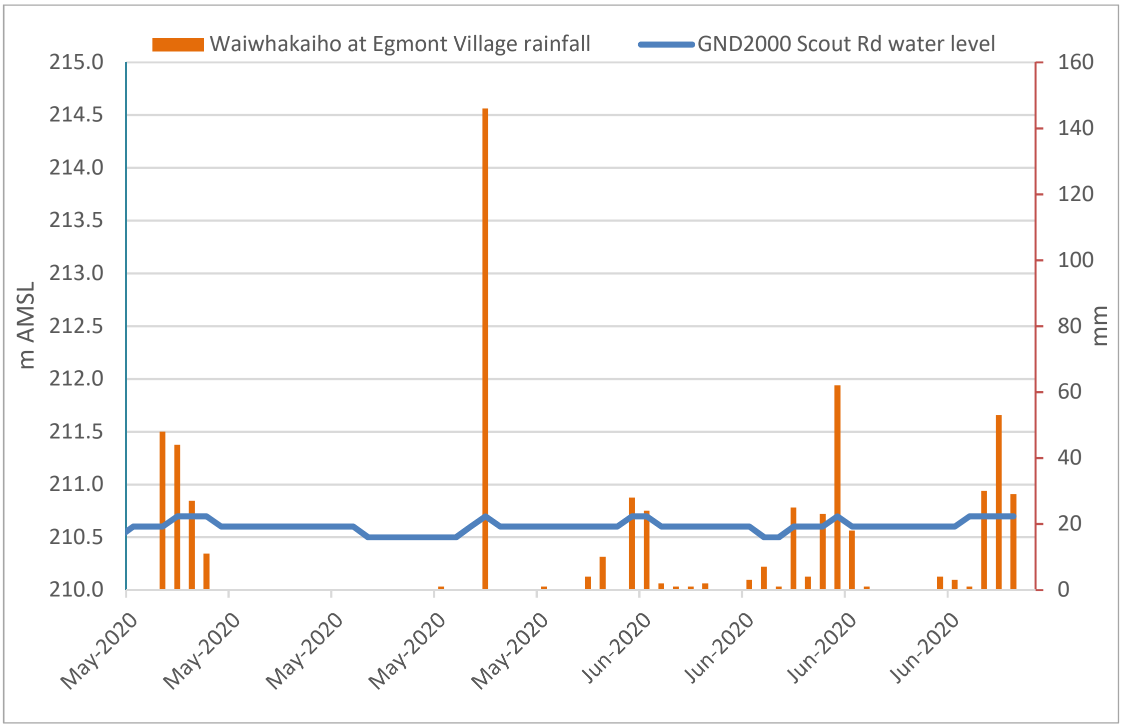


Figure 12 GND2000 comparison of water level response to rainfall from May to July 2020

5.4.2.9 Long-term meaningful trend summary

The results show that for eight of the nine sites where sufficient data was available to enable long-term trend analysis, there has been no meaningful change in groundwater level over the full period of their respective data records. The one exception to this was site GND0708, which has shown a slightly declining trend (the water level is falling) over its 21 year data record.

5.4.3 GND0708 long-term declining water level investigation

Following identification of the long-term declining trend in water level at GND0708 in the 2015-2017 monitoring report an investigation into the likely cause of the decline was recommended.

The investigation included a desktop study that identified an additional five bores that take water from the Whenuakura aquifer within a 3.5 km radius of GND0708. As no consents were in place in relation to the bores an assumption was made that all bores were abstracting under the permitted water take rules set out in RFWP and were therefore very unlikely to have any discernable effects on the aquifer. A field investigation was then initiated to identify any additional sites and to ensure that the registered bores were complying with the permitted take limit of <50 m^3/day. The investigation involved two Council Officers surveying the area, talking to landowners and inspecting any bore/wells to ascertain whether the cause of the declining water levels could be related to abstractions from the aquifer.

During the investigation the Council Officers located several additional shallow unregistered historical wells that were no longer in use and confirmed that all bores or wells still in use were operating within the permitted take rules.

Further examination of the water level data indicates that the decline in the bore appears to be following a loosely decadal pattern, with each ten year period including a decline in levels lasting around five years followed by a period of relative stability (Figure 13).

Statistical analysis of the short-term data also indicated a slight decline in groundwater level over the most recent five year period although this was at a reduced rate and not deemed statistically significant.

Rainfall is monitored at the Tawhiti at Duffy’s rainfall site approximately 8 km to the south-east of the bore. The historical rainfall data available at this site is presented alongside the groundwater level in GND0708 in Figure 13. Rainfall shows a slight downward trend in comparison to water level over the monitored period.

Over the most recent three year period (displayed in Figure 13 alongside historical data) water levels appear to be increasing which may indicate the commencement of a period of recovery or stabilisation. As the decline is localised and is not indicative of an overall decline in the Whenuakura aquifer the levels will continue to be monitored and no further investigation is deemed necessary at this time.

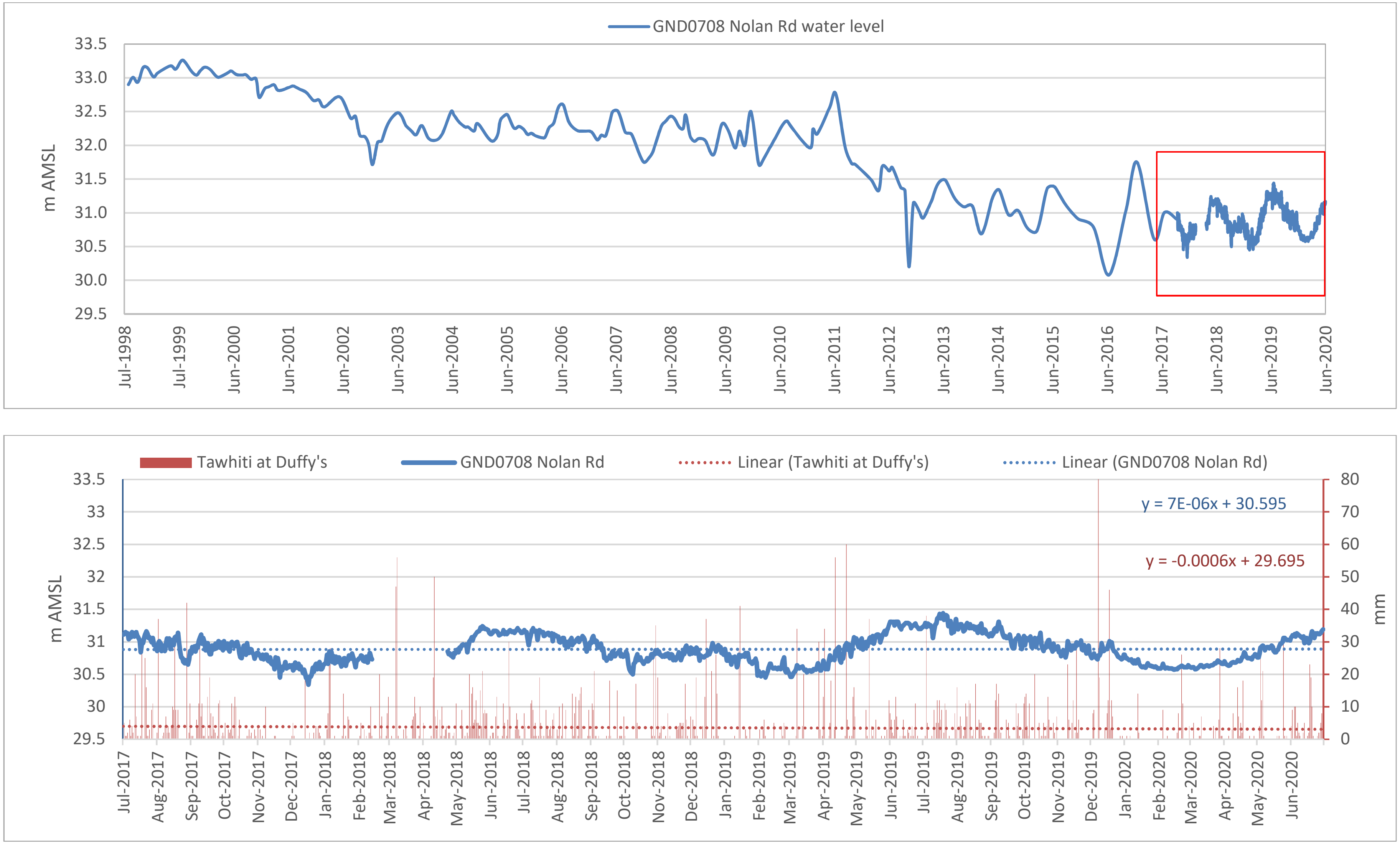


Figure 13 Plot of historical water levels in GND0708 since 1998 (higher) and compared to recent rainfall response 2017-2020 (lower)

6 Discussion

6.1 Allocation pressures

The volume of groundwater allocated for abstraction across the Taranaki region remains low, with only 73 consents authorising the taking of groundwater current as of 30 June 2020. The demand for groundwater has increased slightly over the last decade, but remains low with the total groundwater allocation to 30 June 2020 equating to less than 2% of the regions estimated sustainable yield.

The highest level of allocation is currently seen in the Whenuakura aquifer, where a combined total of 10.6% of estimated sustainable yield is allocated across the aquifer The Matemateaonga aquifer has approximately 2.7% allocated. All other aquifers have insignificant volumes of water allocated (<1% of estimated sustainable yield).

The relatively low demand placed on groundwater resources for abstractive purposes across Taranaki is likely due to several factors. Firstly, most areas of Taranaki receive regular and plentiful rainfall, with a steep rainfall gradient inward from coastal areas. The high rainfall experienced in Taranaki also means that, outside of coastal areas, soil moisture deficits are generally low and when there is a deficit, it is generally short lived. As a result Taranaki has not seen the rapid increase in water demand for pasture irrigation, as has been seen elsewhere in New Zealand. The rainfall characteristics and topography within Taranaki also means there is an abundance of surface water systems, which means rivers and streams are generally accessible when water supply is needed. Where available, surface water supplies are typically preferred to groundwater sources, given they can be obtained at a much lower capital cost. The low yields from Taranaki aquifers often mean that multiple bores are required to supply high demand uses, making the use of groundwater uneconomic. Surface water systems are generally able to sustain the majority of current water demand in Taranaki, although several catchments are fully allocated.

