Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

The current state of groundwater quantity in the Waimakariri Zone (2016)

Report No. R18/81
ISBN 978-1-98-859305-0 (print)
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Kaunihera Taiao ki Waitaha

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Summary

Background:

Environment Canterbury is working with the Waimakariri Water Zone Committee and local community to develop a land and water solutions programme as part of the Canterbury Water Management Strategy.

Objective:

The objective of this report is to aid in evaluating whether the priority outcomes identified by the Waimakariri Water Zone Committee are currently being met. The main outcomes relevant to this report relate to flows in spring-fed streams, reliable drinking water supply and highly reliable irrigation water supply.

What we did:

We used available data to assess groundwater allocation and usage and to evaluate trends in climate, groundwater levels and stream flows.

What we found:

Groundwater allocation in the Waimakariri zone has increased significantly over the last decade. Allocation in the Eyre River and Ashley Groundwater Allocation Zones (GAZs) is at or close to the plan limits, with about 70% of available water having been allocated for the Waimakariri zone as a whole.

Roughly 70% of the consented groundwater use is for agriculture, with approximately 24% used for community water supply. On average, consent holders use approximately 43% of their consented volumes.

Groundwater recharge in the Eyre and Cust GAZs comes mainly from land surface recharge. In the Ashley GAZ, recharge is dominated by losses from the Ashley River/Rakahuri.

Groundwater levels have remained steady across most of the Waimakariri zone since 1999, despite several dry years. In fact, levels have increased in some areas. This is likely to be due to the mitigating effects of water losses from the stockwater and irrigation race networks and increased groundwater recharge due to irrigation with water from the Waimakariri River. We would expect groundwater levels and flows in some of the spring-fed streams to reduce if race losses were reduced significantly.

Groundwater levels have declined in some of our monitoring wells in the Ashley GAZ. This has probably been accompanied by decreased flows in some spring-fed streams and reduced well reliability. The declines are probably related to decreased flows in the Ashley River/Rakahuri in response to a drier climatic period, and to increased groundwater abstraction.

Declining groundwater levels in a monitoring well near Silverstream probably reflect increased groundwater abstraction and conversion from border-dyke to spray irrigation in the area. They may indicate decreasing flows in Silverstream.

What it means:

Priority outcomes related to spring-fed stream flow and reliable water supply are not being met in the Eyre River and Ashley GAZs, but they are being met elsewhere in the Waimakariri zone.

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1 Introduction

1.1 Background

Environment Canterbury is working with the Waimakariri Water Zone Committee and local community to develop a water management programme called the Waimakariri Land and Water Solutions Programme. Some of the recommendations in the programme will be used to inform future changes to the Waimakariri sub-regional section of the Canterbury Land and Water Regional Plan (LWRP). They will also inform 'on the ground' actions and, together with regulation, will help deliver on the priority outcomes identified by the zone committee in the Waimakariri Zone Implementation Programme (2012).

The priority outcomes included safe and secure drinking water for the zone, protection of indigenous biodiversity, enhancement of spring-fed streams and improved mahinga kai, 95% reliability for irrigation water, protection of the Waimakariri River as a recreation resource, and improved ecosystem health of the Ashley/Rakahuri River. The outcomes of most relevance to our report are:

- the quantity of water in spring-fed streams maintains or improves mahinga kai gathering and diverse aquatic life
- reliable drinking water; and
- highly reliable irrigation water, to a target of 95%.

1.2 Purpose

Groundwater abstraction in the Waimakariri zone has increased significantly over the last decade, with parts of the zone now being fully allocated under our current allocation limits (see Section 2.2). Increases in groundwater abstraction can cause groundwater levels to decline, which may affect the reliability of water supply wells and reduce flow rates in groundwater-fed streams and rivers. The main purpose of this report is to assess whether the priority outcomes listed above are being met with regard to groundwater quantity. In order to do this we have evaluated how groundwater levels in the Waimakariri zone have responded to the recent increase in abstraction.

1.3 Report overview

Section 1: Introduction, purpose and report overview.

Section 2: Provides information on groundwater allocation and abstraction rates in the Waimakariri zone, and shows how allocation has increased over time.

Section 3: Provides some groundwater budgets for the zone to show how the amount of groundwater that is allocated and actually abstracted compares to the inflows to and other outflows from the groundwater system.

Section 4: Assesses how climatic conditions have varied over the last 45 years to provide background information for analysis of groundwater level trends.

Section 5: Examines groundwater level records in the context of abstraction patterns and climate variability, discusses what effect the increase in groundwater abstraction has had on water levels and comments on the implications of this for the priority outcomes.

Section 6: Provides a set of technical indicators that can be used as a basis for assessing whether the Waimakariri priority outcomes are currently being met.

Sections 7 and 8: Draw some conclusions on how future changes in abstraction rates, water use efficiency and climate variability could impact on these priority outcomes, and make recommendations for further work required to address these issues.

2 Groundwater allocation and usage

2.1 Background

The Waimakariri Water Zone has been subdivided into five Groundwater Allocation Zones (GAZs): Eyre River, Cust, Ashley, Loburn and Kowai, as shown in Figure 2-1. Environment Canterbury defined groundwater allocation limits for these zones in 2004 and updated one of them 2012. Allocation limits define the maximum amount of groundwater that can be abstracted from a GAZ over the course of a year. The purpose of these limits is to allow groundwater abstraction and the associated economic and social benefits to occur, without causing significant adverse effects on the water environment.

2.2 Waimakariri zone groundwater allocation

The groundwater allocation limits for the Eyre River, Cust, Ashley, Loburn and Kowai GAZs allow 50% of the average year LSR[1] to be taken (Table 2-1). Intermittent stream recharge from the Ashley River/Rakahuri was included for the Ashley GAZ. Dodson *et. al.* (2012) calculated a groundwater budget for the Waimakariri zone and concluded that the groundwater allocation limit for the Eyre River GAZ could be increased without significantly affecting aquifer storage. Their recommended Eyre River GAZ allocation limit of 99.1×10^6 m³/year was subsequently adopted. The characterisation of the hydrological system presented in the Dodson *et. al.* (2012) report showed that surface water and groundwater are a highly connected resource across the plains, however. The study therefore also concluded that abstracting groundwater would ultimately affect surface water flows. We discuss this further in Section 5.5.

Determining how much water has been allocated on an annual basis is not straightforward. This is because many of the water take consents issued before 2004 did not have an annual volume limit specified in the consent conditions. We therefore need to estimate how much water could be feasibly taken under these consents over the course of a year, based on the area of land that can be irrigated and/or the maximum daily abstraction limit specified on the consent. In the past, a number of different methods have been used to provide these estimates, making comparison difficult. Our estimates for 2016 in Table 2-1 use the annual volume limits specified on consents where applicable, and the current LWRP methodology where no annual volume limit is given. The estimates indicate that the Eyre River GAZ is fully allocated, but additional water is available for consenting in the other allocation zones.

[1] Which is taken as both rainfall and irrigation-induced recharge in the case of the Cust, Ashley, Loburn and Kowai GAZs, and rainfall recharge only in the case of the Eyre River GAZ

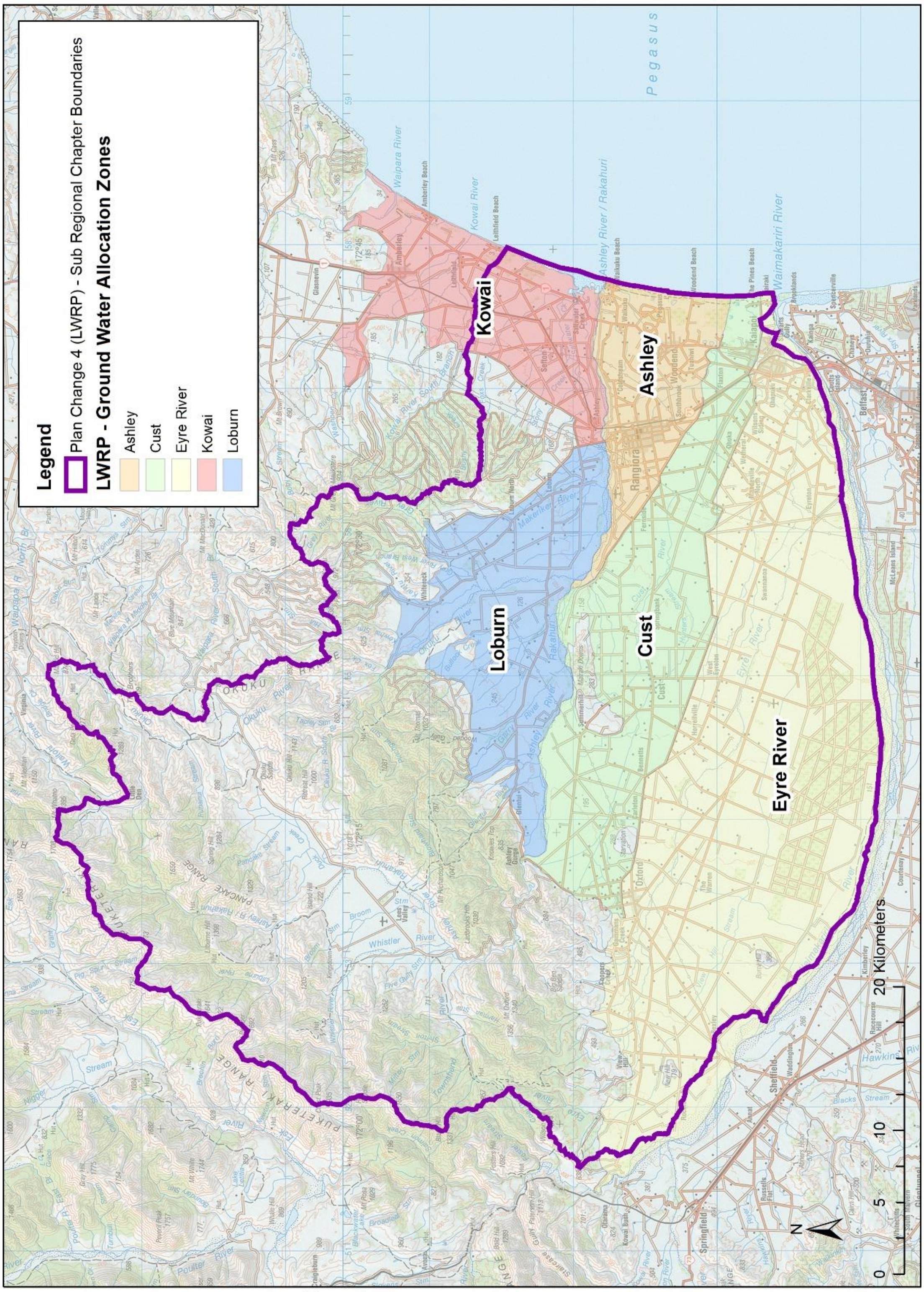

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Figure 2-1: Groundwater allocation zones

Table 2-1: 2016 groundwater allocation ($m^3 \times 10^6$/yr)

GAZ	Allocation limit	Estimated net allocation[2]	% allocated	Estimated gross allocation[3]
Eyre	99.1	100.5	101%	111.7
Cust	56.3	15.5	27%	20.3
Ashley	29.4	15.5	53%	22.4
Kowai	17.4	10.4	59%	10.4
Loburn Fan	40.8	0.1	0.2%	0.2
Total	243	138.7	68%	164.9

2.3 Allocation by usage type

Most of the groundwater allocation in the Waimakariri zone is used for irrigation (see Figure 2-2), followed by community water supply. Applying the allocation proportions shown on Figure 2-2 to the total estimated gross allocated volume in Table 2-1 gives an average allocation of approximately 3.7 m^3/s (116 m^3/year x 10^6) for irrigation, 1.2 m^3/s (39 m^3/year x 10^6) for community water supply and approximately 0.3 m^3/s (9 m^3/year x 10^6) for the three remaining usage categories together.

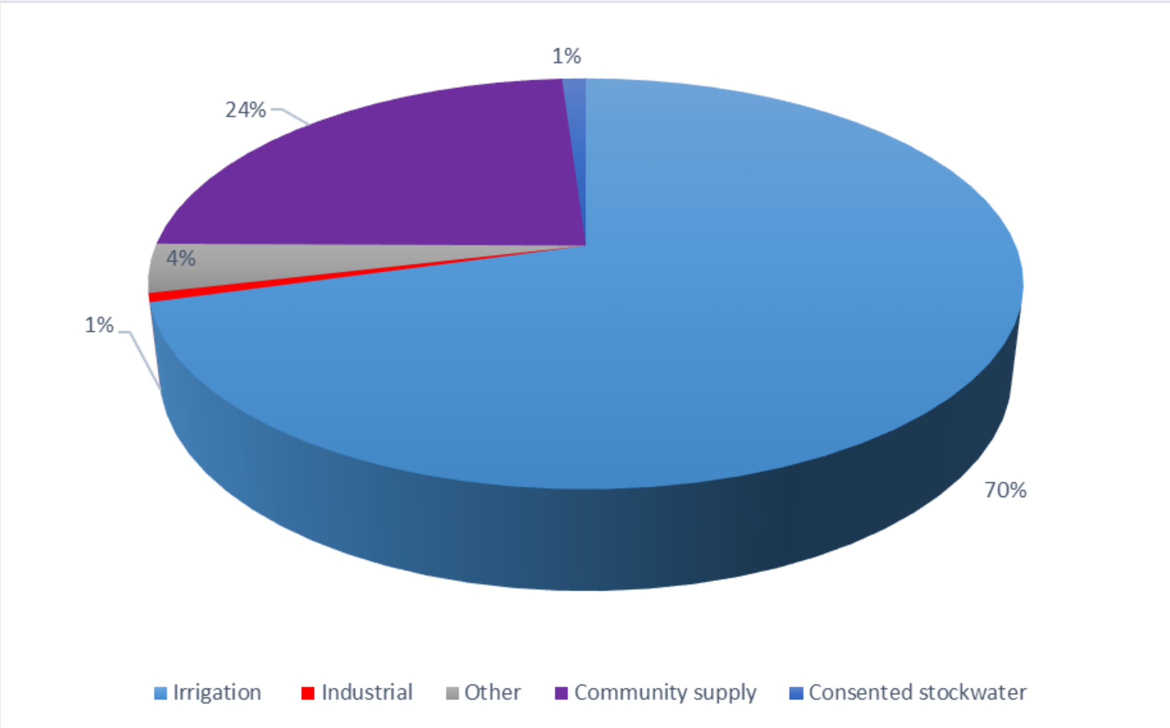

Figure 2-2: Groundwater allocation by use type

2.4 Groundwater usage

In 2009 Environment Canterbury began a programme to better understand the relationship between water use and water allocation, largely through the installation of water measuring devices for consented takes (Tricker *et. al.,* 2012). The number of consented water takes with meters installed was relatively low in the first few years of the programme, with less than 10% of consents being reliably measured in some areas. This improved over time, and by 2012 metering had become sufficiently widespread to provide a useful picture of water use. Analysis of water metering data from the Waimakariri zone (Table

[2] Effective allocation as of August 2016, after accounting for stream depletion. This figure is lower than the gross allocated groundwater volume, because the volume of groundwater which would otherwise discharge to surface water courses has been subtracted.

[3] Effective allocation as of August 2016, does not account for stream depletion.

2-2) shows that our database holds records for around 50% of the consented annual volume for the 2014-2015 period.

Because our abstraction metering database only covers a portion of the total allocated groundwater take, we need to estimate total groundwater usage for the whole Waimakariri zone based on the percentage of allocated volume that is used by those takes with metering data. Estimated use ratios for the zone overall (Table 2-2) have ranged between 25% and 52% over the record period, with an average of 43%.

Table 2-2: Metering data summary for Waimakariri zone

Use category	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2012-2015 average
	Metering coverage					
% of allocated volume measured (all categories)	5%	14%	35%	46%	46%	42%
Actual usage ratios - % of maximum annual volume used						
Irrigation	40%	25%	41%	38%	54%	44%
Industrial	No data	No data	62%	38%	11%	37%
Other	No data	0%	1%	23%	20%	15%
Community supply	24%	No data	53%	No data	15%	34%
Zone total	36%	25%	41%	36%	52%	43%

The 2014-2015 irrigation season was very dry, with land surface recharge being 70% below the long-term average (see Figure 3-2). Given that annual water allocation volumes are typically based on an estimate of the demand in an 80th percentile dry year (i.e. only 20% of years are dryer), we would expect consent holders to have used a high proportion of the estimated allocation volume for 2015. This is not the case, with only 52% of the estimated annual volume used across the whole zone. One possible explanation for this is that many irrigators in the Waimakariri Irrigation Ltd (WIL) command area hold consents to take groundwater which are only used when WIL scheme water is not available (i.e. when Waimakariri River flows are below the water take threshold). This explanation seems to be broadly supported by the metering data, which indicate that a high proportion (87%) of the annual allocated volume was used in the Ashley GAZ (where only ~20% of which is covered by the WIL command area) and much lower proportions in the Eyre River and Cust GAZs (see Table 2-3). Comparing usage rates for WIL scheme customers who hold groundwater consents shows that WIL customers use a lower proportion of their annual volumes than non-customers.

Table 2-3: 2014-2015 water use proportions by GAZ

GAZ	% covered by WIL command area	% annual allocated volume used in 2014-2015
Ashley	18	87
Cust	87	36
Eyre River	95	53

We have also analysed groundwater abstraction records from the Waimakariri District Council (WDC) for town and community water supply wells which are not currently incorporated in our water use database. The WDC water metering data cover approximately 90% of the allocated volume for this use category and indicate that only ~20% of the annual volume allocation is used on average for the 2012-2015 period. We have used the higher 2012-2015 usage ratio from Table 2-2 for the analysis in this report.

Water usage varies with climatic conditions. Water usage for irrigation (see Table 2-2) was lowest in 2013-2014, a wet year, and highest in 2014-2015, a dry year. Taking the mean water use proportions for the 2012-2015 period smooths out this climate variability. We have therefore estimated average groundwater use in the Waimakariri zone using the mean proportion of allocated volume used for the 2012-2015 period.

Estimated actual[4] groundwater usage rates summarised in Table 2-4 indicate that approximately 70% of groundwater abstracted from the Waimakariri zone is used for irrigation and around 18% for community water supply. We have included the Permitted Take[5] water use from Dodson and Lough (2013) in the table, which accounts for approximately 9% of total water abstraction.

Table 2-4: Estimated groundwater abstraction by use category for 2012-2015

Use category	Allocated volume $m^3/y \times 10^6$	Mean % use	Water use $m^3/y \times 10^6$	Water use m^3/s	% of total use
Irrigation	115	44%	51	1.46	70%
Industrial	1	37%	0.4	0.01	1%
Other	6	15%	0.9	0.03	1%
Community supply	39	34%	13.2	0.39	18%
Consented stockwater	2	40%[6]	0.7	0.02	1%
Permitted use	N/A	N/A	6.4	0.20	9%
Total	163	-	72.1	2.3	

We have summarised groundwater usage estimates per groundwater allocation zone in Table 2-5 below.

Table 2-5: Estimated groundwater usage by GAZ

GAZ	2016 allocation ($m^3 \times 10^6$) including stream depletion[7]	Assumed use ratio	Water use $m^3/y \times 10^6$	Water use m^3/s
Eyre River	111.7	40%	44.7	1.4
Cust	20.3	40%	8.1	0.3
Ashley	22.4	55%	12.3	0.4
Loburn Fan	0.1	55%	0.1	0.0
Kowai	10.4	55%	5.7	0.2
Total	165	43%	70.9	2.2

2.5 Groundwater allocation trends

Groundwater allocation in the Waimakariri Zone has increased significantly since 2009 predominantly due to expansion of irrigation in the Eyre River GAZ. The data plotted in Figure 2-3 indicate that groundwater allocation in the Eyre River GAZ doubled between 2009 and 2015. We discuss this further in the context of groundwater level trends in Section 5. Our data show a sharp decline in Eyre River GAZ allocation in 1999-2000, which may relate to expiry of groundwater takes for irrigation when the WIL scheme came on line.

[4] Note that these values are for actual water use, not consented use as per elsewhere in this report

[5] 'Permitted takes' is a term we use to refer to water that is used without the need for a consent. It allows for reasonable domestic and stockwater use (up to 10 m³/d for properties <20 ha and up to 100 m³/s for properties > 20 ha)

[6] Assumed value due to insufficient metering data

[7] This differs from the data in Table 2-1 because the data in Table 2-1 have been adjusted to discount stream depletion effects. This is done by estimating how much water comes from surface water (stream depletion) for each groundwater take, and removing the total volume from the groundwater allocation estimate for each GAZ.

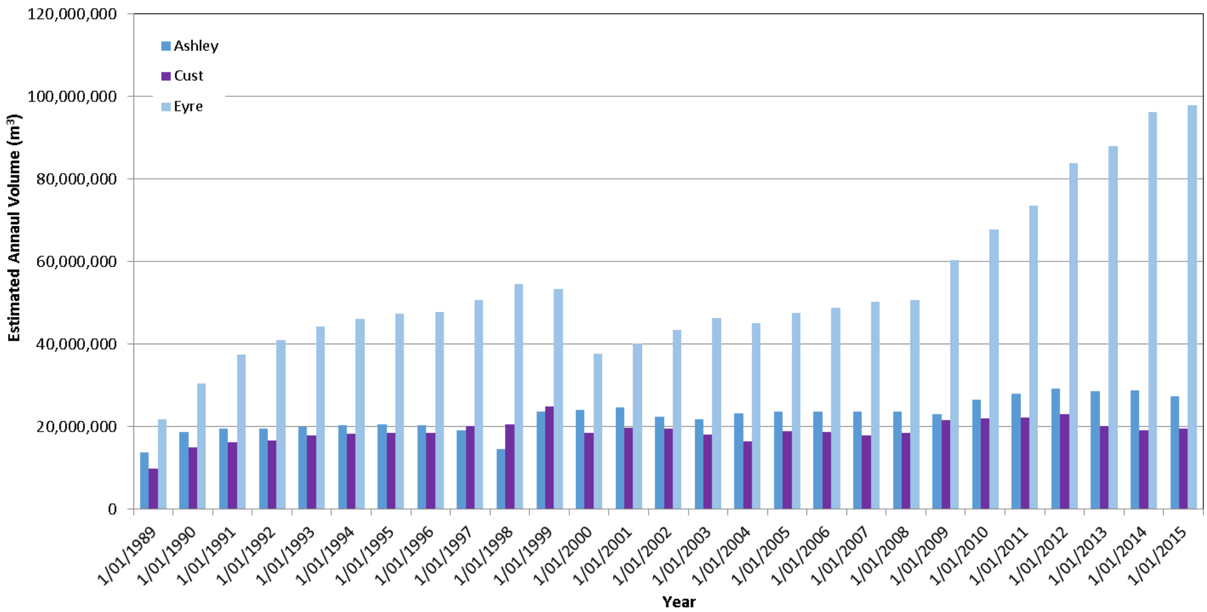

Figure 2-3: Groundwater allocation over time

3 Water budget

The Ashley-Waimakariri plains[8] groundwater budget presented in Dodson *et. al.* (2012) indicates that approximately 70% of groundwater recharge is sourced from LSR with the remaining 30% supplied by surface water and irrigation race losses. The authors estimated that 80% of LSR was from rainfall with the remaining 20% classified as “irrigation-induced” recharge. This second component represents the extra groundwater recharge from irrigated land associated with irrigation water losses, and the extra infiltration that occurs when rain falls on soils that are wetter.

We have revised these previous water budget estimates for the Eyre River, Cust and Ashley GAZs using more recent data and knowledge. The updated water budget results (Figure 3-1) indicate that LSR provides 69% of groundwater recharge in the Eyre River GAZ and around 54% in the Cust GAZ, but only 7% in the Ashley GAZ. Information sources for the water budget are provided in Appendix 4, which includes details of the main streams which are sustained by groundwater discharges in each GAZ. We have not analysed water budgets for the Loburn and Kowai GAZs because groundwater usage is relatively low in these areas.

[8] Area between Waimakariri River and Ashley River

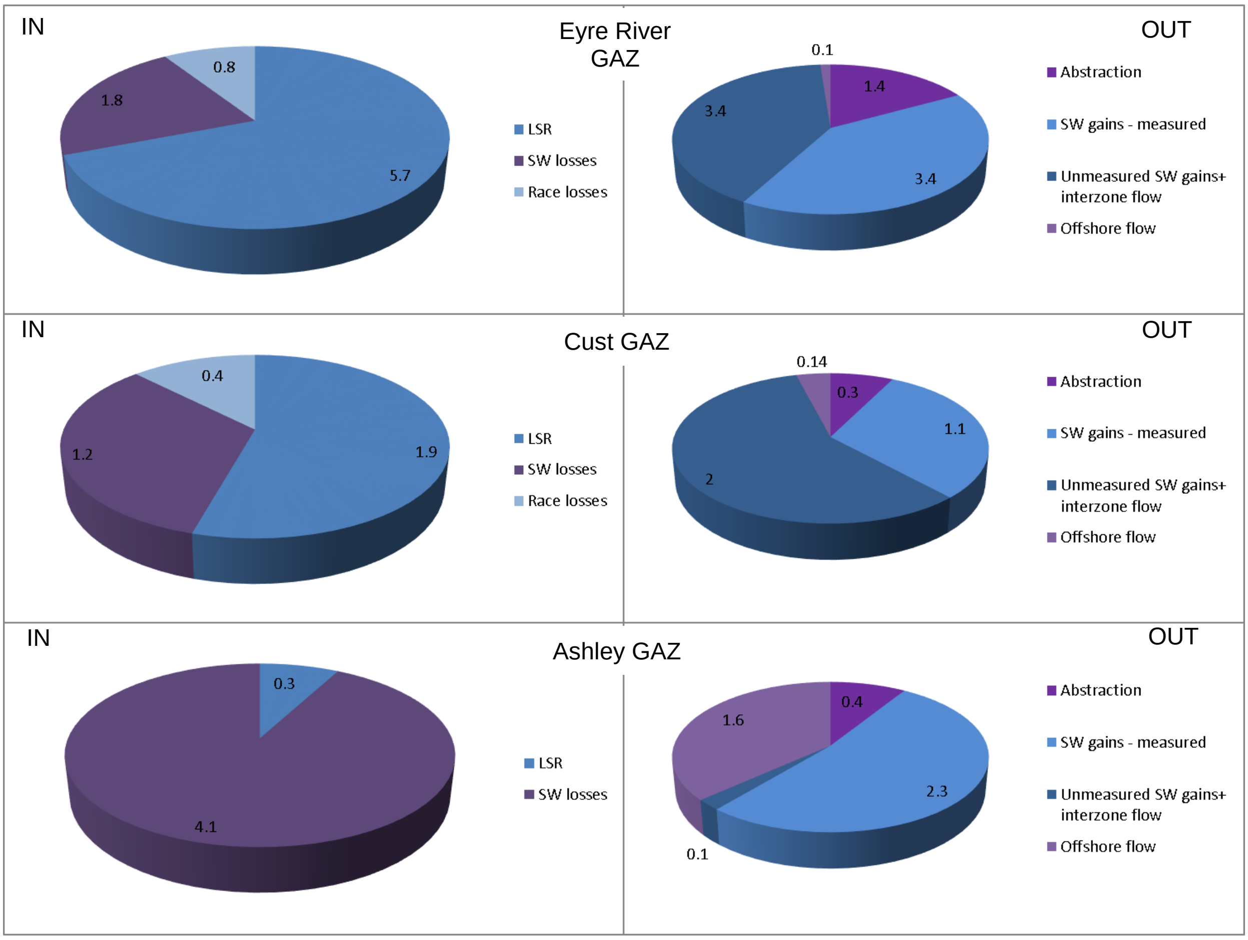

Figure 3-1: Long term average groundwater budgets for Eyre, Cust and Ashley GAZs (m³/s)

Groundwater inflows to the Waimakariri zone aquifers comprise LSR, surface water (SW) losses and losses from irrigation and stockwater races. The main groundwater outflows are abstraction, offshore flow and discharges to spring-fed streams. We have included an *unmeasured SW gains+ inter-zone flow* term on the outflow side to balance the budget. Although we can measure groundwater discharge to surface water courses under baseflow conditions at our gauging sites, these sites are located several kilometres from the coast to avoid tidal influences. We believe that additional groundwater discharges occur below these gauging sites, in the tidal reaches, and we have therefore included the *unmeasured SW gains* term to account for these. The term also accounts for the minor streams and drains which we have not measured, but there are relatively few of these and their contribution to the groundwater outflow budget is unlikely to be significant. The GAZs are not separated by hydraulic boundaries, and groundwater flow between adjacent GAZs is expected to occur. We cannot measure or easily estimate this cross-GAZ flow, and have therefore assumed that part of the imbalance between our inflow and outflow estimates is due to this water exchange. Further details are provided in Appendix 4.

