

Technical Report  
Investigations and  
Monitoring Group

# **Pareora – Waihao River: Water Resource Summary**

Report No. R06/20

# Pareora – Waihao River: Water Resource Summary

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## Executive summary

The water resources of the rivers and associated groundwater resources draining The Hunters Hills in South Canterbury are described and quantified. These rivers include the Pareora River in the north and the Waihao River in the south, and those between. None of the rivers is large and while they sometimes flood, their usual state is to convey very low flows. Given the population in the region, including Timaru which takes much of its water supply from the upper Pareora River, the region is arguably the most water deficient in the country.

More than 100 years of record are available for several raingauges in the region. Mean annual rainfalls are less than 600 mm on the coast, increasing to about 1200 mm at higher points in The Hunters Hills. Monthly rainfalls show a slight tendency toward lower values in winter months. Typical (median) monthly totals range from about 25 mm to about 80 mm. Particularly dry periods occurred in 1914-1916, 1984-1985, 1989-1999 and 2001 to 2003. Since 1996, annual rainfalls have exceeded the mean annual values in only two or three years. Overall, however, no trends or shifts are evident in the annual rainfalls.

Both temperature and wind records show substantial variation between day and night and between seasons. On the coast, prevailing summer wind direction is northerly to southeasterly; prevailing winter wind is southwesterly. Northwesterly wind, commonly associated with Canterbury climate, is very infrequent.

Gaugings of stream flows undertaken at sites across the catchments since the 1950s are assembled, adjusted for the effects of abstractions and correlated with corresponding flows at recorders. Fitted regression equations are used to estimate flow statistics at the gauging site, given normalised statistics for the recorder sites. Typically, along the main channels, flow is lost to unconfined gravels and even in the absence of abstractions, middle reaches of most of the streams cease flowing in low flow conditions. Some recovery of flow occurs in the lower reaches and the lost water sustains flows in a number of lowland spring-fed streams. A map of the seven-day mean annual low flows per unit area of catchment includes estimates of losses and gains along main channels.

A map of mean annual discharge per unit area of catchment shows that annual runoff ranges from zero near the coast to more than 20 L/s/km<sup>2</sup> (631 mm/yr runoff) in catchment headwaters.

A water balance for the Wainono lagoon is presented. The largest uncertainty appears to be sea water inflows to the lagoon and seepage from the lagoon through the barrier. Valuable insight is gained from the measured variables that influence the level of the lagoon. A water balance model scenario limiting the flow into the lagoon from Waihao River floods showed that high lagoon levels could still occur because of breaches by the sea and high flows from the Hook River, however extreme levels were reduced.

In recent years, groundwater has become the main source of water for irrigation. Groundwater resources include:

- shallow aquifers comprised of Quaternary age alluvium located within the river valleys and adjacent to the coast where they are recharged by rivers and streams, but they can also discharge back into them;
- aquifers in the Pliocene-Pleistocene Cannington gravels (particularly in the marine sequence);
- deeper aquifers within the Tertiary age sediments of the Southburn Sands and Taratu Formation.

A preliminary water balance is presented which accounts for inputs from land-surface recharge (rainfall and irrigation return water) and river recharge, and outputs to spring-fed streams, the Wainono Lagoon, abstractions, and offshore leakage.

Groundwater, particularly from the Quaternary Alluvium and Cannington Gravel aquifers, accounts for 69% of total water allocation of 413,000 m<sup>3</sup>/day. The increase in surface water use has levelled off for most catchments since the mid 1980s. Actual annual water use in a dry year, such as 1997-98, would be around 42.5% from allocated, if taken at the average daily allowed rate in a 150-day irrigation season.

Recommendations for resource use focus on setting minimum flow/groundwater levels, and seasonal groundwater allocation limits. For the lower Pareora River where continual monitoring of river flow is impracticable, a management regime for abstractions based on observed groundwater levels in a hydraulically connected well is suggested. Acceptable residual flows need to be determined through the processes set out in the Natural Resources Regional Plan. For groundwater, a management approach for each of the distinct aquifer types based on an allocatable volume of annual recharge is presented.

### **Acknowledgements**

This report has been review externally by Frank Scarf (Surface water and Wainono Lagoon chapters) and Richard de Joux (Groundwater chapters). Special thanks to Jim Morrison of the Timaru field party for his dedication in maintaining the acoustic flow recorder at Poingdestres Road, the first time this method was used in New Zealand.

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## 1 Introduction

The Pareora-Waihao area is located between Timaru and the Waitaki River on the east coast of the South Island (Figure 1.1). It covers a substantial part of the Waimate District which has a population of just over 7000, about 2750 of whom are resident in Waimate (2001 census figures). Farming is the dominant land use, along with associated industries such as meat and vegetable processing. Farms are a mix of pastoral, arable and horticultural. There are specific areas of horticulture, such as potato growing, around Waimate to supply the processing plants. The 2003 figures for land-use in the Waimate district indicate around 87% is pastoral land, 7% arable, 5% dairy and the remaining made up of lifestyle and horticulture (Hill, 2004). Since 1995 pastoral land use has decreased by 4%, dairying increased by over 200% and irrigated arable land has also increased.

The rivers in this study area drain the eastern and southern flanks of the Hunters Hills, a north-northwest south-southeast trending range, with the exception of the Waihao River which also drains part of the western flanks of the Hunters Hills. The Pareora River in the north and the Waihao River in the south are the two largest rivers in the region. Smaller streams that drain eastwards from the Hunters Hills to the coast are the Otaio, Makikihi and Hook Rivers, and Waimate Creek, as well as a number of smaller lowland streams, some that flow intermittently and some that are groundwater-fed. None of the rivers are large, and while they sometimes flood, their usual state is to have extremely low flows.

The recent trend of more irrigation has increased water usage, particularly from groundwater resources. Groundwater, especially deeper groundwater, has become a preferred option for many irrigators to avoid minimum flow restrictions on surface and hydraulically-connected groundwater, and to allow irrigation of downland areas where surface water and shallow groundwater are not available. Irrigation of gently rolling downlands has become viable mainly due to the K-Line irrigation system which was developed in the Waimate area. The long-term sustainability of deeper groundwater resources is unknown, which combined with the recent rapid increase in abstractions may present a future resource problem.

Given the relatively small rivers in the region (in comparison with the Waitaki to the south and the Rangitata to the north), the limited groundwater resources (in contrast to much of the Canterbury Plains), the dry climate and the population of the region including centres such as Waimate and also Timaru (2001 census population 26,700, which takes its main water supply from the Upper Pareora River), the region is arguably the most water-deficient in the country.

Apart from some lowland spring-fed rivers, all the rivers in this study cease to flow in their middle lower reaches during dry periods: flow reductions along the stream channels occur naturally where water is lost into underlying gravels. This limits their value as fish and wildlife habitats. River ecology has probably been further stressed as a result of human activity, including land development and drainage, land use and abstraction.

The purpose of this study is to quantify the surface and groundwater resources of the region with the aim of providing information to assist in the implementation of the Natural Resources Regional Plan (NRRP) for the region.

The water balance of the Wainono Lagoon, a lagoon behind the gravel beach barrier to the east of Waimate, and specifically the variations of levels, is the topic of a separate report.

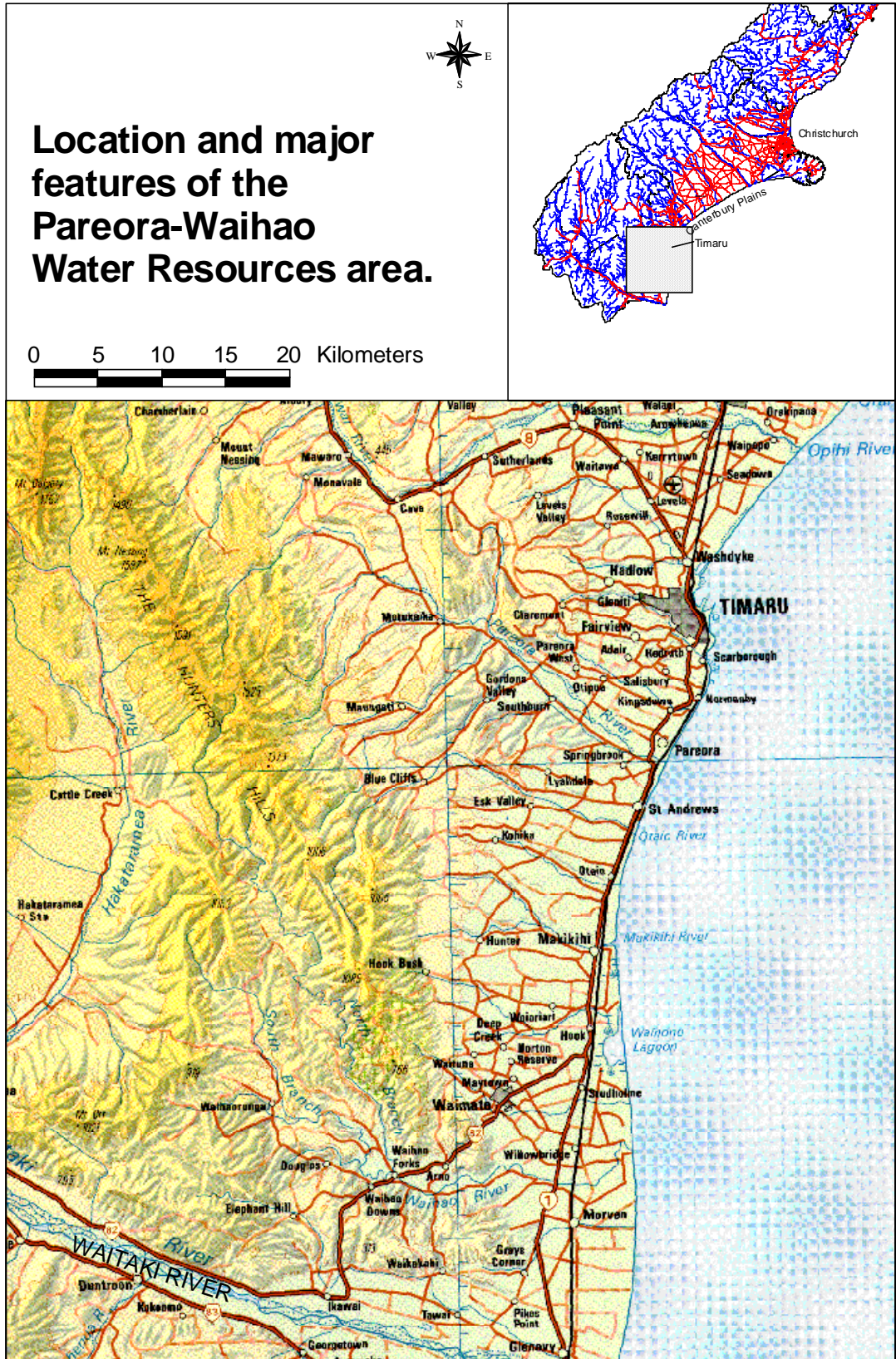


Figure 1.1 Location and major features of the Pareora-Waihao water resources area

## 1.1 Planning framework

The Resource Management Act 1991, with its purpose to promote the sustainable management of natural and physical resources, provides the mandate and the initial direction for managing the region's water resources, as outlined in section 5 of the Act. The Act is generally restrictive towards water and relies on resource consents and/or regional plans to enable access to the water resource. The Resource Management Act sets out the functions and duties of regional councils which, in relation to water quantity, include establishing, implementing and reviewing objectives, policies, and methods to achieve integrated management of the natural and physical resources of the region (s.30(1)(a)). In carrying out these functions, Environment Canterbury must also ensure that this is done in accordance with section 6- Matters of National Importance, section 7- Other Matters, and section 8- Treaty of Waitangi. This has been reflected in the preparation and implementation of the operative Canterbury Regional Policy Statement (CRPS).

Chapter 9 of the CRPS identifies issues that arise from the demand for, and the use of, water. It also establishes the framework for managing the region's water resources, both in terms of water quantity and water quality. In relation to water quantity, Chapter 9 Objective 1 is to enable people to use water while protecting, safeguarding or preserving the values listed. Objective 2 provides for people to use land where it affects the flows and levels of Canterbury's water bodies while protecting the same values listed in Objective 1.

In order to give effect to the CRPS, Environment Canterbury has notified the Proposed Natural Resources Regional Plan, Variation 1 (NRRP). Chapter 5 of the NRRP addresses water quantity management topics, including the setting of flow or level regimes to protect in-stream/intrinsic values of waterbodies and the allocation of water above any set flow or level regime to out-of-stream/consumptive uses.

Objective WQN1 states:

*Enable present and future generations to access the region's surface and groundwater resources to gain cultural, social, recreational, economic and other benefits, while:*

- (a) *safeguarding their existing value for efficiently providing sources of potable water for people and for stock;*
- (b) *safeguarding the life-supporting capacity of the water, including its associated aquatic ecosystems, significant habitats of indigenous fauna, and areas of significant indigenous vegetation;*
- (c) *safeguarding their mauri and existing value for providing mahinga kai for Ngai Tahu;*
- (d) *protecting wāhi tapu and other wāhi taonga of value to Ngai Tahu;*
- (e) *preserving the natural character of lakes and rivers and protecting them from inappropriate use and development;*
- (f) *protecting outstanding natural features and landscapes from inappropriate use and development;*
- (g) *protecting significant habitat of trout and salmon; and*
- (h) *maintaining, and, where appropriate, enhancing amenity values.*

Except for provision (a) which now includes stockwater, and the addition of "mauri" in provision (c), (a) to (h) of Objective WQN 1 are identical to Objective 1 in the CPRS Chapter 9 Water. However, NRRP Chapter 5 contains more detailed policies and methods, including rules that regulate water management, to help achieve the objective.

The NRRP provides for the systematic inclusion of further schedules to give effect to its objectives and policies. This report on the Pareora-Waihao provides background information and issue identification to assist with the planning process associated with the further inclusions.

Regard must also be given to the Canterbury Regional Coastal Environment Plan (which is almost confirmed as an Operative Plan), which was developed to be consistent with the New

Zealand Coastal Policy Statement. The coastal environment area can include the mouths of rivers, estuaries, and coastal wetlands that may be impacted upon water management that occurs in these areas or inland of these. The coastal plan describes the importance of *‘wetlands such as Wainono that are significant habitats for a large number of bird species, including waders and water fowls’*.

## 1.2 Scope and objectives

The objectives of the investigations summarised in this report were:

- Characterise surface water/groundwater interactions
- Quantify the surface water resource
- Describe the nature and occurrence of the groundwater resources
- Provide estimates of groundwater allocation limits and surface water minimum flows
- Identify gaps in understanding and future investigations

It is anticipated that the report will provide technical information to assist in identifying management issues and options.

## 2 Climate

The climate of the Waihao-Pareora area is reviewed in this section. The location of the region between the sea and the Hunters Hills distinguishes it climatically from other regions in Canterbury. Features are the relatively low rainfalls, even at the higher elevations in the Hunters Hills, strong seasonal and diurnal patterns in coastal wind, and much less nor-westerly wind than in other parts of Canterbury. The long-term rainfall records for the region suggest that the last few years have been much drier than usual.

A detailed overview of climate for Canterbury is presented in Ryan (1987). This present study complements Ryan (1987) by presenting additional summaries of data specific to the South Canterbury region between the Rangitata and Waitaki Rivers.

### 2.1 Rainfall

The South Canterbury region south of Timaru is largely sheltered from rain accompanying westerly and southwesterly weather by the Hunters Hills. Rain occurs infrequently, mostly from easterly or southeasterly directions.

Rainfall has been measured across the region with standard raingauges for more than 100 years. The longest monthly record available, for Oamaru, commences in 1866. More details of long records are presented in Table 2.1. Estimated mean annual rainfall across the region is presented in Figure 2.1, which also indicates the location of the raingauges used. This figure shows that mean annual rainfall ranges from about 500 mm near the coast to about 1200 mm in the Hunters Hills inland from Waimate.

**Table 2.1 Long rainfall records selected for South Canterbury and North Otago**

Number	Name	Start	End	Notes
H40272	Te Ngawai	Feb 1907	1 Dec 2004	Various gaps filled by scaling Orari data by ratio of 1951-1980 normals.
H41111	Kakahu Bush	Jul 1909	1 Dec 2004	Various gaps filled by scaling Orari data by ratio of 1951-1980 normals.
H41131	Orari Estate	Oct 1897	1 Dec 2004	
H41421	Timaru Gardens	May 1881	1 Dec 2004	Use from 1897 since no data 1887-1896. Various gaps filled by scaling Orari data by ratio of 1951-1980 normals. H41404 (Timaru 2) record used from Dec 1985.
H41701	Waimate	Jan 1908	1 Dec 2004	Various gaps filled by scaling Orari data by ratio of 1951-1980 normals. Low falls recorded after site change in 1992 and hence June 1992-Jan 2005 is scaled to Duntroon by ratio of 1951-1980 normals.
I41861	Duntroon	Jun 1913	1 Jan 2005	Waimate data scaled by ratio of 1951-1980 normals used to extend record back in time to Jan 1910.
I41901	Oamaru	Jul 1866	1 Jan 2005	Data until Dec 1982 from Thompson (1984) who compiled a continuous record from 10 separate sites. Data for 1950 to Nov 1985 is for I41901, Oamaru Airport. Dec 1985 to 1999 by scaling I50085, Enfield. Data for 2000-2004 from I49902, Oamaru AWS.

Seasonal patterns for the rainfall are shown by the box-plots of monthly totals for records for seven of the longest records in the region which range from 95 to 139 years (Figure 2.2). The box-plots summarise the distribution of data in each month of the year by showing the minimum, the totals exceeded in 75%, 50% and 25% of months and the maximum for each month. The figures show a consistent mild seasonal pattern for highest monthly rainfalls in summer, particularly December and January and lowest rainfalls in winter (June, July and August). Minimum monthly rainfalls are typically 2 to 12 mm and months with nil rainfall are rare. Highest monthly median values (typically in summer months) are in the range 50 to 80 mm, whereas lowest median values (typically in winter) are in the range 25 to 40 mm. Rainfall totals can exceed 150 mm in any month. Analysis of long-term variations of these records is presented below (section 2.5).

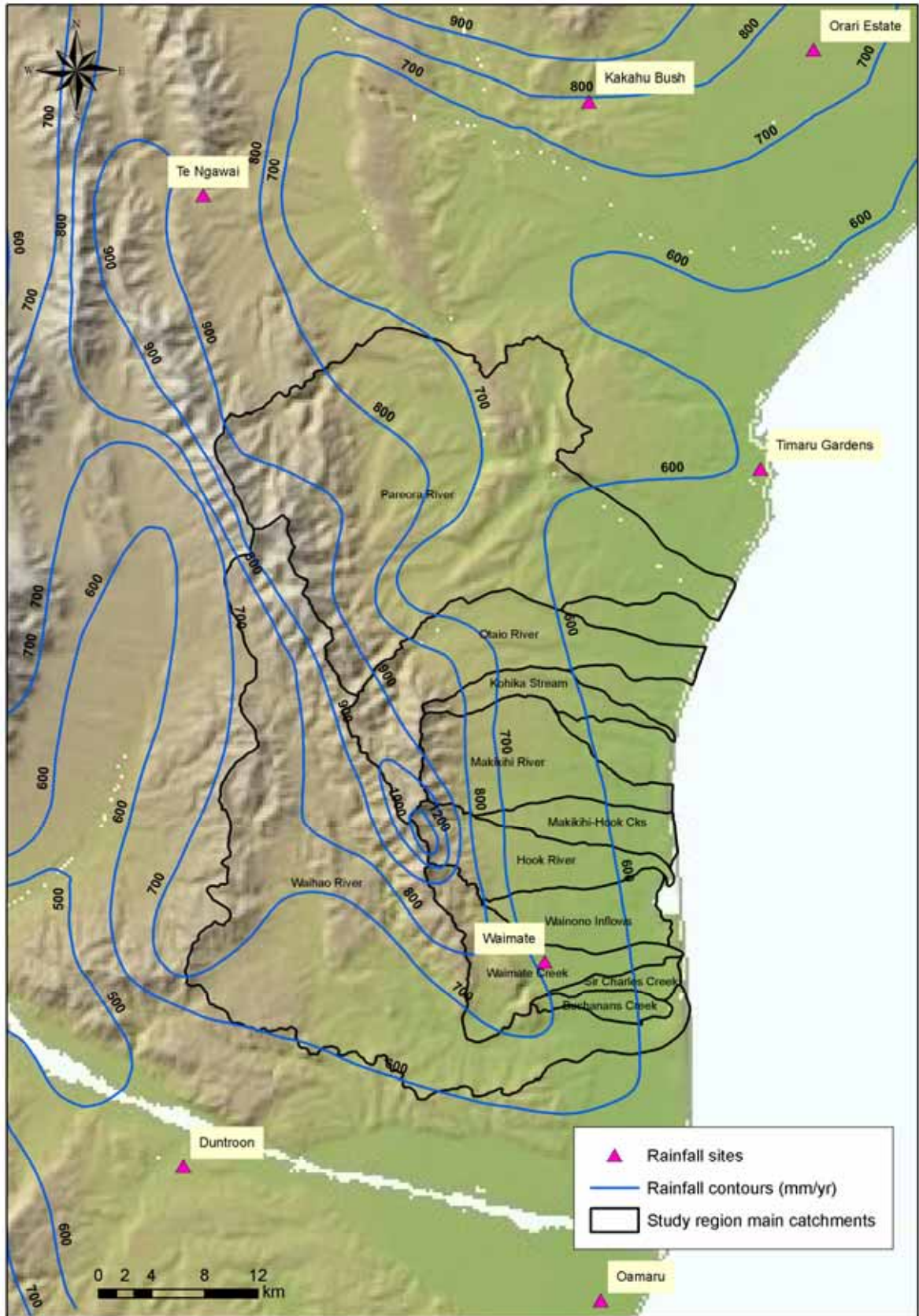


Figure 2.1 Mean annual rainfall (mm) contour map and rainfall sites

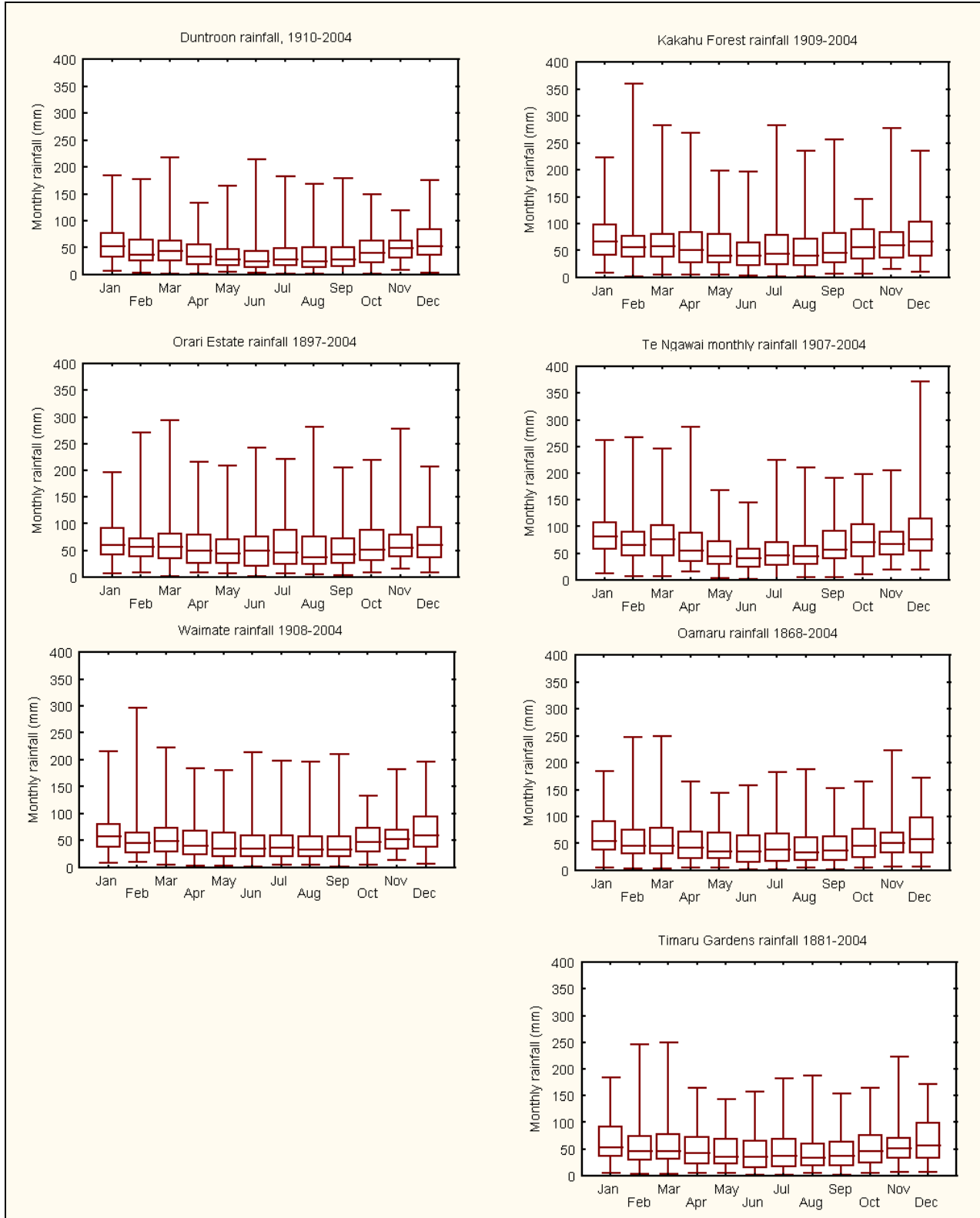


Figure 2.2 Box plots of monthly rainfalls

## 2.2 Temperature

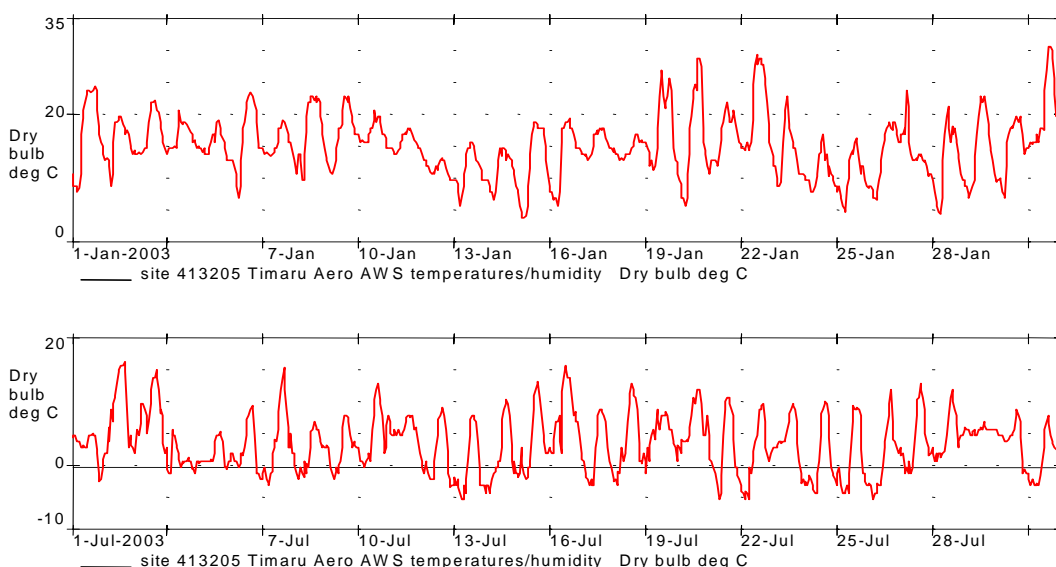
Summaries of monthly temperature data recorded up to 1980 for a number of climate stations in the region are published in NZ Meteorological Service (1980). For each of the 12 months in a year, the data include (for temperature): highest recorded, average monthly and daily maximum, mean, average daily range, average monthly and daily minimum, and lowest recorded. Also included are the grass and soil temperatures, average number of days with frost and the average monthly relative humidity at 0900h. The data are based on daily manual readings.

For New Zealand as a whole, Zheng et al. (1997) used composite temperature records to determine that the national average air temperature increased over 1896 to 1994 at a rate of 0.11 °C per decade, which is about double the trend reported for global data. However trends in maximum and minimum temperatures were not statistically significant. These findings probably apply for the South Canterbury region.

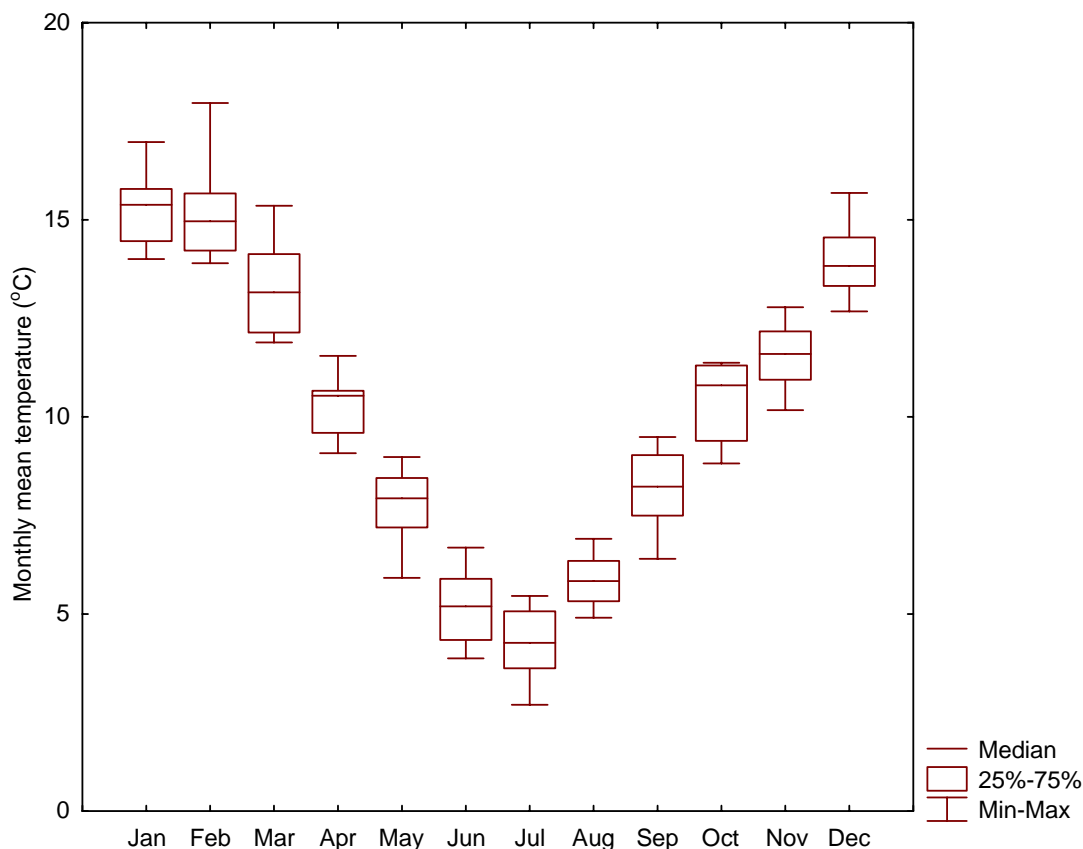
Modern automatic weather stations (AWS) provide hourly observations, and samples of the hourly temperature data for the Timaru Aero AWS for January and July 2003 are presented in Figure 2.3 (January and July are considered to typify summer and winter conditions). Features of this figure are the daily temperature ranges in both summer and winter, which typically are about 10 °C, but can exceed 20 °C, with frequent frosts in July.

Monthly mean temperatures for this record are summarised in Figure 2.4, which presents the monthly data as boxplots. The important feature of this figure is the strong seasonal signal with summer highs and winter lows, but also a range of several degrees for values in any month.

Similar patterns are anticipated for temperature records for other locations in the region.



**Figure 2.3** Hourly temperature data for Timaru Aero AWS for January and July 2003



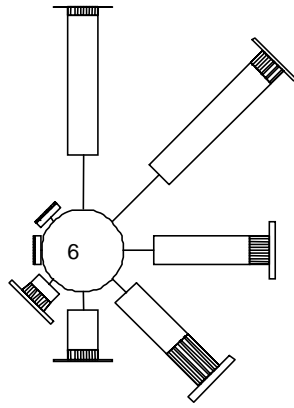
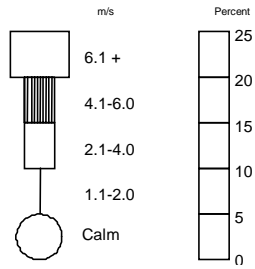
**Figure 2.4** Boxplots of monthly mean temperatures Timaru Aero AWS, Nov. 1991 to April 2004

## 2.3 Wind

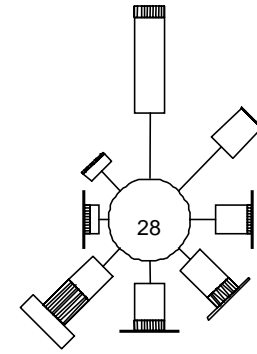
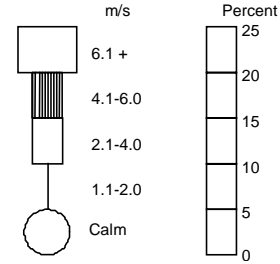
A range of wind records is available in the region. Longer records include daily wind run and wind speed observations at 3 hourly intervals during daylight hours as assessed from Beaufort scale estimates. Modern records are logged as the average speed and direction for the last 10 minutes of each hour as sensed by cup anemometers mounted on 10 metre high masts with standard exposure conditions. Hourly data in the South Canterbury region are available for Timaru and Oamaru Airports, and also for a site named Poingdestres Road beside the Dead Arm of the Wainono Lagoon, located one kilometre inland from the sea. Data for the latter site (which is at 6 m height) for June 2001 through May 2004, presented as wind roses in Figures 2.5 and 2.6, illustrate pronounced seasonal and diurnal patterns.

Strong contrasts between day (nominally 0900 h to 2100 h NZ Standard Time) and night (nominally 2100 h to 0900 h NZ Standard Time) are immediately evident. For example, during summer days calm (nominally less than 1.0 m/s) occurs only 6% of the time, whereas at night calm occurs 54% of the time (Figure 2.5). In winter, calm occurs in 35% of the daytime, and 62% of the night (Figure 2.6). Westerly and northwesterly wind is infrequent but northerly and southwesterly wind is frequent in all seasons. Daytime northeasterly, easterly and southeasterly wind occurs in all seasons, but particularly in spring and summer. Average seasonal wind speeds for day and night listed in Table 2.2 summarise the seasonal and diurnal contrasts. The daytime seasonal variation is evident with highest wind speeds in summer and lowest wind speeds in winter. In contrast, there is little seasonal variation in the night data. The higher summer values probably enhance the summer evaporation.

