Waterways
Centre for Freshwater Management

The extent of the dry reaches in tributaries of the Avon/Ōtākaro River

Summer Scholarship Report

WCFM Report 2017-004

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH • NEW ZEALAND
New Zealand's specialist land-based university

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

REPORT: WCFM Report 2017-004

TITLE: **The extent of the dry reaches in tributaries of the Avon/Ōtākaro River**

PREPARED FOR: Carl Hansen & Maureen Whalen (Environment Canterbury)

PREPARED BY: **Irene Setiawan** BAgSc

REVIEW & FINAL EDITING BY: Dr Leanne Morgan & Prof Jenny Webster-Brown

AFFILIATION: Waterways Centre for Freshwater Management
University of Canterbury & Lincoln University
Private Bag 4800
Christchurch
New Zealand

DATE: **21 September, 2017**

Executive Summary

The purpose of this study was to systematically survey the upper tributaries of the Avon/Ōtākaro River in Christchurch, to identify the current extent of the dry reaches. The Avon/Ōtākaro River tributaries are fed by shallow groundwater from the Christchurch-West Melton aquifer system, via artesian springs and seepage through soils and stream bed gravels. The flow in these tributaries had been observed to be particularly low in the summer of 2015/2016, with unusually extensive dry reaches being reported throughout the upper catchment.

For all of the major tributaries of the Avon/Ōtākaro River, the point at which flow commenced was located and mapped, and the source of flow identified. Where possible flow rates and length of the flowing reaches were measured and compared to previous flow data. Contextual data on rainfall, depth to the groundwater table, water use and discharge consents and height, and spring flows were compiled to test relationships with stream flow.

The investigation found that there was a significant downstream migration in the position that flow commenced (via active springs or seepage) between 1980 and 1985, in most of the streams in the upper Avon/Ōtākaro catchment for which the 1980 data were available. This included Hewlings, Wairarapa, Wai-iti and Waimairi streams, as well as Taylors drain. Since 1985, flow has commenced in or around the same position, or has only slightly recovered (moved upstream again) in most of these streams. In Okeover Stream, Avon/Ōtākaro River main stem (and in Cross Drain) the most recent summer flows commenced downstream of their position prior to 2001. Ilam Stream was the only stream where the position of flow commencement has moved upstream since 1993, and this appears likely to be due to contribution of Waimakariri River water from the Paparua stockwater channel.

A correlation was found between stream flow data and groundwater level in the upper catchment. The significant change in flow commencement position between 1980 and 1985 may be at least partially due to a very dry period prior to 1985, and low groundwater levels at this time. However, the fact that flow has not recovered in most of the streams since this time, suggests that higher density housing and groundwater extraction in this part of the catchment may be continuing to depress groundwater levels.

Table of contents

Section 1 Introduction

The base flows of the Avon/Ōtākaro River and its tributaries are sustained by shallow groundwater seepage and springs emanating from the Christchurch-West Melton aquifers (Scott, 2000). The flow in the headwater tributaries typically fluctuates seasonally, but had been observed to be particularly low in the summer of 2015/2016. There were extensive dry reaches in urban streams which were deemed highly unusual by concerned residents (Salmons, 2016). This study was initiated to determine how unusual this occurrence was, in the context of previous monitoring information, and identify possible reasons for the low flow.

1.1 Avon/Ōtākaro River hydrology and hydrogeology

The city of Christchurch sits on top of a layered confined aquifer system (Environment Canterbury, 2001). The uppermost confined aquifer (Aquifer 1) plays an important role in sustaining the base flow of the Avon/Ōtākaro River and its tributaries. This shallow aquifer generates the groundwater pressure that enables artesian springs to flow, and shallow seepage through soils and stream beds to occur (Environment Canterbury, 2001). In terms of a water budget, the inflows to the shallow urban aquifer system are estimated as; 60% of the seepage from the base of the Waimakariri River, 35% rainfall recharge that occurs mainly during winter periods and 5% seepage from the base of the Paparua stock water race system (Environment Canterbury, 2001). Outflow from the aquifer is estimated as 55% to springs in the urban area, 20% groundwater outflow to the south and to the seabed, and 25% extraction through wells for public reticulated supply, industrial and irrigation purposes (Environment Canterbury, 2001).

The Avon/Ōtākaro River base flow fluctuates seasonally, responding to the seasonal fluctuations in shallow groundwater levels (Cameron, 1992). However, Daglish (1985) and Cameron (1992) also noted that the lengths of flowing reaches and their flow rates decreased between 1980 to 1992; a continuation of a longer term decline in the Avon/Ōtākaro River's base flow since the European settlement in Christchurch in the 1850's, based on anecdotal and historical evidence (Cameron, 1992). Dry reaches in the tributaries have been increasingly frequent over this time (Daly, 2001, 2006; Environment Canterbury, 2001).

This trend has been attributed to factors such as extraction, urbanisation and climate variations (Jenkins, 2016). As well as increasing the demand for groundwater, urbanisation leads to increased impermeable surfaces, such as roads and roofs, which decreases infiltration capacity and enhances surface runoff rates, thereby reducing groundwater recharge (Cameron, 1992). Variations in rainfall and temperature also affect base flow in spring-fed streams. A dry period, particularly over winter, decreases groundwater recharge by rainfall, and lowers groundwater levels. The usual winter recharge peak in groundwater level was absent in winter 2015 (Jenkins, 2016; Webster-Brown & Barr, 2016), and again in 2016 (Environment Canterbury, 2017). Over this period rainfall was markedly below average, and failed to recharge the shallow aquifer system.

1.2 Research aims and objectives

The purpose of this research was to determine whether the dry reaches in the tributaries of the upper Avon/Ōtākaro have expanded in recent years, and if so, to identify the likely cause.

The research objectives were to;

i. Identify where flow commences and the source of flow
ii. Map the location and elevation of flow commencement
iii. Measure the flow volume and channel depth
iv. Compare collected data with that of previous investigations
v. Compile contextual data on rainfall, groundwater table, local water extraction and discharge consents and compare with stream flow characteristics.

Section 2 Methodology

The field survey of the Avon/Ōtākaro River and its tributaries took place between December 2016 and January 2017, during the low (base) flow period. The tributaries that are the main focus of this study are located in the western area of the catchment, and included the following streams: Ilam, Waimairi, Okeover, Wairarapa, Wai-iti and Hewlings, as well as constructed drains: Fendalton, Taylors and Cross Drains, and the main stem of the Avon/Ōtākaro River. The survey identified the positions of springs that contribute to the headwaters, as well as the flow rate, water velocity, surface water elevation, mean water temperature, channel depth and width close to the position at which flow commenced in the stream.

2.1 Measurement of dry reach extent and stream flows

The extent of dry reaches of the Avon/Ōtākaro River tributaries were determined by walking the length of the tributaries and recording the locations where flow commenced, and the extent of the dry bed. The survey did not include parts of the stream that could only be accessed via private property.

Table 1. Measurements taken and equipment used in the dry reach survey of the upper Avon/Ōtākaro catchment.

Measurements	**Equipment**
Water discharge/flow rate	SonTek FlowTracker Handheld ADV
Mean water velocity	SonTek FlowTracker Handheld ADV
Channel cross-section area	SonTek FlowTracker Handheld ADV
Stream water surface elevation	Trimble GeoExplorer 6000 Series
Stage & water depth	Visual readings on wading rod or ruler
Channel width	Tape measure
Location coordinates	Trimble GeoExplorer 6000 Series

Flow measurement sites are shown in Figure 1, with details given in Table 2. Sites were chosen based on the sites described in Daglish (1985), Cameron (1992) and recent monitoring of surface flows by Environmental Canterbury (hereafter referred to as "ECan"). Flow was measured at these sites using a SonTek FlowTracker Handheld ADV to measure water velocity, and channel width and depth were measured to calculate cross sectional area. Discharge was then calculated using the mean-section method. ECan data include SonTek FlowTracker Handheld ADV measurements taken since January

2009 (gauging logger (glogger) measurements were used 2004-2009). The Sontek instrument used in this study was therefore calibrated twice against ECan's similar instrument. Results obtained for the same sites at 5 minute intervals showed only a 1-3% difference, confirming the field survey results to be comparable to the ECan data. Flow measurement sites used by ECan, but accessed via private property and construction areas, were not gauged in this study

Surface water elevation and the depth of stream water were also measured where flow commenced, usually immediately downstream of the springs. A ruler was used to measure stream depth by measuring random points close to the spring area. GPS coordinates were recorded, to unambiguously identify the location of flow commencement. Mean water temperature was measured to supplement the ECan database.

Table 2. Flow gauging site location details. Note that sites 66638, 66642, 66647 & 66648, were located in private properties or construction areas.

Site No.	Waterway	Location	Coordinates (NZGD2000)		Coordinates (NZTM2000)	
			Latitude	Longitude	Northing	Easting
66635	Addington drain	Hagley Park	43°31'55.3"S	172°37'23.0"E	5180033	1569542
66636	Riccarton drain	Near Riccarton Ave at Hagley Park	43°31'54.8"S	172°37'05.5"E	5180046	1569149
66637	Avon/ Ōtākaro River	Harakeke St bridge	43°31'26.84"S	172°36'18.17"E	5180904	1568083
66638	Avon/ Ōtākaro River	University of Canterbury (UC), on University Dr in front of Rec Centre	43°31'31.65"S	172°34'56.14"E	5180747	1566242
66640	Okeover Stream	UC, behind Forestry Building	43°31'23.20"S	172°35'12.86"E	5181009	1566616
66641	Waimairi Stream	Daresbury Park	43°31'17.1"S	172°36'13.6"E	5181202	1567979
66642	Fendalton Drain	7 Royd Street	43°31'15.53"S	172°36'7.17"E	5181252	1567834
66643	Waimairi Stream South Branch	Barlow Street	43°31'5.39"S	172°34'56.77"E	5181557	1566252
66644	Waimairi Stream	Coldstream Court	43°31'4.80"S	172°34'57.04"E	5181575	1566258
66645	Wairarapa Stream	Garden Road bridge	43°31'2.04"S	172°36'37.28"E	5181671	1568508
66646	Taylors Drain	Elmwood Park	43°30'46.28"S	172°36'35.61"E	5182157	1568469
66647	Wairarapa Stream	42 Gleneagles Terrace	43°30'45.71"S	172°35'20.35"E	5182166	1566779
66648	Wai-iti Stream	218 Clyde Road	43°30'42.33"S	172°35'25.31"E	5182271	1566890
66649	Wairarapa Stream	Lake Outlet at Jellie Park	43°30'28.64"S	172°34'59.06"E	5182691	1566298
66650	Avon/ Ōtākaro River	Ilam Road	43°31'25.08"S	172°34'44.15"E	5180948	1565972
66651	Okeover Stream	Downstream Dewatering Pipe	43°31'17.36"S	172°34'48.23"E	5181186	1566063
66602	Avon/ Ōtākaro River	Gloucester Street Bridge	43°31'34.55"S	172°39'2.04"E	5180682	1571763

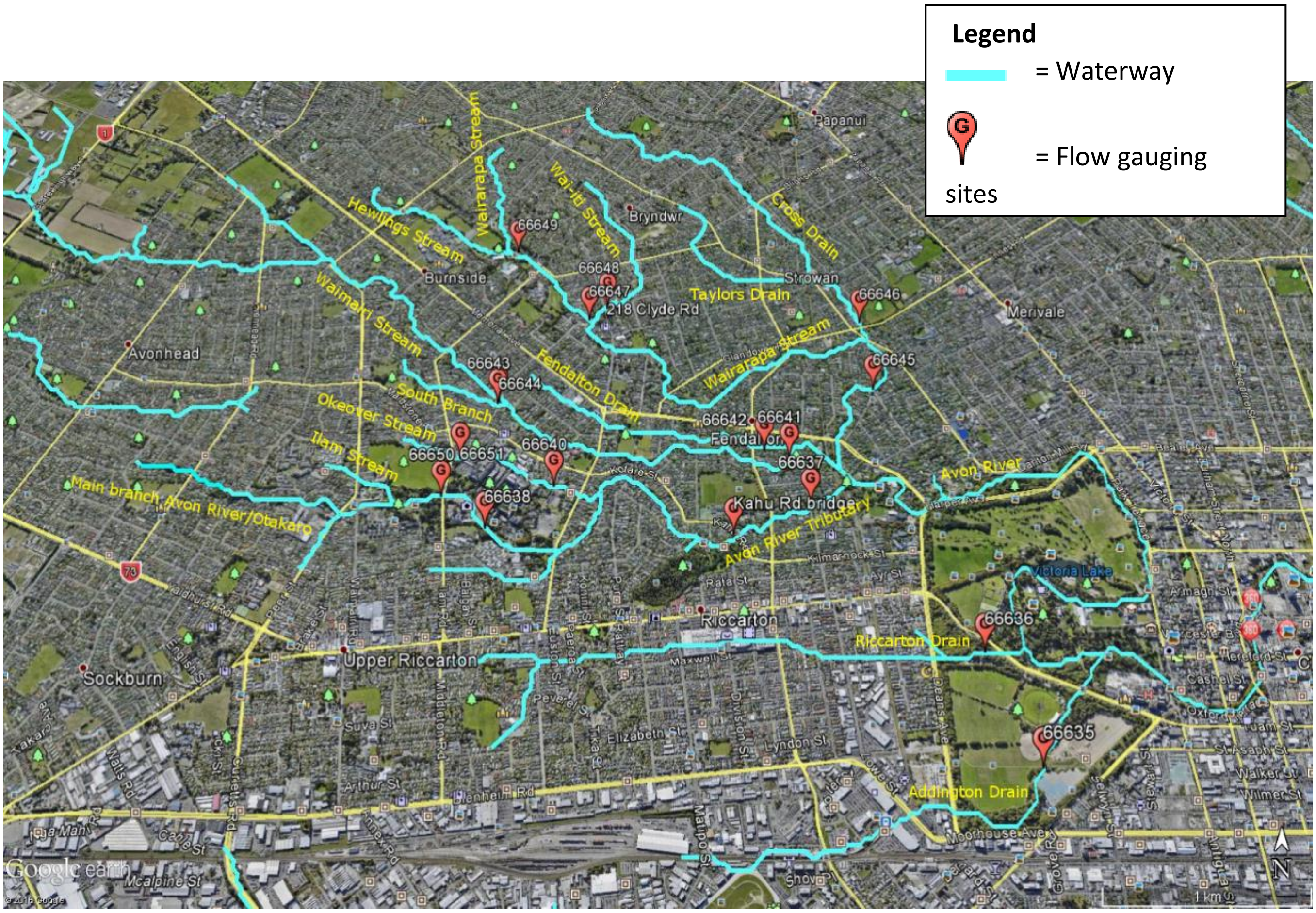


Figure 1. Map of flow gauging sites used in this study, in the upper catchment of the Avon/Ōtākaro River, showing site identifiers (666XX) and stream names. Refer Table 2 for details, and Appendix E for a larger version of the same map.

2.2 Map creation

The maps shown in this report were created using Google Earth 6.2.2.6613, with river positions mainly sourced from ECan maps. Maps indicating the headwater or flow commencement sites from previous investigations were overlaid on the current map to compare headwater sites and their migration with time.

2.3 Comparison with historical data

The earliest data documenting flow commencement positions for this catchment is that of the Christchurch Drainage Board (1980), which has been assumed to have been collected during the summer of 1979/80. The next study was by Daglish (1985) which occurred in April. Thereafter Cameron (1992) monitored base flow conditions in the summer of 1992 and 1993. Notably the water table in the summer of 1991/92 was higher than that of 1985, which had been one of the lowest in the 25 year record (Cameron, 1992). The most recent study was that of Daly (2001), undertaken in February to March of 1999-2001, during low flow conditions. Currently, ECan undertakes long-term regular flow gauging runs and groundwater level measurements (ECan 2017).

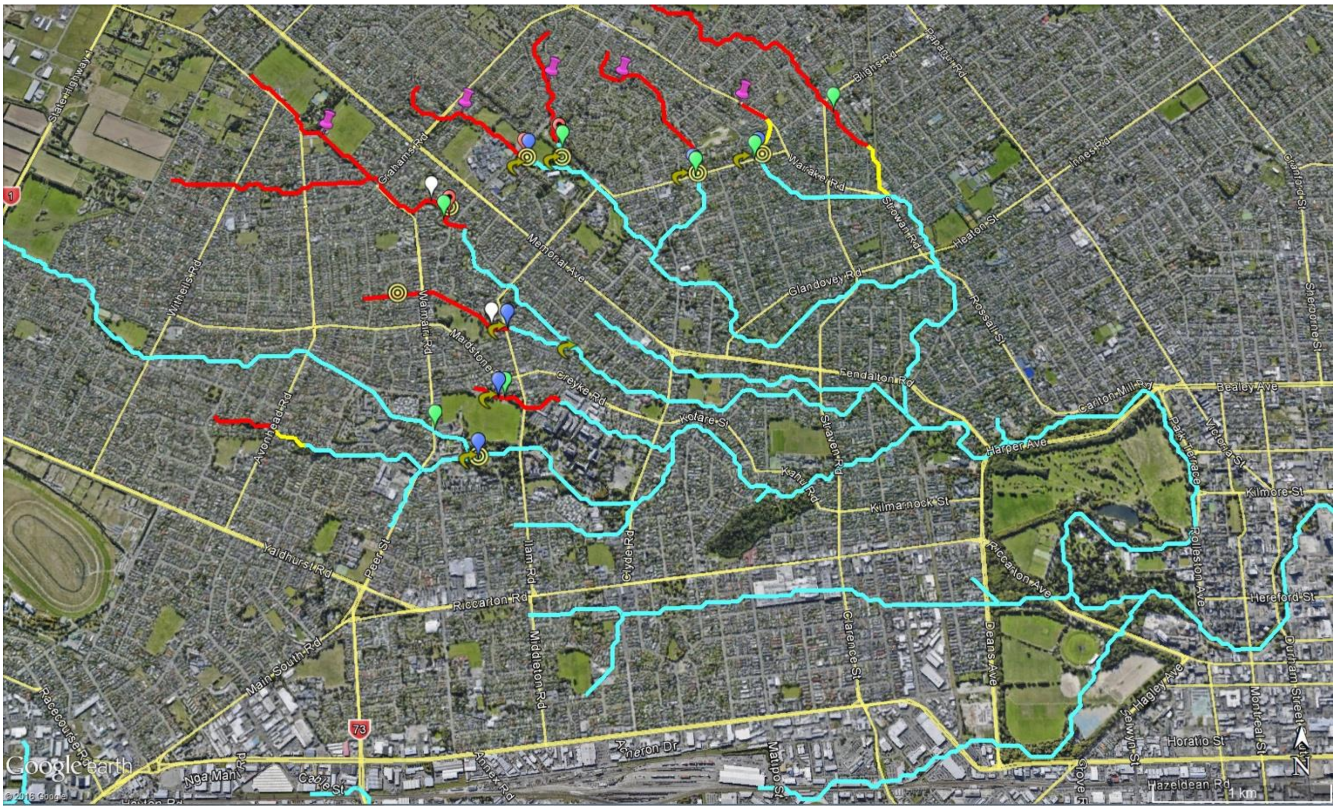
Comparable historical data were acquired from these sources to compare and extend trends identified in this study. The maps of headwater or flow commencement locations from the previous studies lacked location coordinates, so locations have been based on descriptions and therefore may have only a moderate accuracy.

All rainfall records were derived from the CliFlo database (NIWA, 2017). The rainfall data from the earliest record until 1 November 2016 were for the Christchurch Gardens weather station (station number 4858). The rainfall data from 2 November 2016 on were from the Kyle St weather station (number 24120). Note that neither of these weather stations were located in the groundwater recharge area, which lies out to the west of Christchurch city.

Section 3 Results & Discussion

3.1. Dry reach position and extent

The locations of the dry reaches in the summer of 2016/17 are shown in Figure 2. The flow commencement locations are represented by the transition from a red (dry) to blue (wet) line, as stream flows are from NW to SE. Yellow lines represent the area of stream bed that was unable to be investigated. The GPS coordinates of the flow commencement locations along with photographic evidence are shown in Table 3.



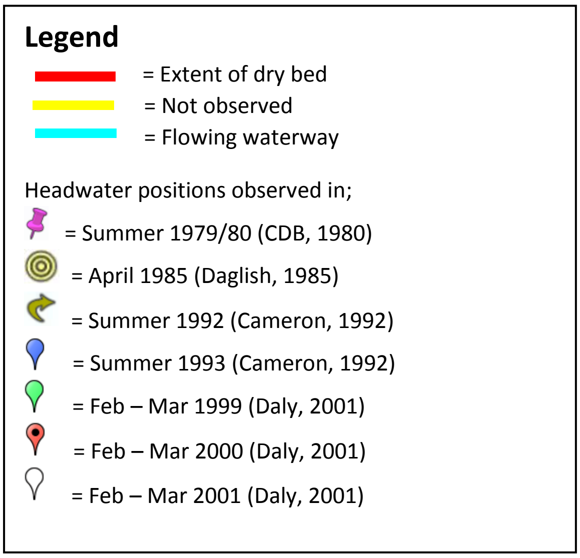


Figure 2. Wet (blue) and dry (red) reaches of the tributaries of the Avon/ Ōtākaro River, as measured over the period December 2016 to February 2017. Refer Table 3 for details, and Appendix E for a larger version of the same map.

The historical headwater positions during low flow conditions, derived from the Christchurch Drainage Board (1980), Daglish (1985), Cameron (1992) and Daly (2001), are also shown. The dry reaches of Riccarton Drain, Addington Drain and Fendalton Drain or Drain 23 were not identified.

Table 3. Flow commencement positions and associated monitoring information, as measured in summer 2016/17.

Waterway	NZTM2000 Coord: Northing Easting	Horizontal accuracy (m)	Time and Date	Location	Flow commence-ment	Photo
Wai-iti Stream	5182642.194 1567045.857	0.2	11.15 am 11/01/17	Brookside Tce	Immediately downstream of this location	
Hewlings Stream	5182745.647 1566005.942	0.1	11.53 am 14/12/16	Jellie Park	Immediately downstream of this location	
Wairarapa Stream	5182849.255 1566207.202	0.4	2.15pm 14/12/16	Jellie Park	Immediately downstream of this location	
Waimairi Stream	5182298 1565642 (Google Earth estimate)	N/A	12.41pm 5/01/17	30E Greers Rd	Immediately downstream of this location	
Waimairi south branch	5181665.808 1565918.419	0.2	10.08am 2/02/17	166 Ilam Rd	Immediately downstream of this location	
Avon/ Ōtākaro River main branch	5180957.993 1564714.7	1.2	12.33pm 9/12/16	Corfe Reserve	Immediately downstream of this location	

Okeover Stream	5181221 1566225 Estimated from Google Earth	N/A	13/01/17	1.43pm ~11m downstream of Engineering Rd footpath	Immediately downstream of location	
Taylors Drain	N/A		1.40pm 10/01/17	Along Wairakei Rd; Elmswood Retirement Village	Wairakei Rd - Ilam Rd	
Cross Drain	N/A		19/01/17	42 Westholme St	Westholme St - cycleway near 53 Strowan Rd	

3.2 Flow measurements

Stream discharge was measured as close as possible to the point of flow commencement in the stream, and ranged from 12 L/sec in Addington drain to over 370 L/sec in the main branch of the Avon/Ōtākaro River and in the Wairarapa Stream. There was also a ponded (zero flow) area of Waimairi Stream (Table 4). Temperatures ranged from 13.1 to 16.8°C, with the highest temperature measured in the shallow Addington Drain.

Table 4. Channel width (m), mean depth (m), velocity (m/sec) and calculated discharge (L/sec) measurements for flow gauging sites (as shown in Figure 1 and Table 2) .