Notwithstanding the above, there is potential for growth in groundwater demand in the future. Any significant growth would likely be driven by a shift in current land use, development of new land uses or industrial activities that require greater higher water inputs than those activities that predominate currently. If more surface water systems across the region reach their allocation limit in coming years, any future increases in regional water demand may necessitate the need for more groundwater sourced water supply.

Climate change also has the potential to influence future rainfall patterns in Taranaki and, as a result, the volume of water recharging its groundwater systems. This could impact both the regional water demand and the volume of groundwater available for allocation. It is currently projected however that Taranaki will see little change in its annual rainfall volumes in the short to medium-term, and potentially a slight increase in rainfall by 2090, particularly over winter months, when the majority of groundwater recharge occurs. If current predictions are realised, it's unlikely that the volume of groundwater available for allocation across the region will change significantly in the future. Predicted longer-term reductions in summer low flows in Taranaki's rivers may result in further development of the regions groundwater resources.

6.2 Groundwater levels

Groundwater level data is currently collected from 15 monitoring sites across the region. The length of data records from these sites is variable. Sites have been classified as having long-term records where data has been collected for a minimum of ten years, while short-term sites have a minimum of five year's data available. The method of data collection has also varied over the course of the programme, with electronic data capture replacing manual monthly measurements.

The data collected illustrates the natural variability in water levels across the region's aquifers. Monitoring of water levels at sites intersecting unconfined aquifers, primarily in the Taranaki volcanic and marine terrace hydrogeological units, show strong response to seasonal rainfall patterns. This generally results in water levels rising during periods of the year with higher rainfall (winter, spring) and falling during drier periods (summer, autumn). The magnitude of seasonal fluctuations and the speed of level response to rainfall is also influenced by factors other than aquifer confinement though: these include the permeability and storage characteristics of strata in which the groundwater resides, its water storage capacity, the depth to the water table and the overlying land cover and proximity to a stable surface water boundary.

The impact of seasonal fluctuations in rainfall recharge volumes on groundwater levels are more subdued in confined aquifers, which are disconnected from direct rainfall recharge by overlying low permeability strata. As a result, the magnitudes of level fluctuations are typically much less than seen in shallow unconfined groundwater systems where the water table is close to the surface and receiving direct rainfall recharge.

The water level data from some specific sites also illustrate the influence of water abstraction on groundwater systems, whereby drawdown of water levels occurs as a result of pumping, with a corresponding rebound in water level when pumping stops.

Data collected over the last three years of monitoring at each site (2017-2020) has been assessed to determine the current state of groundwater levels across monitored aquifers. The assessment shows that current water levels do not differ significantly from historical long-term averages at monitored sites. The analysis also illustrated similarities in spatial and temporal responses to rainfall across some sites.

Trend analysis was carried out on the data collected at all sites with a minimum of five years' data. This data was used to assess short-term (recent) trends in groundwater level change. Where a site had a minimum of ten years of available data, an analysis of the full data record from that site was also conducted to assess longer-term trends in groundwater level. The results of the trend analysis were assessed against a set criteria of statistical significance to define a trend classification.

Following the statistical trend analysis any site exhibiting a trend were further examined to ascertain if the trend was meaningful. To assess the meaningfulness of the trend the levels have to be taken in context. In a shallow bore that exhibits a strong seasonal response any change in levels needs to be compared against both long and short-term rainfall patterns. In a confined bore with no discernible seasonal influence some consideration to any changes in local or regional abstraction needs to be given.

The results of the trend analysis show that at the vast majority of sites, there has been no meaningful change in water level over time.

The exception to this was site GND0708 (Hawera – Whenuakura Aquifer), which was found to have experienced a slightly declining trend in water level over both its long-term data record of 21 years and the most recent five year period. Localised abstraction pressure was investigated following a recommendation in the previous report and found not to be the cause of observed declines in water level at site GND0708.

The slightly declining trend in GND0708 appear to be localised as other monitoring sites in the same aquifer do not show similar trends. It is therefore concluded that the observed trends are not indicative of any widespread changes in groundwater levels across the aquifer.

The slightly declining water levels observed at site GND2252 discussed in the previous monitoring report now appear relatively stable following a slight reduction in abstraction, which has allowed the aquifer to recover. The reduction in abstraction is also likely the cause of the slightly increasing trend seen in GND2253 which could not be attributed directly to rainfall.

The short-term declining levels in GND2220 will continue to be monitored closely to determine whether the decline is temporary and therefore likely to recover, or is indicating issues with the sustainability of the current abstraction.

In summary, analysis of groundwater level data found slight changes in water level trend at specific sites but overall, groundwater levels remain stable at the majority of monitored locations. The results of the analyses undertaken show that groundwater abstraction and usage is well within current allocation limits, with little pressure on the region's groundwater systems at the present time. This suggests that Council's policies relating to groundwater abstraction and usage continue to support sustainable management of the region's groundwater resource.

7 Recommendations from the 2015-2017 biennial report

It is recommended:

1. THAT any of the planned responses outlined in Section 7.0 be implemented as proposed, where not already completed; and
2. THAT the Council's regional groundwater level monitoring network be extended as further suitable sites are identified. Sites intersecting aquifers where current monitoring coverage is limited should be prioritised, as should sites to the west of Taranaki Maunga.

These recommendation were implemented during the period being reported.

8 Recommendations

It is recommended:

1. THAT the Council's regional groundwater level monitoring network be extended as further suitable sites are identified. Sites intersecting aquifers where current monitoring coverage is limited should be prioritised, as should sites to the west of Taranaki Maunga.

Glossary of common terms and abbreviations

The following abbreviations and terms may be used within this report:

Anisotropic	Different physical properties in all directions.
Aquifer	A permeable water-bearing geological formation through which water moves under natural conditions and which yields water to wells at a sufficient rate to be a practical source of water supply.
Bore	Bore means a hole drilled into the ground and completed for the abstraction of water or hydrocarbons to a depth of greater than 20 metres below the ground surface.
Confined aquifer	When an impermeable formation, such as clay, overlies an aquifer so that air and water are no longer in contact and the pressure is no longer equal to atmospheric pressure. Water in a well will stand at a different level to the water table.
ENSO	El Nino-Southern Oscillation - is a recurring climate pattern involving changes in the temperature of waters in the central and eastern tropical Pacific Ocean.
Heterogeneity	The quality or state being diverse in physical character or content.
Heterogeneous	See Heterogeneity.
Hydraulic head	A measurement of liquid pressure above a specified datum.
m	Metres
m AMSL	Metres above mean sea level
m asl	Metres above sea level (the equivalent of m AMSL in this report)
Permitted activity	An activity that can be undertaken without the need for a resource consent, provided specified conditions are met, as set out in the RFWP.
Policy	A specific statement that guides or directs decision making. A policy indicates a commitment to a general course of action in working towards the achievement of an objective.
Recharge	The addition of water from other sources to an aquifer, e.g., seepage from rivers, percolation of rainfall.
Resource consent	Refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15).
RFWP	Regional Freshwater Plan for Taranaki (2001).
RMA	Resource Management Act 1991 and including all subsequent amendments.
Saline intrusion	The movement of saline water into freshwater aquifers.
Sustainable yield	The quantity of groundwater that can be abstracted from an aquifer for a prolonged period without depleting the resource or causing other adverse effects on groundwater quality or other groundwater users.
Unconfined aquifer	Groundwater which is freely connected to the atmosphere and which is free to rise and fall in the saturated zone, or water of an unconfined aquifer, or water under water table conditions.
Water table	The upper level of an underground surface in which the soil or rocks are permanently saturated with water.
Well	A hole dug, augured or drilled, tapping the water-table or springs to a depth of 20 metres or less below the ground surface.
Yield	The volume of water per unit of time able to be abstracted from a bore or well.

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Appendix I

Results of statistical short-term water level trend analysis by site

Groundwater Level Trend Report

07 December, 2021

Trend Analysis

Five year trend results are presented in a summary table. The direction and magnitude of monotonic trends is reported accompanied by the confidence in the reported result being true.

Trend analyses on groundwater level data for Taranaki boreholes is carried-out to characterize and document changes in the hydrologic status of the system. Water levels in individual bores vary in response to natural and anthropogenic stresses on daily, seasonal, decadal, and longer time scales. A key purpose of the analysis is to evaluate the long-term availability and sustainability of groundwater resources in the Taranaki Region, the focus of the data analysis is to examine persistent decadal or longer trends that have occurred in bores since the onset of widespread irrigation and groundwater pumping.

Water-level measurements from these identified wells then were used in the analyses. To remove daily and seasonal variation in groundwater levels induced by irrigation pumping, the median groundwater level measured in winter between January and March of each year was used in the analysis. The resulting data reflect the influence of multi-year precipitation patterns and the cumulative effects of pumping and irrigation recharge.

The data used comprises manual monthly samples during the early phase of monitoring, and continuously recorded data for the later parts of the record. For the trend analyses, continuous data are aggregated to monthly mean values to be consistent with earlier records. A comparison with random monthly re-sampled values from the continuous data, found that the trends were almost invariable for each random re-sampling.