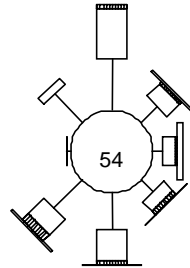
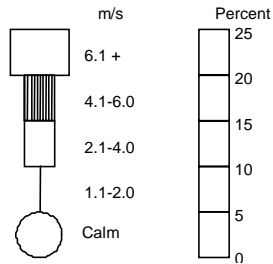
Dec/Jan/Feb 0900h-2100h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



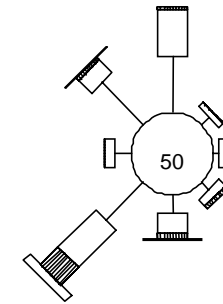
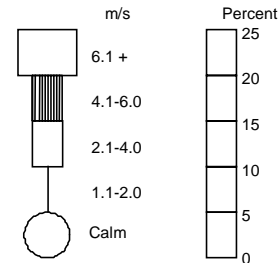
Mar/Apr/May 0900h-2100h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



Dec/Jan/Feb 2100h-0900h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



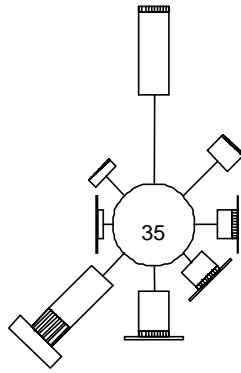
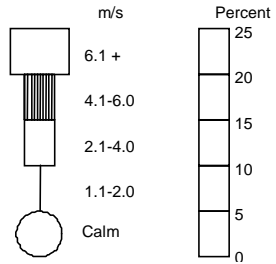
Mar/Apr/May 2100h-0900h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



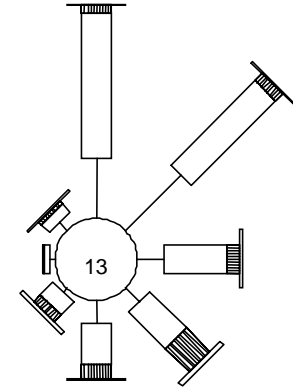
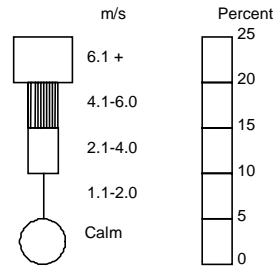
**Figure 2.5 Poingdestres Road summer and autumn wind rose data**

Wind rose data for day-time and night-time data for the Poingdestres Road recorder for summer (Dec/Jan/Feb) (left column) and autumn (Mar/Apr/May) (right column).

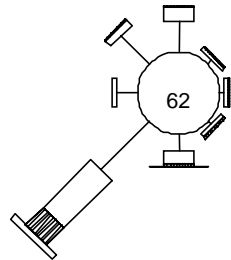
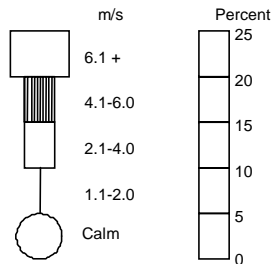
Jun/Jul/Aug 0900h-2100h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



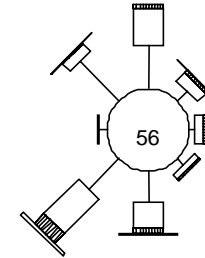
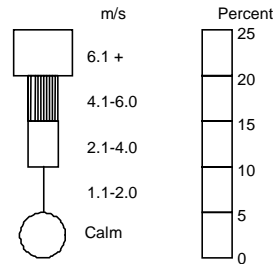
Sep/Oct/Nov 0900h-2100h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



Jun/Jul/Aug 2100h-0900h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



Sep/Oct/Nov 2100h-0900h  
 Site 270906 Poingdestres wind  
 31-May-2001 to 31-May-2004



**Figure 2.6 Poingdestres Road winter and spring wind rose data**

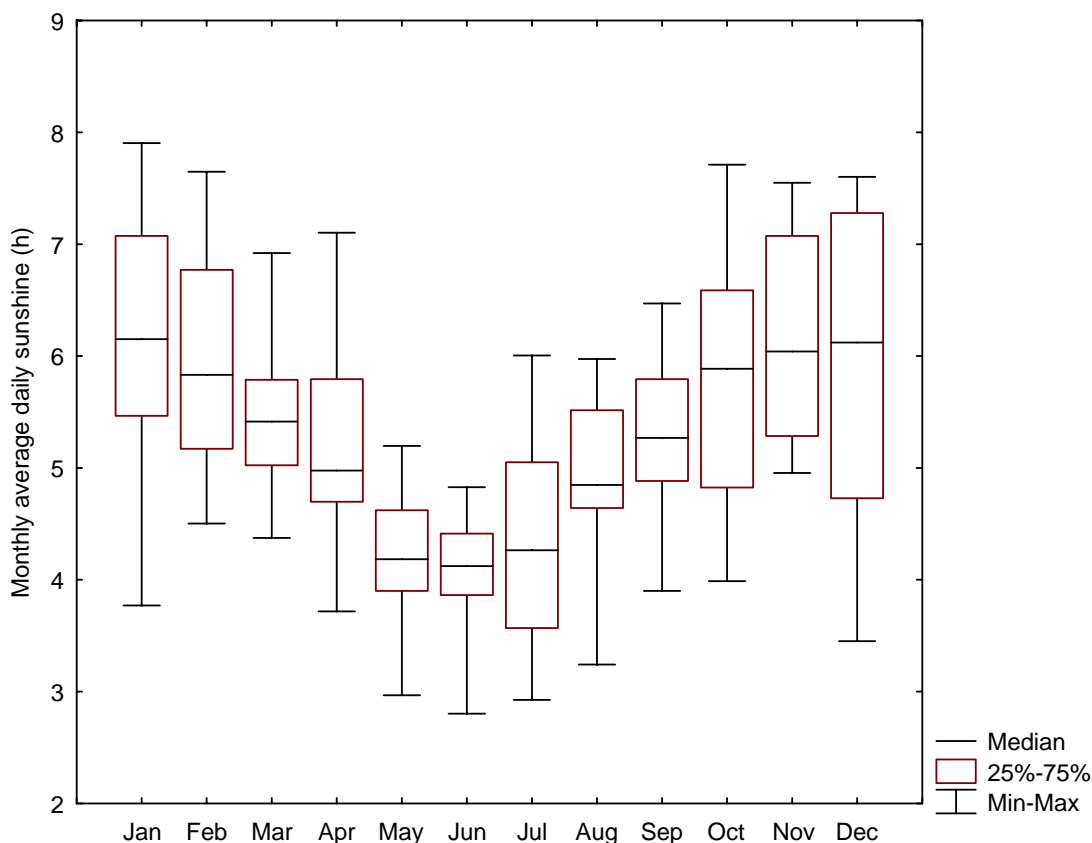
Wind Rose Data Wind Rose data for day-time and night-time data for the Poingdestres Road recorder for winter (Jun/Jul/Aug) (left hand column) and spring (Sep/Oct/Nov) (right hand column).

**Table 2.2 Average seasonal wind speeds (m/s) for day and night**

Season	Day 0900 h to 2100 h NZST	Night 2100 h to 0900 h NZST
Summer (Dec/Jan/Feb)	2.81	1.35
Autumn (Mar/Apr/May)	2.17	1.52
Winter (Jun/Jul/Aug)	1.87	1.27
Spring (Sep/Oct/Nov)	2.55	1.32

## 2.4 Sunshine

Sunshine data from Timaru (siteH41424) for February 1985 to August 2005 are presented as a boxplot in Figure 2.7. This plot shows average daily sunshine hours for each month of the year. Strong seasonal variation is obvious. However the year-to-year variability for summer months particularly is surprisingly: for example in December daily average sunshine has ranged between 3.5 and 7.6 hours, and the interquartile range is from 4.8 to 7.3 hours.



**Figure 2.7 Sunshine hours Timaru**  
**Boxplot of monthly average daily sunshine hours recorded at Timaru (site H41424) for 1985-2005.**

## 2.5 Evaporation

Open pan evaporation data was collected at Adair, south of Timaru for the period 1972-1986, albeit with some missing values. Boxplots showing the distributions of monthly totals are in Figure 2.2. The strong seasonal pattern is immediately evident, as is the relatively low year-to-year variation for a particular month. For example the January values range from 133 to 233 mm, with a median of 170 mm, and the July values range from 18 to 52 mm with a median of 34 mm. The annual totals range from 1022 to 1378 mm and the mean annual total is 1191 mm. Using the factor of 0.69 recommended by Finkelstein (1973), the open-water estimate is 821 mm, which is consistent with other Canterbury values mapped in Finkelstein (1973). Finkelstein also shows that open water evaporation estimates from the Penman energy balance methods are well-correlated with the raised-pan estimates.

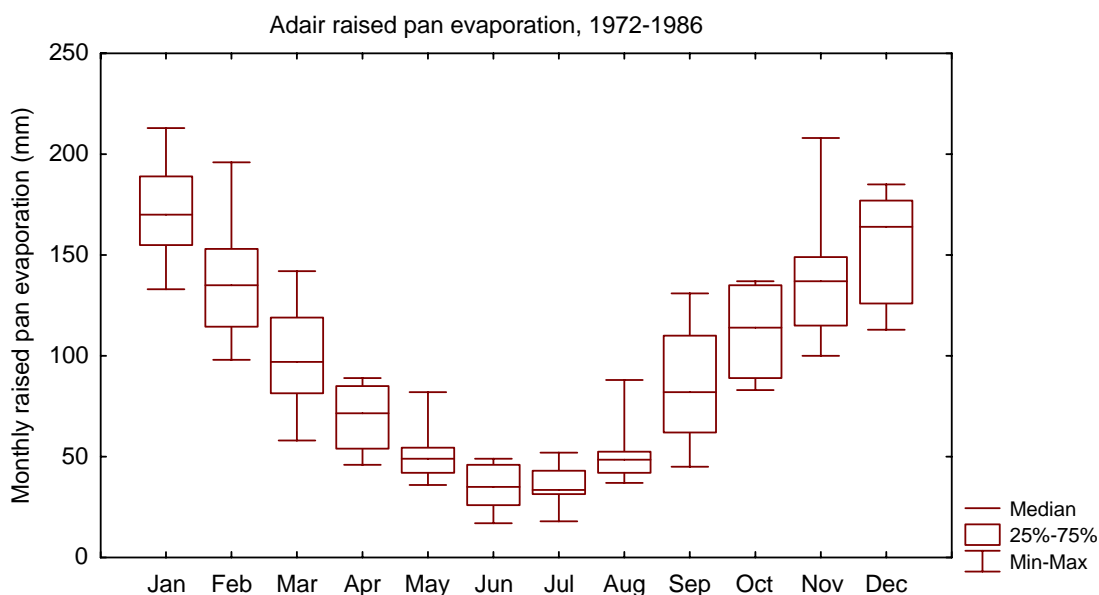
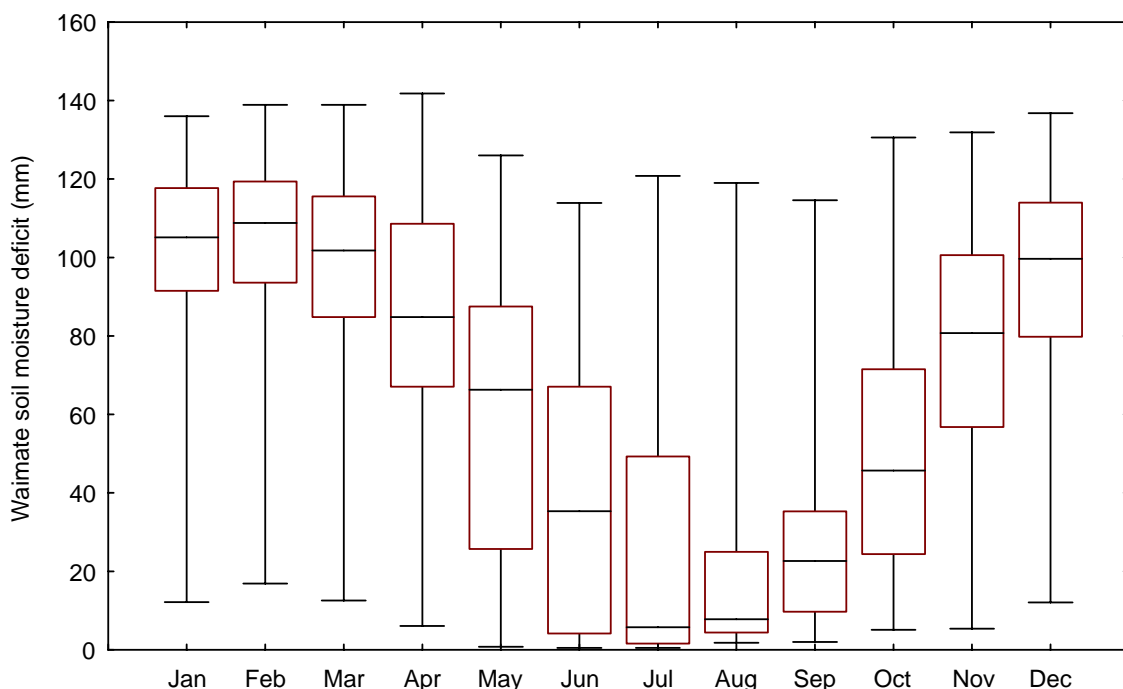


Figure 2.8 Monthly evaporation totals for Adair, south of Timaru, 1972-1986

## 2.6 Soil moisture deficit

Monthly soil moisture deficits are routinely calculated by NIWA for standard climate stations assuming a soil moisture capacity of 150 mm. This is a reasonable estimate for the predominant Claremont soils in the region. The calculation is essentially a bucket model in which moisture is received from rain and is lost through evaporation and transpiration, drainage to groundwater and by runoff when the soil column is saturated. Data for Waimate for 1908-2005 (gap 1931-1941) are displayed as boxplots in Figure 2.9. Despite occasional low deficits that can occur in any month, the figure shows a strong seasonal pattern with the largest deficits typically occurring in December through March.



**Figure 2.9 Modelled monthly soil moisture deficits for Waimate for 1908-2005**

While the exact amount of the larger deficits are a function of the soil mantle capacity, the modelled deficits provide a useful depiction of the seasonal and year-to-year variation. From the maximum deficits for each year, deficits occurring on average 1 in 2 years, 1 in 5 years and 1 in 10 years are estimated in Table 2.3. This shows that severe deficits, exceeding 100 mm, are likely. These all occur within the September through April irrigation season.

**Table 2.3 Estimated soil moisture deficits for Waimate for the irrigation season (September through April) and for October for a range of annual probabilities**

Annual probability	Soil moisture deficit (mm) for irrigation season	Soil moisture deficit (mm) October
1 in 2 (Median annual deficit)	120	46
1 in 5	130	72
1 in 10	134	90

However for some applications, the variability of certain months is of more interest. For example the deficits in October, given in third column of Table 2.3 display a much wider range than the annual maxima over the irrigation season. These figures show that for October at Waimate, there is an even chance of a moderate soil moisture deficit (46 mm), but that there is a 1 in 5 chance of a 72 mm deficit and a 1 in 10 chance of a 90 mm deficit. That is, there is a reasonable expectation of a moderate October soil moisture deficit, but substantial deficits are possible. Note that the 1 in 5 year value (i.e. value exceeded in 80% of years) is quite close to the upper limit of the rectangle (the 75% value) for the October boxplot in Figure 2.9.

## 2.7 Changes over time

The variation of water resources in the region over a long time period is of particular interest. This variation is assessed using the long-term rainfall records for the region. In this study, the records listed in Table 2.1 are used. Of the stations used, only the Waimate raingauge is located within the Pareora-Waihao catchment area. However the intention is that by presenting results for a group of stations within the broader region that are expected to be affected by the same patterns of climate variations, some conclusions about long-term variability may be apparent. For this reason the records from more northerly stations (Te Ngawai, Kakahu Bush, Orari Estate, Timaru Gardens), Duntroon to the west and Oamaru to the south, are included.

Over the years, all the records listed in Table 2.1 have probably undergone changes in recording site, instrumentation and exposure, and it is unlikely any one is homogenous in the strict sense. Thompson (1984) reports some details of the Oamaru record changes up to 1982, but even that study is inconclusive. Subsequently, in 1985 the manually-read Oamaru Airport (I41901) record was superseded by an Oamaru Automatic Weather Station (AWS) (I41902) record which has numerous missing values until late 1999 and an alternative more distant record was used to infill this period of poor quality record (Table 2.1).

The analyses presented here are residual mass curves, also known as cumulative sums (CUSUMs). CUSUMs are calculated as:

$$X_t = \sum (P_t / P_{mean} - 1)$$

where:

$P_t$  is rainfall on day  $t$  (mm);

$P_{mean}$  is mean daily rainfall (mm);

$X_t$ , the CUSUM for day  $t$ , is the cumulative sum of departures from the long-term mean. It is the number of days of mean rainfall by which the cumulative rainfall up to day  $t$  departs from the mean.

When a CUSUM is plotted, successively increasing values of  $X_t$  plot with positive gradients, indicating a period of above normal rainfalls. Similarly, a sequence of decreasing values, with negative gradients, indicates a period of below normal rainfalls.

CUSUMs for the seven records for the common time base 1910-2004 (Figure 2.10) display a fair degree of variability, but also a number of common features. For example, all the records show consistent responses from 1910 to about 1918 and from about 1960 to 2004. Particularly wet periods, indicated by rapidly increasing CUSUMs, occurred during 1943-1946 and 1986-1987, and droughts, indicated by rapidly decreasing CUSUMs, occurred during 1914-1916, 1984-1985, 1988-1989 and 1997-2004. The CUSUMs indicate anomalous trends for:

Te Ngawai, 1930-1945;

Kakahu Bush, 1925-1929;

Oamaru Airport, 1930-1940, 1948-1955.

Considering the remaining four records (Orari Estate, Timaru Gardens, Duntroon & Waimate), the CUSUMs are reasonably constant for 1910-1940, increasing for 1941-1970 and decreasing overall for 1971-2004, albeit with some particularly wet and dry years in the latter period. For clarity, CUSUMs for these four records, considered to be more reliable, are replotted in Figure 2.11.

For these four stations, dry periods in the last 34 years are also illustrated in Figure 2.12 which compares annual totals with the normals for 1971-2000. As shown by the CUSUMs, the years 1984-1985 and 1988-1989 had low rainfalls and except for years 2000, 2002 and 2004, all the years since 1997 had lower than normal rainfall. The years 1984-1985, 1988-1989 and 1997-1998 are noted as periods of drought in Canterbury.

The distributions of annual rainfalls for these sites for three intervals, 1911-1940, 1941-1970 and 1971-2004 are illustrated by the boxplots in Figure 2.13. There are slight (2% to 5%) increases when the means for 1911-1940 are compared with the mean for 1941-1970, and slight decreases (5%-10%) when the 1941-1970 means are compared with those for 1971-2004.

Standard statistical tests (nonparametric Mann-Whitney, Student t test for differences of the means) offer no support for doubting the null hypothesis that the statistics of the samples for each series data derive from the same frequency distributions. In other words, the mild shifts apparent in the data can reasonably be attributed to sampling errors. This contrasts with analyses of annual rainfall series for the west and south of the South Island where shifts in the range 11% to 17% were evident and tests rejected the null hypothesis (McKerchar & Henderson, 2003).

In summary, individual long-term rainfall records are not necessarily reliable estimators of long-term rainfall variability in this region, particularly because of the influence of changes in gauge location that are known to have occurred for some of the gauges. CUSUMs is a way of identifying anomalies in records and of confirming that records from gauges in the same region have consistent patterns. The analysis undertaken suggests that the thirty-year period 1941-1970 was slightly wetter, on average, than both the preceding and the following 30 years. No causative factor has been identified and the differences are such that they can reasonably be attributed to sampling errors. Also, the period 2001 to late 2004 is identified as being drier than the long-term average.

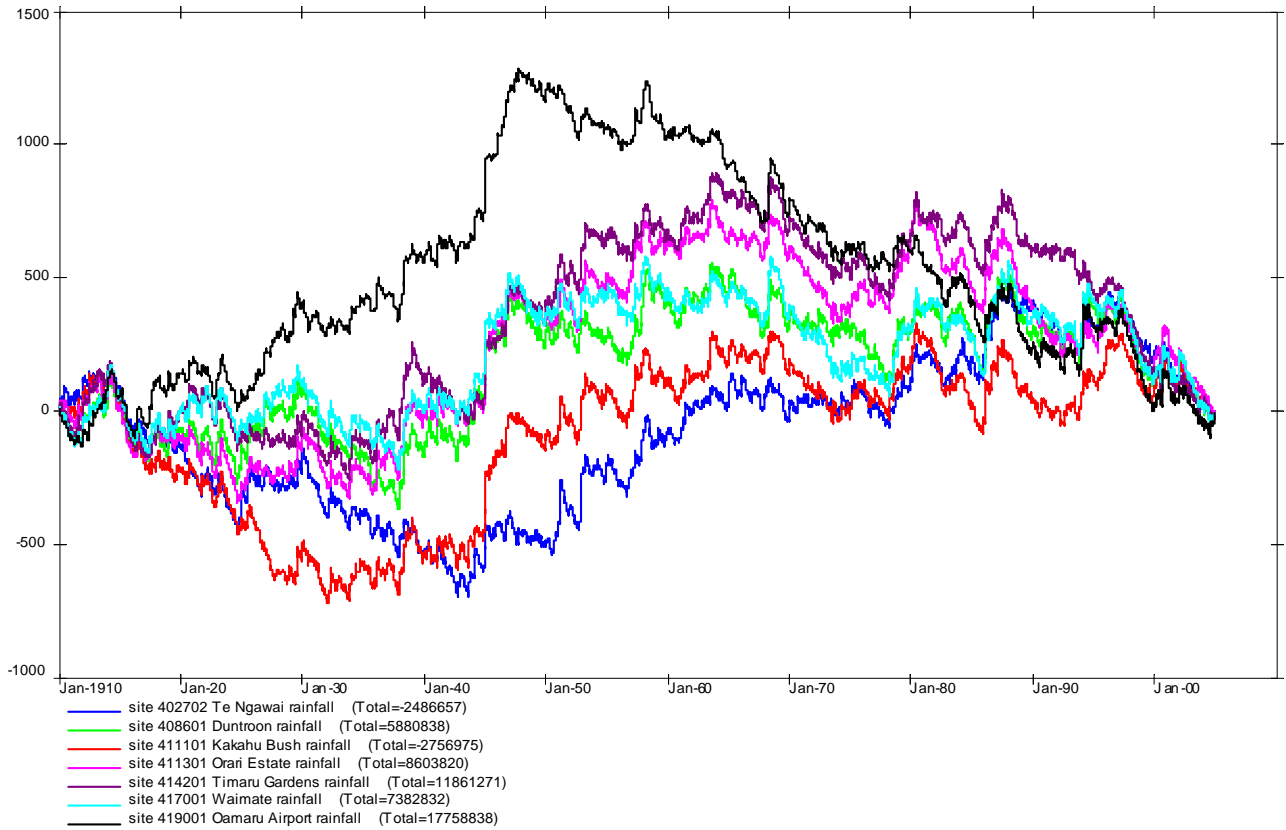


Figure 2.10 CUSUMs for seven records, 1910-2004

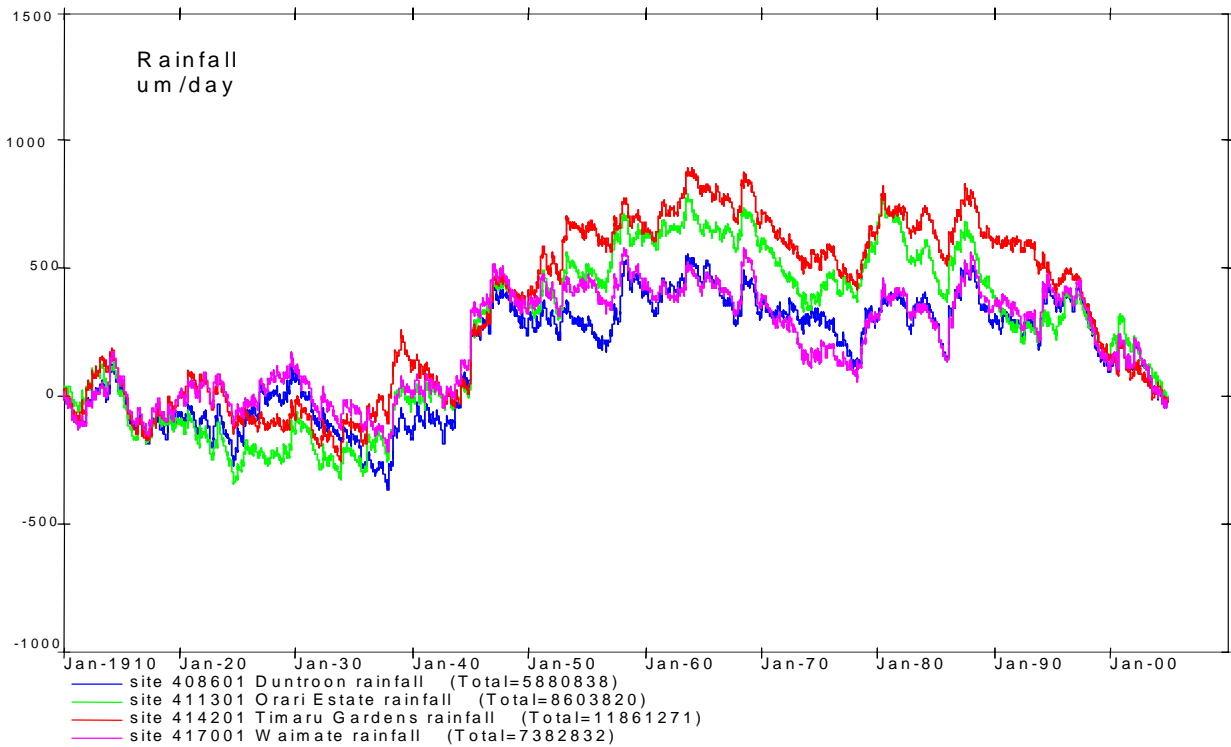
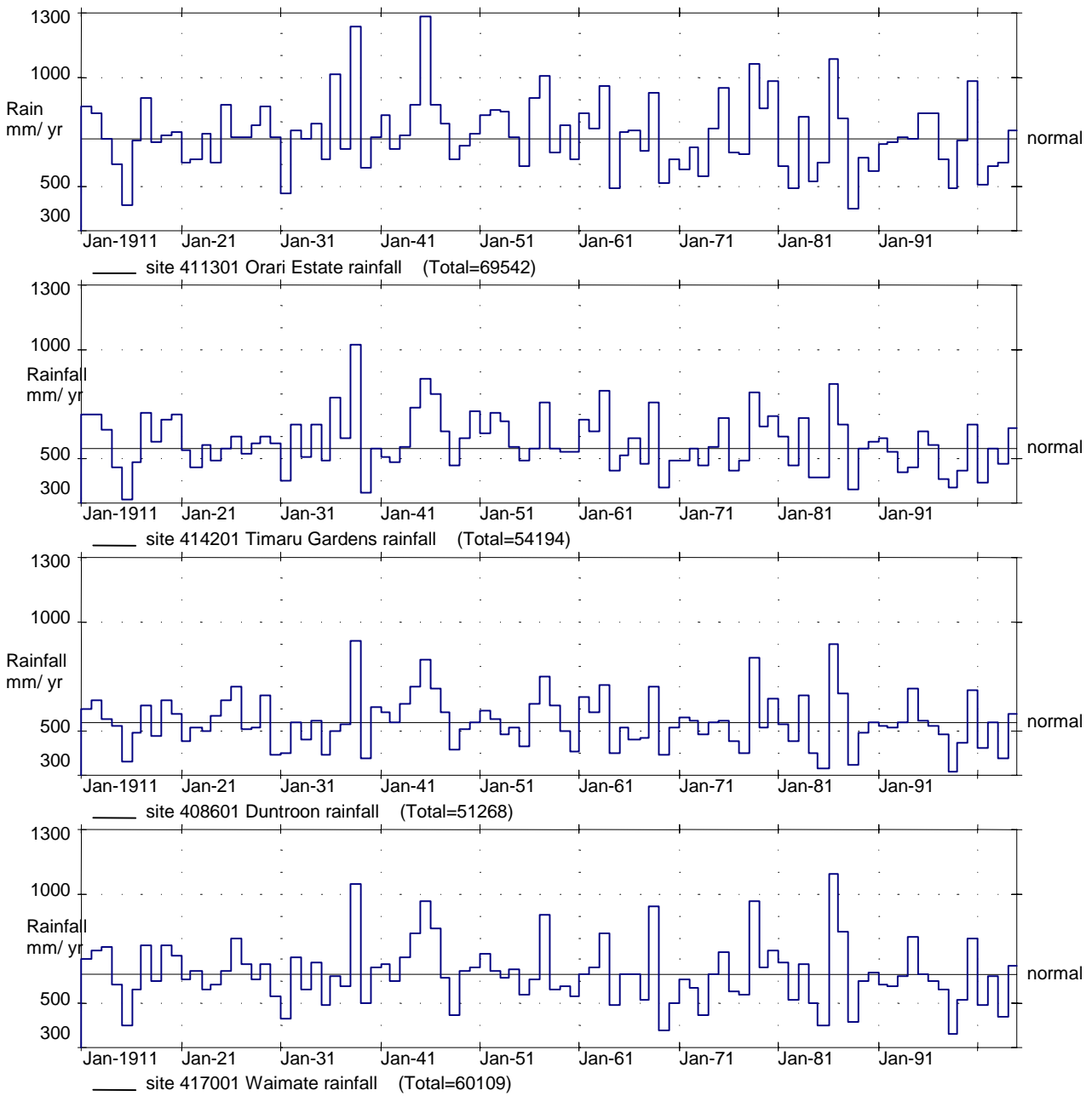
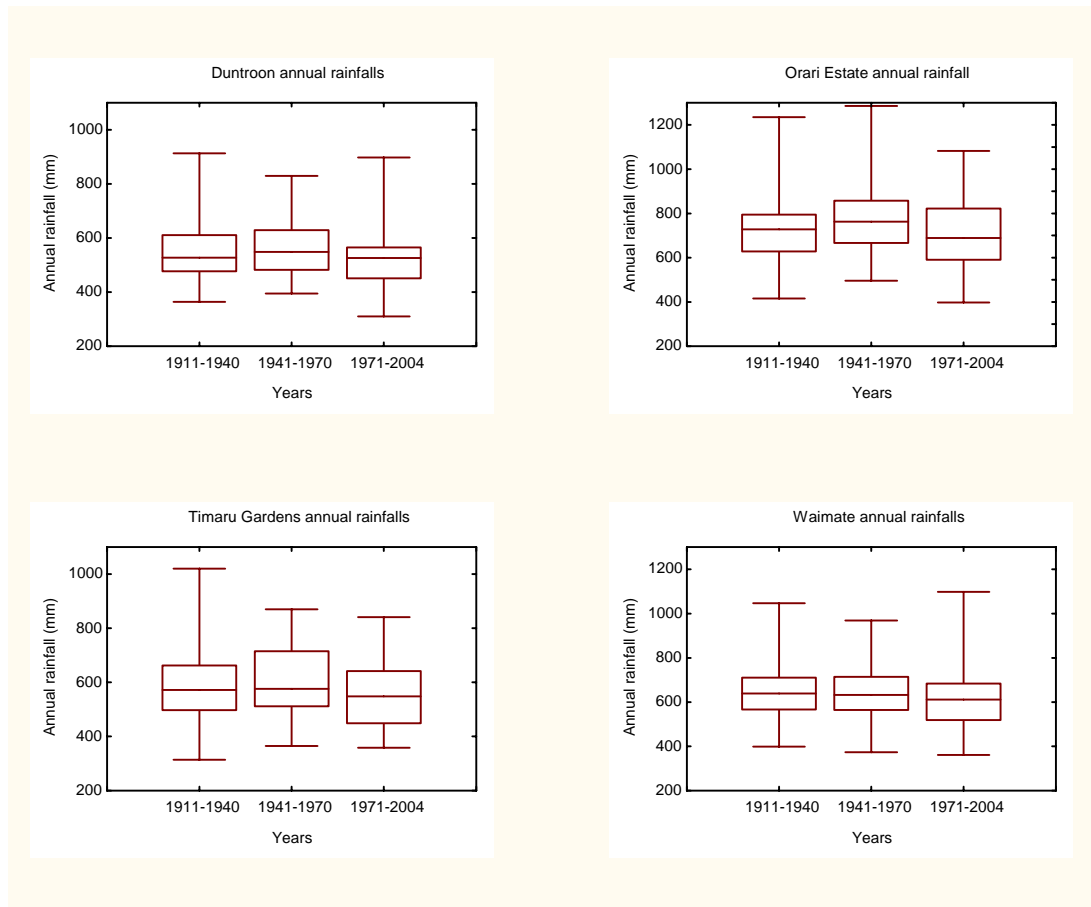


Figure 2.11 CUSUMs for four records considered more reliable, 1910-2004



**Figure 2.12 Rainfall comparison with 4 homogeneous stations**

Annual rainfall totals for 1911-2004 compared with the rainfall normals for 1971-2000 for the four stations considered having relatively homogenous records.



**Figure 2.13 Thirty year rainfall boxplots**

Boxplots of annual rainfalls for three thirty year plus periods for four records. The boxes indicate annual rainfalls exceeded in 75%, 50% and 25% of years, as well as the maxima and minima.

## 3 Geology and soils

### 3.1 Geology

The geology of the Pareora-Waihao area is described and mapped in Forsyth, (2001), as part of the Geological and Nuclear Sciences QMap programme. Previous mapping in the area had been completed most notably by Gage (1957), Gair (1959) and Mutch (1963). The descriptions of the geology below are taken from Forsyth (2001), and reproduced in Figure 3.1. Table 3.1 outlines the geological units encountered in the study area.

**Table 3.1 Geological formations of the Pareora-Waihao region**

(NB name in bold indicates formation contains aquifers)

Group Name	Formation Name	Local Name	
		Pareora	Waihao
<b>Quaternary Sediment</b> – glacial, alluvial, loess, swamp and beach/estuary			
	Timaru Basalt (Pt)	Timaru Basalt	-
	Kowai Formation (Pk)	<b>Cannington Gravels</b>	<b>Cannington/Elephant Hill Gravels</b>
Otakau Group (Mo)	White Rock	<b>White Rock Coal Measures</b>	-
	Southburn/Mt Harris	<b>Southburn Sands</b>	Mt Harris Formation
	Gee	Bluecliffs Silt	
Kekenodon Group (eMk)	Otekaike	Craigmore Limestone	Arno Limestone
	Kokoamu	Squires Greensand/Kokoamu Greensand	Waikakahi
Onekakara Group (Eo)	Burnside	Holme Station Limestone	Burnside Mudstone
	Waihao/Opawa	-	Waihao Greensand/Opawa Sandstone
	Abbotsford	Little Pareora Silt	-
	Kauru	Otaio Gorge Sandstone	Campbell
	<b>Taratu (IKt)</b>	Colliers Coal Measures	Broken River Formation (Eeb)
Greywacke and argillite basement (Yt)			

Physiographically, the Pareora – Waihao area is termed the ‘South Canterbury Downlands’ and comprises of streams and fan alluvium with loess ridges up to 20m thick. The downlands topography has been formed by accumulation of loess on interfluvies. The eastern boundary of the downlands is formed by the Hunter Hills, a north-south trending, fault controlled basement rock range.

The basement rocks of the area are the Permian age (250-300 Million years before present) Rakaia terrane quartzofeldspathic sandstone (greywacke) and mudstone (argillite) (blue on map in Figure 3.1). This basement is overlain by the transgressive Onekakara Group (brown on map in Figure 3.1). The basal beds of this group are the terrestrial Broken River

Formation (equivalent to Taratu Formation of North Otago), which unconformably overlies leached greywacke. The Broken River Formation is of variable thickness, and can be absent locally. This thickness variation is due to the topography of the ancient land surface (with the formation accumulating in valleys, fluvial plains, swamps and estuaries) and also to subsequent marine erosion. The Broken River formation contains quartzose sandy gravels, sands and silts, as well as deposits of coal and other carbonaceous material. Higher in the Onekakara Group is a shallow marine environment sequence, with units such as the Waihao Greensand, Tapui Glauconitic Sandstone, Little Pareora Silt and Opawa Sandstone. The top of the Onekakara group is marked by the Marshall Paraconformity (a regionally extensive surface of erosion or non-deposition).

Overlying the Paraconformity is the late Oligocene to early Miocene marine Kekenodon Group (dark orange on map in Figure 3.1, Kokoamu Greensand and Otekaike Limestone). The Otekaike Limestone at Craigmore in the Upper Pareora form an extensive plateau. Above this is the marine Otakou Group (light orange on map in Figure 3.1), which consists of a mid shelf sand and siltstone (Mt Harris Formation) succeeded by a shallow marine sandstone (Southburn sand) and a marginal marine environment quartz sandstone, carbonaceous mudstone and lignite (White Rock Coal Measures).