Site No.	Waterway	Date	Width	Mean depth	Flow velocity	Discharge	Temperature
66635	Addington Drain	16/01/17	1.61	0.12	0.063	12.1	16.8
66636	Riccarton drain	16/01/17	1.18	0.29	0.215	73.2	14.8
66637	Avon/Ōtākaro River	13/12/16	3.20	0.46	0.255	376.8	13.5
66640	Okeover Stream	11/01/17	2.25	0.27	0.095	56.6	14.8
66641	Waimairi Stream	13/12/16	3.60	0.28	0.215	215.6	13.1
66643	Waimairi -South Branch	8/12/16	1.70	0.07	0.119	13.9	13.7
66644	Waimairi Stream	8/12/16	-	-	0	0	-
66645	Wairarapa Stream	6/12/16	6.60	0.26	0.223	378.5	14.9
66646	Taylors Drain	11/01/17	2.90	0.26	0.081	61.9	14.5
66649	Wairarapa Stream	14/12/16	1.14	0.07	0.766	62.7	14.4

3.3 Elevation of water surface

The elevation (masl) of the water surface was measured at key points in the catchments (Figure 3, Table 4) The highest elevation was measured on Ilam Stream (21.4 masl) to the west, and the lowest at the junction of Wairarapa Stream and Cross Drain in the east of the catchment (7.5 masl). Elevations specifically measured close to the point of flow commencement, ranged from 16.6 masl on the main branch of the Avon River in the west, to 11masl on Wai-iti Stream further east. Not all first flow commencement sites were assessed for elevation.

Water depth ranged from 5-6cm in the upper reaches (in Wai-iti Stream for example) to 40cm in lower Wairarapa Stream.

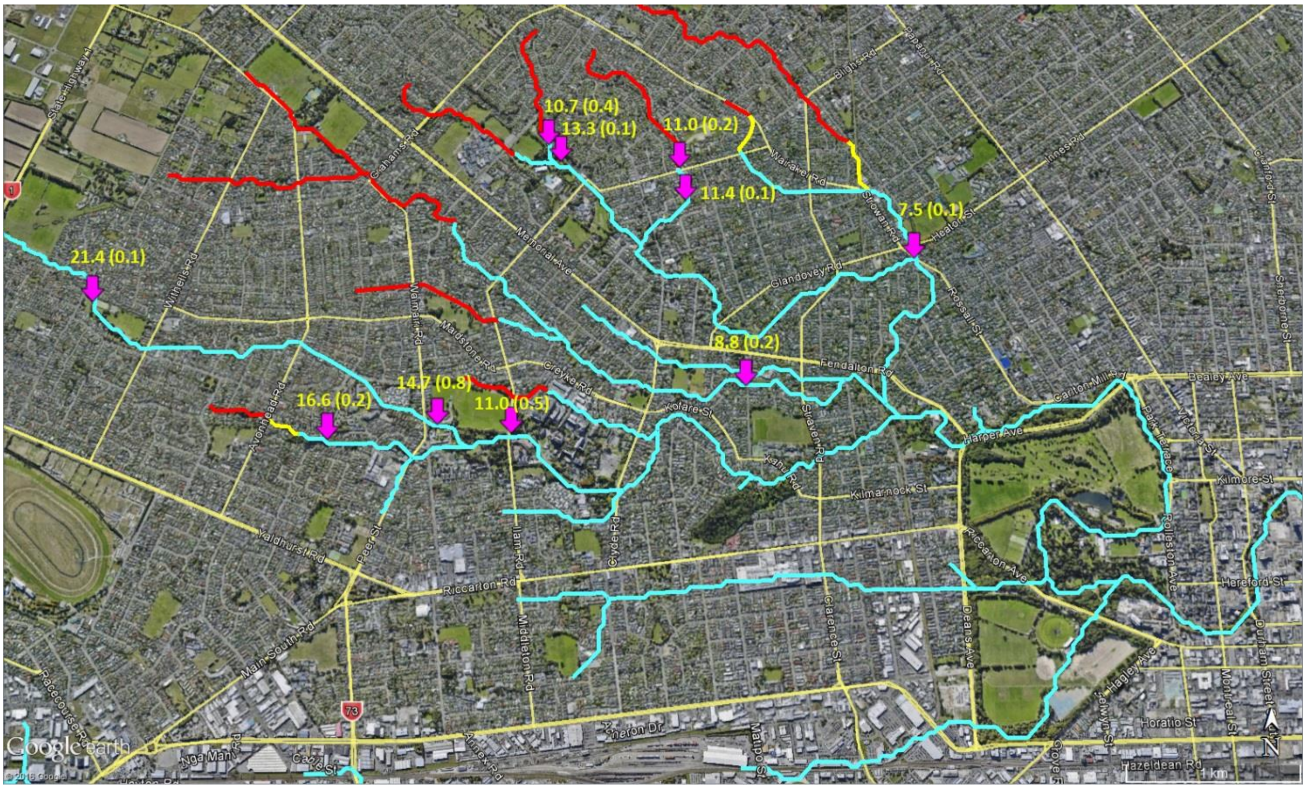
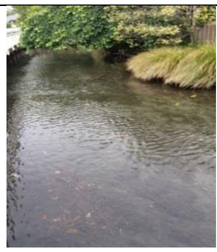


Figure 3 Map of elevation data (global DMA 10x10 geoid) in masl. Numbers in brackets indicate the vertical uncertainty (m). A larger version is given in Appendix E.

Table 4. Elevation of the water surface at specific sites in the tributaries of the upper Avon/Ōtākaro River, as measured in summer 2016/2017.

Waterway	NZTM2000 Coordinates: Northing Easting	Elevation (masl)	Vertical accuracy (± m)	Date	Water Depth (cm)	Notes	Photo
Wai-iti Stream	5182426.145 1567079.564	11.4	0.1	11:53am 7/12/16	~6	Surface water elevation of the riffle at Wai-iti Tce	
Wai-iti Stream	5182642.194 1567045.857	11.0	0.2	11.15am 11/01/17	Max 11, mean 9.5	Surface water elevation of the spring (flow commencement) at the corner of Brookside Tce and Ilam Rd. Spring flow was 3 L/s on April 1985 (Daglish, 1985).	
Wairarapa Stream	5182802.095 1566220.138	10.7	0.4	2.09pm 14/12/16	No record	Surface water elevation of the riffle flow at Jellie Park	No photo record
Wairarapa Stream	5181926.868 1567172.408	17.2	0.7	12.50pm 9/01/17	~20	Surface water elevation of the spring at Waiwetu Reserve.	
Wairarapa Stream	5182031.266 1568491.299	7.51	0.1	2.02pm 9/01/17	40	Surface water elevation of the stream with riffle flow at Rossall St, measured from the footpath	
Wairarapa Stream	5182690.744 1566298.142	13.3	0.1	10.28am 14/12/2016	Mean 9	Surface water elevation of the Jellie Park Lake Outlet site 66649	

Waimairi Stream	5181239.343 1567425.949	8.8	0.2	4.07pm 9/01/17	~5	Surface water elevation of the stream with riffle flow at Tui St	
Ilam Stream	5181810.340 1563420.854	21.4	0.1	1.57pm 6/01/17	No record	Surface water elevation of the stream at Crosbie Park; this was not the point of flow commencement	
Ilam Stream	5181022.533 1565559.405	14.7	0.8	3.50pm 13/01/17	Max 17	Surface water elevation of the spring at Waimairi Village on Waimairi Rd	
Avon/ Ōtākaro River main branch	5180938.548 1564901.223	16.557	0.2	1.05pm 16/01/17	Mean 5.3	Surface water elevation of the spring at Corfe St near the walkway bridge	
Avon/ Ōtākaro River main branch	5180964.387 1566005.171	10.988	0.5	10.04am 9/12/2016	No record	Surface water elevation of the spring at University Dr, UC	

3.4 Comparisons with historical and consented discharge data

The following section relates flow commencement locations noted in summer 2016/2017 to those reported in previous studies, in the context of information about water take and discharge consents that may be affecting flow conditions (details given in Appendix D).

3.4.1. Hewlings Stream

The flow commencement position in Hewlings Stream has changed little since 1985, but had previously moved more than 500m downstream from the first records, prior to 1980 (Figure 4). The transition between dry and wet stream beds occurred within Jellie Park between 1985 and 2016, whereas the location of the headwater prior to 1980 was approximately 540 m upstream. The Jellie Park lake, fed by groundwater seepage, is the immediate source of flow in Hewlings Stream. When visited in December 2016 only stagnant water was found upstream of the lake. Anecdotal information indicated that Hewlings Stream has been routinely dry during dry weather since 1972, however a base flow of 35 L/s was reported for summer 1992-1993 (Cameron, 1992).

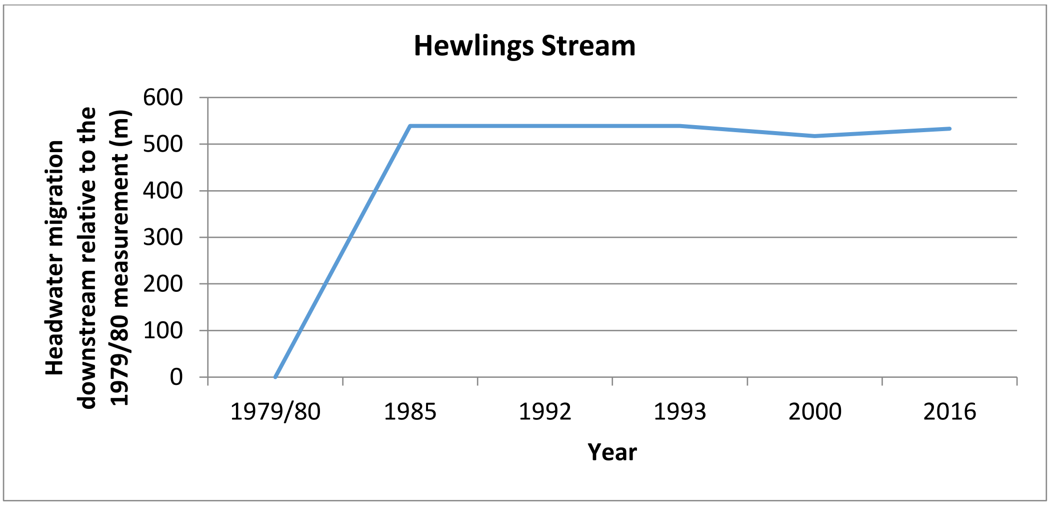


Figure 4. Hewlings Stream headwater migration downstream after 1980.

3.4.2 Wairarapa Stream

Since 1985, the flow in Wairarapa Stream has consistently commenced in Jellie Park, but the exact point has moved progressively downstream in recent years (Figure 5). The most obvious source of flow in the Wairarapa Stream is the Jellie Park lake outlet (site 66649). Daglish (1985) estimated the flow to be 50 L/s in April 1985, and discharge has averaged 53 L/s since 1992. The flow measured in this study was somewhat higher, at 63 L/sec. Cameron (1992) indicated that groundwater enters the Wairarapa Stream (upstream of the lake outlet) by seepage through stream bed gravels. A spring downstream of the lake outlet was noted by ECan (spring number M35/8072, Canterbury Maps, 2017b).

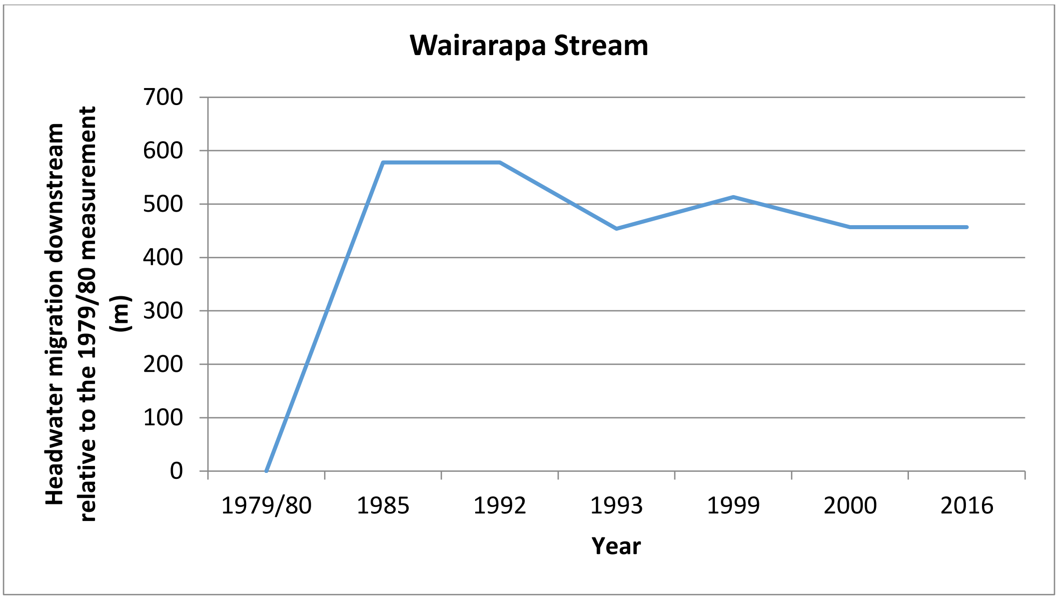


Figure 5. Wairarapa Stream headwater migration downstream after 1980.

The lake outlet at Jellie Park delivers artificial discharge from a swimming pool system into the Wairarapa Stream, at a consented maximum volume of 1,600 m^3/day and rate of 20 L/s (Canterbury Maps, 2017a). At the Garden Road Bridge there were artesian springs present upstream of the gauging site on Bradnor Street (Cameron, 1992), and some bubbling from the stream bed was observed during this study. Active discharge consents upstream of the gauging location include contaminated water (Christchurch City Council, unspecified amount).

At 42 Gleneagles Terrace Cameron (1992) indicated that the groundwater enters through seepage upstream of this site. The stream seepage areas upstream of Jellie Park in both Hewlings and Wairarapa Streams were historically found to be dry during summer (Figure 2).

3.4.3 Wai-iti Stream

The location of summer flow commencement in Wai-iti Stream has been constant since 1985 (Figure 6), but had previously migrated 900 m downstream after 1980 (Christchurch Drainage Board, 1980). Between 1985 and 2017 the headwaters were consistently located near the intersection of Brookside Terrace and Ilam Road. ECan noted the existence of a small artesian spring (M35/8072) approximately 40 m upstream of the current headwater location in May 1998, and Daglish (1985) had estimated the spring flow to be 3 L/s in April 1985. In this study a dry bed with wet sediment was found where Cameron (1992) reported groundwater seepage into the stream along Brookside Terrace. ECan reported that the flow gauging site 66648 on Clyde Road (Figure 1) downstream of the 2017 summer headwater location, was dry on multiple occasions from 16 January 2012 to 1 March 2016 (including through the 2015 winter). This indicates that the Wai-iti Stream dry reach has been more extensive than was recorded in this and previous studies. Wai-iti Stream does not receive artificial discharge (Canterbury Maps, 2017a).

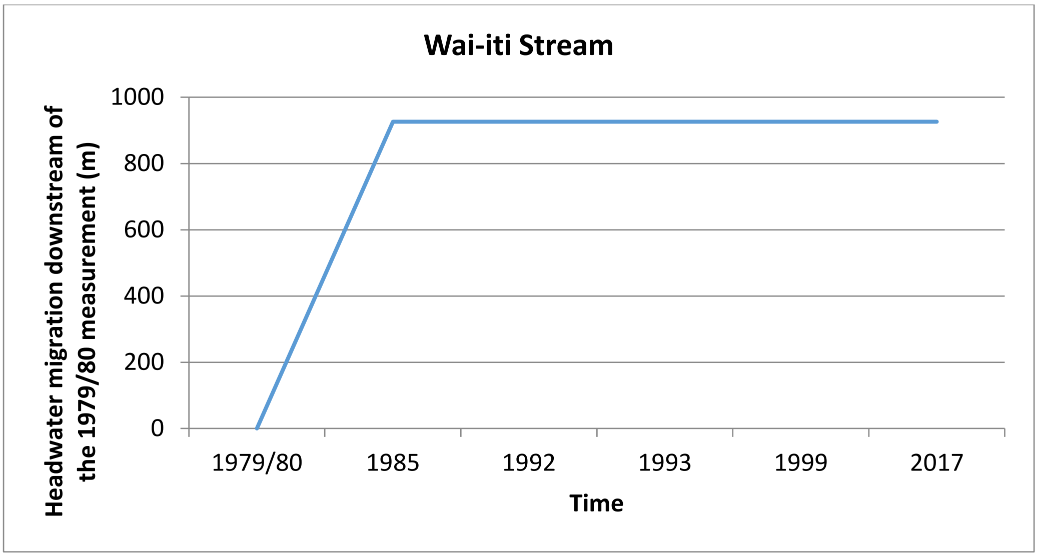


Figure 6. Wai-iti Stream headwater migration downstream after 1980

3.4.4. Okeover stream

The Okeover Stream flowing channel length has decreased significantly over the last 20 years. During this study, the Okeover Stream headwaters were located over 1 km downstream of the 1992 flow commencement point (Figure 7). The obvious sources of flow to the stream were the cooling waters discharging from University of Canterbury. The dry bed upstream of the discharging pipes had moist earth and there were few deep puddles, but this had previously been identified as an active spring area on Okeover Stream (Cameron, 1992).

Groundwater extraction by the university occurs from 12 wells located in the University grounds close to both to the Okeover Stream and the Avon/Ōtākaro River (Canterbury Maps, 2017a). Okeover stream receives artificial discharges from UC such as cooling water from the air-conditioning system (maximum volume 1,300 m^3/day, maximum rate 31 L/s) and dewatering water for the construction of the 'New Education Building' (unspecified amount) (Canterbury Maps, 2017a). During summer, this artificial discharge comprises the majority of flow source (Cameron, 1992). Okeover Stream has several artesian spring vents (Cameron, 1992) but those that were upstream of Engineering Road and in front of the Engineering Wing at the university were not observed to be flowing in this 2016/17 study.

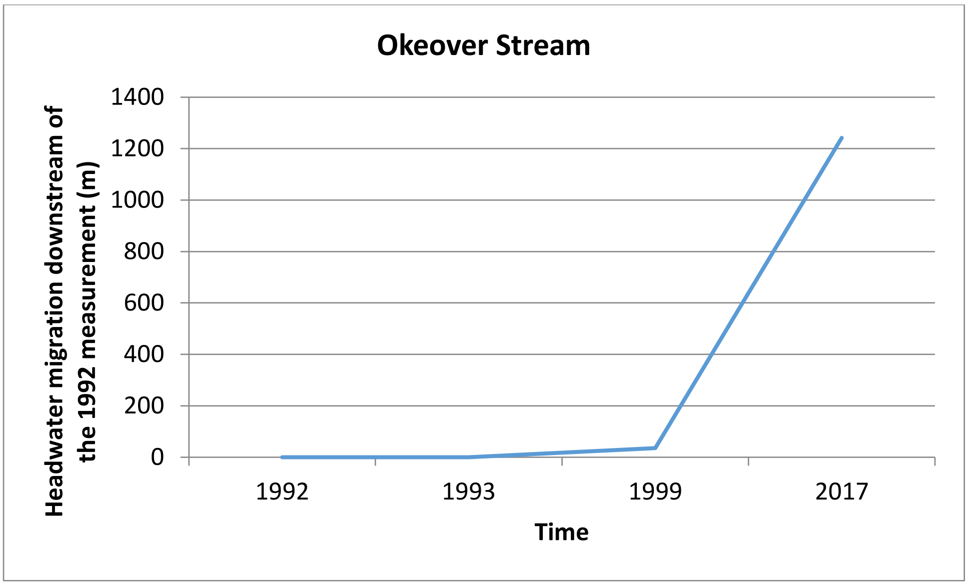


Figure 7. Wairarapa Stream headwater migration downstream after 1980

3.4.5 Ilam Stream

In January 2017, flow commenced in Ilam Stream approximately 3.5 km further *upstream* than the 1985 - 1993 headwater location (Figure 8). This is the only stream in this study where channel length has increased since 1985 (there were no data for earlier). Flow commenced in Avonhead Park, sourced from a drain under the State Highway 1. It is highly likely that the source of this flow is the Paparua stockwater scheme, originally fed from the Waimakariri River (Selwyn District Council, 2013).

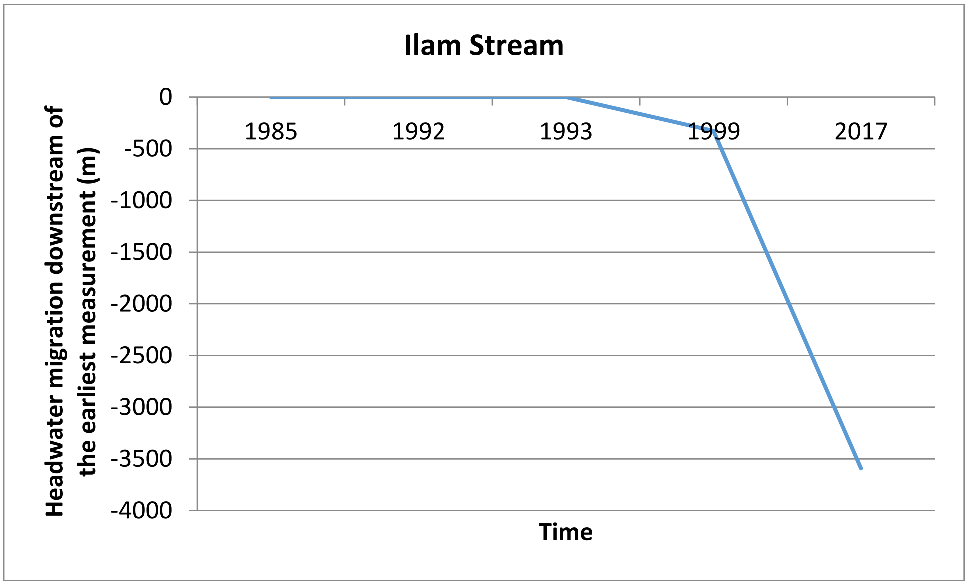


Figure 8. Ilam Stream headwater migration downstream after 1980

3.4.6 Waimairi Stream

The headwaters of Waimairi Stream moved significantly downstream between 1980 and 1992 when the channel length was at its shortest (Figure 9), but recovered after 1992. In 1999 the flow commenced approximately 1.3km upstream of the 1992 position, and has fluctuated little since then. Springs have been reported on the stream along Greers Road by ECan (spring numbers M35/8004, M35/8005 and M35/8006; Canterbury Maps, 2017b), but these spring sites were found to be dry in this study. They had also been found to be dry during the autumn of 1998, but flowing in the spring of 2010 by ECan. Daglish (1985) noted that the spring flow alongside Greers Road was estimated to be 5 L/s in April 1985.