Alkhaier (2016) modelled LSR in the Waimakariri zone and used maximum, minimum and average scenarios to explore the possible range of recharge rates. These scenarios encapsulated some of the uncertainty in our knowledge of LSR. We note that modelling results for the *minimum LSR scenario* presented in Alkhaier (2016) indicate that the LSR across the Waimakariri Zone could be around 200 mm/year. The LSR water budget components presented in Figure 3-1 are based on the *average LSR scenario*, which gives a zone average of 250 mm/year. This means that LSR could feasibly be around 20% lower than the values assumed below, and the *unmeasured SW* [surface water] *gains+ inter-zone flow* term would become smaller, particularly in the Eyre River GAZ water budget.

It is important to understand that the water budgets presented above are based on long term averages. LSR is much lower in dry years, as shown in Figure 3-2, and surface water losses from hill-fed streams (such as the Eyre River, Coopers Creek and Ashley River/Rakahuri) can also be much lower[9].

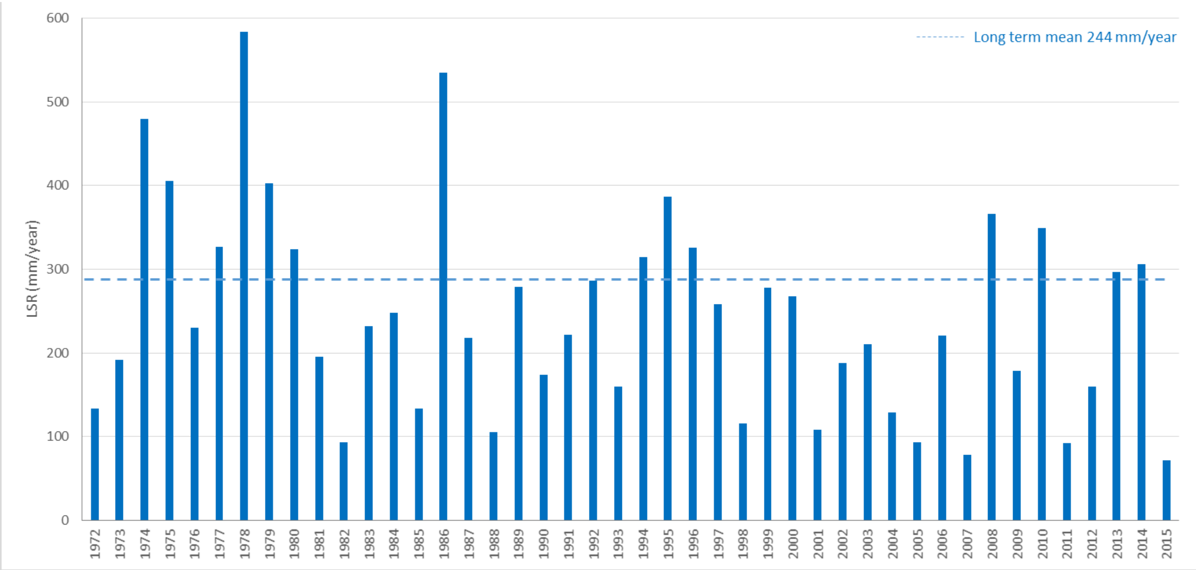

Figure 3-2: Annual Land Surface Recharge over time[10]

Groundwater abstraction rates are higher in dry years, and overall this means that less water is available to sustain flows in the spring-fed streams. We have provided a combined water budget estimate below for Eyre, Cust and Ashley GAZs for the 2015 calendar year, to illustrate this point.

The modelled land surface recharge for 2015 was 70 mm, i.e. 70% below average. Data from the Ashley Gorge recorder site show that river flows in 2015 were approximately 40% below the long-term average, and on this basis we have assumed that losses to groundwater from all surface watercourses in the Waimakariri zone were 40% below average[11]. We assumed that abstraction rates were 20% above average in the Eyre River and Cust GAZs, and 80% above average in the Ashley GAZ in 2015. Data from the Cust Main Drain recorder site at Threlkelds Road show that the median flow in 2015 was 0.6 m^3/s compared to the 1992-2015 average of 1 m^3/s – i.e. 40% below the 1992 – 2015 average. Data from our Silverstream recorder site indicate that the 2015 flow was about 50% below average, but the data only extend back to 2009 so the long-term average is poorly defined. The budget estimate for the three main GAZs is summarised in Table 3-1.

The 2015 water budget in Table 3-1 below does not balance, with outflows being greater than inflows. This indicates a decrease in storage, consistent with a decline in groundwater levels over the year. A 0.5 m decline in the water table over the ~100,000 ha area of the three GAZs, for example, would equate to 50 M m^3 of water for an aquifer storage coefficient of 0.1, equivalent to 1.6 m^3/s averaged over a year. This would account for the difference between estimated inflows and outflows.

Lesser contributors to the budget imbalance could include:

- Losses from the stockwater and irrigation race network may be higher in dry years, when groundwater levels are low.

[9] Flows in alpine rivers such as the Waimakariri can potentially be higher in Canterbury Plains dry years, however, since the westerly weather systems that cause dry spells on the plains are often associated with higher rainfall in the Southern Alps.

[10] By calendar year

[11] This is probably reasonable, for a coarse estimate, given that the losing rivers in the Waimakariri zone are all sourced from the foothills to the west.

- Additional recharge associated with irrigation of the Ngāi Tahu Eyrewell Forest development may also have helped to sustain stream flows in the Eyre River GAZ, although this could only explain a small part of the water budget imbalance.

Table 3-1: Groundwater budget for 2015 calendar year for Eyre River, Cust and Ashley GAZs

IN m^3/s		Out m^3/s	
LSR	2.5	Abstraction	2.7
SW losses	4.2	SW gains + inter-zone flow	6.0
Race losses	1.2	Offshore flow	0.9[12]
Total	7.9		9.6

We have plotted average year and dry year (2015) water budgets for the Eyre River, Cust and Ashley GAZs in Figure 3-3 to show the relative importance of the main components under dry conditions. The data plotted in Figure 3-3 suggest that

1. Irrigation race losses are equivalent to around 30% of dry year spring-fed stream baseflows in the Eyre River and Cust GAZs.
2. Groundwater abstractions in the Eyre River, Cust and Ashley GAZs use approximately 45%, 20% and 30% of the total groundwater recharge in a dry year.
3. Consented groundwater abstraction in the Cust GAZ currently stands at 35% of the allocation limit. If the full allocation limit was taken up, dry year groundwater abstraction could triple to 0.9 m^3/s. This would represent around 55% of total groundwater recharge in a dry year.
4. Consented groundwater abstraction in the Ashley GAZ currently stands at 53% of the allocation limit. If the full allocation limit was taken up, dry year groundwater abstraction could double to 1.3 m^3/s. This would represent around 50% of total groundwater recharge in a dry year.

This simplistic analysis suggests that although full uptake of the current groundwater allocation limit for the Cust and Ashley GAZs would probably reduce dry year flows in the spring-fed streams, water would still be available from race leakage and losses from the Ashley River/Rakahuri to sustain some flow in the spring-fed streams. It also highlights that race losses from the WIL and stockwater network are vital for maintenance of stream flows in dry years.

[12] Assumes that unmeasured groundwater outflows to the spring-fed streams are lower in proportion with measured SW gains

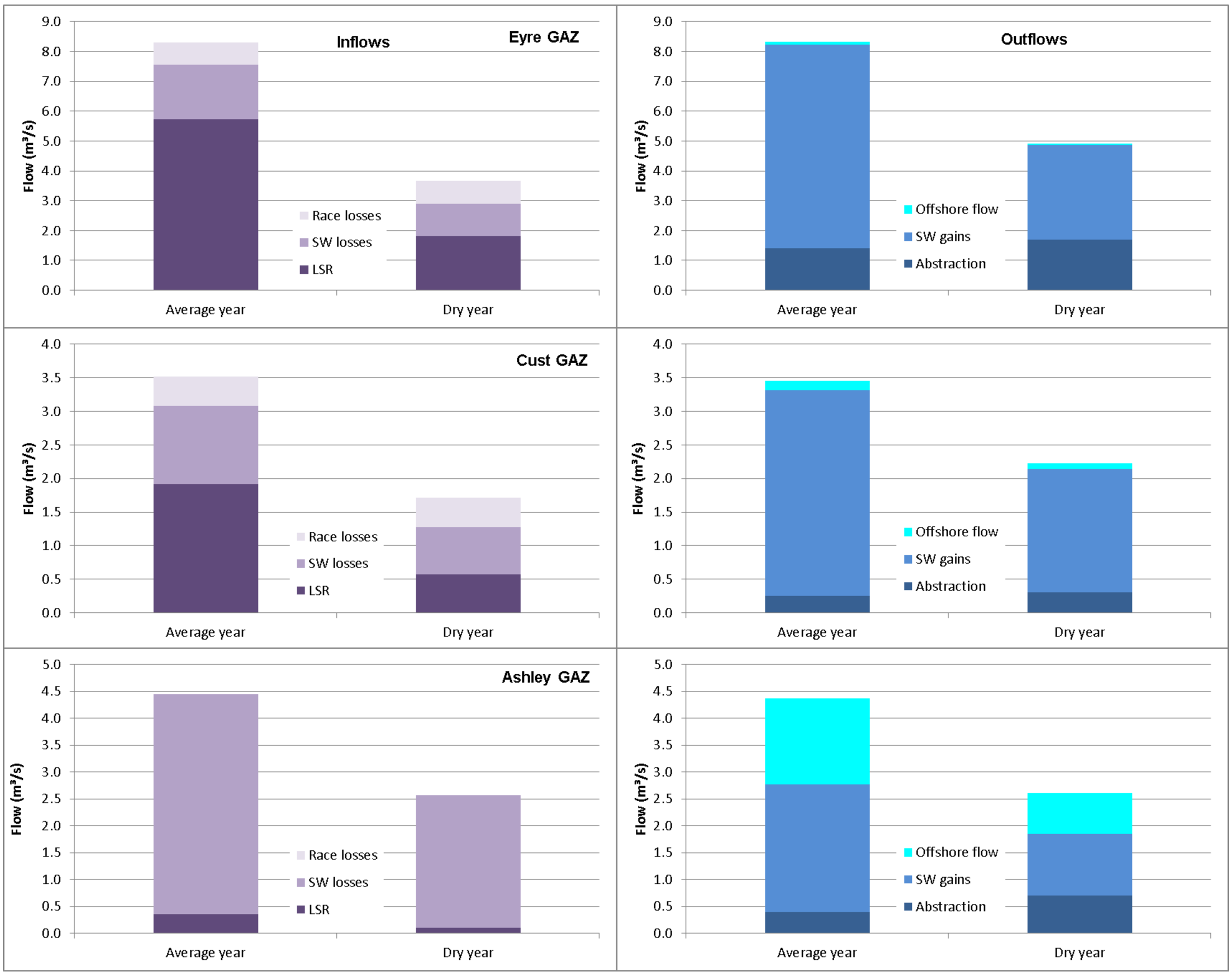

Figure 3-3: Average year and dry year groundwater budgets

4 Climate trends

As we explained in the previous report section, LSR is the main input to the groundwater budget. Year to year variations in LSR can have a significant impact on the water budget and on groundwater levels. It is therefore important to understand long-term trends in LSR prior to assessing the effects of groundwater abstraction on groundwater levels.

We need to consider two factors when evaluating LSR trends: climate and land use. The main climate factors are the volume and seasonal distribution of rainfall, and the evapotranspiration rate. Land use conversion from dryland farming to irrigated land can also be a significant factor when considering trends in LSR as well as conversions from border-dyke to spray. Also, in terms of the overall water balance, there is a significant difference depending on whether the irrigation water is sourced from a river or from local groundwater abstraction.

Border dyke irrigation sourced from river intakes can provide significant groundwater recharge. Conversion from border dyke to more efficient spray irrigation can reduce groundwater recharge significantly, and cause groundwater levels to decline. Although border dyke irrigation was used in some parts of the Waimakariri zone, this was not as prevalent as other parts of Canterbury. Nonetheless, conversion from border dyke to spray irrigation could have affected water level trends in a few of our monitoring wells.

The model used to generate the LSR time series (see Alkhaier, 2016) does not account for the extensive conversion of dryland framing to irrigated land that has occurred in the Waimakariri zone over the record period and therefore shows only the climate-driven component of LSR changes over time. We have used statistical analysis to determine whether a long-term trend is evident in the climate data.

The Mann-Kendall method is a test that can be applied to a set of data to assess whether a variable (such as LSR or groundwater levels) tends to increase or decrease over time. The seasonal Mann-Kendall test takes into account the seasonality of a dataset. When we use this test on a monthly data series, the test assesses whether there is a trend from one January to the next, and from one February to the next etc., rather than analysing for a trend in the bulk dataset.

We have applied the seasonal Mann-Kendall test to our monthly LSR data to assess whether there is a climate-driven trend since the beginning of the dataset (in 1972) and since 1999. The results (summarised in Table 4-1 and plotted in Figure 4-1) indicate that there are statistically significant declines (P value[13] <0.05) in LSR over both the 1972 to 2016 and 1999 to 2016 record periods, with the annual average having declined by 32% and 16% respectively.

Table 4-1: LSR trend analysis results

Data period	Mean LSR (mm/year)	Annual trend (mm/month)	Change over data period (mm)	Change over data period (% of mean annual)	P value
1972-2016	246	-0.15	-79	-32%	0
1999-2016	197	-0.15	-31	-16%	0.006

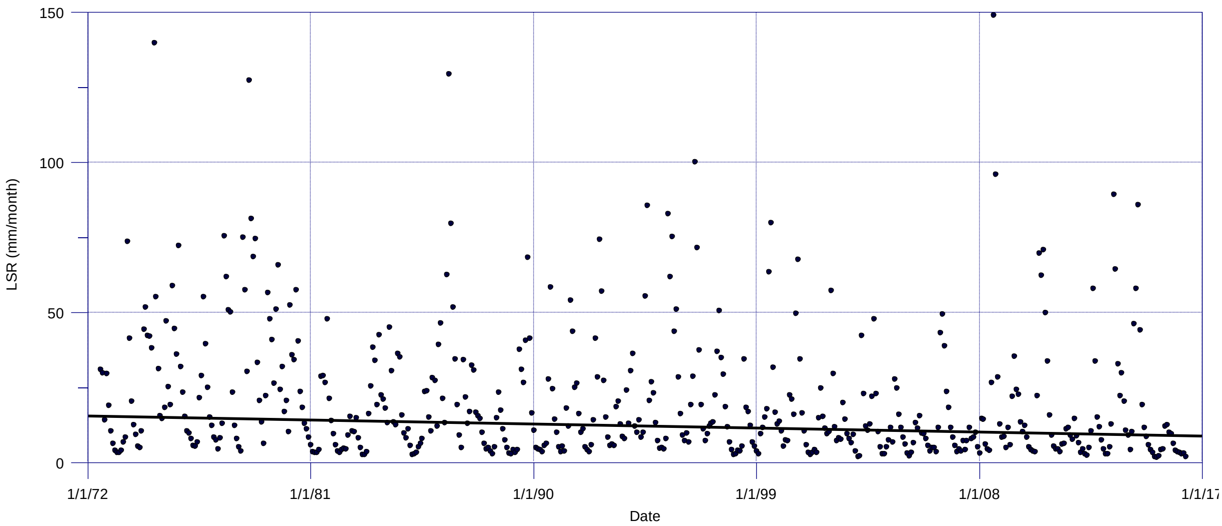

Figure 4-1: LSR trend since 1972

Information provided in Dodson *et. al.* (2012) indicates that irrigation-induced recharge can account for around 22% of total LSR, as discussed previously. The data presented in this 2012 study suggest that, ignoring climate-driven trends, LSR has increased by nearly 30% relative to dryland conditions, due to irrigation.

If LSR increased by 30% due to irrigation conversion between 1973 and 2016, but declined by around 30% due to a dryer climate over this period, there would have been no net change in recharge.

Analysis of our consents database records of year by year irrigated land suggests that approximately 35% of the irrigation conversion occurred between the late 1980s and 1999 with the remaining 65% occurring between 1999 and 2015. This suggests that LSR could have increased by around 18% over this 1999 - 2015 period due to irrigation. Our trend analysis results indicate that LSR has declined by 16% due to climate over this period, and hence we estimate that net LSR has increased by around 2%. This suggests that LSR is unlikely to be a significant factor in any declines in groundwater levels in the Waimakariri zone since 1999.

[13] See standard texts on statistical trend analysis for definition and significance of P value

5 Groundwater levels

5.1 Overview

This section of the report provides information on groundwater levels in the Waimakariri zone and in particular whether any long-term trends are apparent in our monitoring data. Increasing groundwater levels help to improve reliability of groundwater supplies and improve baseflow conditions in spring-fed streams, but in some areas of shallow groundwater they could signal an increase in flooding risk. Conversely, declining groundwater levels could signal a risk of declining stream flows and well reliability, but they could also signal a lessening of flooding risk in areas of shallow groundwater levels.

5.2 Groundwater level monitoring

Environment Canterbury's Wells database includes groundwater level readings from over 500 currently active wells in the Waimakariri zone. Of these, 76 are monitored regularly by our Groundwater Field Team. Fifty-five wells are manually measured on a monthly basis and the remaining 21 are monitored continuously with data loggers or telemetry. The locations of our groundwater level monitoring wells are shown in Figure 5-1. Seasonal water level variations are discussed below.

5.3 Seasonal range

Groundwater levels vary seasonally in line with recharge and abstraction patterns. Water abstraction for irrigation and community water supplies is greatest over the summer months, and groundwater recharge is often very low over this period due to high evapotranspiration rates. Groundwater levels are therefore usually at their lowest at the end of summer and highest at the end of winter.

Figure 5-1 shows the typical seasonal water level range in our monitoring wells, with estimated average groundwater abstraction rates[14] plotted as proportional symbols. We observe the following seasonal patterns in the groundwater levels:

1. In the coastal lowland plains area, which we refer to as the lowland streams area (see Figure 5-1) in this report, the variability is relatively small (<1 m). This is because the extensive drainage network of spring-fed streams and the presence of the coastline moderate groundwater level variability.
2. In the inland Cust GAZ, variability is typically 3 - 6 m, reflecting natural drainage and groundwater abstraction over the summer months, and water level recovery over winter due to LSR.
3. The seasonal range is greatest (6 – 10 m) in the inland Eyre GAZ, where groundwater abstraction is greatest and highly variable recharge from the ephemeral reach of the Eyre River occurs.

[14] See Section 2.4 for details of how actual usage was estimated

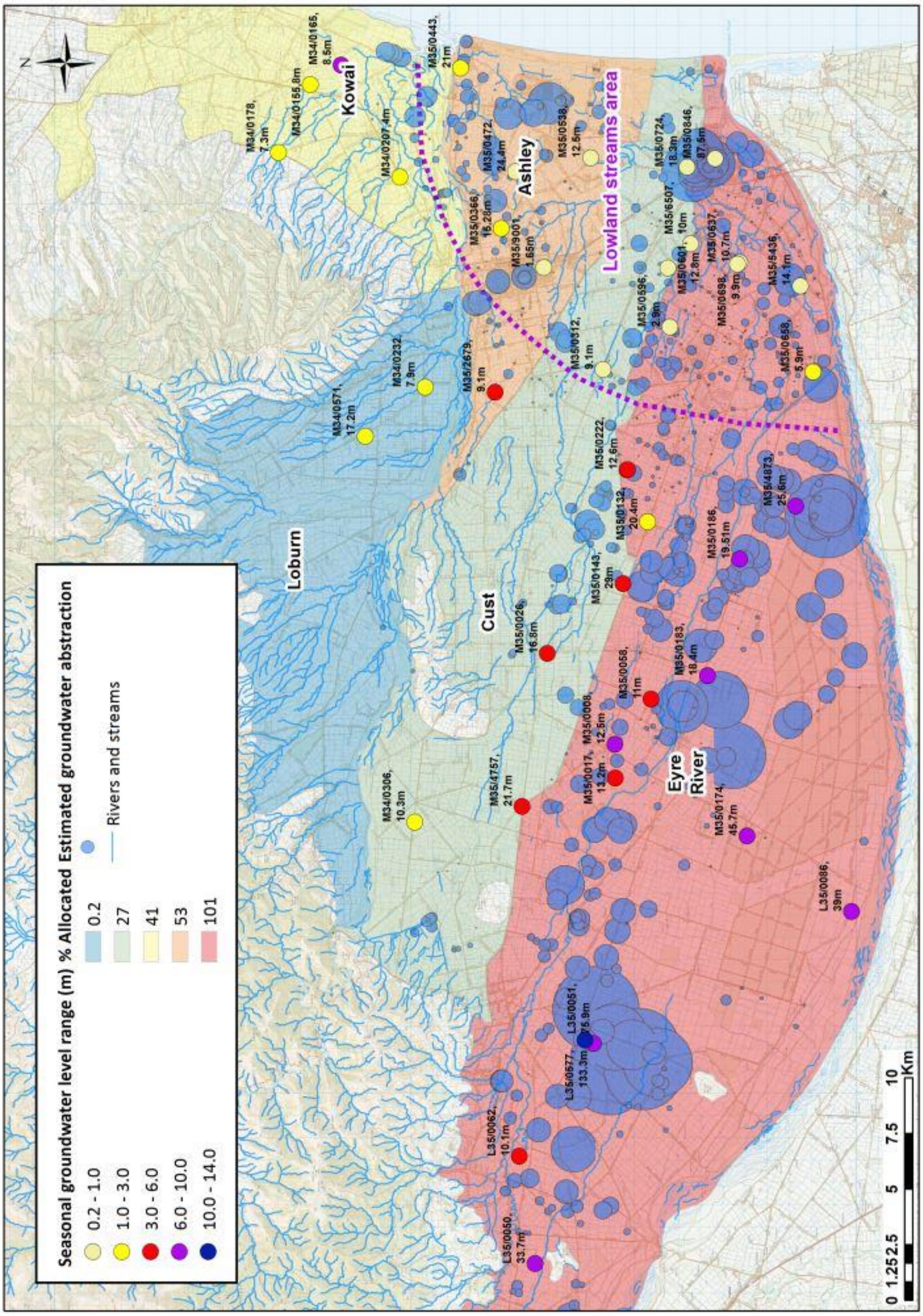

Figure 5-1: **Seasonal groundwater level range (well depths labelled)**

5.4 Long term trend analysis

We used the following process to evaluate long term groundwater level trends in the Waimakariri zone:

1. Select wells with sufficient record length (see Appendix 1 for criteria)
2. Undertake first-pass trend analysis using simple linear regression
3. Use statistical analysis to evaluate trends

5.4.1 Linear regression analysis

We analysed groundwater level data from the 39 wells[15] in the Waimakariri zone with long-term records to identify groundwater level trends for each well, from the start of the record[16] to present (2016). Results (summarised in Table 5-1 and Figure 5-2) indicate that groundwater levels have declined in about 41% of the wells we monitor, increased in about 23% of them and have not changed significantly in the remainder. Full details are provided in Appendix 1.

Table 5-1: Long term groundwater level trend summary

Area	Groundwater level trends (number of wells)			
	Decline	Increase	Minor decline/no trend	Minor increase /no trend
Ashley GAZ	4	-	1	-
Coastal wetland	1	-	-	-
Cust GAZ	-	4	-	1
Eyre River GAZ	6	4	1	3
Kowai GAZ	3	-	-	1
Loburn GAZ	-	-	1	1
Lowland Stream	2	1	4	1
Grand Total	**16 (41%)**	**9 (23%)**	**7 (18%)**	**7 (18%)**

Whilst the linear regression analysis provides a useful preliminary assessment of groundwater level trends for the entire dataset, it does not provide any information on how reliable the interpreted trend is. The method is also not well suited to data which are affected by seasonal variability.

5.4.2 Statistical trend analysis

We analysed the water level data collected since 1999 from 39 wells with long term records using the seasonal Mann-Kendall method described in Section 4. We chose 1999 as a start date because the WIL scheme became operative at this time and caused groundwater levels in some areas to rise in response to the associated increase in groundwater recharge, although water intake records indicate that full scheme development was not reached until the 2002–03 irrigation season. The data plotted in Figure 2-3 also indicate that groundwater allocation in the Eyre River GAZ has increased significantly since around 2000, and hence the post 1999 period water level data should provide information on the effects of this increasing allocation.

We generally assume that a P value of 0.05 or less demonstrates that the interpreted trend is valid, or statistically significant. A P value of 0.05 indicates that there is only a 5% probability that we have interpreted a trend in the data, but in reality there is no trend. We have increased the sensitivity of our trend analysis for the groundwater level data by including interpreted trends for all analyses with a P value <0.1. Although this means that there is a slightly higher chance that we have incorrectly assumed that our interpreted trend is valid but in reality it is not, it provides a more complete picture of likely water level changes. There are only two wells with P values in the 0.05 – 0.1 range in any case. We also used the normal seasonal water level range for each well as a criterion for assessing whether the long-term water level change determined from the trend analysis could have potentially significant implications for

[15] see Appendix 1

[16] Note that not all records start at the same time – some start in the 1970s, others in the 2000s

the priority outcomes. Where the water levels change was greater than or equal to 10% of the normal seasonal range (based on the 95th percentile) we classified the change as significant. Where the change was less than 10%, we classified the water level change as *minor*.

The statistical analysis results (summarised in Figure 5-3 and Appendix 5) indicate that groundwater levels have generally declined in nine wells, increased in eight wells and have not changed very much in the remaining 22 wells we assessed. Four of the declining wells are located within the Ashley GAZ, with two in the Eyre River GAZ and two in the part of the zone we have referred to as the Lowland Stream area and one in the coastal wetland area. Water levels have increased in more WIL command area wells than have decreased. Outside of the WIL command area there have been more wells with declining water levels than increasing water levels. We discuss groundwater levels trends by GAZ in Section 5.5 below.

Table 5-2: Seasonal Mann-Kendall analysis results

Area	**Groundwater level trends (number of wells)**					
	No trend	**Decline**	**Increase**	**Mean change**	**Max change**	**Min change**
Ashley GAZ	1	4	0	-46% (-0.8 m)	-18% (-0.3 m)	-77% (-1.1 m)[17]
Coastal wetland	0	1	0	-21% (-0.2 m)	-	-
Cust GAZ	2	0	3	+17% (+2.0 m)	+24% (+4.0 m)	+10% (0.9 m)
Eyre River GAZ	10	2	2	+1% (-1.3 m)	+25% (+2.3 m)	-19% (-1.5 m)
Kowai GAZ	3	0	1	+20% (+0.5 m)	-	-
Loburn GAZ	2	0	0	-	-	-
Lowland Stream	4	2	2	-6% (0.0 m)	27% (+0.2 m)	-40% (-0.2 m)
Grand Total	***22***	***9***	***8***	***+0.2 m***	***+4.0 m***	***-1.5 m***
Within WIL command area	12	4	5	**-2% (+0.8 m)**	**+25% (+4.0 m)**	**-40% (-1.2 m)**
Outside WIL command area	10	5	3	**-16% (-0.4 m)**	**+27% (0.5 m)**	**-77% (-1.5 m)**

[17] Includes trend interpreted for well M35/0472, in which a sharp and sustained water level drop was observed after the 2010-2011 Canterbury earthquakes. The maximum and mean trends excluding this well are -0.9 m and -0.7 m respectively.