Following the Tertiary sediments, the Pliocene-Pleistocene sediments of the Kowai Formation are deposited (pink on map in Figure 3.1). This formation overlies much of the South Canterbury Downlands, although is only exposed in the Upper Pareora and the Makikihi Rivers. The predominantly terrestrial Kowai Formation is locally called the Cannington Gravels, and consists of weathered gravels sands and muds derived from the rising Hunter Hills to the east. The basal part of the sequence is marine, and the unit dips towards the east. At Timaru the Kowai Formation is overlain by the Timaru Basalt, a sheet basalt extruded from a vent near Mr Horrible, and covering an area of 130km<sup>2</sup>.

The youngest geological deposits of the area are Quaternary sediments (dark yellow (oldest) - lighter yellow (younger) – white (recent) on map in Figure 3.1), which are widespread over the whole area. The deposits include alluvial fans, terraces and floodplains, beach estuarine and swamp deposits, and extensive loess layers. Loess thicknesses are greatest on older terraces (up to 20m thick), grading to 1-3m on more recent terrace deposits. Recent alluvium has been deposited in the present day river valleys of the Pareora, Otaio, Makikihi, Hook, Waimate and Waihao Rivers, as well as from the extensive Waitaki River floodplain to the south. An old coastal cliff is apparent in the geomorphology, and can be seen as a change from dark yellow older gravels to light yellow younger coastal gravels in Figure 3.1, extending from near the Pareora River Mouth to Gray's Corner north of the Waitaki River.

**Table 3.2 Soil categories and areas in the Pareora-Waihao catchments**

Soil Category	Soil Series	Approximate % of area	Description
Soils of the Downs	Claremont	28.3	Loess derived soil with impeded drainage, although some parts of upper Pareora are derived from limestone/lime rich sandstones.
	Opuha	9.4	Loess derived soils on strongly rolling foothills, which grades into Claremont soils in the east.
	Timaru	8.4	Loess derived soil with slow drainage, waterlogged in winter, but droughty in summer
	Waikakahi	4.3	Soft marl and shell bed derived soil found in the Waihao Downs area. Medium – free draining.
	Rapuwai	3.8	Sandstone derived soil formed on moderately steep and rolling slopes in the Upper Pareora Valley
	Taiko	2.9	Partly weathered early Pleistocene conglomerate gravels and thin loess mantle derived soils occurring in narrow strips of strongly rolling and moderately steep slopes with free – rapid draining.
	Kauru	2.5	Tertiary sandstone derived soil which may be sandy or gravelly depending on outcrop, hence freely draining.
	Ngapara	1.2	Loess overlying limestone, sandstone and conglomerate beds derived soil occurring on easy rolling to moderately steep downlands, free draining.
	Kakahu	1.2	Greywacke derived soil found on moderately steep foothills
	Oamaru	0.1	Limestone derived medium draining soil on the South Bank of the Waihao River
<b>Subtotal</b>		<b>62.1</b>	
Soils of the Downs Margin	Waitohi	9.9	Loess/resorted loess derived soil on flat to gently undulated high terraces with poor drainage.
Soils of the Plains	River Bed	6	No soil or mix of river bed and other soil types.
	Templeton	3.3	Greywacke alluvium derived soil that is moderately – free draining with moderate moisture retention.
	Lismore	2.0	Greywacke river fan derived soil with free to very rapid drainage, prone to wind erosion.
	Wakanui	1.8	Greywacke alluvium derived soil that is moderately to slow draining and occurs in depressions on low terraces and the fringe of former coastal swamps.
	Eyre	1.8	Greywacke alluvium derived soils found on stony ridges, low terraces and fan margins. Free draining.
	Morven	0.9	Mixed glauconitic and greywacke alluvium derived soil occurring in depression ear the Waihao River mouth with slow drainage and waterlogging.
	Tengawai	2.0	Greywacke bedrock (higher slopes) and greywacke conglomerate gravel (lower slopes) derived soils occurring on a steep fault scarp from Opuha Gorge to Cave, with medium to free drainage.
	Rakaia	1.8	Recent greywacke alluvium derived free draining soil.
	Willowbridge	1.3	Tertiary glauconitic sandstone and greywacke derived soil on the lower flood plain of the Waihao River, deeply friable and moisture retentive.
	Temuka	1.2	Greywacke alluvium derived soil with impeded drainage for much of the year. If the water table falls, the soil can dry and crack.
	Motukarara	0.5	Derived from estuarine deposits and greywacke alluvium veneer, low lying poorly drained soils near estuaries and salt-water lagoons.
	Paparua	0.3	Greywacke terrace alluvium derived soil that is freely to rapidly draining.
<b>Subtotal</b>		<b>22.9</b>	
	All Others	15	

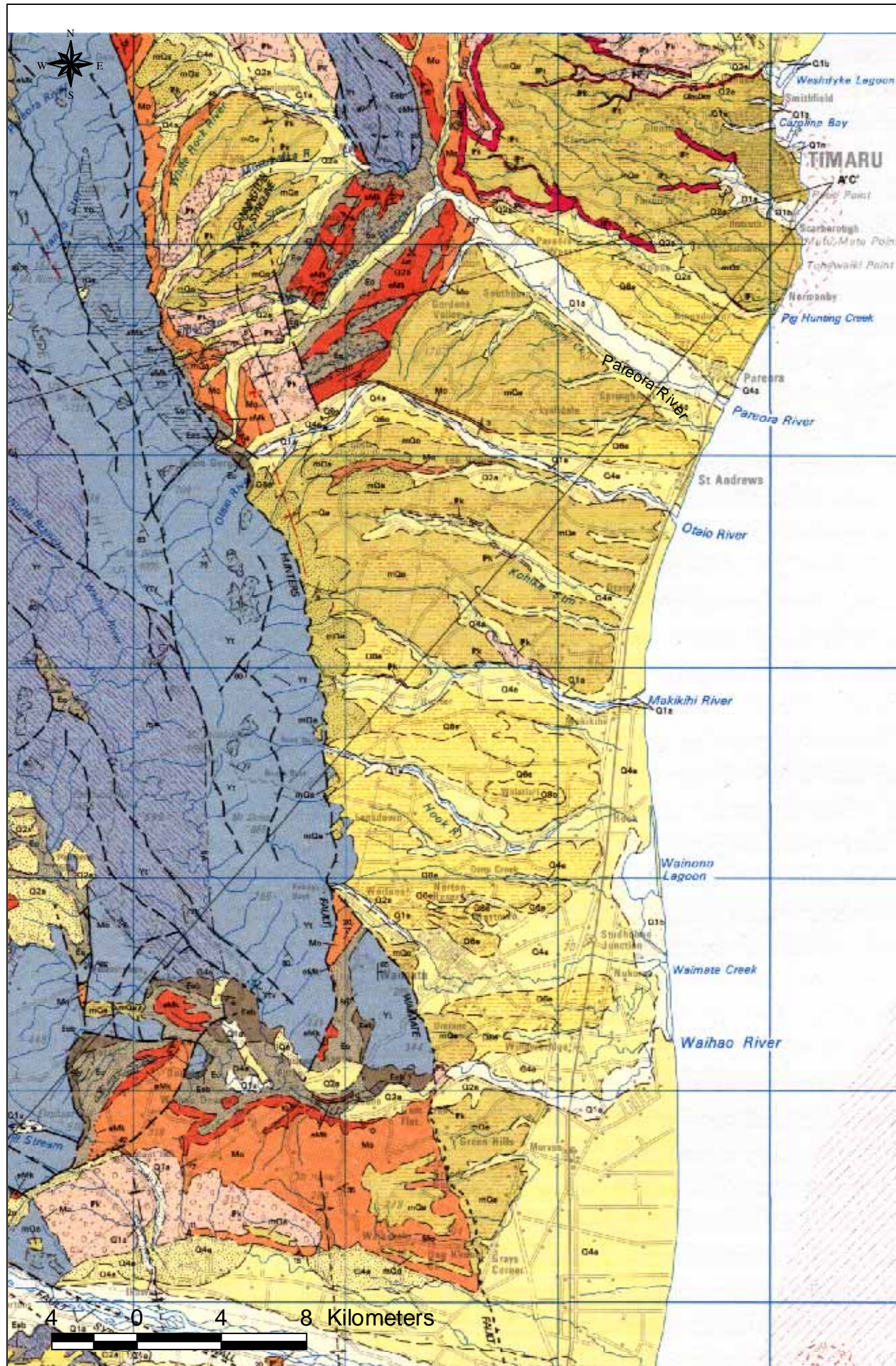


Figure 3.1 Geology of the Pareora-Waihao Catchments (Forsyth, 2001)

### 3.2 Soils

Soils of the Downs and Plains of South Canterbury between the Pareora and Waihao River catchments are mapped and described in DSIR Soil Bureau – Bulletin 14 (Kear, et al, 1967). This survey was used, along with all other available soil surveys, in the compilation of the Soil layer in the NZ Land Resource Inventory (Water and Soil Division, Ministry of Works and Development, Wellington 1975). Landcare Research have subsequently made some ad hoc improvements to soil series identification and their spatial distribution within the study area. Figure 3.2 and Table 3.1 summarise the major soil series of the area, within 2 distinctive landform groupings of rolling downlands and flat outwash plains.

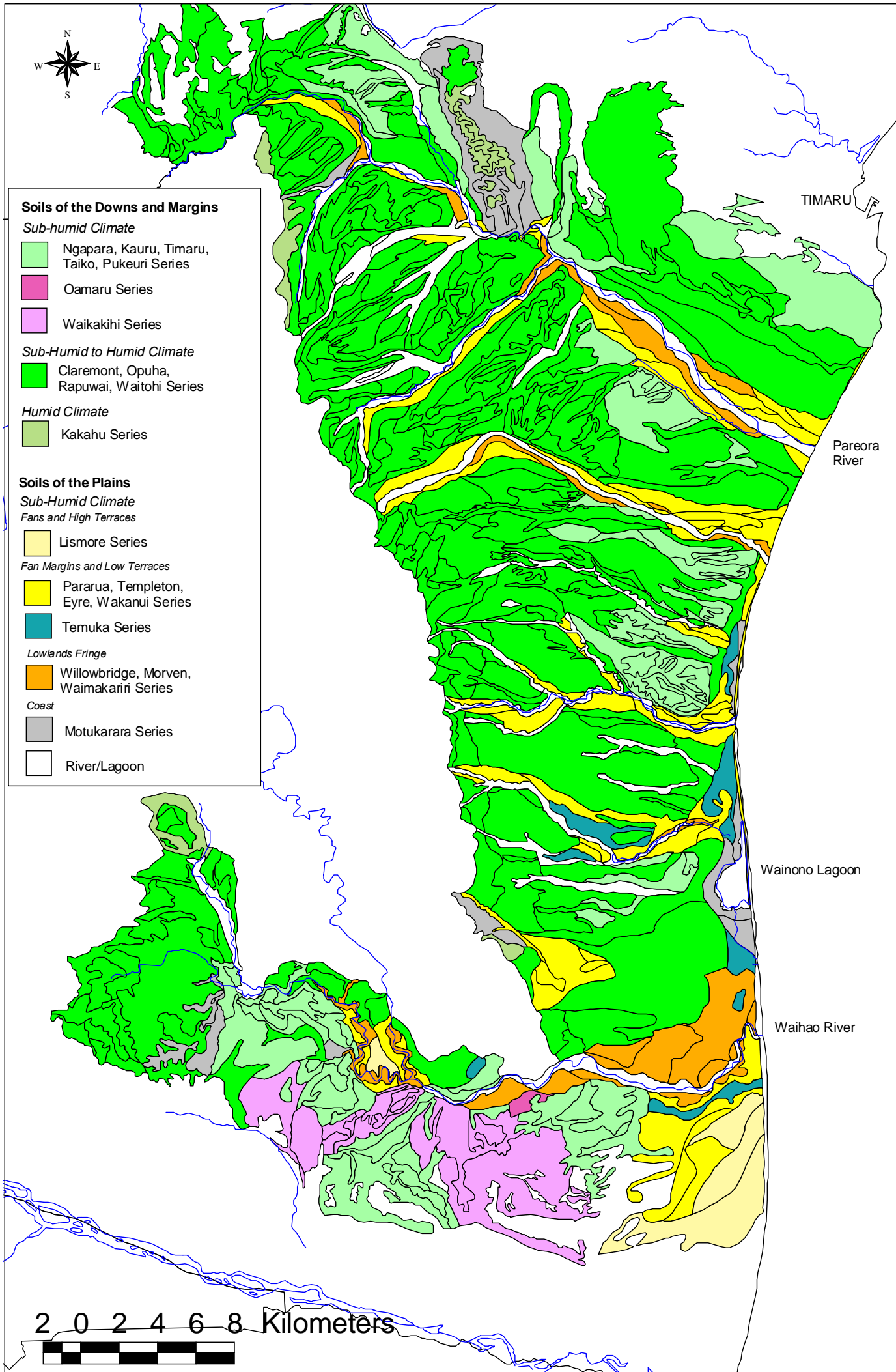


Figure 3.2 Soils categories of the Pareora-Waihao River Catchments  
(Source: ECan GIS database compiled by J Cuff).

## 4 Surface water resources

### 4.1 Introduction

This part of the report provides estimates of statistics of the naturally occurring river flows in the region for the management of surface and groundwater resources. The statistics estimated are the seven-day mean annual low flow, the median flow and the mean flow. The study uses gaugings undertaken in the region since the 1950s and continuous river flow records of various lengths. Figure 4.1 shows the main catchments of the region along with the location of flow recorder and gauging sites.

### 4.2 Methodology

Regression relationships are used to provide flow estimates for the spot gauging flow sites (or tertiary sites), corresponding to flow statistics estimated for the primary or secondary recorder sites. A primary site may be defined as a recorder site with at least 30 years of record and fully representative of long-term conditions. Ultimately it would be best to use only sites with this quantity of record. However, a lack of record availability makes it necessary to use secondary sites. A secondary site may be defined as a recorder site with less than 30 years of record and with potential to be biased. Because of the potentially biased nature of secondary sites, “normalisation” with a primary site is required.

Since most of the flow data within the region are affected by abstractions, the first step in assessment of the water resource is to reconstitute the flows that would have occurred in the absence of abstractions. Environment Canterbury’s consents database is used to estimate the surface water and groundwater abstractions. This process of adding the abstractions back to the recorded and gauged flows is termed “naturalising”.

The particular flow statistic used in this study is the seven-day annual low, which is the lowest flow recorded in a year at a given recorder site over seven consecutive days. Averaging over seven days lessens the influence of isolated short-duration errors in a flow record. The mean of these annual values for a record of several years is known as the seven-day mean annual low flow, denoted as 7DMALF and sometimes abbreviated as MALF. Other statistics used are the mean and median flow. The mean flow is the average of all the recorded flows, while the median is the flow that is exceeded 50% of the time. The mean flow, which is partially determined by magnitudes and durations of flood flows, is often much greater than the median and, in South Canterbury is typically exceeded approximately 25 percent of the time, compared with the 50 percent value which defines the median. These statistics calculated for the primary and secondary sites are inserted into the regression equations derived with the tertiary sites, yielding in turn estimates of the statistics for the tertiary sites.



Figure 4.1 Main catchments of the study region, water level recorder sites and flow gauging sites.

In most cases standard linear regression is used to obtain estimates of flow statistics at the tertiary sites. The summaries of results presented include the standard errors of the fit of the linear regressions, the squared correlation coefficients (coefficient of determination) and the standard errors for individual estimates of the flow statistics expressed as percentages. In a few cases, where log-log regressions are used in preference to linear regressions, the standard error is a factorial standard error. Here the range for one standard error is determined by multiplying and dividing the estimated statistic by the factorial standard error.

The standard errors for the individual estimates only account for errors incurred in the regressions and do not include error involved in estimates of the statistics at the primary or the secondary sites. Experience indicates that these errors will be of a lower order than the regression errors.

Estimates for the primary, secondary and tertiary sites are then used to prepare maps showing lines of equal seven-day mean annual low flow yield and mean annual yield, both having units of litres per second per square kilometer (L/s/km<sup>2</sup>).

#### **4.2.1 Naturalising flows**

All the rivers in the region are affected by abstractions from streams and hydraulically connected aquifers for water supply, stockwater and irrigation. An important feature of this study is that estimates are made of the abstractions to enable the natural flows to be predicted.

The assumptions made in estimating the actual amount of abstraction compared with that allocated through the consent process are:

- The irrigation season runs from 1 October to 30 April, therefore consented abstractions for irrigation are added back only to measure flow during this period.
- 50% of the consented quantity for surface water, and 50% of the stream depletion rate for groundwater consents, has been added back to the river flows below the abstraction point, unless actual usage is known. This is to account for the variability in actual water usage versus consented quantity. Various investigations have been carried out (Sanders, 1997; Sanders and Glubb, 2005) and are continuing to be carried out (Glubb, 2005) to try to quantify actual versus consented usage.
- Some takes are governed by a consent condition where if flows drop below a certain level at a given point in the river (usually at the flow recorder site) surface water and groundwater consent holders are required to take only 50% of their take or cease taking completely. These rules have been followed when adding back the abstractions. Abstractions have been added back according to the flow at the consent-monitoring site. In the case of the Pareora River, the main Timaru District Council surface water take has been calculated using an equation, see section 4.3.1 for more details.
- Stream depletion rates for the groundwater consents have been calculated for this investigation and are detailed in Appendix 38. Stream depletion estimates have been added back to sites below the abstraction point according to the above assumptions. Stream depletion rates were initially calculated in February 2004 and provided to hydrologists. However, subsequent changes in planning policy with regard to the estimation of effective allocation (annual volumes) led to changes in calculated stream depletion rates over an irrigation season. There are thus minor differences between the figures originally provided to hydrologists, and current figures. Where the differences are significant the new numbers were used to naturalise flows, but where differences were minimal the numbers remain unchanged. This should have little bearing on the end results.

## 4.2.2 Normalising flows

Where possible, the estimated secondary site flow statistics are normalised to the values for the 30-year period 1971-2000. The adoption of this 30-year period conforms to climatological practice. The primary site Rocky Gully at Rockburn (site number 69621, map reference J38:325-513), which has flow records dating back to 1965, is used. The Rocky Gully at Rockburn site is particularly useful because there are no upstream abstractions. The flow statistics for this river used throughout this report are given in Table 4.1. Another nearby long-term recorder site, Hakataramea River at above Main Highway Bridge, has not been used in this analysis for normalising. This river is heavily committed to abstractive use and that abstraction represents a significant proportion of the total flow in the river during the irrigation season, thus making the natural flow very difficult to quantify.

For this investigation the normalising process was usually carried out as follows:

- 1) The 7DMALF, mean and median flows (the statistics) were calculated for the primary site for the period 1971-2000.
- 2) The statistics were calculated for the primary site and the secondary site for the shorter period of record that the data aligned at the two sites (usually the whole length of record at the secondary site and the corresponding period at the primary site).
- 3) The ratio between the shorter period of record and the 30-year period was calculated for each of the statistics at the primary site.
- 4) The above ratios were applied to the statistics for the period of record at the secondary site.

Regression analysis between the primary site and the secondary site flows was often undertaken first to determine if there was indeed a relationship between the two sites.

Also given in Table 4.1 are the ratios of mean to median flows for Rocky Gully at Rockburn, and the percentages of time that the mean flow is exceeded. The mean flow is considerably greater than the median, and is exceeded only 25% of the time. In other words the river is below mean flow for the majority of the time, as is typical for much of the east coast of the South Island. A consequence is that mean flow has limited utility in assessing water resources in low flow conditions.

**Table 4.1 7DMALF, median flow and mean flow (L/s) for primary site Rocky Gully at Rockburn for 1971-2000**

Long-term recorder site:	Flow Statistics:			Ratio mean/median	% time mean exceeded
	7DMALF	Median	Mean		
Rocky Gully at Rockburn	80	192	327	1.70	25

## 4.3 Pareora River

### 4.3.1 Introduction

The Pareora River catchment of 539 km<sup>2</sup> (Figure 4.1) is the northern-most of the rivers in the study region. The aspect is generally to the northeast. About one third is steep land and the remainder is hilly to rolling which becomes more subdued towards the coast. Flat areas are generally alongside stream channels. An earlier report on the water resources was completed by Waugh (1987).

The river branches into two 16.5 km from the coast. The North Branch (also referred to as the Upper Pareora) is a combination of the Motukaika, White Rock and North Pareora catchments, while the South Branch comprises Elder Stream and the South Pareora catchments.

Flows in the rivers draining the higher rainfall steeplands are mostly perennial whereas many of those draining the lower rainfall downlands region are intermittent.

The main primary water level recorder on the Pareora River is at a site named Huts (site number 70105, map reference J39:553-423), also known as Mt Horrible. The Huts record commenced in 1982, and is classed as a secondary site because there is less than 30 years of flow record. The Huts site is also affected by abstractions, such that the measured flows are not the flows that would occur naturally. The Rocky Gully at Rockburn primary site has been used to normalise the Huts flow statistics.

The Pareora River is particularly important for Timaru City: the main city water source is the upper reach of the North Branch. The abstraction by the Timaru District Council (TDC) for the city of approximately 200 L/s has operated since 1940 (Waugh, 1987). There is a condition on this take to maintain 30 L/s flow below the dam. In dry years the TDC take is therefore restricted. Analysis by Frank Scarf (Pers. Comm. August 2005), using information supplied by TDC, has yielded the following equation for calculating the quantity of the TDC abstraction when the observed flow at the Pareora at Huts recorder is less than 750 L/s:

$$\text{TDC take} = 0.1975 \times \text{Observed Flow at Huts} + 52.65$$

Above 750 L/s at the Huts recorder, the TDC take is assumed to remain constant at 200 L/s.

Abstractions from other parts of the river and adjacent groundwater systems for rural and stock water supply and for irrigation have increased markedly since the 1980s (see section 6.1).

Sequences of flow gaugings over the catchment at the sites indicated in Figure 4.1 have been conducted to enable flows at other points to be related to the flows at the Huts site, and to determine where gains and losses of flows occur. Abstraction rates have been estimated from consents issued by ECan and its predecessors and added to measured flows to yield estimates of the natural flows.

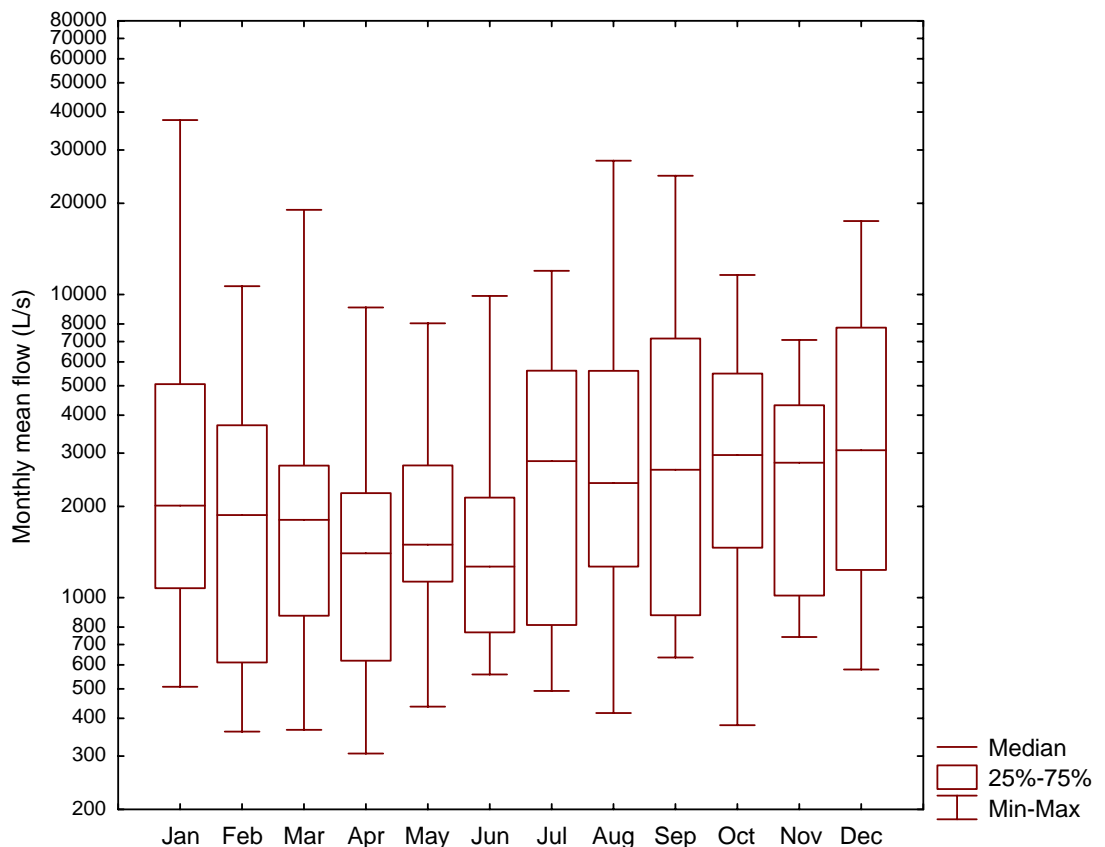
Regression relationships have been prepared to enable estimates of natural flow statistics at gauging sites on the channel network, using estimates of statistics for the natural flows at the Pareora River at Huts site and the Rocky Gully at Rockburn site. These statistics have been used to construct contour maps of equal seven-day mean annual low flow yield and mean annual flow yield, both having units of litres per second per square kilometre (L/s/km<sup>2</sup>).

#### **4.3.2 Pareora River at Huts**

The catchment area above the Pareora River at Huts water level recorder is 424 km<sup>2</sup>. The recorded mean discharge for the Pareora River at Huts recorder site is 3583 L/s. With the addition of 210 L/s, taking into account the Timaru city abstraction, the mean natural flow is approximately 3793 L/s; normalising this with Rocky Gully gives a mean flow of 4001 L/s. The runoff rate is therefore approximately 298 mm/year (that is the mean natural flow multiplied by the seconds in a year, divided by the catchment area). This is less than the Rocky Gully at Rockburn (with the catchment area to the recorder approximately 23 km<sup>2</sup>) estimated runoff rate of 430 mm/year. The naturalised median flow for the Pareora at Huts is estimated to be 1573 L/s, and the normalised median 1736 L/s.

Monthly mean recorded flows for the Pareora River at Huts for May 1982 to December 2004 are presented in Figure 4.2. It shows a very wide flow range from less than 40 L/s to greater than 800 L/s. Monthly mean flows tend to be least in April, May and June, and tend to be somewhat greater from July to December.

The recorded 7-day annual low flows for the Huts record are presented in Appendix 1. The initial estimate of 7DMALF based on the recorded data is 468 L/s. The table also shows the estimated takes upstream of this site. The major take is for the Timaru District Council’s water supply, which has been relatively constant from year to year, whereas the irrigation takes have increased gradually over the years (Figure 6.2). Natural seven-day annual low flows for the site are estimated by adding back the abstractions according to the assumptions given in section 4.2.1. With the abstractions above the site added back, the naturalised estimate of 7DMALF is 643 L/s. Finally, the naturalised 7DMALF estimate of 643 L/s for the Huts site is normalised with reference to the longer Rocky Gully flow record to obtain a final naturalised and normalised estimate of 7DMALF for the Pareora River at Huts of 659 L/s.



**Figure 4.2** Box plot of recorded monthly mean flows for the Pareora River at Huts water level recorder site for May 1982 to December 2004

Table 4.2 presents the relevant naturalised and normalised flow statistics for the Pareora River at Huts. Detail of the estimated surface and groundwater abstractions from the consents data are presented in Appendix 2.

**Table 4.2 Naturalised and normalised 7DMALF, median and mean flow (L/s) statistics for the Pareora River at Huts**

Huts Flow Statistic	Recorded	Naturalised	Normalising ratio	Normalised
7DMALF	468	643	1.026	659
Median	1363	1573	1.103	1736
Mean	3583	3793	1.055	4001

### 4.3.3 Flows at other locations in the Pareora catchment

Simultaneous flow gaugings at other locations (tertiary sites) within the Pareora catchment have been conducted over a number of years and enable the flows at the gauging sites to be related to the flows at the Pareora at Huts recorder site. Table 4.3 lists the sites included in this investigation. Environmental Consultancy Services (ECS), Timaru, provided some or all data for six of the sites. Appendix 3 lists the flow gaugings for all the sites. The gaugings have been naturalised by adding back the surface water and groundwater abstractions as estimated from the consents data (Appendix 2) and the resulting naturalised gauging data are listed in Appendix 4.

**Table 4.3 Pareora River catchment sites included in this investigation**

Site Number	River and Site Name	Map Reference
1857 + ECS	Pareora River at Dam - Upper Gorge	J39:379-489
2258 + ECS	Pareora River at Gorge Road Top Bridge	J38:403-508
ECS	Pareora River at Scotts Bend	J39:4425-4973
ECS	Pareora River at Cannington Rd Bridge	J39:4493-4762
ECS	Pareora River at Cave Pareora Rd Bridge	J39:4875-4630
1856 + ECS	Pareora River at Lower Gorge	J39:527-439
70106	Pareora River at Evans Crossing	J39:540-437
70105	Pareora River at Huts (Recorder)	J39:553-423
1853	Pareora River at Purves Crossing	J39:566-412
1851	Pareora River at Holme Station Bridge	J39:581-403
1852	Pareora River at Talbots	J39:594-396
1854	Pareora River at Jefcoates Road	J39:600-391
170101	Pareora River at Brasells Bridge	J39:618-371
1858	Pareora River at Midgleys Track	J39:642-346
170103	Pareora River at SH1	J39:667-333
70107	Pareora River at Railway Bridge (Recorder)	J39:675-327
2239	Motukaika River at Backline Road Bridge	J39:415-389
2236	Nimrod Stream at Backline Road Bridge	J39:410-401
2227	Matata Creek at Backline Road	J39:412-420
2065	White Rock River at Upstream Nimrod Stream Confl	J39:412-400
2068	White Rock River at Second Bridge Upstream Pareora Confl	J39:422-449
2067	White Rock River at First Bridge Upstream Pareora Confl	J39:436-466
2275	Taiko Stream at Pareora Ford Road Ford	J39:542-440
2130	Elder Stream at Backline Road Bridge	J39:420-356
170102	Pareora River South Branch at Timaunga Road	J39:487-366
1876	Pareora River South Branch at Golf Links	J39:492-374
2274	Pareora River South Branch at Pareora Gorge Road	J39:543-424
2278	Gordons Stream at Holme Station Road	J39:574-397

Regression equations fitted to the plots of the tertiary site gaugings with the secondary (or in some cases primary) site are presented in Appendix 5, and the results are summarized in Table 4.4. The locations of the sites are shown in Figure 4.1. Linear regressions fitted most of the sites well.

The primary purpose of the regressions is to provide estimates of 7DMALF for the sites. In cases where the gaugings extend to the vicinity of mean flow at the primary/secondary site, estimates of the mean and median flows are also given.

In several cases, zero flows occurred at the gauging sites. It is not clear how frequently these sites are dry. In these cases, the estimated 7DMALF has no practical meaning and the value is noted as zero.

Where possible, the regressions are with the Pareora at Huts site data, but in a number of cases the gaugings pre-date the establishment of the Huts site in 1982, and the record for the long-standing adjacent Rocky Gully catchment is used. In two cases (Purves Crossing and Talbots) others of the tertiary sites (Holmes Station and Brasells Bridge respectively) were used as secondary sites because they had been gauged often and consecutively and provided a better estimate.

**Table 4.4 Pareora Catchment regression results summary**

River and Site Name	Number Gaugings	Primary Site	Regression Equation y=mx+c		Adjusted R <sup>2</sup>	Std Error of Equation L/s	Flow Statistics (L/s) and Standard Error (SE) of Estimate					
			m	c			7DMALF	SE (%)	Median	SE (%)	Mean	SE (%)
Pareora at Dam - Upper Gorge	32	Huts	0.2936	-50.387	0.85	178	143	128	459	39	1124	17
Pareora at Gorge Road Top Bridge	6	Huts	0.419	-135.5	0.98	84	141	67	592	15	1541	7
Pareora at Scotts Bend	4(1 Zero)	Insufficient data										
Pareora at Cannington Rd Bridge	5 (2 Zero)	Insufficient data										
Pareora at Cave Pareora Rd Bridge	5 (2 Zero)	Insufficient data										
Pareora River at Lower Gorge	6	Huts	0.7251	-176.04	0.99	100	302	37	1083	10	2725	5
Pareora at Evans Crossing	25	Huts	0.7091	26.230	0.99	93	494	19	1257	8	2863	3
Pareora at Huts (Recorder)							659		1736		4001	
Pareora at Purves Crossing	10	Holme Station	0.895	218.79	0.97	125	561	25	1548	9	3624	5
Pareora at Holme Station Bridge	22	Huts	1.0242	-292.89	0.99	139	382	38	1485	10	3805	4
Pareora at Talbots	9	Brasells Bridge	0.8889	219.67	0.97	141	346	49	1348	11	3453	6
Pareora at Jefcoates Road	7	Huts	0.9814	-497.75	0.97	312	149	210	1206	25	3429	10
Pareora at Brasells Bridge	27	Huts	1.0458	-546.7	0.99	125	142	90	1269	10	3638	4
Pareora at Midleys Track	7	Huts	0.9747	-511.97	0.99	183	130	161	1180	17	3388	6
Pareora at SH1	28	Huts	1.0779	-424.8	0.97	280	286	100	1446	20	3888	8
Pareora at Railway Bridge (Recorder)	36	Huts	1.0145	-315.33	0.99	242	353	70	1446	17	3745	7
White Rock at Upstream Nimrod Stream Confl	9	Rocky Gully	0.6341	-3.74	0.81	9	47	19	Unreliable		Unreliable	
Nimrod Stream at Backline Rd Bridge	9	Rocky Gully	0.5254	-19.027	0.82	7	23	32	Unreliable		Unreliable	
Matata Creek at Backline Rd	6	Rocky Gully	0.2405	0.677	0.66	6	20	30	Unreliable		Unreliable	
White Rock at First Bridge Upstream Pareora Confl	6	Rocky Gully	1.754	-3.696	0.71	37	137	30	Unreliable		Unreliable	
Motukaika at Backline Rd Bridge	9	Rocky Gully	1.0879	-27.926	0.95	7	59	12	181	6	328	7
Elder Stream at Backline Rd Bridge	7	Rocky Gully	1.0239	-1.725	0.45	16	80	21	Unreliable		Unreliable	
White Rock at Second Bridge Upstream Pareora Confl	8	Rocky Gully	1.9883	-61.1	0.81	29	98	31	Unreliable		Unreliable	
Pareora Sth Branch at Timaunga Rd	7	Huts	0.1215	42.213	0.95	32	122	29	253	13	528	8
Pareora Sth Branch at Golf Links	128	Huts	0.1671	113.75	0.93	51	224	25	404	13	782	8
Pareora Sth Branch at Pareora Gorge Rd	13	Huts	0.2514	5.607	0.98	51	171	31	442	12	1011	6
Taiko Stream at Pareora Ford Rd Ford	13						0		Insufficient data		Insufficient data	
<b>Gordons Stream at Holme Station Rd</b>	13						0		Insufficient data		Insufficient data	
Rocky Gully at Rockburn							80		192		327	

#### 4.3.4 Gains and losses along the main channel

Linear regressions fitted most of the sites well and these are used across the catchment. These equations provide insight into the pattern of gains and losses along the main channel. In the regression equations for the main channel downstream of the Huts recorder, the regression constant for the sites correlated with the Huts record is consistently negative. Its magnitude increases progressively to the Brasells Bridge site, consistent with water loss to groundwater, and then decreases downstream towards the coast, consistent with re-emergent groundwater (see also Section 5.2.5.1).

The 7DMALF, median and mean flow estimates along the main channel are plotted as a function of distance downstream from the Upper Gorge in Figure 4.3. Downstream from the Lower Gorge the variation of the 7DMALF along the channel follows the pattern of the low flow gaugings.

Also shown in Figure 4.3 is a sample of the naturalised gaugings for sites located along the main stem of the river to illustrate the changes in flows that occur along the channel. The data show that at higher flows, but not at low flows, considerable gains to flows occur just above the Huts site where the South Branch joins. This indicates that the South Branch has poor low flow yields. Steady losses occur downstream of the Huts recorder to Midgelys Track, below which flows appear to be augmented by emergent groundwater. Two water races enter the main channel in the lower reaches: the first between Brasells Bridge and Midgelys Track and the second between Midgelys Track and State Highway 1. At the time gauging runs were carried out in this part of the catchment these water races were not flowing.