5 Years Trends						
Site	n monthly means	Year range	Slope (cm/yr)	Trend Direction	Confidence in Trend	Confidence (%)
GND0213 Motunui M39	60	2016-2020	-3.346	Decreasing	Likely Falling	69.0
GND0229 Kiwi-1	60	2016-2020	-2.418	Decreasing	Very Likely Falling	100.0
GND0447 Manutahi-1	49	2016-2020	-0.080	Indeterminate	Indeterminate	50.0
GND0508 Carrington Rd	58	2016-2020	-12.502	Decreasing	Very Likely Falling	93.9
GND0519 Mangamahoe-1		2016-2020				
GND0599 STDC 7	60	2016-2020	-4.069	Decreasing	Likely Falling	82.1
GND0600 STDC 7a	58	2016-2020	-7.026	Decreasing	Very Likely Falling	91.9

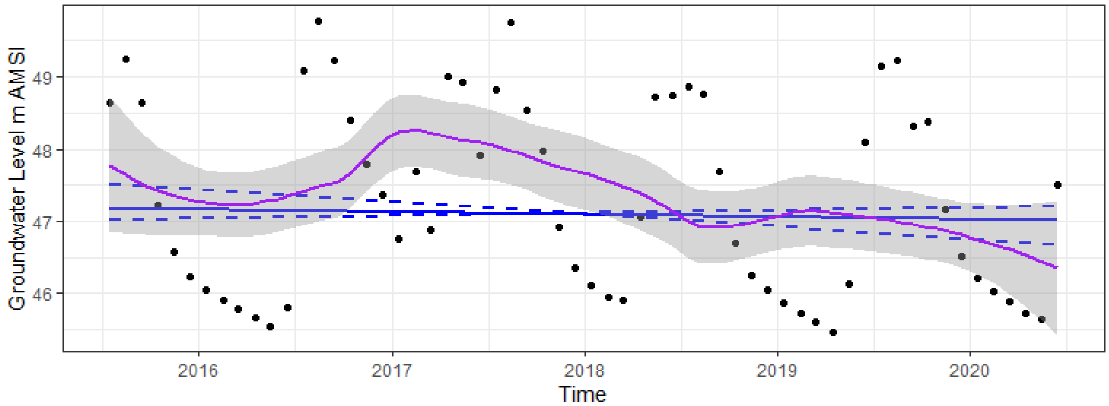
5 Years Trends						
Site	**n monthly means**	**Year range**	**Slope (cm/yr)**	**Trend Direction**	**Confidence in Trend**	**Confidence (%)**
GND0708 Nolan Rd	59	2016-2020	-0.122	Decreasing	Indeterminate	52.9
GND1015 at Stratford landfill	56	2016-2020	1.569	Increasing	Indeterminate	53.1
GND2000 Scout Rd	48	2016-2020	-3.988	Decreasing	Very Likely Falling	99.7
GND2220 STDC Swinbourne Mon Bore	60	2016-2020	-100.970	Decreasing	Very Likely Falling	100.0
GND2242 STDC Waverley Swinbourne bore	59	2016-2020	-209.808	Decreasing	Very Likely Falling	100.0
GND2252 Patea Sentinel Lower Aquifer	56	2016-2020	-4.221	Decreasing	Very Likely Falling	99.2
GND2253 Patea Sentinel Upper Aquifer	53	2016-2020	6.472	Increasing	Very Likely Rising	100.0

Trend Plots

Five year groundwater level trends are plotted for each site.

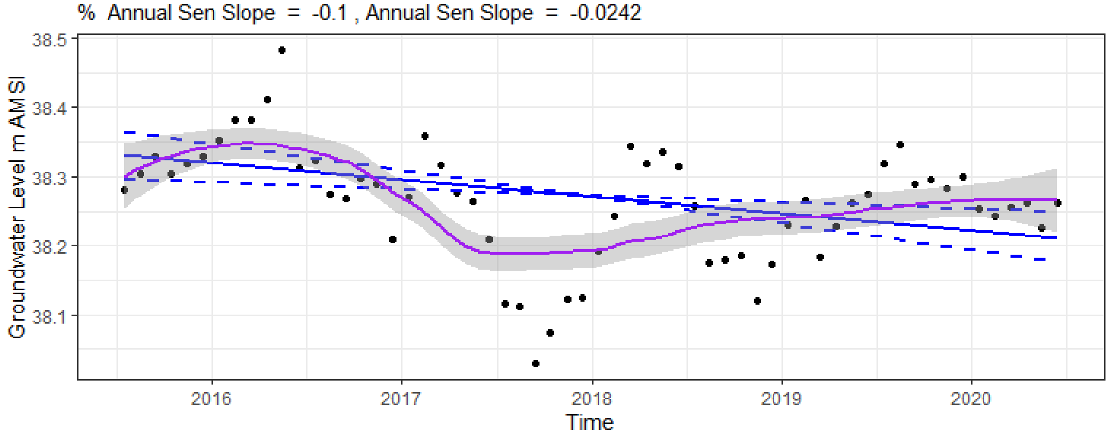
GND0213 Motunui M39 Seasonal Trend Analysis

% Annual Sen Slope = -0.1 , Annual Sen Slope = -0.0335



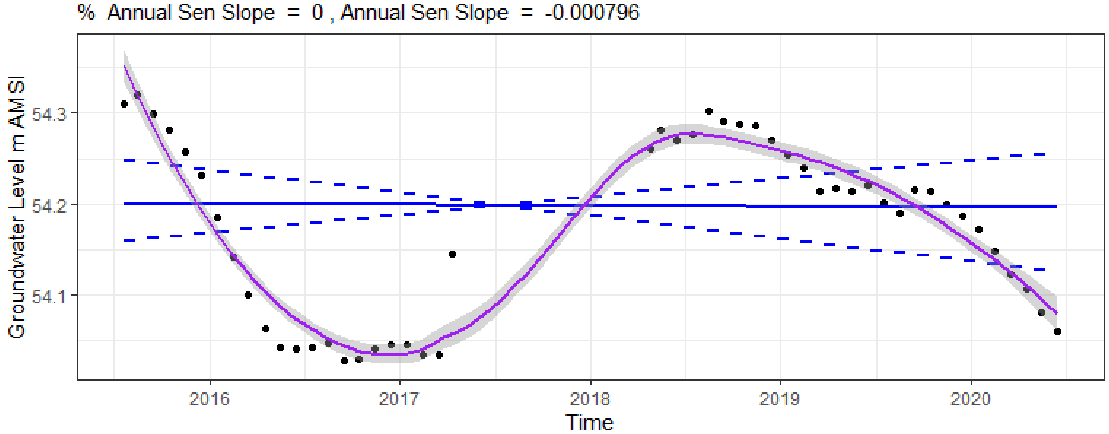
GND0229 Kiwi-1 Seasonal Trend Analysis

% Annual Sen Slope = -0.1 , Annual Sen Slope = -0.0242



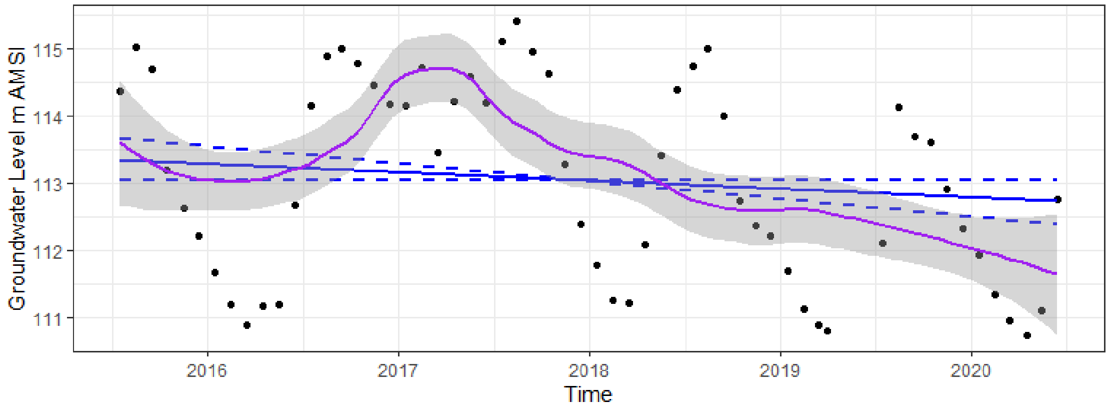
GND0447 Manutahi-1 Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.000796



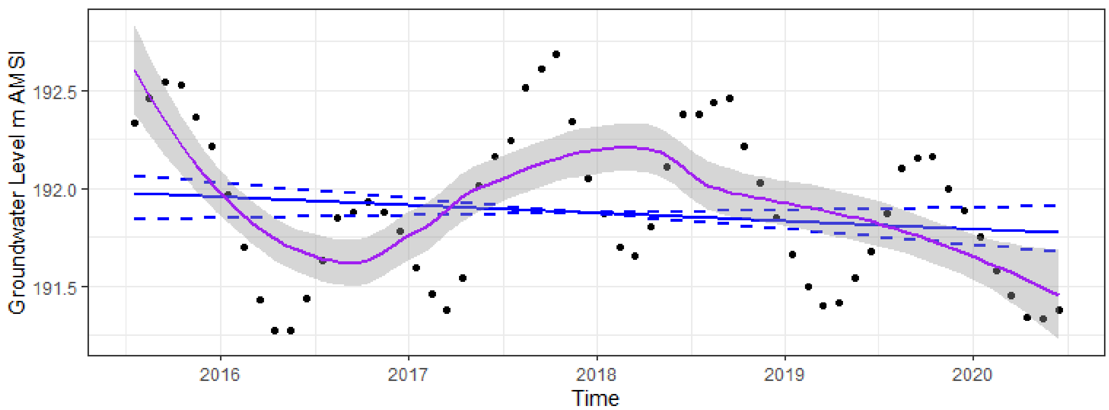
GND0508 Carrington Rd Seasonal Trend Analysis

% Annual Sen Slope = -0.1 , Annual Sen Slope = -0.125



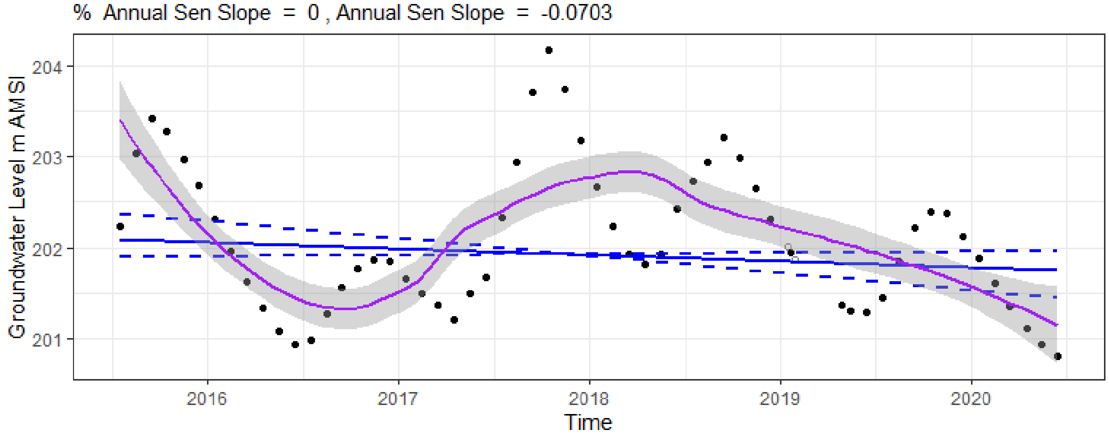
GND0599 STDC 7 Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.0407