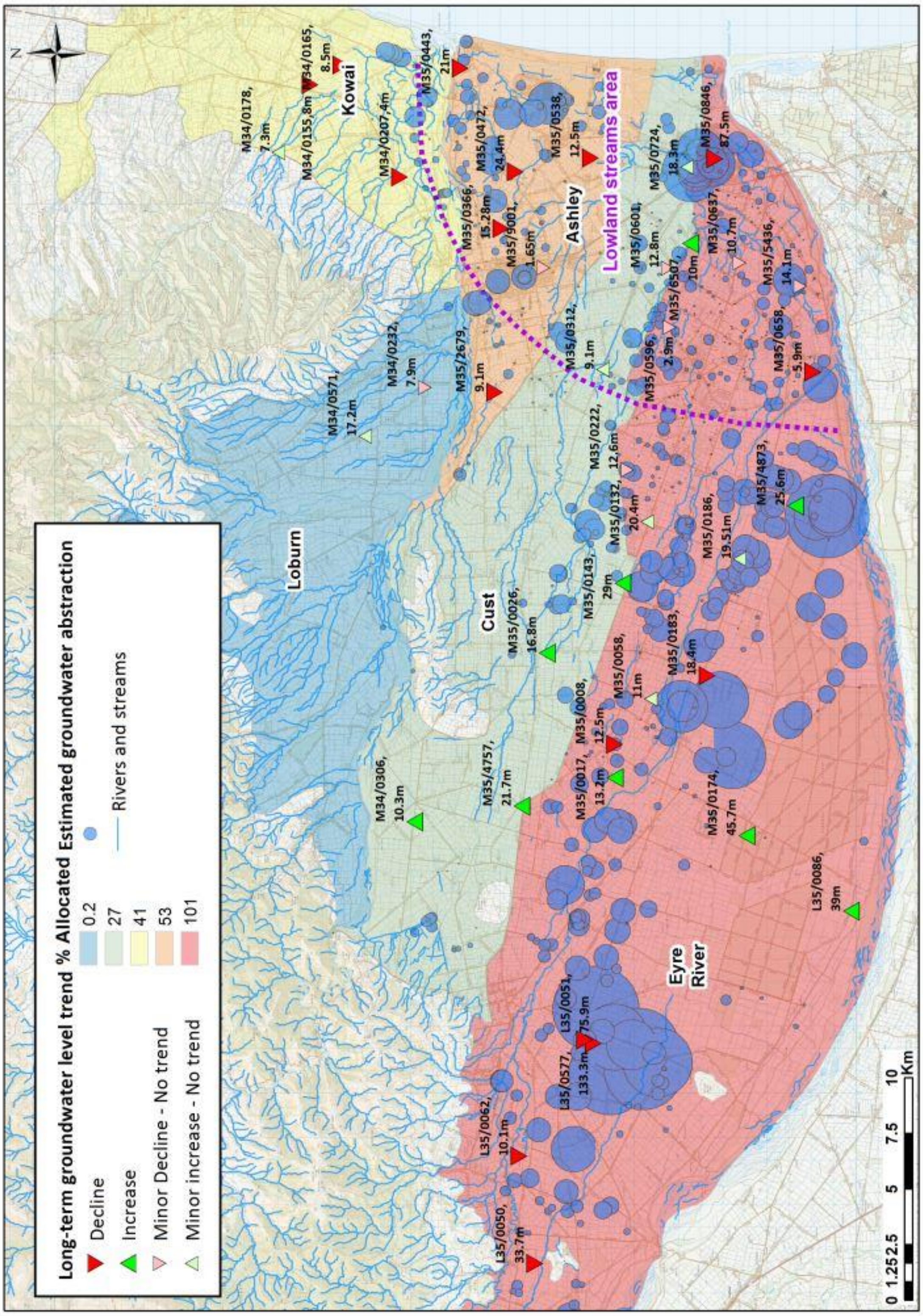

Figure 5-2: Long-term groundwater level trend based on linear regression analysis (well depths labelled)

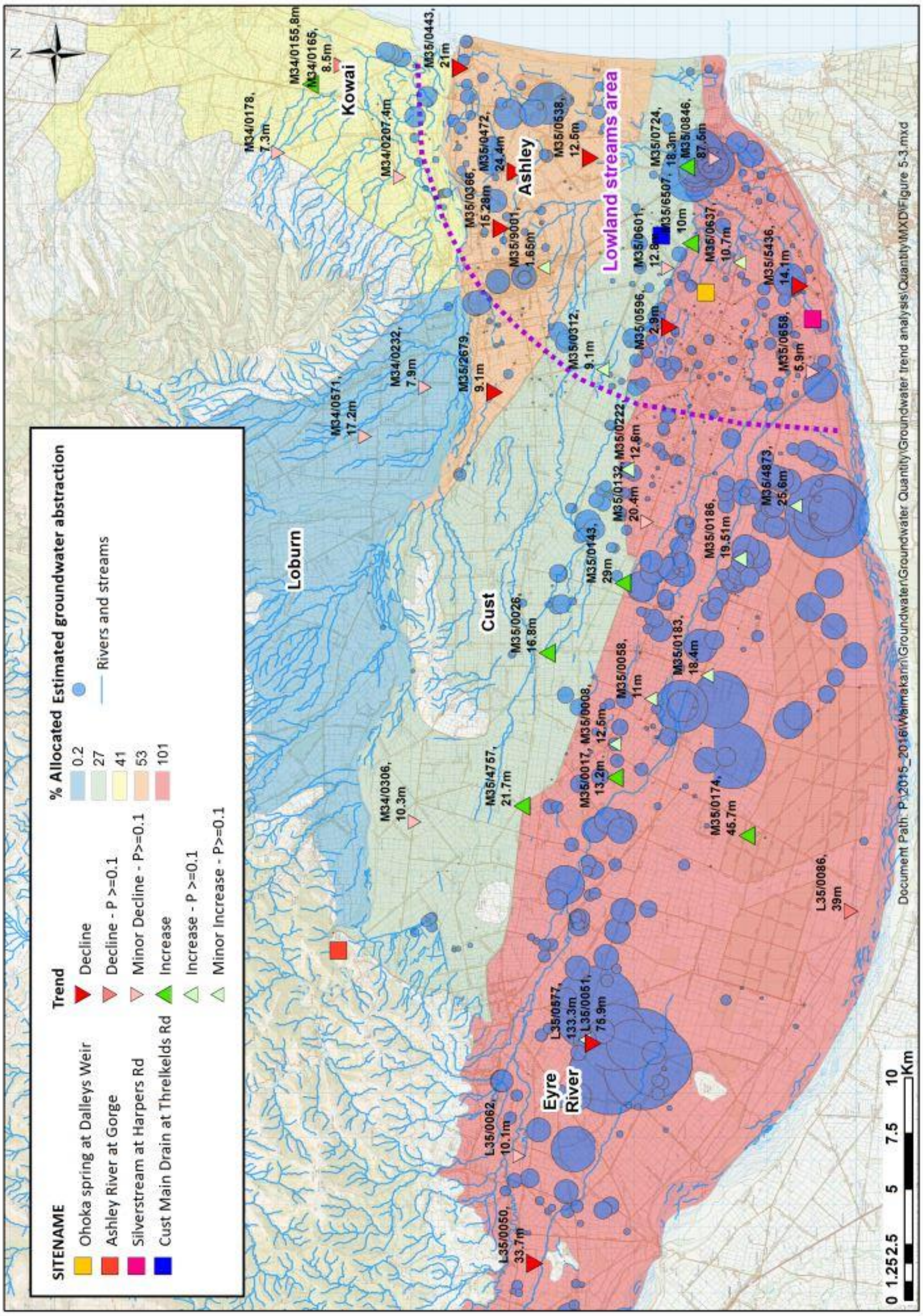

Figure 5-3: Long-term groundwater level trend (post WIL Scheme) based on Seasonal Mann-Kendall analysis

5.5 Causes and implications of groundwater level trends

5.5.1 Objective

In this section of the report we evaluate the causes of declining groundwater levels seen in some parts of the Waimakariri zone, and discuss the implications of these for the priority outcomes discussed in Section 1. Previous studies (e.g. Dodson *et. al.,* 2012) have shown that groundwater levels increased in parts of the zone after the WIL irrigation scheme was commissioned in 1999. We have not considered this increase specifically here, and only discuss wells with a rising trend where this has potential implications for flooding risk. It should be noted, however, that groundwater levels stabilised significantly after the WIL scheme was commissioned. Seasonal low water levels increased without an associated increase in seasonal high-water levels. The extra water from the WIL scheme has also improved base flows in the spring-fed streams. This is discussed further below.

5.5.2 Ashley GAZ

We identify a significant declining trend post 1999 in most shallow monitoring wells in the Ashley GAZ (0.01-0.06 m/year). Our water budget estimates (Section 3) suggest that the Ashley GAZ is mainly recharged by losses from the Ashley River. Analysis of flow records from the Ashley River/Rakahuri at our Gorge recorder site using seasonal Mann-Kendall suggest a slight declining trend over the same post 1999 period (Figure 5-4). Median flow has declined by an average of 0.08 m^3/s per year, or a total flow decline of 1.4 m^3/s since 1999. Mean flow has also declined. This is similar to the climate-driven downward trend in LSR discussed in Section 4. Etheridge (2016) estimated total recharge to groundwater to the Ashley GAZ by the Ashley River/Rakahuri[18] and Loburn Fan at 5.6 m^3/s. We estimate that this may have decreased by 0.8 m^3/s[19] due to the declining river flow trend. It is important to understand that this reduction in river recharge to the aquifer relates to the reduction in flows recorded at the Gorge recorder site (see Figure 5-3). Because the Gorge site is upstream of any stream-depleting groundwater takes and significant surface water takes, the decline is predominantly related to climate trends.

Groundwater allocation in the Ashley GAZ has increased by around 0.3 m^3/s since 1999, as discussed in Section 3. This, in combination with the estimated 0.8 m^3/s reduction in river recharge, reduces groundwater resource availability by 1.1 m^3/s. We believe this is the driver behind observed declines in groundwater levels. The decrease in river losses to the aquifer could account for around 70% of the reduction while the increase in groundwater abstraction accounts for the remaining 30%.

This finding is broadly consistent with the findings of Smith (2012), who concluded that the long-term decline in Rangiora area groundwater levels seen at that time may have been at least partially due to a climate-driven streamflow decline in the Ashley River/Rakahuri.

We do not have enough flow data for spring-fed creeks, such as Taranaki Creek, to determine if spring flows are reducing in tandem with groundwater levels. We would expect some reduction in flow because of a strong positive correlation (Pearsons R = 0.73) between creek flow and well M35/0472, located 200 m from the creek.

The decline in groundwater levels could also signal a reduction in well reliability in the Ashley GAZ. There are 11 shallow (<25 m deep) community water supply wells in this allocation zone, as shown in Figure 5-5. Some of these wells could experience reliability issues in dry years as a result of the general groundwater level decline in this area.

[18] Based on Ashley River/Rakahuri flow data collected between 2012 and 2016

[19] From >5.3 m^3/s in 1999 to the current estimate of >4.5 m^3/s.

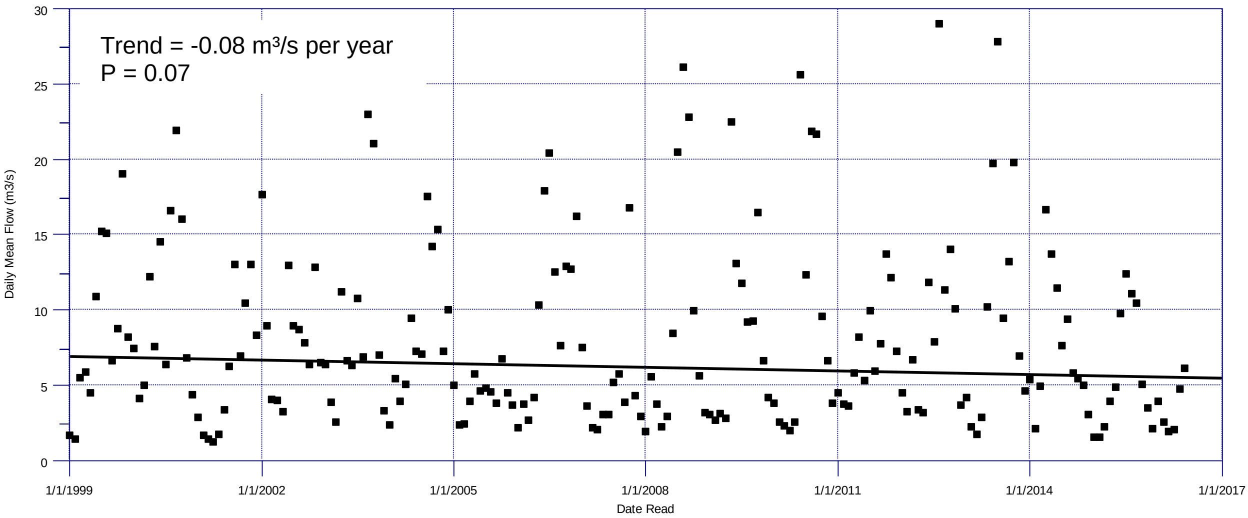

Figure 5-4: Ashley River flow trend

5.5.3 Cust GAZ

An increase in groundwater level has occurred in three wells in the Cust GAZ; no significant groundwater level declines have been interpreted. The seasonal high groundwater level in all three wells with increasing trends is at least 5 m below ground level, so the interpreted increase is not expected to have amplified the flooding risk associated with groundwater inundation at the land surface. Because of this we have not considered the possible causes of these increasing water level trends.

Seasonal Mann-Kendall analysis of continuous flow records from the groundwater-fed Cust Main Drain (Threlkelds Road site, see Figure 5-3) yields a statistically significant increasing trend since 1999 (see Figure A6-6 in Appendix 6). The inferred increase in median flows over this period is around 0.2 m^3/s, equivalent to ~15% of the long-term median flow. This increase in flows aligns with the increase in groundwater levels and is consistent with the findings of Megaughin and Hayward (2016).

5.5.4 Eyre River GAZ

Water levels have declined in two wells in the inland Eyre River GAZ. One of these wells (L35/0051) screens both the deeper and shallower parts of the aquifer system and is located in an area of intensive groundwater abstraction, as shown in Figure 5-3. The total 1.2 m water level decline here could have some implications for well reliability, but assuming that this trend reflects the deeper part of the aquifer only, we would expect any implications to be minor. This is because the seasonal low water level is around 30 m below ground level, meaning that the height of the water column between the base of the well and the groundwater level has only reduced by about 3%. The water level in nearby well L35/0577, which is 133 m deep, has not changed significantly over the 1999-2016 period. The water level decline in well L35/0050 (33 m deep) may reflect a climate-driven decline in flows from the hill-fed streams (e.g. Eyre River, Coopers Creek), which recharge the aquifer here. It would be reasonable to assume that flow trends in these streams mirror those of the Ashley River/Rakahuri to some degree given that they are also sourced from the foothills on the western margin of the Waimakariri zone.

The two wells with increasing water level trends in the Eyre River GAZ are not a cause for particular concern in terms of flooding risk, because groundwater levels are at least 3 m below ground level in these wells. The increasing trends probably reflect local increases in irrigation-induced recharge.

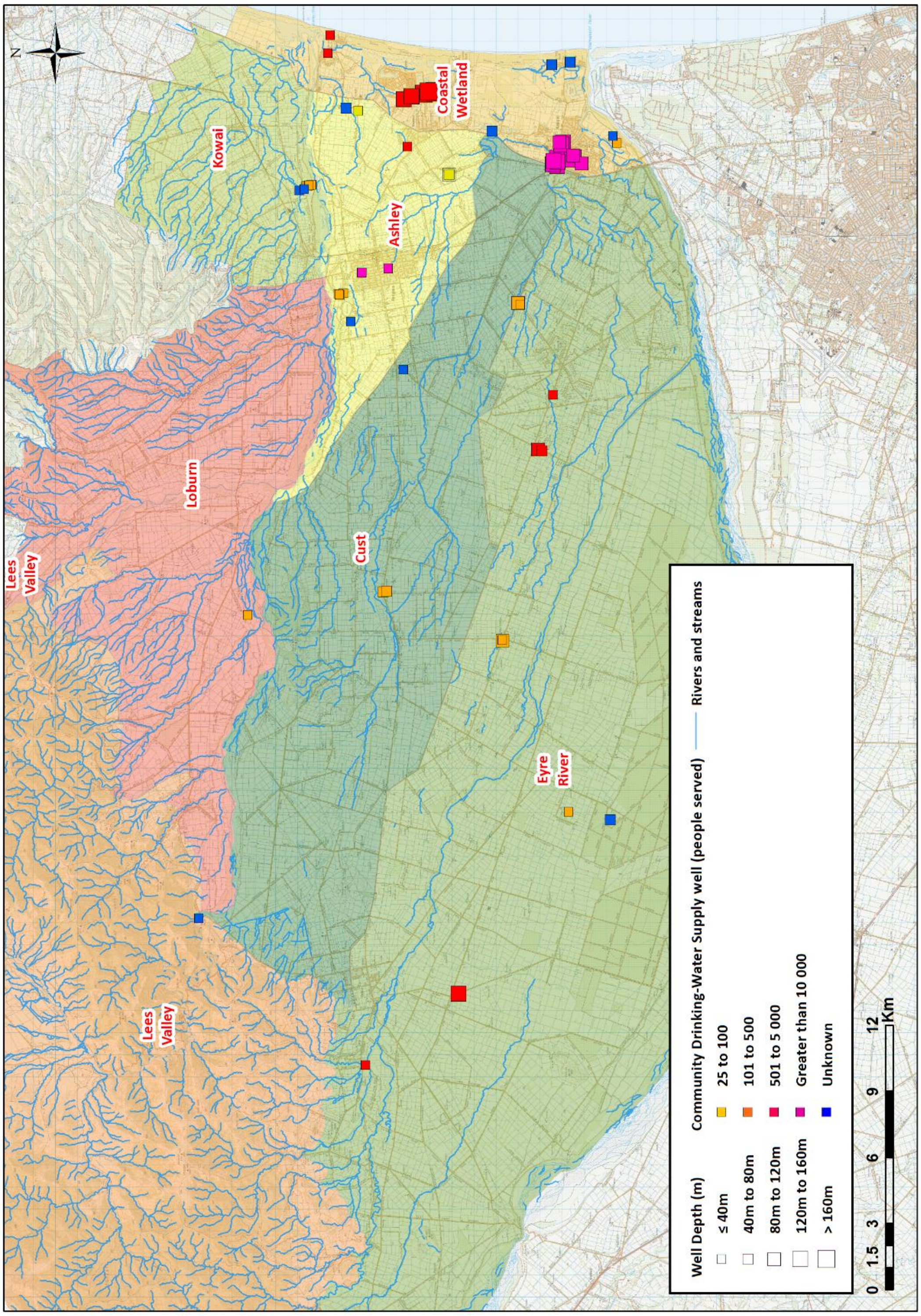

Figure 5-5: Distribution of community drinking water supply wells

5.5.5 Lowland streams area

Trends in Silverstream area

Groundwater levels in well M35/5436, located close to the headwaters of the spring-fed Silverstream, show an overall decline of around 0.2 m over the period 1999-2015. This suggests that flows in the Silverstream may also have declined over the period, but this assessment is uncertain due to gaps in the stream flow record. The available data do suggest a relationship between groundwater levels, stream flows and LSR, with low flows and groundwater levels corresponding to years of low LSR (Figure 5-6). The pattern suggests that low flows during dry periods have not reduced, but the missing stream flow data between 2000 and 2009, along with a weak correlation between the groundwater levels and stream flows (Figure A6-3 in Appendix 6) make it difficult to determine conclusively whether the groundwater level decline equates to a general stream flow reduction.

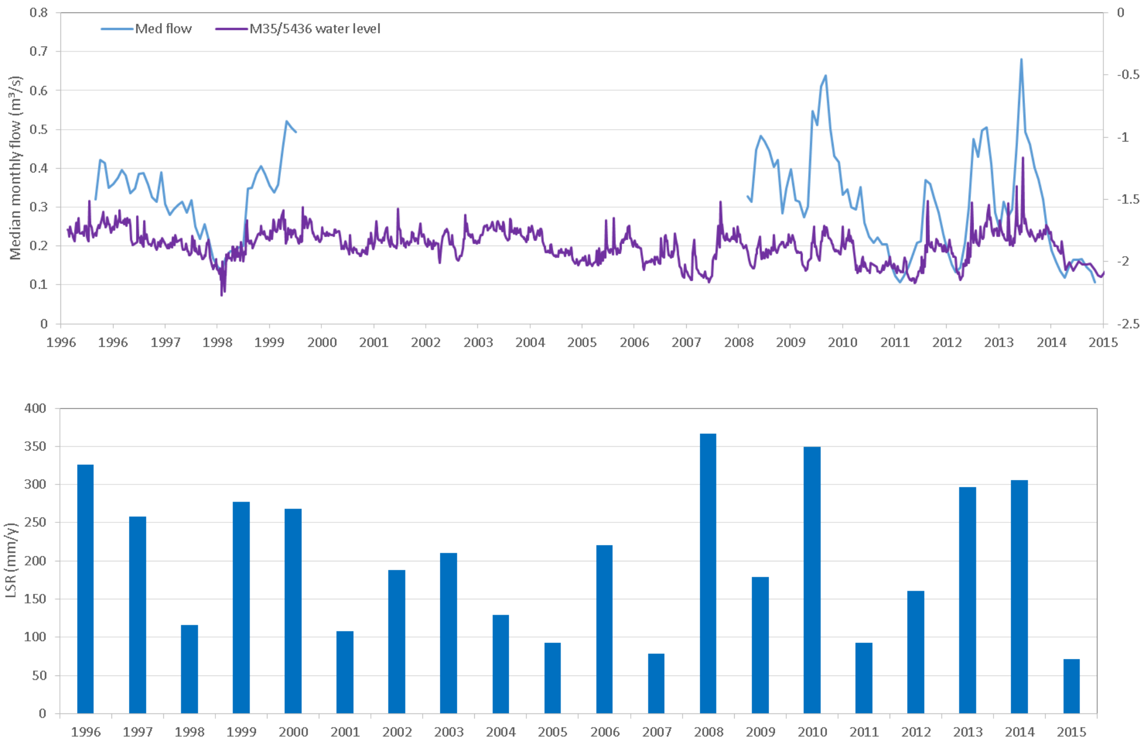

Figure 5-6: M35/5436 water level, median monthly Silverstream flow[20] and annual LSR

Groundwater allocation in the Eyre River GAZ (within which well M35/5436 is located) has roughly doubled since the late 1990s, but LSR has not declined significantly over this period (see Section 4 discussion). Therefore, the groundwater level decline and potential reduction in Silverstream flow would be consistent with increased groundwater abstraction. The reduction in local groundwater recharge associated with conversion from border dyke to more efficient spray irrigation in the Spencer-Bower irrigation scheme area, upstream of the Silverstream headwaters, may also have played a role in the groundwater level and possible stream flow decline.

Trends in Ohoka Stream area

We observe a 0.1 m groundwater level decline since 1999 in groundwater levels in well M35/0596, located in the source zone for the spring-fed Ohoka Stream. We have assessed correlation/regression relationships between Ohoka Stream at Kaiapoi confluence, Dalleys Weir spring flow and well M35/5436 in Appendix 6. The best relationship is between Dalleys Weir spring and the Ohoka Stream, with a less strong relationship between groundwater levels and stream flow. We have therefore used the Dalleys Weir record as our primary indicator of shallow groundwater levels and spring flow for Ohoka Stream. Seasonal Mann-Kendall analysis of the post 1999 Dalleys Weir flow record shows a statistically

[20] At Harpers Road site, see Figure 5-3

significant (P = 0.00) increasing trend (Figure 5-7). The Dalleys Weir data therefore suggest that flows may not have declined in the Ohoka Stream.

Sanders and Lovell (1999) investigated flows in the Ohoka Stream following two dry summer and a winter of below average rainfall as a result of El Niño and La Niña weather patterns between 1997 and 1999. The Ohoka Stream was the focus of significant public interest in the dry summer of 1998/1999 since very low flows in the upper reaches of the catchment resulted in fish strandings. The streams and drains of the upper Ohoka catchment were dry over much of their length throughout the summer of 1998/1999. Our LSR model data indicate that recharge in 1998 was 115 mm, which is around 50% below the long-term average. Modelled LSR for 2015 was around 70 mm, 70% below the long-term average. Despite LSR in 2015 being significantly lower than in 1998, we have no information to suggest that there were any significant issues with flows in the Ohoka Stream in the more recent dry period. This provides further support for the view that flows in the Ohoka Stream have not declined in the post 1999 period, but may have increased in line with the Dalleys Weir data. This is likely to be due to the significant groundwater recharge provided by the WIL scheme, both through race losses and irrigation-induced LSR. Consequently, the decline in monitoring well M35/0596 may be due to a localised drawdown effect from nearby groundwater abstraction and not an indicator of the more widespread groundwater situation that affects Ohoka Stream flow.

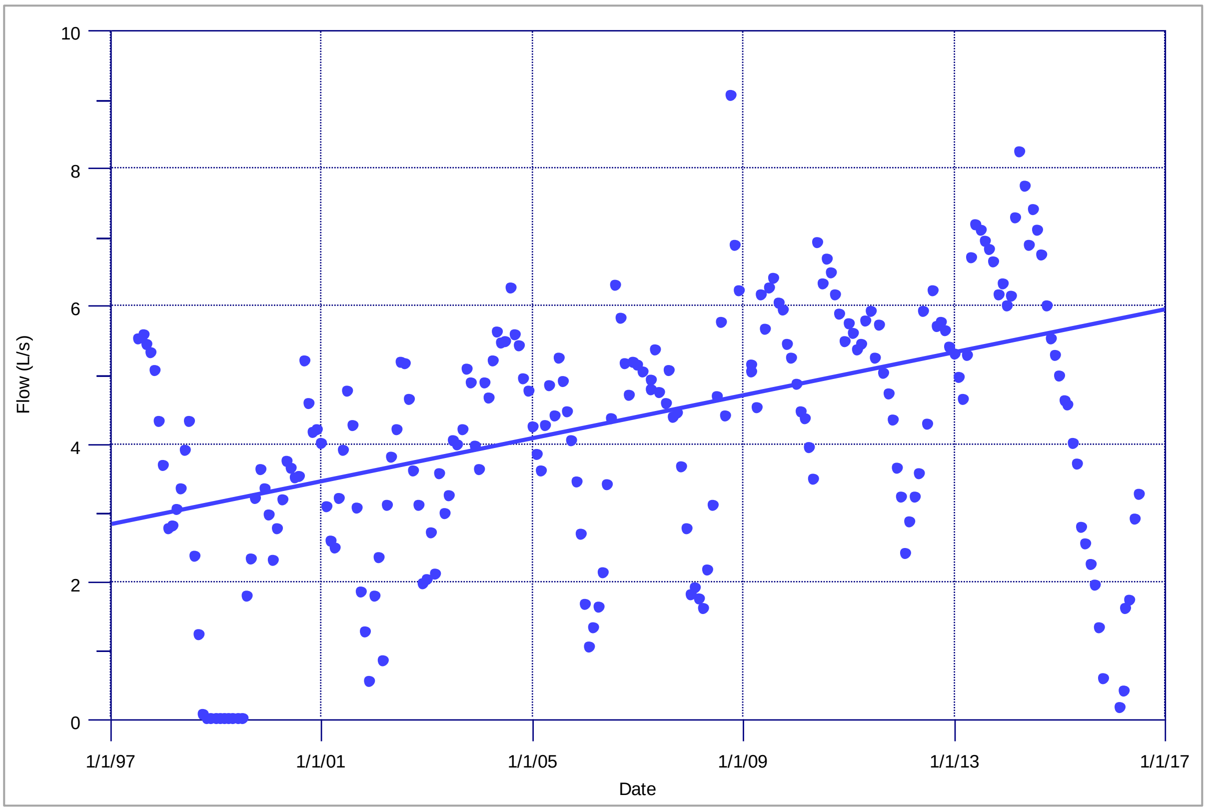

Figure 5-7: Trend analysis for Ohoka Spring at Dalleys Weir

Water levels in wells M35/6507 and M35/0724, both of which are <20 m deep and are located west of Kaiapoi, have increased by approximately 0.1 m and 0.2 m respectively according to our trend analysis. The apparent increase in water levels in M35/6507 may be because the record ends in 2013, after a major rainfall event and before the dry weather experienced in the last few years. If the record continued until 2016 the interpreted trend may be different. The increasing groundwater level trend in M35/0724 is genuine, however. It is not clear why groundwater levels are increasing here, but possible explanations include a local reduction in shallow groundwater abstraction for industrial/commercial use[21], or a local increase in recharge (e.g. through stormwater discharge in the area of the well, or local irrigation). This increase in groundwater levels could mean that flows in the lower part of the Kaiapoi River have increased to some degree. Because peak seasonal groundwater levels are within 1–1.5 m of the ground

[21] We note that there are a number of former brewery and other industrial wells in this vicinity.

surface here, the increasing groundwater level could signal an increased risk of inundation for any lower lying ground in the area of this well. The increasing flows at the Dalleys Weir site also suggest that groundwater levels have increased here, which may signal an increased risk of inundation.