According to the regression equations given in Table 4.4, flows first go to zero in the lower Pareora at the Midgelys Track site, at which point the flow at the Huts recorder is 525 L/s. Estimated flows at other sites for this flow are listed in Table 4.5, which includes corresponding values for the 7DMALF, the median and the mean.

Over the first reach, between the Upper Gorge and the Gorge Road Bridge, the results in Figure 4.3 suggest that there is a gain inflow of about 20 L/s at the 7DMALF, increasing to about 150 L/s at median and mean flows. This gain is most likely due to runoff and tributary inflows. This reach is characterised as having a thin veneer of boulders and cobbles overlying greywacke bedrock (de Joux, 2000).

The data between the Gorge Road Bridge and Lower Gorge are too sparse to accurately assess gains and losses. In general, water is lost into unconsolidated gravels but is expected to re-emerge as surface flow upstream of the Lower Gorge site, augmented by contributions from the White Rock and Motukaika Rivers and other smaller tributaries. For mapping purposes (see section 4.8) the losses in these reaches have been estimated from concurrent gaugings as: 10 L/s loss between Gorge Road Bridge and Scotts Bend, 65 L/s loss between Scotts Bend and Cannington Road Bridge, 50 L/s loss between Cannington Road Bridge and Cave Pareora Road Bridge. These are likely to be underestimates as there are other unquantified tributary inflows between these sites. The inflows between Cave Pareora Road Bridge and Lower Gorge make losses or gains in this reach impossible to estimate. The water lost from the above reaches is likely to re-emerge at or just above the Lower Gorge site as the river flows over bedrock.

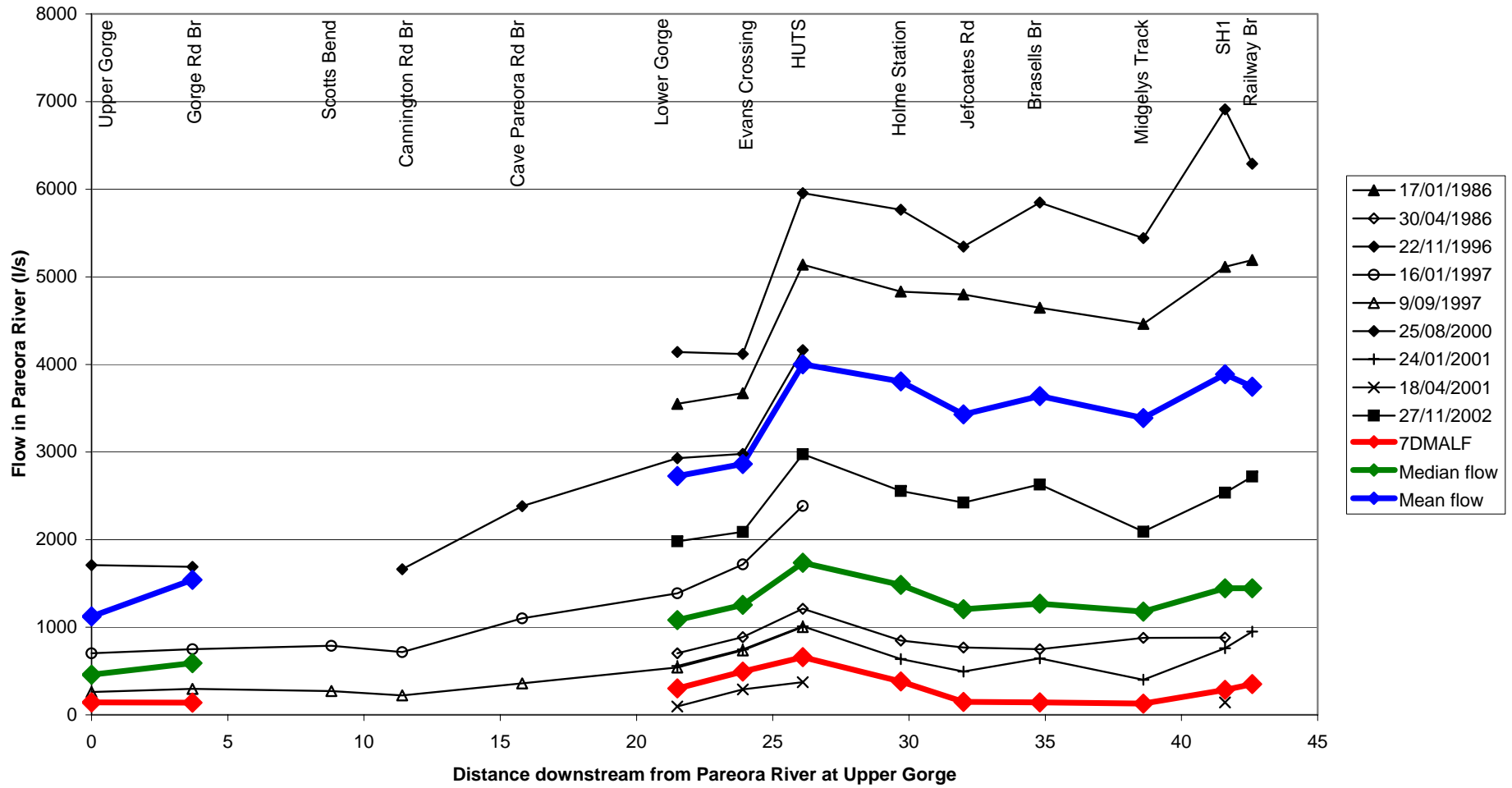


Figure 4.3 Sample of simultaneous gaugings plotted along the main channel of the Pareora River.

**Table 4.5 Estimates of flows statistics and gains and losses (L/s) along the main stem of the Pareora River from the Lower Gorge downstream.**

Pareora River at:	Flow for zero flow at Midgleys Track	Reach gain/loss	7DMALF	Reach gain/loss	Median	Reach gain/loss	Mean flow	Reach gain/loss
Lower Gorge	205		302		1083		2725	
Evans Crossing	398	193	494	192	1256	173	2863	138
Huts	525	127	659	165	1736	480	4001	1138
Purves	438	-87	561	-98	1548	-188	3624	-377
Holme Stn	245	-193	382	-179	1485	-63	3805	181
Talbots	221	-24	346	-36	1348	-137	3453	-352
Jefcoates	17	-204	149	-197	1206	-142	3429	-24
Brasells Bridge	2	-15	142	-7	1269	63	3638	209
Midgleys Track	0	-2	130	-12	1180	-89	3388	-250
SH1	141	141	286	156	1446	266	3888	500
Railway Bridge	217	76	353	67	1446	0	3745	-143
Sum of gains & losses		12		51		363		1020

There is also a probable loss to Quarternary sediments at low flows in the reach between Pareora River South Branch at Golf Links Road and the Pareora River South Branch at Pareora Gorge Road. The loss has been estimated for mapping purposes (see Sections 4.8.3 and 4.8.4.1) to be 45 L/s at 7DMALF.

## 4.4 Waihao River

### 4.4.1 Introduction

The Waihao River catchment is the southern-most catchment in the study region and is slightly larger than the Pareora, draining an area of 541 km<sup>2</sup> at its mouth (see Figure 4.1). This excludes those catchments drained by the Waihao River mouth via the Wainono Lagoon and the Dead Arm.

The river has two branches, the north branch draining the western slopes of the Hunters Hills and the south branch draining the downlands of the Waihaorunga area together with the hill country that forms the catchment divide between the Hakataramea River to the west and the Waitaki River to the south. Perennial streams drain the western flanks of the Hunters Hills and the hill country divide. The Waihoarunga Downs have a subdued topography and intermittent drainage.

The two branches combine at the Waihao Forks, 10 km southwest of Waimate, and flow as the Waihao River in an easterly direction for about 19 km to the coast. Below the Forks the tributaries are small and intermittent and most of the natural river flow originates from above the Forks. However, flows in the lower reaches are augmented by drainage of surplus water from the Morven-Glenavy Irrigation Scheme (MGIS) which is sourced from the Waitaki River. This surplus drainage, also known as “bywash”, enters the Waihao at two locations downstream of SH1: Horsnells Road (site number 71174, just upstream of the South Island

Main Trunk Railway bridge) and Crowes Road (site number 71173). To achieve natural flow estimates downstream of these sites it is necessary to subtract the bywash flows from the gauged flows. According to Mike Burns (Pers. Comm. Jan 2005) the MGIS scheme became operational in Feb 1974, and would have started discharging into the Waihao in the Sept 1974 to May 1975 irrigation season.

There is potential for the flow in the lower reaches of the Waihao River to reduce as abstractions from the Waihao River increase (see Figure 6.2) and as the bywash from the MGIS scheme decreases due to increased efficiency. Consideration of this should be factored in to any future planning for the lower reaches of the Waihao River. Figure 4.4 shows the range of flows over time discharged from the MGIS scheme at both Crowes Road and Horsnells Road. There is some evidence that the flow range at particularly the Crowes Road site is reducing. Figure 4.5 shows the average flow for each irrigation season (1 September – 30 April) from 1987 to 2004 with bywash from the two sites considered. There is some evidence of a decline in the bywash flow in recent times.

Abstraction rates have been estimated from consents issued by ECan and its predecessors and added to measured flows to yield estimates of the natural flow. Sequences of river flow gaugings over the catchment at the sites indicated in Figure 4.1 have been assembled and corrected for the abstractions to give naturalised flows. These are then regressed with the naturalised and normalised flows at the Waihao at McCulloughs Bridge water level recorder site to enable estimates of natural flow statistics at the gauging sites on the channel network, given estimates of statistics for the natural flows at Waihao at McCulloughs Bridge. The Waihao at McCulloughs Bridge data has been normalised using the Hakataramea above Main Highway Bridge long-term flow record.

Details of the analysis are presented in the following sections.

#### **4.4.2 Waihao River at McCulloughs Bridge**

The main water level recorder at McCulloughs Bridge (site number 70902, map reference J40:497-989), located approximately 4 km downstream of the North Branch and South Branch confluence, has operated since 1982. The catchment area above the McCulloughs site is 484 km<sup>2</sup>. The naturalised and normalised mean flow at the McCulloughs Bridge site is 3775 L/s, representing a mean runoff rate of approximately 246 mm/year.

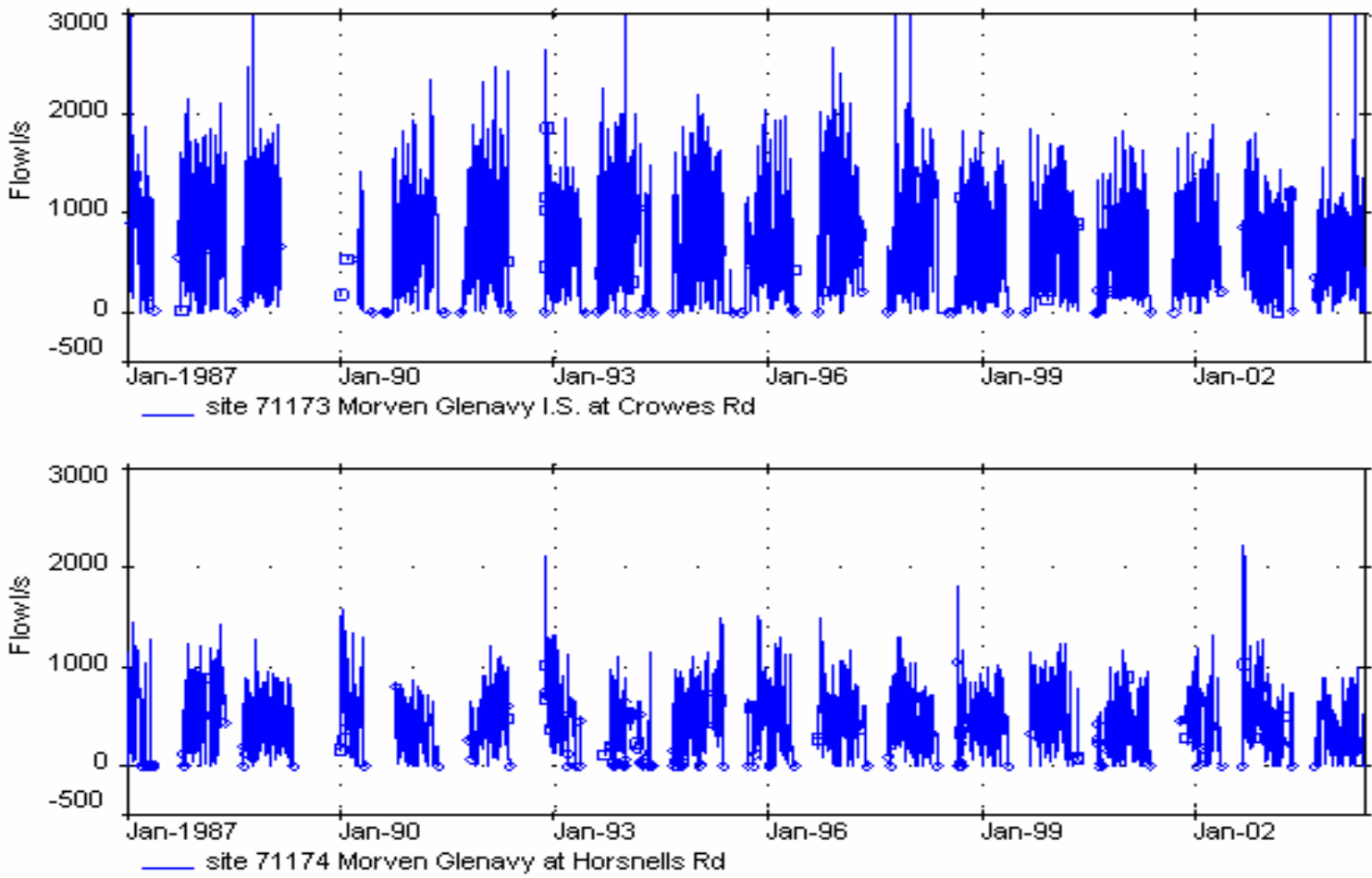
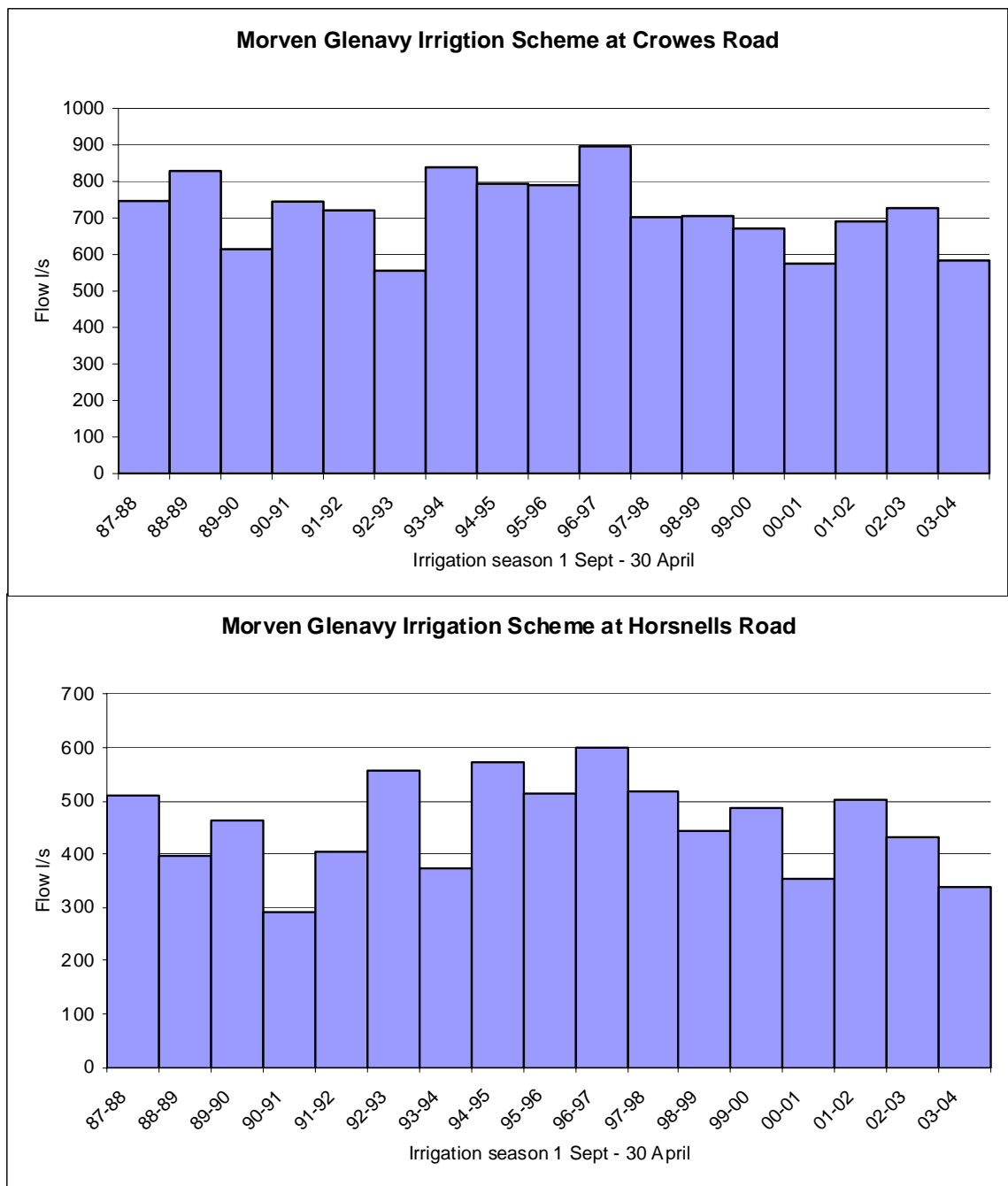
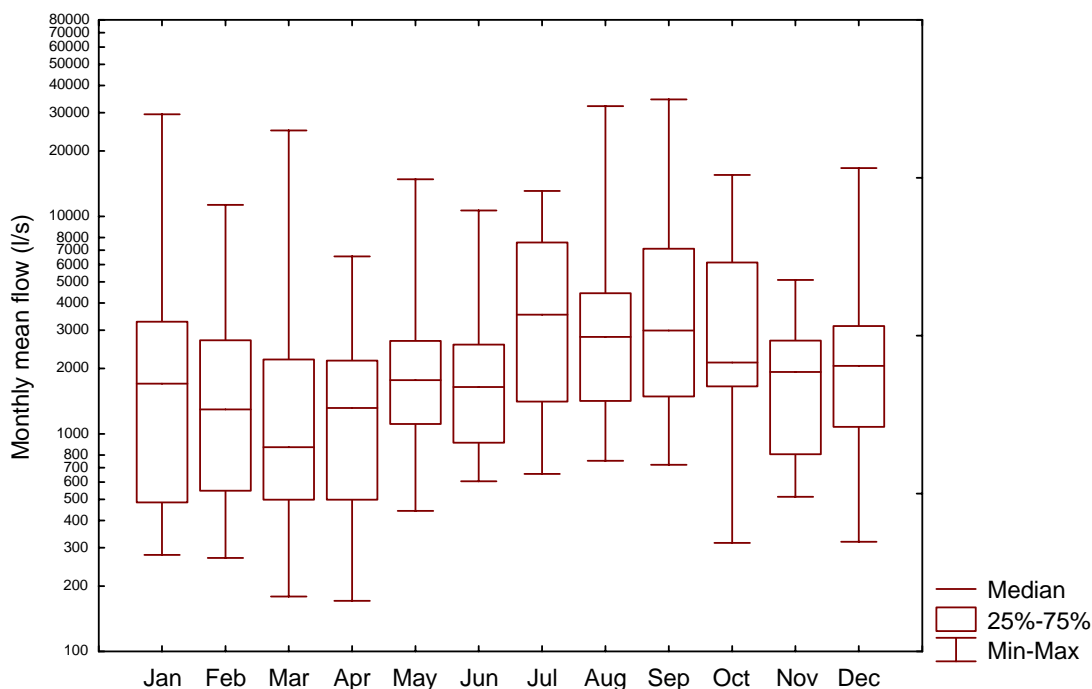


Figure 4.4 Range of flows over time discharged into lower reach of the Waihao River from the MGIS



**Figure 4.5 Mean flow for irrigation season 1 September – 30 April for MGIS at Crowes Road and MGIS at Horsnell's Road**

The monthly mean recorded flows for October 1982 to February 2005 are plotted in Figure 4.6. There is a wide range in the monthly mean flows for each month. The medians of the monthly means exceed 1000 L/s for all months apart from March. March and April are the months with lowest flows and have recorded monthly means of less than 200 L/s, but monthly means of less than 500 L/s have occurred in any of the months from October to May. Higher flows typically occur in July to September. The logarithmic scale is used to emphasise the lower flows.



**Figure 4.6 Mean monthly flows recorded for 1982-2005 at station 70902, Waihao River at McCulloughs Bridge**

The mean recorded flow at McCulloughs for the period of record is 3585 L/s, and with an allowance for average annual abstractions of 40 L/s the natural mean flow is estimated as 3625 L/s. For the Rocky Gully catchment, the naturalised mean flow for this period is 314 L/s compared with the mean for the 30 year period 1971-2000 of 327 L/s (Table 4.1). Applying the ratio of these means ( $327/314 = 1.041$ ) to the McCulloughs mean gives a natural normalised mean flow of 3775 L/s.

Similarly, the normalised median flow is estimated as 1459 L/s, based on a recorded median for the period of 1282 L/s.

The recorded 7-day annual low flows for the McCulloughs Bridge record are presented in Appendix 6. The initial estimate of 7<sup>DMALF</sup> based on the recorded data is 341 L/s. The table also shows the correction for estimated takes upstream of this site; no groundwater takes occur upstream of this site. Natural seven-day annual low flows for the site are estimated by adding back the abstractions according to assumptions given in section 4.2.1. With the abstractions above the site added back the naturalised estimate of 7<sup>DMALF</sup> is 368 L/s. Finally, the naturalised 7<sup>DMALF</sup> estimate of 368 L/s for the McCulloughs site is normalised with reference to the longer Rocky Gully flow record to obtain a final naturalised and normalised estimate of 7<sup>DMALF</sup> for the Waihao River at McCulloughs Bridge of 377 L/s.

Table 4.6 presents the relevant naturalised and normalised flow statistics for the Waihao River at McCulloughs Bridge. Detail of the estimation of the surface water and groundwater takes using the consents data are presented in Appendix 7. These data show that for the 33-year period 1973-2005 over the whole Waihao catchment, the consented surface water takes increased from zero to 266 L/s and permitted groundwater takes increased from 2 to 45 L/s (see also Figures 6.2 and 6.3).

**Table 4.6 Naturalised and normalised 7<sup>DMALF</sup>, median and mean flow (L/s) statistics for the Waihao River at McCulloughs Bridge**

McCulloughs Flow Statistic	Recorded	Naturalised	Normalised
7 <sup>DMALF</sup>	341	368	377
Median	1282	1322	1459
Mean	3585	3625	3775

#### 4.4.3 Flows at other locations in the Waihao catchment

Simultaneous flow gaugings at other locations (tertiary sites) within the Waihao catchment have been carried out since the 1970s. Table 4.7 lists the sites included in this investigation. Appendix 8 lists the flow gaugings for all the sites. The gaugings adjusted for the effect of abstractions are in Appendix 9.

**Table 4.7 Waihao River catchment sites included in this investigation**

Site Number	River and Site Name	Map Reference
170901	Waihao River North Branch at Kaiwarua Footbridge	J40:382-191
170905	Waihao River North Branch at Waihao Forks	J40:471-003
2228	Meyers Creek at Meyers Pass Road - Gorge	J40:323-105
1822	Waihao River South Branch at Kaiwarua Ford	J40:350-148
170902	Waihao River South Branch at Pentland Hills	J40:358-106
170903	Waihao River South Branch at Waihao Forks	J40:465-999
70902	Waihao River at McCulloughs Bridge (Recorder)	J40:497-989
70912	Waihao River at Downstream McCulloughs Bridge	J40:502-989
170904	Waihao River at Elliots	J40:540-999
70910	Waihao River at Wains Crossing	J40:567-009
70909	Waihao River at SH1	J40:594-996
2381	Waihao River at Upstream Horsnells Road Outflow	J40:607-996
70911	Waihao River at Crowes Road Ford	J40:622-995
70913	Waihao River at Upstream Bradshaws Bridge (Recorder)	J40:642-014

Regression equations fitted to the plots of the tertiary sites with the secondary site, Waihao River at McCulloughs Bridge, are presented in Appendix 10, and the results are summarised in Table 4.8. For all the sites where a satisfactory regression could be achieved simple linear regressions provide reasonable fits to the non-zero data. Three sites had insufficient data for a regression to be achieved: Waihao upstream Horsnells Road Outflow, Meyers Creek at Gorge – Meyers Pass Road, and Waihao South Branch at Kaiwarua Ford.

The regression equations obtained for the sites enable estimates as in Table 4.8 of 7<sup>DMALF</sup>s for sites with perennial flows. Since the regression equations fit flows at least as high as the mean flow at McCulloughs Bridge, they are also used to give estimates of the mean and median flows at the other sites. Standard error estimates are included with these estimates. Buchanans Creek is a sub-catchment of the Waihao River and is dealt with separately in section 4.4.5.

**Table 4.8 Regression equations fitted to Waihao catchment gaugings. In all cases, the primary site is the recorder on the Waihao River at McCulloughs Bridge**

River and Site Name	Number of Gaugings	Primary Site	Regression Equation $y=mx+c$		Adjusted $R^2$	Std Error of Equation	Flow Statistics (L/s) and Standard Error of Estimate					
			m	c			L/s	7DMALF	% Std Error	Median	% Std Error	Mean
Waihao Nth Branch at Kaiwarua Footbridge	8	McCulloughs	0.401	95.7	0.964	194	247	86	681	30	1610	13
Waihao Nth Branch at Waihao Forks	9	McCulloughs	0.669	53	0.973	263	305	94	1029	27	2578	10
Meyers Creek at Meyers Pass Rd - Gorge	4	Insufficient data										
Waihao Sth Branch at Kaiwarua Ford	7	Insufficient data										
Waihao Sth Branch at Pentland Hills	7	McCulloughs	0.19	-47.6	0.95	39	24	185	230	18	670	9
Waihao Sth Branch at Waihao Forks	7	McCulloughs	0.335	-95.4	0.963	59	31	217	393	16	1169	8
Waihao at McCulloughs Br. (Recorder)		McCulloughs					377		1459		3775	
Waihao downstream McCulloughs Br.	14	McCulloughs	0.949	-44	0.992	137	314	46	1341	11	3538	4
Waihao at Elliots	12	McCulloughs	1.085	-32.2	0.994	204	377	58	1551	14	4064	5
Waihao at Wains Crossing	16	McCulloughs	0.982	-274	0.945	429	96 <sup>1</sup>	474	1159	39	3433	12
Waihao at SH1	12	McCulloughs	0.88	-580	0.989	129	0		704	19	2742	5
Waihao upstream Horsnells Rd Outflow	3	Insufficient data					0					
Waihao at Crowes Rd Ford	7	McCulloughs	0.755	-387	0.991	144	0		715	27	2463	6
Waihao upstream Bradshaws Br.	6	McCulloughs	0.948	-373	0.991	121	0		1010	13	3206	5

1 – Value calculated from the regression equation. Gauging data suggests the Waihao River at Wains Crossing is actually dry at 7DMALF.

#### 4.4.4 Gains and losses along the main channel

Figure 4.7 shows the flow estimates as a function of distance downstream from the top site on the main channel. This plot shows a drop in flow immediately below McCulloughs Bridge, a recovery downstream to Elliots, then increasing losses downstream to SH1 at least, and a modest recovery of flows at the last two sites. This pattern is consistent over a range of flows from very low to mean.

According to the regression equations in Table 4.8, the first site where flow ceases in low flow conditions is the SH1 site. The equation predicts that flow ceases at SH1 when the McCulloughs Bridge flow is 659 L/s, which is significantly higher than the 7DMALF estimate for McCulloughs Bridge. With this flow the regression equations are used to estimate corresponding flows at the sites downstream of McCulloughs Bridge, as in Table 4.9. Differences between the estimates at successive sites enable estimates of reach losses or gains to be made for low flow conditions (Table 4.9). Differences between the means at the downstream sites provide a second set of loss or gain estimates (Table 4.9). Also given in Table 4.9 are estimates of the losses and gains at 7DMALF and median flow at McCulloughs.

**Table 4.9 Estimation of mean annual flows gains or losses (L/s) along the Waihao River downstream of McCulloughs Bridge**

Site	Flow for zero at SH1	Gain/loss	7DMALF	Gain/loss	Median	Gain/loss	Mean	Gain/loss
McCulloughs Br.	659		377		1459		3775	
D/S McCulloughs Br.	581	-78	314	-63	1341	-118	3538	-237
Elliots	682	101	377	63	1551	210	4064	526
Wains	373	-309	96 <sup>1</sup>	-281	1159	-392	3433	-631
SH1	0	-373	0	-96	704	-455	2742	-691
Crowes	212	212	0	0	715	11	2463	-279
Upstream Bradshaws	111	-101	0	0	1010	295	3206	743
Sum of gains and losses		-548		-377		-449		-569

1 – Value calculated from the regression equation. Gauging data suggests the Waihao River at Wains Crossing is actually dry at 7DMALF.

For the four cases considered, the sums of the gains and losses are remarkably consistent. Much of this water probably appears as flow in spring-fed creeks in the lower catchment such as Buchanans Creek and Sir Charles Creek. See also Sections 4.8.4.2 and 5.2.5.3.

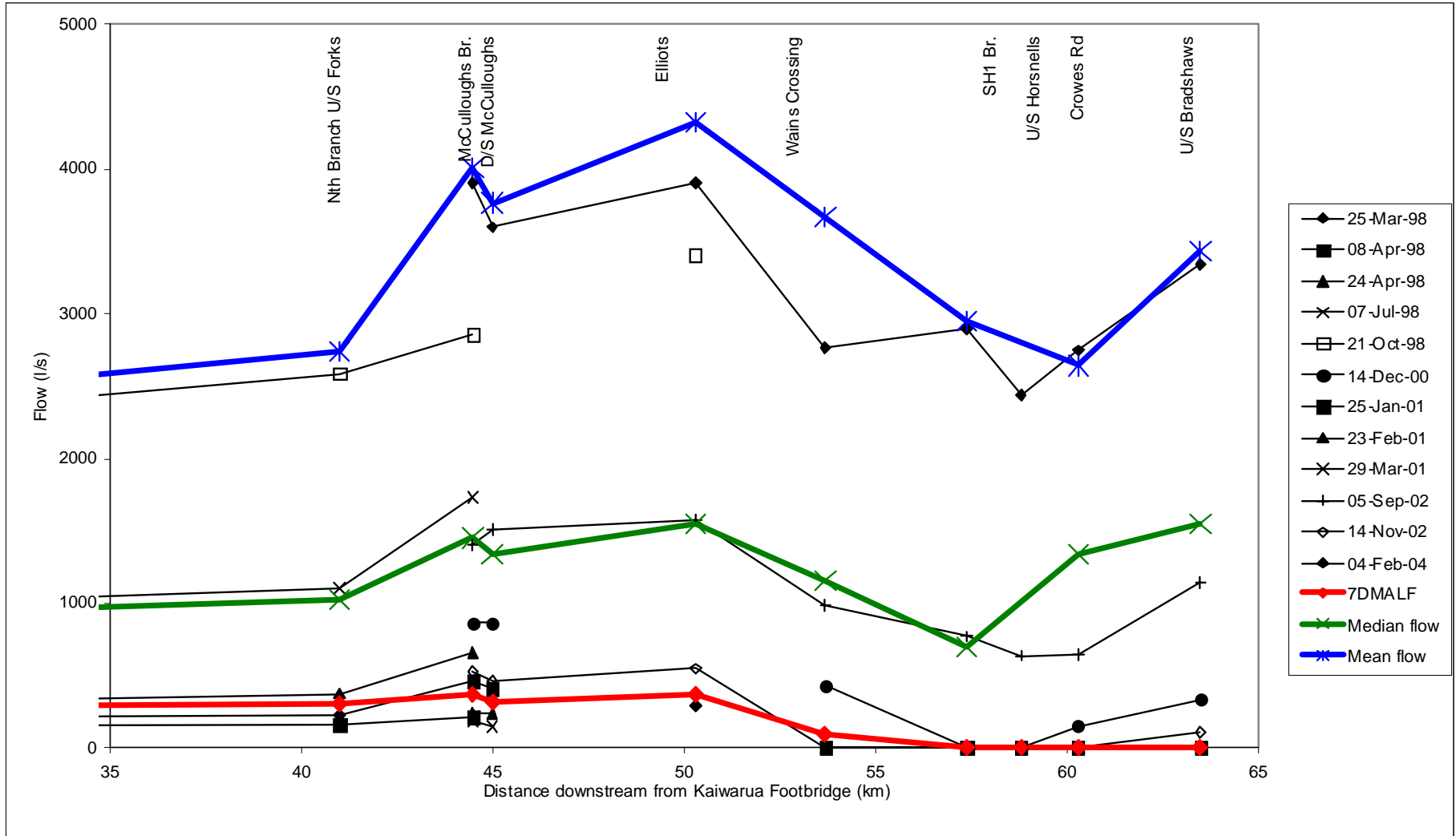


Figure 4.7 Samples of simultaneous gaugings plotted along the North Branch (beginning at Kaiwarua Footbridge) and the main channel of the Waihao River, together with estimates of the mean and median flows and 7DMALF.

#### 4.4.5 Buchanans Creek

A water level recorder (site number 70908, map reference J40:630-019, catchment area 15 km<sup>2</sup>) has operated since 1999 on Buchanans Creek at Fletchers Bridge. Buchanans Creek is a spring-fed creek that flows in an easterly direction and enters the Waihao River in the reach between Bradshaws Bridge and the Waihao Box (Figure 4.1). Because the flow is perennial and well sustained, the creek is a particularly important local water resource. For resource consent purposes, interest centres on the low flows, particularly the 7DMALF and with data only from late 1999, the connection with the Waihao flows is examined.

It is anticipated that the Buchanans Creek flow is mainly water lost from the Waihao River below McCulloughs Bridge. This is illustrated in Figure 4.8, which presents, as an example, the 2004 data. This confirms that there is a general linkage between the recorded flows in this creek with levels for a groundwater well, Ruddenklaus (J40/0071), in its upper reaches and with the McCulloughs Bridge flow record and, ultimately, with rainfall as indicated by the Morven daily rainfalls. In particular, the lower well levels tend to follow periods flow recession at McCulloughs Bridge.

Several methods were tried in order to calculate a value for 7DMALF for Buchanans Creek, including the ratio method with Waihao flows and regression with the Ruddenklaus well level data. The most robust relationship however was a regression of the naturalised 7DALFs (7-day annual low flows) at Buchanans Creek Fletchers Bridge with naturalised 7DALFs at the Waihao River at McCulloughs Bridge site. This analysis was carried out later than that for other catchments in this report and therefore the 2005 7DALF was available for each site. Figure 4.9 gives the regression relationship. Using a naturalised and normalised 7DMALF for Waihao at McCulloughs of 386 L/s (which includes the 2005 7DALF), the naturalised and normalised 7DMALF for Buchanans Creek at Fletchers Bridge is estimated to be 233 L/s.

The median recorded flow for the Buchanans Creek at Fletchers Bridge water level site is 330 L/s and with an allowance for abstractions, a naturalised median flow of 339 L/s is estimated. Without a basis for normalising this estimate, it must be recognised as approximate. Likewise, the mean recorded flow for the Buchanans Creek at Fletchers Bridge water level site is 346 L/s, and a naturalised mean flow of 355 L/s is estimated.