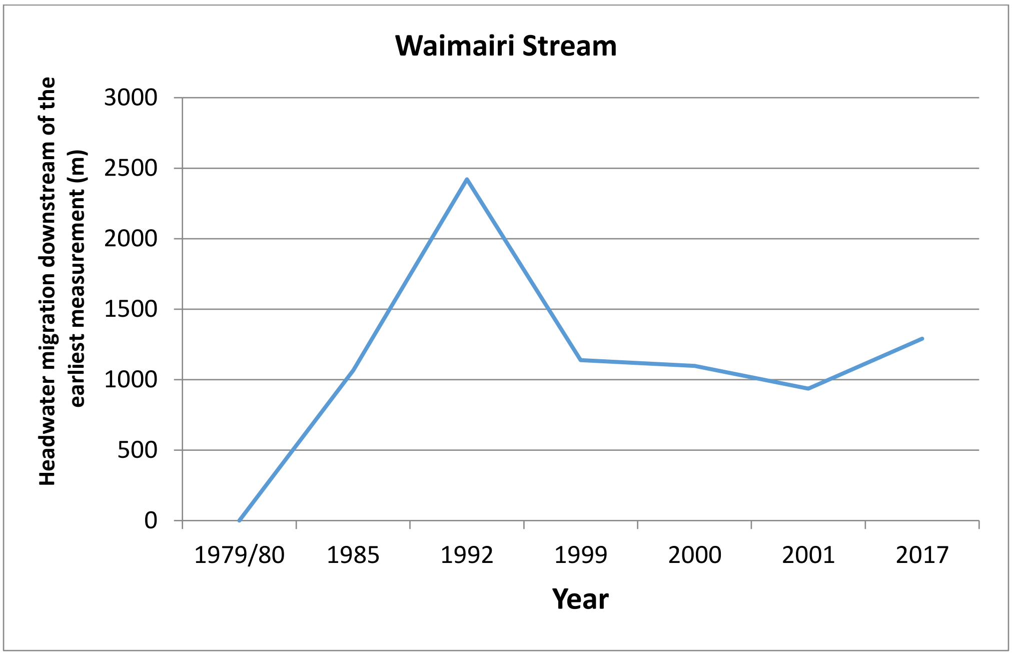


Figure 9. Waimairi Stream headwater migration downstream after 1980

Waimairi South Branch

In 1992, flow commenced in the south branch of Waimairi Stream approximately 2.5km downstream of the 1985 site. As in the main branch of the Waimairi Stream, channel length then increased as the headwater had moved upstream again in 1999 (Figure 9), and has remained relatively stable since. Notably the headwaters in 2001 were approximately 100 m upstream of their 2017 position. Cameron (1992) indicated that the groundwater enters the stream through artesian springs upstream of 1992, 1993 and 2017 flow commencement locations, and via seepage downstream of these sites, but the stream was found to be dry upstream of Ilam Road during this study. At Coldstream Court the stream was found to be stagnant on five occasions between August 2016 – January 2017 by ECan, and on one occasion during this investigation (Table 3). No active discharge consents to the stream were found on Canterbury Maps (2017a).

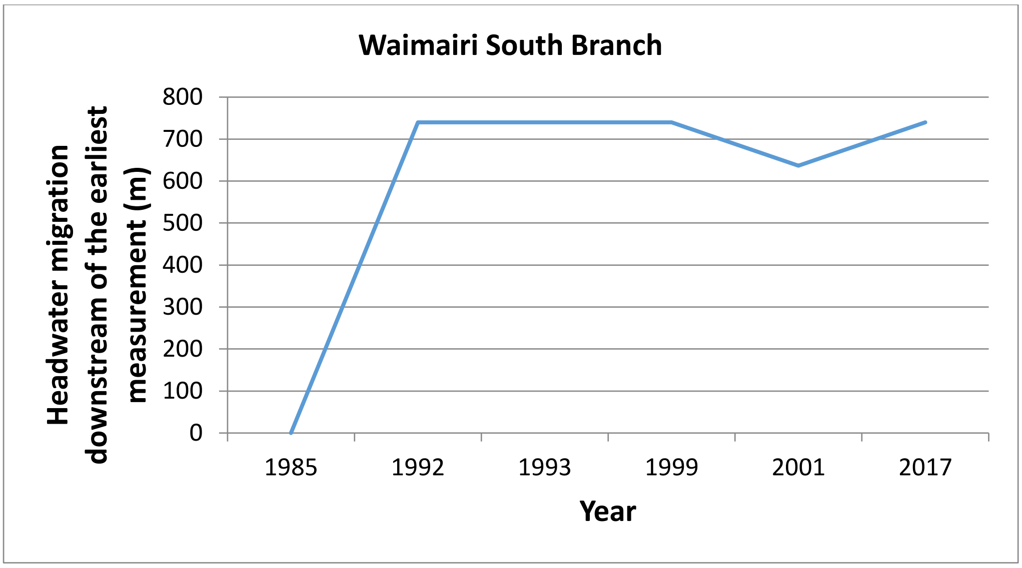


Figure 10. Waimairi Stream headwater migration downstream after 1985

3.4.7 Avon/ Ōtākaro River (main branch)

The main branch tributary of the Avon/Ōtākaro River maintained a constant channel length from 1980 until 2001 (Figure 11). Cameron (1992) indicated that flow was maintained at least partially by stormwater drain discharge upstream of Avonhead Road. However, in this study, in December 2016 the Avon/Ōtākaro River was flowing (slowly) through Corfe Reserve, and the small side branch that led to a stormwater culvert was found to be dry. The river was found to be dry upstream of this location on Avonhead Road, but the exact location of flow commencement was not able to be located between Avonhead Road and Corfe Reserve.

In February 2017, flowing water was found at 41 Balrudry Street, which is upstream of Corfe Reserve, but there was no flow at Nortons Road, which is reported to be the usual headwaters. The December 2016 and January 2017 flow commencements positions were estimated to be at Avonhead Road and 41 Balrudry Street respectively.

The University of Canterbury is consented to discharge up to 948 m^3/day of stormwater at a maximum rate of 125 L/s into the Avon/Ōtākaro River upstream of the gauging site (Canterbury Maps, 2017a). The flow gauging site does not receive artificial discharge upstream and, according to Cameron (1992), the gauging site was located in the middle of a spring, with more springs located upstream of the confluence with Ilam Stream, such as in Corfe Reserve.

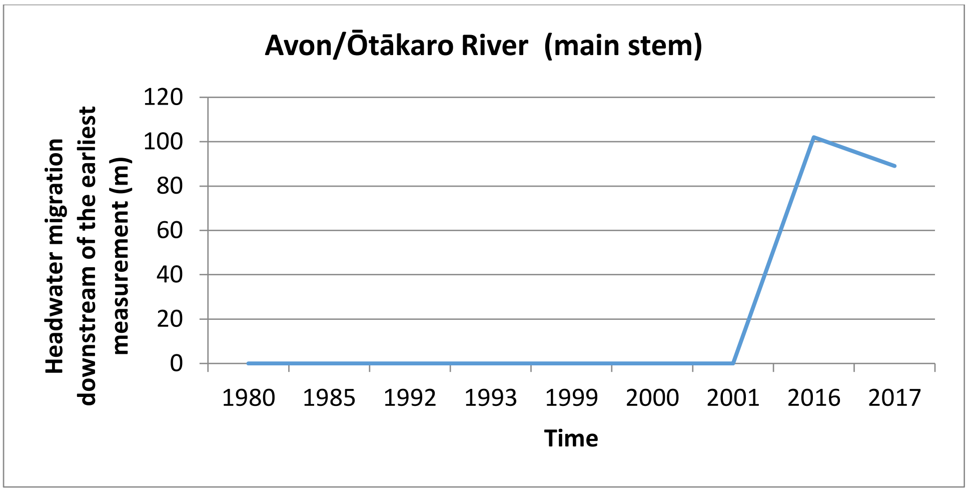


Figure 11. Avon/Ōtākaro River main stem headwater migration downstream after 1980

3.4.8 Taylors Drain

The exact headwater position in Taylors Drain could not be determined in January 2017, but the channel length has remained relatively consistent since 1985 (Figure 12). Taylors Drain is fed by groundwater seepage through stream bed gravels (Cameron, 1992), and no active discharge consents for use of the drain were found (Canterbury Maps, 2017a).

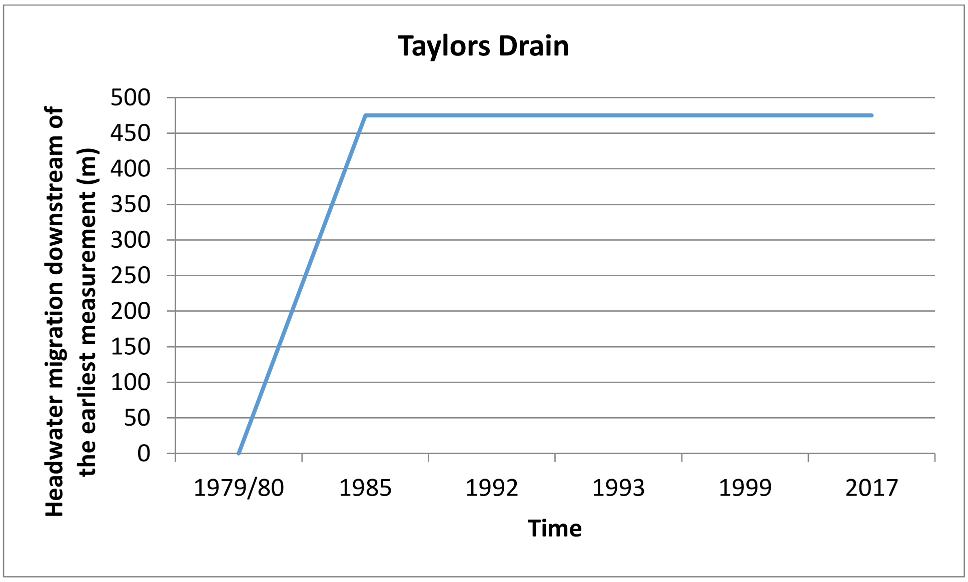


Figure 12 Taylors Drain headwater migration downstream after 1980

3.4.9 Cross Drain

The channel length in Cross Drain has reduced by an estimated 700 m, compared to its length in 1999 length (Figure 13).

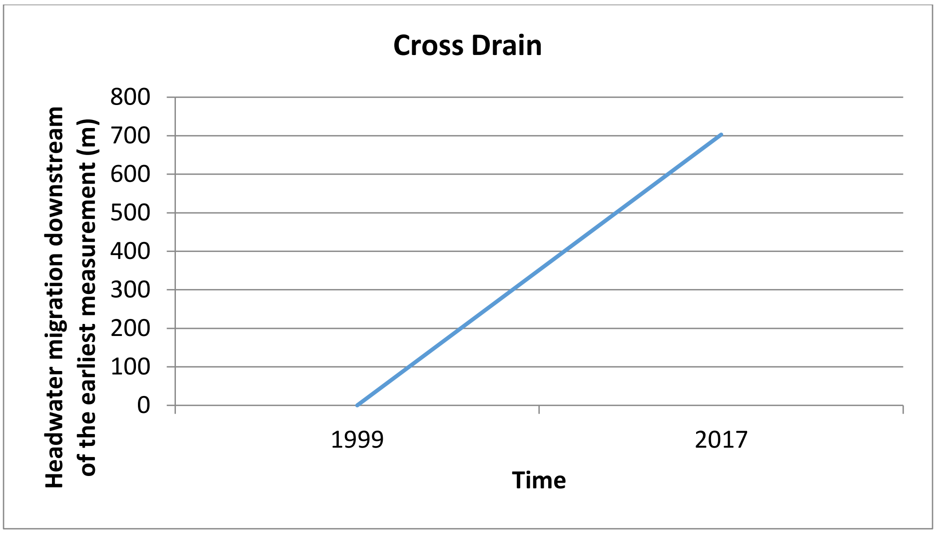


Figure 13. Cross drain headwater migration downstream after 1999

3.4.10 Addington Drain

There is little historical information on flow commencement locations in Addington Drain. There were no artesian springs reported in the constructed channel by Cameron (1992). Active discharge consents into Addington Drain includes the discharge of stormwater drainage (issued to Christchurch City Council and Ngai Tahu Property Limited), contaminants (issued to Orion New Zealand Limited) and water tracer (issued to EOS Ecology Limited) (Canterbury Maps, 2017a). The discharge rates were unspecified in Canterbury Maps (2017a).

3.4.11 Riccarton Drain

There is also little historical information available for Riccarton Drain. When assessed at Riccarton Ave on 16 January 2017 (11:30am), this drain was observed to have a tile drainage outlet on Deans Ave discharging continuously into the Drain. There were no springs observed in the channel. Active discharge consents into the Riccarton Drain include de-watering water during construction phase from Z Energy (Canterbury Maps, 2017a), for which the rate was unspecified.

3.4.12 Fendalton Drain or Drain 23 at 7 Royds Street (66642)

This drain is reported to be groundwater-fed by artesian spring flow (Cameron, 1992). The site was located in the artesian spring area.

3.5 Correlations with groundwater and rainfall data

Stream flow data derived from Cameron (1992), ECan gaugings and this study have been used to explore the relationship between flow and;

- Groundwater level
- Spring flow
- Rainfall

These are derived from the graphs shown in Appendix A.

3.5.1 Relationship with groundwater level and spring flow.

Table 5 shows the correlation coefficients (R^2 values) for the relationship between either year-round discharge rates or summer (Dec-Feb) discharge rates, and groundwater levels in well M35/5560. This well is in the Ilam Sports Fields, which is central to the upper Avon/Ōtākaro catchment. The stream flow records sourced from ECan span from the early 1990's up to present day. A high degree of scatter in the regression plot is expected, due to short term variability in both flow and groundwater levels, due to stormwater discharges and abstraction variability (Cameron, 1992).

The strongest correlations between stream flow and groundwater level were observed for the upper reaches of Waimairi Stream, Wairarapa Stream, Wai-iti Stream, Taylors Drain and the Avon/Ōtākaro River. This reflects stream flow principally generated from shallow groundwater, either via artesian springs or via seepage. An artesian spring is defined as water that flows out under pressure through openings or cracks in a confining layer that lies on top of an aquifer (Cameron, 1992; Schieferdecker, 1959). In this study, an artesian spring was identified as water bubbling from the ground. Seepage through stream bed gravels occurs at very low flows that are not obvious to the eye, but is evident when flow continually increases downstream in the absence of surface water inputs (Cameron, 1992). In this study, seepage was identified as the presence of wet earth on the stream beds and banks.

Poor correlations existed for stream flow and groundwater level in those streams affected by active discharge consents, such as the University of Canterbury's cooling water discharges (Okeover and the Avon/ Ōtākaro River downstream of this point) and the various drains. Wairarapa Stream at the lake outlet in Jellie Park also shows a poor correlation, likely due to flow being largely controlled by lake level.

An estimate of potential change in flow with time was also made from a best (linear) fit to the stream flow dataset (refer Appendix A, which shows the best fit trend for the flow data, which has been plotted together with rainfall data). The only waterways showing an increase in flow over time were the Avon River at University of Canterbury (likely due to increased cooling water discharges) and Wairarapa Stream at Jellie Park. Other streams either showed little change, or an apparent decrease in flow (Waimairi Stream, Wai-iti Stream, Talyors Drain and Fendalton Drain) with time.

Table 5. Coefficients of correlation (R^2) for stream flow vs. shallow groundwater level in well M35/5560, the existence of active discharge consents as indicated in Canterbury Maps (2017a) and overall flow trend with time.

Site No.	Waterway	Location	R^2	R^2 (Dec-Feb)	Active Discharge Consents
66643	Waimairi -South Branch	Barlow Street	0.87	0.74	No
66644	Waimairi Stream	Coldstream Court	0.83	0.75	No
66647	Wairarapa Stream	42 Gleneagles Terrace	0.78	0.77	Yes
66650	Avon/ Ōtākaro River	Ilam Road	0.75	0.56	No[A]
66648	Wai-iti Stream	218 Clyde Road	0.74	0.70	No
66641	Waimairi Stream	Daresbury Park	0.71	0.66	No
66646	Taylors Drain	Elmwood Park	0.69	0.65	No
66645	Wairarapa Stream	Garden Road bridge	0.68	0.64	Yes
66637	Avon/ Ōtākaro River	Harakeke St bridge	0.60	0.41	Yes
66638	Avon/ Ōtākaro River	University Dr near UC Rec Centre	0.55	0.46	Yes
66635	Addington drain	Hagley Park	0.24	0.00	Yes
66649	Wairarapa Stream	Lake Outlet at Jellie Park	0.15	0.03	Yes
66636	Riccarton drain	Near Riccarton Ave, Hagley Park	0.13	0.17	Yes
66640	Okeover Stream	UC, behind Forestry Building	0.01	0.00	Yes
66651	Okeover Stream	Downstream Dewatering Pipe	0.01	0.02	Yes
66642	Fendalton Drain	7 Royd Street	0.00	0.00	NF*

*NF = Waterway not found on Canterbury Maps (2017a)

[A] A stormwater network was seen to be discharging to the waterway

The flow measured in artesian springs at Jellie Park (M35/8073) and in Ilam Gardens, as measured by Barr & Webster-Brown (2016), have also been compared to flow data for Wai-iti Stream and the Avon/Ōtākaro River main stem at Ilam road respectively (Appendix B). As expected, there is covariance in flow. There is also a relationship with groundwater level in M35/5560, as had previously been identified in Webster-Brown & Barr (2016).

3.5.2 Relationship with rainfall

We would not expect to find a direct relationship between the base stream flow measured in this study and rainfall, given the important roles that groundwater seepage and artificial discharges play in stream flow. Although peak stream flows respond to recent heavy rain, as can be seen in the graphs shown in Appendix A, this has little bearing on base flow variation in summer.

An analysis of the relationship between rainfall and groundwater level in Ilam groundwater well M35/5660, appears to indicate an approximate 3 month time lag between rainfall and peak groundwater levels (Figure 14). This is consistent with the finding of Webster-Brown and Barr (2016), who showed that the Ilam Garden Springs typically begin to flow in early September, approximately 3 months after the main winter recharge occurs.

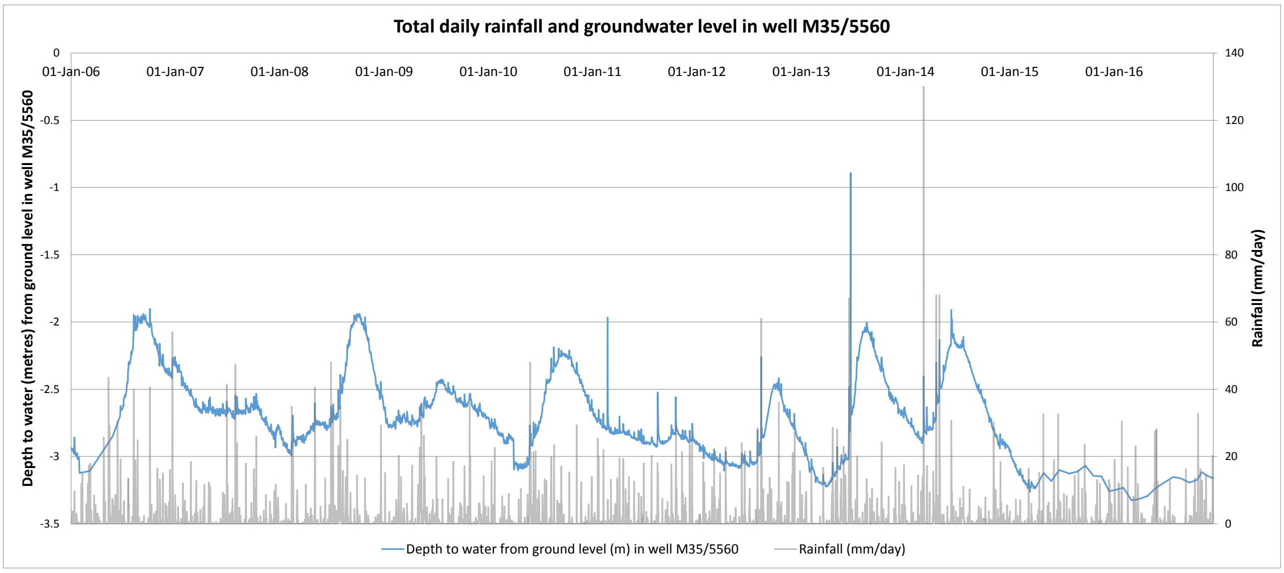


Figure 14. Rainfall (mm/day, NIWA 2017) and depth to the water table in well M35/5560 (ECan, 2017), with time.

3.5.3 Relationship with groundwater extraction

Over 40% of Christchurch water supplies are taken from the shallowest aquifer (Environment Canterbury, 2001). There are five active groundwater-pumping wells near the headwater location of Waimairi Stream at Burnside Park, four of which pump from the shallow Riccarton Gravel aquifer (Canterbury Maps, 2017a; Appendix C). Four of the wells are consented to pump a maximum combined volume of 16,000 m^3/day, an extraction rate which may cause groundwater drawdown and affect springs such as those feeding Waimairi Stream (Scott, 2000).

Additional extractions include groundwater from the shallow Riccarton aquifer through bore M35/4146 in Jellie Park, which is consented to take a maximum volume of 4320 m^3/day and at a maximum rate of 50 L/s (Appendic C) (Canterbury Maps, 2017a). Additionally, bore M35/3040 located upstream of the 2017 dry reach in Jellie Park was consented to extract 821 m^3/day from the same shallow aquifer, at a maximum rate of 7.6 L/s (Canterbury Maps, 2017a). These extractions might have some drawdown impacts on the groundwater-fed Hewlings and Wairarapa Streams (Scott, 2000).

Section 4 Conclusions

From the survey of dry reach and flowing stream length positions, and comparison with previous survey results, the following can be concluded;

- There was a significant downstream migration of flow commencement (i.e., active spring or seepage position) between 1980 and 1985, in all of the streams in the upper Avon/Ōtākaro catchment for which the 1980 data were available, except the Avon/Ōtākaro River main stem. This included Hewlings, Wairarapa, Wai-iti, Waimairi streams, as well as Taylors drain.

- Since 1985, flow commencement positions have remained relatively constant or have partially recovered (moved upstream again) in most of these streams. In Waimairi Stream the shortest channel length was in 1992, after which the flow commencement position migrated upstream again in the main channel, while it remained constant in the south branch.

- In Okeover and Avon/Ōtākaro River main stem, the most recent summer flows have commenced downstream of their position prior to 2001; 1.2 km downstream in the Okeover and 100m in the Avon/Ōtākaro main stem. In Cross Drain 2017 flow commenced 700m downstream of the flow commencement position in 1999.

- In Ilam Stream, the position of flow commencement has moved upstream since 1993 and is now 3.5 km above the first flow position between 1985 and 1993. This is most likely due to contribution of Waimakariri River water from the Paparua stockwater channel.

4.1 Possible reasons for migration of flow

It seems likely that the significant change in flow commencement position between 1980 and 1985 maybe at least partially due to the very dry period prior to 1985, when groundwater levels were at their lowest in 25 years (Cameron 1992). However, flow has not recovered in most of the streams since 1985, suggesting additional factors are affecting stream conditions. It may be that low groundwater levels are persisting due to higher density housing or increased groundwater extraction in this part of the catchment. Urbanisation leads to increased impermeable surfaces, decreased infiltration capacity, enhanced runoff and thus reduced groundwater recharge, as well as an increased demand for water supply (Cameron, 1992). Anectodal evidence suggests that spring flow reduced after housing developments in the upper catchment area were undertaken (Cameron, 1992).

Changes in stream flow since 1985 are also likely to be in direct response to fluctuations in groundwater level, and perhaps also to any new consented discharges to the streams. Flow rates in the upper reaches of Waimairi Stream, Wairarapa Stream, Wai-iti Stream, Taylors Drain and the Avon/Ōtākaro River correlate strongly with groundwater level, indicating that their base flow is principally generated from shallow groundwater, either via artesian springs or via seepage. Spring flow shows a strong relationship with groundwater level (Webster-Brown & Barr 2016), with springs

such as Ilam Gardens and Jellie Park “switching off” once the groundwater level falls beyond a given level.

In streams where base flow is augmented by consented discharges during the summer, there is little relationship with groundwater level. Numerous storm water drains discharge into the urban streams in Christchuch (Canterbury Maps, 2017c), and these contribute to the total flow, especially after a storm event. Active consented discharges include waste pool water discharges from Jellie Park Aqualand and cooling waters from the University of Canterbury, with most marked effects on flow in Wairarapa and Okeover Streams respectively. There was no flow upstream of the artificial discharge sites in both cases in summer 2016. Additionally, Ilam Stream appears likely to have been receiving stock water from the Paparua stock water race (Selwyn District Council, 2013), at this time.

While this study did not (and did not expect to) find an apparent relationship between flow and rainfall, there is of course a relationship. Rainfall on the plains west of Christchurch between Waimakariri River and the City recharges the shallow groundwater system beneath the city, but not immediately. There is a lag time between the rain falling and the recharge affecting spring flow and therefore stream flow in the urban streams. This lag time appears to be in the order of 3 months, from the results of this study. The low annual rainfall in 2015 and 2016 therefore directly contributed to the low groundwater levels, and consequently to low spring and stream flows. The total rainfall in 2015 was 22% less than the 1986-2016 average (NIWA, 2017), while the total rainfall in 2016 was 9% less than the 1986-2016 average (NIWA, 2017).