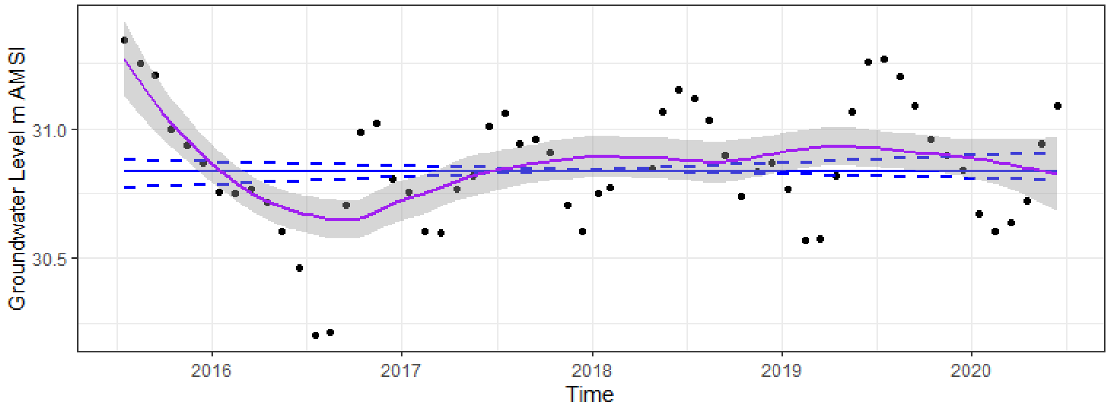
GND0600 STDC 7a Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.0703



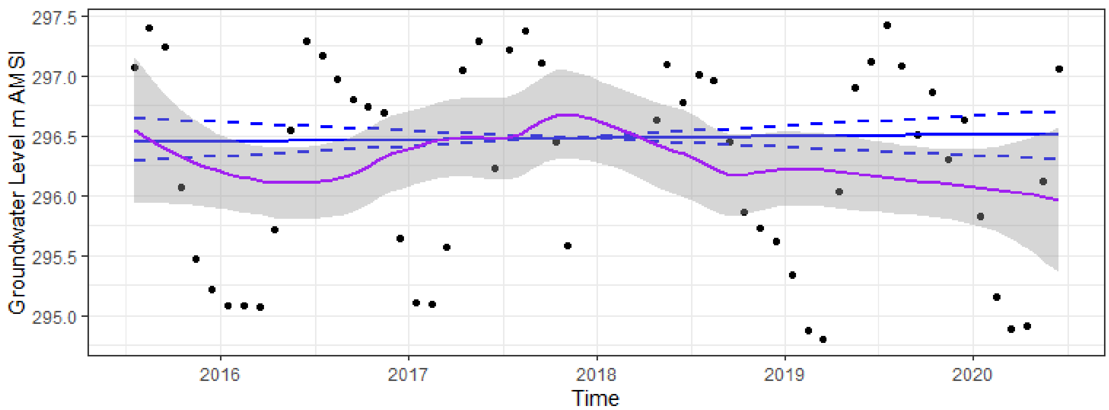
GND0708 Nolan Rd Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.00122



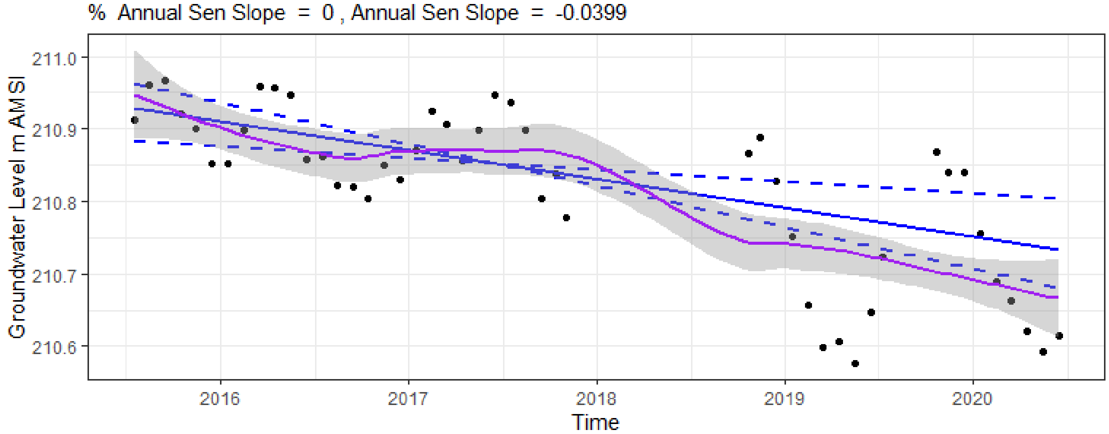
GND1015 at Stratford landfill Seasonal Trend Analysis

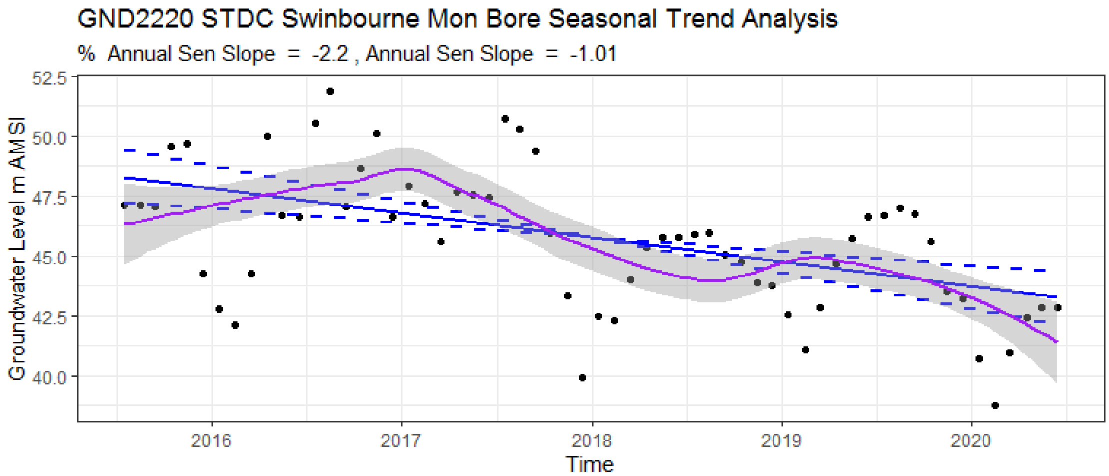
% Annual Sen Slope = 0 , Annual Sen Slope = 0.0157

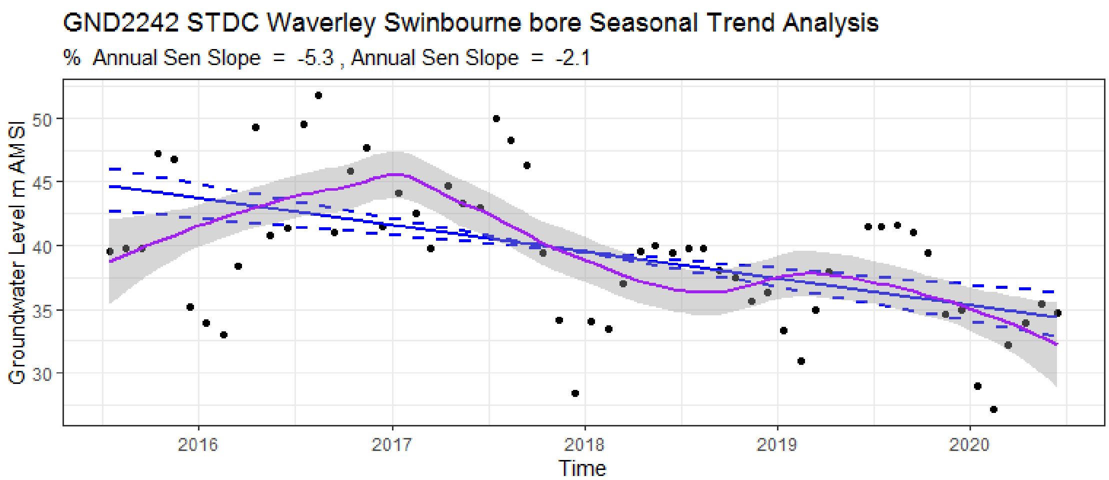


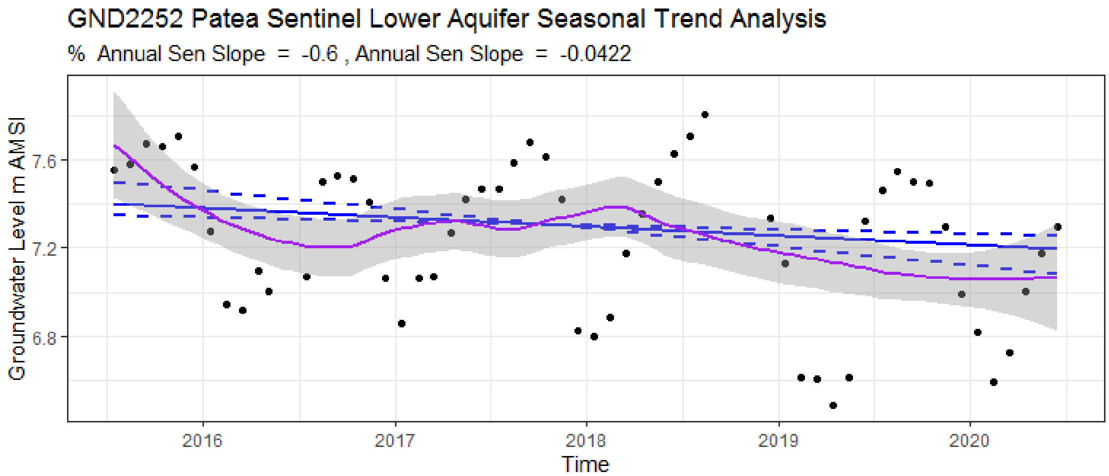
GND2000 Scout Rd Seasonal Trend Analysis