A specific local issue is the flow regime in Buchanans Creek at Willowbridge Road, about 1.7 km upstream of the Fletchers Bridge water level recorder. Flow gaugings have been undertaken at this site since late 1996. Flows were measured over much of 1997, but have often been zero since then. The time-series of the gaugings is shown in Figure 4.10, together with well levels from monthly readings for a well (J40/0050) near Willowbridge, the Waihao flows as recorded at McCulloughs Bridge, and the surplus MGIS water (bywash) flows discharged into the Waihao River from the Horsnells Race averaged over seven-day intervals.

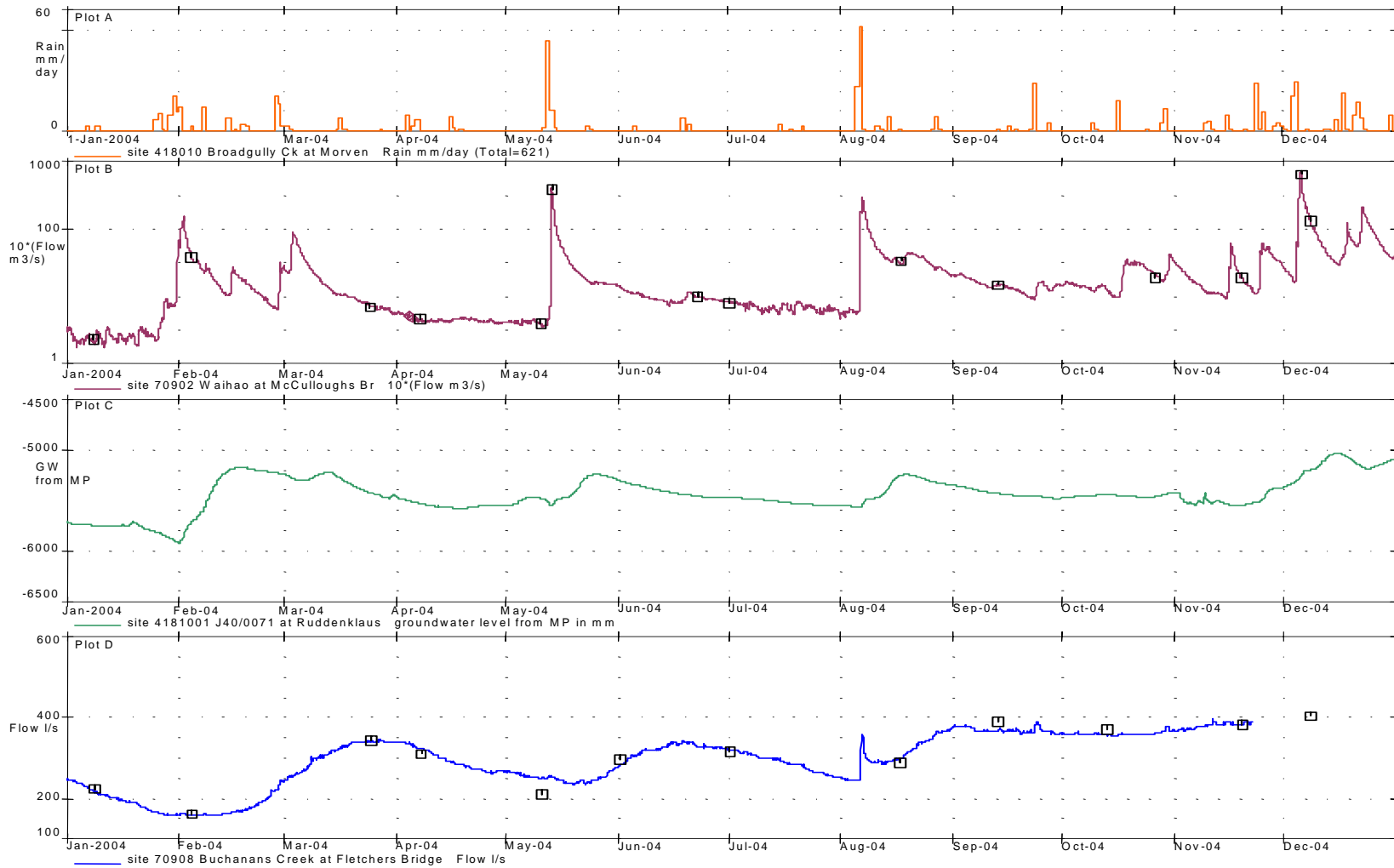
Well levels corresponding to the Willowbridge Road gaugings (observed, not naturalised) plotted in Figure 4.11 confirm the impression that flows are likely only when the well level for J40/0050 is above the -1500 mm threshold. Figure 4.12 compares the well levels with the mean Waihao River flow at McCulloughs Bridge over the preceding 100 days. Flow over the preceding 100 days is used as a way to identify periods of low flow apparent in Figure 4.10. The data on this plot indicate that well levels below -1500 mm correspond with average flows over the last 100 days of less than 2000 to 3000 L/s.

Combining this information, it is inferred that flow in Buchanans Creek at Willowbridge Road is likely when the average flow in the Waihao River at McCulloughs Bridge over the last 100 days exceeds 2000-3000 L/s. On the other hand, when the McCulloughs Bridge 100 day average flow is less than 2000 L/s, the probability is high that the well J40/0050 is below -1500 mm and that flow in Buchanans Creek at Willowbridge Road ceases.

This result is also evident in Figure 4.13 which compares the non-zero Willowbridge Road gaugings with the average Waihao flows for the preceding 100 days. Observations of zero flows are included on this plot by nominally assigning them a value of 1.0 L/s, which for partial purposes can be regarded as zero flow. One observation of zero flow, on 22 November 2000 with an exceptionally high associated 100 day Waihao flow of 22,207 L/s is omitted from this figure: this high average flow is an atypical result of a sequence of floods in the river in late August and early September 2000, 70 to 100 days before the observation.

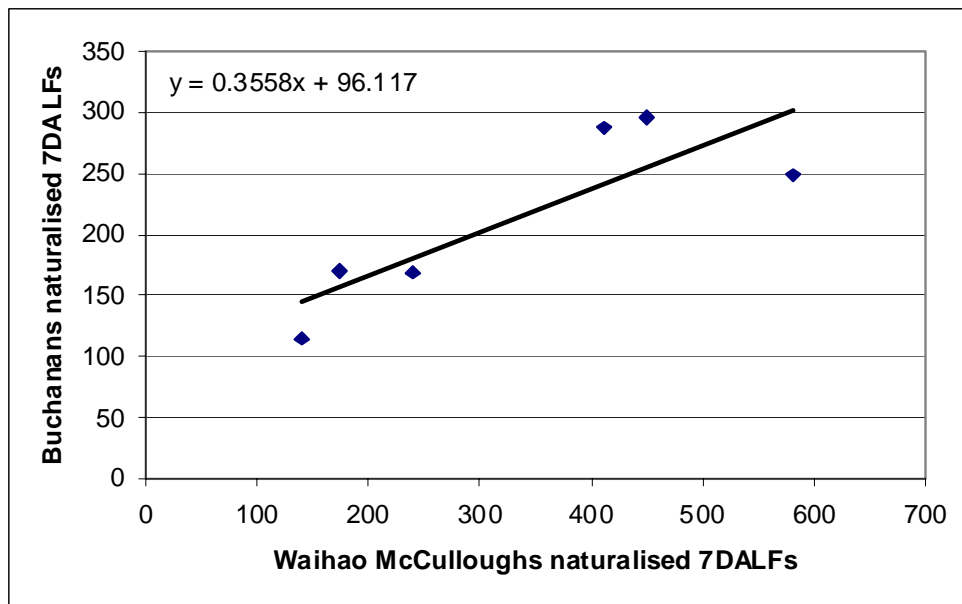
No relationship was apparent between the well levels for J40/0500 and MGIS bywash flow, as measured by the Horsnells Road Race flows.

Finally, Figure 4.10 shows that well levels above the -1500 mm threshold persisted for most of the period 1992-1997. The analysis above suggests that flows would have occurred at Willowbridge Road over most of this period. In contrast, from 1998 well levels regularly dropped below the -1500 mm threshold and no flow was often observed at Willowbridge Road. This confirms the local perception that the Buchanans Creek flow regime has reduced in recent years. The most likely reason for the reduced groundwater levels is lower rainfalls and, presumably, reduced Waihao River flows in recent years (Section 2.5).

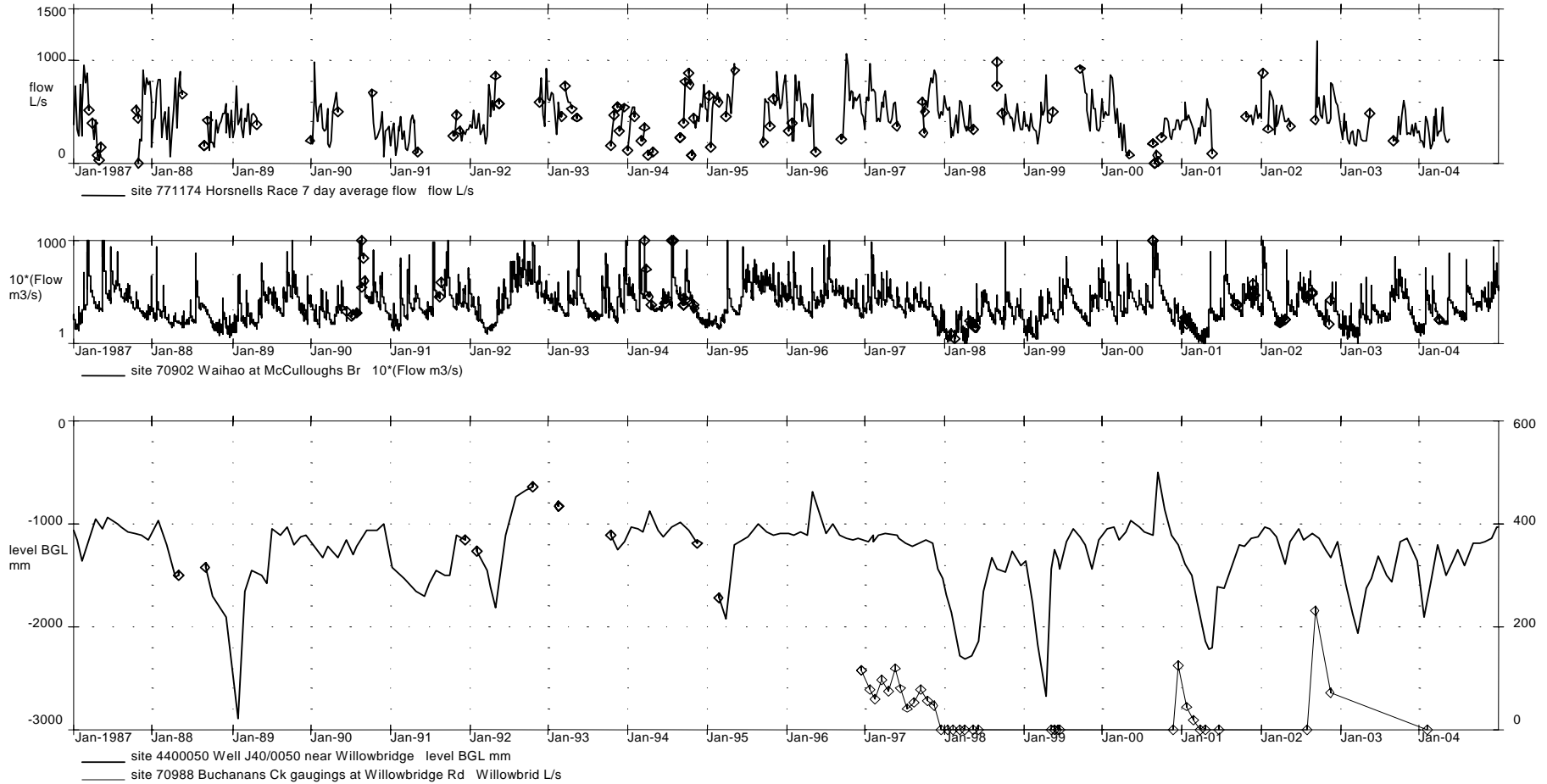


**Figure 4.8 Illustration of relationship between the flows recorded at McCulloughs Bridge**

A groundwater level record and Buchanan's Creek flow. Plot A, daily rainfalls at Morven (mm/day); Plot B, Waihao River at McCulloughs Bridge flows (L/s); Plot C, Well J40/0071 at Ruddenklaus (m below ground level); Plot D Buchanan's Creek flow (L/s). Note the logarithmic scale for the Waihao flows.

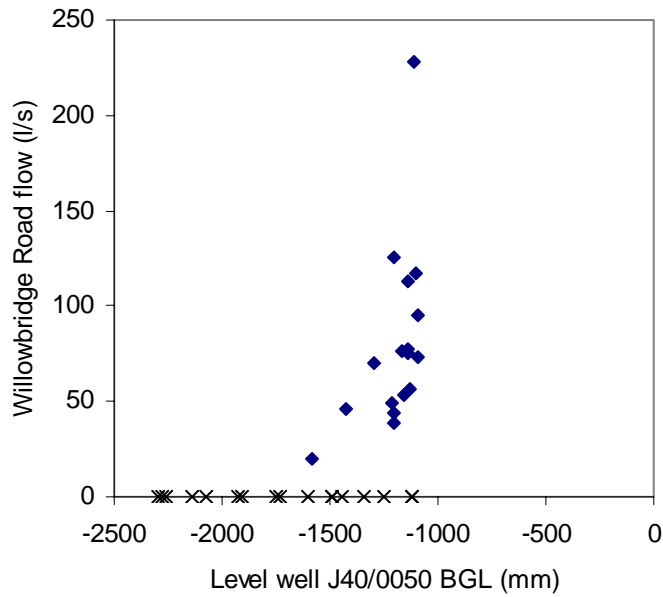


**Figure 4.9** Relationship between naturalised 7-day annual low flows in the Waihao River at McCulloughs Bridge, and naturalised 7-day annual low flows in Buchanans Creek at the Fletchers Bridge recorder.

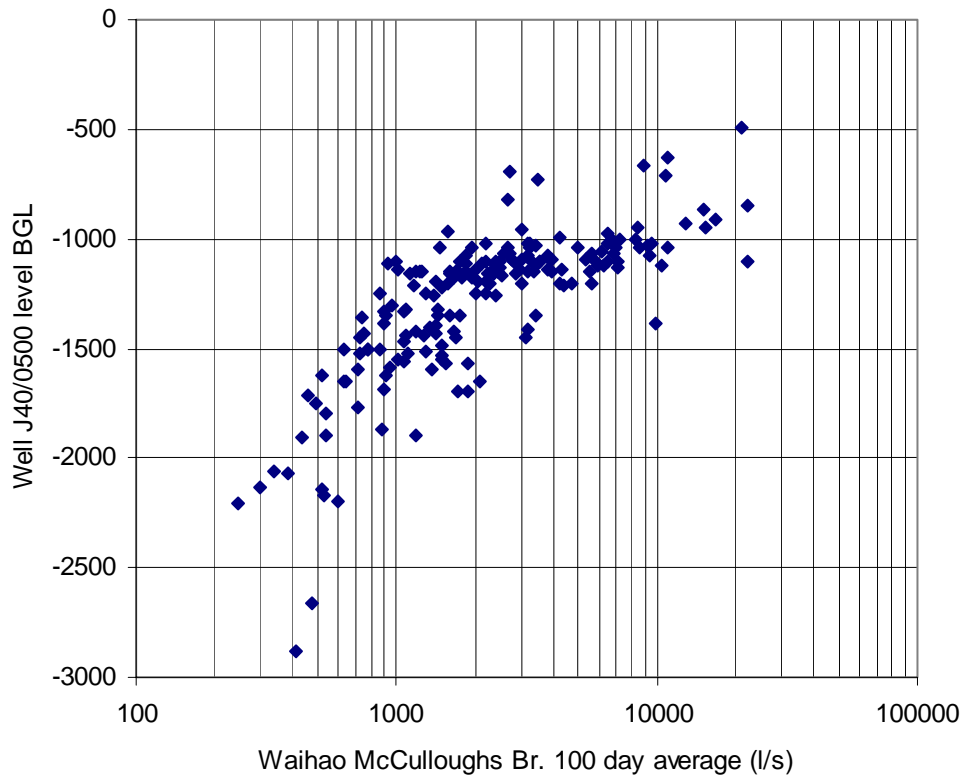


**Figure 4.10 Buchanans Creek Gaugings, groundwater levels well J40/0050 and Waihao flows recorded at McCulloughs Bridge**

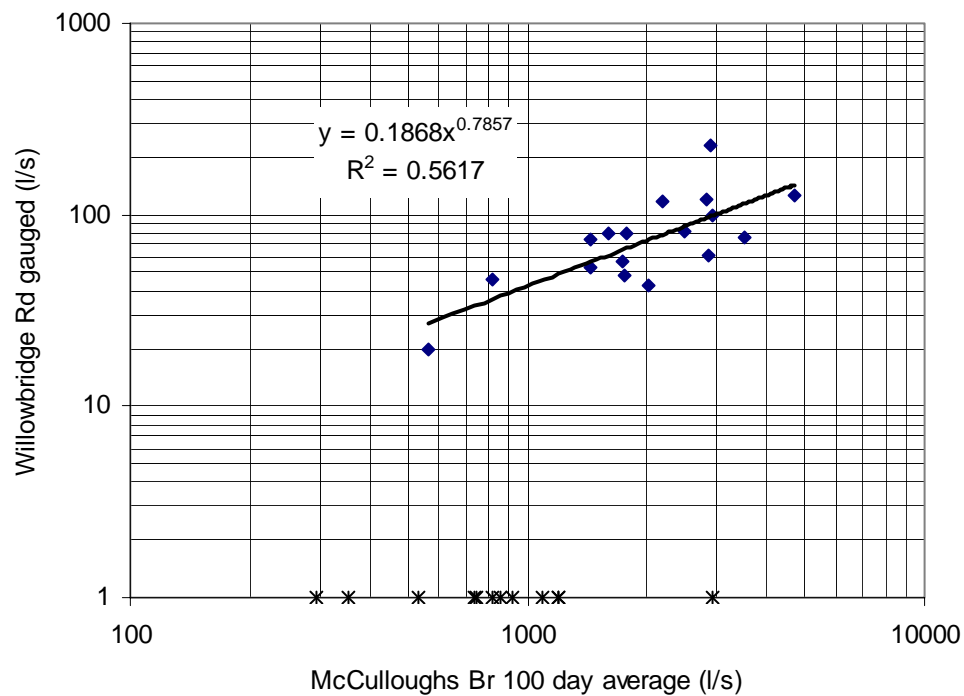
Gaugings undertaken on Buchanans Creek at Willowbridge Road compared with monthly well levels for well J40/0050 (lower panel), Waihao flows recorded at McCulloughs Bridge (middle panel) and surplus water (bywash) from the MGIS discharged into the Waihao River by the Horsnells Race (averages over seven-day intervals, top panel).



**Figure 4.11 Willowbridge Road gaugings compared with levels for well J40/0050**



**Figure 4.12 Well levels for well J40/0500 plotted against the average flow at McCulloughs Bridge over the preceding 100 days**



**Figure 4.13 Gauged flows in Buchanan's Creek at Willowbridge Road compared with average flows in the Waihao River at McCulloughs Bridge**

For the preceding 100 days with a best-fitting function for the non-zero gaugings. Zero flows at Willowbridge Road have been nominally adjusted to 1.0 L/s to enable them to be added to this plot.

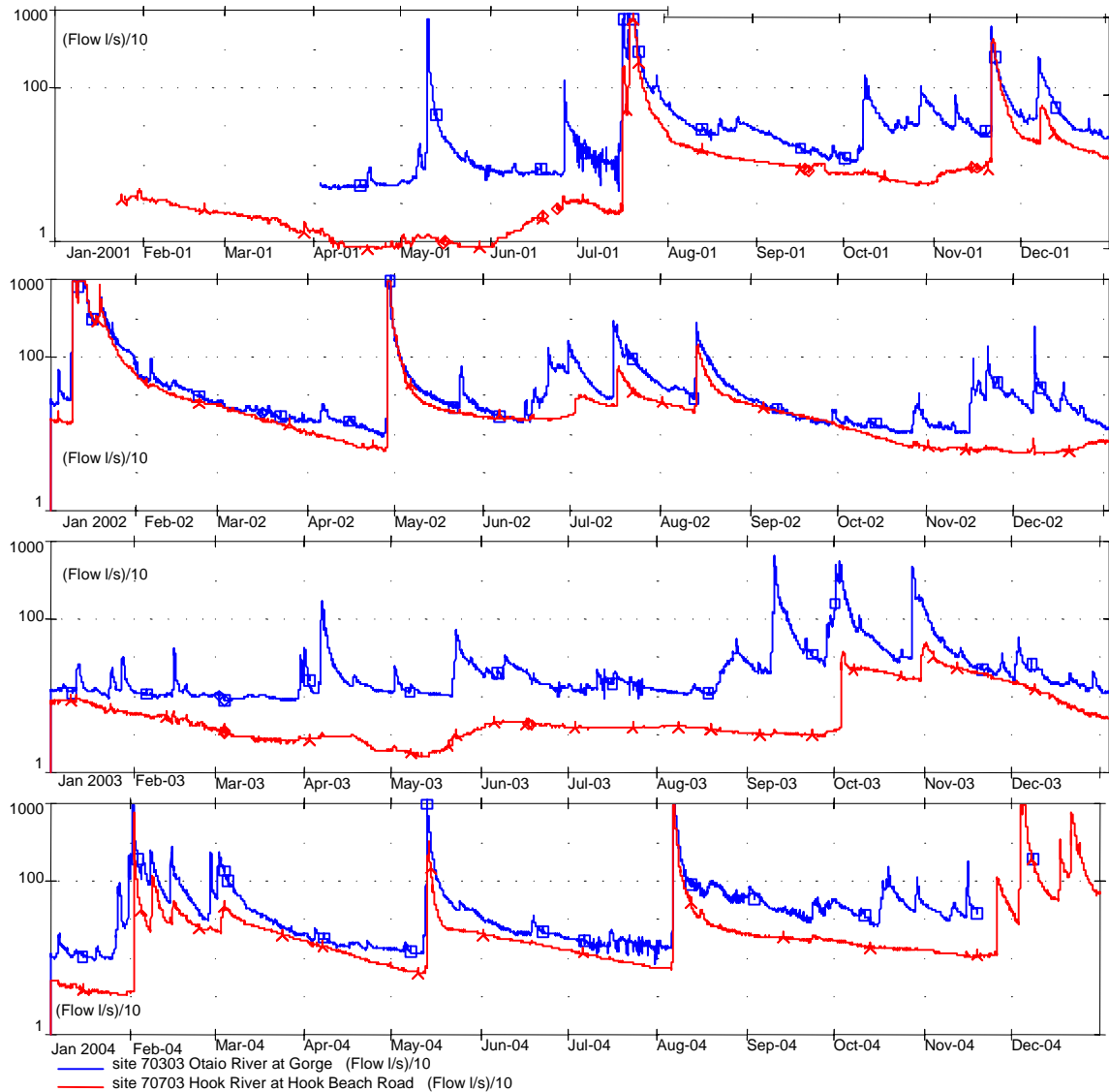
## 4.5 Otaio River

### 4.5.1 Introduction

The Otaio River catchment is approximately 144 km<sup>2</sup> in area and lies immediately to the south of the Pareora catchment. The Otaio River drains the eastern faces of the Hunters Hills and flows in an easterly direction to the coast. The flow is perennial where the river emerges from the hills, but is lost in the river gravels downstream of the gorge and for much of its course flow in the river channel is intermittent. Since 2001 flows have been monitored at a water level recorder, Otaio River at Gorge (site number 70303, map reference J39:454-296) where the river emerges from the hills.

### 4.5.2 Otaio River at Gorge

The catchment area to the water level recorder is 47 km<sup>2</sup>. The mean flow recorded for April 2001 to November 2004 is 616 L/s; the normalised flow however is 741 L/s, representing a runoff rate of approximately 497 mm/yr. There are no abstractions upstream of the recorder. The times series of river flows for this site is plotted in Figure 4.14. The flow record for the adjacent Hook River at Hook Beach Rd (site number 70703, map reference J40:631-131) is overplotted because it is expected to demonstrate broadly similar flow patterns.



**Figure 4.14 Otaio River at Gorge flows with the Hook at Hook Beach Road flow record overplotted**

Note: the use of a logarithmic scale to emphasize low flows.

From the record of less than four years, the 7DMALF is calculated as 103 L/s, and for the same period the Rocky Gully primary site 7DMALF is 69 L/s. For the normalising period 1971-2000 the Rocky Gully 7DMALF is 80 L/s, and applying the ratio of the Rocky Gully estimates gives an estimate for the normalised Otaio River at Gorge 7DMALF of 119 L/s.

Another 7DMALF estimate is obtained from a regression of Otaio gaugings with corresponding daily mean flows for the Pareora River at Huts (Figure 4.15). With the naturalised and normalised Rocky Gully estimate and the regression equation on Figure 4.15, a second 7DMALF estimate for the Otaio River at Gorge is 117 L/s.

From these two estimates, a value for 7DMALF of 117 L/s is adopted for the Otaio River at Gorge.

Mean flow for the same period for Rocky Gully is 267 L/s, which is substantially less than the mean for the normal period 1971-2000 of 327 L/s. This is consistent with the analysis of the long-term rainfalls which demonstrated that the period 2000 to 2004 was unusually dry. Using the ratio of the Rocky Gully means gives a normalised mean flow estimate for the

Otaio at Gorge of 754 L/s. With the naturalised and normalised Pareora at Huts estimate and the regression equation given in Figure 4.15, a second mean flow estimate for the Otaio is 741 L/s. In a similar way, corresponding estimates for the Otaio at Gorge median flow have been derived. The estimates of 7DMALF, median and mean flow are summarised in Table 4.10, which also gives the recommended values.

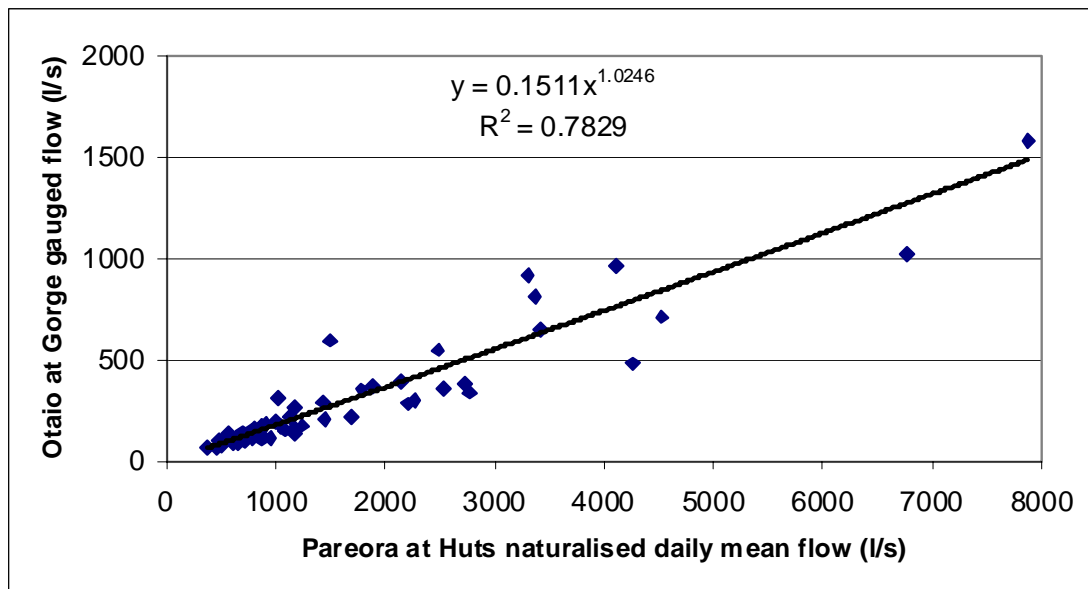


Figure 4.15 Regression plot Otaio River at Gorge and Pareora at Huts flows

Table 4.10 Estimates of 7DMALF, median and mean flow for the Otaio River at Gorge

Quantity	Estimate source	Estimate (L/s)	Recommended Estimate (L/s)
7DMALF	Record April 2001 – November 2004	103	117
	<b>Normalised using Hakataramea</b>	119	
	Regression equation in Fig. 4.13 using Pareora 7DMALF = 659 L/s	117	
Median	Record April 2001 – November 2004	248	315
	Normalised using Hakataramea	274	
	Regression equation in Fig. 4-8 using Pareora median = 1736 L/s	315	
Mean	Record April 2001 – November 2004	584	741
	Normalised using Hakataramea	944	
	Regression equation in Fig. 4-8 using Pareora mean = 4001 L/s	477	

#### 4.5.3 Flows at other locations in the Otaio catchment and gains and losses along the main channel

Simultaneous flow gaugings at other locations (tertiary sites) within the Otaio catchment have been carried out since the 1960s. Table 4.11 lists the sites included in this investigation. Appendix 11 lists the flow gaugings for all the sites. The estimated surface water and groundwater abstractions affecting the gauging sites are listed in Appendix 12 and the gaugings adjusted for the effect of abstractions are in Appendix 13.

**Table 4.11 Otaio River catchment sites included in this investigation**

<b>Site Number</b>	<b>River and Site Name</b>	<b>Map Reference</b>
70303	Otaio River at Gorge (Recorder)	J39:454-296
1860	Otaio River at Bluecliffs School	J39:489-313
1861	Otaio River at McAlwees Crossing Road	J39:506-330
1862	Otaio River at Drinnans Bridge	J39:533-326
1866	Otaio River at Eskbank Ford	J39:550-315
2033	Otaio River Tributary at Esk Bank Ford	J39:554-313
1867	Otaio River at Church Hill Road	J39:576-303
1869	Esk Valley Stream at Otaio River Road Bridge	J39:603-289
1868	Otaio River at Grays Crossing	J39:603-291
70301	Otaio River at SH1	J39:654-274

Plots of the regressions with the Otaio at Gorge site for the gaugings at sites further down the main channel are in Appendix 14. Simple linear regressions provide reasonable fits to the non-zero data. Since the regression equations fit flows at least as high as the mean flow at the Gorge, they are used to give estimates of the mean and median flows in addition to 7DMALF estimates at the other sites, as summarised in Table 4.12. All the sites downstream of the Gorge go dry.

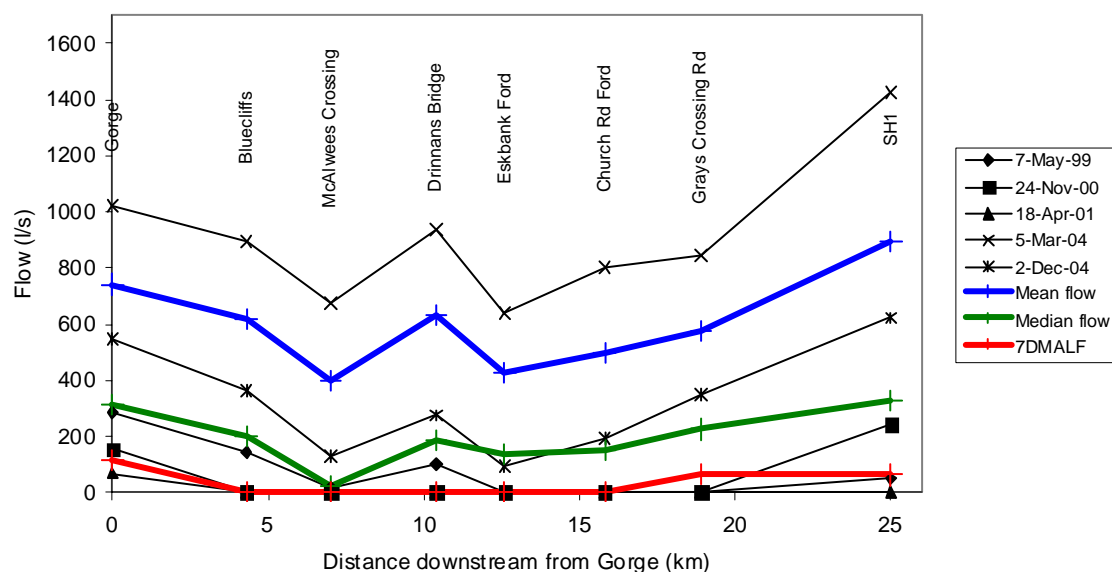
Considerable flow losses occur in the reaches between the Gorge site and McAlwees Crossing (which is the first site that goes dry), such that a flow at the level of the 7DMALF at the Gorge will soon vanish. Below McAlwees Crossing, there is a general recovery of flows, apart from a further loss between Drinnans Bridge and the Eskbank Ford. This pattern is illustrated by the sequences of gaugings plotted in Figure 4.15. See also Sections 4.8.3 and 4.8.4.3.

Mean, median and 7DMALF flow estimates for the Otaio are also given in Table 4.12, and the pattern of losses and gains repeats that estimated for the low flows (Figure 4.15). The sums of gains and losses for the whole river suggest that tributaries downstream of the recorder contribute very little water. The two tributaries investigated have insufficient non-zero gauged flows to form a relationship with the Gorge recorder site; in fact, no flows have been gauged for the Esk Valley Stream which normally appears to be dry at the Otaio River road bridge gauging site.

The channel losses suggest that there will be a modest groundwater resource in the catchment. See also Section 6.2.5.2.

**Table 4.12 Assessment of gains and losses along the Otaio River and estimates of 7DMALF, median and mean flows.**

Site: Otaio at	Number of non-zero gaugings	Flows for 0 flow at McAlwees Crossing	Reach gain or loss	Regression equation $y=mx+c$		7DMALF	Std error of estimate (%)	Reach gain or loss	Median flow	Std error of estimate (%)	Reach gain or loss	Mean flow	Std error of estimate (%)	Reach gain or loss
				m	c									
Gorge		288				117			315			741		
Bluecliffs	6	172	-116	0.989	-113	0		-117	199	31	-116	620	9	-121
McAlwees Crossing	4	0	-172	0.879	-253	0			24	418	-175	398	25	-222
Drinnans Bridge	8	159	159	1.043	-141	0			188	46	164	632	14	234
Eskbank Ford	6	117	-42	0.684	-80	0			135	103	-52	427	33	-205
Church Hill Rd	6	131	14	0.811	-103	0			152	87	17	498	25	71
Grays Crossing Rd	7	204	74	0.817	-31	65	267	65	226	71	74	574	28	76
SH1	30	290	85	1.329	-93	62	228	-3	326	43	99	892	16	317
Sum of gains & losses			2			244					11			151



**Figure 4.16** Concurrent flow gaugings and 7DMALF, mean and median flows for sites on the main stem of the Otaio River downstream from the Gorge water level recorder.

## 4.6 Other rivers

Between the Otaio River in the north and the Waihao River in the south, a number of smaller rivers drain in an easterly direction (Figure 4.1). The Makikihi River and adjacent small creeks drain to the sea, whereas the Hook River and streams further south enter the Wainono Lagoon. Gaugings have been undertaken at the sites indicated in Figure 4.1 to provide flow estimates by correlation.

### 4.6.1 Kohika Stream

Ten gaugings (Appendix 15) on this stream at SH1 were carried out between 2000 and 2005 and had a range from 0 to 25 L/s and a median of 1 L/s. As no abstractions were known to ECan over this period, the flows are assumed to be natural. No useful relationship could be established with other streamflow records.

### 4.6.2 Makikihi River

The Makikihi River has a catchment area of 103 km<sup>2</sup> from its headwaters to the coast, which is larger than the other small streams considered in this section. Gauging sites used in this investigation are:

- 1863 Makikihi River at Teschemaker Valley Road, map reference J40:581-200
- 1864 Teschemaker Creek at Teschemaker Valley Road, map reference J39:581-201
- 1865 Makikihi River at SH1 Bridge, map reference J40:625-183

The Makikihi River flow at SH1 has been gauged only twice and was dry the other times it was visited. In order to obtain an understanding of the flow regime at this site and the flow loss above this site, the river needs to be gauged here when the flows in the Waihao at McCulloughs are between 1000 and 4000 L/s, or the flows in the Otaio at Gorge between 150 and 1200 L/s. The two upstream sites appear to have perennial flows.