This study did not address the role that ongoing or increasing extraction may have had on spring and stream flows. Spring flows and groundwater wells compete for groundwater, and they are both naturally variable (Scott, 2000). Increased groundwater extraction causes greater water table drawdown (Scott, 2000), extending the dry reaches of groundwater-fed streams and decreasing their flows. Abstracting groundwater from deeper confined aquifers might be a short-term solution to replenish flows in Christchurch streams, but could possibly be ineffective in the long-term. Over-pumping from Aquifer 1 may also lead to contamination and saltwater intrusion (Environment Canterbury, 2001).

4.2 Recommendations for future research

There are several studies which could be undertaken to clarify aspects of this study;

- An analysis of when major changes in urban intensification occurred in the catchment, and its relationship to groundwater level.
- An analysis of current groundwater abstraction rates, well depths and locations, and how this relates to change sin spring and stream flow.
- A more detailed survey of flow rates in flowing reaches of the streams, to identify spring inputs downstream of flow commencement.

References

Barr, E., & Webster-Brown, J. (2016). *Fluctuations in the flow of artesian springs in Christchurch*. WCFM Technical Report 2016-003. Retrieved from http://waterways.ac.nz/reportsindex.shtml

Cameron, S. G. (1992). *A hydrogeological study of the interaction between Avon River baseflow and shallow groundwater, Christchurch, New Zealand*. Unpublished Master of Science thesis, University of Canterbury, Christchurch, New Zealand.

Canterbury Maps. (2017a). *Consent Application Resources*. Retrieved from http://www.arcgis.com/home/webmap/ viewer.html? webmap=e4eb6b25372340448 d0e46403d1507c8

Canterbury Maps. (2017b). *Groundwater.* Retrieved from https://mapviewer.canterburymaps.govt.nz/?webmap=0c3ca2ccfe1145c5849dc39864590d0b

Canterbury Maps. (2017c). *Water Services*. Retrieved from https://mapviewer.canterburymaps.govt.nz/?webmap=c74e0c9501de4204bc1965597557f269

Christchurch Drainage Board. (1980). *A Biological Survey of The Rivers Of Metropolitan Christchurch Area and Outlying Districts - The Avon, Heathcote and Styx Rivers and their Tributaries*.

Daglish, W. H. (1985). *Flow Regimes and Spring Locations in the Styx and Avon River Systems*. Unpublished report by the Groundwater Section, North Canterbury Catchment Board.

Daly, A. B. (2001). *Avon River and Heathcote River and tributaries:* Report of a survey on waterways appearance during low flows. Report U01/62. Environment Canterbury, Christchurch.

Daly, A. B. (2006). *Christchurch Rivers Survey, September 2006*: Report of a survey on waterways appearance and flows. Environment Canterbury, Christchurch.

Environment Canterbury. (2000). *Guidelines for the assessment of groundwater abstraction effects on stream flow.* Report number ROO/11. Retrieved from https://api.ecan.govt.nz/TrimPublicAPI/documents/download/301801

Environment Canterbury. (2001). *Our water in the balance: Christchurch West Melton rivers and groundwater.* Retrieved from https://api.ecan.govt.nz/TrimPublicAPI/documents/download/330161

Environment Canterbury (2017). *Groundwater level monitoring data.* Retrieved from http://previous.ecan.govt.nz/services/online-services/monitoring/groundwater-levels/pages/default.aspx.

Google Earth. (2012). Christchurch, New Zealand (Version 6.2.2.6613).

Jenkins, B. (2016). *Christchurch's Dry Streams: Action needed to address drought, urbanisation and abstraction*. Report to the Chch-West Melton Zone Committee (Unpublished)

Ministry of the Environment. (2016). *Climate change projections for the Canterbury region*. Retrieved from http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/how-might-climate-change-affect-my-region/canterbury

NIWA. (2017). *CliFlo: NIWA's National Climate Database on the Web*. Retrieved 19/12/2016 http://cliflo.niwa.co.nz/

Salmons, M. (2016, July 12 2016). *Christchurch rivers lowest they've been in decades*. Retrieved from http://www.stuff.co.nz/environment/82007545/Christchurch-rivers-lowest-they-ve-been-in-decades

Schieferdecker, A. A. G. (1959). *Geological Nomenclature.* Publication of the Royal Geological and Mining Society of the Netherlands.

Scott, D. M. (2000). *Christchurch - West Melton Groundwater Investigation*: Simulation of alternative groundwater abstraction scenarios and their effects on baseflows of the Avon and Heathcote Rivers. Environment Canterbury, Christchurch.

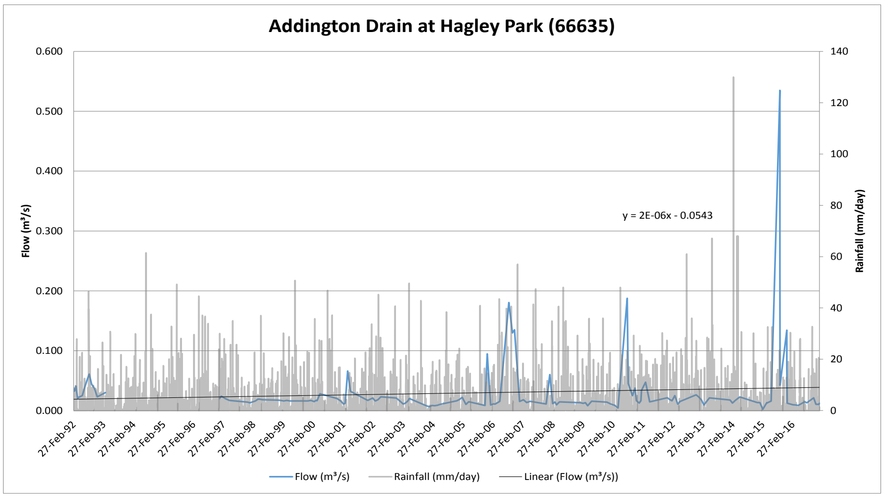
Selwyn District Council. (2013). *Water Race Management Plan*. Retrieved from http://www.selwyn.govt.nz/__data/assets/pdf_file/0010/180649/Water-Race-Management-Plan_Jul-2013-V6-Part-1.pdf

Webster-Brown J. and Barr, E. (2016). *Fluctuations in the flow of artesian springs in Christchurc*h. NZ Hydrological Society Conference Proceedings, Queenstown (NZ) 2016. 8pp.

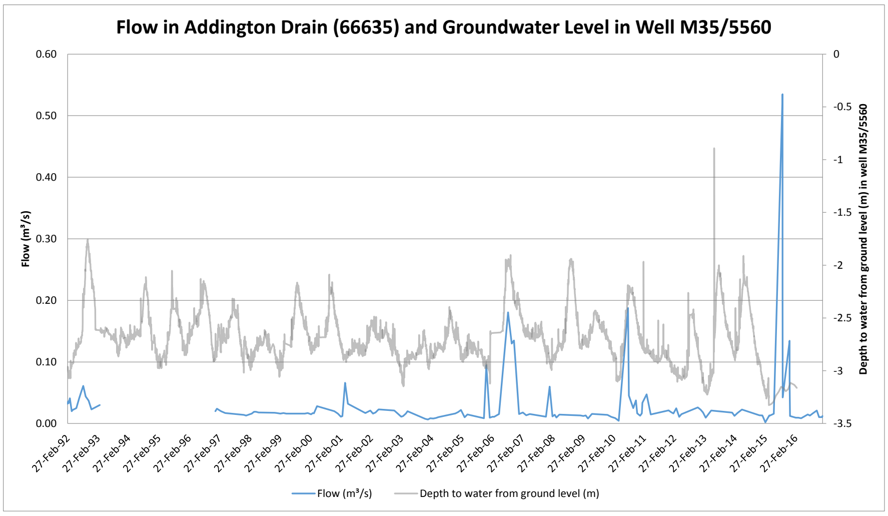
Appendix A: Relationships between stream flow and rainfall or groundwater level.

Note: Unless otherwise credited, rainfall data is from NIWA (2017) from # 4858 and # 24120 weather stations as explained in the text. Groundwater level and stream flow data is from ECan monitoring data (e.g., ECan 2017) and this study.

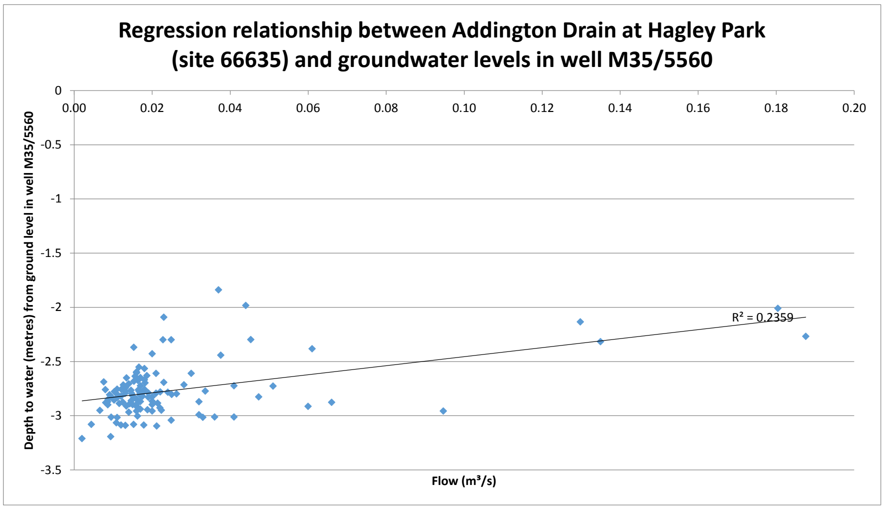
A-1. Addington Drain at Hagley Park (site 66635)



Flow (m^3/s) in relation to rainfall (mm/day).

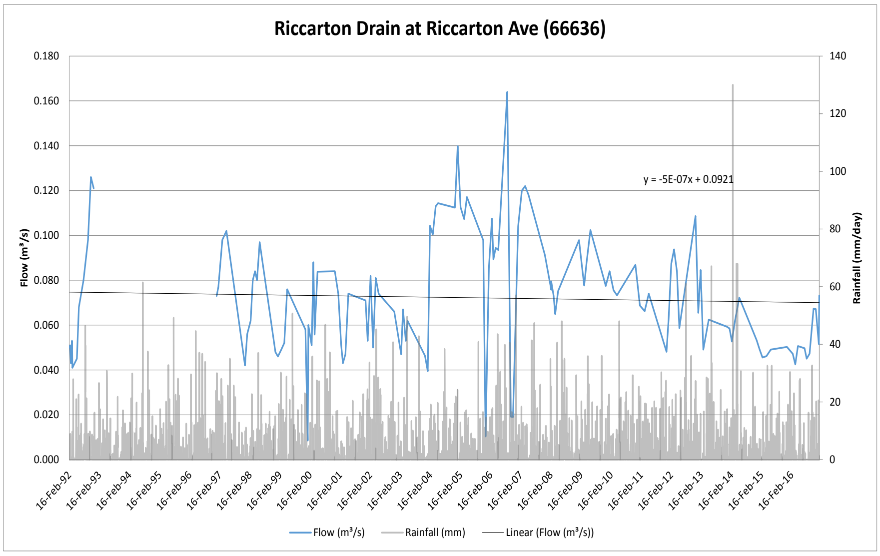


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

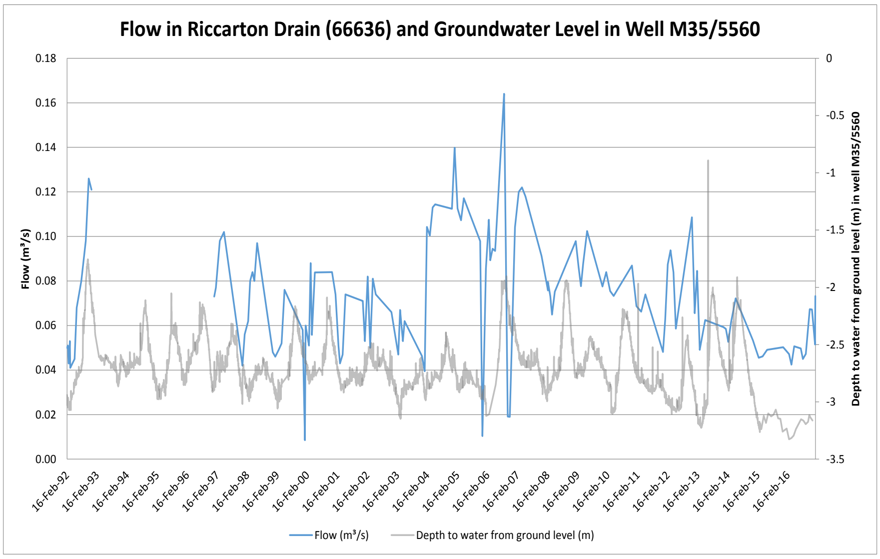


Correlation between groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 23 February 1992 until 27 February 2015.

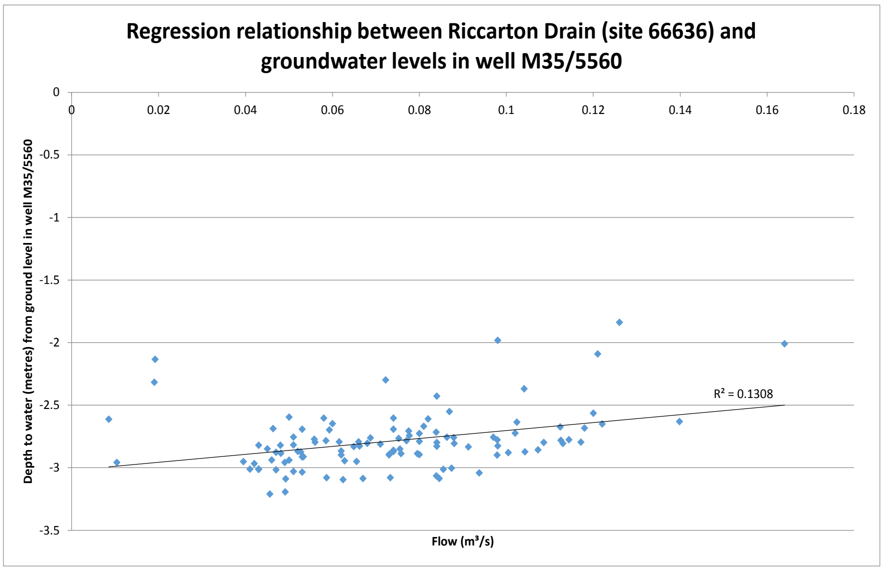
A-2 Riccarton Drain at Riccarton Ave (site 66636)



Flow (m^3/s) in relation to rainfall (mm/day).

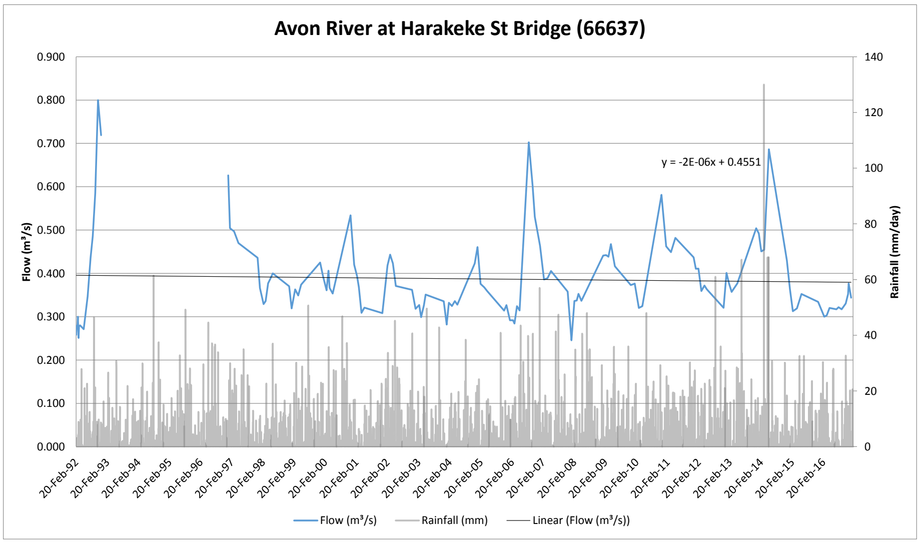


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

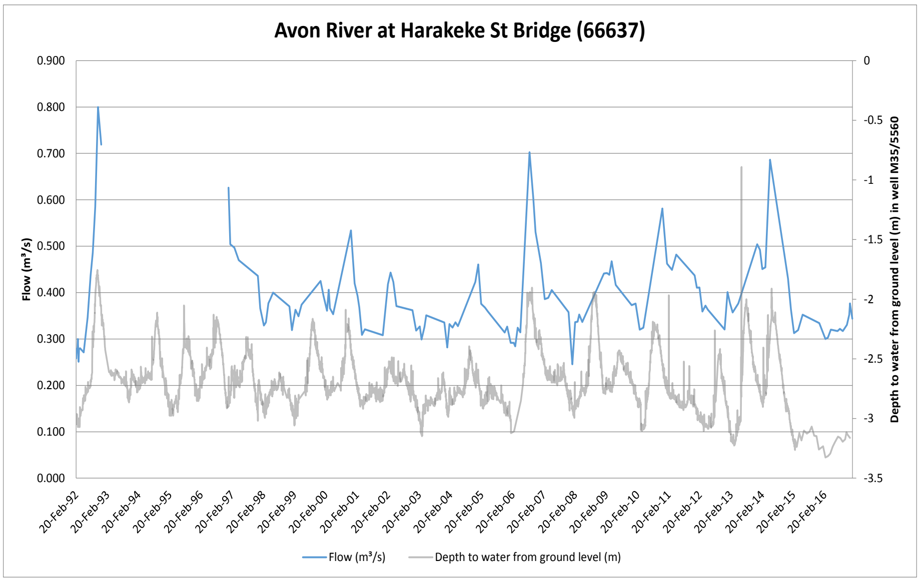


Correlation between groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 23 February 1992 until 27 February 2015.

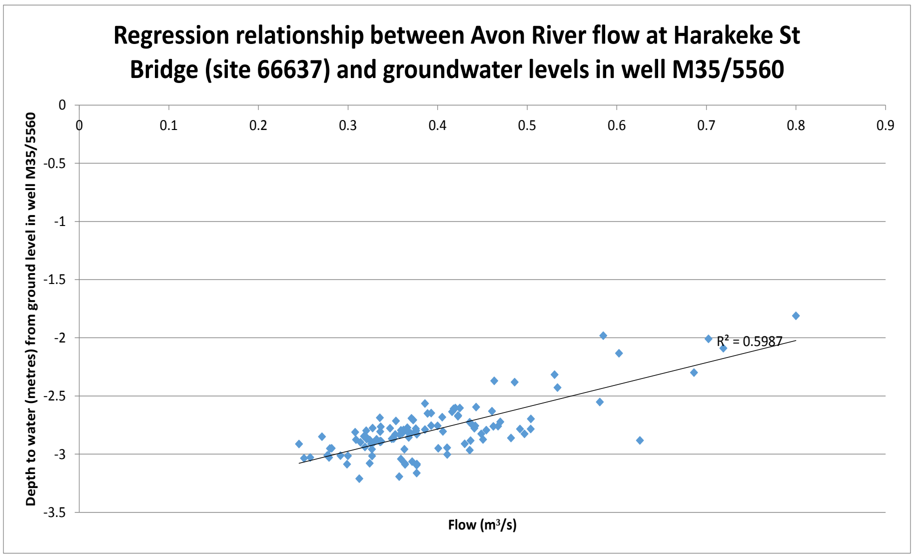
A-3 Avon/Ōtākaro River at Harakeke St bridge (site 66637)



Flow (m^3/s) in relation to rainfall (mm/day).

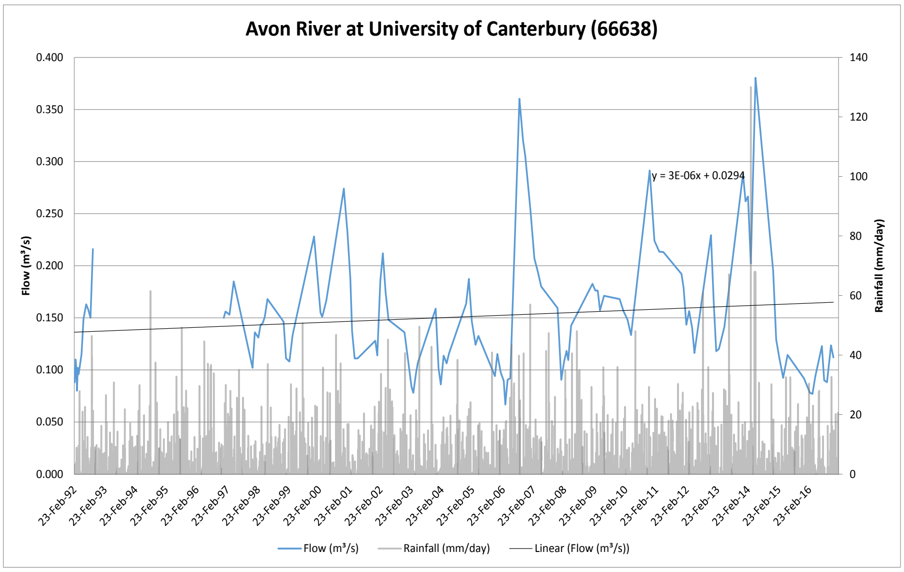


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

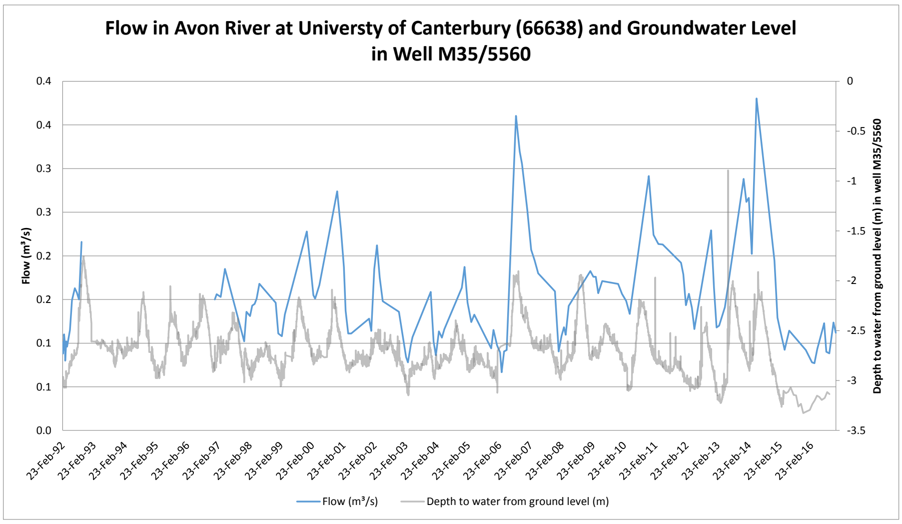


Correlation between ground-water level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 23 February 1992 until 27 February 2015.