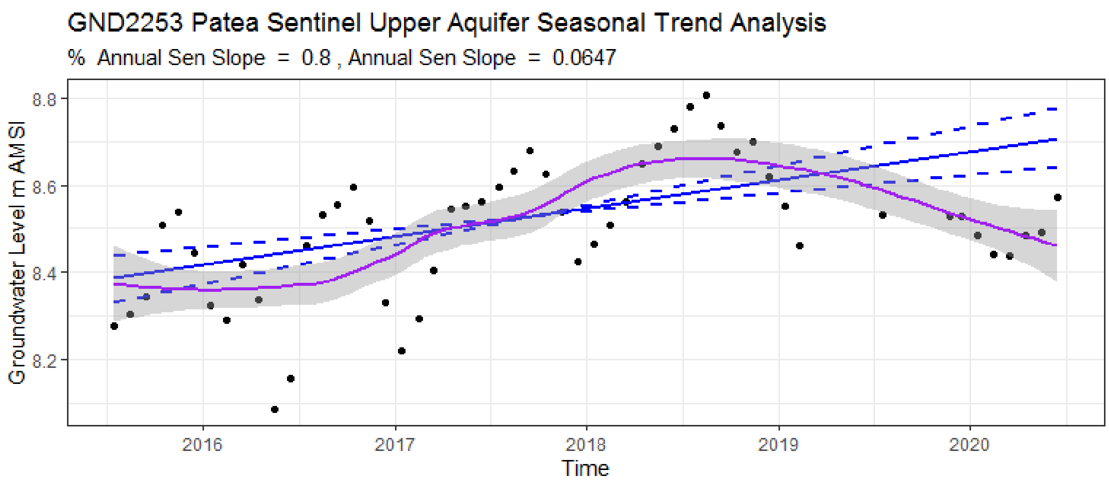
% Annual Sen Slope = 0 , Annual Sen Slope = -0.0399




GND2220 STDC Swinbourne Mon Bore Seasonal Trend Analysis
% Annual Sen Slope = -2.2 , Annual Sen Slope = -1.01
Groundwater Level m AMSl
52.5
50.0
47.5
45.0
42.5
40.0
2016
2017
2018
2019
2020
Time


GND2242 STDC Waverley Swinbourne bore Seasonal Trend Analysis
% Annual Sen Slope = -5.3 , Annual Sen Slope = -2.1
Groundwater Level m AMSl
50
45
40
35
30
2016
2017
2018
2019
2020
Time



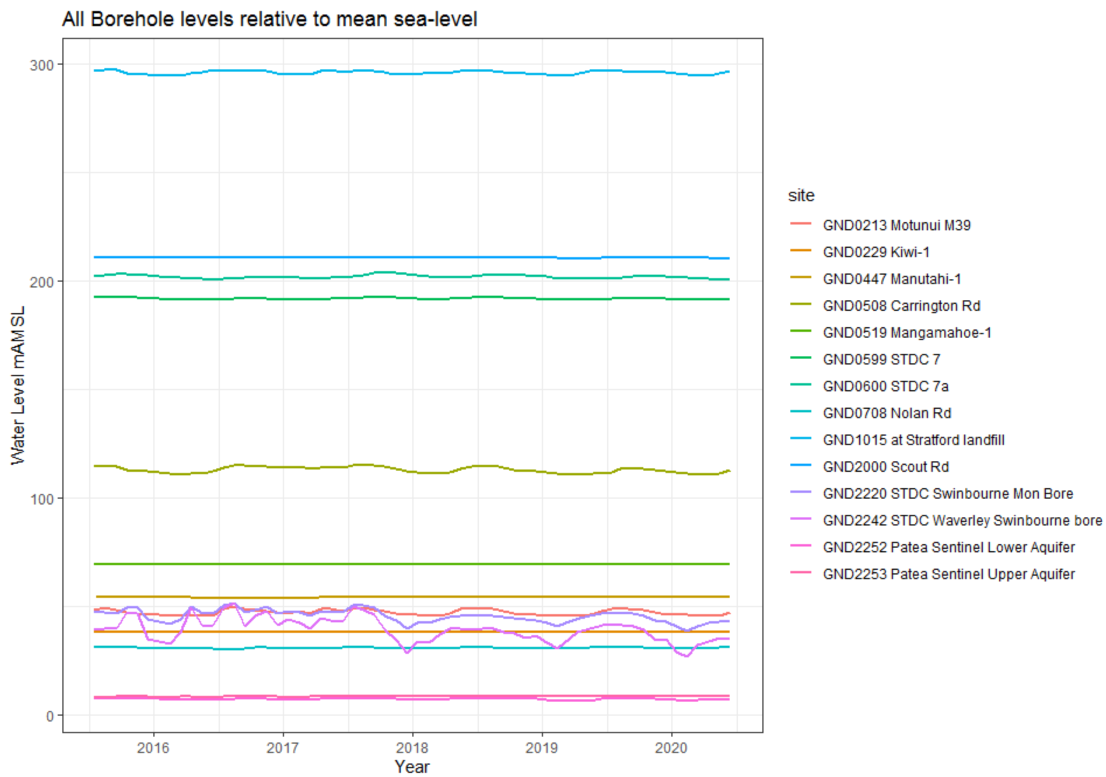


Change in groundwater level distribution over time

By plotting how often each level occurs over a period of time, we can see what the general level is, and also the upper and lower level range. When we overlay the plots for two periods we can see if there has been a change over time. The plots below show confirm the trend patterns and high variability from location to location and at a location.

All Sites Plot

With both sites all years.



All Borehole levels relative to mean sea-level
Water Level mAMSL
300
200
100
0
2016
2017
2018
2019
2020
Year
site
GND0213 Motunui M39
GND0229 Kiwi-1
GND0447 Manutahi-1
GND0508 Carrington Rd
GND0519 Mangamahoe-1
GND0599 STDC 7
GND0600 STDC 7a
GND0708 Nolan Rd
GND1015 at Stratford landfill
GND2000 Scout Rd
GND2220 STDC Swinbourne Mon Bore
GND2242 STDC Waverley Swinbourne bore
GND2252 Patea Sentinel Lower Aquifer
GND2253 Patea Sentinel Upper Aquifer

Appendix II

Results of statistical long-term water level trend analysis by site

Groundwater Level Trend Report

07 December, 2021

Trend Analysis

Long-term trend results are presented in a summary table. The direction and magnitude of monotonic trends is reported accompanied by the confidence in the reported result being true.

Trend analyses on groundwater level data for Taranaki boreholes is carried-out to characterize and document changes in the hydrologic status of the system. Water levels in individual bores vary in response to natural and anthropogenic stresses on daily, seasonal, decadal, and longer time scales. A key purpose of the analysis is to evaluate the long-term availability and sustainability of groundwater resources in the Taranaki Region, the focus of the data analysis is to examine persistent decadal or longer trends that have occurred in bores since the onset of widespread irrigation and groundwater pumping.

Water-level measurements from these identified wells then were used in the analyses. To remove daily and seasonal variation in groundwater levels induced by irrigation pumping, the median groundwater level measured in winter between January and March of each year was used in the analysis. The resulting data reflect the influence of multi-year precipitation patterns and the cumulative effects of pumping and irrigation recharge.

The data used comprises manual monthly samples during the early phase of monitoring, and continuously recorded data for the later parts of the record. For the trend analyses, continuous data are aggregated to monthly mean values to be consistent with earlier records. A comparison with random monthly re-sampled values from the continuous data, found that the trends were almost invariable for each random re-sampling.

All Data Trends						
Site	n monthly means	Year range	Slope (cm/yr)	Trend Direction	Confidence in Trend	Confidence (%)
GND0213 Motunui M39	448	1983-2020	-0.444	Decreasing	Very Likely Falling	96.3
GND0229 Kiwi-1	197	1998-2020	0.374	Increasing	Very Likely Rising	99.9
GND0447 Manutahi-1	235	1995-2020	1.997	Increasing	Very Likely Rising	100.0
GND0508 Carrington Rd	165	2004-2020	1.398	Increasing	Likely Rising	83.2
GND0519 Mangamahoe-1	146	1995-2020	-1.185	Decreasing	Very Likely Falling	100.0
GND0599 STDC 7	241	1997-2020	-0.265	Decreasing	Likely Falling	83.9

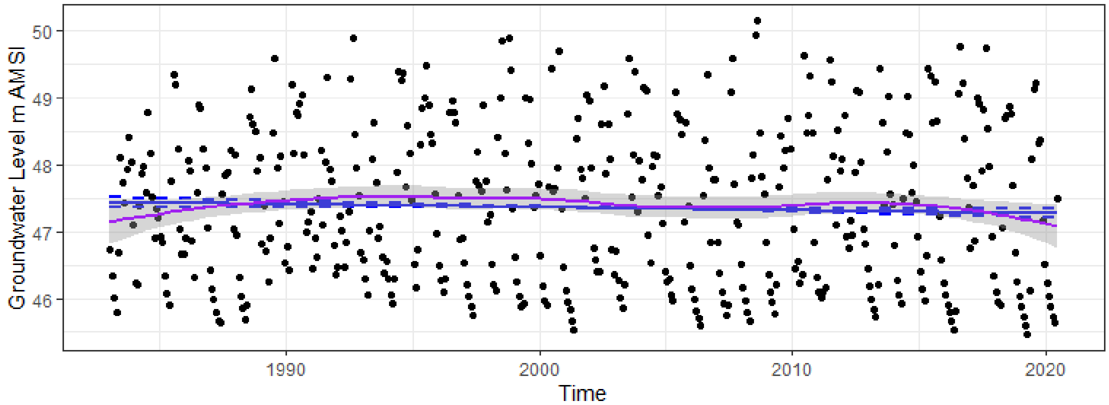
All Data Trends						
Site	n monthly means	Year range	Slope (cm/yr)	Trend Direction	Confidence in Trend	Confidence (%)
GND0600 STDC 7a	243	1997-2020	1.297	Increasing	Very Likely Rising	99.1
GND0708 Nolan Rd	225	1999-2020	-11.465	Decreasing	Very Likely Falling	100.0
GND1015 at Stratford landfill	57	2015-2020	-1.122	Decreasing	Indeterminate	55.9
GND2000 Scout Rd	106	2009-2020	2.490	Increasing	Very Likely Rising	99.9
GND2220 STDC Swinbourne Mon Bore	91	2013-2020	-52.012	Decreasing	Very Likely Falling	100.0
GND2242 STDC Waverley Swinbourne bore	81	2014-2020	-147.364	Decreasing	Very Likely Falling	100.0
GND2252 Patea Sentinel Lower Aquifer	89	2013-2020	-5.611	Decreasing	Very Likely Falling	100.0
GND2253 Patea Sentinel Upper Aquifer	86	2013-2020	3.039	Increasing	Very Likely Rising	100.0

Trend Plots

Long Term groundwater level trends are plotted for each site.