5.5.6 Summary and discussion

Overall, the significant increase in groundwater abstraction in the Waimakariri zone (principally in the Eyre River GAZ) since 1999 has not caused significant widespread declines in groundwater levels across the zone. On the contrary, groundwater levels and spring-fed stream flows have actually increased in some areas. This is probably because water leakage from the irrigation and stockwater network has been sufficient to counteract the effects of abstraction. The increase in irrigated land area, with an associated increase in land surface recharge, also appears to have offset the effects of the generally dryer climate trend we have seen from the start of the millennium.

A groundwater level decline in one of our monitoring wells suggests that flows may have declined in the Silverstream. Our analysis of groundwater abstraction information indicates that the volumetric increase in abstraction from the spring-fed streams area is sufficient to account for the inferred reduction in stream flow, although conversion of border-dyke to more efficient spray irrigation in recent years may also have been a factor.

Groundwater levels have generally declined in the Ashley GAZ, and this means that flows in some of the spring-fed streams are also likely to have reduced here. We have estimated that 70% of the decline in groundwater levels can be attributed to climate factors and the remaining 30% to increased groundwater abstraction.

The potential for new groundwater takes in Eyre River GAZ is limited because this area is already fully allocated. This means that any reduction in flows that has occurred to date will not be exacerbated significantly by allocation of new water. Increased utilisation of existing consents could reduce groundwater levels and spring-fed stream flows, however. The data in Table 2-3 earlier in this report indicate that only 50% of the allocated water was used in the 2014-2015 irrigation season. If utilisation of the consented volumes increased, e.g. to 75% in dry years, we would expect flows in some of the spring-fed streams to decline. We have no reason to believe that this will occur though, particularly if a reliable source of water can be maintained through the WIL scheme.

Additional groundwater is available for allocation in the Ashley, Cust, Loburn and Kowai GAZs. We do not expect groundwater abstraction to increase very much in the Loburn GAZ because well yields are very low here. It is feasible that increased abstraction from the Cust GAZ could exacerbate groundwater level declines in the spring-fed streams area to some extent, but this is by no means certain because poor well yields are often encountered in this area, particularly to the west.

6 Priority outcomes

6.1 Groundwater quantity outcomes

As we explained at the start of this report, the zone committee has identified a set of priority outcomes for the Waimakariri zone. The outcomes of most relevance to this study are:

1. The quantity of water in spring-fed streams maintains or improves mahinga kai gathering and diverse aquatic life
2. Reliable drinking water
3. Highly reliable irrigation water, to a target of 95%

6.2 Technical indicators

6.2.1 Quantity of water in spring-fed streams

Although minimum flows can be used as an indicator of *adequate quantity in spring-fed streams*, these do not provide an early warning of whether flows are reducing in the long term. Where flows in spring-fed streams are monitored continuously (e.g. Silverstream, Cust Main Drain, Cam River), analysis of trends in these data can be used as a technical indicator. Where flows are not monitored continuously, and where a relationship can be established between groundwater levels and stream flows (e.g. Taranaki Creek), groundwater levels can be used as a technical indicator. The key indicator is whether groundwater levels are stable in the long term.

6.2.2 Safe and reliable drinking water and highly reliable irrigation water

Most drinking water supplies and many irrigation water takes in the Waimakariri zone come from wells. Groundwater levels are a key metric when assessing the reliability of these supplies. Declining groundwater levels would signal an increasing risk to reliability.

6.2.3 Outcome assessment

We have assessed groundwater quantity outcomes in Table 6-1 using groundwater level trends as the technical indicator. The analysis suggests that outcomes are generally being met in the Cust and Kowai GAZs and in parts of the Eyre GAZ. The extra groundwater recharge provided by the WIL scheme has provided a significant contribution to this. Flows in spring-fed streams are potentially at risk in the Ashley and to a lesser extent Eyre River GAZ. Declining groundwater levels in the Ashley GAZ suggest that the reliability of water supply wells, particularly shallow wells, is potentially at risk here. We note that there are 11 shallow community water supply wells in the Ashley GAZ, and it is possible that the reliability of some of these wells has reduced over the last 15 years or so. Our analysis suggests that water levels have also declined in some areas of irrigation water abstraction in the Eyre River GAZ, although the decline does not appear to be a cause for significant concern.[22]

We have not assessed outcomes for the Loburn GAZ because there is very little groundwater abstraction and general groundwater availability here, and we have only limited data for this GAZ.

It is important to understand that groundwater quantity/groundwater levels are only one of the indicators of whether the community outcomes are being met. Other indicators such as groundwater and surface water quality also need to be considered as part of the overall outcome assessment. Furthermore, our current analysis of the well reliability outcome is purely based on water level trends. We have not considered how many wells in the zone are currently likely to meet the 95% reliability criteria. It should also be noted that this assessment is based on the current state only, and does not consider future trends (e.g. climate change and increases in water use). The Eyre River GAZ is fully allocated as we explained previously, and hence the risk of future abstraction-driven groundwater level declines is probably low here. The Ashley, Cust and Kowai GAZs have additional water available for allocation under the current limits, and hence the potential for abstraction-driven groundwater level declines is greater in these areas. Possible future trends will be considered as part of the Scenarios Assessment phase of the Land and Water Solutions Programme.

Table 6-1: Groundwater quantity outcome assessment

Priority outcome	**Indicators**	**Currently being met in GAZ**			
		Eyre	***Cust***	***Ashley***	***Kowai***
Adequate flows in spring-fed streams	Stable groundwater levels in spring zone	Mixed	Yes	No	Yes
Safe and reliable drinking water	Stable groundwater levels in community drinking water supply wells	Yes	Yes	No	Yes
Highly reliable irrigation water	Stable groundwater levels in irrigation wells	Mixed	Yes	No	Yes

[22] See discussion in Section 5.5.4

7 Conclusions

Groundwater abstraction in the Waimakariri zone has increased significantly over the last decade, with part of the zone now being fully allocated. Roughly 70% of the consented groundwater use in the Waimakariri zone is for agriculture and horticulture, with approximately 24% used for community water supply.

The available metering data suggest that on average around 43% of the consented annual volume is used. Usage was still relatively low (just over 50% of the consented volume) in 2014-2015, despite this being a severely dry year. WDC water metering data indicate that only ~20% of the annual volume allocation is used on average for their community water supplies.

Our water budget calculations indicate that land surface recharge (LSR) provides 69% of groundwater recharge in the Eyre River GAZ and around 54% in the Cust GAZ, but only 7% in the Ashley GAZ in an average year. Irrigation race losses provide around 30% of dry year spring-fed stream baseflows in the Eyre and Cust GAZs. This means that race losses from the WIL and stockwater network are vital for maintenance of stream flows in the Eyre and Cust GAZs in dry years, while losses from the Ashley River/Rakahuri sustain spring-fed stream flows in the Ashley GAZ.

Groundwater abstractions in the Eyre River, Cust and Ashley GAZs use approximately 45%, 20% and 35% of the total groundwater recharge in a dry year. Consented groundwater abstraction in the Cust GAZ currently stands at 35% of the allocation limit. If the full allocation limit was taken up, dry year groundwater abstraction could triple to 0.9 m^3/s. This would represent around 55% of total groundwater recharge in a dry year. It suggests that although full uptake of the current allocation limit would probably reduce dry year flows in the spring-fed streams (principally the Cust Main Drain and its tributaries), some water would still be available to sustain flows.

Land surface recharge associated with climatic variability has generally reduced over the last 45 years in the Waimakariri zone, with a decline of around 15% since 1999. However, this decline has been entirely offset by conversion from dryland to irrigated farmland because the addition of irrigation water increases the rate of rainfall infiltration to the underlying aquifer system.

Overall, the significant increase in groundwater abstraction in the Waimakariri zone (principally in the Eyre River GAZ) since 1999 has not caused significant widespread declines in groundwater levels across the zone. This is likely to be due to the mitigating effects of irrigation and stockwater race losses on groundwater abstraction.

Groundwater levels have generally declined in the Ashley GAZ, and this means that flows in some of the spring-fed streams are also likely to have declined here. There are 11 shallow community water supply wells in this allocation zone. Some of these wells could experience reliability issues in dry years as a result of the general groundwater level decline in this area. We have estimated that 70% of the decline can be attributed to climate factors and the remaining 30% to increased groundwater abstraction. Full uptake of the current allocation limit for the Ashley GAZ could exacerbate climate-driven groundwater level declines and any associated decline in spring-fed stream flows.

A groundwater level decline in one of our monitoring wells in the Silverstream spring zone suggests that flows may have declined in this stream too. Our analysis of groundwater abstraction information indicates that the volumetric increase in abstraction from aquifers in the spring-fed streams area is sufficient to account for the inferred reduction in stream flow.

The potential for new groundwater takes in Eyre River GAZ is limited because this area is already fully allocated. However, increased utilisation of existing consents could reduce groundwater levels and spring-fed stream flows.

Groundwater levels have increased in some low-lying areas of the Waimakariri zone. This will improve baseflows in spring-fed streams, but in some areas may signal an increased risk of groundwater flooding.

The Waimakariri Water Zone Committee identified a set of priority outcomes for the zone, including:

- The water quantity of spring-fed streams maintains or improves mahinga kai gathering and diverse aquatic life
- Safe and reliable drinking water
- Highly reliable irrigation water, to a target of 95%

We have suggested that groundwater level trends could be used as one indicator of whether these outcomes are being met. Using this indicator, we have concluded that spring-fed stream flow and reliable water supply outcomes are potentially not being met in the Ashley GAZ, and to a lesser extent the Eyre River GAZ. Elsewhere the outcomes probably are being achieved. The additional groundwater recharge provided by the WIL irrigation scheme has been a significant factor in achievement of these outcomes.

8 Acknowledgements

We are very grateful to Philippa Aitcheson-Earl, Peter Callander, Maureen Whalen, Carl Hanson and Matt Dodson who provided useful review comments which helped to shape this report.

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Appendix 1 Monitoring well summary

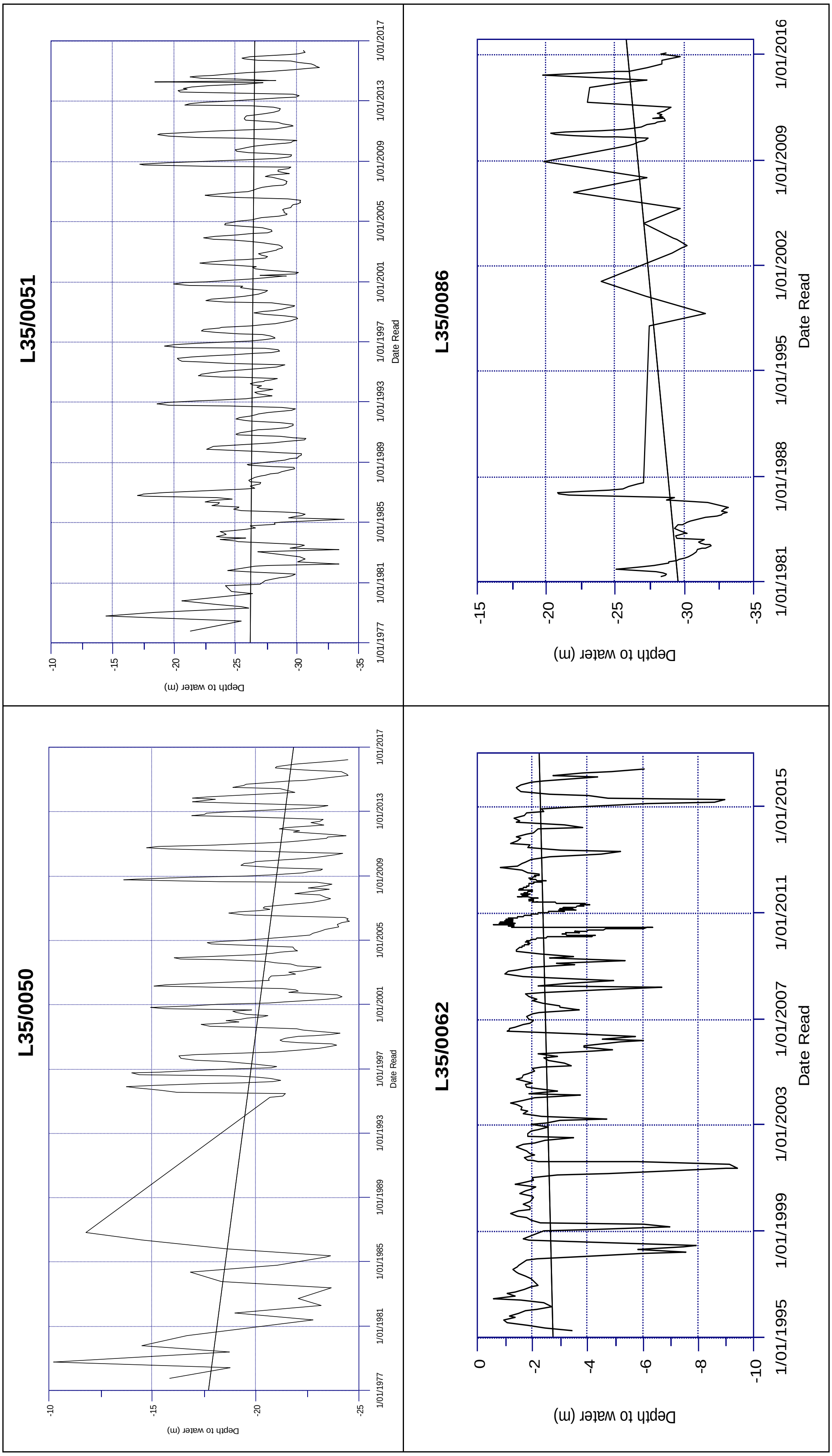
Well No	Depth (m)	NZTMX	NZTMY	Monitoring Type	1st Read	Last Read	Reading count	Long-term trends
L35/0050	33.7	1522334	5204444	M	20/09/1977	8/03/2016	241	Decline
L35/0051	75.9	1532240	5201833	M	20/09/1977	4/05/2016	421	Decline
L35/0062	10.1	1527159	5205154	M	1/10/1964	4/05/2016	1255	Decline
L35/0086	39	1538163	5190242	Z	2/04/1981	19/01/2016	116	Increase
L35/0577	133.3	1532381	5202200	M	17/05/2001	3/09/2014	111	Decline
M34/0155	8	1575345	5214532	M	24/05/1967	4/05/2016	258	Decline
M34/0165	8.5	1576226	5213157	M	20/09/1977	4/05/2016	113	Decline
M34/0178	7.3	1572295	5215965	M	20/09/1977	4/05/2016	147	Minor increase - No trend
M34/0207	4	1571197	5210521	M	27/05/1963	4/05/2016	269	Decline
M34/0232	7.9	1561746	5209388	M	9/08/1971	4/05/2016	355	Minor Decline - No trend
M34/0306	10.3	1542185	5209851	M	23/09/1977	4/05/2016	1106	Increase
M34/0571	17.2	1559530	5212078	Z	25/11/1997	19/01/2016	59	Minor increase - No trend
M35/0008	12.5	1545683	5200859	M	7/10/1946	4/05/2016	2793	Decline
M35/0017	13.2	1544173	5200841	M	15/11/1949	4/05/2016	625	Increase
M35/0026	16.8	1549776	5203895	M	6/09/1950	4/05/2016	531	Increase
M35/0058	11	1547726	5199244	R	22/09/1977	3/05/2016	6833	Minor increase - No trend
M35/0132	20.4	1555685	5199400	GWQ	22/09/1977	1/12/2015	194	Minor increase - No trend
M35/0143	29	1552915	5200500	M	23/09/1977	4/05/2016	575	Increase
M35/0174	45.7	1541563	5194925	R	20/09/1977	3/05/2016	447	Increase
M35/0183	18.4	1548763	5196711	M	23/03/1977	4/05/2016	275	Decline
M35/0186	19.51	1554015	5195253	Private	6/11/1946	1/02/2016	521	Minor increase - No trend
M35/0222	12.6	1558026	5200299	M	8/03/1995	4/05/2016	254	Minor Decline - No trend
M35/0312	9.1	1562530	5201394	M	30/08/1973	4/05/2016	498	Minor increase - No trend
M35/0366	15.28	1568873	5205963	R	23/11/1978	3/05/2016	12372	Decline
M35/0443	21	1576091	5207796	M	10/06/1968	4/05/2016	455	Decline
M35/0472	24.4	1571438	5205332	M	14/07/1976	4/05/2016	432	Decline
M35/0538	12.5	1572051	5201955	M	20/09/1977	4/05/2016	297	Decline
M35/0596	2.9	1564453	5198391	M	20/09/1977	4/05/2016	1070	Minor Decline - No trend
M35/0601	12.8	1567107	5198473	M	30/08/1973	4/05/2016	360	Minor Decline - No trend
M35/0637	10.7	1567348	5195260	M	20/09/1977	4/05/2016	504	Minor Increase - No trend

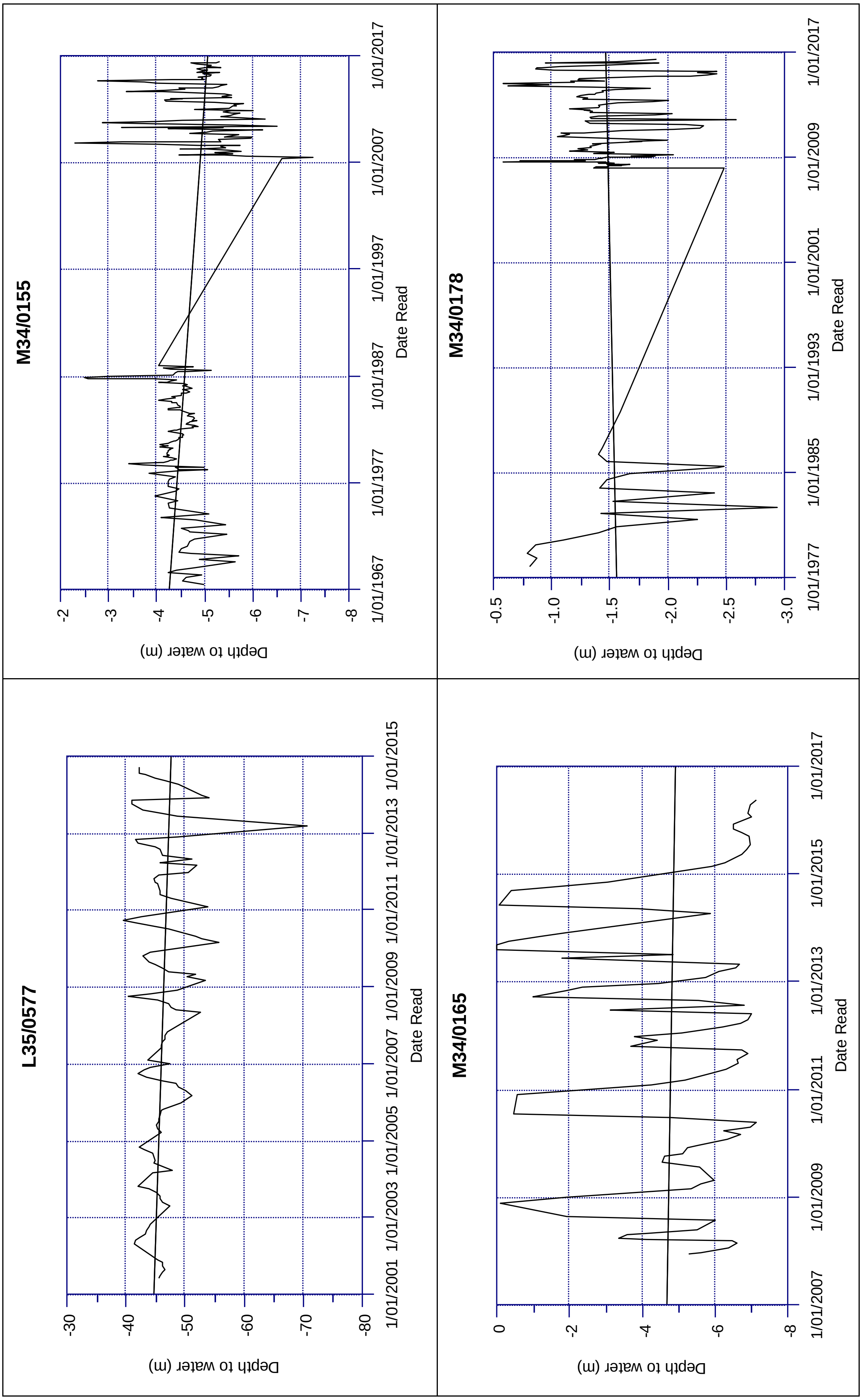
Well No	Depth (m)	NZTMX	NZTMY	Monitoring Type	1st Read	Last Read	Reading count	Long-term trends
M35/0658	5.9	1562430	5191961	M	10/09/1953	4/05/2016	347	Decline
M35/0724	18.3	1571647	5197622	M	9/03/1960	4/05/2016	528	Minor increase - No trend
M35/0846	87.5	1572013	5196358	R	27/03/1984	3/05/2016	10977	Decline
M35/2679	9.1	1561524	5206242	R	13/12/1983	3/05/2016	9970	Decline
M35/4757	21.7	1542883	5205029	M	2/07/1986	4/05/2016	475	Increase
M35/4873	25.6	1556403	5192730	R	4/09/1985	3/05/2016	732	Increase
M35/5436	14.1	1566302	5192525	R	14/02/1996	3/05/2016	6736	Minor Decline - No trend
M35/6507	10	1568187	5197459	Z	19/03/1999	22/07/2013	168	Increase
M35/9001	1.65	1567114	5204056	M	1/04/2001	4/05/2016	181	Minor Decline - No trend

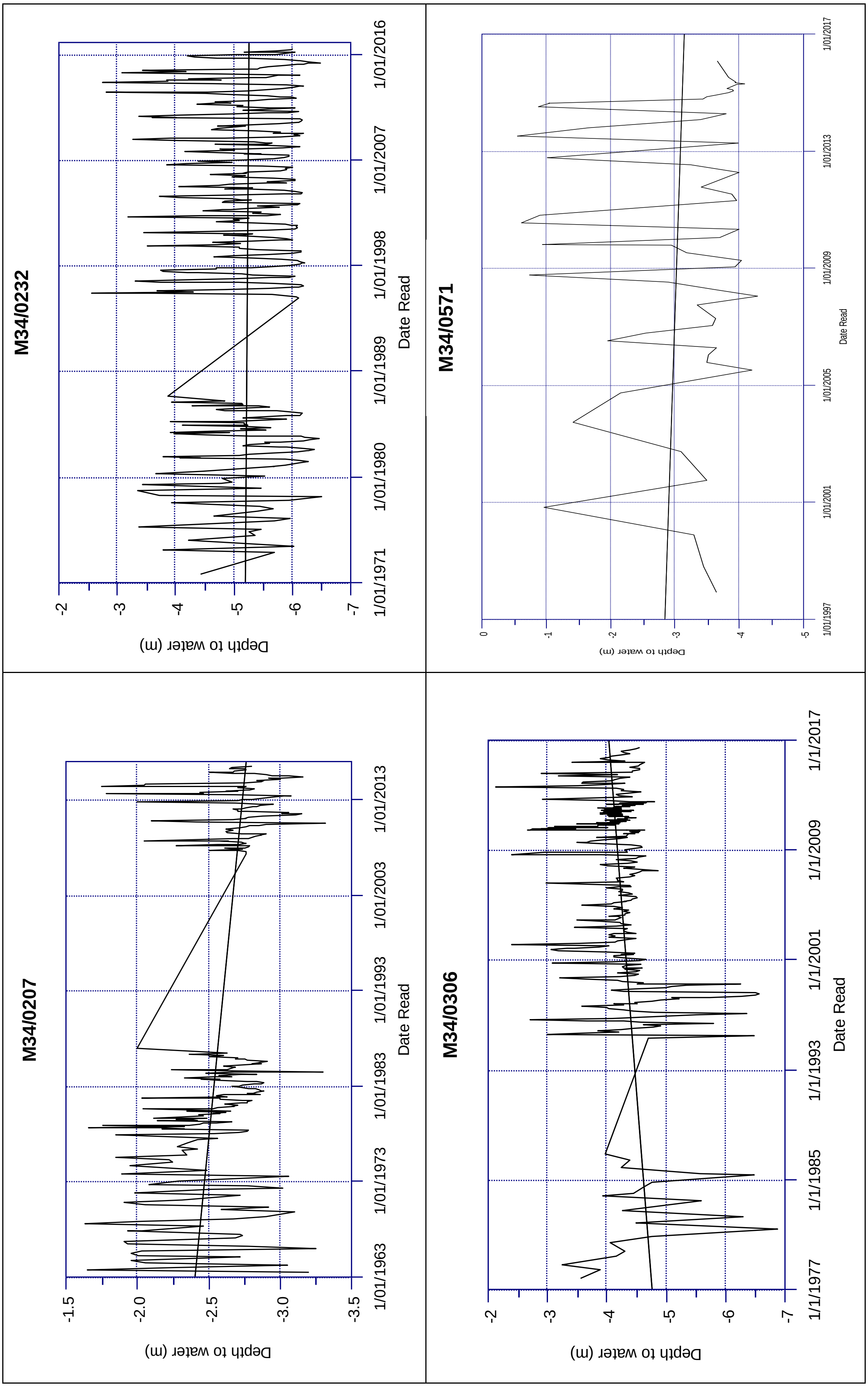
Notes: Well selection criteria =

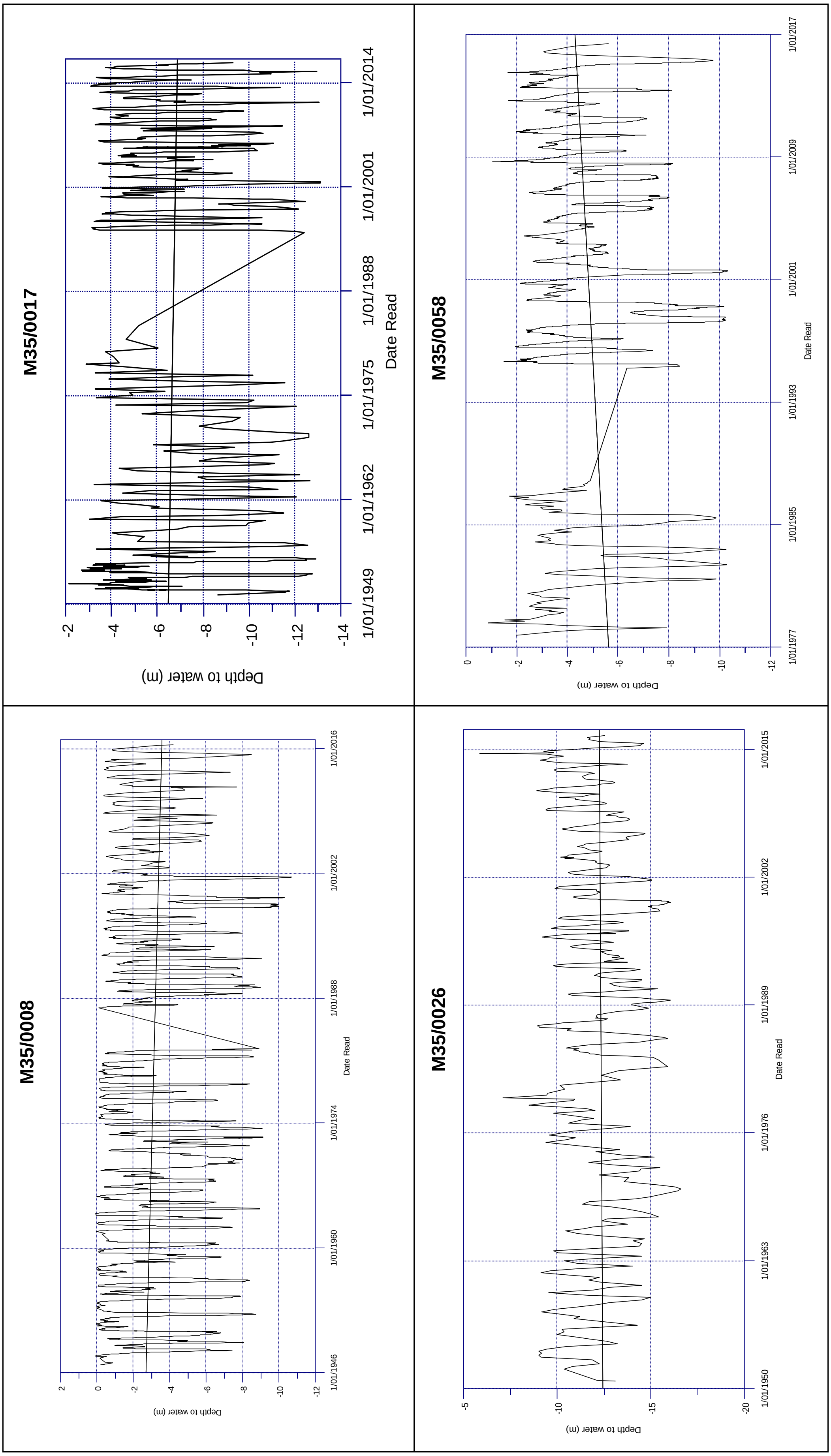
- Record length ≥ 10 years
- No. of readings ≥50
- Record end date ≥1/1/2013