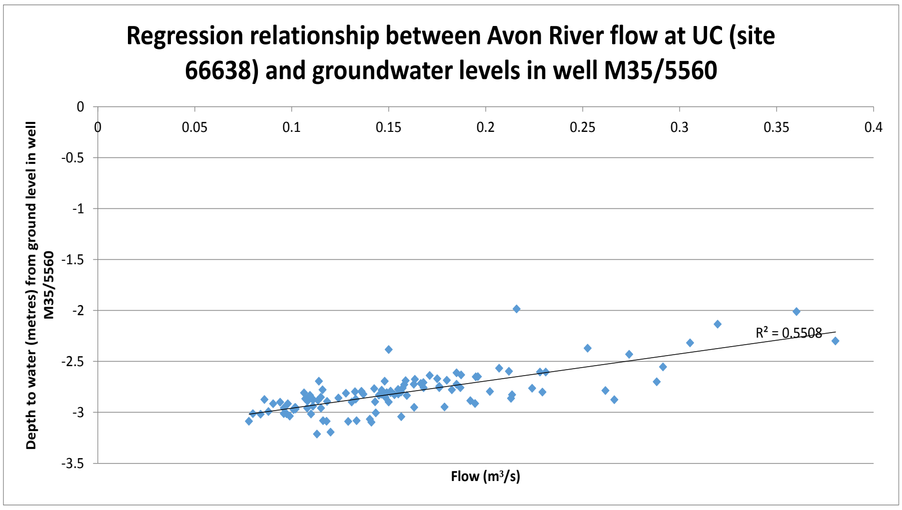
A-4 Avon/Ōtākaro River at University of Canterbury (site 66638)



Flow (m^3/s) in relation to rainfall (mm/day).



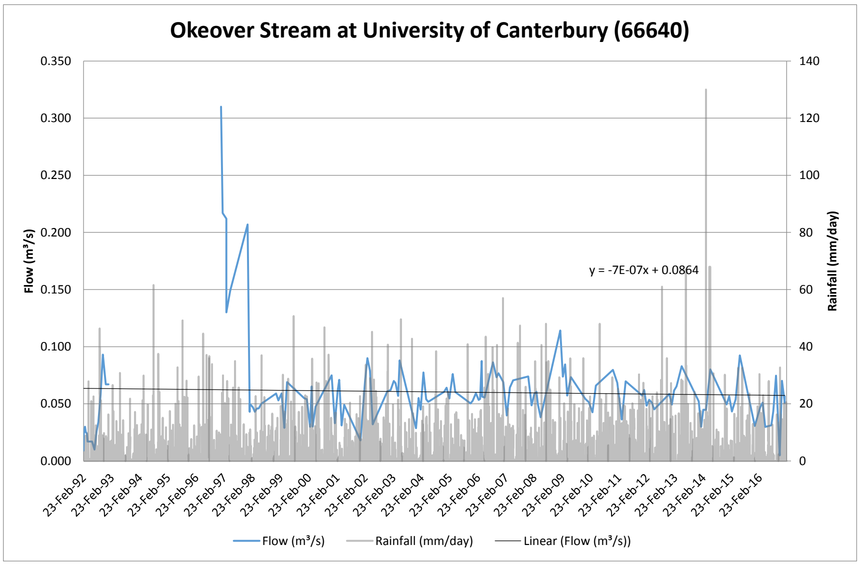
Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.



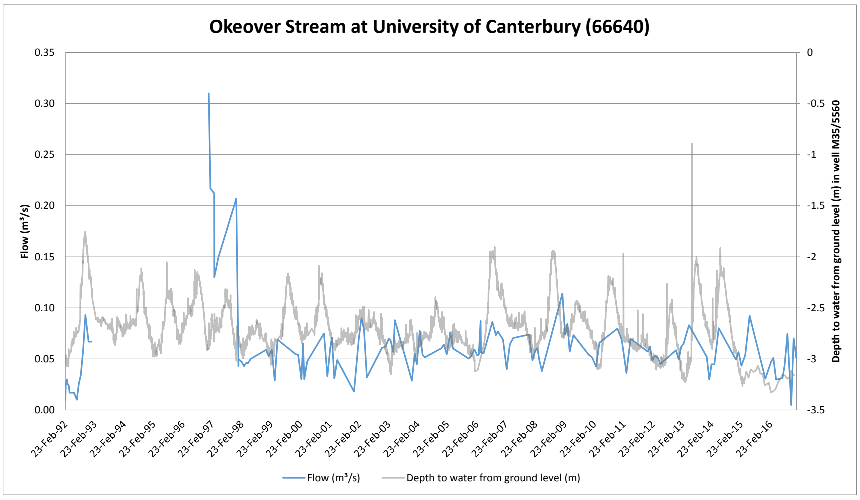
Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s), from 23 February 1992 until 27 February 2015.

NB. The removal of three outliers increased the R^2 value into 0.6461. While the regression relationship between summer base flow and groundwater level had a weaker R^2 value of 0.4634.

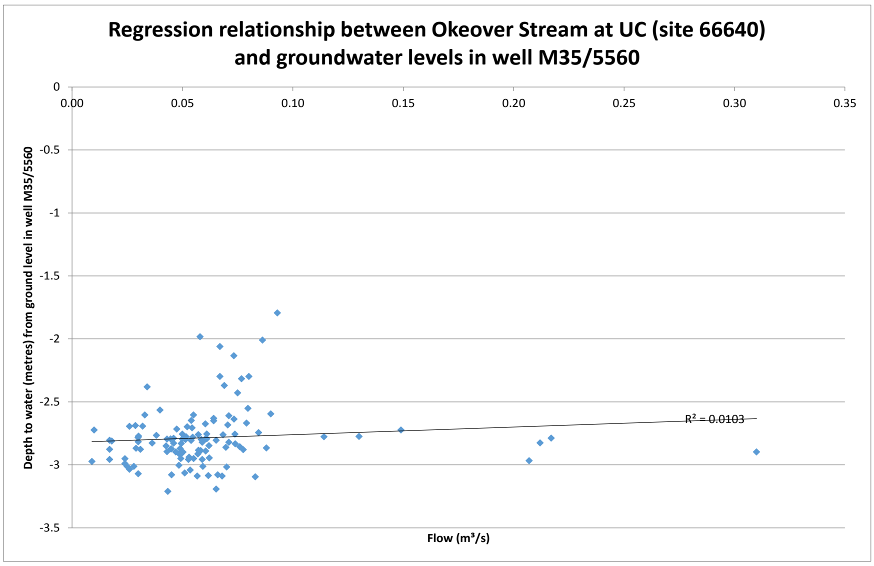
A-5 Okeover Stream at University of Canterbury *(site 66638)*



Flow (m^3/s) in relation to rainfall (mm/day).

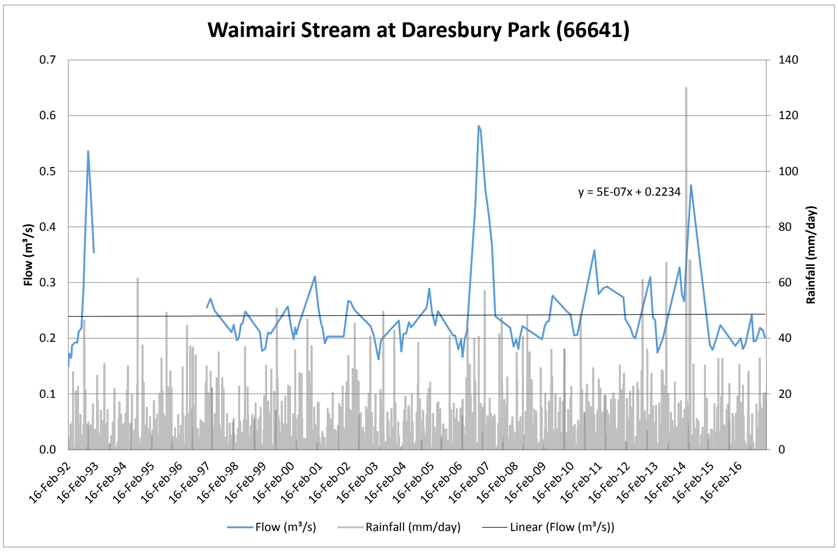


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

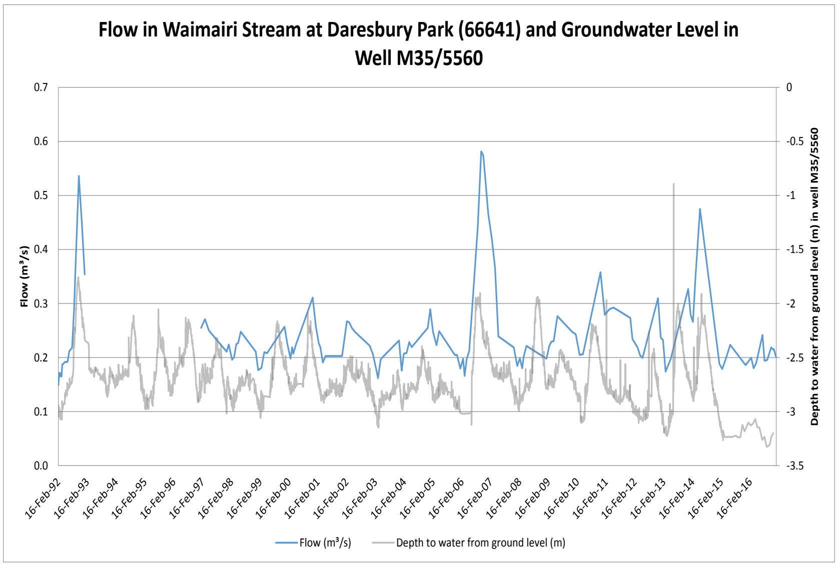


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s), from 23 February 1992 until 27 February 2015.

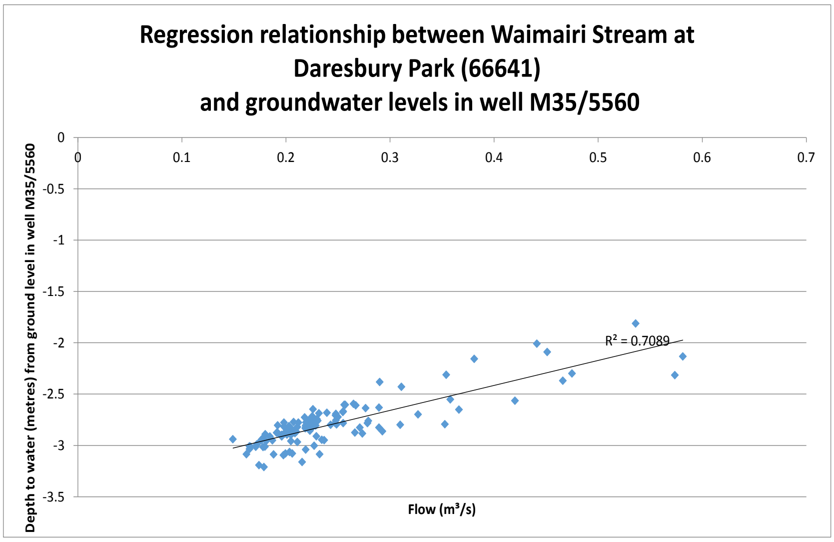
A-6 Waimari Stream at Daresbury Park (site 66641)



Flow (m^3/s) in relation to rainfall (mm/day).

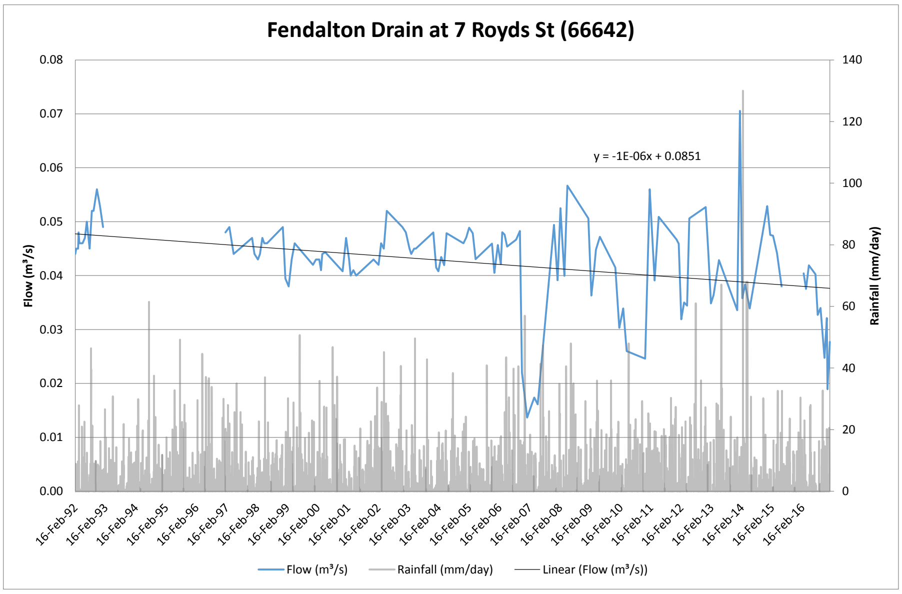


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

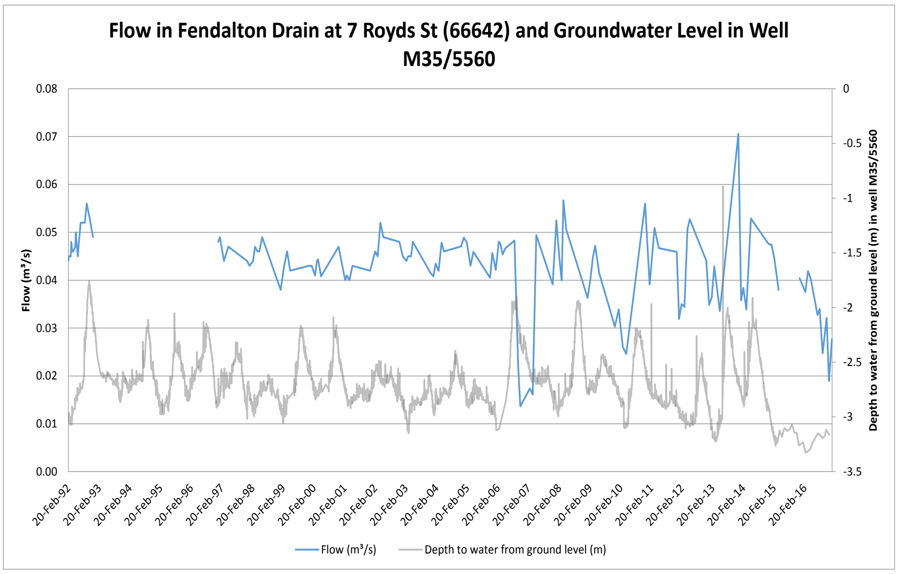


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 16 February 1992 until 13 December 2016.

A-7 Fendalton Drain (or Drain 23) at 7 Royds Street (*site 66642*)

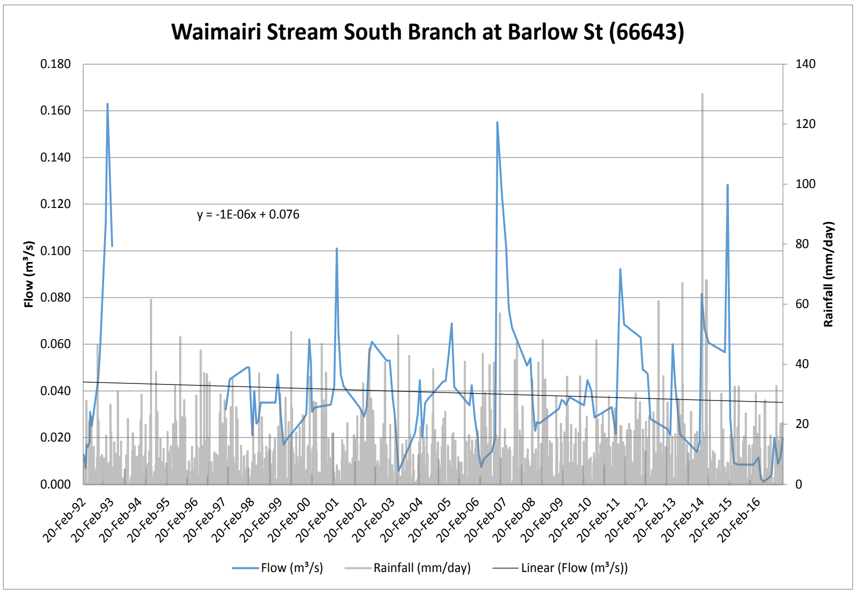


Flow (m^3/s) in relation to rainfall (mm/day).

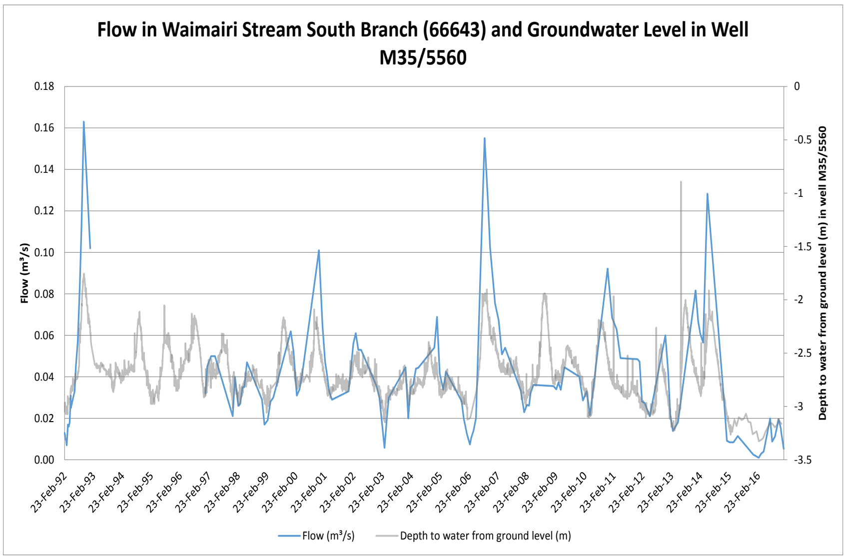


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

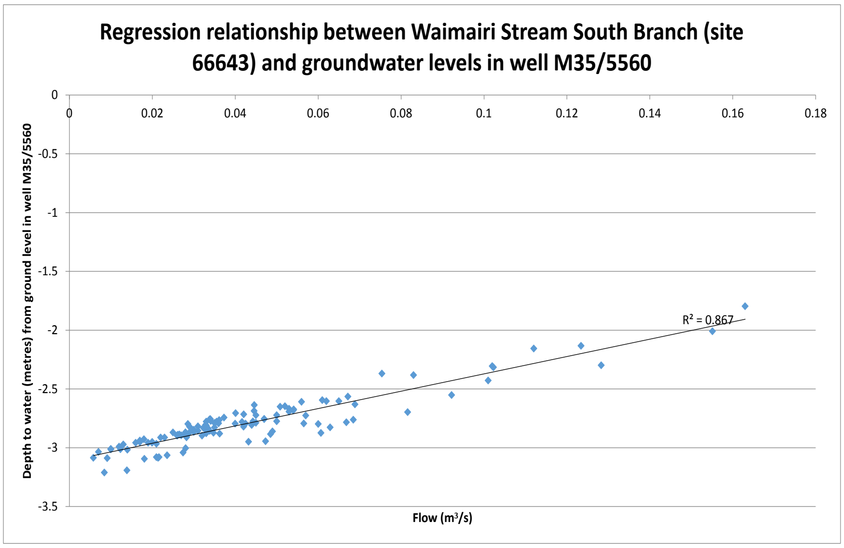
A-8. Wairmari Stream South branch at Barlow St (site 66643)



Flow (m^3/s) in relation to rainfall (mm/day).

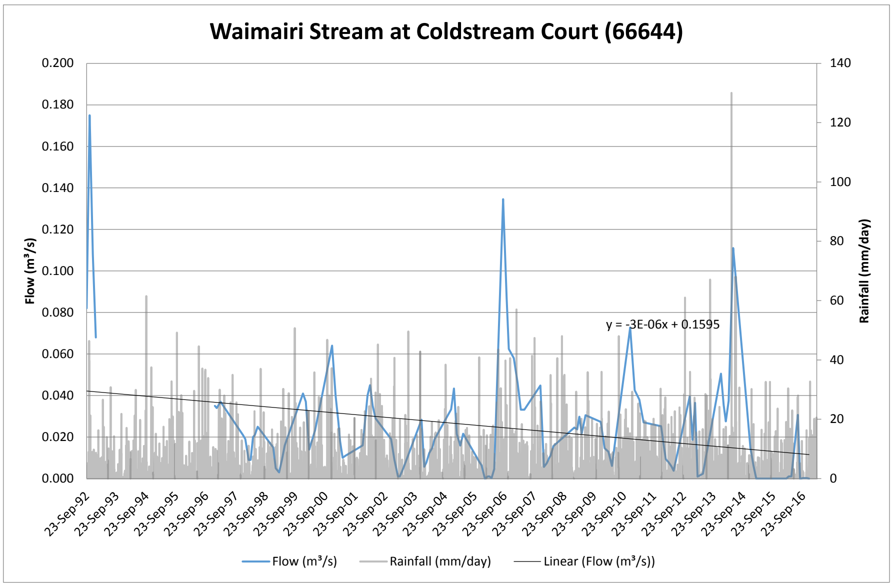


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

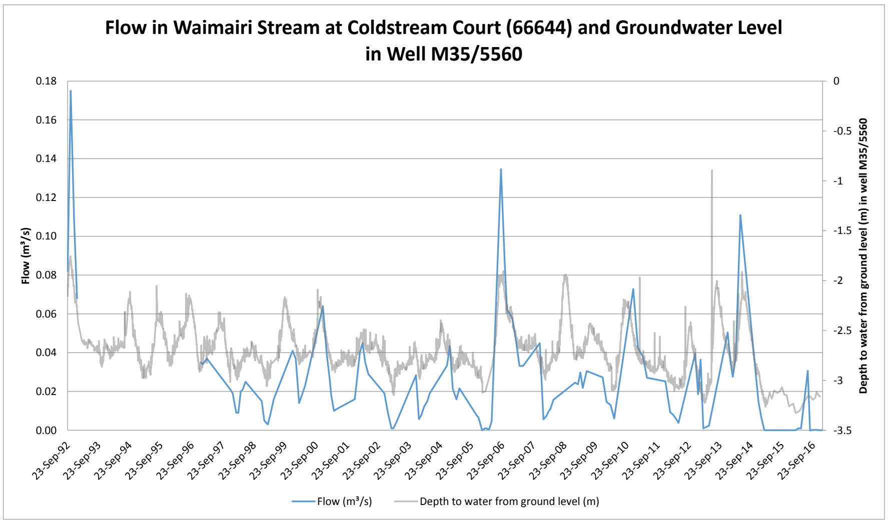


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s), from 23 February 1992 until 27 February 2015.

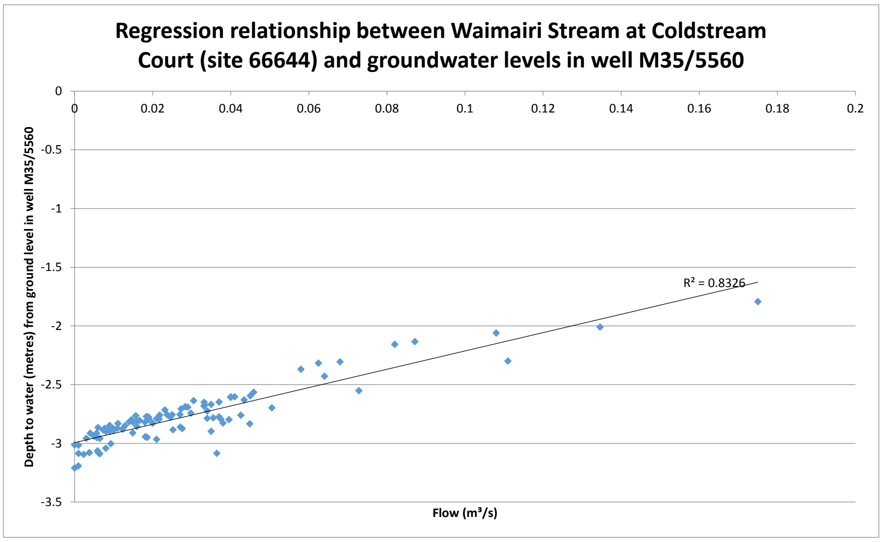
A-9. Waimari Stream at Coldstream Court (site 66644)



Flow (m^3/s) in relation to rainfall (mm/day).