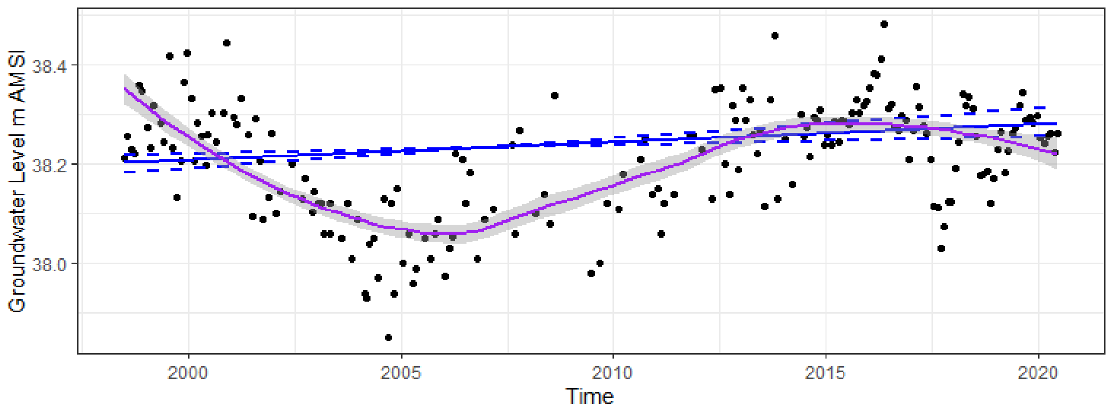
GND0213 Motunui M39 Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.00444



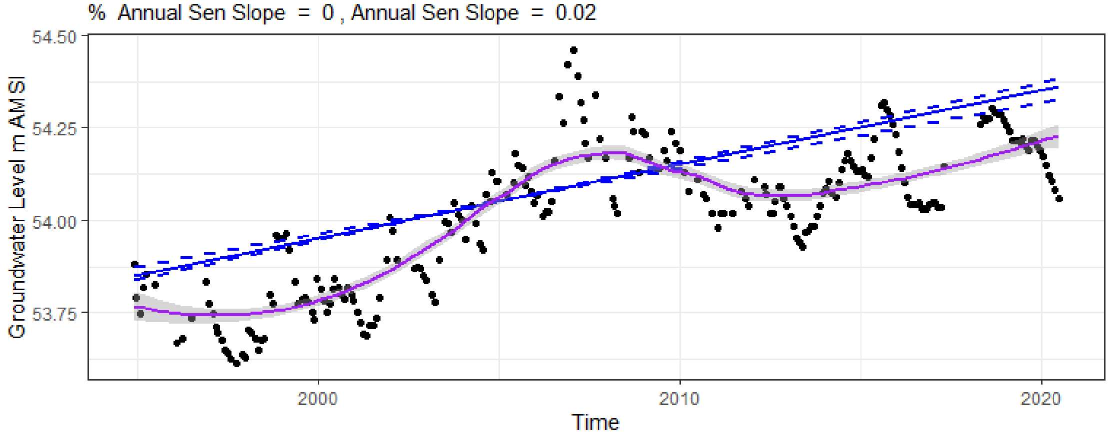
GND0229 Kiwi-1 Seasonal Trend Analysis

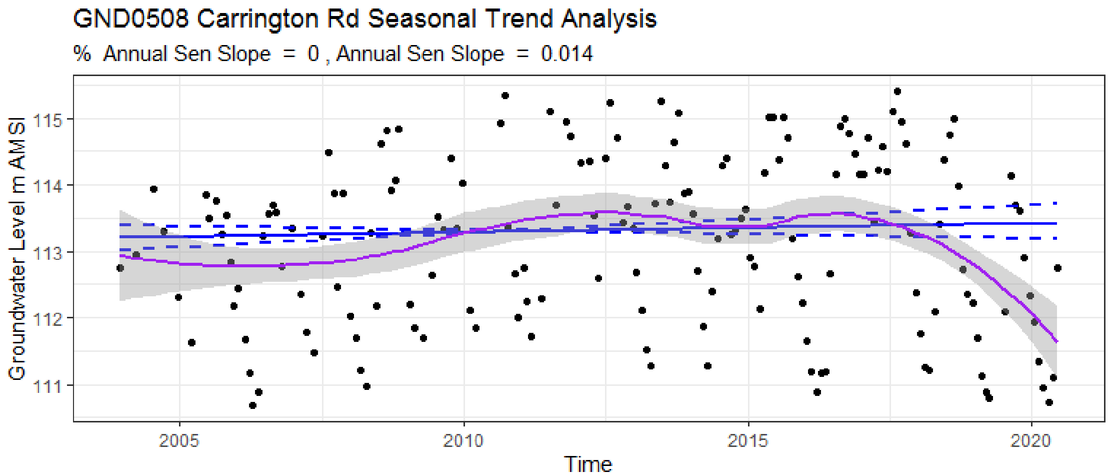
% Annual Sen Slope = 0 , Annual Sen Slope = 0.00374

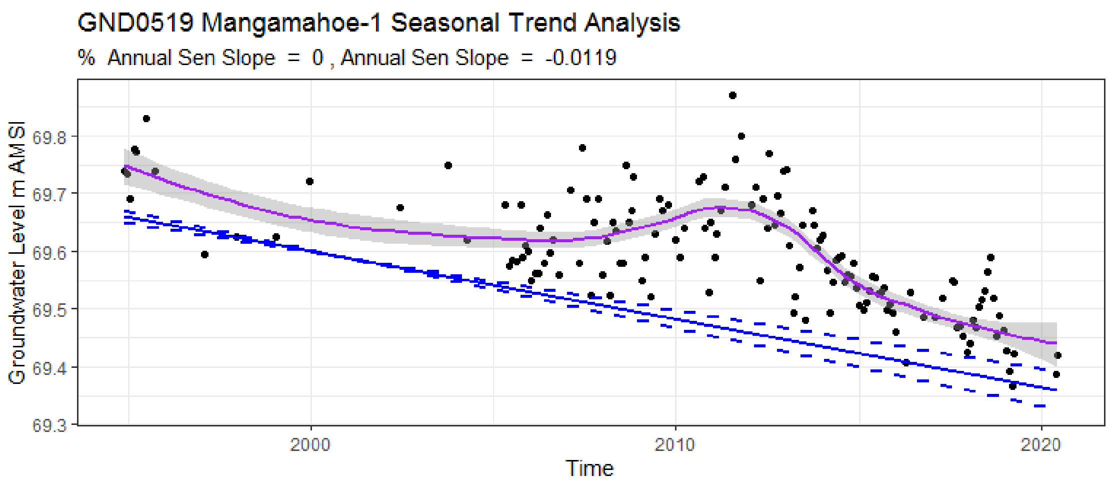


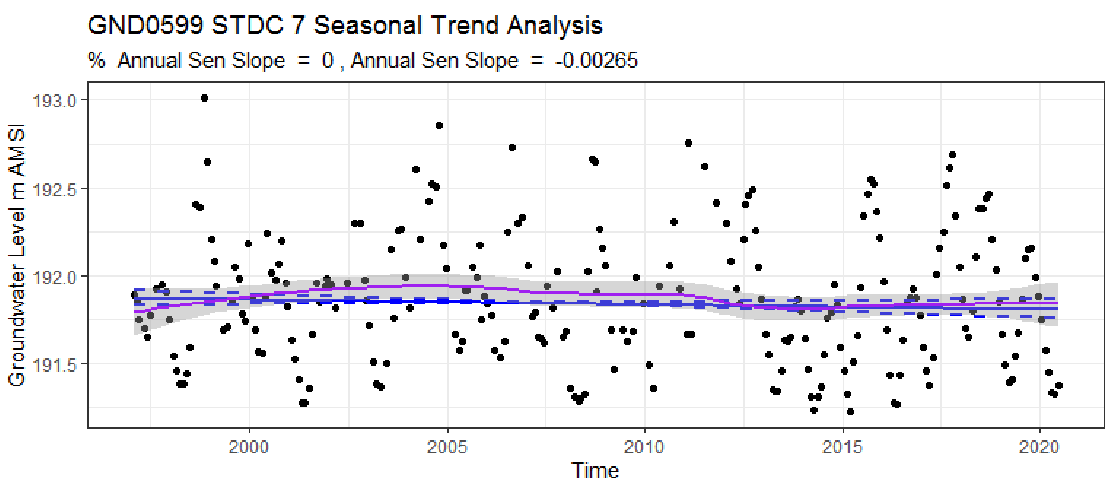
GND0447 Manutahi-1 Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = 0.02