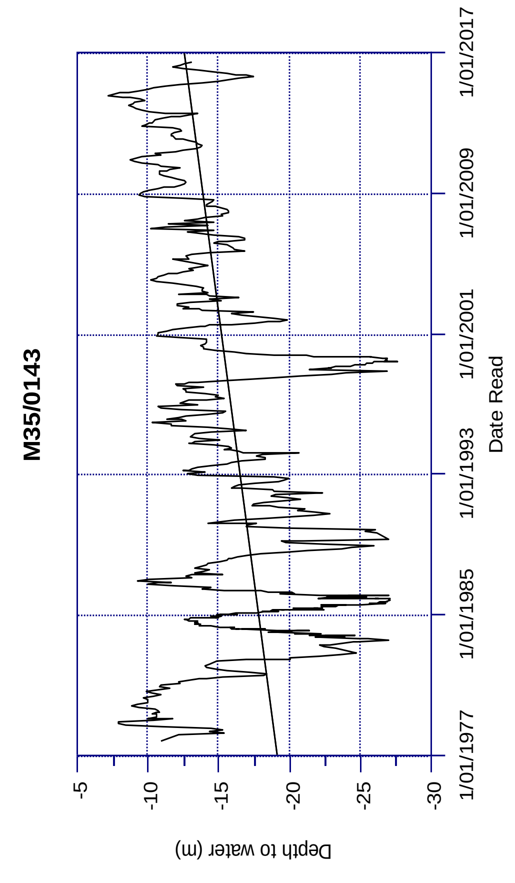
Appendix 2 Water level time series plots (full record period)

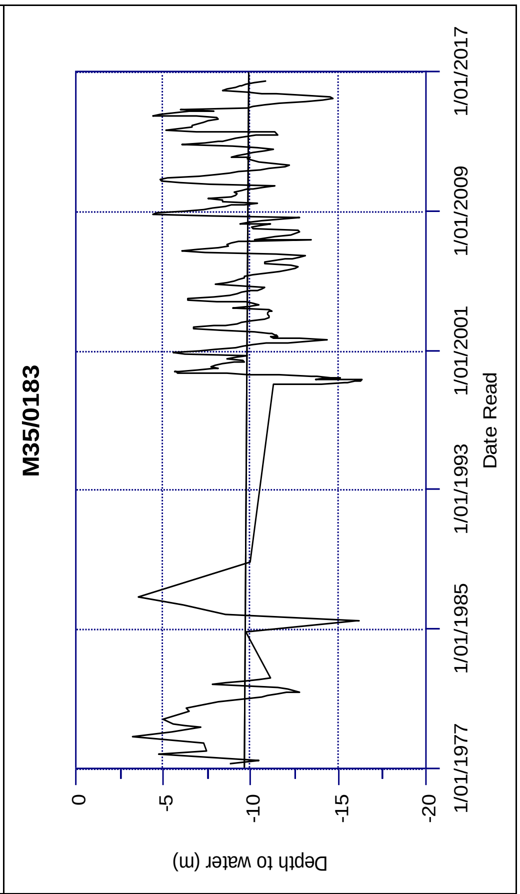

L35/0051
Depth to water (m)
Date Read
L35/0050
Depth to water (m)
Date Read
L35/0086
Depth to water (m)
Date Read
L35/0062
Depth to water (m)
Date Read

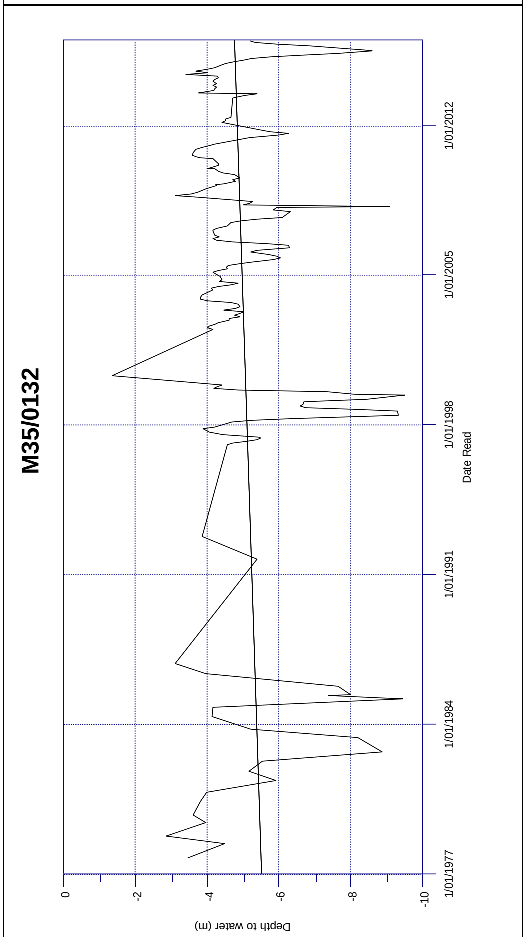

M34/0155
Depth to water (m)
Date Read
L35/0577
Depth to water (m)
Date Read
M34/0178
Depth to water (m)
Date Read
M34/0165
Depth to water (m)
Date Read

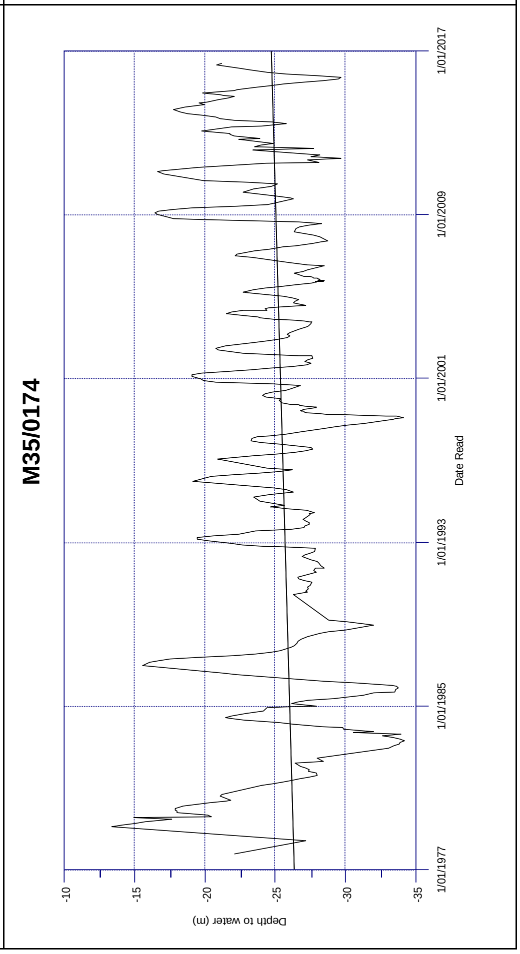

M34/0232
Depth to water (m)
Date Read
M34/0571
Depth to water (m)
Date Read
M34/0207
Depth to water (m)
Date Read
M34/0306
Depth to water (m)
Date Read

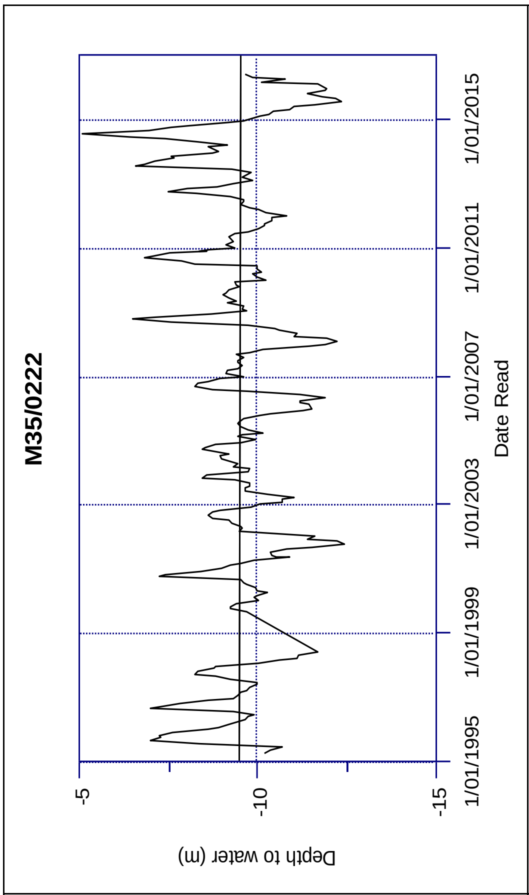

M35/0017
Depth to water (m)
Date Read
M35/0058
Depth to water (m)
Date Read
M35/0008
Depth to water (m)
Date Read
M35/0026
Depth to water (m)
Date Read

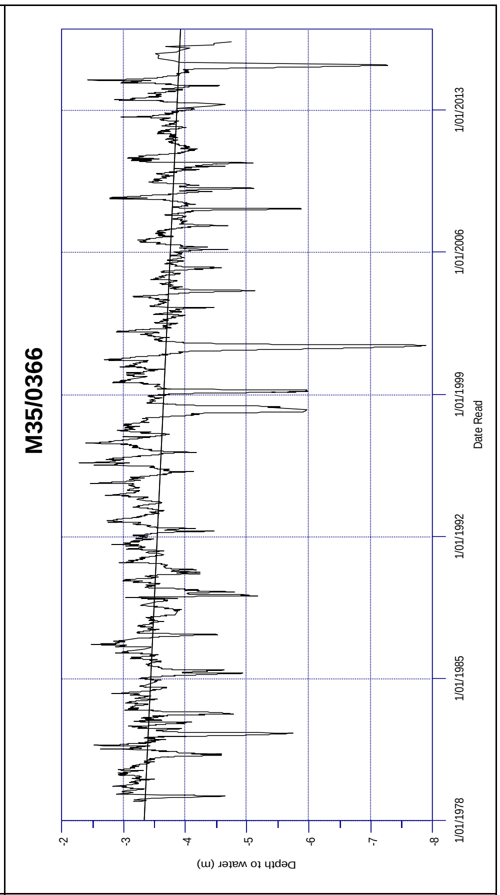

M35/0143
Depth to water (m)
Date Read

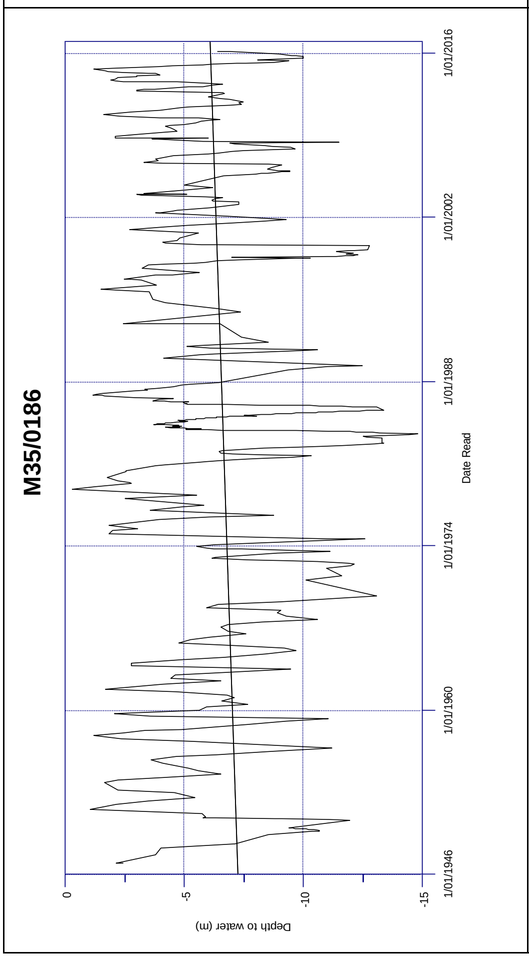

M35/0183
Depth to water (m)
Date Read

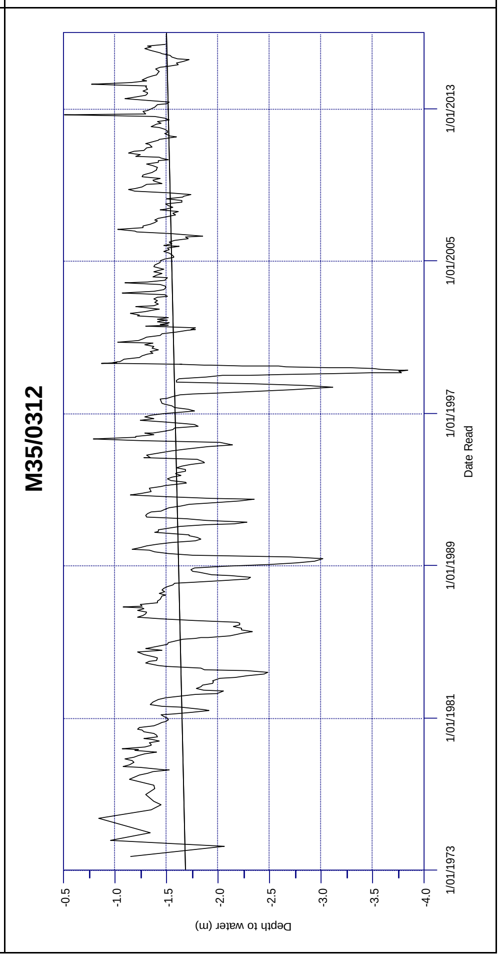

M35/0132
Depth to water (m)
Date Read

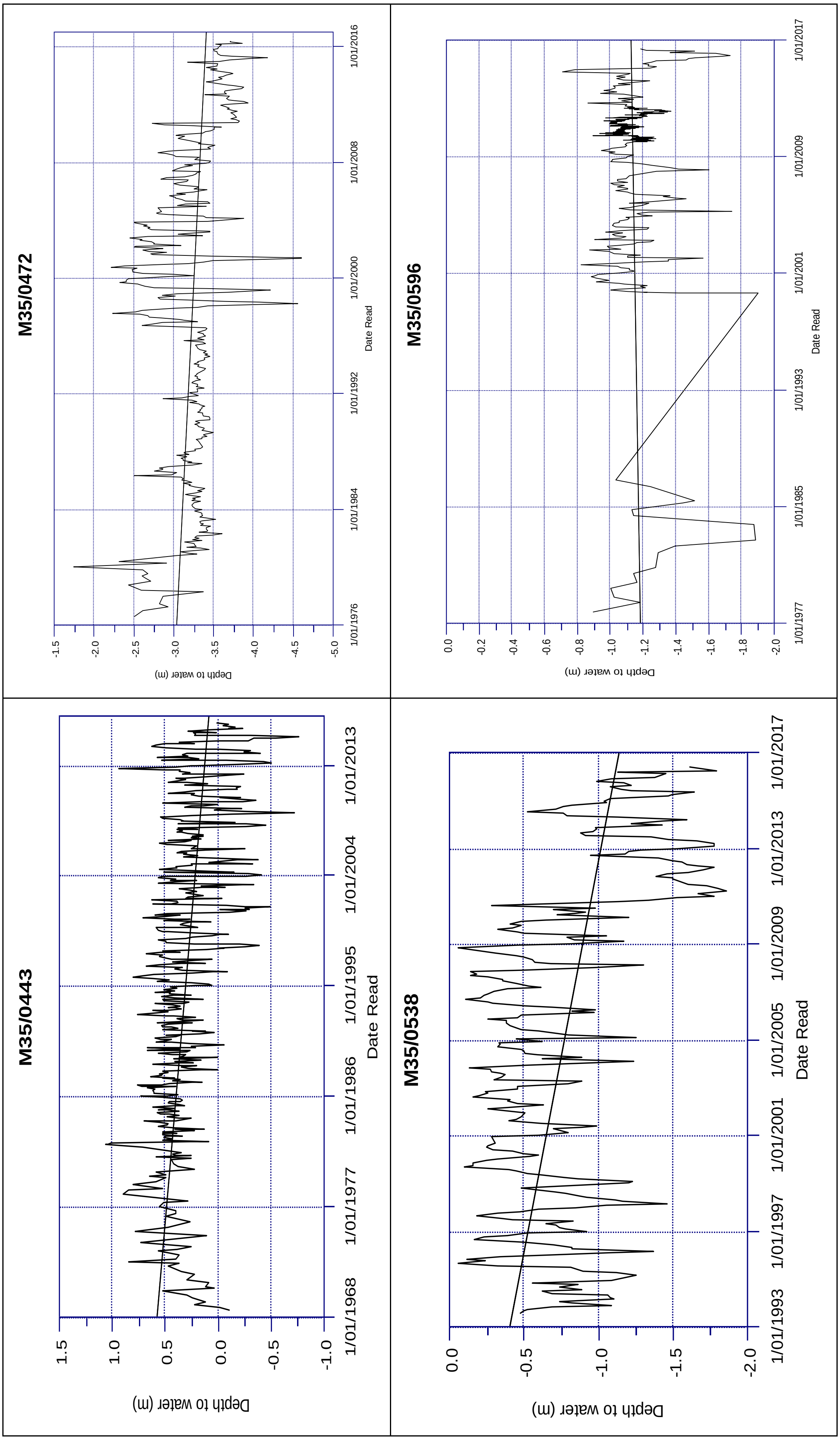

M35/0174
Depth to water (m)
Date Read

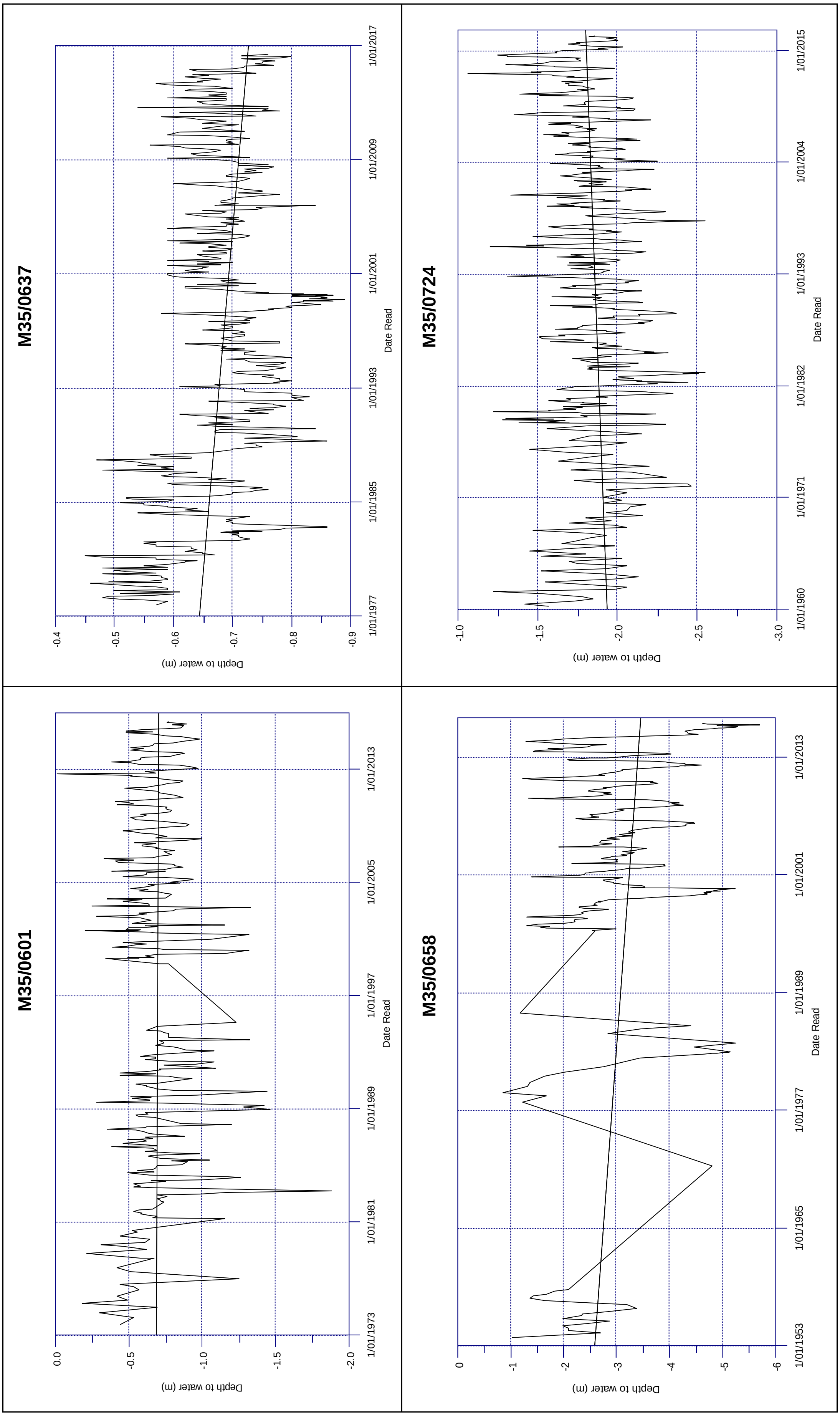

M35/0222
Depth to water (m)
Date Read
1/01/1995
1/01/1999
1/01/2003
1/01/2007
1/01/2011
1/01/2015


M35/0366
Depth to water (m)
Date Read
1/01/1978
1/01/1985
1/01/1992
1/01/1999
1/01/2006
1/01/2013

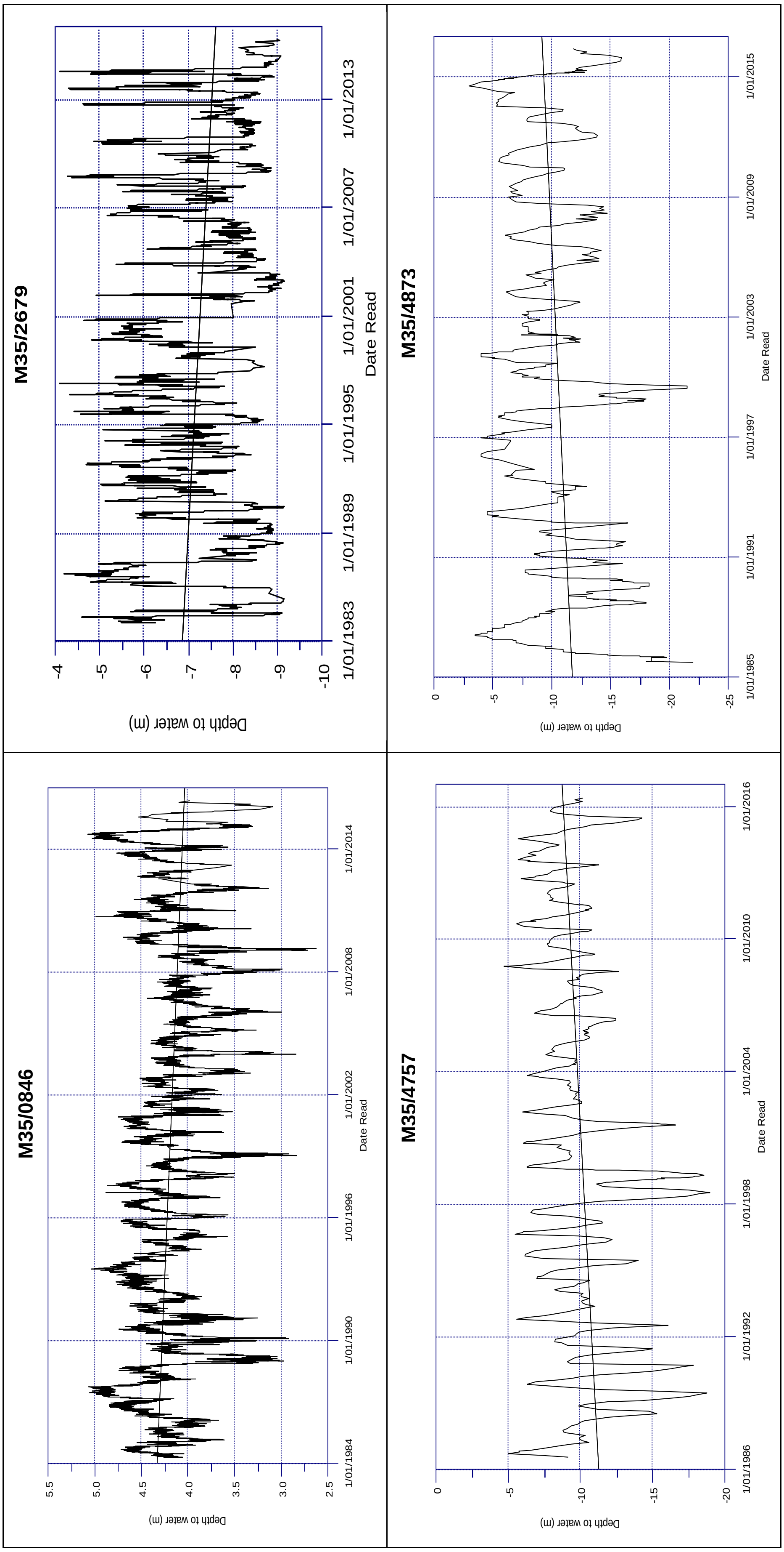

M35/0186
Depth to water (m)
Date Read
1/01/1946
1/01/1960
1/01/1974
1/01/1988
1/01/2002
1/01/2016

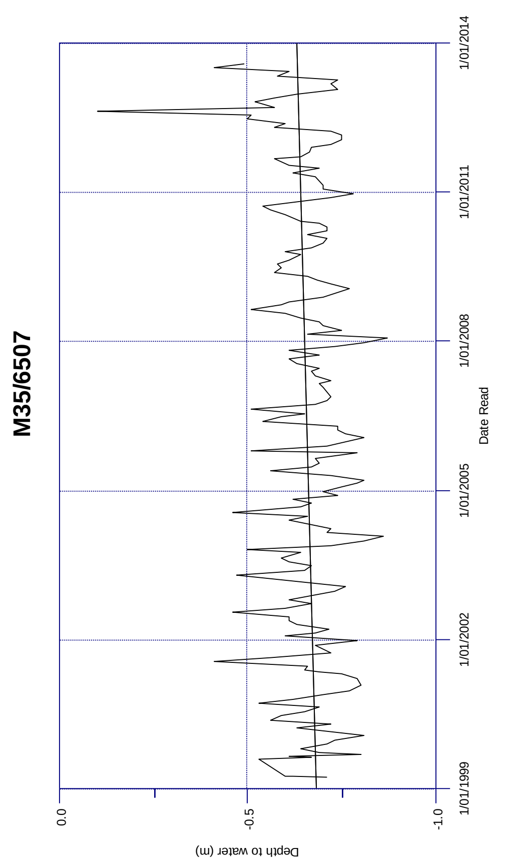

M35/0312
Depth to water (m)
Date Read
1/01/1973
1/01/1981
1/01/1989
1/01/1997
1/01/2005
1/01/2013