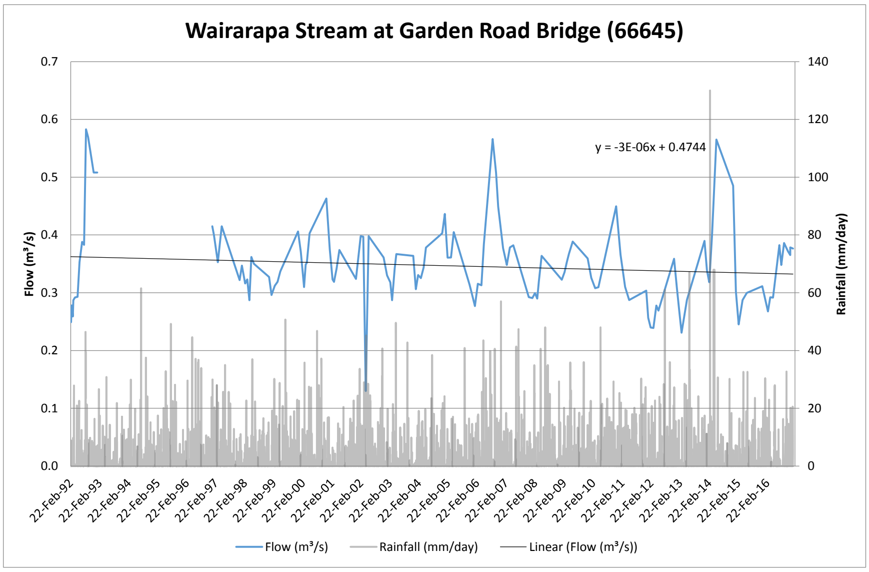


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

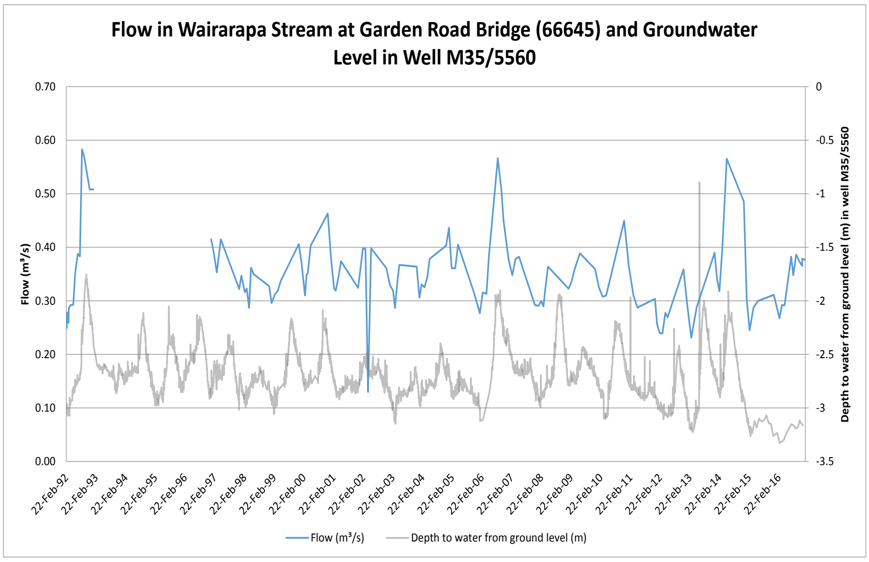


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 23 September 1992 until 27 February 2015.

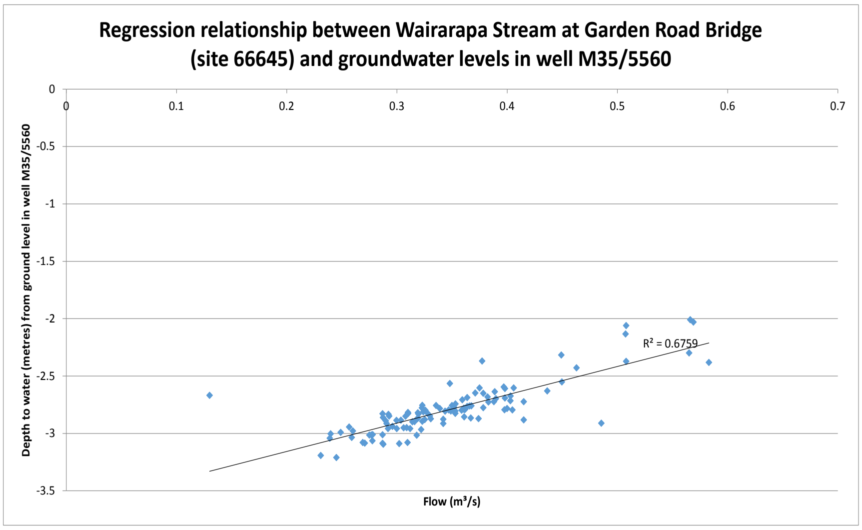
A-10. Wairarapa Stream at Garden Road Bridge (site 66645)



Flow (m^3/s) in in relation to rainfall (mm/day).

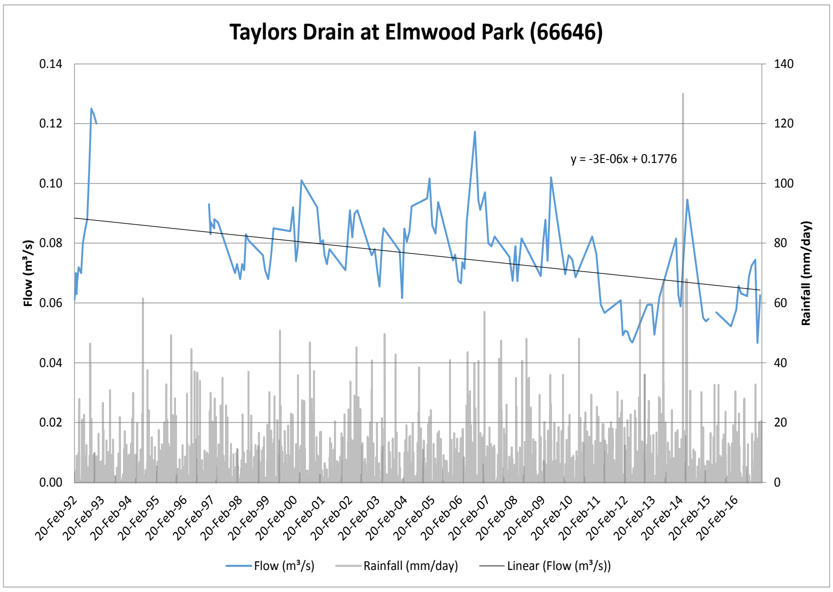


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

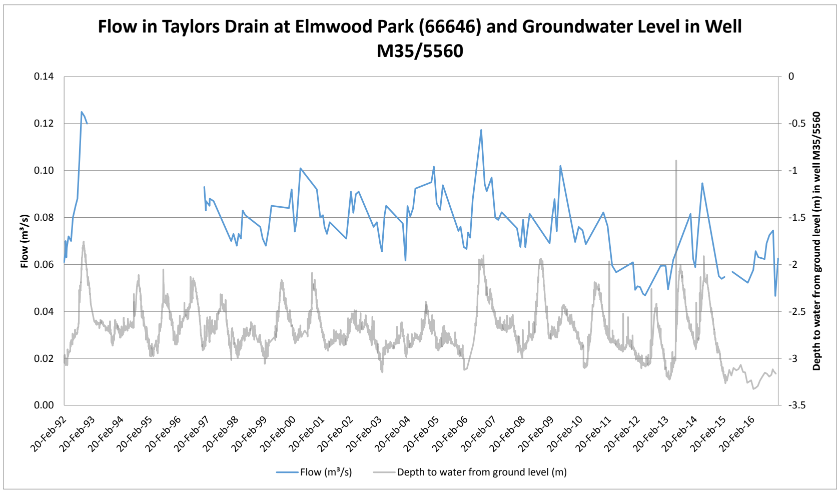


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

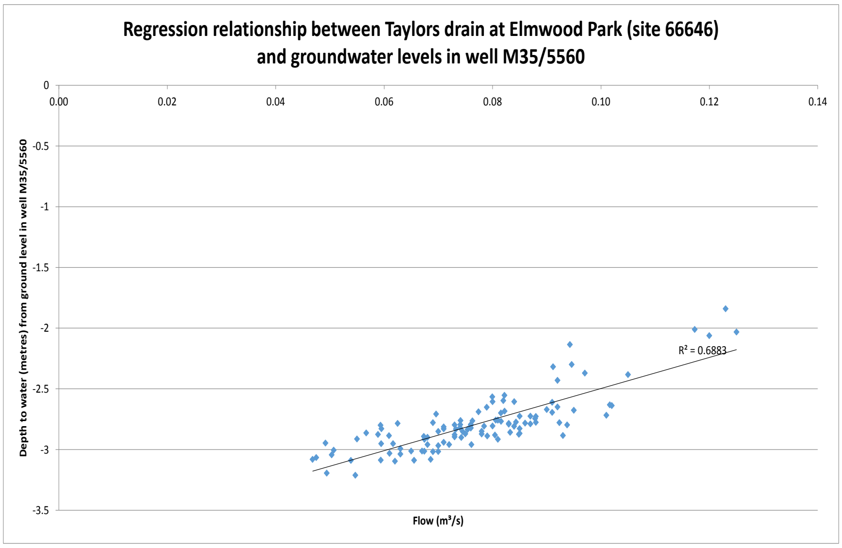
*A-11 **Taylors drain at Elmwood Park*** *(site 66646)*



Flow (m^3/s) in relation to rainfall (mm/day).

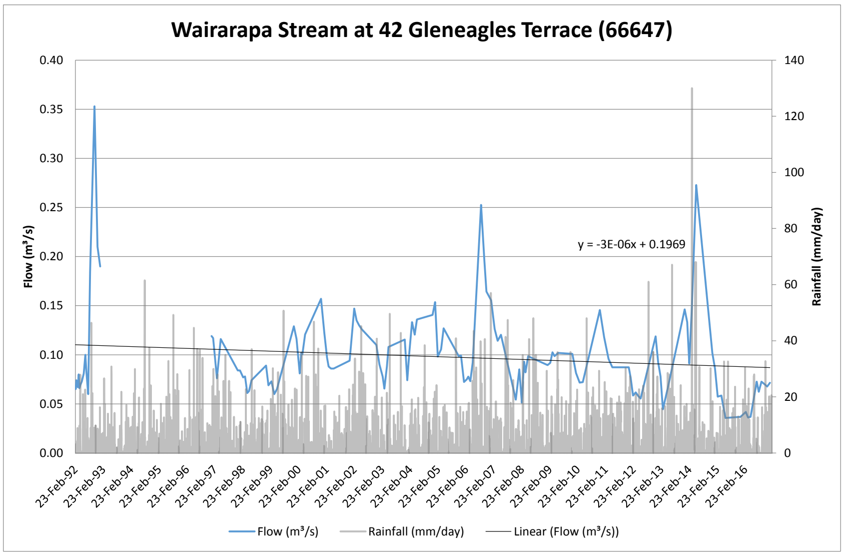


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

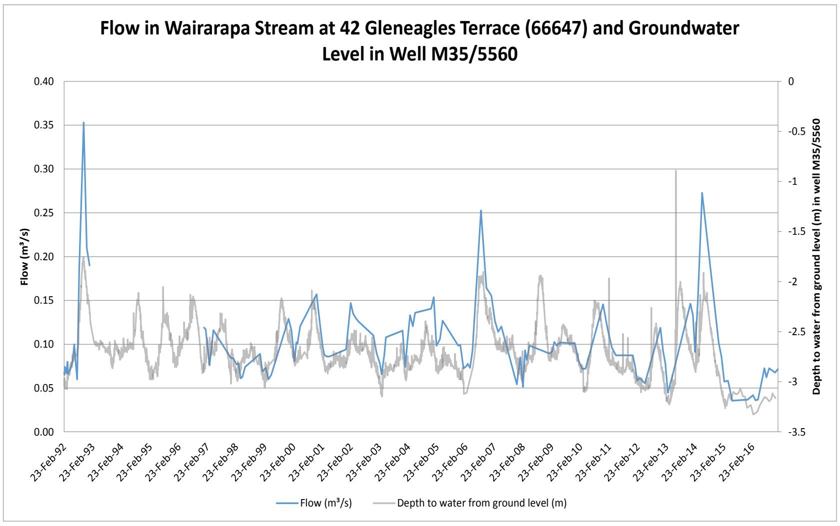


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

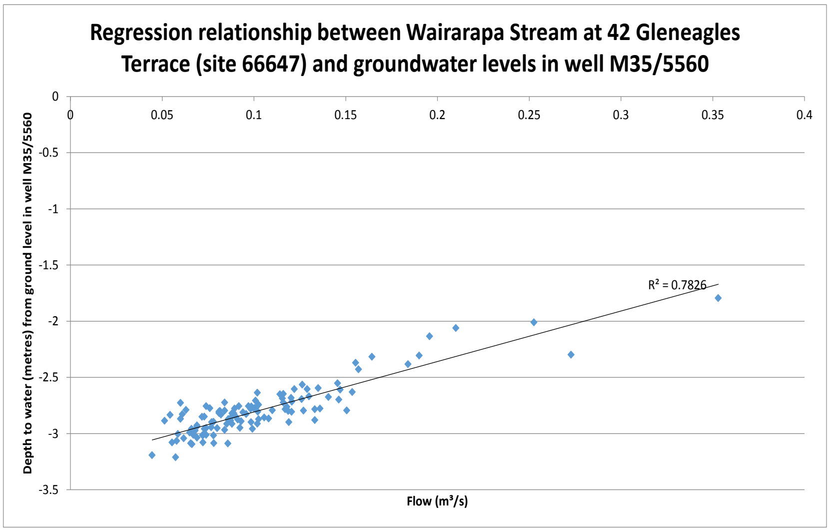
A-12 Wairarapa Stream at 42 Gleneagles Terrace (site 66647)



Flow (m^3/s) in relation to rainfall (mm/day).

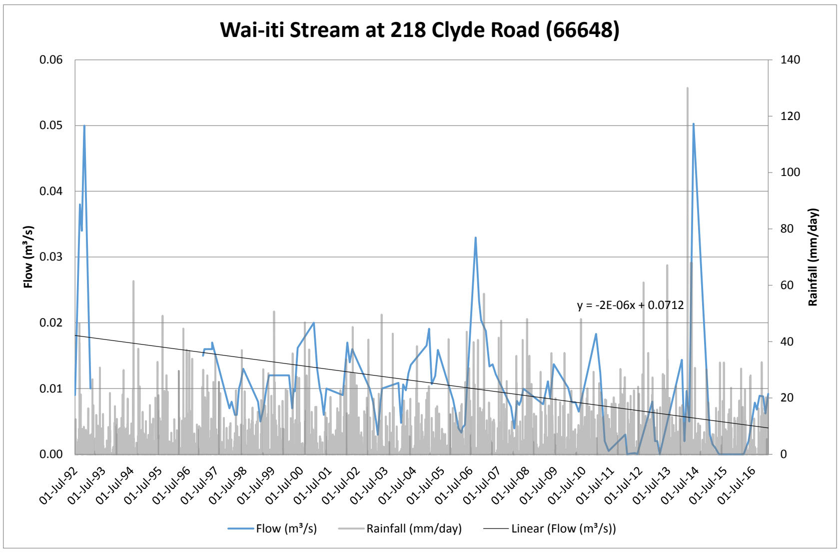


Flow (m^3/s) in in relation to depth to water from ground level (m) in well M35/5560.

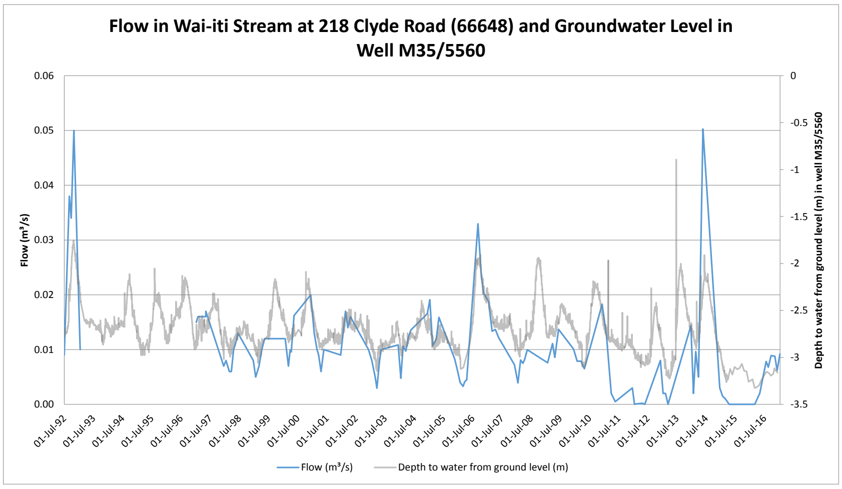


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s) from 20 February 1992 until 16 December 2016.

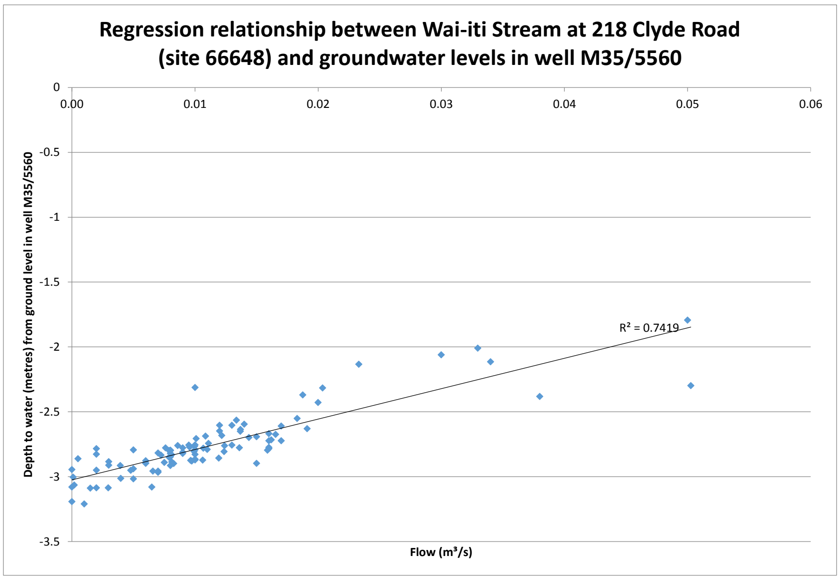
A-13 Wai-iti Stream at 218 Clyde Rd (site 66648)



Flow (m^3/s) in relation to rainfall (mm/day).

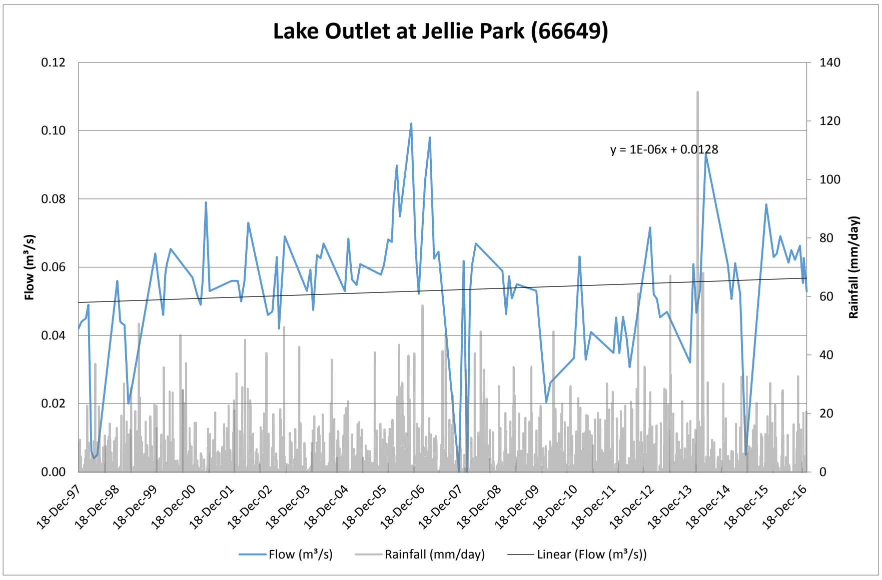


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

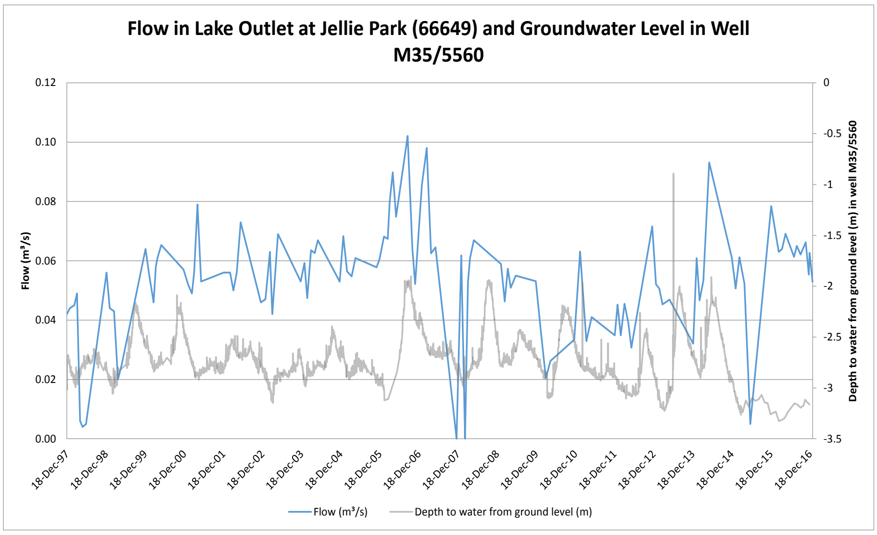


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

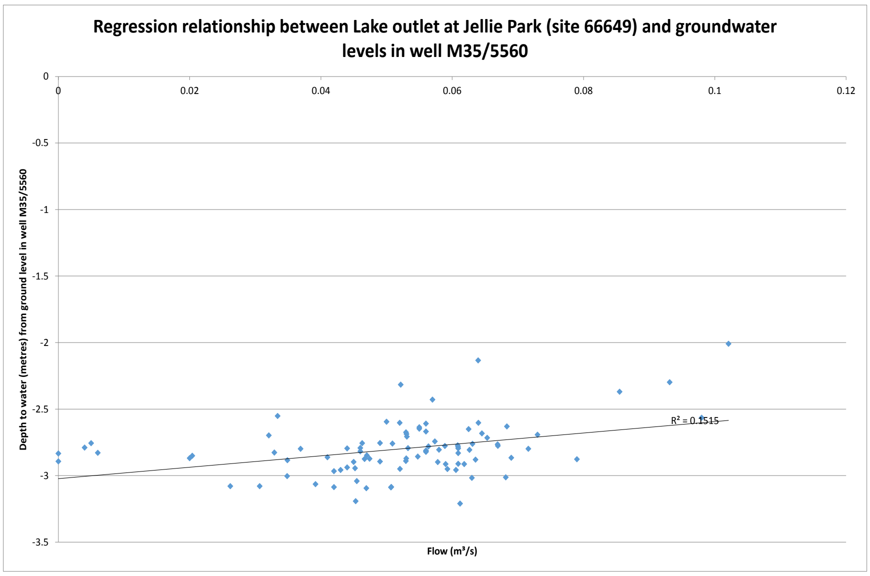
A-14. Lake Outlet at Jellie Park (site 66649)



Flow (m^3/s) in relation to rainfall (mm/day)