Lists of the gaugings for the two perennial sites are presented in Appendix 16. The surface water and groundwater abstractions affecting the gauging sites are listed in Appendix 17 and the naturalised gaugings in Appendix 18. With just four concurrent gaugings, one being well above mean flow, regression with the Otaio at Gorge site is not possible; more gaugings could profitably be undertaken at the two Makikihi sites concurrently with the Otaio site to investigate this relationship. The gaugings are plotted against the Waihao River at McCulloughs Bridge flows (Appendix 19). These are log-log plots (to accentuate the low flows). Note the log-log regression relationship used; the multiplicative standard errors are likely to be large. For the interim, the Waihao equations are used to predict the flow statistics in Table 4.13.

**Table 4.13 Estimates of 7DMALF, median and mean flow for the two upstream sites on the Makikihi River catchment**

Site	Number of gaugings	Regression equation $y=mx^c$		Adj $R^2$	Standard Error of Equation	7DMALF	Median flow	Mean flow
		m	c					
Teschemaker Creek	7	0.097	0.9084	0.78	0.47	21	73	172
Makikihi at Teschemaker Valley Rd	10	0.0122	1.2592	0.93	0.37	21	118	389

The loss to SH1 is too difficult to quantify due to the log-log regression relationship used and the lack of information for the SH1 site.

#### 4.6.3 Makikiki-Hook Creeks

Several unnamed lowland creeks drain into the Hook swamp near the coast between the Makikihi River and the top of the Wainono Lagoon (Appendix 20). Gaugings on the Hook Drain leading from this swamp to the Wainono Lagoon range between zero and 69 L/s and do not appear to correlate well with any of the sites with flow recorders. It is thought that these water bodies drain surplus rainfall runoff when the groundwater is high.

#### 4.6.4 Hook River

Also draining the eastern faces of the Hunters Hills, the Hook River is similar to the Makikihi, but with a lesser catchment area (71 km<sup>2</sup>). There are two gauging sites in the headwaters used in this investigation:

- 70701 Hook River at Upstream Intake, map reference J40:492-161
  - 70702 Hook River Tributary at Gunns Bush, map reference J40:498-143
- The gaugings for these sites are listed in Appendix 21.

In 2001 a water level recorder was established on the downstream end of the Hook River at Hook Beach Road (site number 70703, map reference J40:631-131, catchment area to recorder 70 km<sup>2</sup>), primarily to measure inflows into the lagoon. There are a number of surface and groundwater takes in the lowland region.

Flows recorded at the Hook Beach Road recorder for 2001-2004 are plotted in Figure 4.13 where they are compared with the Otaio River at Gorge flows. Summer and autumn flows as low as 10 L/s are a residual flow after abstractions for irrigation. However, at other times, for example for much of 2001, the flow is quite similar to the Otaio site. Because of the effects of

surface and groundwater abstractions, which can exceed 50 L/s (Appendix 22), the naturalised Hook flows are used to assess flow statistics (Appendix 23).

Regressions with the Otaio River at Gorge flows are presented in the plots in Appendix 24. Estimates of flows statistics for the three Hook River sites are summarised in Table 4.14. The estimates, particularly for the Upstream Intake site where a log-log regression is used, are approximate, but the mean (499 L/s) for the Beach Road recorder site is comparable with the mean of 380 L/s from the four years of record with allowance for the influence of the abstractions.

**Table 4.14 Flow statistics for three sites in the Hook River catchment based on statistics for the Otaio River (Table 4-10)**

Site	No. of Gaugings	Regression Equation	Adjusted R <sup>2</sup>	Std Error of Equation	Flow statistics (L/s) and Standard Error (SE) of Estimate					
					7DMALF	% SE	Median	% SE	Mean	% SE
Hook at Hook Beach Rd (recorder)	7	$y = 0.744x - 29.6$	0.90	40	57	91	205	32	522	27
Hook U/S Intake	52	$y = 0.858x^{0.787}$	0.78	1.46 (Fact. SE*)	36	-	79	-	156	-
Hook Trib. at Gunns Bush	7	$y = 0.0714x + 6.9$	0.89	3.6	15	26	29	14	60	13

\*Fact. SE is factorial standard error.

#### 4.6.5 Wainono Lagoon inflows

Several unnamed watercourses and Waituna Stream drain into the Wainono Lagoon. On a number of runs to gauge the flows (all sites being gauged on the same days), nil flows were observed most of the time (Appendix 25). These streams, which will undoubtedly flow in response to storms, are not considered further.

#### 4.6.6 Waimate Creek

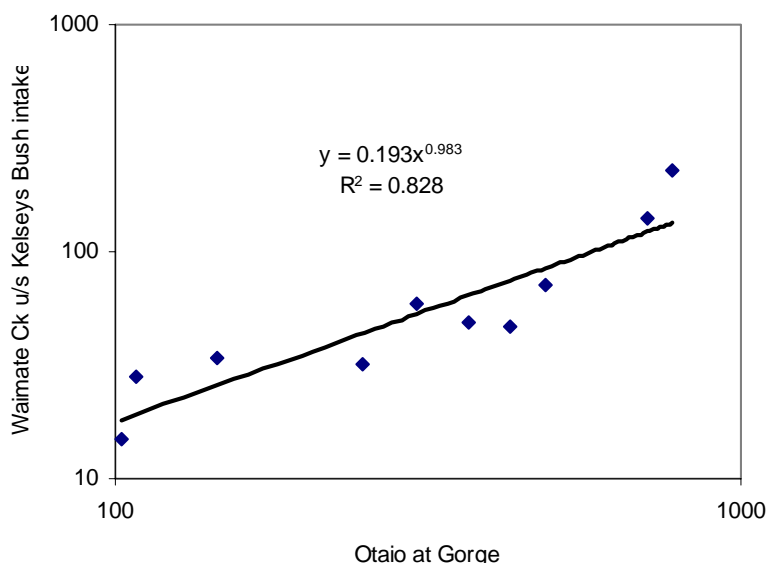
Waimate Creek catchment (area 78 km<sup>2</sup>) includes a portion of the southern Hunters Hills inland from Waimate and drains eastwards into the Dead Arm of the Wainono Lagoon (Figure 4.1). Only one site on Waimate Creek had sufficient gaugings to be used in this investigation, that site being Waimate Creek at Kelseys Bush Top Intake (site number 70806, map reference J40:486-105, site also known as Waimate Creek at Upstream Waimate Intake). The gaugings for this site are listed in Appendix 26. Estimations and gaugings for other sites within the catchment are also listed in Appendix 26. Estimated abstractions affecting gauging sites are listed in Appendix 27 and the naturalised gaugings listed in Appendix 28.

Flow at the Kelseys Bush Top Intake site is almost perennial, though zero flow was noted at this site on 25 March and 8 April 1998. A resource consent to take 26.3 L/s of water for Waimate township's water supply from just below this site expired in 2001 and the water supply is now taken from groundwater. Flow in the creek at SH1 and downstream (e.g. at Meyers Road) (Appendix 26) is intermittent, usually dry.

A feature of Waimate Creek is that 2 km downstream from SH1 is a long-abandoned concrete water level recording tower. Why was such a structure placed on a stream that normally has zero flow? The explanation, according to Mr J. R. Waugh of Timaru (Pers.

Comm. 2005), a hydrologist formerly with the South Canterbury Catchment Board, is not to do with water resources. Rather, a sequence of floods in the district in the late 1940s and early 1950s prompted action by the newly formed Soil Conservation and Rivers Control Council. One local action was for the then Ministry of Works to install a water level recorder in 1954. The recorder was housed in a standard concrete recorder tower, as replicated at many other sites around the country. Floods subsequently occurred infrequently, priorities changed, the recorder was removed, but the tower remains. Some high flow gaugings for this site dating from the 1950s are listed in Appendix 26 but have not been used in analysis.

Correlations of flows for Waimate Creek at Kelseys Bush Top Intake with Otaio River at Gorge flows are presented in Figure 4.16 (ignoring the two days from a drought period in March & April 1998 with zero flows and a pair of gaugings for 4 February 2004 that were clearly erratic). Flow statistics predicted for the site are given in Table 4.15.



**Figure 4.17** Regression plot of gaugings for Waimate Creek at Kelseys Bush Top Intake and Otaio River at Gorge flow

**Table 4.15** Estimates of 7DMALF, median and mean flow for Waimate Creek at Kelseys Bush Top Intake using the log-log regression equation as in Figure 4-12. The factorial standard error for this equation is 1.42

Flow statistic (L/s)	Waimate Creek at Kelseys Bush Top Intake
7DMALF	21
Median flow	55
Mean flow	128

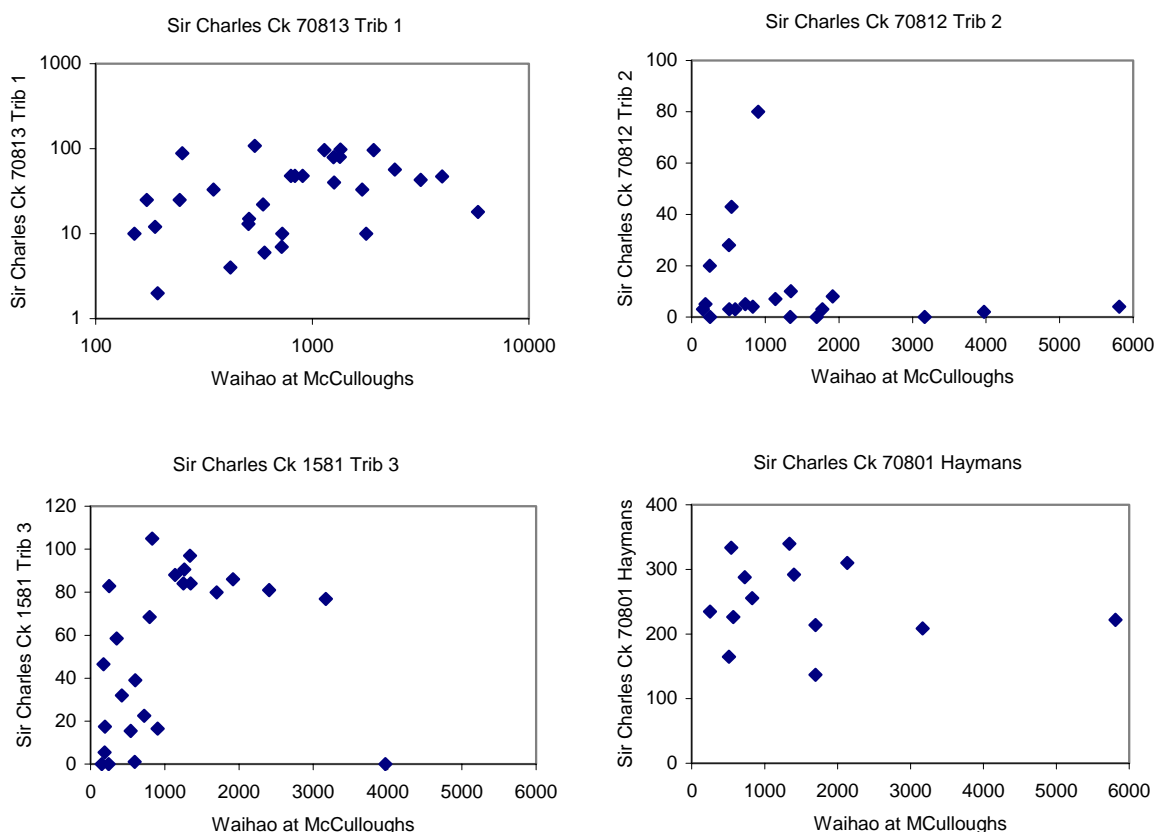
#### 4.6.7 Sir Charles Creek

Sir Charles Creek (catchment area 14 km<sup>2</sup>) is a lowland spring-fed stream to the south of Waimate Creek that enters the Wainono Dead Arm approximately mid-way between the Waihao Box and the Wainono Lagoon. The main gauging site on this stream is approximately 2 km upstream of the Dead Arm at Haymans Road (site number 70801, map reference J40:641-050). In addition, there are gaugings for three upstream tributaries:

70813 Sir Charles Creek Trib 1 at Lindsays Road, map reference J40:627-049  
 70812 Sir Charles Creek Trib 2 at Lindsays Road, map reference J40:632-035  
 1581 Sir Charles Creek Trib 3 at Lindsays Road, map reference J40:633-033

The gauging data for these sites are listed in Appendix 29. The estimated abstractions affecting these site are listed in Appendix 30, and the naturalised gaugings are listed in Appendix 31. Sir Charles Creek is dry above Hannaton Road.

Gaugings plotted against the naturalised flows for the Waihao at McCulloughs Bridge are presented in Figure 4.17. No correlations are apparent. The plots do however display the range of flows at the sites. Tributary 1 has some extremely low flows and Tributaries 2 and 3 have a number of occasions with zero flows and for practical purposes, the 7DMALF for all three tributary sites can be taken as zero.



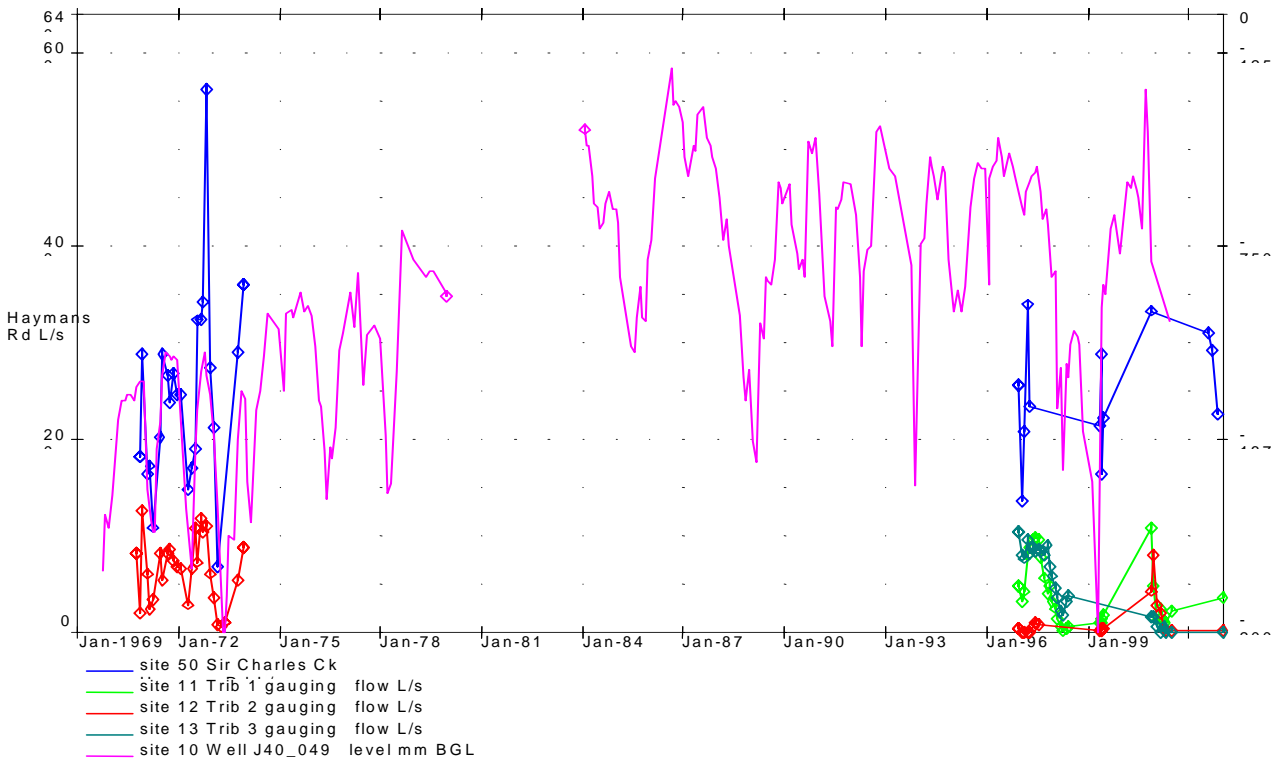
**Figure 4.18 Concurrent gaugings for Sir Charles Creek gauging sites and Waihao at McCulloughs flows**

Figure 4.18 compares the gaugings with well levels read at monthly intervals for well J40/0049 which is approximately 1 km from the Haymans Road gauging site. The plot confirms, at least for the group of gaugings for 1970-1973, that the flows are closely related to the groundwater levels. There is a gap of 13 years to a second group of gaugings for 1996-2002. This second group is somewhat sparse and no clear relationship with the groundwater levels is apparent.

Median values of the gaugings for the four sites are given in Table 4.16. This tabulation suggests that much of the Haymans Road flow originates downstream of the tributaries.

**Table 4.16 Medians of gaugings for four sites on Sir Charles Creek**

Site	Median of gaugings
Sir Charles Ck Trib 1	33
Sir Charles Ck Trib 2	4
Sir Charles Ck Trib 3	47
Sir Charles Ck at Haymans Rd	235



**Figure 4.19 Gaugings for Sir Charles Creek at Haymans Rd and three tributaries compared with monthly well levels for well J40\_049**

## 4.7 Regional water balance

The normalised mean annual flows for the three main secondary sites together with the mean annual rainfalls for the catchments upstream of these sites enable simple water balances to be deduced. With the rainfalls estimated from the map of rainfall contours Figure 2.1, the results are summarised in Table 4.17. In this table mean annual actual evapotranspiration is estimated as the difference between mean annual rainfall and runoff. The location of the three water level recorders in confined valley sections with little underlying sediments supports the assumption of minimal loss to groundwater. Some losses are expected for the Hook catchment above the Hook at Hook Beach Road recorder and it is not included here. Note that the rainfalls in the table have been multiplied by 1.07 to correct for systematic error in rainfalls measured with standard gauges standing 305 mm above ground level (Sevruk, 1982).

**Table 4.17 Mean annual evapotranspiration as estimated from the difference between mean annual rainfall and mean annual runoff.**

Recorder site	Normalised mean annual runoff (flow/time/area) (mm)	Annual mean rainfall (mm)	Annual mean evapotranspiration (mm)
Pareora at Huts	298	836	538
Waihao at McCulloughs Bridge	246	803	557
Otaio at Gorge	497	993	496

## 4.8 Seven-day mean annual low flow and mean flow mapping

### 4.8.1 Introduction

The natural flow statistics in the preceding sections form the basis for the construction of the seven-day mean annual low flow (7DMALF) and mean flow isohydral maps for the Pareora to Waihao study region. Water resource mapping assists in providing estimates of the water resources for tributaries where there is no information. This mapping is part of a larger project to map the 7DMALFs and mean flows for the entire Canterbury region.

### 4.8.2 Methodology

The estimated natural 7DMALF and mean values (L/s) are divided by the catchment area above the water level recorder or gauging site. This then gives a specific yield for the catchment in terms of litres per second per square kilometre (L/s/km<sup>2</sup>). Specific yield contours across all the catchments are accordingly drawn, integrated (using a GIS [Geographic Information System] program) and adjusted until generated flows balance those at known points. The target percentage difference between the values estimated from regression analysis and those calculated from the resulting contour map is less than plus or minus 5%. Estimated gains and losses along the reaches of the main river channels are also mapped.

### 4.8.3 Results

Details of the regression analyses undertaken to calculate the 7DMALF and mean flows for each sub-catchment (with data available) in the region are given in the above Sections 4.3 to 4.6. Estimates of specific yield based on these values and the catchment area are given in Table 4.18 and Table 4.19 for the 7DMALFs and mean flows respectively. The 7DMALF and mean flow values calculated from the specific yield contours are also provided in these tables, along with the percentage difference between the estimated values (from regression analysis) and the integrated mapped values. Estimated gains and losses between sites are given in Table 4.20 and 4.21 for the 7DMALF and mean flow respectively. These have been taken into consideration when calculating the percentage difference between the estimated values and the integrated mapped values. Losses and gains are calculated on a per sub-catchment basis, therefore not compounding the differences between the estimated (from the regression analyses) and calculated (from the map) flows of upstream sites where no gains or losses are suspected. In some instances it is impossible for water to be lost or gained along the whole reach between gauging sites due to the underlying geology (see Figure 3.1). In these cases the loss or gain is represented as just occurring where it is most likely in the reach. If this location is not known the loss or gain is shown to occur between the gauging sites. The results are considered in the discussion section 4.8.4.

Figure 4.19 shows the mapped 7DMALF specific yield contours for the region along with lines indicating gains and losses along the main channels (units being L/s/km). Figure 4.20 shows the same for the mean flows.

The specific yield contours and gain and loss lines for both the 7DMALF and mean flow maps are stored as GIS layers:

```
Q:\GISdata\Nat_Res\SWater\7DayFlow\Pareora_WaihaoMALFCont
Q:\GISdata\Nat_Res\SWater\7DayFlow\Pareora_WaihaoMALFgain_loss
Q:\GISdata\Nat_Res\SWater\MeanFlows\Pareora_WaihaoMeanCont
Q:\GISdata\Nat_Res\SWater\MeanFlows\Pareora_WaihaoMeangain_loss
```

**Table 4.18 Sub-catchment specific yields and 7DMALF estimates compared with the mapping results**

Sub-Catchment	Catchment Area (km <sup>2</sup> )	Specific Yield (L/s/km <sup>2</sup> )	Estimated 7DMALF from Regression Analysis (L/s)	Integrated 7DMALF from Mapped Contours (L/s)	Percentage Difference
<b>PAREORA CATCHMENT</b>					
Pareora River at Upper Gorge	62.6	2.3	143	144	1
Pareora River at Gorge Rd Bridge	66.5	2.1	141	147	4
Pareora River at Huts (Recorder)	423.7	1.6	659	648	-2
White Rock River at U/S Nimrod Stm Confl	11.4	4.1	47	46	-2
Nimrod Stream at Backline Rd Bridge	6.5	3.5	23	23	0
Matata Creek at Backline Rd	6.2	3.2	20	19	-5
White Rock River at Second Bridge	33.5	2.9	98	102	4
White Rock River at First Bridge	48.4	2.8	137	141	3
Motukaika Stream at Backline Rd Bridge	13.2	4.5	59	58	-2
Elder Stream at Backline Rd Bridge	16.7	4.8	80	80	0
Pareora River Sth Branch at Timaunga Rd	47.7	2.6	122	121	-1
Pareora River Sth Branch at Golf Links Rd	81.1	2.8	224	216	-4
Pareora River Sth Branch at Pareora Gorge Rd	101.5	1.7	171	216-45=171 <sup>1</sup>	0
Taiko Stream at Pareora Road Bridge	38.3	0.0	0	0	
Gordons Stream at Holme Station Bridge	31.0	0.0	0	0	
<b>WAIHAO CATCHMENT</b>					
Waihao Nth Branch at Kaiwarua Footbridge	124.3	2.0	247	254	3
Waihao Nth Branch at Waihao Forks	217.8	1.4	305	316	4
Waihao Sth Branch at Pentland Hills	68.4	0.4	24	25	4
Waihao Sth Branch at Waihao Forks	247.5	0.1	31	39-8=31 <sup>2</sup>	0
Waihao River at McCulloughs (Recorder)	483.8	0.8	377	354+5=359 <sup>3</sup>	-5
Buchanans Creek at Fletchers Farm (Recorder)	15.4	15.1	233 <sup>4</sup>	0	
<b>OTAIO CATCHMENT</b>					
Otaio River at Gorge (Recorder)	47.0	2.5	117	118	1
<b>MAKIKIHI CATCHMENT</b>					
Teschemaker Creek at Teschemaker Valley Rd	28.8	0.7	21	5+15=20 <sup>5</sup>	-5
Makikihi River at Teschemaker Valley Rd	55.6	0.4	21	21	0
<b>HOOK CATCHMENT</b>					
Hook River at Upstream Intake	12.0	3.0	36	36	0
Hook River Tributary at Gunns Bush	5.3	2.8	15	15	0
Hook River at Hook Beach Rd (Recorder)	70.2	0.8	57	59	4
<b>WAIMATE CATCHMENT</b>					
Waimate Creek at U/S Kelseys Bush Intake	8.3	2.5	21	20	-5

Notes:

- 1 - 45 L/s likely lost to gravels (Quaternary sediments) between Golf Links Road and Pareora Gorge Road.
- 2 - Possible loss of 8 L/s above site, regained between Forks and McCulloughs.
- 3 - Possible spring inflow of approximately 5L/s.
- 4 - All from springs - re-emergent flow from Waihao River.
- 5 - Extra water in here can come from springs carrying water from outside the catchment - see Appendix 36 for springs.

**Table 4.19 Sub-catchment specific yields and mean flow estimates compared with the mapping results**

Sub-Catchment	Catchment Area (km <sup>2</sup> )	Specific Yield (L/s/km <sup>2</sup> )	Estimated Mean from Regression Analysis (L/s)	Integrated Mean from Mapped Contours (L/s)	Percentage Difference
<b>PAREORA CATCHMENT</b>					
Pareora River at Upper Gorge	62.6	17.9	1124	1146	2
Pareora River at Gorge Rd Bridge	66.5	23.2	1541	1177	-24
Pareora River at Huts (Recorder)	423.7	9.4	4001	3951	-1
White Rock River at U/S Nimrod Stm Confl	11.4	Insufficient data		212	?
Nimrod Stream at Backline Rd Bridge	6.5	Insufficient data		118	?
Matata Creek at Backline Rd	6.2	Insufficient data		90	?
White Rock River at Second Bridge	33.5	Insufficient data		508	?
White Rock River at First Bridge	48.4	Insufficient data		662	?
Motukaika Stream at Backline Rd Bridge	13.2	24.9	328	235	-28
Elder Stream at Backline Rd Bridge	16.7	Insufficient data		247	?
Pareora River Sth Branch at Timaunga Rd	47.7	11.1	528	527	0
Pareora River Sth Branch at Golf Links Rd	81.1	9.6	782	885	13
Pareora River Sth Branch at Pareora Gorge Rd	101.5	10.0	1011	930	-8
Taiko Stream at Pareora Road Bridge	38.3	Insufficient data		83	?
Gordons Stream at Holme Station Bridge	31.0	Insufficient data		35	?
<b>WAIHAO CATCHMENT</b>					
Waihao Nth Branch at Kaiwarua Footbridge	124.3	13.0	1610	1723	7
Waihao Nth Branch at Waihao Forks	217.8	11.8	2578	2494	-3
Waihao Sth Branch at Pentland Hills	68.4	9.8	670	661	-1
Waihao Sth Branch at Waihao Forks	247.5	4.7	1169	1168	0
Waihao River at McCulloughs (Recorder)	483.8	7.8	3775	3714	-2
Buchanans Creek at Fletchers Farm (Recorder)	15.4	23.2	355 <sup>1</sup>	0	
<b>OTAIO CATCHMENT</b>					
Otaio River at Gorge (Recorder)	47.0	15.8	741	742	0
Esk Valley Stream at Otaio River Road Bridge	29.0	Insufficient data		31 <sup>2</sup>	?
<b>MAKIKIHI CATCHMENT</b>					
Teschemaker Creek at Teschemaker Valley Rd	28.8	6.0	172	105+65=170 <sup>3</sup>	-1
Makikihi River at Teschemaker Valley Rd	55.6	7.0	389	402	3
<b>HOOK CATCHMENT</b>					
Hook River at Upstream Intake	12.0	13.0	156	155	-1
Hook River Tributary at Gunns Bush	5.3	11.3	60	62	3
Hook River at Hook Beach Rd (Recorder)	70.2	7.4	522	514	-2
<b>WAIMATE CATCHMENT</b>					
Waimate Creek at U/S Kelseys Bush Intake	8.3	15.4	128	124	-3

Notes:

1 - All from springs - re-emergent flow from Waihao River.

2 - Likely lost to downstream gravels of Esk Valley Stream.

3 - Extra water in here can come from springs carrying water from outside the catchment - see Appendix 36 for springs.

**Table 4.20 Estimated gains and losses at 7DMALF for the catchments of the study region**

Reach	Estimated 7DMALF (L/s)	Integrated 7DMALF (L/s)	Loss or Gain	Flow Difference (L/s)	Reach Length <sup>4</sup> (km)	Loss/Gain Rate (L/s/km)
<b>PAREORA CATCHMENT</b>						
MAIN CHANNEL:						
Gorge Rd Bridge to Scotts Bend			Loss	-10 <sup>1</sup>	4.5	-2.2
Scotts Bend to Cannington			Loss	-65 <sup>1</sup>	2.1	-30.4
Cannington to Cave Pareora Rd			Loss	-50 <sup>1</sup>	4.2	-11.9
Flow gains and losses below Lower Gorge from Table 4-5:						
Lower Gorge to Evans Crossing	494	302	Gain	192	1.8	106.7
Evans Crossing to Huts	659	665 <sup>2</sup>	Loss	-6	2.0	-3.0
Huts to Purves Crossing	561	659	Loss	-98	1.7	-57.6
Purves Crossing to Holme Station	382	561	Loss	-179	1.7	-105.3
Holme Station to Talbots	346	382	Loss	-36	1.4	-25.7
Talbots to Jefcoates	149	346	Loss	-197	0.7	-281.4
Jefcoates to Brasells Bridge	142	149	Loss	-7	2.8	-2.5
Brasells Bridge to Midgleys Track	130	142	Loss	-12	3.7	-3.2
Midgleys Track to SH1	286	130	Gain	156	3.0	52.0
SH1 to Railway Bridge	353	286	Gain	67	1.0	67.0
SOUTH BRANCH:						
Golf Links Rd to Pareora Gorge Rd	171	216	Loss	-45	8.2	-5.5
<b>WAIHAO CATCHMENT</b>						
SOUTH BRANCH:						
Pentland Hills to Waihao Forks	31	39	Loss	-8	4.2	-1.9
Waihao Forks to McCulloughs	377	354	Gain	13 <sup>3</sup>	3.5	3.7
Flow gains and losses below McCulloughs Bridge from Table 4-9:						
McCulloughs to D/S McCulloughs	314	377	Loss	-63	0.3	-210.0
D/S McCulloughs to Elliots	377	314	Gain	63	4.6	13.7
Elliots to Wains	96	377	Loss	-281	3.8	-73.9
Wains to SH1	0	96	Loss	-96	3.4	-28.2
BUCHANANS CREEK:						
Willowbridge Rd to Fletchers Br.	233	0	Gain	233	2.3	99.3
<b>OTAIO CATCHMENT</b>						
Gorge to Bluecliffs	0	118	Loss	-118	3.8	-31.1
Flow gains and losses below Bluecliffs from Table 4-12:						
Church Rd to Grays	65	0	Gain	65	2.8	23.2
Grays to SH1	62	65	Loss	-3	5.4	-0.6
<b>MAKIKIHI CATCHMENT</b>						
TESCHEMAKER CREEK:						
Above Teschemaker Valley Rd	21	5	Gain	15 <sup>3</sup>	12.4	1.2

## Notes:

1 - Likely some water lost in upstream reaches already re-emerged above the Lower Gorge, therefore estimates from section 4.3.4 (paragraph 6) are mapped.

2 - Includes South Branch flow (with loss subtracted).

3 - See discussion.

4 - In some instances it is impossible for water to be lost or gained along the whole reach between gauging sites due to the underlying geology (see section and figure 3.1). In these cases the loss or gain is represented as just occurring where it is most likely in the reach. If this is not known the loss or gain is shown to occur between the gauging sites.