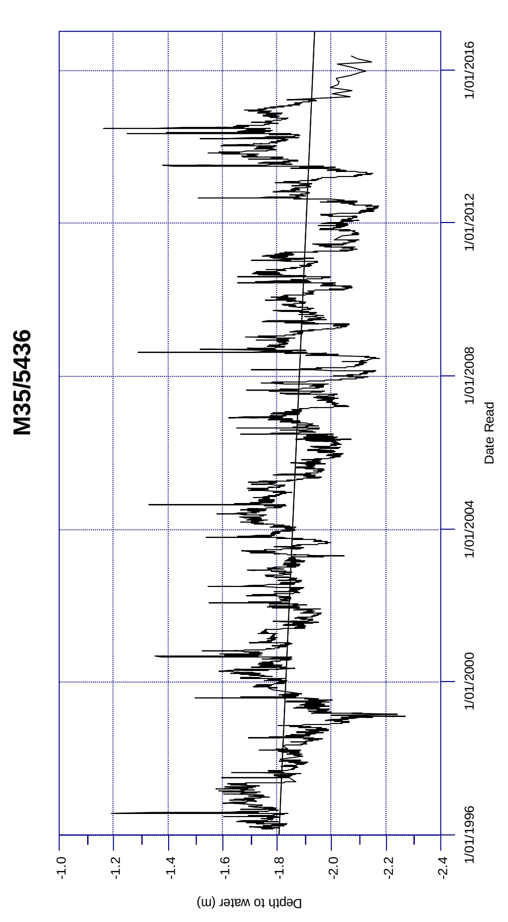

M35/0472
M35/0596
M35/0443
M35/0538
Depth to water (m)
Date Read

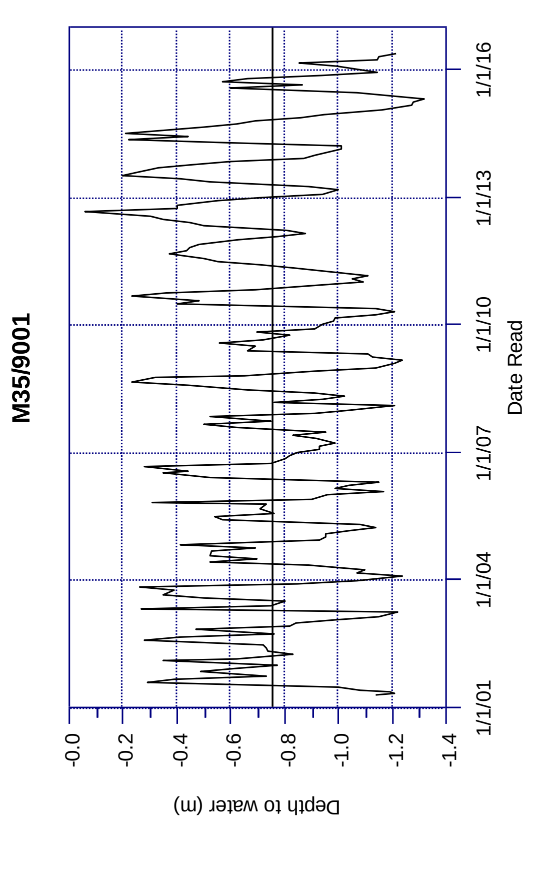


M35/0637
Depth to water (m)
Date Read
M35/0724
Depth to water (m)
Date Read
M35/0601
Depth to water (m)
Date Read
M35/0658
Depth to water (m)
Date Read

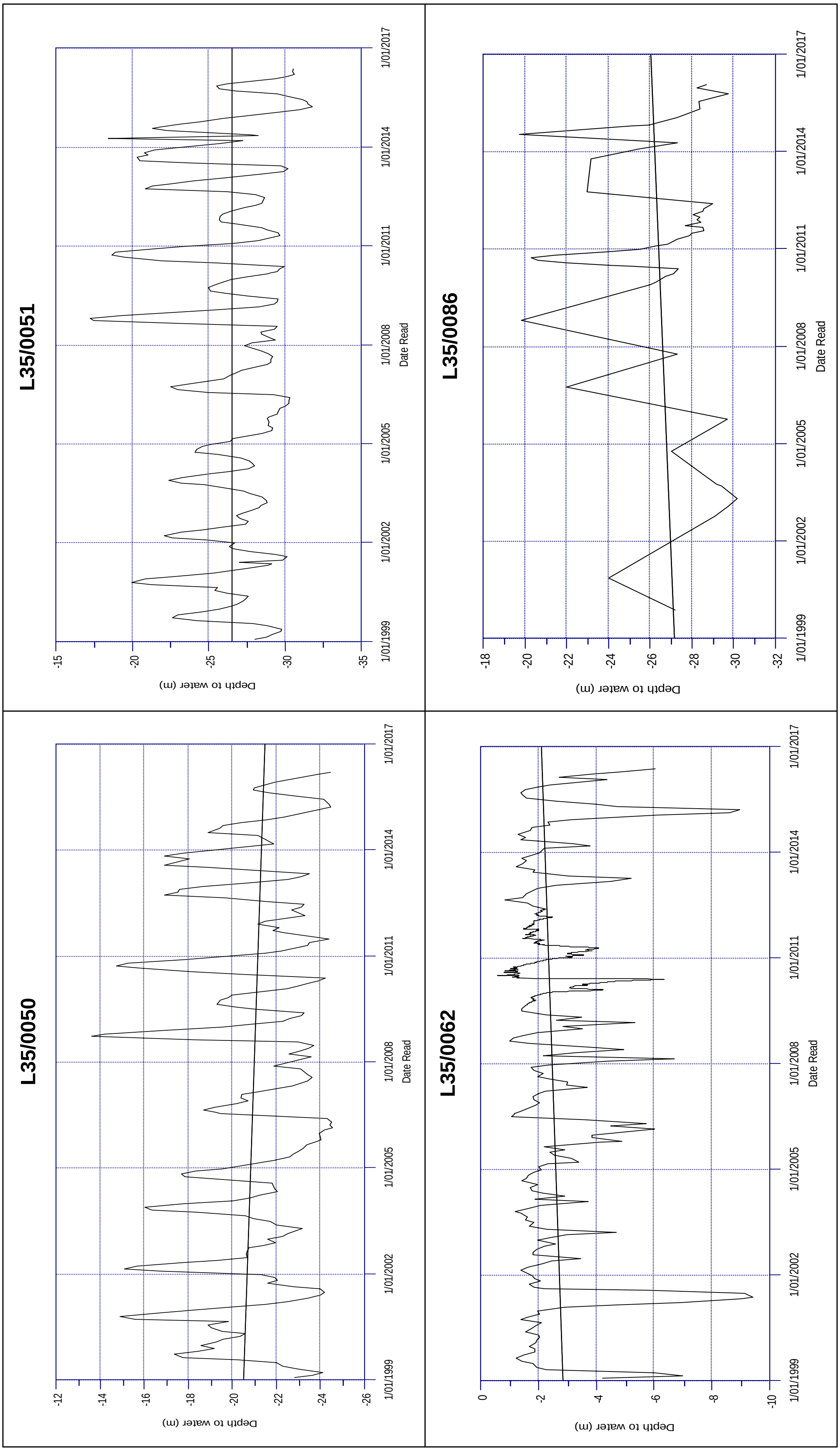

M35/2679
Depth to water (m)
Date Read
M35/4873
Depth to water (m)
Date Read
M35/0846
Depth to water (m)
Date Read
M35/4757
Depth to water (m)
Date Read

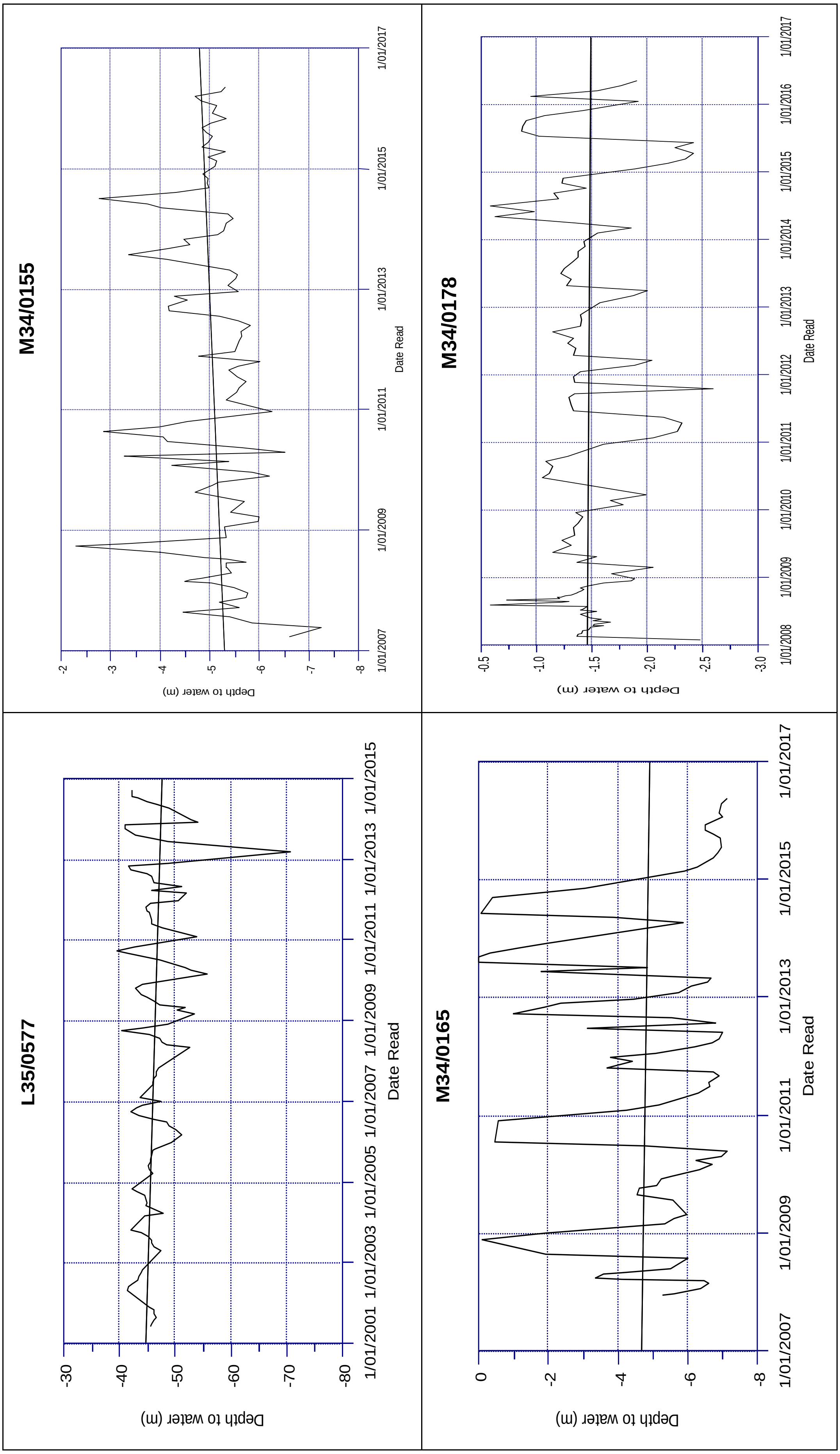

M35/6507
Depth to water (m)
Date Read
0.0
-0.5
-1.0
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014

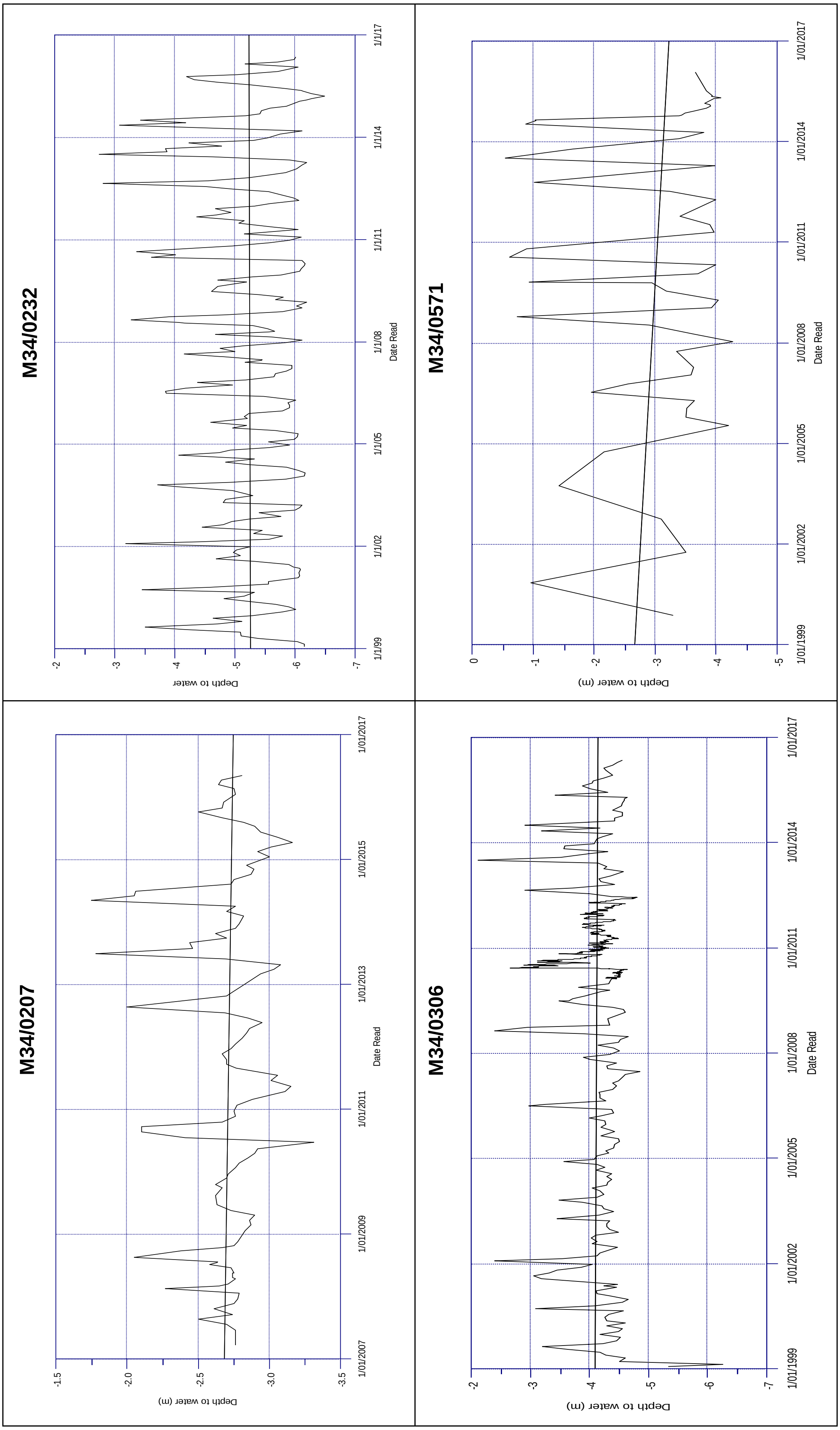

M35/5436
Depth to water (m)
Date Read
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
1/01/1996
1/01/2000
1/01/2004
1/01/2008
1/01/2012
1/01/2016

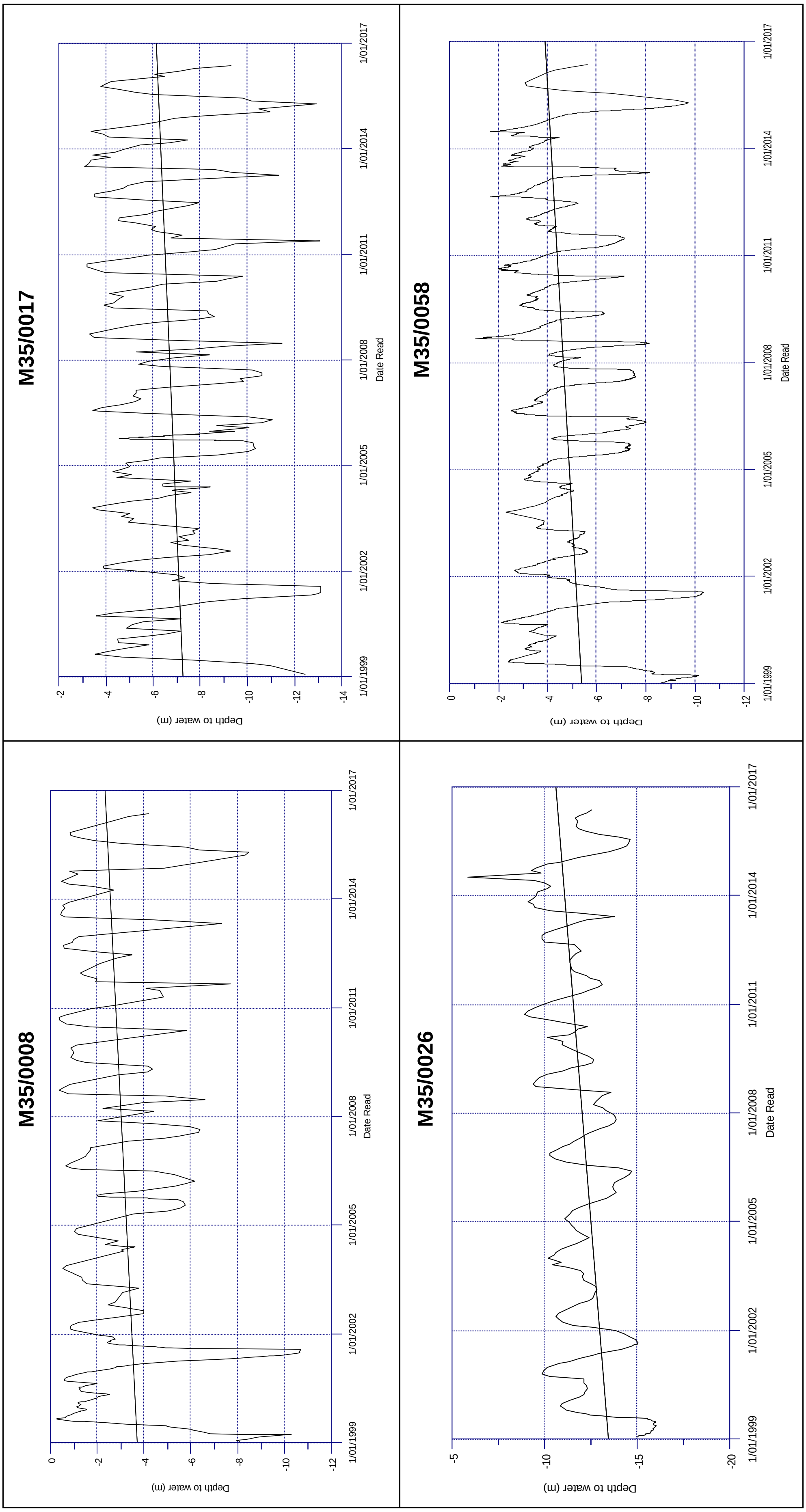

M35/9001
Depth to water (m)
Date Read
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
1/1/01
1/1/04
1/1/07
1/1/10
1/1/13
1/1/16

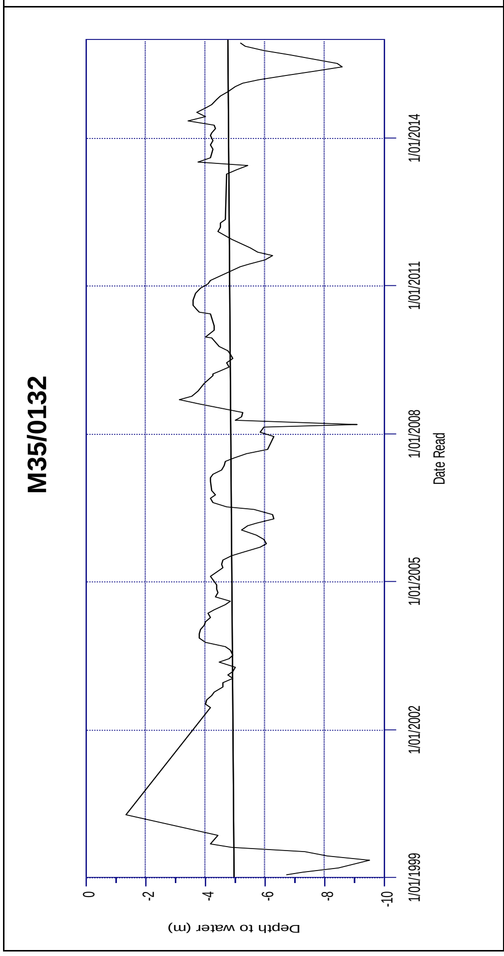
Appendix 3 Water level time series plots (Post 1999)

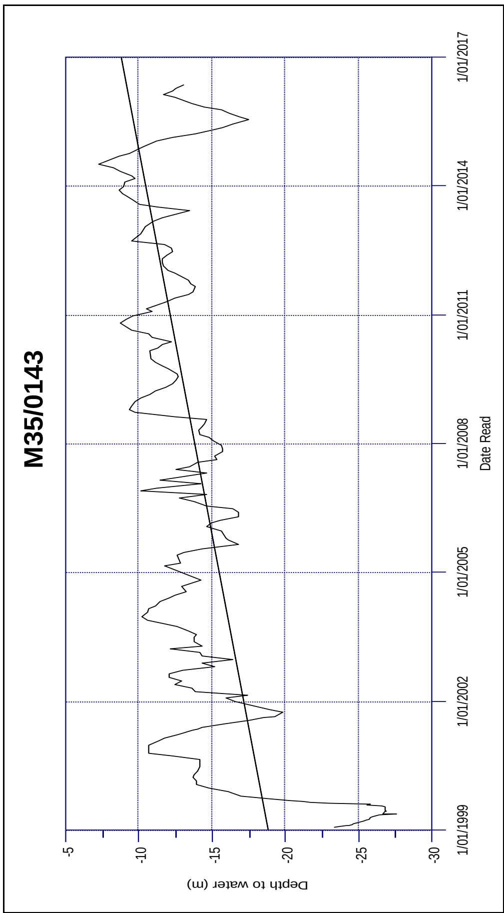

L35/0050
L35/0051
L35/0062
L35/0086
Depth to water (m)
Date Read
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017

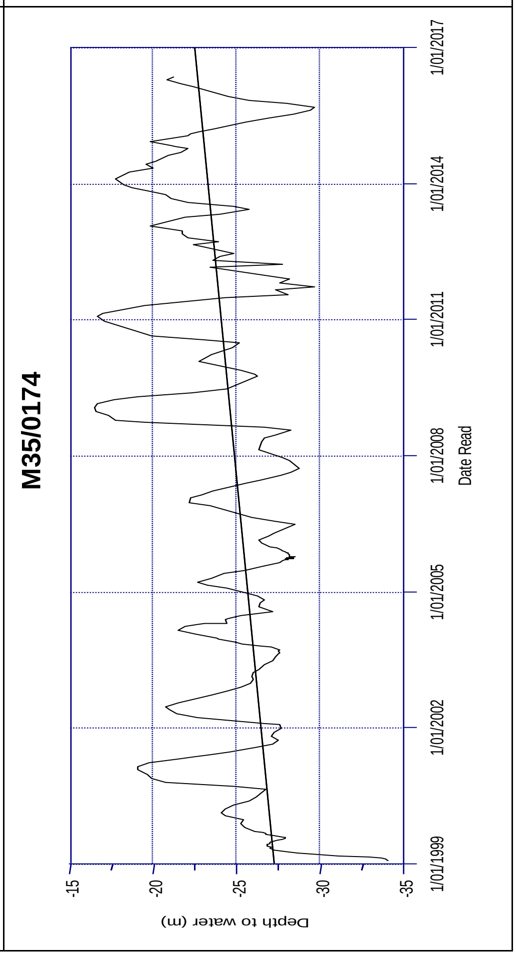

M34/0155
Depth to water (m)
Date Read
M34/0178
Depth to water (m)
Date Read
L35/0577
Depth to water (m)
Date Read
M34/0165
Depth to water (m)
Date Read

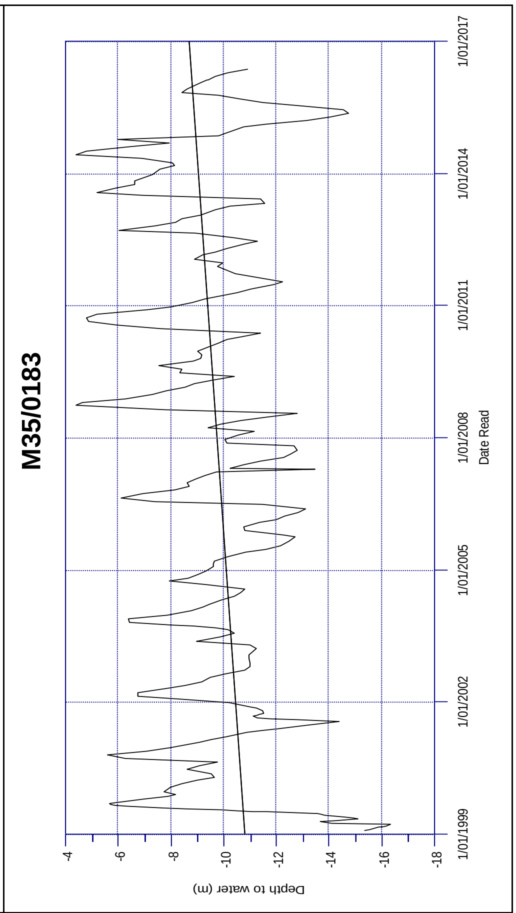

M34/0232
Depth to water
Date Read
M34/0571
Depth to water (m)
Date Read
M34/0207
Depth to water (m)
Date Read
M34/0306
Depth to water (m)
Date Read

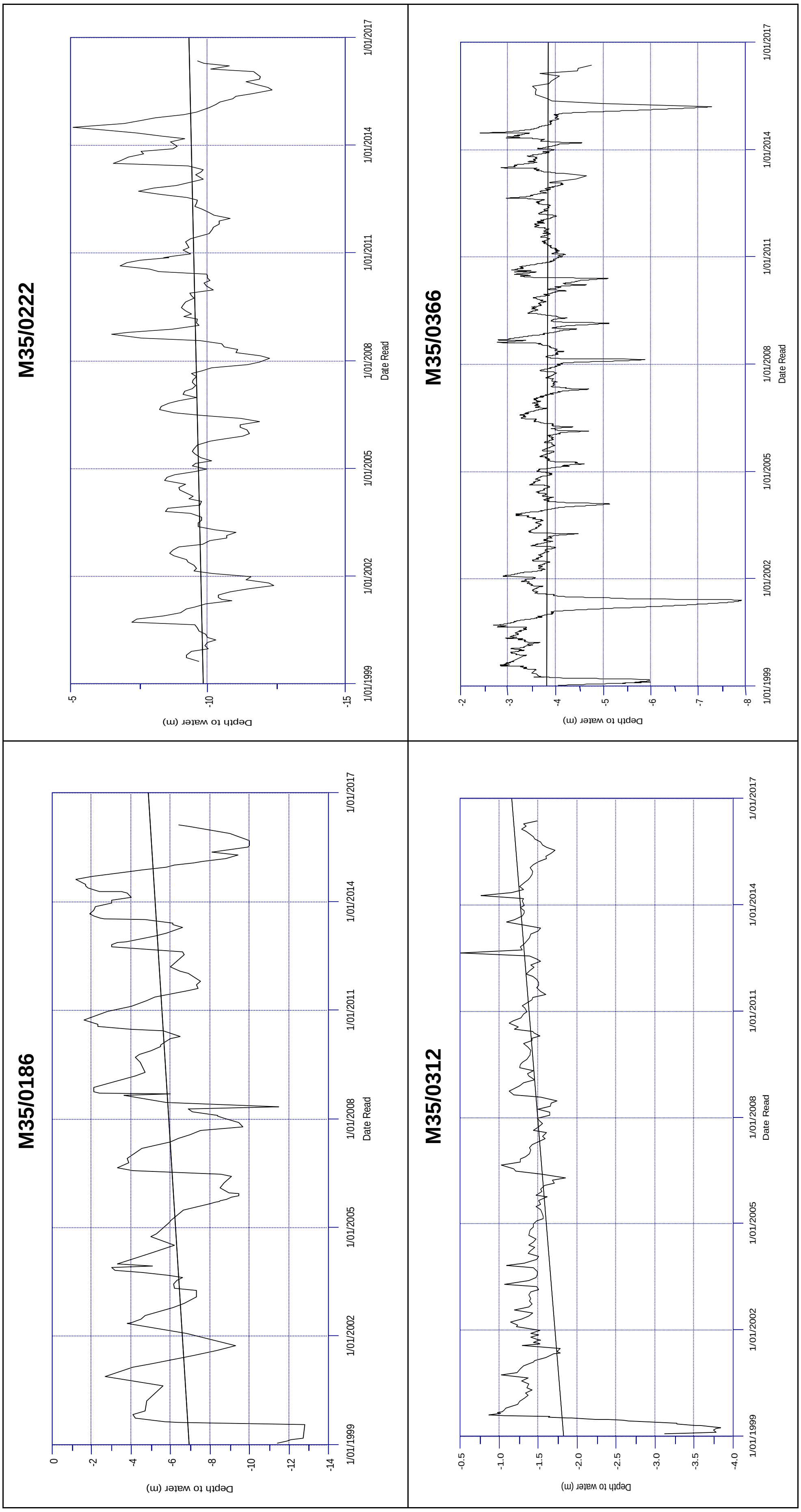

M35/0017
Depth to water (m)
Date Read
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017
M35/0058
Depth to water (m)
Date Read
M35/0008
Depth to water (m)
Date Read
M35/0026
Depth to water (m)
Date Read