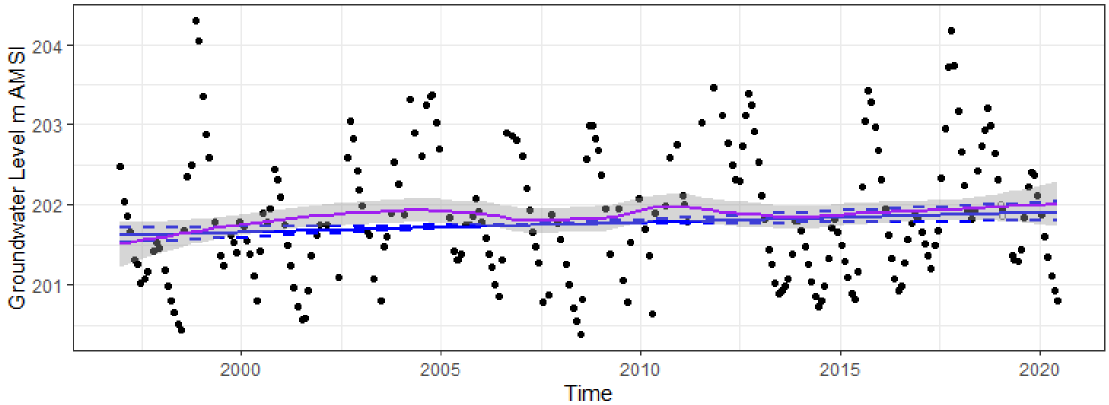

GND0508 Carrington Rd Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = 0.014
Groundwater Level m AMSl
115
114
113
112
111
2005
2010
2015
2020
Time


GND0519 Mangamahoe-1 Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = -0.0119
Groundwater Level m AMSl
69.8
69.7
69.6
69.5
69.4
69.3
2000
2010
2020
Time


GND0599 STDC 7 Seasonal Trend Analysis
% Annual Sen Slope = 0 , Annual Sen Slope = -0.00265
Groundwater Level m AMSl
193.0
192.5
192.0
191.5
2000
2005
2010
2015
2020
Time

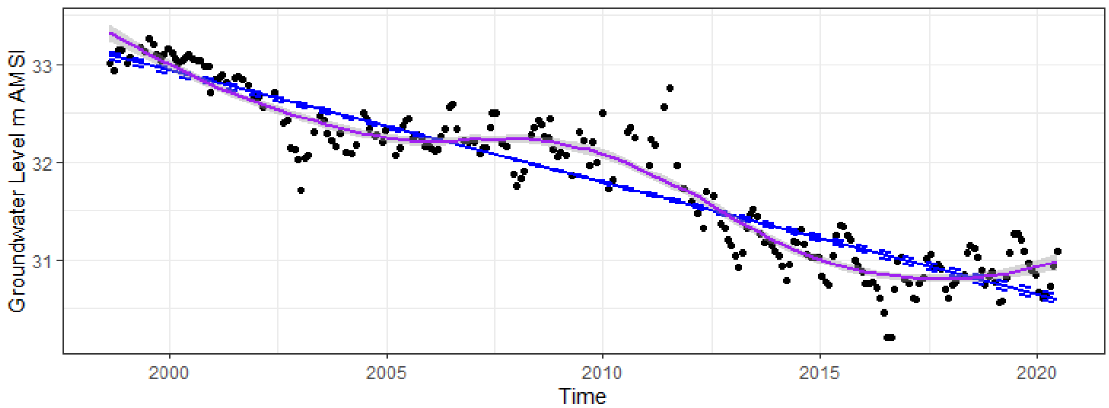
GND0600 STDC 7a Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = 0.013



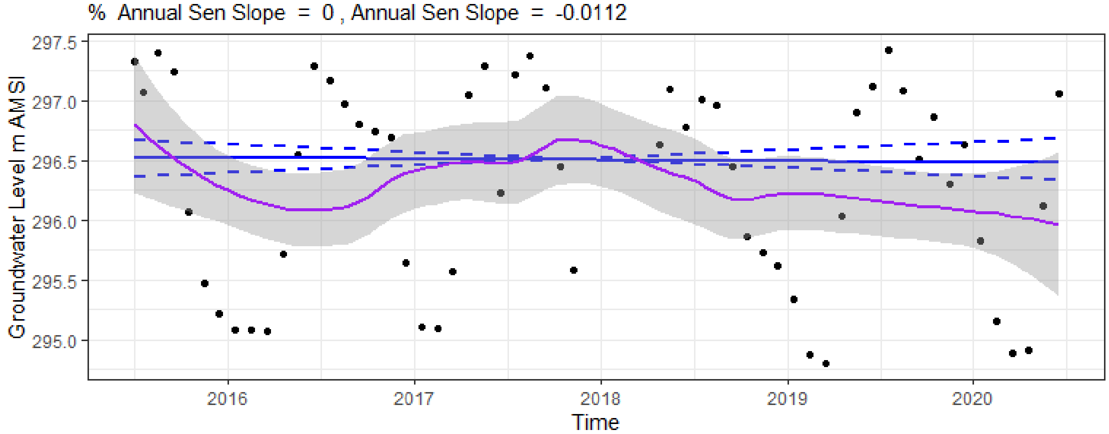
GND0708 Nolan Rd Seasonal Trend Analysis

% Annual Sen Slope = -0.4 , Annual Sen Slope = -0.115



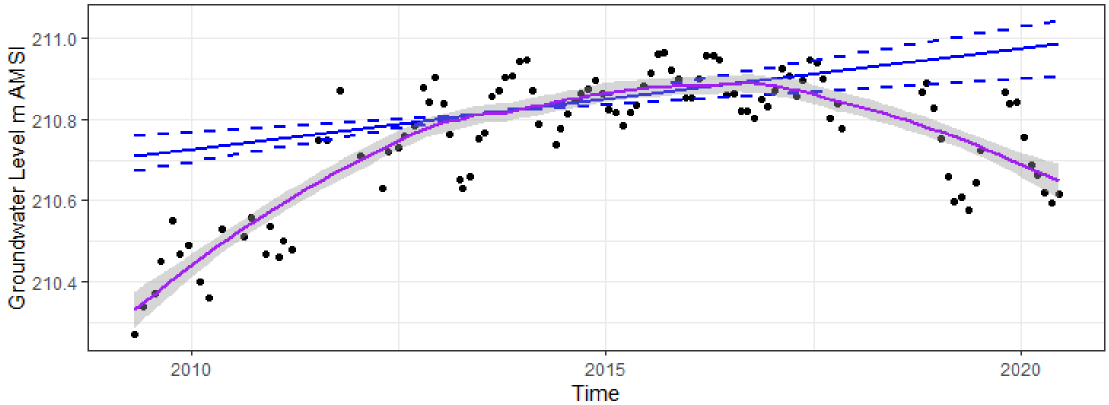
GND1015 at Stratford landfill Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = -0.0112



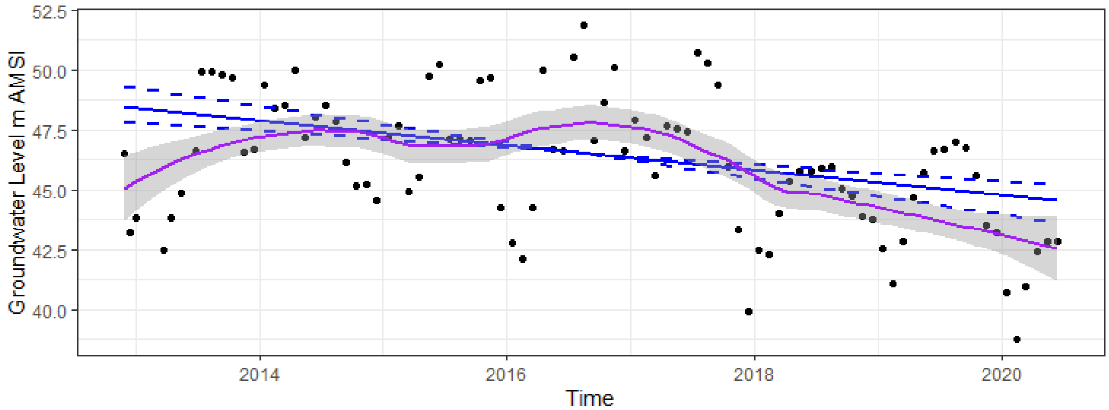
GND2000 Scout Rd Seasonal Trend Analysis

% Annual Sen Slope = 0 , Annual Sen Slope = 0.0249



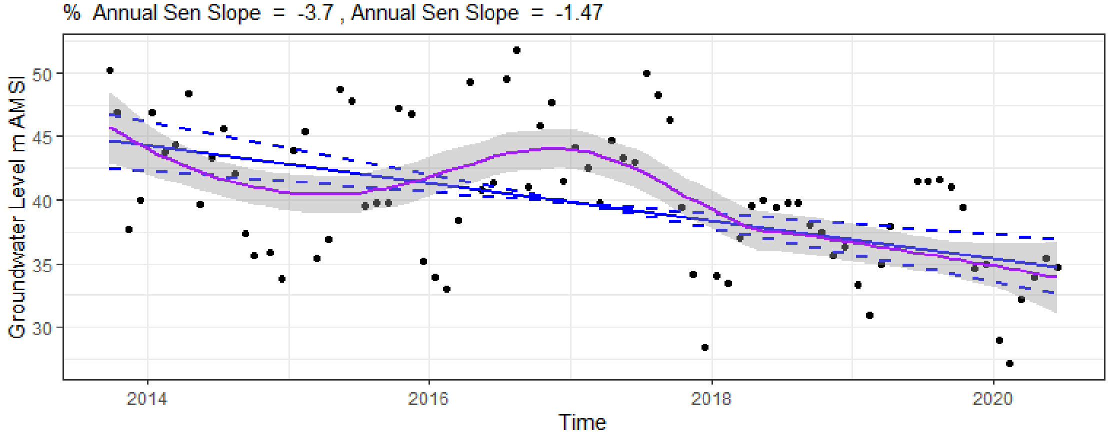
GND2220 STDC Swinbourne Mon Bore Seasonal Trend Analysis