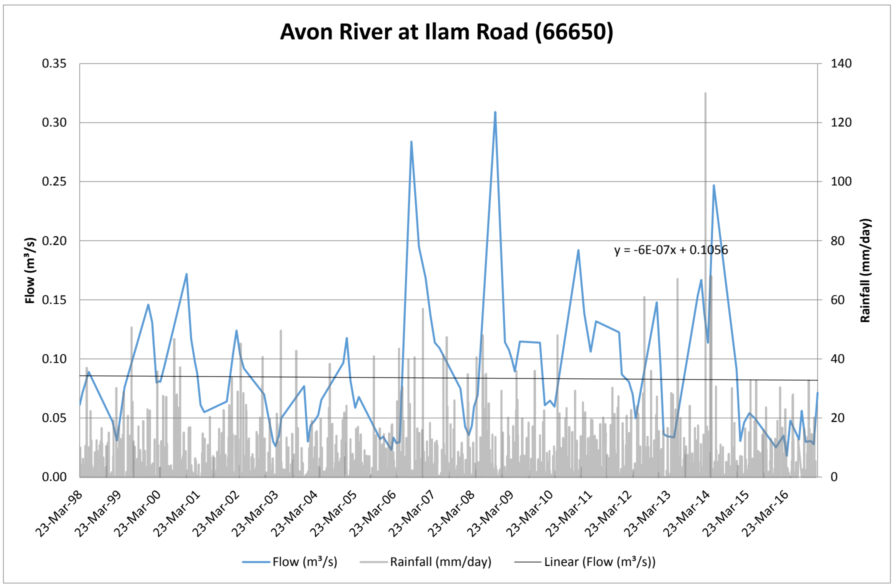


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

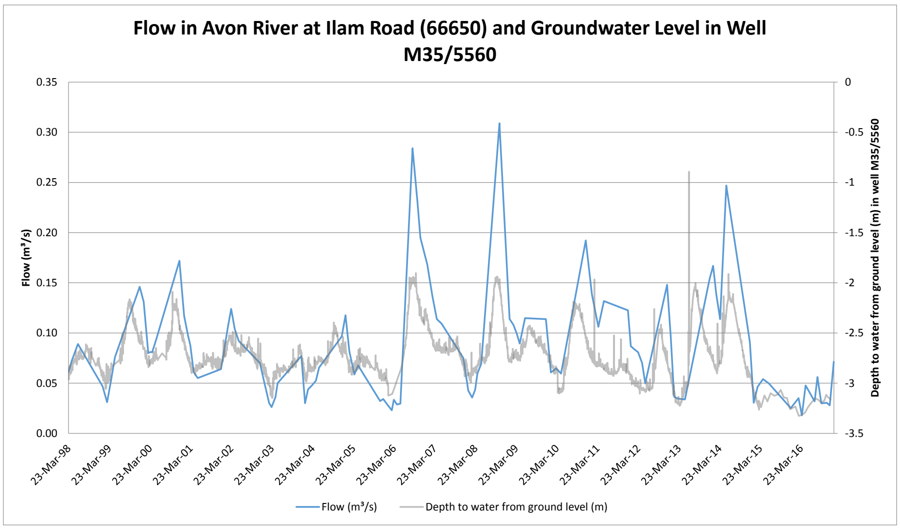


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

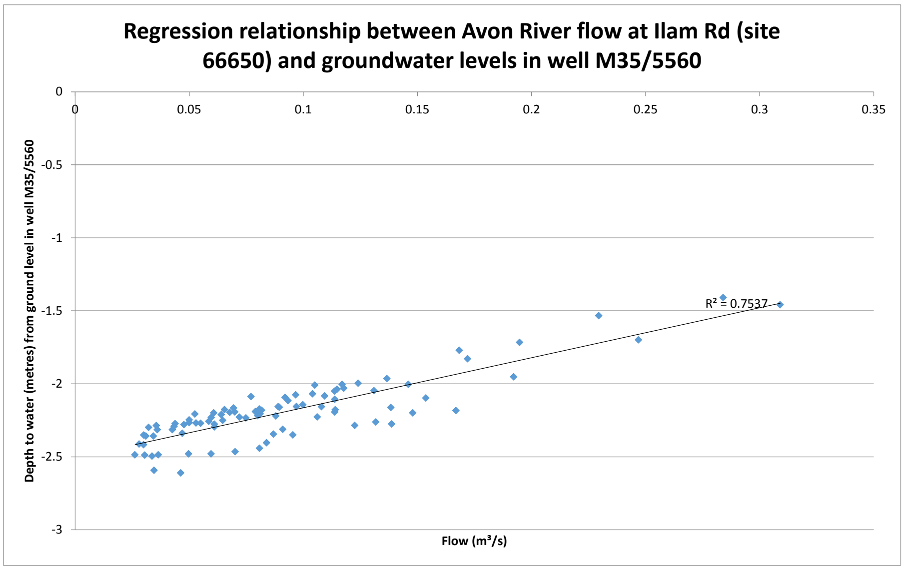
A-15 Avon/Ōtākaro River at Ilam Rd (site 66650)



Flow (m^3/s) in relation to rainfall (mm/day).

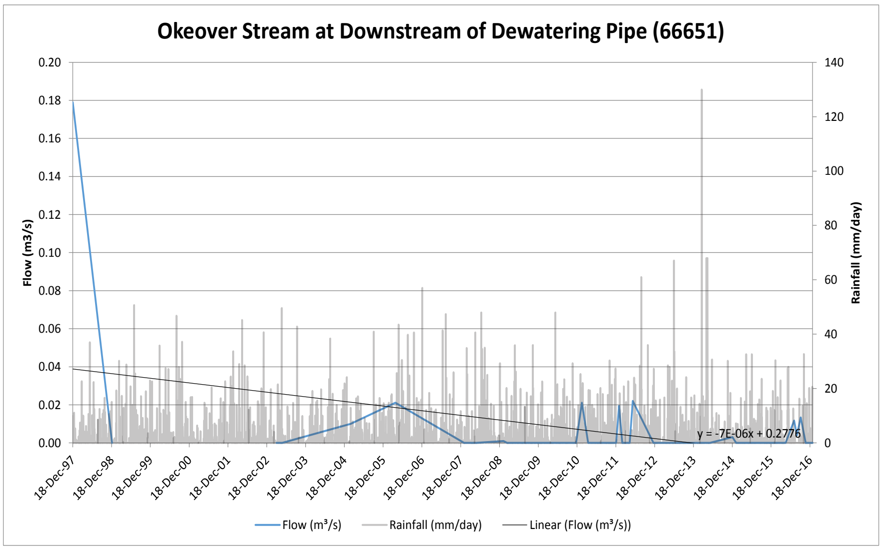


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

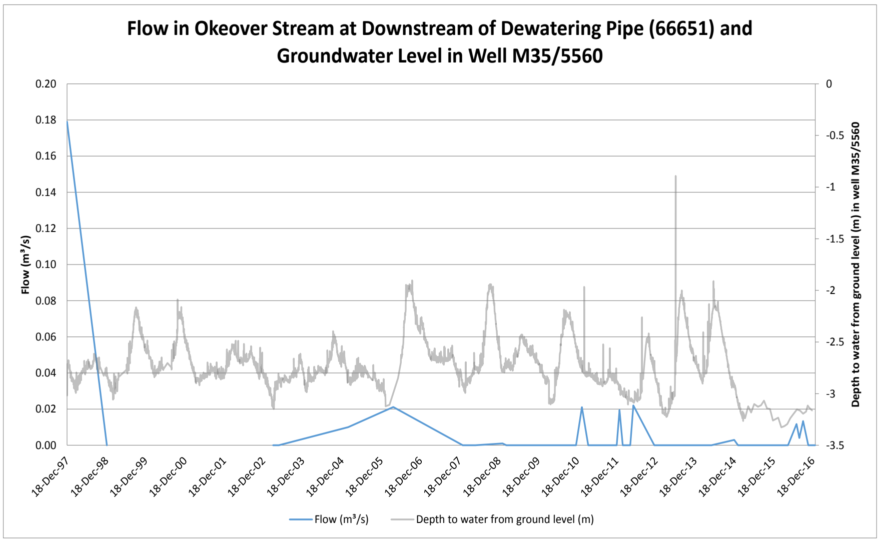


Corrleation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

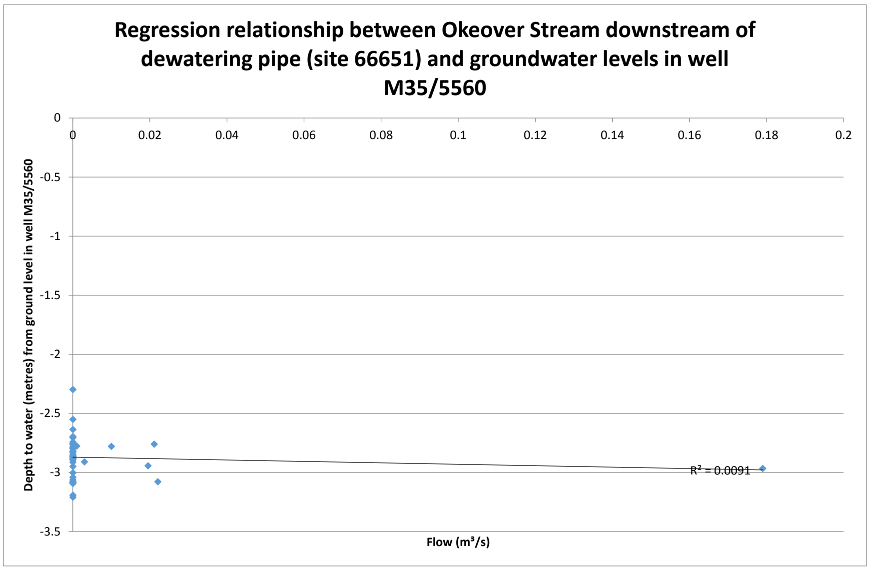
A- 16 Okeover stream downstream of dewatering pipe (site 66651)



Flow (m^3/s) in relation to rainfall (mm/day).

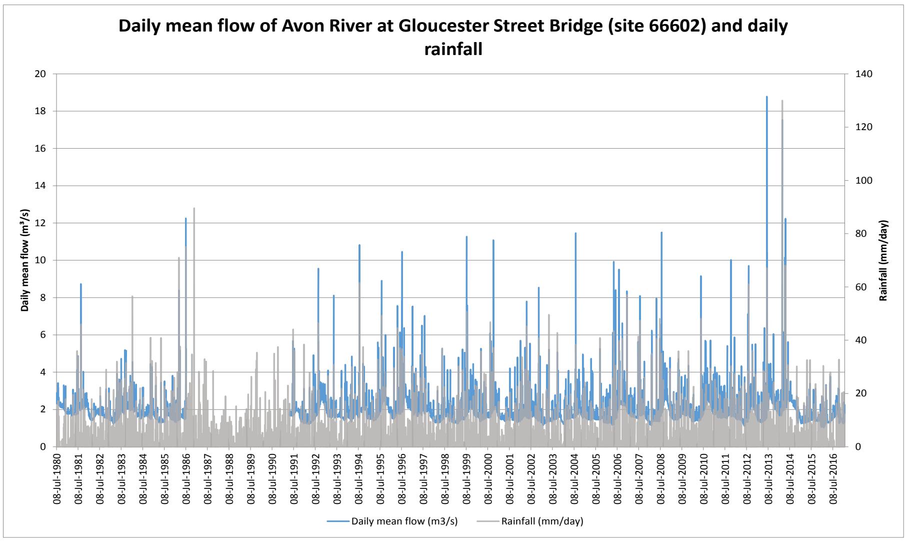


Flow (m^3/s) in relation to depth to water from ground level (m) in well M35/5560.

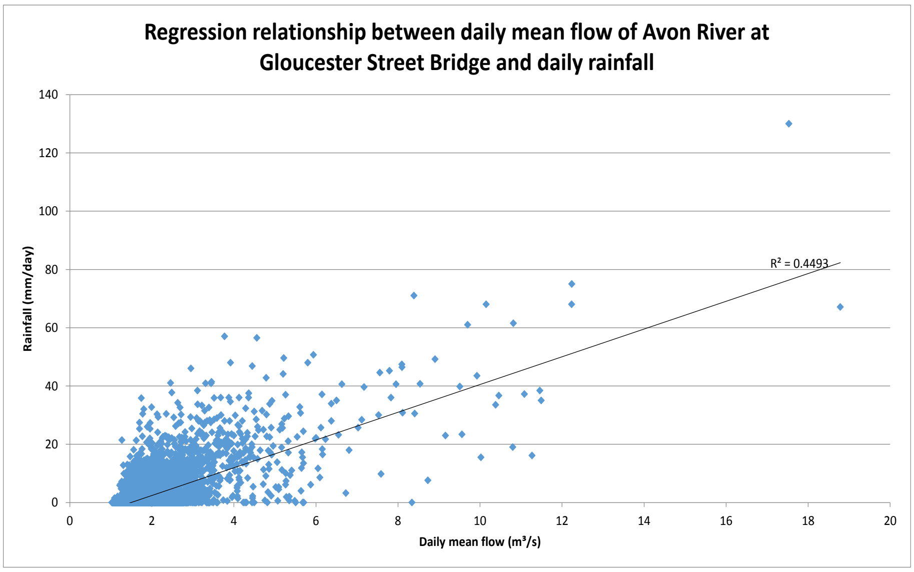


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

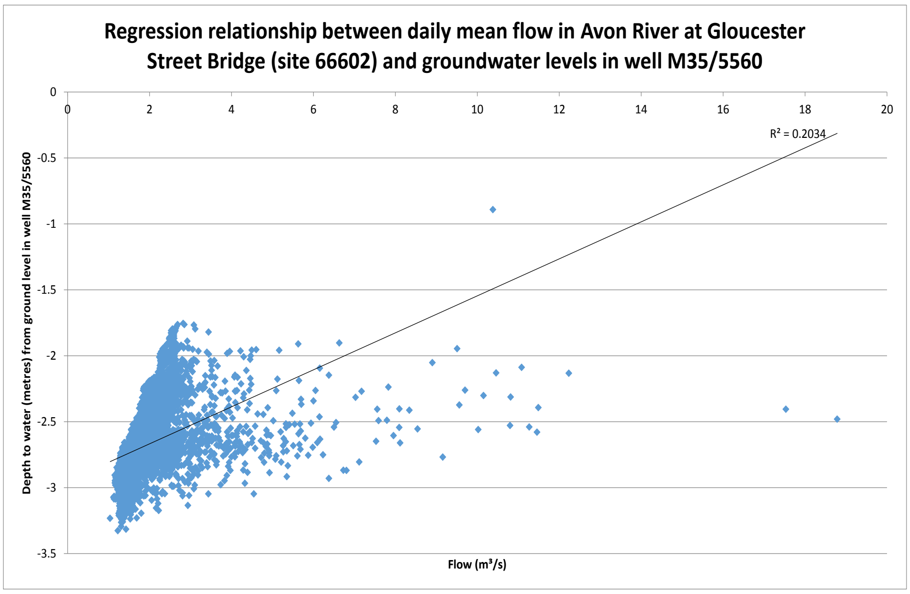
*A-17 **Avon/Ōtākaro River at Glouchester Street bridge** (site 66602)*



Daily mean flow (m^3/s) in relation to rainfall (mm/day) recorded at weather stations 4858 and 24120.

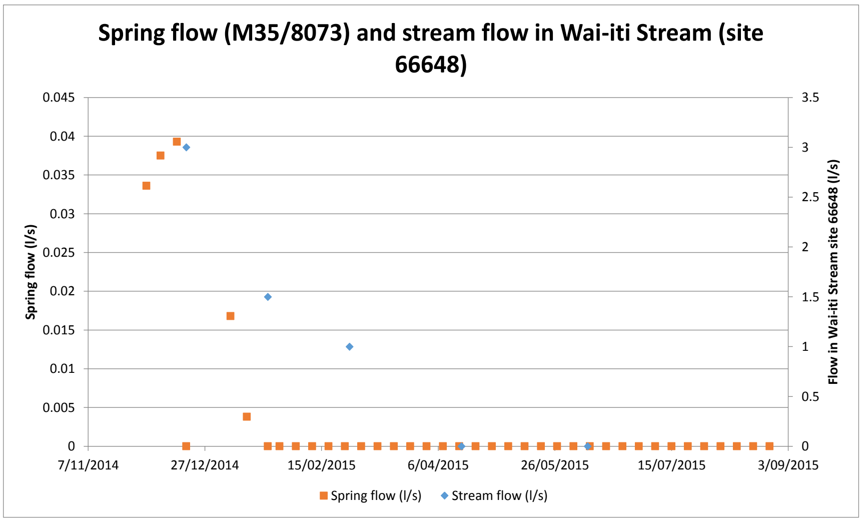


Correlation between daily mean flow (m^3/s) and rainfall (mm/day)..

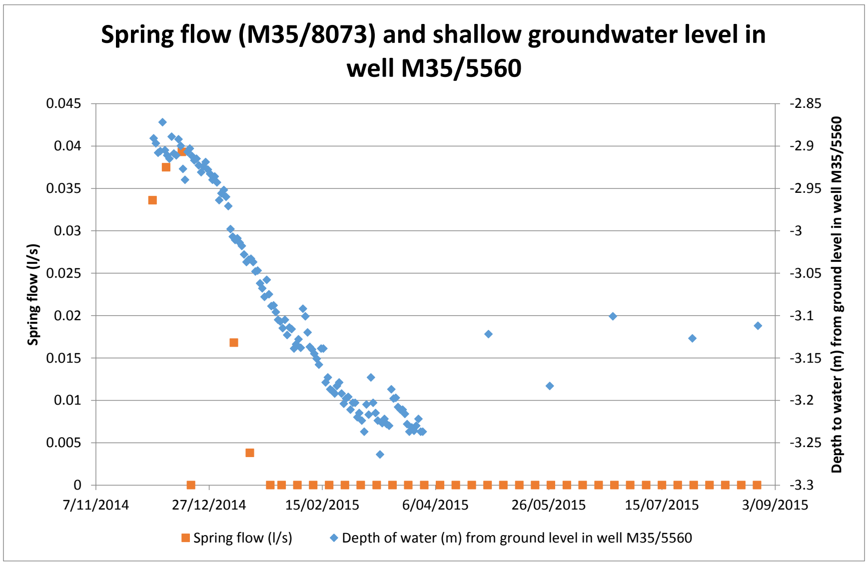


Correlation between shallow groundwater level in well M35/5560 (depth to water from ground level in metres) and flow rate (m^3/s).

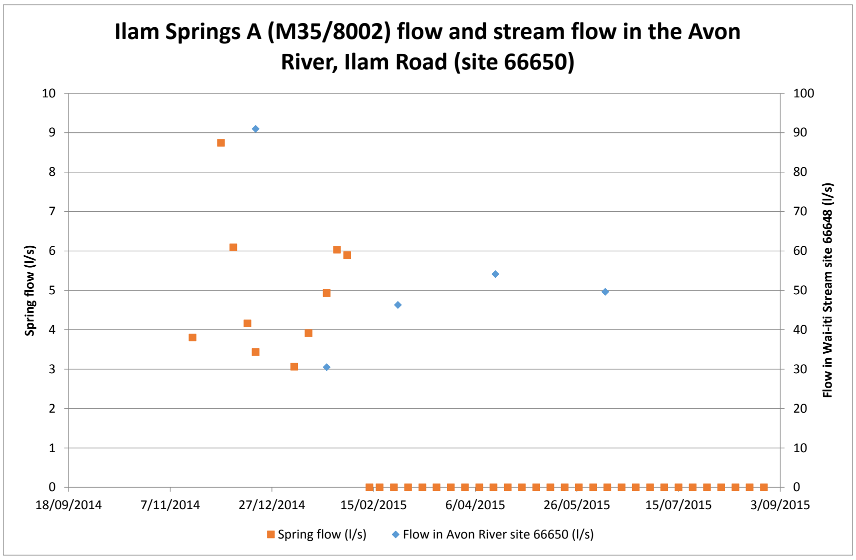
Appendix B. Relationship between river flow and spring flow.



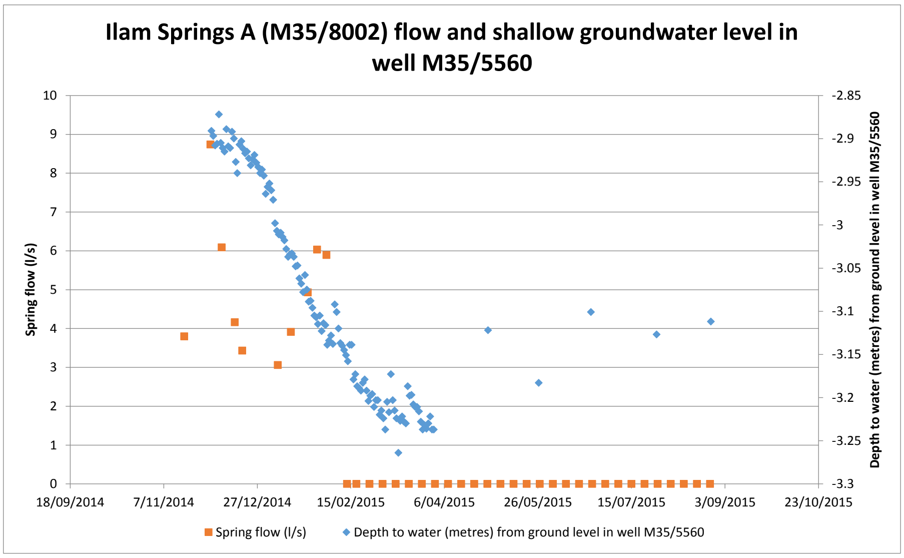
M35/8073 (Jellie Park) spring flow (L/s, from Webster-Brown & Barr, 2016) in relation to stream flow in Wai-iti Stream (L/s, site 66648), located in the corner of Brookside Terrace and Ilam Road.



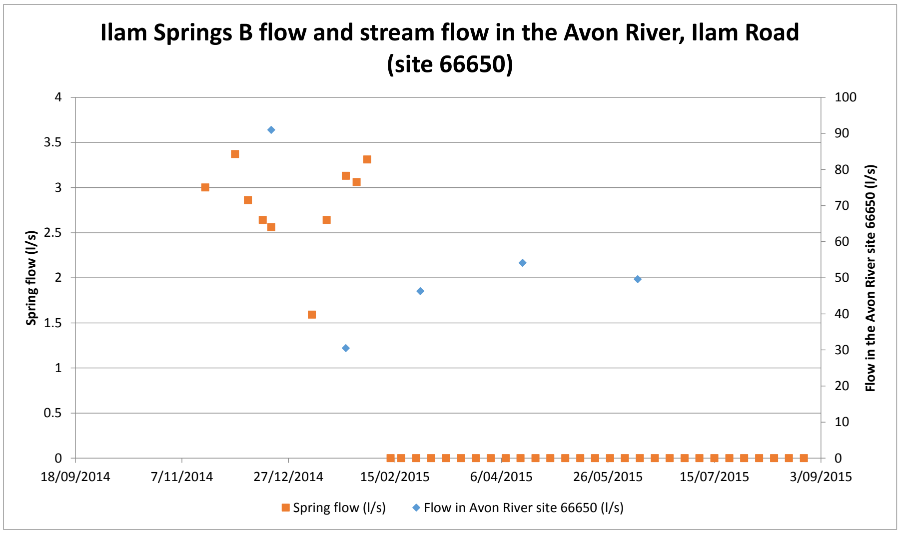
M35/8073 (Jellie Park) spring flow (L/s, from Webster-Brown & Barr, 2016) in relation to shallow groundwater level in well M35/5560 (depth to water from ground level in metres).