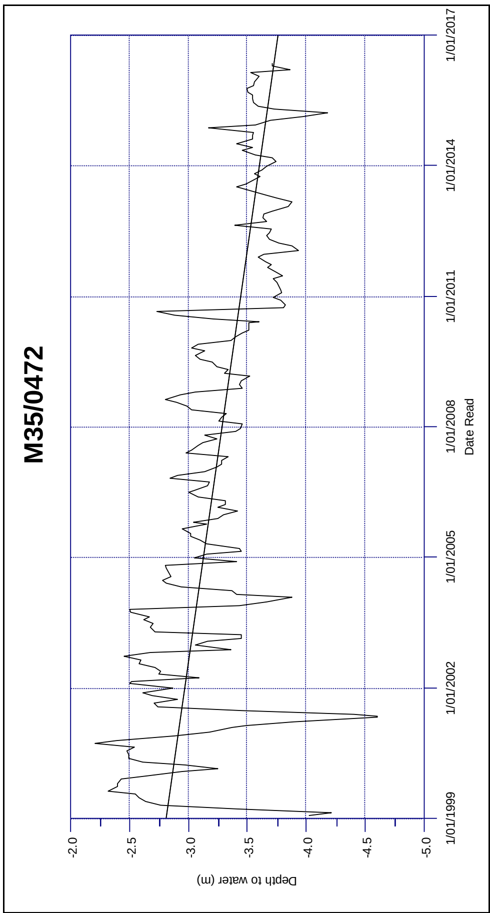

M35/0132
Depth to water (m)
0
-2
-4
-6
-8
-10
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
Date Read

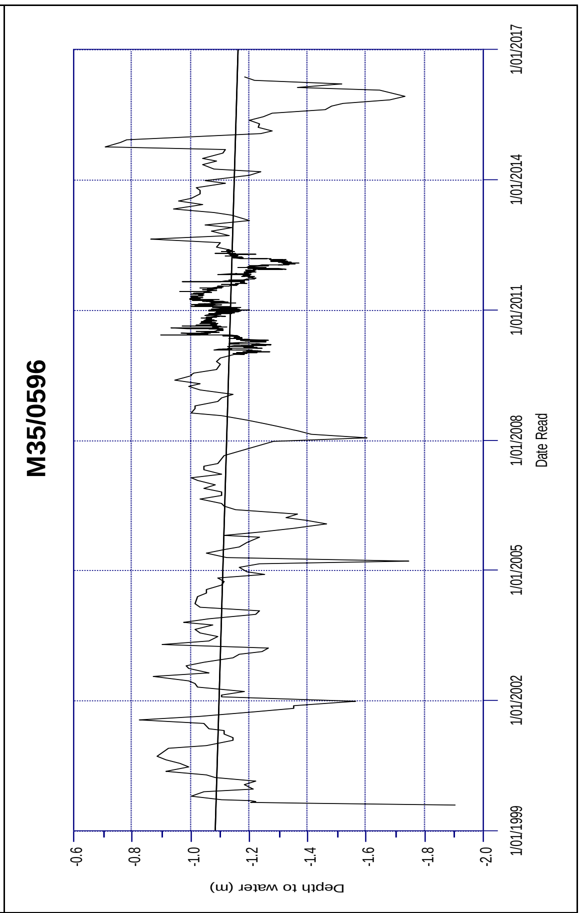

M35/0143
Depth to water (m)
-5
-10
-15
-20
-25
-30
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017
Date Read

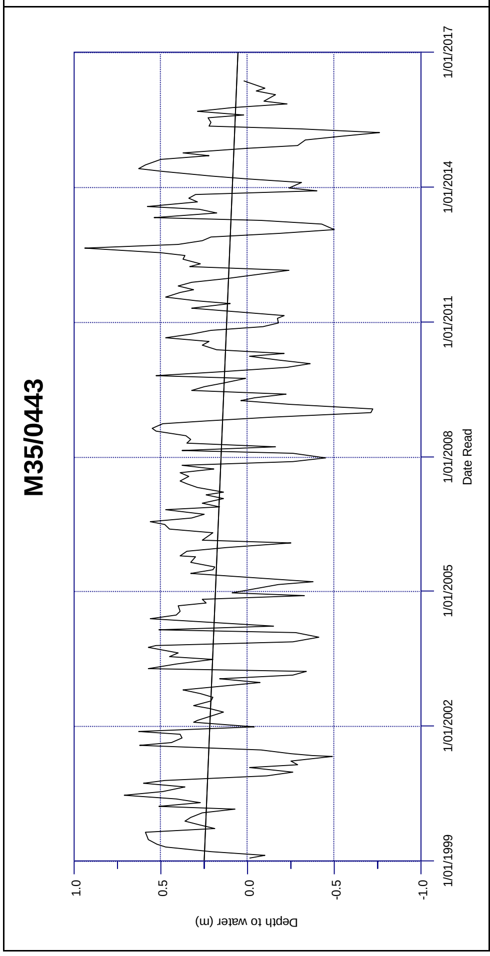

M35/0174
Depth to water (m)
-15
-20
-25
-30
-35
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017
Date Read

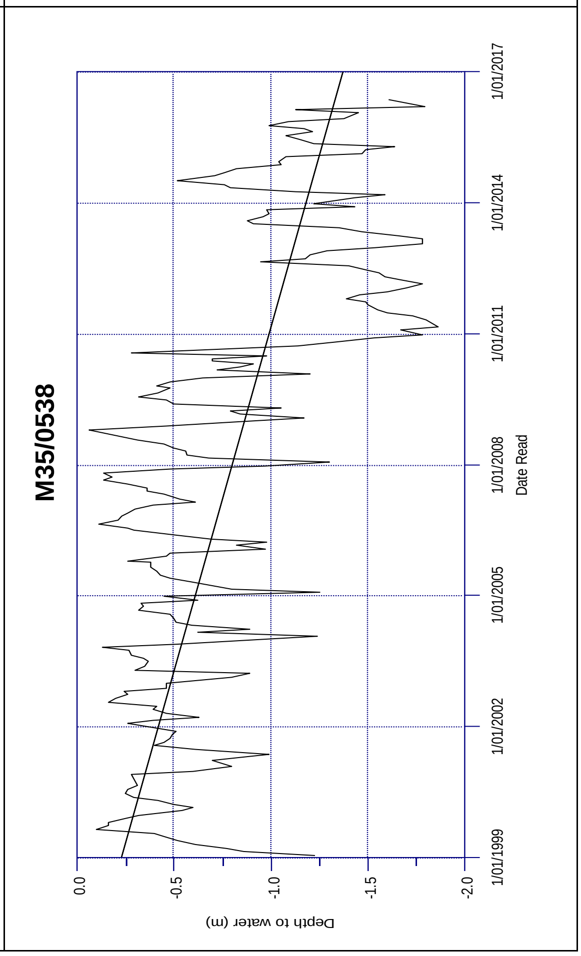

M35/0183
Depth to water (m)
-4
-6
-8
-10
-12
-14
-16
-18
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017
Date Read

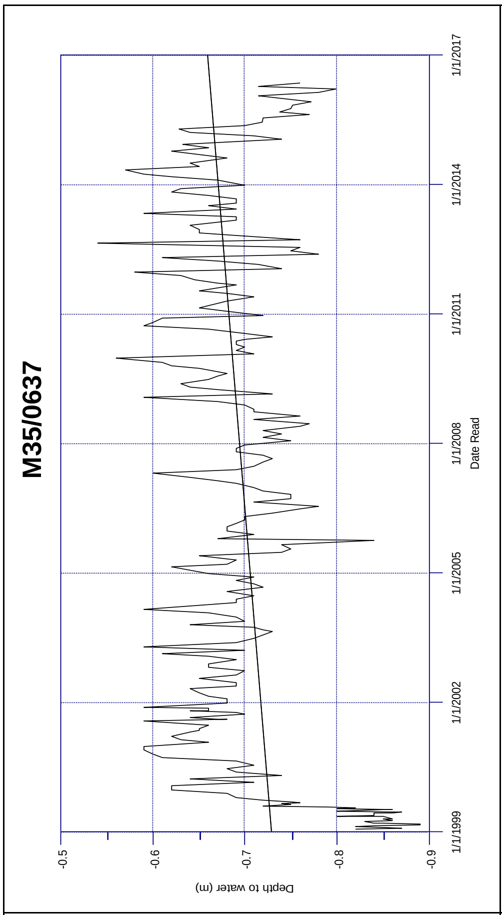

M35/0222
M35/0366
M35/0186
M35/0312
Depth to water (m)
Date Read
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014
1/01/2017

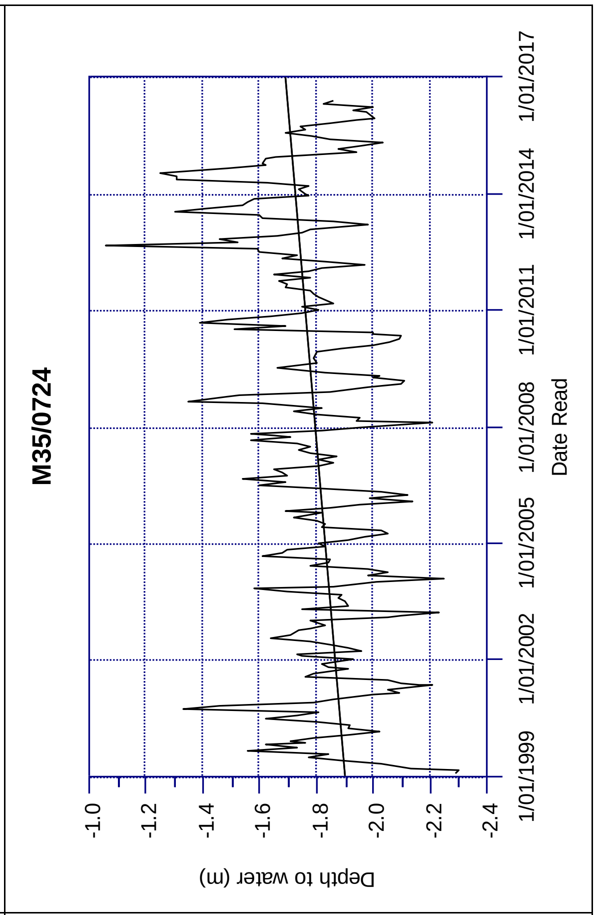

M35/0472
Depth to water (m)
Date Read

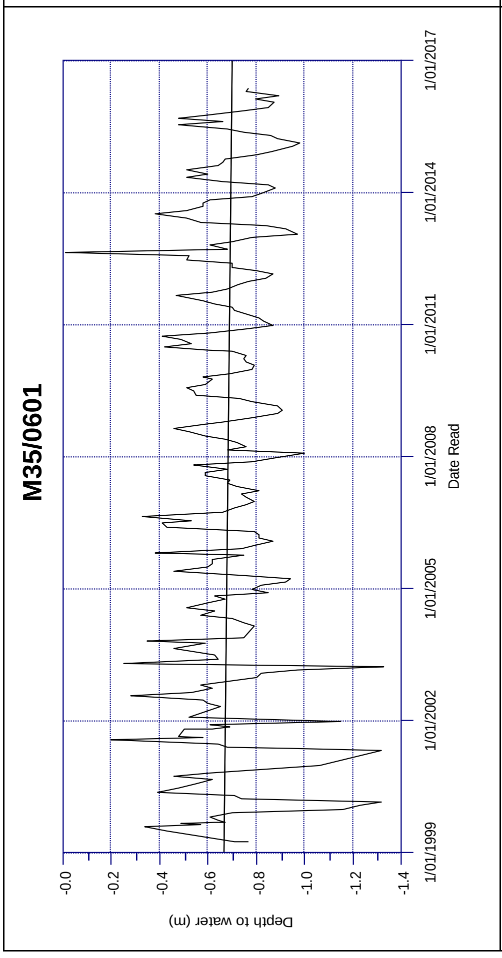

M35/0596
Depth to water (m)
Date Read

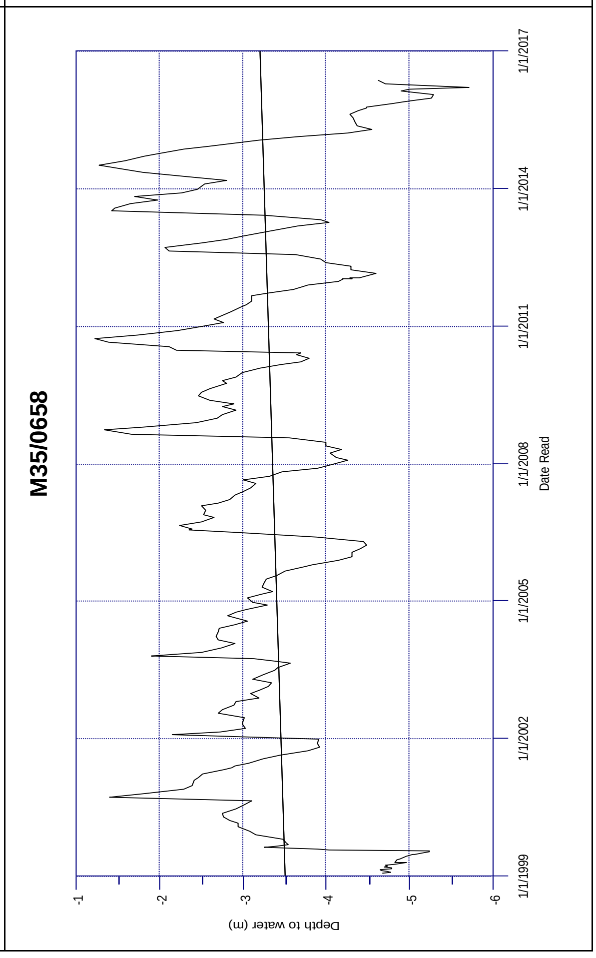

M35/0443
Depth to water (m)
Date Read

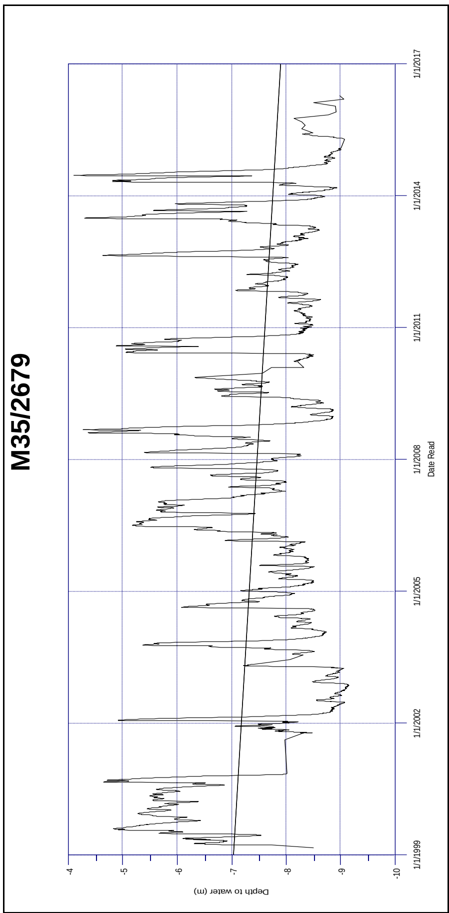

M35/0538
Depth to water (m)
Date Read

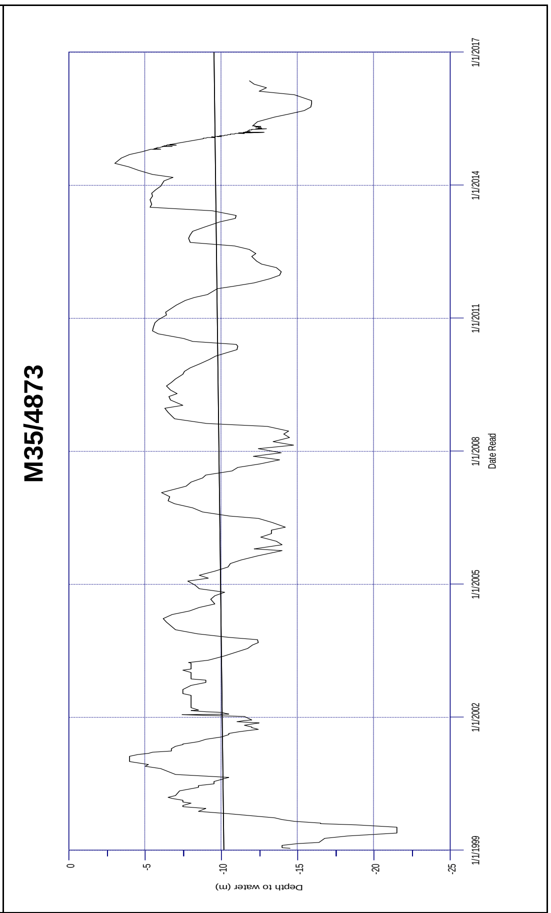

M35/0637
Depth to water (m)
Date Read

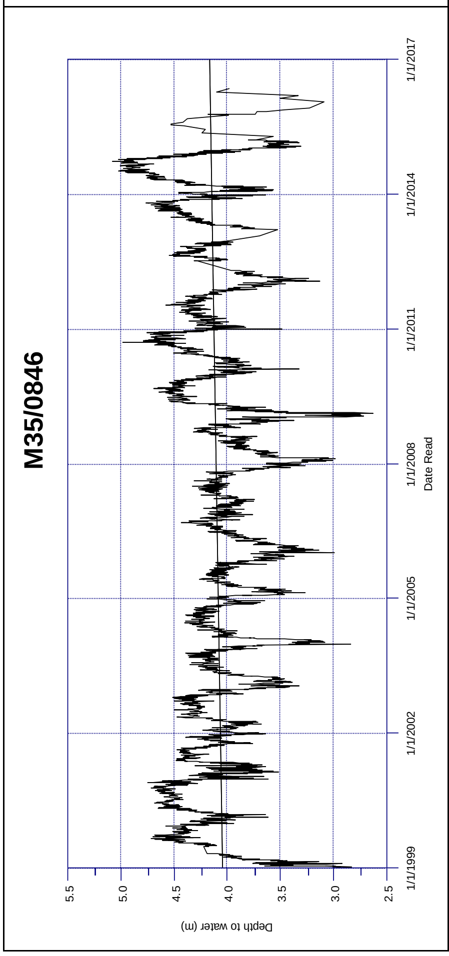

M35/0724
Depth to water (m)
Date Read

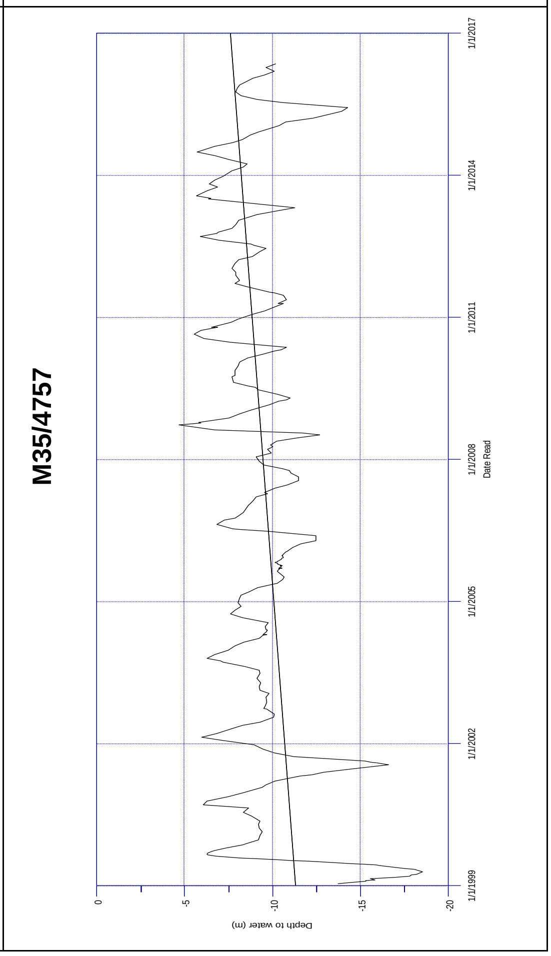

M35/0601
Depth to water (m)
Date Read

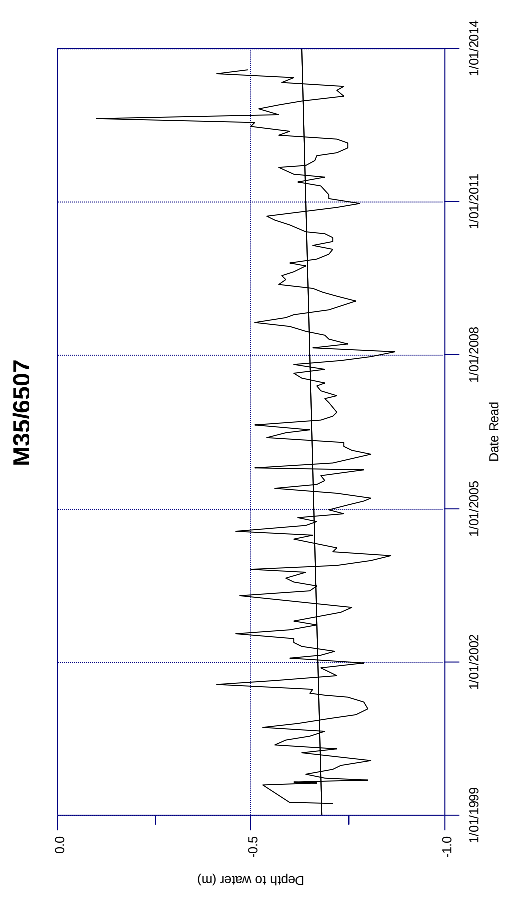

M35/0658
Depth to water (m)
Date Read


M35/2679
Depth to water (m)
Date Read


M35/4873
Depth to water (m)
Date Read


M35/0846
Depth to water (m)
Date Read


M35/4757
Depth to water (m)
Date Read


M35/6507
Depth to water (m)
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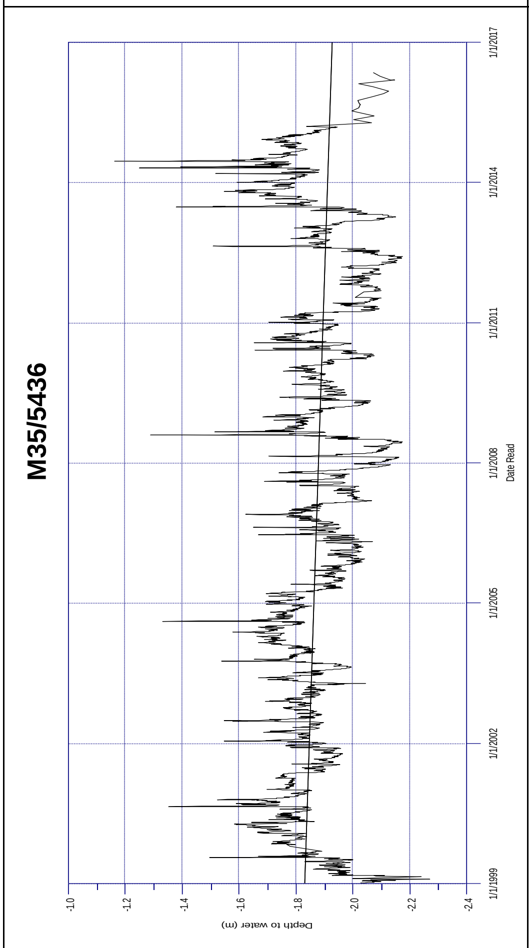
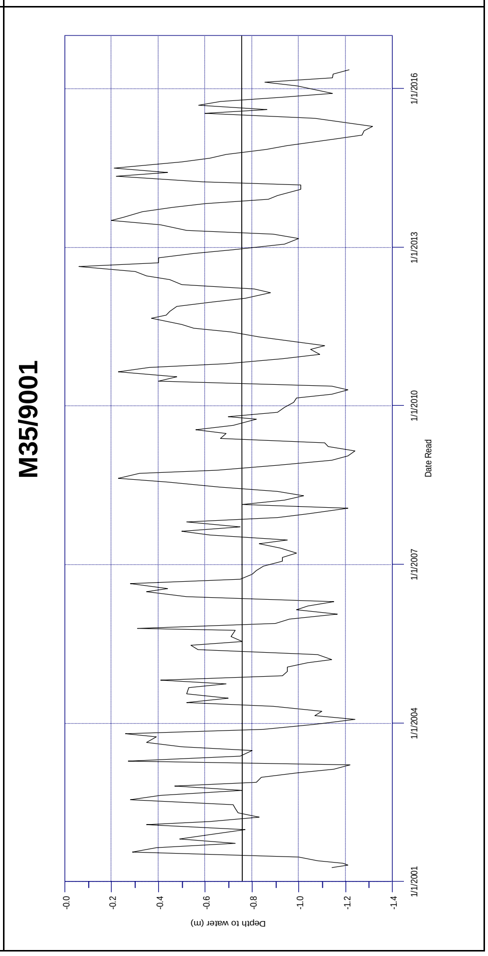
-0.5
-1.0
Date Read
1/01/1999
1/01/2002
1/01/2005
1/01/2008
1/01/2011
1/01/2014


M35/5436
Depth to water (m)
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
Date Read
1/1/1999
1/1/2002
1/1/2005
1/1/2008
1/1/2011
1/1/2014
1/1/2017


M35/9001
Depth to water (m)
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-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
Date Read
1/1/2001
1/1/2004
1/1/2007
1/1/2010
1/1/2013
1/1/2016

Appendix 4 Groundwater budget data sources

Eyre					
Data source	**IN m³/s**		**Data source**	**OUT m³/s**	
Alkhaier (2016)[1]	LSR	5.7	This report[4]	Abstraction	1.2
Megaughin & Hayward (2016)[2]	SW losses	1.8	Table A4-1[5]	SW gains - measured	3.4
Hanson and Etheridge (2019)[3]	Race losses	0.8	Assumed value to close water budget[6]	Unmeasured SW gains+ interzone flow	*3.6*
			Etheridge (2016b)[7]	Offshore flow	*0.1*
	Total	8.3			8.3

Cust					
Data source	**IN m³/s**		**Data source**	**OUT m³/s**	
Alkhaier (2016)[1]	LSR	1.9	This report[4]	Abstraction	0.3
Megaughin & Hayward (2016)[8]	SW losses	1.2	Table A4-1[5]	SW gains - measured	1.1
Hanson and Etheridge (2019)[3]	Race losses	0.4	Assumed value to close water budget[6]	Unmeasured SW gains+ interzone flow	2.0
			Etheridge (2016b)[7]	Offshore flow	0.2
	Total	3.5			3.5

Ashley					
Data source	**IN m³/s**		**Data source**	**OUT m³/s**	
Alkhaier (2016)[1]	LSR	0.3	This report[4]	Abstraction	0.5
Etheridge (2016c)[9]	SW losses	4.1	Table A4-1[5]	SW gains - measured	2.3
Hanson and Etheridge (2019)[3]	Race losses	0	Assumed value to close water budget[6]	Unmeasured SW gains+ interzone flow	0.1
			Etheridge (2016b)[7]	Offshore flow	1.5
	Total	4.4			4.4

Notes

1. We used the results of the long term mean LSR estimates generated in the Alkhaier (2016) study to estimate LSR for each GAZ.
2. Estimated loss = combined mean flow of Eyre River, White Stream, Coopers Creek, Mounseys Stream, Gammans Creek and Trout Creek presented in Megaughin & Hayward (2016), assuming that the entire mean flow infiltrated to ground within the zone. Assumes no significant loss from Waimakariri River into Waimakariri Zone. This assumption needs to be interrogated as part of the ongoing groundwater science work for the Waimakariri zone land and water solutions programme.
3. We split the race lost estimates presented in Hanson and Etheridge (2019) between the Eyre and Cust GAZs based on the proportion of race network within each zone.
4. See Table 2-5.
5. See Table A4-1.
6. Assumed groundwater discharge to surface water below gauging points + interzone transfer (e.g. Ashley to Cust GAZ). Significant stream gains from groundwater are possible in these reaches based on upward hydraulic gradient and well logs, which show fine-grained post glacial surface confining layer to be thin or absent in some areas. The size of the lower

Kaiapoi River (tidal reach) and visual observations of seepages along the northern Waimakariri River bank suggest that significant outflows into these watercourses could be occurring. Groundwater contours also indicate that groundwater flows from Ashley GAZ into Cust GAZ north of Kaiapoi, and flows from the Cust GAZ into the Eyre River GAZ are also possible.