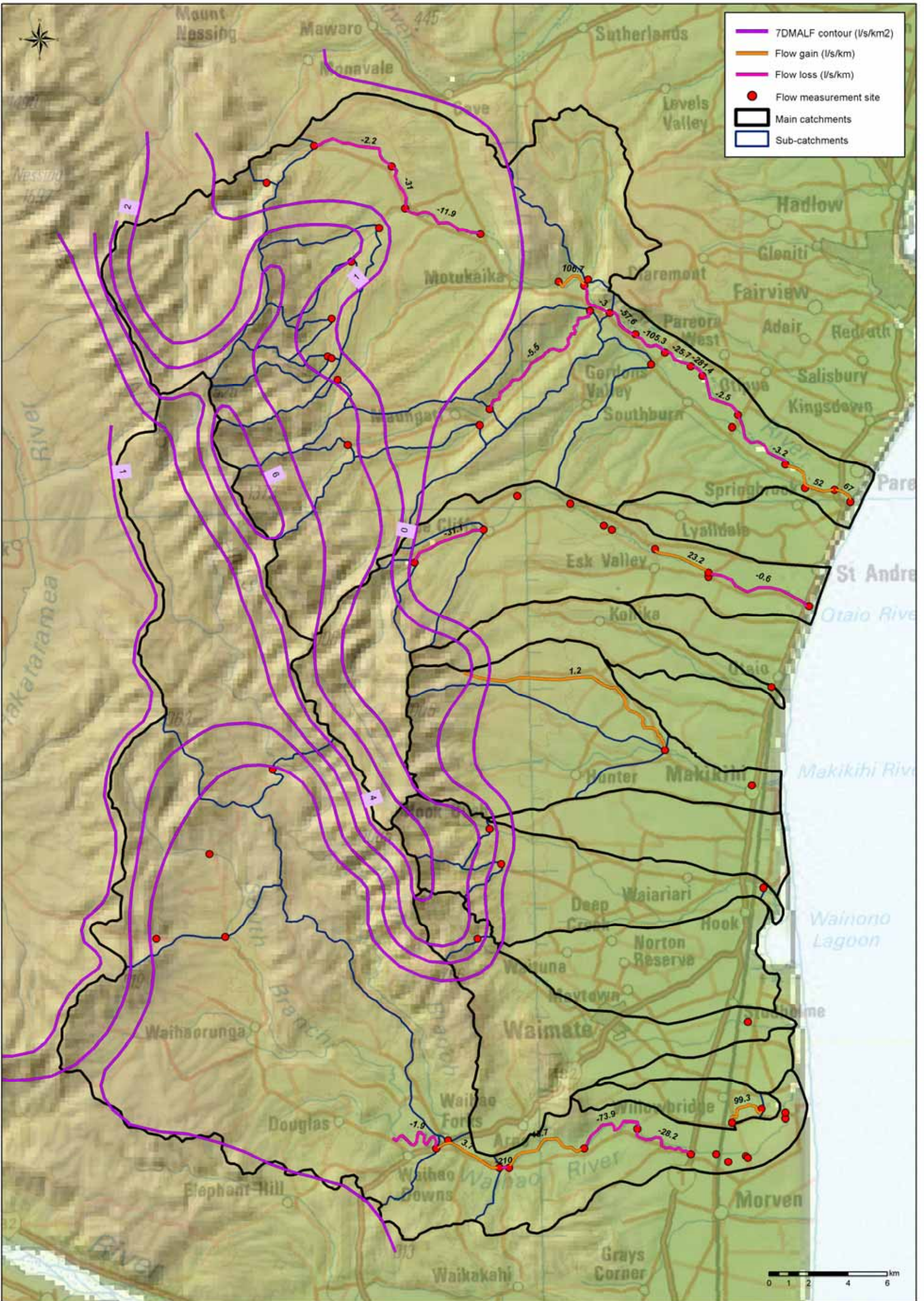


Figure 4.20 Mapped 7DMALF specific yield (L/s/km<sup>2</sup>) contours with lines indicating gains and losses (L/s/km) along the main channels

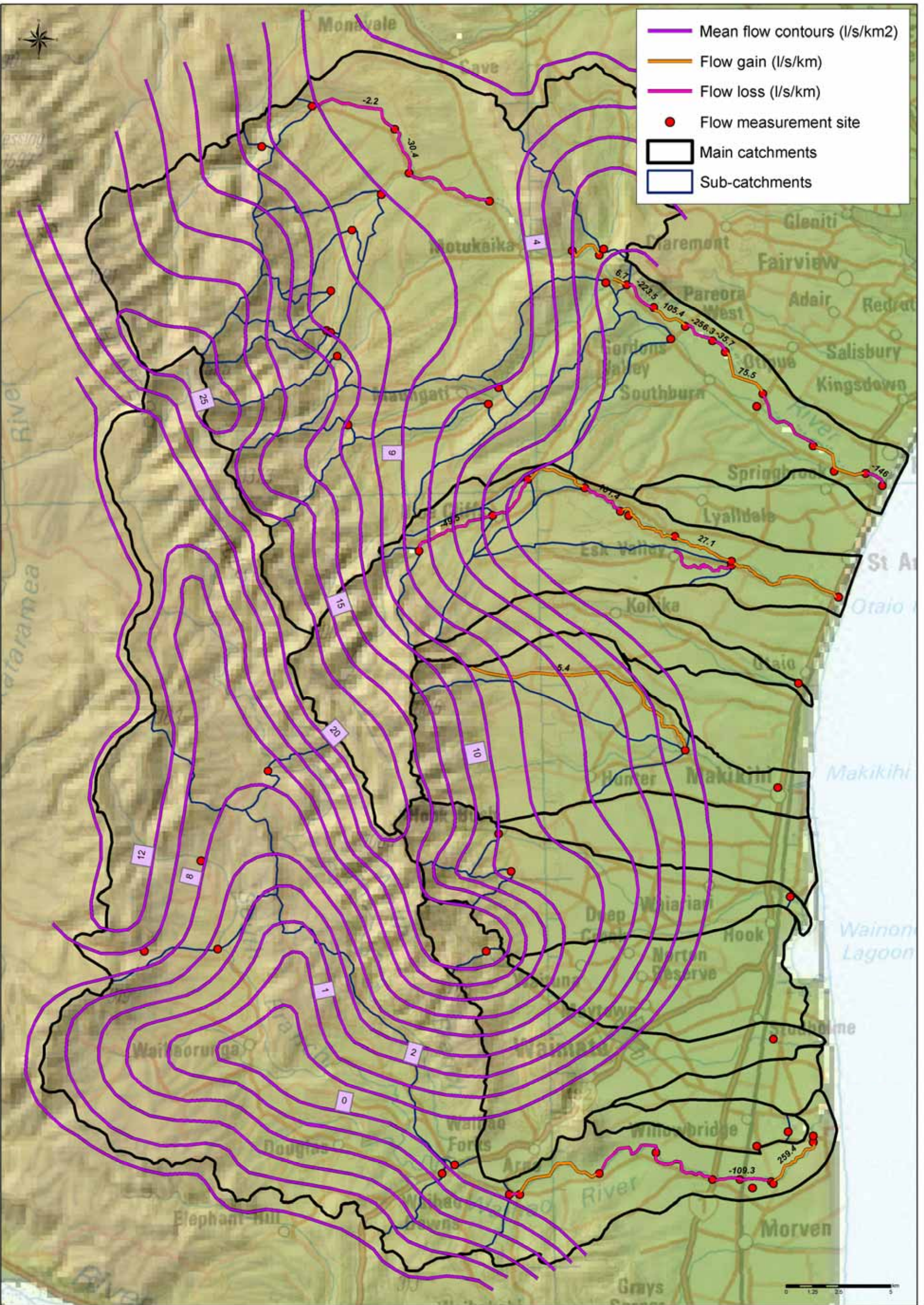


Figure 4.21 Mapped mean flow specific yield (L/s/km<sup>2</sup>) contours with lines indicating gains and losses (L/s/km) along the main channels

**Table 4.21 Estimated gains and losses at mean flow for the catchments of the Pareora to Waihao region**

Reach	Estimated Mean (L/s)	Integrated Mean <sup>1</sup> (L/s)	Loss or Gain	Flow Difference (L/s)	Reach Length <sup>5</sup> (km)	Loss/Gain Rate (L/s/km)
<b>PAREORA CATCHMENT</b>						
MAIN CHANNEL:						
Gorge Rd Bridge to Scotts Bend			Loss	-10 <sup>2</sup>	4.5	-2.2
Scotts Bend to Cannington			Loss	-65 <sup>2</sup>	2.1	-31.0
Cannington to Cave Pareora Rd			Loss	-50 <sup>2</sup>	4.2	-11.9
Lower Gorge to Evans Crossing	2863	2732	Gain	131	1.8	72.8
Evans Crossing to Huts	4001	3957 <sup>3</sup>	Gain	4	0.6	6.7
Flow gains and losses below Huts from Table 4-5:						
Huts to Purves Crossing	3624	4001	Loss	-377	1.7	-221.8
Purves Crossing to Holme Station	3805	3624	Gain	181	1.7	106.5
Holme Station to Talbots	3453	3805	Loss	-352	1.4	-251.4
Talbots to Jefcoates	3429	3453	Loss	-24	0.7	-34.3
Jefcoates to Brasells Bridge	3638	3429	Gain	209	2.8	74.6
Brasells Bridge to Midgleys Track	3388	3638	Loss	-250	3.7	-67.6
Midgleys Track to SH1	3888	3388	Gain	500	3.0	166.7
SH1 to Railway Bridge	3745	3888	Loss	-143	1.0	-143.0
<b>WAIHAO CATCHMENT</b>						
SOUTH BRANCH:						
McCulloughs to D/S McCulloughs	3538	3785	Loss	-247	0.3	-823.3
D/S McCulloughs to Elliots	4064	3540	Gain	524	4.6	113.9
Flow gains and losses below Elliots from Table 4-9:						
Elliots to Wains	3433	4064	Loss	-631	3.8	-166.1
Wains to SH1	2742	3433	Loss	-691	3.4	-203.2
SH1 to Crowes	2463	2742	Loss	-279	2.6	-107.3
Crowes to Upstream Bradshaws	3206	2463	Gain	743	2.9	256.2
<b>OTAIO CATCHMENT</b>						
Gorge to Bluecliffs	620	813	Loss	-193	3.9	-49.5
Bluecliffs to McAlwees	398	621	Loss	-223	2.4	-92.9
McAlwees to Drinnans	632	410	Gain	222 <sup>4</sup>	3.1	71.6
Flow gains and losses below Drinnans from Table 4-12:						
Drinnans to Esk Bank Ford	427	632	Loss	-205	2.0	-102.5
Esk Bank Ford to Church Road	498	427	Gain	71	3.1	22.9
Church Rd to Grays	574	498	Gain	76	2.8	27.1
Grays to SH1	892	574	Gain	318	5.7	55.8
ESK VALLEY STREAM:						
Above Otaio River Road Bridge	0	30	Loss	-30	3.8	-7.9
<b>MAKIKIHI CATCHMENT</b>						
Above Teschemaker Valley Road	172	105	Gain	67 <sup>4</sup>	12.4	5.4

## Notes:

1 - Losses and gains are calculated on a per sub-catchment basis, therefore not compounding the differences between estimated and integrated statistics of upstream sites. For example, the integrated mean for the Evans Crossing site (2732 L/s) is the **integrated** mean for just the Evans Crossing catchment (between Lower Gorge and Evans Crossing), 7 L/s, plus the **estimated** mean for the Lower Gorge site (2725 L/s).

2 - Likely some water lost in upstream reaches already re-emerged above the Lower Gorge, therefore estimates from section 4.3.4 (paragraph 6) are mapped.

3 - Includes South Branch flow and an integrated estimate of the Taiko flow.

4 - See discussion.

5 - In some instances it is impossible for water to be lost or gained along the whole reach between gauging sites due to the underlying geology (see section and figure 3.1). In these cases the loss or gain is represented as just occurring where it is most likely in the reach. If this is not known the loss or gain is shown to occur between the gauging sites.

#### 4.8.4 Discussion and recommendations

##### 4.8.4.1 Pareora Catchment

The Pareora River at Huts record site has proved useful for specific yield flow mapping. In seven years time the recorder will have been operating for 30 years (the minimum length required for a primary site). The Pareora catchment has been gauged at some useful sites in the past and the coverage of gaugings for flow mapping is generally good. However, further gaugings should be carried out in the White Rock River catchment and the upper Pareora River South Branch catchment because the sites within these catchments were mostly gauged before the Huts recorder was operational. It would be desirable to increase the number of gaugings in the upper reaches of the Pareora River main stem (at Gorge Road, Scotts Bend, Cannington Road Bridge and Cave Pareora Road Bridge) in order to get a more accurate understanding of gains and losses. This would enhance the accuracy of the resulting flow estimates and maps.

At 7DMALF the Pareora River catchment below the lower gorge yields no inflows. Taiko Stream and Gordons Stream are both dry at 7DMALF. However, it is possible that there is some yield in the upper part of the Taiko Stream catchment, which could be resolved with further gaugings in the upper reaches. A site on Burnett Stream could also be useful. At mean flow the Pareora River catchment below Huts is considered (from the mapping) to yield no inflows. The Taiko Stream catchment to Pareora Road Bridge has an integrated mean flow of 84 L/s, which is consistent with a known gauged flow of 127 L/s when the Huts flow (5944 L/s) was greater than mean. The Gordons Stream catchment to Holme Station Bridge has an integrated mean flow of 35 L/s, which is consistent with a known gauged flow of 51 L/s when the Huts flow was greater than mean.

While constructing both the 7DMALF and mean flow specific yield contours some difficulty was experienced in balancing the flows in the Pareora River South Branch. At 7DMALF it became evident that there is a loss of flow (45 L/s) between the Golf Links Rd site and the Pareora Gorge Road site. This is consistent with the geology of the reach (see Figure 3.1) where the river flows over Quaternary sediments through which it may lose flow. At mean flow, neither the integrated mean to Golf Links Road nor the integrated mean to Pareora Gorge Road is within +/-5% of the estimated mean. According to local hydrologist Frank Scarf (pers. comm. 2005) there is no evidence to suggest the Craigmere area is a wetter part of the region, therefore higher yield contours around this region in order to align the integrated and estimated flows at Pareora Gorge Road are not justified. Future gaugings in the South Branch at sites underlain by bedrock should be carried out to investigate this further.

The loss in flow for the reach of the Pareora River main stem between Gorge Road Bridge and Lower Gorge was estimated to be 125 L/s. However, given the gain in flow between the Lower Gorge and Evans Crossing, calculated to be approximately 192 L/s at 7DMALF and 131 L/s at mean flow, the 125 L/s is likely to be an underestimate. Bedrock is exposed upstream of the Lower Gorge site so it is likely that some of the water lost in the upper reaches of the Pareora River has already re-emerged before the Lower Gorge site. The loss estimates given in section 4.3.4 for the sites from Gorge Road Bridge to Cave Pareora Road have been included in the mapping.

##### 4.8.4.2 Waihao Catchment

The Waihao River at McCulloughs Bridge recorder site requires only seven more years of record before it can be considered a stand-alone primary site for specific yield flow mapping. The coverage of sites gauged downstream of Waihao at McCulloughs Bridge is good and gains and losses in these reaches can be calculated. The gauging coverage in the upper reaches of the north and south branches of the Waihao River however is poor. Further tributary gaugings carried out in these upper catchments would increase the accuracy of the

flow estimates and resulting maps. In addition, low flows could be affected in the future by increased forestry in the area; therefore it is important that information is collected prior to this occurring.

While constructing the 7DMALF specific yield contours some difficulty was experienced in balancing the flows at the Waihao River at McCulloughs Bridge site considering the low flow contribution from the Waihao River South Branch. From the map integration a gain of 13 L/s over the 3.5 km reach between the Waihao River Forks (where the north and south branches meet) and the McCulloughs Bridge site is estimated. This equates to a gain rate of 3.7 L/s/km. The low flows in the South Branch would suggest that yields in this region are close to zero. It is therefore possible that losses occur within certain reaches of the South Branch. A possible loss (estimated at 8 L/s) has been identified above the Waihao River South Branch at Waihao Forks site where the geological map (Figure 3.1) indicates recent river gravels. In addition, limited well logs indicate gravel thicknesses of between 3 and 8 metres around the Forks gauging site. Any water that is lost above the Forks site most likely re-emerges between the Forks and the main stem at McCulloughs Bridge. In addition to this gain from re-emergent flow above McCulloughs Bridge, there is evidence of spring activity in the vicinity. A spring arises from the greensands and sandstones of the Onekarara Group at Arno (Oborn, 1952). It is possible that the Onekarara Group (which underlies the Waihao River in this vicinity) is also discharging to the river. An additional 5 L/s per second has been estimated to be contributed from this source. Although the combined flow of the re-emergent groundwater and the spring contribution to the McCulloughs Bridge site is only estimated to be 13 L/s (10 L/s less than the estimated 23 L/s gain from integration), the integrated 7DMALF at McCulloughs Bridge is within 5% of the estimated McCulloughs Bridge flow. There is no evidence of losses in the Waihao River North Branch.

Buchanans Creek flows into the Waihao River near the mouth. All the flow in Buchanans Creek is considered to come from springs and re-emergent flow lost in the reaches of the Waihao River between McCulloughs Bridge and SH1.

#### 4.8.4.3 Otaio Catchment

The Otaio River at Gorge recorder site is a useful recorder site due to the lack of takes upstream and, being sited on bedrock, there is no opportunity for water to be lost into gravels. This site has only been operational since 2001, so several more years are required before it can be considered to have representative long-term data.

A number of sites have been gauged down the main stem of the river below the gorge, which provide a good indication of gains and losses. At 7DMALF the Otaio River catchment is considered to yield no inflows below the Gorge recorder site. At 7DMALF all flow is lost between the Gorge and Bluecliffs School sites and some re-emerges between Church Hill Road and Grays Crossing. At mean flow the catchment is considered to yield no further inflows below Drinnans Bridge. The gain/loss pattern at mean flow is similar to that at 7DMALF with two exceptions: there is a gain between McAlwees Crossing Road and Drinnans Bridge, and down the lower reach of the river the flow begins to re-emerge between Esk Bank Ford and Church Hill Road. The gain in flow between McAlwees Crossing Road and Drinnans Bridge is consistent with the piezometric contours and direction of groundwater flow in the Otaio Valley indicated in Appendix 34.

For Esk Valley Stream, the mean specific yield mapped contours indicate that the headwaters of this catchment yield approximately 30 L/s. A site on this stream at the Otaio River Road Bridge has been visited in order to gauge the flow several times and the stream has not been flowing at these times (including one time when the Otaio River at Gorge flow was well above mean). It is likely that any flow in the upper reaches of Esk Valley Stream is lost to gravels in the lower reaches. This has been indicated on the map.

#### 4.8.4.4 Other Rivers

It was difficult to construct the 7DMALF and mean specific yield contours for the Makikihi River in such a way as to achieve a balance between the estimated and integrated flow for Teschemaker Creek at Teschemaker Valley Road. The water in this creek is likely to be augmented by springs carrying water from outside the catchment. See Appendix 36 for the location of springs.

The upper, foothills parts of the Hook River and Waimate Creek catchments apparently yield a comparatively high quantity of water at 7DMALF. The 7DMALF specific yields above Hook River at Upstream Intake, Hook River Tributary at Gunns Bush and Waimate Creek at Upstream Kelseys Bush Intake are consistently similar. This, in conjunction with the rainfall contour map, confirms that this is likely to be a comparatively wet part of the region. However, the 7DMALF specific yield for each of the catchments drops to zero beyond the foothills.

Further gaugings over a range of flows (particularly median and mean flow) in the Makikihi, Hook and Waimate catchments could be useful to ascertain gains and losses in the downstream reaches of these rivers.

## 4.9 Summary

This study uses intermittent flow gaugings gathered over a long period from many sites as well as systematic flow records to quantify the naturally occurring water resources of the Pareora–Waihao region, as indicated by the statistics of 7DMALF, mean flow and median flow. The study demonstrates that resources are very limited and in terms of the population serviced by the resources, which includes much of Timaru, it is likely that this region is the most water-deficient of the country.

For the tertiary sites, the low flow estimates are given together with estimates of their standard errors. Some of these are quite large, particularly where log-log regressions are used. In some cases further low flow gaugings would improve the confidence in the estimated flow statistics. The confidence in the estimates needs to be considered when the estimates are used for resource management purposes.

The low flows are a consequence of the relatively low rainfalls over the catchments combined with the lithology, which is generally fairly free draining loess-derived soils. The 7 day mean annual low flow yielded per unit area of catchment (specific 7DMALF) provides a comparative index which is listed in Table 4.22 for river flow records from the study region and some other comparable catchments in the wider Canterbury region. The yields for the catchments studied are less than the values for the catchments that drain foothills of the Southern Alps (e.g. Selwyn, Orari) but are comparable with other Canterbury catchments.

Even without any abstractions, all the streams in the region go dry in their middle to lower reaches where water is lost into unconsolidated gravels, and this severely restricts the value of these reaches as fish and wildlife habitats. Some of this water resurfaces before the rivers reach the coast and some sustains lowland spring-fed streams such as Buchanans Creek and Sir Charles Creek.

**Table 4.22 Comparison of specific 7DMALF for streams in the Pareora-Waihao region compared with a selection of other Canterbury streams**

<b>River &amp; recorder site</b>	<b>Specific 7DMALF (L/s/km<sup>2</sup>)</b>
Pareora at Huts	1.6
Otaio at Gorge	2.5
Waihao at McCulloughs Br.	0.8
Waipara at White Gorge	0.3
Selwyn at Whitecliffs	4.8
Kaituna at Kaituna Valley Rd	0.8
Orari at Gorge	5.4
Rocky Gully	3.3
Hakataramea	1.3
Maerewhenua at Kellys Gully	3.1

## 5 Wainono Lagoon

### 5.1 Introduction

The Wainono Lagoon in South Canterbury lies on the coast between Timaru and Oamaru, due east of Waimate. The average elevation of the lagoon is about 1.0 m above mean sea level (AMSL), at which stage its surface area is 3.7 km<sup>2</sup> and average depth is about 0.5 m. The lagoon is illustrated in Figure 5.1, which shows how the eastern side is separated from the sea by a gravel beach barrier that typically is 50 to 100 m wide and 4 to 5 m AMSL in height.

Kirk and Lauder (2000) classify the Wainono Lagoon as a “Waituna” type lagoon (named after the prominent Southland lagoon) that is essentially a coastal lake. Most of the time, lagoons of this type are closed to the sea and the water is typically brackish or fresh. This distinguishes them from estuaries that are open to the sea and experience prevailing tidal oscillations. Other South Island lagoons of this type are the Wairau Lagoon and Lake Grasmere/Kapara Te Hau in Marlborough, Coopers Lagoon/Muriwai, Lake Ellesmere/Waihora and Washdyke Lagoon in Canterbury.

Typically, they occur on coastlines where the tidal range is less than about 2.0 m, where the coastal line is exposed to an effectively unlimited fetch for wave generation in the Southern Ocean and where the beach sediment is a mix of sand and gravel.

Management of the lagoon, and the possibility of identifying and maintaining a regime of preferred levels, is an issue that has been under consideration for many years. Hall (2003) for example, assessed the effect of establishing an adjustable weir on the Dead Arm that “... would be designed to return the lagoon to a water level of 1 m a.s.l. within a reasonable time after flood-producing rainstorms and coastal storms, so as to avoid excessive and attenuated flooding of farmland around the perimeter of the lagoon and adjacent to the Hook River and coastal drains.” It was concluded that “... a weir on the upper Dead Arm would not achieve its intended purpose during the greater part of any year when daily net evaporation rates exceeded 2-3 mm. This situation arises as a result of the deprivation of balancing inflow from the Dead Arm to the south.” That study was limited by the data available and in particular, it did not have measured flow data for the Dead Arm.

The aim of the Wainono study is to understand the water balance for the lagoon and to investigate further management options, particularly the influence of a weir at Poingdestres with a one-way-valve stopping inflow from the Waihao River or the Dead Arm.

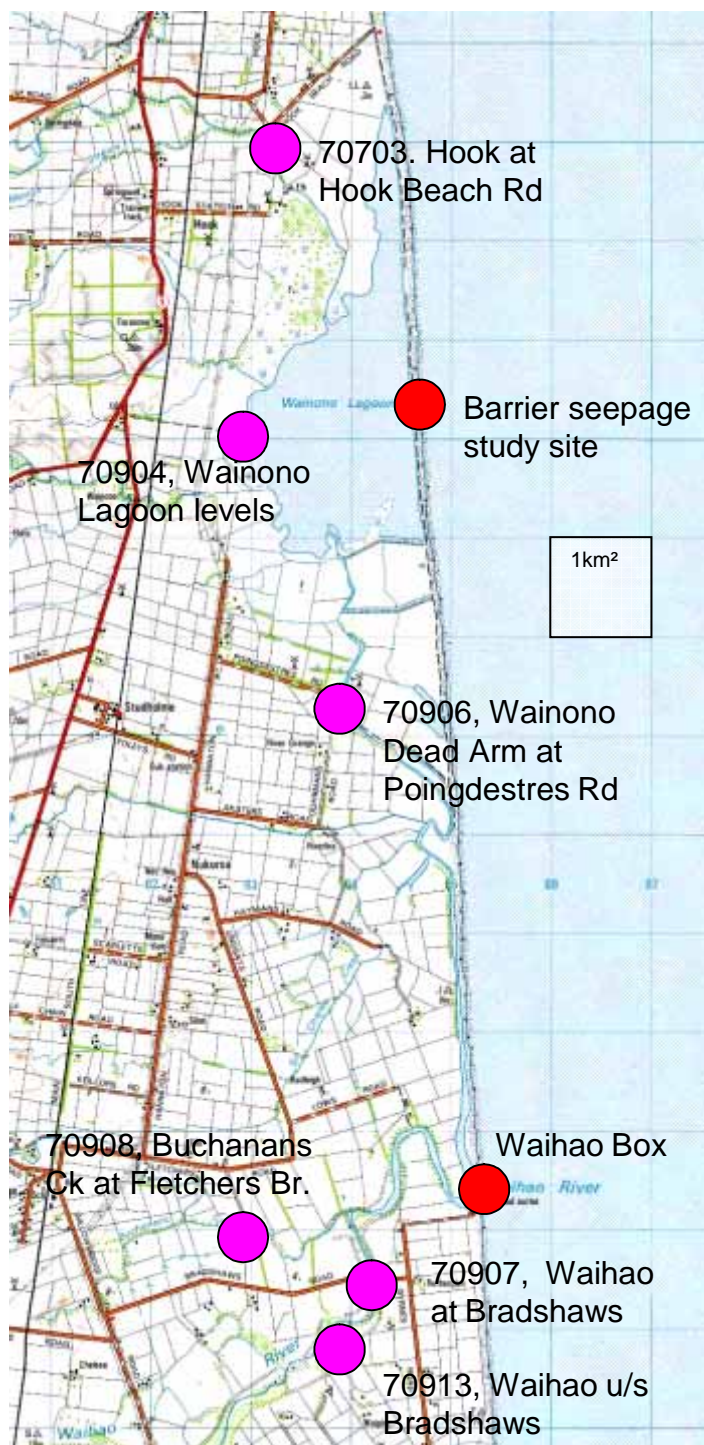


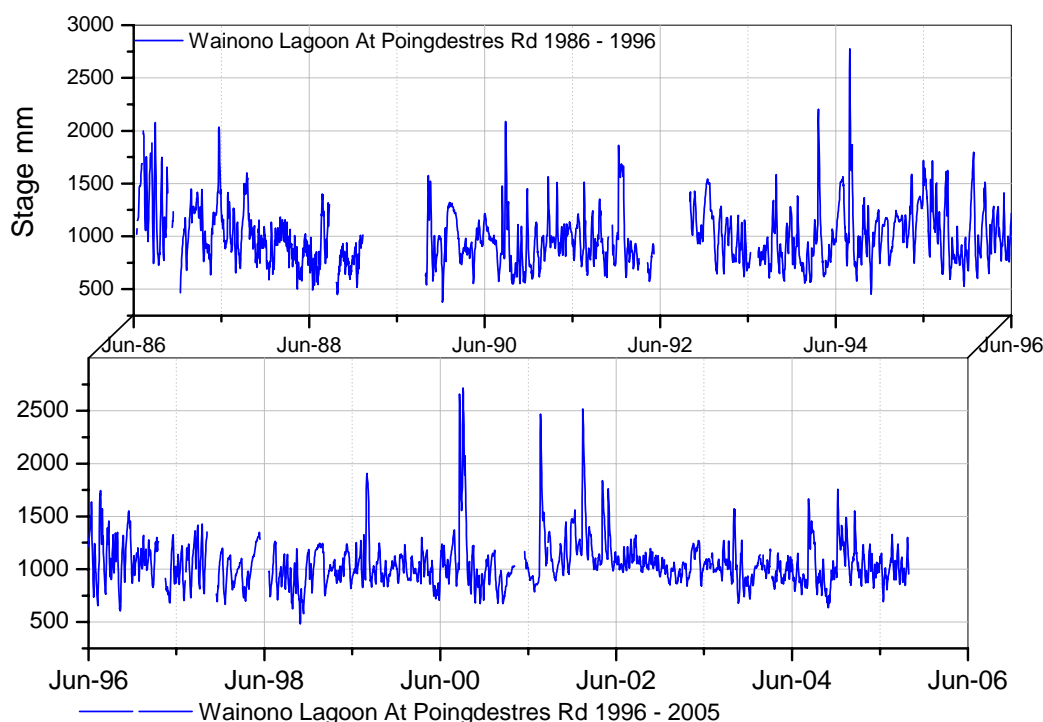
Figure 5.1 Wainono Lagoon NZMS 260 map

### 5.1.1 Description of the Lagoon area

As indicated in Figure 5.1, marshy land separates the Wainono Lagoon from drained productive farmland to the north, west and south. The wetland and the lagoon is an important wildlife habitat and mahinga kai, particularly for eels, that is degraded when the lagoon level drops below 1.0 m AMSL. It is an important link in a chain of lagoons on the east coast of the South Island for migratory birds. Over time, agricultural development of low lying fertile land has impinged on the lagoon boundaries and low levels are preferred by the

farming community to enhance drainage (Kirk & Lauder 2000) (Taylor, Champion & Main 1998).

Periodically, in stormy conditions the sea breaches the coastal barrier and causes extensive flooding of the surrounding farmland. Such an episode occurred in July 2001 (Cope & Young, 2001). Consideration of Figure 5.2, a plot of the lagoon levels for the period 1986 to 2005, shows that the lagoon levels reached in July 2001 were exceeded in July 1994 and September 2000. On these occasions, and in other earlier events (Pemberton, 1980) the Dead Arm at the south end of the lagoon has been blocked by gravel washed in by the high seas. Mechanical clearance has been necessary. Inland retreat of the beach barrier due to ongoing coastal erosion is likely to exacerbate the blocking of the Dead Arm in storms conditions.



**Figure 5.2 Average Daily water level Wainono Lagoon 1986 -2005**

Figure 5.2 indicates that level data from late 2001 are somewhat anomalous in that lower levels (less than 1.0 m AMSL) have been less frequent since then compared with the period before late 2001. The slowly encroaching barrier is constricting the Dead Arm more frequently, restricting the outflows of the Lagoon hence lower Lagoon levels becoming less frequent.

The lagoon is supplied with water from the Hook River, which enters at the northern end, the Hook Drain and the Waituna and other small un-named streams and drains that enter to the western side. A contribution of groundwater to the lagoon is likely given the high groundwater levels around.

The south end of the lagoon is connected to the Waihao River by the “Dead Arm”, a channel about 8 km long running north-south behind the beach barrier. The Waihao River normally flows to the sea through a timber culvert through the barrier beach known as the “Waihao

Box” (Figure 5.3 and Figure 5.4) that was originally constructed early in the 20th century to promote drainage. This culvert is 60 m long, 4.6 m wide and 1.2 m high. The Dead Arm connects to the Waihao at the box site. The Dead Arm also receives water from two streams directly, the Sir Charles Creek and the Waimate Creek when they have flow in them. Buchanans Stream, the most southern of the small streams in the area, connects up to the Waihao River, just before it reaches the Waihao Box.



**Figure 5.3 Entry to the Waihao Box looking north along the Dead Arm**

(Photo: A.I. McKerchar, 30.11.04)

*The Waihao River is to the left, and the sea is to the right across the gravel beach.*

The lagoon normally discharges south to the sea via the Dead Arm and the Waihao Box. However, when the box is blocked with gravel or by high seas, or when the Waihao River flow exceeds the box capacity, the river can flow north along the Dead Arm into the lagoon. On other occasions, when the both the lagoon and river are low and the box is open, tidal oscillations of level and flows occur in the Dead Arm.



**Figure 5.4** Exit of the Waihao Box to the sea (photo: A.I. McKerchar, 30.11.04)

From a hydraulic perspective, it is anticipated that the box will behave as a culvert. Normally water flowing through the culvert will have a free surface. However when the upstream water level rises above the crest level of the culvert entrance, the cross-section area of the culvert forms a constriction that chokes the flow with the result that culvert flow increases only slowly as the upstream level rises. In this situation, surcharging is said to occur. Episodes of surcharging are identified by rapid level rises and minor flow increases upstream of the box, followed by rapid level falls. By raising the water level upstream of the box, surcharging can cause the direction of flow in the Dead Arm to reverse. Furthermore, as can be seen in Figure 5.4, the box itself forms a weakness in the gravel barrier and during floods breaches often occur beside the structure rather than the box forming the only opening. During those breaches, the gravel slope, visible in front, becomes extremely hazardous. During calmer periods, the sea closes the gap by depositing gravel around and onto the box, restoring the general barrier profile.

### **5.1.2 The Barrier**

The barrier permanently closes off the whole length of the lagoon from the sea. It is between 70 and 125 m wide and between 4 and 5 m in height. The barrier is built up from gravel and sand, brought on to shore by wave energy. The northerly sea currents transport the material sourced from erosion of the sea cliffs just south of the Wainono Box. The moderately high sea cliffs are built up of gravel deposited by the Waitaki River and eroded back by the sea. The barrier is a remarkable straight geomorphological feature in the landscape. It is also a dynamic feature; the shape of a profile can change within a year depending on the wave action, either depositing continuously new material or occasionally breaching and eroding it. As part of the monitoring programme, Environment Canterbury measures the location and shape of various cross sections of the barrier. (See for an example appendix 51.) In general, the barrier is thought to be moving inland because of the sea level rise since the last ice age. The shift and changes in profile and profile volumes seem to be related to complicated

climatic and tidal events with catastrophic (storm) events thrown in to keep the system dynamic.

The barrier can drain the lagoon directly by transmitting water through the porous material when the lagoon level is higher than the sea level. On the other hand, the waves can overtop the barrier during storms bringing in water that way, but can also possibly cause seepage to flow back into the lagoon from wave run up infiltrating the barrier at the seaward side.

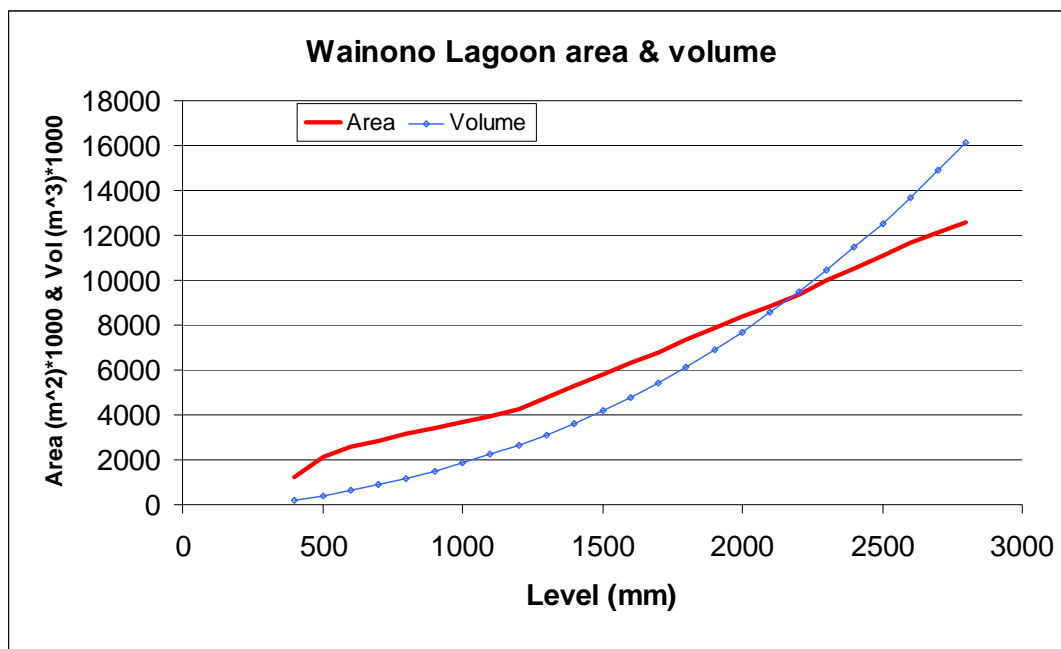
## 5.2 Wainono Lagoon monitoring programme and study

To better understand the behavior of the lagoon, an intensive data collection programme was mounted in 2001. The ongoing monitoring programme includes water level, flow velocity, water temperature, water conductivity, wind speed, wind direction and rainfall. The records collected and other relevant records for the period 2001-2004 are summarised by the time lines in Appendix 40. Other work by NIWA included definition of the lagoon bathymetry and a study of the rate of seepage from the lagoon through the beach barrier to the sea (Appendix 43, 46 and 47). Additional work by Goring assessed the amount of overtopping and 'backward' seepage into the lagoon (Appendix 50).

See appendix 40 for a timeline plot of all available data used in the Wainono Lagoon study.

### 5.2.1 Bathymetry

Bathymetry of the lagoon up to 4.0 m AMSL is reported in NIWA (2002). With the lagoon at 1.2 m AMSL, the surface area was found to be 4.3 km<sup>2</sup> and the maximum lagoon depth was 0.9 m, indicating that the lagoon bed is above mean sea level. At 0.5 m the surface area reduces to 2.1 km<sup>2</sup> and the maximum depth would be 0.2 m, implying that large parts of the lagoon are either extremely shallow or virtually dry (see Figure 5.5).



**Figure 5.5 Wainono Lagoon area and volume versus level**

It can be seen from Figure 5.5 that during high levels, 2m +MSL or above, the lagoon would more than double its area from its usual level of around 1m +MSL, creating some problems for surrounding farmland.

### 5.2.2 Barrier seepage

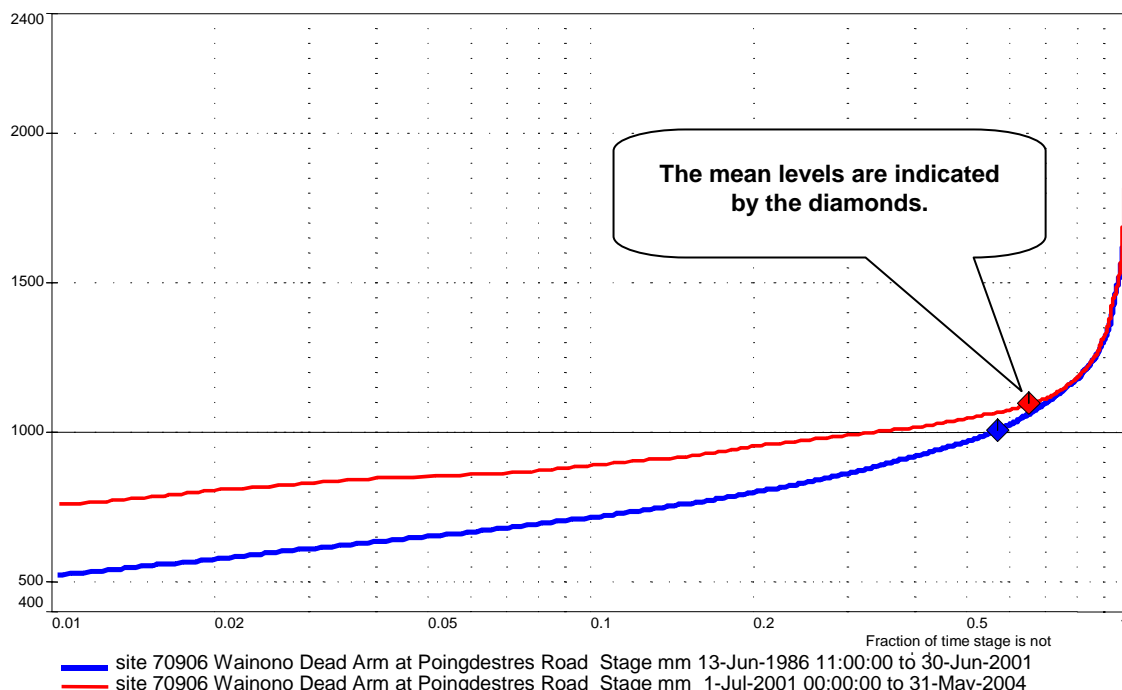
Seepage from the lagoon through the beach barrier to the sea was thought to be the main form of discharge from the lagoon. A procedure to estimate the barrier seepage is given in NIWA (2003) where the discharge through unit length of the barrier is given by:

$$q = K(h_L^2 - h_O^2)/2*(86400*L) \text{ cumecs/m (Dupuit, 1863) (note: original report omitted factor 2)}$$

where the permeability  $K$  is in m/day,  $H_L$  and  $H_O$  are the lagoon and ocean water levels respectively in meters above the impermeable layer, and  $L$  is the width in meters of the barrier. The permeability was estimated from measurements at a pit excavated in the beach as 840 m/day and the depth to a virtually impermeable clay layer was 0.466 m below MSL. A key assumption in using this formula is that these estimates of permeability and depth to the impervious layer apply along the length of the barrier, nearly 5 km. Application of this formula to a 70 day period when the lagoon levels ranged from 0.84 m to 1.26 m yielded seepage estimates ranging from 0.24 to 0.51 m<sup>3</sup>/s.