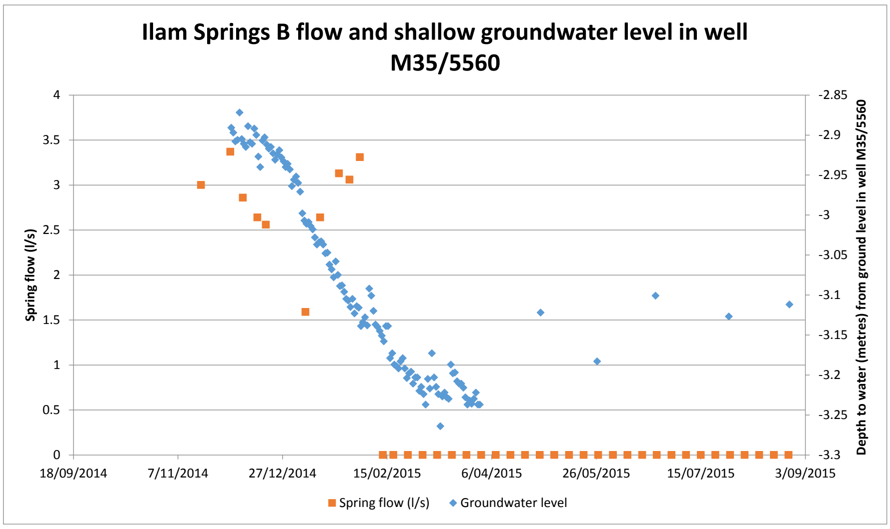
Spring flow in Ilam Spring A (L/s) located in Ilam Fields (data from Webster-Brown & Barr, 2016), in relation to stream flow in the Avon/Ōtākaro River at Ilam Road (L/s) (site 66650).



Spring flow in Ilam Springs A (L/s) located in Ilam Fields (Webster-Brown & Barr, 2016), in relation to shallow groundwater level in well M35/5560 (depth to water from ground level in metres).



Spring flow in Ilam Springs B (L/s) located in Ilam Fields (Webster-Brown & Barr, 2016), in relation to stream flow in the Avon/Ōtākaro River at Ilam Road (L/s) (site 66650).



Spring flow in Ilam Springs B (L/s) located in Ilam Fields (Webster-Brown & Barr, 2016), in relation to shallow groundwater level in well M35/5560 (depth to water from ground level in metres).

Appendix C. Groundwater take consent table (Canterbury Maps, 2017c).

Catchment	RMA Authorisation number	Client	Consent Location	Purpose	Bores	Depth (m)	Maximum volume (m³/day)	Maximum rate (l/s)	Commencement and Exipry Dates
Avon River	CRC971518	UC	Ilam Road	Spray irrigation and aquifer testing	M35/5557	27	3240	15.00	24/12/1997 - 1/07/2032
Okeover Stream	CRC971519			Air conditioning	M35/2244	9.10	706.00	5.60	09/12/1997 - 1/7/2032
					M35/2245	60.9	3272	30.3	
					M35/2246	9.1	286	5.3	
					M35/2476	45.7	959	53.3	
					M35/3083	9.1	7576	18.3	
					M35/3084	9.1	328	9.1	
					M35/3085	12.2	1976	6.1	
	CRC941244				M35/7082	30	1296	30	20/06/1994 - 15/06/2029
	CRC154984				M35/9322	198.3	-	35	20/02/2015 - 30/02/2035
	CRC961873				M35/7412	18-30	1300	40	24/05/1999 - 22/05/2031
	CRC940595				M35/6985	18	1123	26	
Ilam Stream	CRC961226	Crosbie Park	Woodbury St	Public water supply	M35/5273	24.8	combined 6000	98	02/02/1996 - 31/01/2031
					M35/6041	27.3		98	
	CRC961225				M35/6040	176	3600	42	2/02/1996 - 31/01/2031
	CRC103014				M35/18384	125-200	28980	64	21/10/2010 - 20/10/2045
Waimairi Stream	CRC961223.1	Burnside Park (headwater site)	Avonhead Rd	Public water supply	M35/9439	205	Combined 16000	Combined 300	1/12/2004 - 31/01/2031
					M35/2454	16.4			
					M35/2557	17			
					M35/5698	20.4			
	Not found				M35/5697	20.5	Not found	67	Status on 26/02/17: Active But dates not found
	CRC960022	Fendalton Bowling Club Inc	28 Makora Street, Fendalton	Irrigation (up to 0.5 ha)	M35/7281	30	302	2	2/08/1995 - 2/08/2030
Wairarapa Stream	CRC990756	Christchurch City Council (CCC)	Jellie Park Aqualand	Swimming pool filling and heat exchange	M35/4146	24	4320	50	11/03/1999 - 9/03/2034
	CRC971015	Burnside High School Board of Trustees	Greers Road	Irrigation (up to 16 ha)	M35/3040	20.2	821	7.6	12/09/1997 - 1/07/2032
	CRC961219	CCC	Jeffreys Road, Fendalton	Public water supply	M35/2465	33.2	Combined 1089	55	02/02/1996 - 31/01/2031
					M35/2379	22.2		55	
	CRC961220				M35/4112	80.8	Combined 2673	135	02/02/1996 - 31/01/2031
					M35/2468	46.6		135	
	CRC970902				M35/6667	193	5616	65	29/08/1997 - 27/08/2032
Taylors Drain	CRC991316		Blighs Road Pumping Station		M35/2585	47.5	2000	31	11/11/1999 - 8/11/2034
					M35/2054	68.2	2000	31	
	CRC970901		Blighs Road		M35/6203	66	2592	30	29/08/1997 - 27/08/2032

Appendix D. Historical comparisons

Last flow locations and distances of headwater migration downstream (D/S) from the earliest measurements of dry reaches.

Waterway	Month/season	Year	Last flow location*		Location*	Migration D/S of headwater from earliest measurement (m)*	Reference**
			Latitude	Longitude			
Waimairi Stream	Summer	1979/80	43°30'21.01"S	172°33'49.93"E	Burnside Park	0	C; A
	April	1985	43°30'37.23"S	172°34'25.25"E	67 Greers Rd	1066	C; B
	Summer	1992	43°31'5.76"S	172°35'0.02"E	D/S of confluence with South Branch Waimairi	2421	C
	Feb-Mar	1999	43°30'39.34"S	172°34'23.78"E	55 Greers Rd	1139	D
	Feb-Mar	2000	43°30'38.36"S	172°34'25.16"E	65A Greers Rd	1098	D
	Feb-Mar	2001	43°30'35.35"S	172°34'20.28"E	21A Westburn Tce	935	D
	Jan	2017	43°30'40.28"S	172°34'26.43"E	30E Greers Rd	1291	
Waimairi South Branch	April	1985	43°30'54.70"S	172°34'11.87"E	14 St Cilo Street	0	C; B
	Summer	1992	43°31'1.68"S	172°34'41.29"E	170 Ilam Rd	740	C
	Summer	1993	43°31'1.68"S	172°34'41.29"E	170 Ilam Rd	740	C
	Feb-Mar	1999	43°31'1.68"S	172°34'41.29"E	170 Ilam Rd	740	D
	Feb-Mar	2001	43°31'1.30"S	172°34'37.07"E	177A Ilam Rd	637	D
	Feb	2017	43°31'1.80"S	172°34'41.92"E	170 Ilam Rd	740	
Hewlings Stream	Summer	1979/80	43°30'16.80"S	172°34'28.13"E	8 Rubens Pl	0	C; A
	April	1985	43°30'27.05"S	172°34'46.28"E	Jellie Park near Greers Rd	539	C; B
	Summer	1992	43°30'27.05"S	172°34'46.28"E	Jellie Park near Greers Rd	539	C
	Summer	1993	43°30'27.05"S	172°34'46.28"E	Jellie Park near Greers Rd	539	C
	Feb-Mar	2000	43°30'26.46"S	172°34'45.43"E	Jellie Park near Greers Rd	517	C
	Dec	2016	43°30'26.81"S	172°34'46.06"E	Jellie Park near Greers Rd	533	
Wairarapa Stream	Summer	1979/80	43°30'10.26"S	172°34'52.01"E	11 Sevenoaks Dr	0	C; A
	April	1985	43°30'27.11"S	172°34'56.07"E	Jellie Park near lake	578	C; B
	Summer	1992	43°30'27.11"S	172°34'56.07"E	Jellie Park near lake	578	C
	Summer	1993	43°30'23.40"S	172°34'54.91"E	Jellie Park near Greers Rd	454	C
	Feb-Mar	1999	43°30'24.98"S	172°34'55.96"E	Jellie Park near lake	513	D
	Feb-Mar	2000	43°30'23.48"S	172°34'55.01"E	Jellie Park near Greers Rd	457	D
	Dec	2016	43°30'23.48"S	172°34'55.04"E	Jellie Park near Greers Rd	457	
Wai-iti Stream	Summer	1979/80	43°30'10.43"S	172°35'11.70"E	14 Hooker Ave	0	C; A
	April	1985	43°30'30.33"S	172°35'32.35"E	Brookside Tce & Ilam Rd intersection	926	C; B
	Summer	1992	43°30'30.33"S	172°35'32.35"E	Brookside Tce & Ilam Rd intersection	926	C
	Summer	1993	43°30'30.33"S	172°35'32.35"E	Brookside Tce & Ilam Rd intersection	926	C
	Feb-Mar	1999	43°30'30.33"S	172°35'32.35"E	Brookside Tce & Ilam Rd intersection	926	D
	Jan	2017	43°30'30.33"S	172°35'32.35"E	Brookside Tce & Ilam Rd intersection	926	
Okeover Stream	Summer	1992	43°31'15.23"S	172°34'39.25"E	Ilam Fields	0	C
	Summer	1993	43°31'15.23"S	172°34'39.25"E	Ilam Fields	0	C
	Feb-Mar	1999	43°31'15.17"S	172°34'40.81"E	Ilam Fields	36	D
	Jan	2017	43°31'16.27"S	172°34'55.44"E	~11m D/S of Engineering Rd footpath	1242	
Ilam Stream	April	1985	43°31'27.01"S	172°34'34.10"E	Confluence with the Avon River main branch	0	C; A
	Summer	1992	43°31'27.01"S	172°34'34.10"E	Confluence with the Avon River main branch	0	C
	Summer	1993	43°31'27.01"S	172°34'34.10"E	Confluence with the Avon River main branch	0	C
	Feb-Mar	1999	43°31'21.35"S	172°34'22.58"E	Waimairi Rd, west of Ilam Fields	-326	D
	Feb	2017	N/A	N/A	No dry bed found during the period of study up to SH1	-3592	
Avon River (main branch)	Summer	1979/80	43°31'17.98"S	172°33'24.73"E		0	C; A
	April	1985	43°31'17.98"S	172°33'24.73"E		0	C; B
	Summer	1992	43°31'17.98"S	172°33'24.73"E		0	C
	Summer	1993	43°31'17.98"S	172°33'24.73"E		0	C
	Feb-Mar	1999	43°31'17.98"S	172°33'24.73"E	Nortons Rd; no dry bed was found	0	D
	Feb-Mar	2000	43°31'17.98"S	172°33'24.73"E	Nortons Rd; no dry bed was found	0	D
	Feb-Mar	2001	43°31'17.98"S	172°33'24.73"E	Nortons Rd; no dry bed was found	0	D
	Dec	2016	43°31'20.86"S	172°33'40.57"E	Avonhead Road - Corfe Reserve [A]	102	
	Jan	2017	43°31'18.74"S	172°33'28.13"E	41 Balrudry St [A]	89	
Taylors Drain	Summer	1979/80	43°30'27.03"S	172°35'49.76"E	Ilam Road	0	C; A
	April	1985	43°30'27.03"S	172°35'49.76"E	Ilam Road	475	B
	Summer	1992	43°30'27.03"S	172°35'49.76"E	Ilam Road	475	C
	Summer	1993	43°30'27.03"S	172°35'49.76"E	Ilam Road	475	C
	Feb-Mar	1999	43°30'27.03"S	172°35'49.76"E	Ilam Road	475	D
	Jan	2017	43°30'27.03"S	172°35'49.76"E	Ilam Road [A] ⌂	475	
Cross Drain	Feb-Mar	1999	43°30'17.74"S	172°36'10.98"E	200 Idris Road	0	D
	Jan	2017	43°30'35.96"S	172°36'22.83"E	Christchurch Railway Cycleway near 53 Strowan Rd (confluence with Taylors Drain)[A]	703	

*Estimated from Google Earth, except the 2016/17 coordinates (GPS).

**A = Christchurch Drainage Board (1980), B = Daglish (1985), C = Cameron (1992), D = Daly (2001). [A] Exact point not determined using GPS; coordinates were estimated from last flow observation sites from Google Earth. ⌂ Dry reach changed on different visits, based on the 10-Jan-17 survey.

Appendix E. Enlarged maps

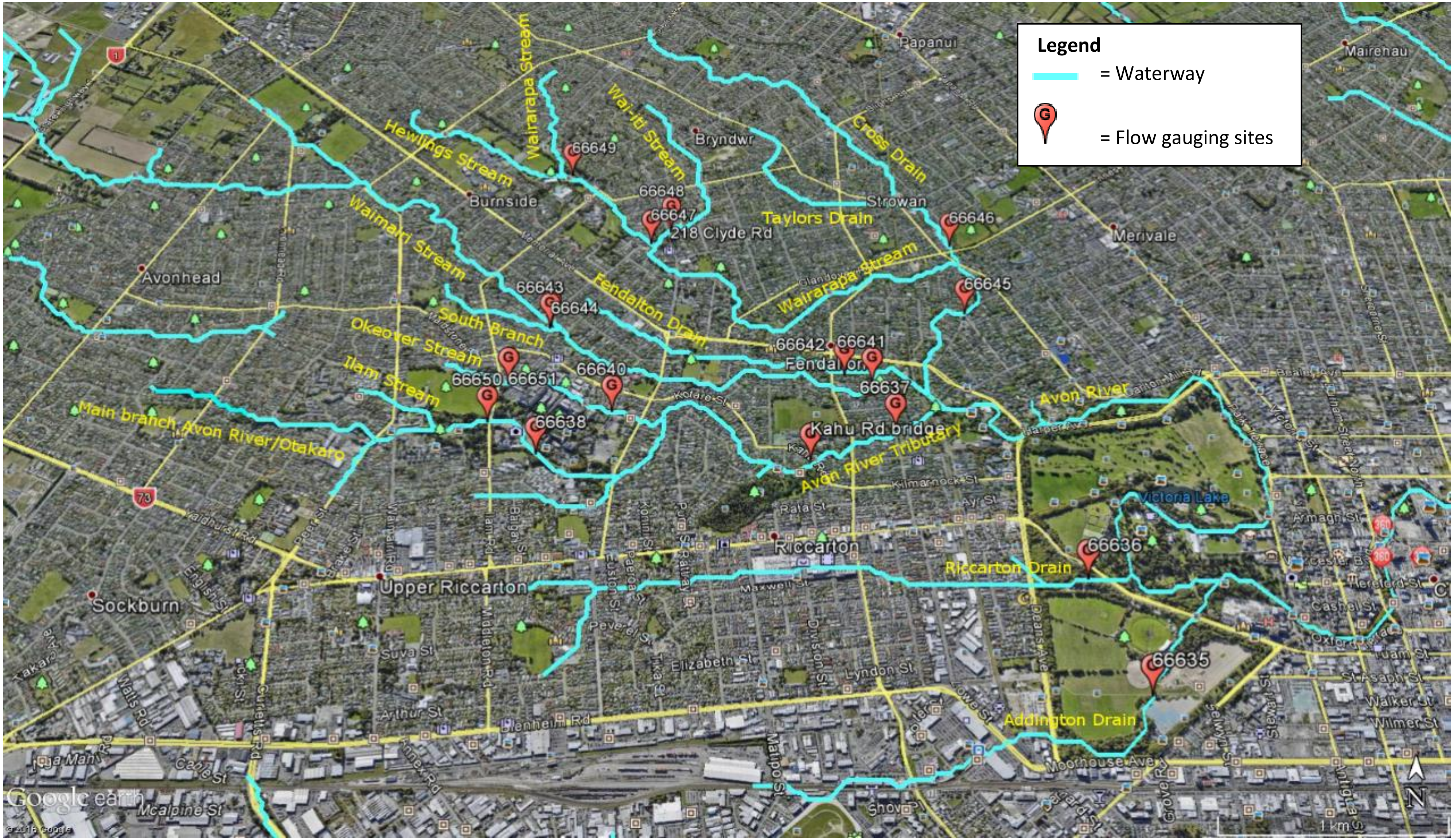


Figure 1 enlarged (refer caption for Figure 1)

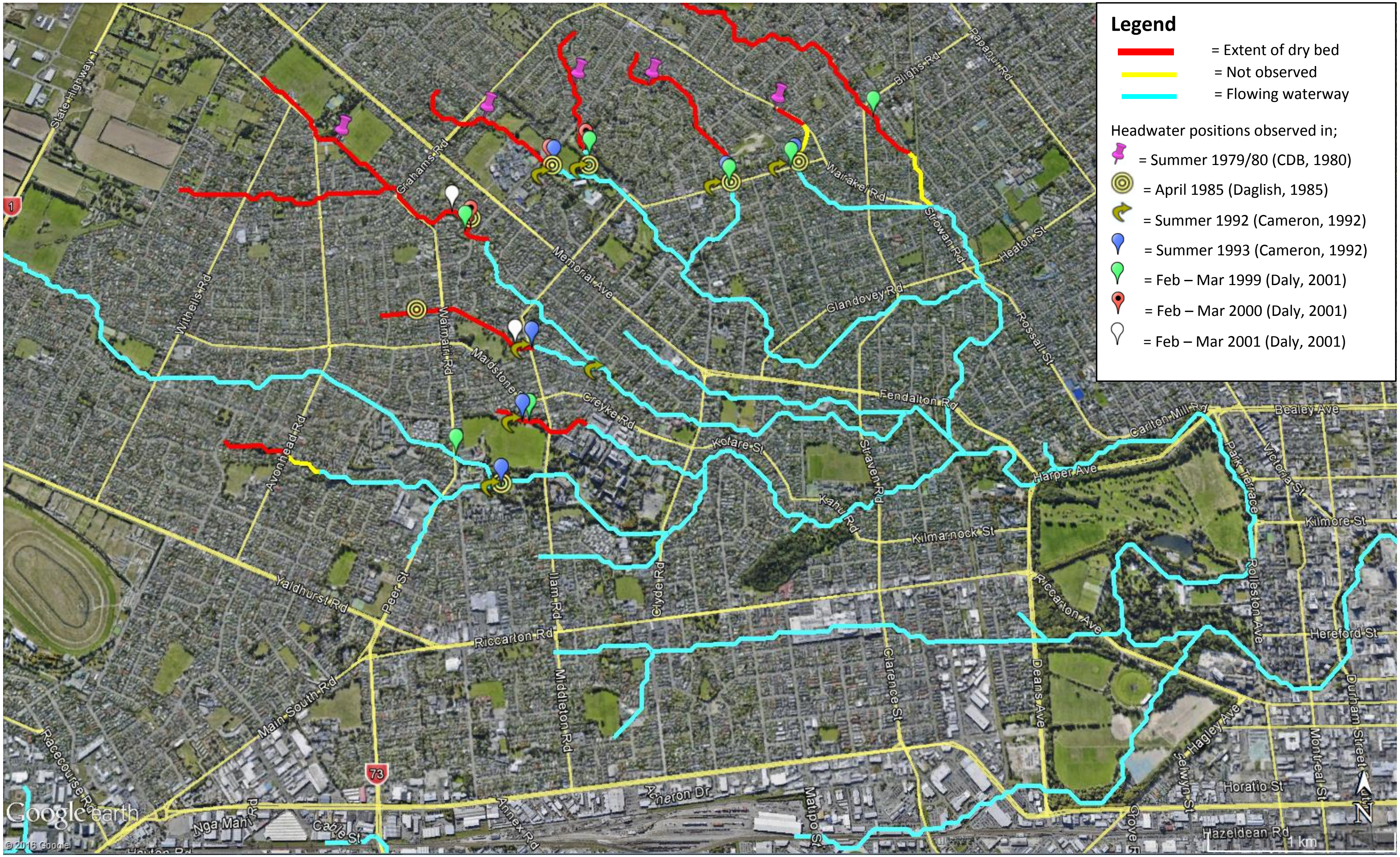


Figure 2 enlarged (refer caption of Figure 2)

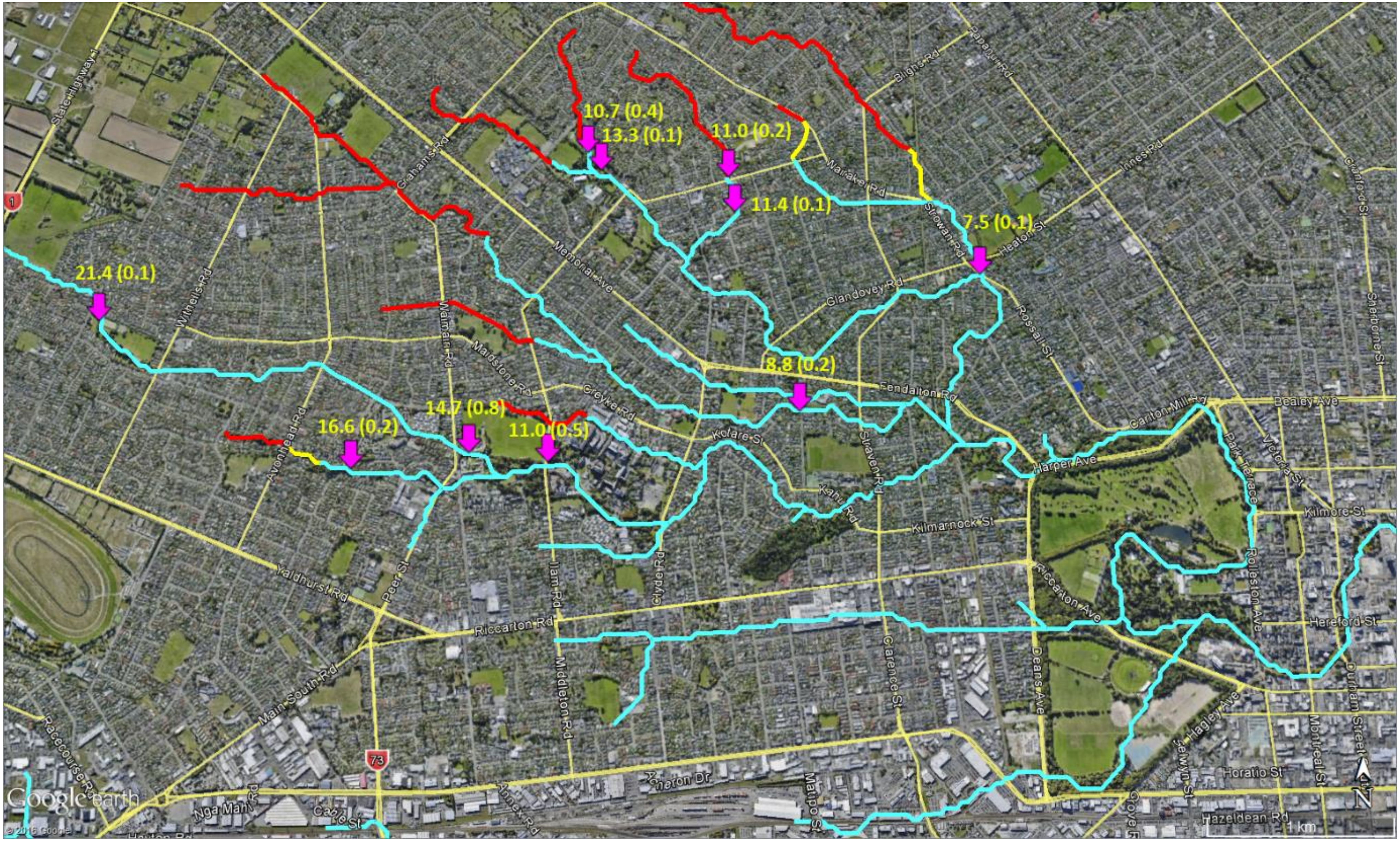


Figure 3 enlarged (refer caption of Figure 3)