7. Etheridge (2016b) concludes that offshore discharge in the southern part of the Waimakariri Zone, south of Pegasus Town is low, probably less than 300 L/s. Higher discharges are likely north of Pegasus Town. The discharge rate estimate for the Ashley GAZ is taken as the value required to close the water balance
8. Estimated loss = combined mean flow of Ellis Drain and Deep Creek presented in Megaughin & Hayward (2016), assuming that the entire mean flow infiltrated to ground within the zone, plus 1 m^3/s loss from Ashley River west of Mairaki Downs. Assumes no significant loss from Cust River.
9. Assumes that 0.5 m^3/s of Ashley River loss occurs through north bank, into Kowai GAZ. Remaining 4.6 m^3/s discharges to Ashley GAZ.

Table A4-1: Median stream flow data

Stream	GAZ	Median flow m^3/s	Source
Cam River at Youngs Rd	Ashley	1.43	Megaughin & Hayward (2016)
Waikuku Stream at Wikuku Beach Rd	Ashley	0.64	Megaughin & Hayward (2016)
Taranaki Creek	Ashley	0.21	Megaughin & Hayward (2016)
Cust Main Drain at Threlkelds Rd	Cust	1.06	Megaughin & Hayward (2016)
Kaiapoi River at Skewbridge Rd	Eyre	1.66	Megaughin & Hayward (2016)
Ohoka Stream at Kaiapoi River confluence	Eyre	0.65	Megaughin & Hayward (2016)
Courtenay Stream at Ashley Meat Factory	Eyre	0.36	Megaughin & Hayward (2016)
Griegs Drain at Taylors Rd	Eyre	0.065	Megaughin & Hayward (2016)
Kairaki Creek at Beach Rd	Eyre	0.1	Mean of 8 flow gaugings between Nov 2015 and June 2016
Macintosh Drain at Kaiapoi River confluence	Eyre	0.08	Mean of 8 flow gaugings between Nov 2015 and June 2016
Waimakariri River	Eyre	0.5	Gain estimate for Waimakariri River between Wrights Cut and Old Highway Bridge from White et. al. (2012)
Saltwater Creek at Factory Rd Bridge	Kowai	0.41	Megaughin & Hayward (2016)

Appendix 5 Seasonal Mann-Kendall trend analysis results for wells

Well No	Depth (m)	GW level change (m/year)			P value[1]	Valid trend?[1]	Years of Record (Post WIL scheme)	Total variation over years of records (m)	Seasonal Variation[2]	Long term change as % of seasonal range[4]	Trend[3]
		Median	5% confidence limit	95% confidence limit							
L35/0050	8	-0.088	-0.140	-0.021	0.016	Valid	17.3	-1.5	2.6	-19%	Decline
L35/0051	9	-0.066	-0.106	-0.005	0.082	Valid	17.4	-1.2	6.6	-12%	Decline
L35/0062	7	-0.004	-0.018	0.013	0.794	Invalid	17.4	-0.1	1.3	-2%	Minor Decline - No Trend
L35/0086	4	-0.099	-0.329	0.203	0.730	Invalid	16.3	-1.6	1.0	-18%	Decline
L35/0577	8	0.014	-0.065	0.122	0.943	Invalid	13.4	0.2	2.3	2%	Minor Increase - No Trend
M34/0155	10	0.056	0.026	0.096	0.002	Valid	9.3	0.5	1.4	20%	Increase
M34/0165	17	-0.096	-0.206	0.005	0.169	Invalid	8.6	-0.8	3.2	-12%	Decline
M34/0178	13	-0.005	0.036	8.417	0.184	Invalid		0.0	8.2	0%	Minor Decline - No Trend
M34/0207	13	-0.008	-0.017	0.003	0.329	Invalid	9.3	-0.1	7.1	-7%	Minor Decline - No Trend
M34/0232	17	-0.004	-0.013	0.003	0.313	Invalid	17.4	-0.1	6.3	-3%	Minor Decline - No Trend
M34/0306	11	-0.001	-0.008	0.007	0.906	Invalid	17.4	0.0	5.5	-1%	Minor Decline - No Trend
M34/0571	20	0.000	-0.047	0.023	1.000	Invalid	16.3	0.0	3.6	0%	Minor Decline - No Trend
M35/0008	29	0.030	-0.006	0.067	0.186	Invalid	17.4	0.5	16.7	6%	Minor Increase - No Trend
M35/0017	46	0.046	0.002	0.088	0.079	Valid	17.4	0.8	9.4	11%	Increase
M35/0026	18	0.062	0.035	0.097	0.001	Valid	17.4	1.1	8.7	17%	Increase
M35/0058	20	0.008	-0.015	0.034	0.617	Invalid	17.4	0.1	7.9	3%	Minor Increase - No Trend
M35/0132	13	-0.008	-0.036	0.008	0.364	Invalid	17.0	-0.1	4.6	-4%	Minor Decline - No Trend
M35/0143	9	0.229	0.178	0.313	0.000	Valid	17.4	4.0	2.0	24%	Increase
M35/0174	15	0.135	0.066	0.227	0.001	Valid	17.4	2.3	1.7	25%	Increase
M35/0183	21	0.025	-0.020	0.077	0.447	Invalid	17.4	0.4	1.0	5%	Minor Increase - No Trend
M35/0186	24	0.071	-0.007	0.143	0.126	Invalid	17.2	1.2	1.4	15%	Increase
M35/0222	13	0.029	-0.002	0.056	0.125	Invalid	16.8	0.5	1.5	11%	Increase
M35/0312	3	0.003	-0.001	0.007	0.282	Invalid	17.4	0.1	0.3	3%	Minor Increase - No Trend

Well No	Depth (m)	GW level change (m/year)			P value[1]	Valid trend?[1]	Years of Record (Post WIL scheme)	Total variation over years of records (m)	Seasonal Variation[2]	Long term change as % of seasonal range[4]	Trend[3]
		Median	5% confidence limit	95% confidence limit							
M35/0366	13	-0.018	-0.027	-0.011	0.000	Valid	17.4	-0.3	0.6	-18%	Decline
M35/0443	11	-0.011	-0.017	-0.005	0.003	Valid	17.4	-0.2	0.3	-21%	Decline
M35/0472	6	-0.061	-0.067	-0.057	0.000	Valid	17.4	-1.1	3.2	-77%	Decline[5]
M35/0538	18	-0.053	-0.063	-0.043	0.000	Valid	17.4	-0.9	0.6	-62%	Decline[5]
M35/0596	88	-0.005	-0.008	-0.003	0.005	Valid	16.9	-0.1	1.2	-28%	Decline
M35/0601	9	-0.002	-0.005	0.000	0.179	Invalid	17.3	0.0	3.6	-6%	Minor Decline - No Trend
M35/0637	22	0.000	-0.001	0.001	0.764	Invalid	17.4	0.0	9.0	0%	Minor Increase - No Trend
M35/0658	26	-0.005	-0.028	0.014	0.823	Invalid	17.4	-0.1	9.0	-3%	Minor Decline - No Trend
M35/0724	14	0.010	0.007	0.014	0.000	Valid	17.4	0.2	0.4	27%	Increase
M35/0846	10	-0.002	-0.008	0.004	0.580	Invalid	17.4	0.0	0.3	-3%	Minor Decline - No Trend
M35/2679	2	-0.053	-0.087	-0.024	0.001	Valid	17.3	-0.9	0.9	-25%	Decline
M35/4757	8	0.051	0.010	0.095	0.025	Valid	17.4	0.9	2.6	10%	Increase
M35/4873	9	0.025	-0.055	0.114	0.617	Invalid	17.4	0.4	6.6	5%	Minor Increase - No Trend
M35/5436	7	-0.009	-0.012	-0.007	0.000	Valid	17.4	-0.2	1.3	-40%	Decline
M35/6507	4	0.004	0.001	0.006	0.007	Valid	14.4	0.1	1.0	18%	Increase
M35/9001	8	0.001	-0.005	0.007	0.757	Invalid	15.2	0.0	2.3	2%	Minor Increase - No Trend

Notes:

1. A P value ≤ 0.05 is normally used as the criteria for determining whether the interpreted trend is statistically significant. We have used a slightly looser criteria of P ≤ 0.1 to classify the validity of interpreted trends
2. We used the 95th and 5th percentile groundwater levels to define the typical seasonal range
3. We used 10% of the seasonal range as the criteria for defining trends. If the total long term water level change is ≥ 10% of the seasonal range, we classified the trend as decline/increase. If the water level change is ≤ 10% of the seasonal range, we classified the trend as minor/no trend.
4. We calculated the % change by dividing the 95th percentile seasonal groundwater level range by total groundwater level change since 1999
5. Water levels in these wells declined sharply in 2010/2011 during the Canterbury earthquakes. This decline is likely to have been a reasonably significant factor in the overall groundwater level trend, but s declining trend is still clear in M35/0472 after accounting for the earthquake effects.

Appendix 6 Spring-fed stream data analysis

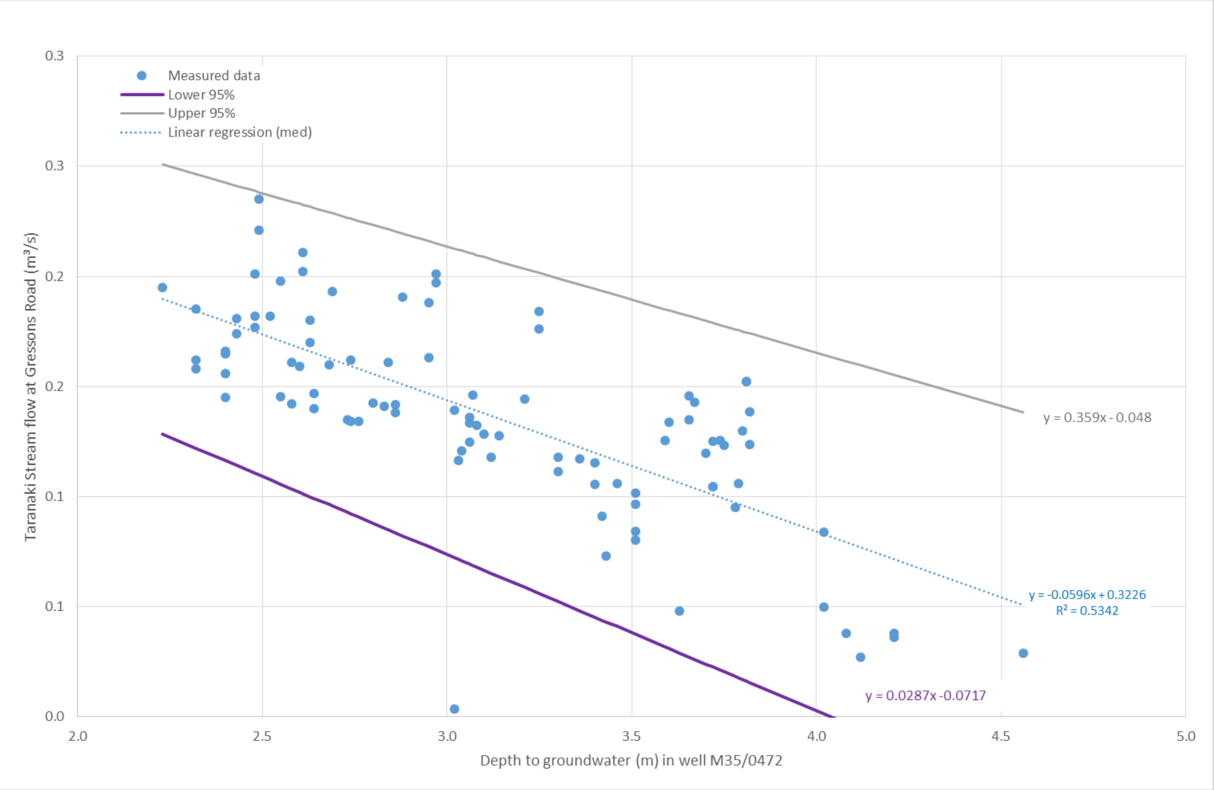

Figure A6-1: M35/0472 groundwater level vs Taranaki Creek flow

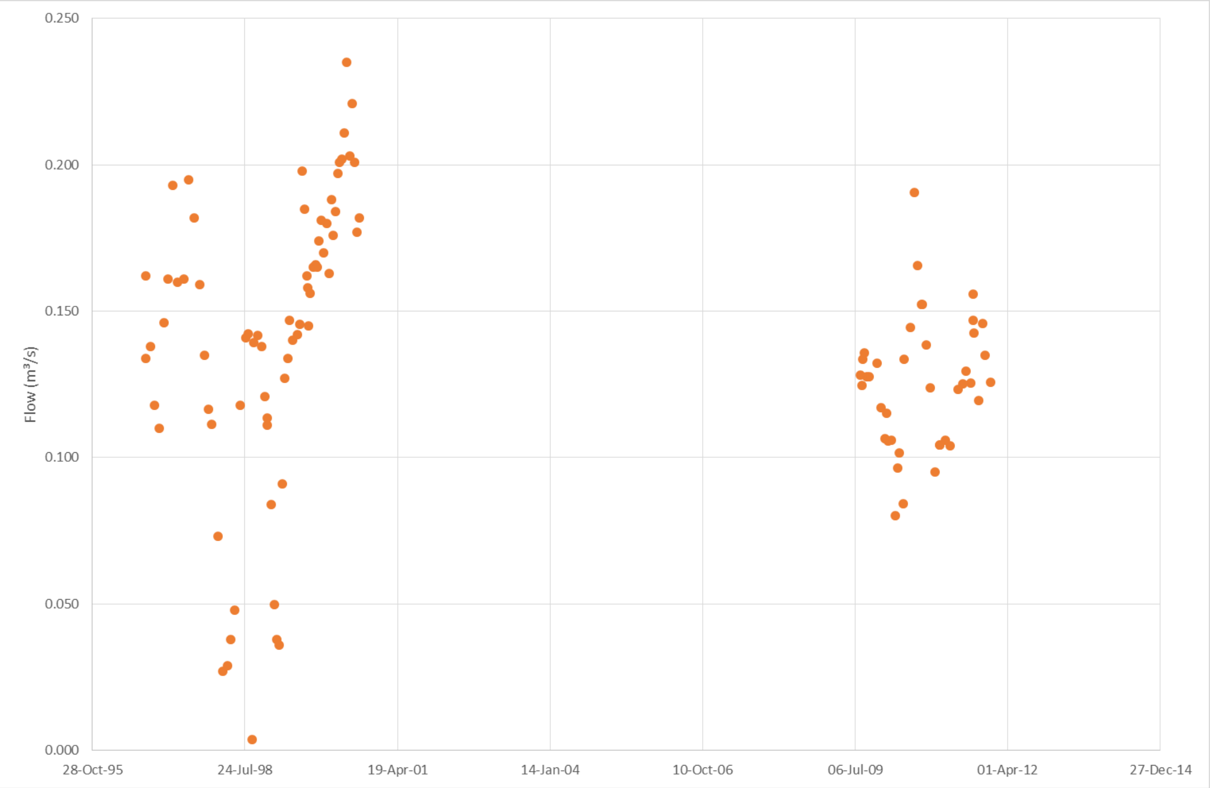

Figure A6-2: Taranaki Creek flow gauging data

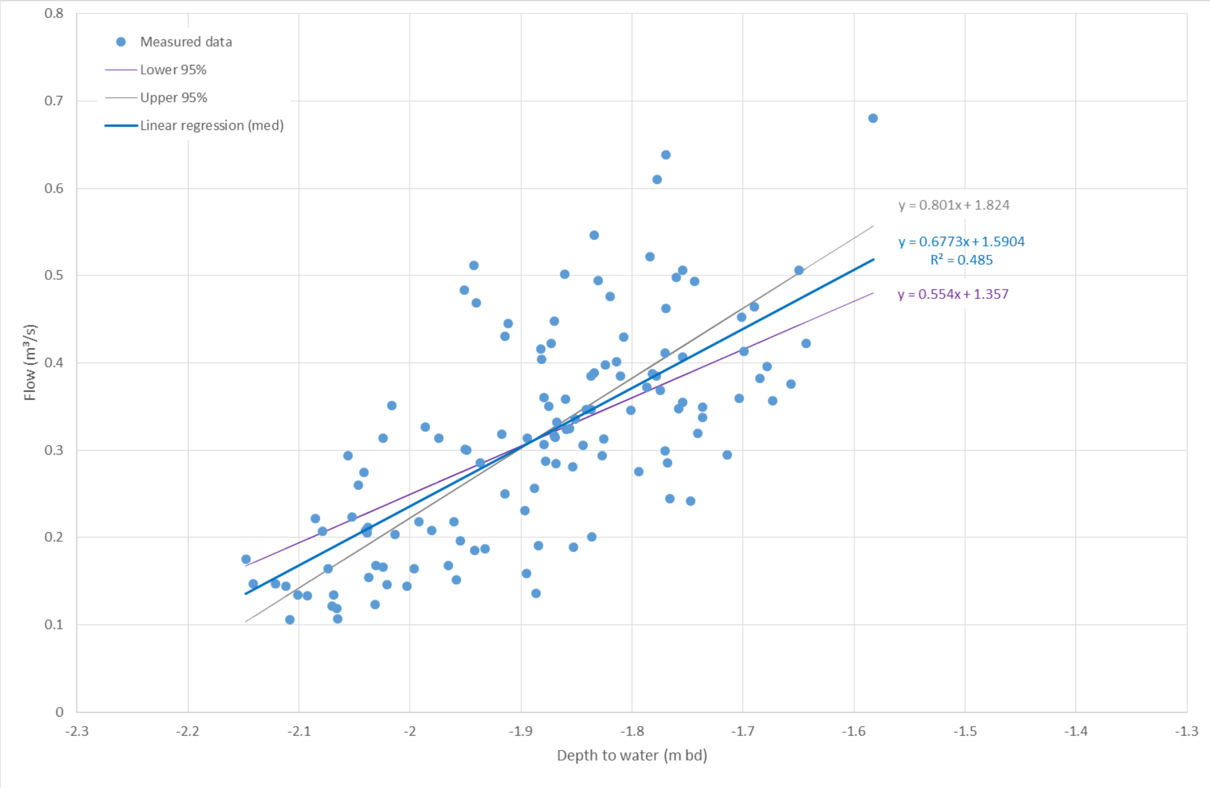

Figure A6-3: M35/5463 groundwater level vs Silverstream flow

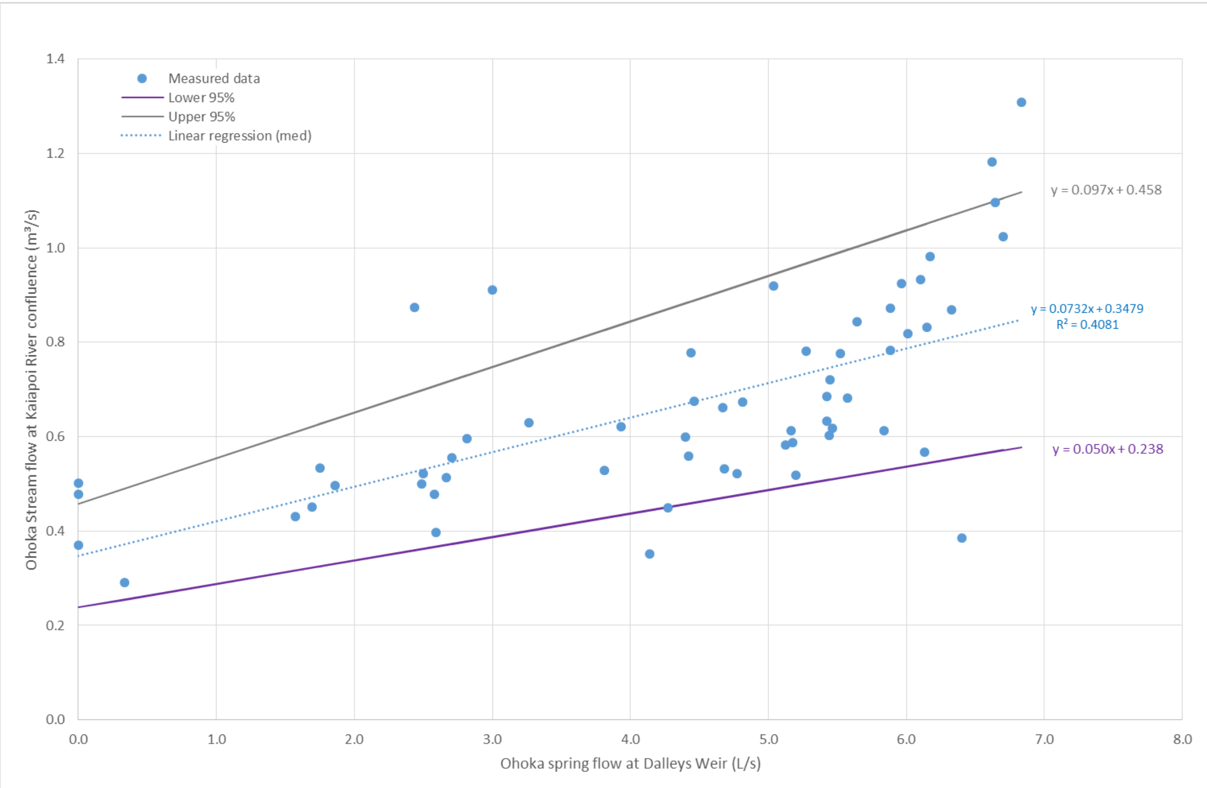

Figure A6-4: Ohoka Stream flow vs Dalleys Weir spring flow

We do not have a continuous flow record for the main stem of the Ohoka Stream: the dataset is limited to 66 manual gaugings between 1997 and 2015 at the Skewbridge Road monitoring site (6 km east of well M35/0596), and continuous measurement of flow from one of the springs at Dalley's Weir (see location in Figure 5-3) since 1997. Analysis of the relationship between gauged flows in the Ohoka Stream at the Kaiapoi River confluence and flows at the Dalleys Weir site show a strong positive correlation (Persons R = 0.64). A linear regression equation fitted through the data only provide a moderately good fit ($R^2 = 0.4$) (Figure A6-4) however, and the 95% confidence range is quite wide (see Figure A6-5). This means that we cannot generate a robust long-term synthetic flow record for the Ohoka Stream using the Dalleys Weir dataset.

We have also evaluated the relationship between gauged Ohoka Stream flows at the Kaiapoi River confluence site and groundwater level[23] from well M35/0596. Statistical analysis shows a moderate positive correlation, with a Persons R of 0.56. A linear regression equation fitted to the data achieves a relatively low R^2 value, of 0.34 for the median regression equation (see Figure A6-5 below). Application of this equation would indicate that a 0.1 m decline in groundwater levels could equate to a flow reduction of 0.09 m^3/s, which is approximately 15% of the 0.6 m^3/s median flow calculated from the manual gauging data. The upper and lower 95% confidence interval flow declines are 0.12 and 0.05 m^3/s respectively, i.e. 20% and 10% of the median flow for the dataset. However, the correlation between the Dalleys Weir record and gauged flows from the Okoka Stream Kaiapoi River confluence site is stronger, and on this basis we conclude that the flows in this stream do not appear to have declined in association with the inferred groundwater level decline in well M35/0596.

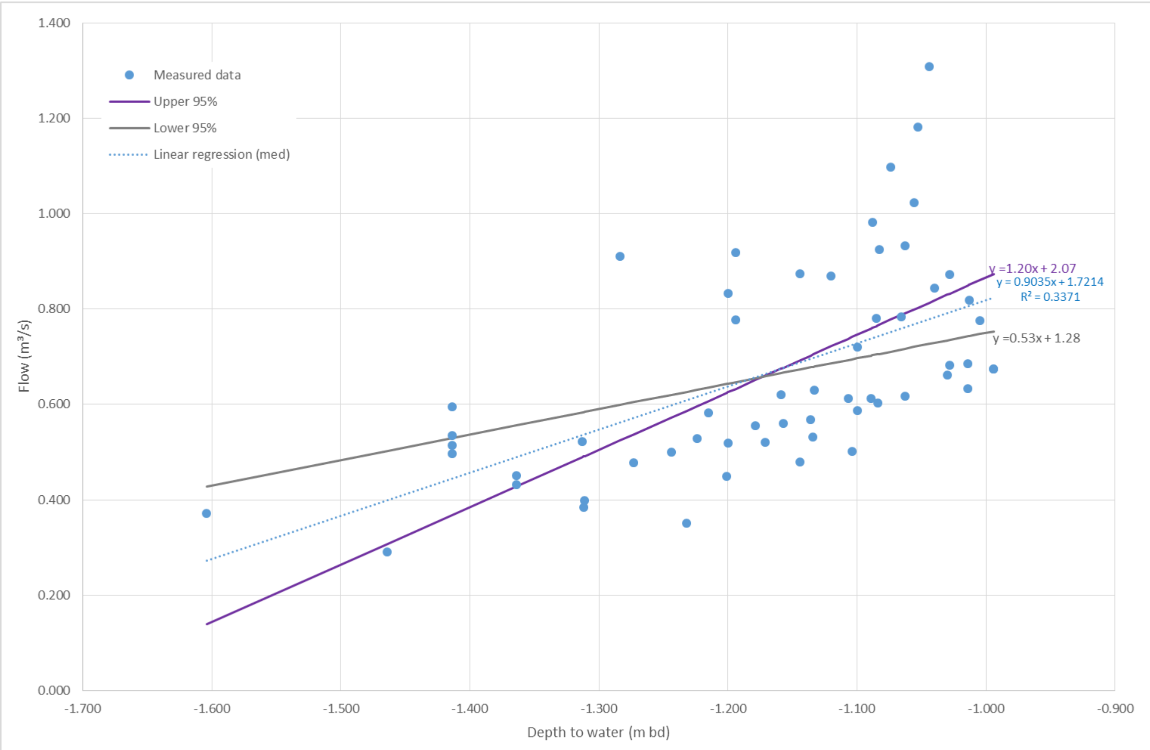

Figure A6-5: M35/0596 groundwater level vs Ohoka Stream flow

[23] Because groundwater level readings and flows were not measured at the same time we assumed that any groundwater level reading taken within 30 days of a manual flow gauging date was valid for the analysis.

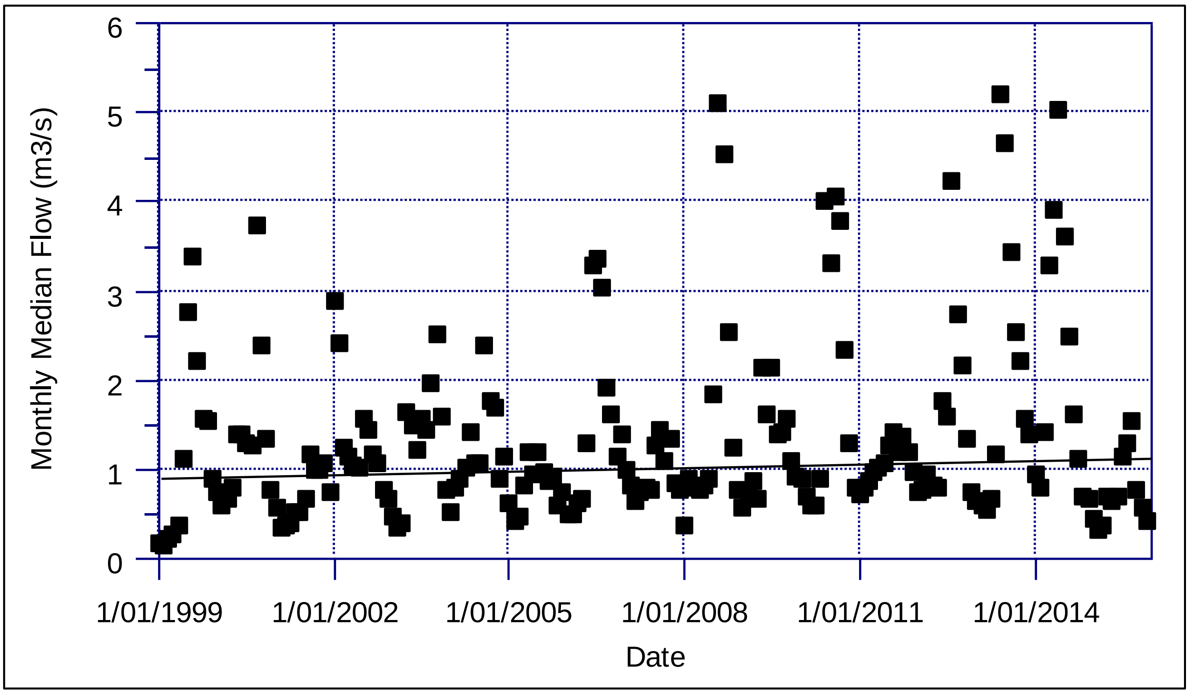

Figure A6-6: Seasonal Mann-Kendal trend analysis for Cust Main Drain (from 1999 to 2015)

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