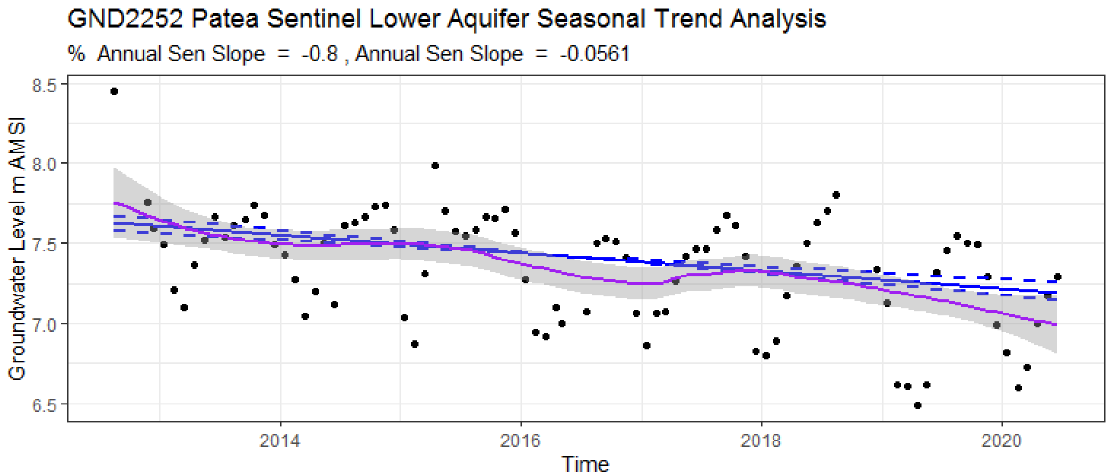
% Annual Sen Slope = -1.1 , Annual Sen Slope = -0.52

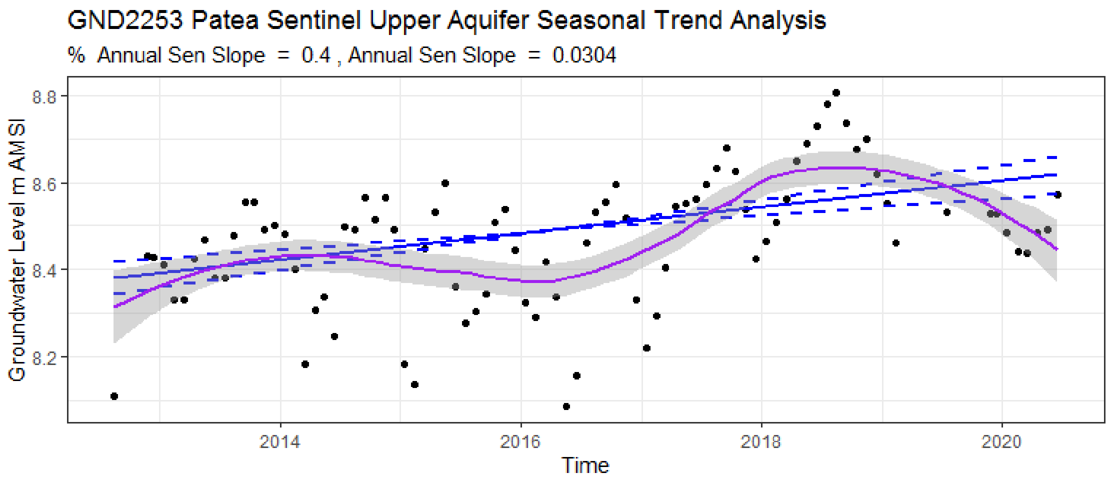


GND2242 STDC Waverley Swinbourne bore Seasonal Trend Analysis

% Annual Sen Slope = -3.7 , Annual Sen Slope = -1.47

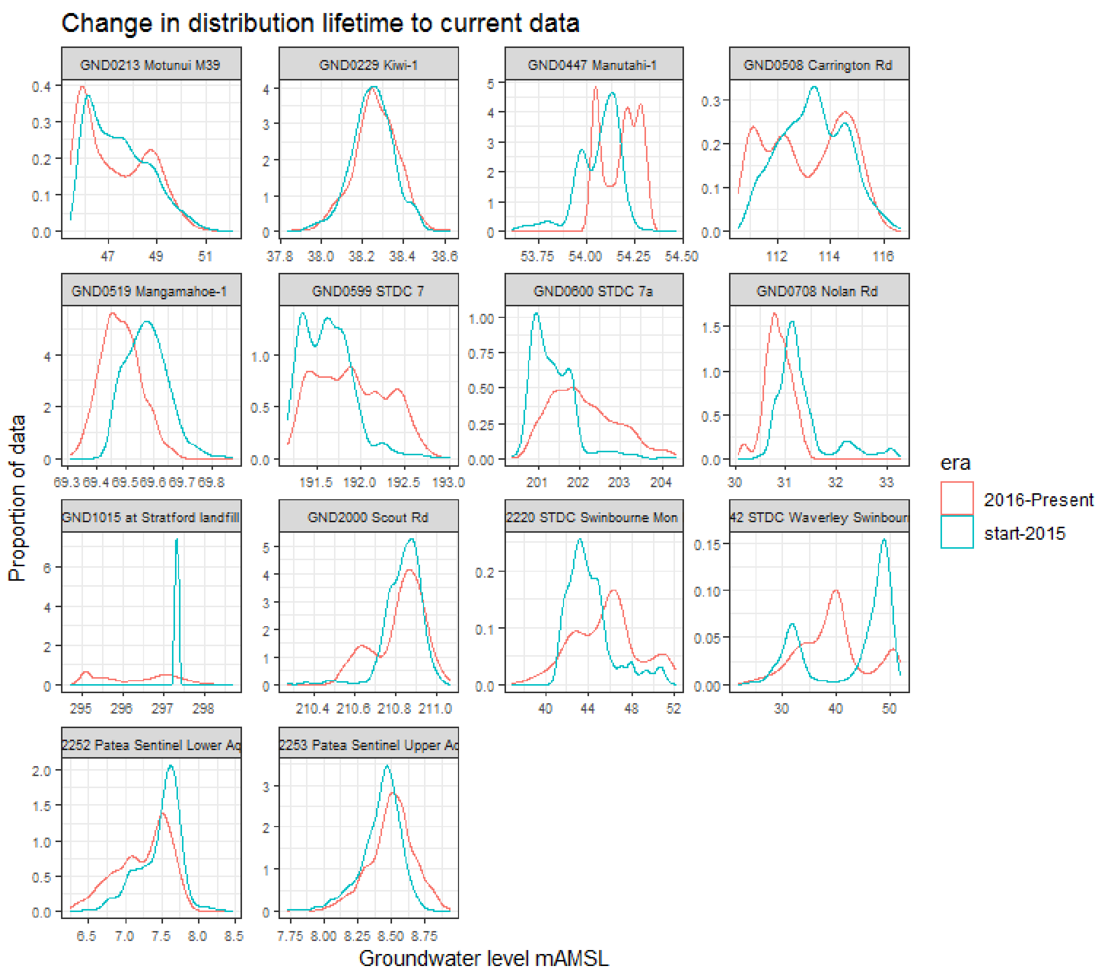






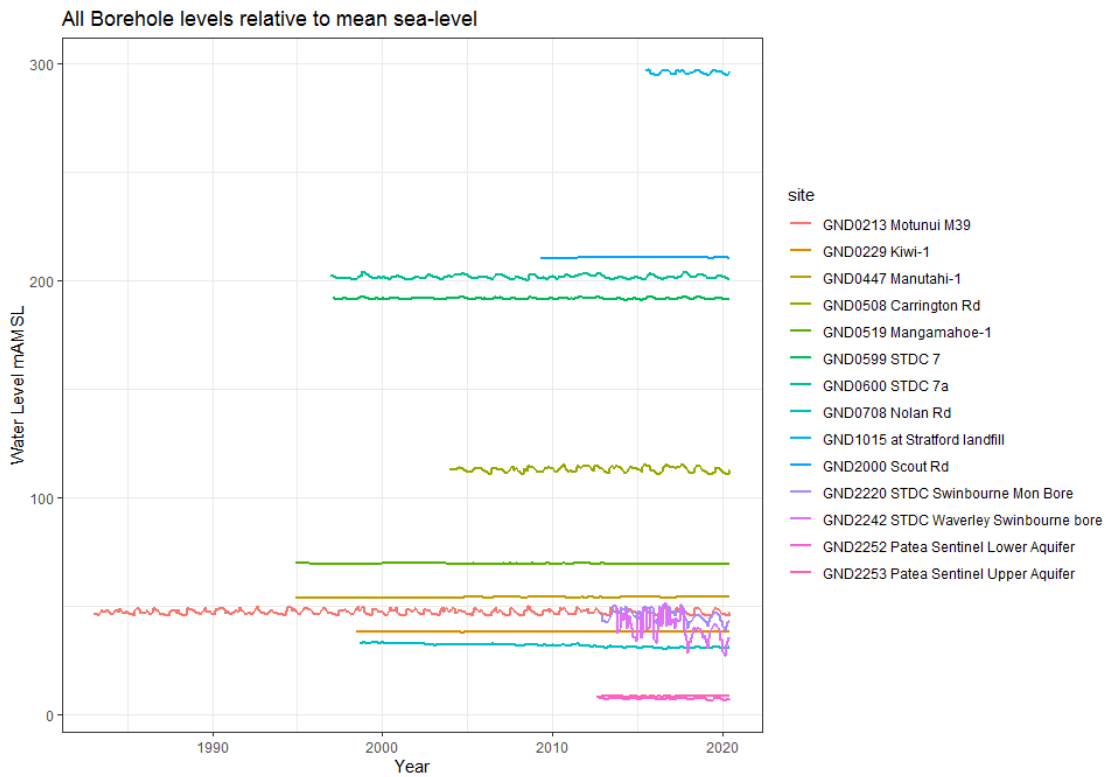
Change in groundwater level distribution over time

By plotting how often each level occurs over a period of time, we can see what the general level is, and also the upper and lower level range. When we overlay the plots for two periods we can see if there has been a change over time. The plots below show confirm the trend patterns and high variability from location to location and at a location.



All Sites Plot

With both sites all years.


All Borehole levels relative to mean sea-level
Water Level mAMSL
300
200
100
0
1990
2000
2010
2020
Year
site
GND0213 Motunui M39
GND0229 Kiwi-1
GND0447 Manutahi-1
GND0508 Carrington Rd
GND0519 Mangamahoe-1
GND0599 STDC 7
GND0600 STDC 7a
GND0708 Nolan Rd
GND1015 at Stratford landfill
GND2000 Scout Rd
GND2220 STDC Swinbourne Mon Bore
GND2242 STDC Waverley Swinbourne bore
GND2252 Patea Sentinel Lower Aquifer
GND2253 Patea Sentinel Upper Aquifer