### 5.2.3 Levels, flows and conductivity for the Dead Arm

Water levels have been measured since 1986 on the Dead Arm at Poingdestres Road, about 1.7 km south of the lagoon. As noted earlier with reference to Figure 5.2, the lagoon has generally maintained higher levels in recent years. This is also indicated in Figure 5.6, which shows the fraction of time levels were less than a specified value. For example before July 2001, for 20 percent of the time the lagoon was below 805 mm AMSL, whereas for July 2001 to May 2004 the level was below 959 mm AMSL for 20% of the time. The reason for this apparent difference is not clear. Increased levels in recent years were also noted in Hall (2003).



**Figure 5.6 Cumulative distributions of Wainono Lagoon levels for June 1986 to June 2001 and July 2001 to May 2004**

The Poingdestres Road recording site (see picture in Appendix 41) is a particularly challenging site for flow measurement because no unique relation exists between level and flow, and flow can reverse several times a day. The solution adopted for measuring discharge at this site has been to install an acoustic-doppler (AD) velocity meter that measures flow velocity across the channel. For more details, see Appendix 41.

**Table 5.1 Flow percentiles for Poingdestres**

Percentile	Flow (m <sup>3</sup> /s)
0 (max)	23.6
5	<b>5.46</b>
10	<b>3.28</b>
20	2.23
48 (mean)	0.681
50	0.564
80	-1.21
90	-2.07
95	-3.22
100 (min)	-61.2

Conductivity measured at this site helps to identify whether the flowing water is fresh, brackish or salt.

#### **5.2.4 Banks Peninsula wave data**

Data from a wave-rider buoy operated by ECan 17 km east of Le Bons Bay off Banks Peninsula is taken as indicative of the offshore sea conditions. The data used in this study are the maximum wave heights and the significant wave heights, the latter being the average of the largest third of waves.

#### **5.2.5 Timaru sea levels**

Timaru sea level data, recorded at the Port of Timaru, are used as sea level data for the coast.

#### **5.2.6 Streamflows and levels**

Streamflow records for conventional stream gaugings for the Hook River, Buchanans Creek and the Waihao River were accessed in ECan archives. The Waihao record used is for station number 70913, (Waihao upstream of Bradshaws Bridge). This record is above the tidal limit and provides the quantities of surface water flowing from the Waihao River into the southern end of the Dead Arm. The Waihao flows are affected by irrigation abstractions (see Chapter 4.4). In addition, it receives water draining from the Morven-Glenavy Irrigation Scheme, which is sourced from the lower Waitaki River. Other small watercourses that drain into the lagoon have been found to be dry when low flow gaugings were made. Levels for station number 70907 (Waihao at Bradshaws Bridge) shows tidal oscillations and is essentially a record of water levels for the southern end of the Dead Arm.

#### **5.2.7 Rainfall**

Rainfall records for the gauge at Poingdestres (site number 417110) were used as an estimator of rainfall over the lagoon. Since standard raingauge data typically report seven percent less than the rainfall on the ground, the data are multiplied by 1.07.

#### **5.2.8 Wind**

Wind data are recorded by an anemometer mounted on a five meter high mast at the Poingdestres Road Bridge. This instrument records mean and maximum wind speeds and wind direction.

### 5.2.9 Open water evaporation

Open water evaporation (potential evaporation) is routinely estimated by NIWA for meteorological stations using the Penman-Monteith equation (e.g. Shuttleworth, 1993). The data required for the estimates are wind speed at two meters, wet and dry bulb temperatures and net radiation. The climate stations nearest to the lagoon for which these estimates are made are Windsor, 12 km inland from Oamaru, and Timaru Airport, just north of Timaru and 6 km inland. For this study the Timaru Airport data are preferred for their proximity to the coast. Estimates of the open water evaporation from the surface of the Wainono Lagoon were calculated using daily Class-A pan evaporation from Timaru Airport with a monthly correction factor as given by Houman (1973) and adjusted to the southern hemisphere by Horrell (1992)

The mean for four years of record 2001-2004 for the Timaru Airport record is 858 mm/yr. The data has a pronounced seasonal pattern with the maximum monthly mean (113 mm) in January and the minimum monthly mean (45 mm) in July. The mean annual value is close to the open water estimate of 796 mm estimated from open pan data for Adair, a site 7 km from the coast southwest of Timaru.

Climate data for a site on the Bleekers property near the lagoon were available for September 2002 to June 2003. These data were not used for estimating evapotranspiration because they cover only part of the period under consideration.

### 5.2.10 Inflow from groundwater seepage

Groundwater inflows to the lagoon were assessed using data from a piezometric survey undertaken from April to September 2002 (Aitchison-Earl, 2004). The study concluded that a "best guess" estimate was that the inflow could lie between 45 L/s and 140 L/s or 3900-12000 m<sup>3</sup>/day, discharging from shallow groundwater into the lagoon. The largest uncertainty in this estimate will be the adopted transmissivity and the assumption that all shallow groundwater will flow into the lagoon. It is also likely that there is a contribution from deep groundwater, given that the area is low lying, coastal with hills closeby creating a steep piezometric gradient. From a catchment point of view, this deep groundwater has to be sourced from tertiary rock formations, which would make this contribution relatively small. There are no deep wells immediately around the lagoon with groundwater level data to even make a "best guess" estimate for this part, but between 10% and 50% of the shallow contribution would be a best estimate with values between 5 L/s and 70 L/s. The value for the total groundwater input used in the water balance study is a constant 12,000 m<sup>3</sup>/day or 140 L/s with a 50% uncertainty (see also Chapter 6.3.2.2).

### 5.2.11 Sea water inflows

Sea water inflows into the lagoon have been observed by the local community and are confirmed as Plot G on Figures 5-9, 5-10, 5-11, 5-13, 5-14, 5-15. Some of the largest lagoon level increases have occurred during large sea storm events.

At the onset of this investigation it was envisaged that the variable that most influenced the lagoon levels was sea inflows and that it was impossible to actually measure this variable as inflows of sea water can occur anywhere along a 5 km long beach barrier which is relatively narrow, approximately 100 m wide and only 4 to 5 m high and consisting of gravel and sand. Therefore, attempts would be made to measure all the remaining variables that affect the Wainono Lagoon water balance, and the resulting misbalance would be termed the sea water inflow variable.

Time series analysis of the water balance showed periods of constant sea inflow during periods of relatively calm sea conditions; this led to redefining the term sea inflow to mean;

- wave run up during storm events resulting in sea water overtopping the barrier beach plus
- sea water inflow through the beach barrier.

It is plausible that sea water over topping and seepage through the barrier from wave run up at high tide with a heavy sea is considerable, mainly because the barrier is relatively narrow near the top and probably more porous to allow for these inflows. Goring has looked at this specific issue in more detail (See appendix 50) and according to his estimate the 'back flow' seepage could only be 5 l/s.

### 5.3 Presentation of lagoon data

Flows and levels for each of the years 2001 to 2004 are plotted in Appendix 42. Features evident from these plots are:

- High lagoon levels (exceeding 2.5 m), and high river inflows in July 2001 and January 2002, the former associated with raised conductivity due to sea water intrusion, the latter apparently due mainly to flooding in the Hook and Waihao Rivers and possible surcharging of the culvert flow at the Waihao Box because the Poingdestres conductivity drops almost to zero (Figure 5.9 and Figure 5.10);
- A moderately high lagoon level (exceeding 2.0 m) in April 2002; unfortunately there were no Poingdestres flow data available for that period to assist with explaining the reasons for such a level (Figure 5.12);
- Highly variable flows at Poingdestres with reversals frequent; Relatively benign conditions for 2003 and the first half of 2004, but with sea water inflow, evident from sudden conductivity increases on a number of occasions, e.g. March 2003, August/September 2003 and April 2004 (Figure 5.14, Figure 5.15, and Appendix 42d).
- Erratic Poingdestres flows occur particularly for the period May – July 2003. This appears to be a problem with the AD velocity record because these levels of fluctuation are impossible to match with corresponding fluctuations in lagoon levels, considering the physical limits of other input and output parameters. During the modeling exercise a few more periods were also found to be unreliable for the same reasons; (appendix 42c)
- Stable flows in the spring-fed Buchanans Creek typically in the range 200 to 500 L/s. This suggests that groundwater contributions to the lagoon should be relatively stable.
- Significant wave heights recorded by the Banks Peninsula wave rider buoy typically exceeding 5 m when storms affect the lagoon. However, the buoy being some distance from the South Canterbury coast, also records storms from northerly and southwesterly directions, which do not affect the coast.

### 5.4 Water balance

A water balance for the lagoon is assessed on a daily basis. It is illustrated here using the data for 2003, as this is the most complete year of record. Daily average data are used, as the daily averaging smooths the Poingdestres flows considerably by eliminating much of the tidal signal and short-term changes attributable to strong wind. Additionally, the data were also looked at, and in some cases presented, on an hourly basis just to illustrate these possible short-term tidal effects, such as what was happening when the barrier was breached.

The water balance is:

$$\Delta S = [I_H + I_h + I_R + I_G + I_P + I_U] - [O_E + O_S + O_P]$$

Where:

$\Delta S$  is rate of change of storage;

$I_H$  is the Hook inflow;

$I_h$  is small drains inflow;

$I_R$  is rainfall on the lagoon;

$I_G$  is groundwater seepage inflow;

$I_P$  is inflow from the Dead Arm (measured at Poingdestres);

$I_U$  is unmeasured inflow to the lagoon,

- Sea overtopping the beach barrier
- Sea water seepage into the lagoon
- Unmeasured tributary inflows (e.g. Waituna Stream);

$O_E$  is evaporation from the lagoon;

$O_S$  is seepage through the beach barrier to the sea;

$O_P$  is outflow into the Dead Arm (measured at Poingdestres).

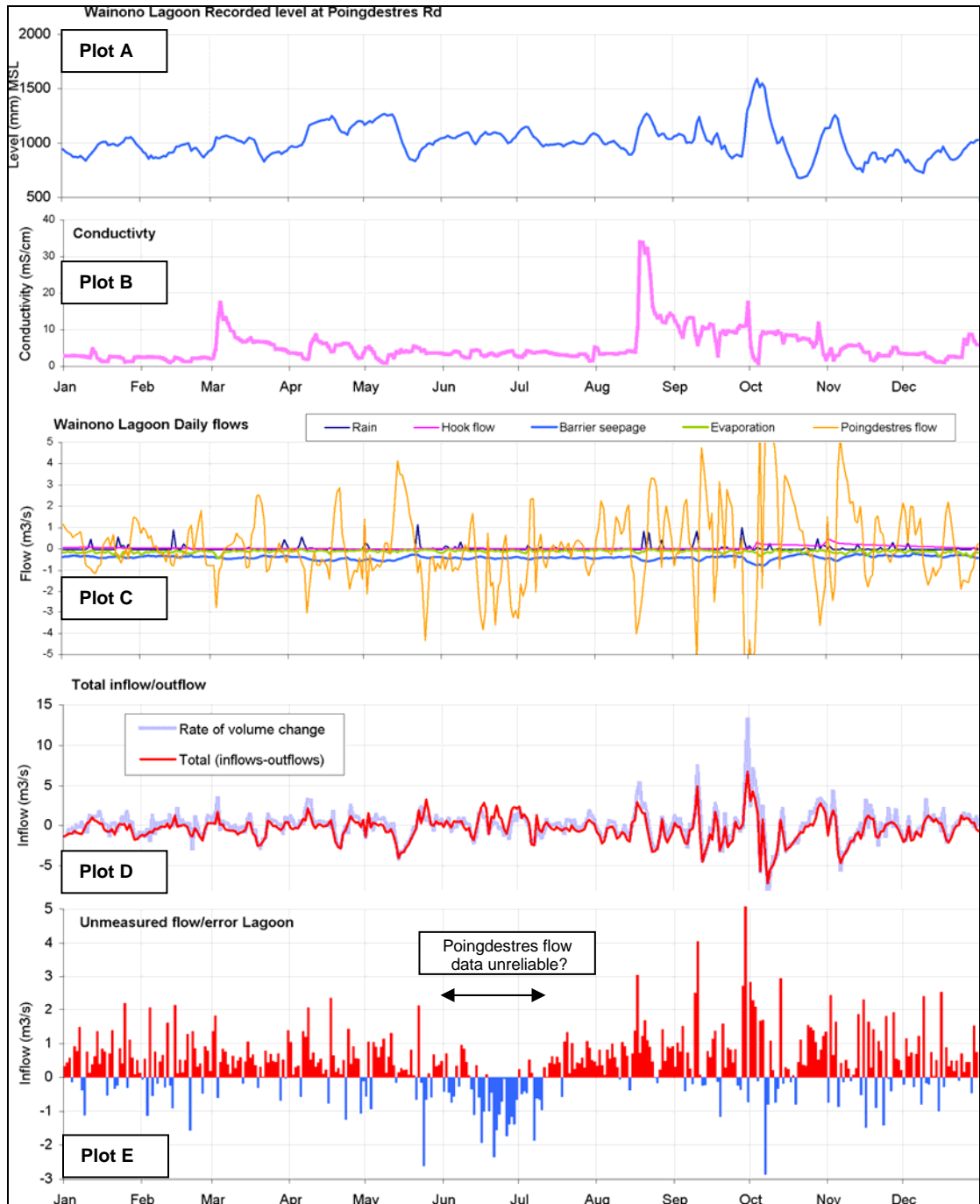
Field inspections have demonstrated that tributary streams other than the Hook River are dry most of the time or have stationary water reflecting the high groundwater levels. However they probably flow during storms, and these flows are included in the term  $I_U$ .

Lagoon area and lagoon volume are taken for each daily mean level. The application of this water balance on a daily basis is presented in a series of five plots on Figure 5.7.

Plot A in Figure 5.7 shows the daily mean lagoon levels for the year.

Plot B shows the daily mean conductivity at Poingdestres, the main feature of which is the rise in late August. Detailed data for this period are presented in Figure 5.14.

Plot C in Figure 5.7 shows the daily mean inflows and outflows. In this plot, the sign of the Poingdestres flows has been reversed to be consistent with the other quantities, so that inflows to the lagoon are shown as positive quantities and outflows are negative. The daily mean Poingdestres flows which range from  $-9 \text{ m}^3/\text{s}$  to  $+8 \text{ m}^3/\text{s}$  are much more variable than the other quantities. The daily mean barrier seepage estimate, for example, is always in the range  $-0.20$  to  $-0.79 \text{ m}^3/\text{s}$ , and the other items are even less variable.



**Figure 5.7 Wainono Lagoon water balance 2003**

Plot D shows the daily mean inflow or outflow as assessed from the summation of the measured water balance quantities in the top panel which in the terms of the water balance equation are  $[I_H + I_h + I_R + I_G + I_P] - [O_E + O_S + O_P]$ . Also shown are the implied total inflows or outflows,  $\Delta S$ , as deduced from the changes in the daily mean lagoon levels. Generally, the two series are quite close.

Plot E is the difference between the two series in Plot D, that is the difference of the implied daily mean inflows or outflows as deduced from the changes in the daily mean lagoon levels and the sum of inflows and outflows from the daily water balance. Rearranging the water balance equation above, this quantity is:

$$I_U = \Delta S - [I_H + I_h + I_R + I_G + I_P] + [O_E + O_S + O_P]$$

This term is unmeasured inflow to the lagoon due to the sea overtopping the beach barrier or seepage through the barrier of wave run up plus unmeasured tributary inflows, as these are not explicitly recognized in the water balance above.

The last two plots provide an assessment of the water balance. Plot D indicates that the daily water balance does a reasonable job in monitoring the fluxes of water into and out of the lagoon. However, the final plot, giving  $I_U$ , indicates that there is disparity between the measured inflows and outflows, which is summarised in Table 5.2 and illustrated in Figure 5.8. This table shows that the average difference between total inflows and total outflows is 381 L/s. This indicates that there could be large measurement or model errors, or (regular) inflows that have not been measured, e.g. sea inflows in the form of overtopping or significant seepage of wave run up through the barrier into the lagoon. Estimates of uncertainties, which define 95% confidence interval ranges, are also given. These include random and systematic uncertainties, and the percentage uncertainties are combined by taking the square root of the sum of squares to give uncertainties for the total inflows and outflows, and the error. The uncertainty estimates are subjective, but are guided by estimates for standard hydrometric practice (e.g. Herschy, 1981). Note that corrections for some of the systematic uncertainties in rainfall and Poingdestres flows are described above.

**Table 5.2 Wainono Lagoon water balance for 2003**

Inflow/outflow	Average for 2003* (L/s)	Uncertainty (±%)	Uncertainty (±L/s)
Hook River inflow $I_T$	75	10	8
Rainfall on lagoon $I_R$	49	10	5
Groundwater seepage $I_G$	140	50	70
Small Tributaries $I_h$	1	100	1
Total inflow	265	26	71
Poingdestres flow ( $I_P - O_P$ )	-173*	10	-17
Evaporation $O_E$	-80	20	-16
Barrier seepage $O_S$	-392	50	-289
Total outflow	-645	46	-299
<b>unmeasured inflow/Error <math>I_U</math></b>	<b>380</b>	81	307

\* excluding the period 20<sup>th</sup>-May-22<sup>nd</sup> July

The large unmeasured inflow or error, which is much larger than the 95% confidence limits, is considered further below. First, the data are examined in more detail.

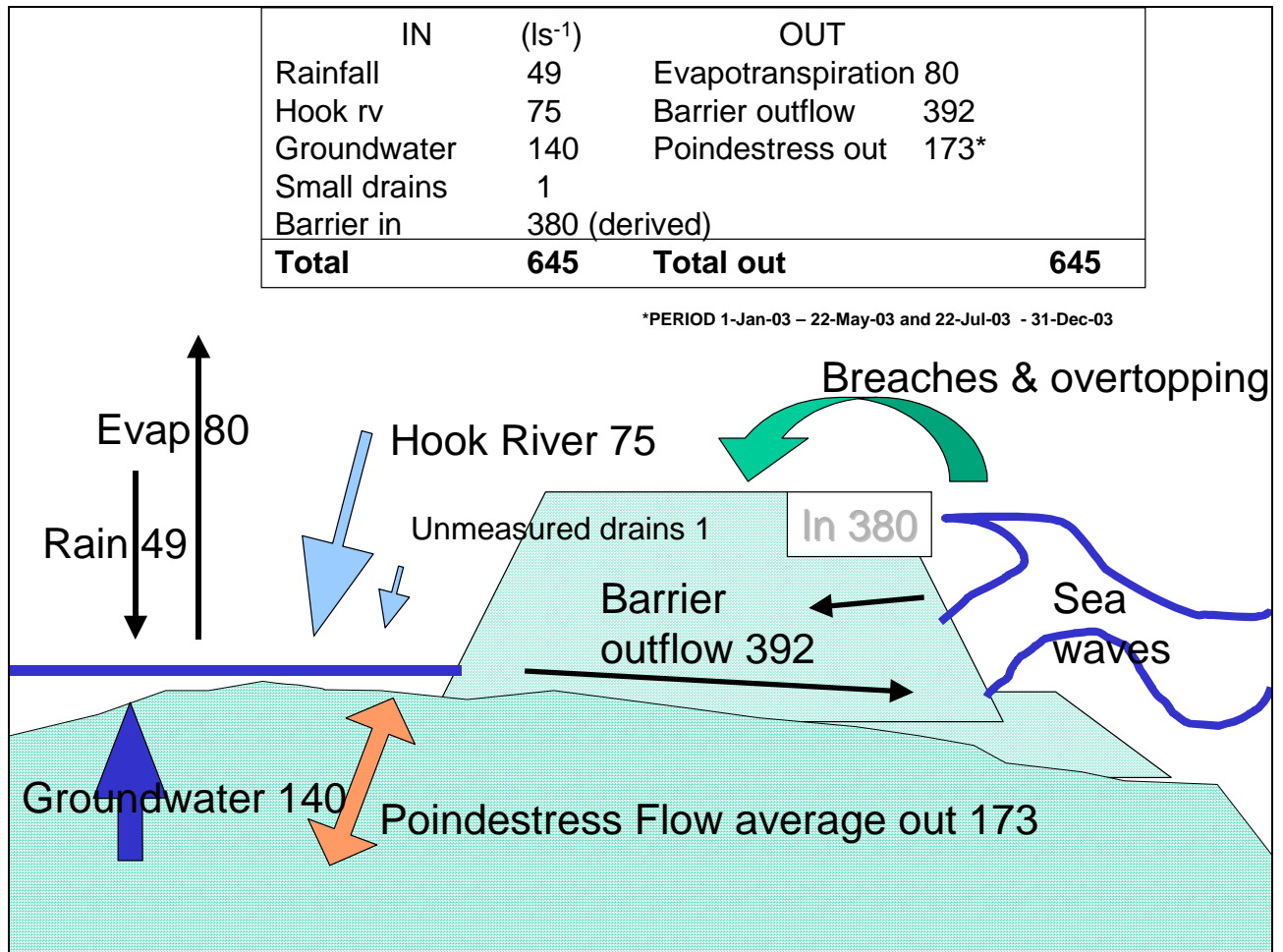


Figure 5.8 Water balance components Wainono Lagoon

### 5.5 Individual events

A number of periods identified from the yearly plots presented in Appendix 42 have been examined here in more detail. These are presented in chapter 5.6.1 and 5.6.2 to follow. A standard format used for the detailed figures is:

- Plot A: flows for Waihao and Hook rivers and Fletchers Creek; level for the Waihao at Bradshaws Bridge;
- Plot B: flow and water temperature at Poingdestres Rd. Here the signs for the flows are as for the archived data: negative flow is inflow to the lagoon; positive flow is outflow to the box;
- Plot C: wind speed at Poingdestres Rd;
- Plot D: wind direction at Poingdestres Rd;
- Plot E: water level and conductivity at Poingdestres Rd;
- Plot F: significant wave height and maximum wave height recorded for the wave rider buoy off Banks Peninsula;
- Plot G (where included): the quantity  $I_U$  in the water balance – the deduced either daily or hourly inflows or outflows due to sea water overtopping the beach barrier as well as freshwater inflows from unmonitored tributaries such as Waituna Stream. Where Poingdestres data are absent, the quantity is  $I_U + (I_P - O_P)$  is included.

### 5.5.1 Periods of high lagoon levels

Detailed data for 17-28 July 2001 are plotted in Figure 5.9. This is a period of severe coastal flooding due to high seas breaching the beach barrier. The plots in the figure are annotated to indicate the sequence of events that occurred. The dominant feature of this event is the barrier breaching and sea water flooding.  $I_U$  for the daily water balance indicates (only) a maximum daily inflow rate on July the 20<sup>th</sup> of 41 m<sup>3</sup>/s due to barrier breaching. The maximum average hourly inflow rate based on the lagoon level fluctuations and the other measured water balance components was at 4:00 am that day and measured 1300m<sup>3</sup>/s, followed 4 hours later with an outflow back to sea of 700 m<sup>3</sup>/s. This paints a picture of a rather vigorous tidal flow during a breach. Each following tidal cycle shows a declining inflow and outflow volume and within 6 tidal cycles the barrier seems closed again. The maximum lagoon level of 2.76 m was exceeded in 1994 and 2000 (Figure 5.2).

Another episode of high lagoon levels occurred in January 2002 (Figure 5.10) when the maximum was 2.62 m. Despite moderately high seas and wind from southerly and southeasterly quarters the conductivity data give little indication of saltwater intrusion through the Dead Arm, indicating that floods in the Waihao and Hook rivers were the main contributors to this episode. Note that the conductivity remains low after outflow commences on 13 January. Surcharging of the Waihao Box culvert occurs at this time. Because of the persisting low conductivity, it is likely that the additional inflow  $I_U$  indicated in plot G is mainly from unmonitored freshwater inflow, such as Waituna Stream. The hourly 'unmeasured' flows show again a large inflow followed by a large outflow; however in this case it is more likely to be seiching of the lagoon. Note the 180-degree change in wind direction on the 10<sup>th</sup> with a declining wind speed, a potential cause for 'sloshing' of the lagoon. A model based on hourly values during this period would produce large calculated inflows and outflows that did not occur. It is just a change of level within the lagoon itself. In the previous example, where the barrier is known to have breached, declining tidal effects are seen in the unmonitored inflows over the next three days, which in this case is absent the next day. The following days however, we do see some tidal effects return.

Soon after this event, early in February, southerly wind and very high seas did cause sea water intrusion. The low river flows, elevated Bradshaws Bridge levels, elevated conductivities and the negative Poingdestres flows around 7 February (indicating lagoon inflow) suggest that the barrier overtopping occurred between Poingdestres and the box.

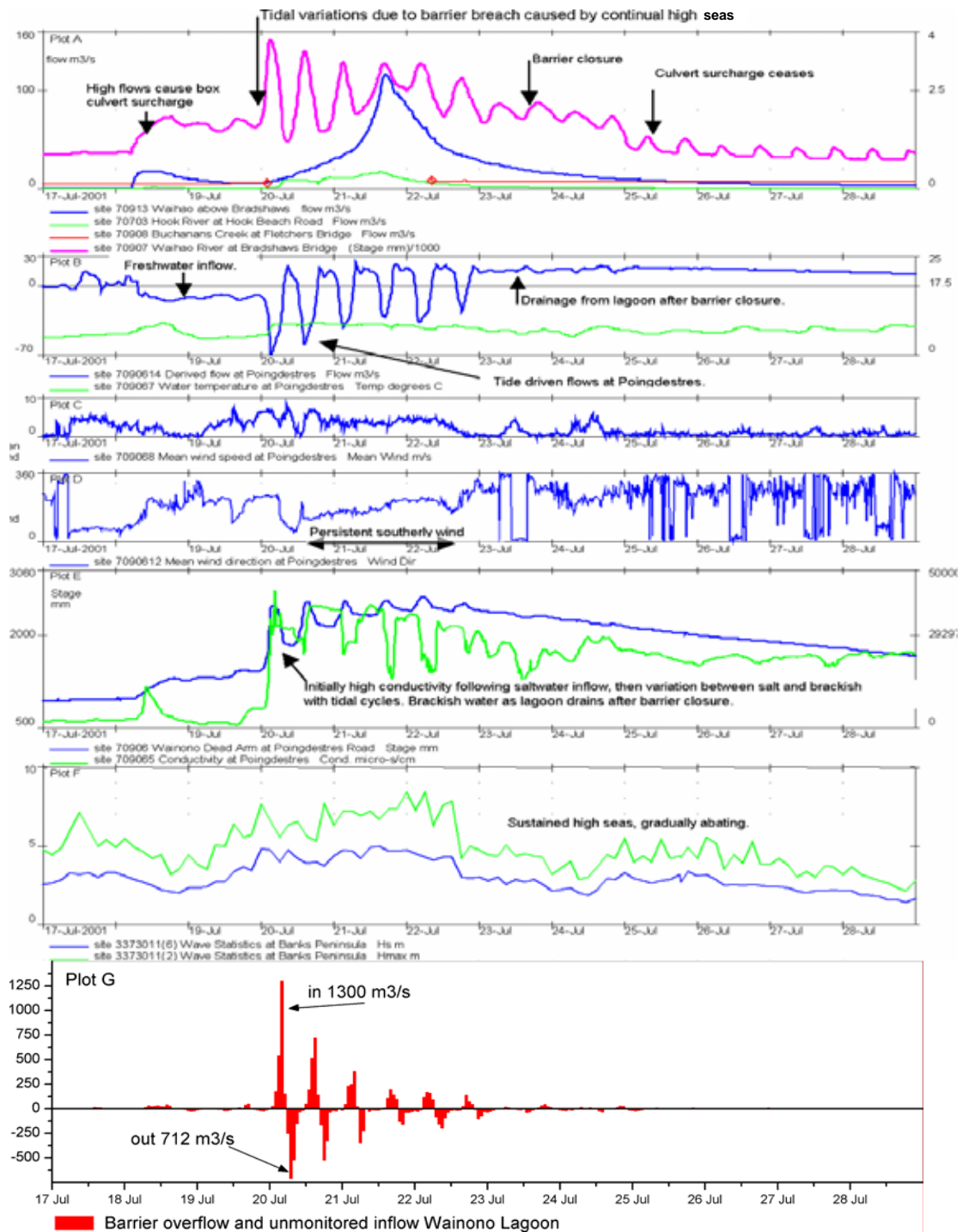


Figure 5.9 Wainono Lagoon data for 17 July – 29 July 2001

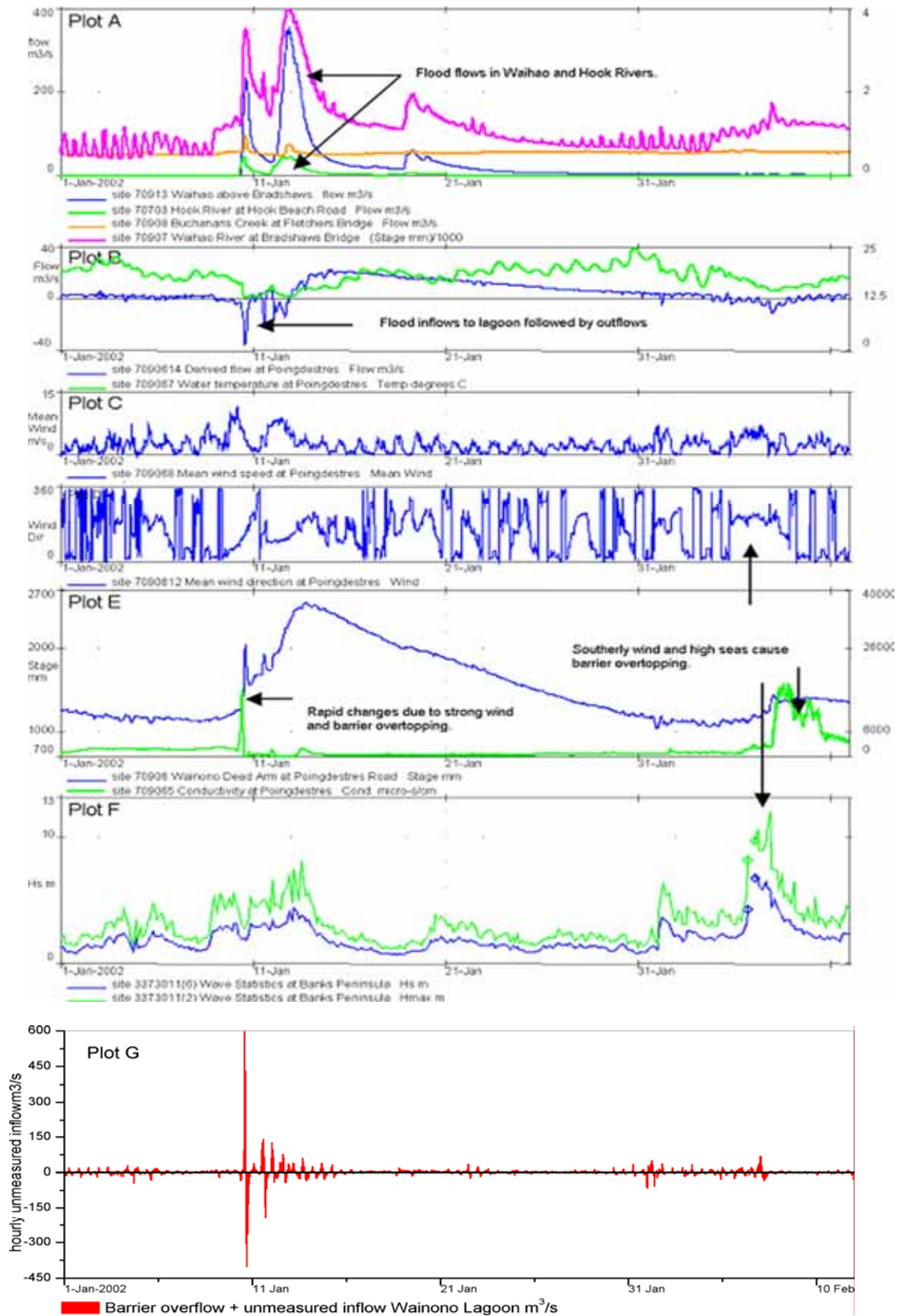


Figure 5.10 Wainono Lagoon data for 1 January – 11 February 2002

### 5.5.2 Other notable events

Other periods of interest selected from the yearly data displayed in Appendix 42 are reported below. None is presented for the quiescent first five months of 2004.

**Detailed data for 19 October – 13 November 2001** (Figure 5.11) illustrate a moderate fresh in the Waihao River, but low flows in the Hook. It appears that surcharging of the box causes freshwater inflow into the lagoon, followed by drainage when the surcharging ceases. The daily water balance suggests an additional inflow at a rate averaging about  $1.4 \text{ m}^3/\text{s}$ , but the persisting low conductivity at Poingdestres indicates that this must be fresh Waihao rather than salt-water inflow. Note also that the conductivity of outflowing water at Poingdestres is generally slightly raised during the rest of the year indicating some sort of continuous sea water contribution to the lagoon.

**Detailed data for 30 March to 3 May 2002** (Figure 5.12) show the lagoon twice reaching levels around 2.0 m, but Poingdestres flow data are available only from 3 May. The conductivity data suggest that the first high-level event is due to sea water breaching the barrier during high seas: the second due to rivers flooding. Maximum daily inflow  $I_U + I_P - O_P$  is estimated as  $43 \text{ m}^3/\text{s}$ . The second event was due to the rivers flooding with some sea water overtopping likely.

**Detailed data for 1-11 March 2003** (Figure 5.14) show a period when high sea conditions caused sea water to enter the Dead Arm, through the box and by barrier overtopping, raising the levels as indicated by the Bradshaws Bridge and lagoon level data. Brackish water flows into the lagoon for nearly two days, raising the lagoon levels slightly. The lagoon conductivity record over this period takes nearly a week to converge to the conductivity measured at Poingdestres, indicating that mixing of water within the lagoon can be quite slow.

**A similar sea water incursion is shown for mid-August 2003** (Figure 5.16). Here the box appears to have stayed closed for about four days. It is associated with high seas and continuing southerly wind for several days. Surcharging may have occurred at this time. Some barrier overtopping, with sea water entering the lagoon directly (Plot G), may have occurred on 18 August. See also Goring (2006) in appendix 50 paragraph 3.2.3. for a discussion of the same period.

**Detailed data for 9 September to 7 November 2003** (Figure 5.15) show two periods when the box flow was surcharged during freshes in the Waihao River. The most likely explanation for the sudden conductivity increases on 29 September and 28 October, followed by drops to low values, is sea water incursion through the box, or overtopping of sea water between the box and Poingdestres into the Dead Arm due to storms. The high conductivity salt water is followed by low conductivity freshwater from the Waihao River, another result of the storms. The daily water balance data indicate that additional inflows occurred to the lagoon, either by barrier overtopping, or from unmonitored streams. The data for 28 September to 9 October, which include two periods with high seas, suggest barrier overtopping, notably on 30 September. The reason that the conductivity data drop to low levels, consistent with fresh water, is that the lagoon is also raised by water from the Waihao River flowing north past the Poingdestres site.

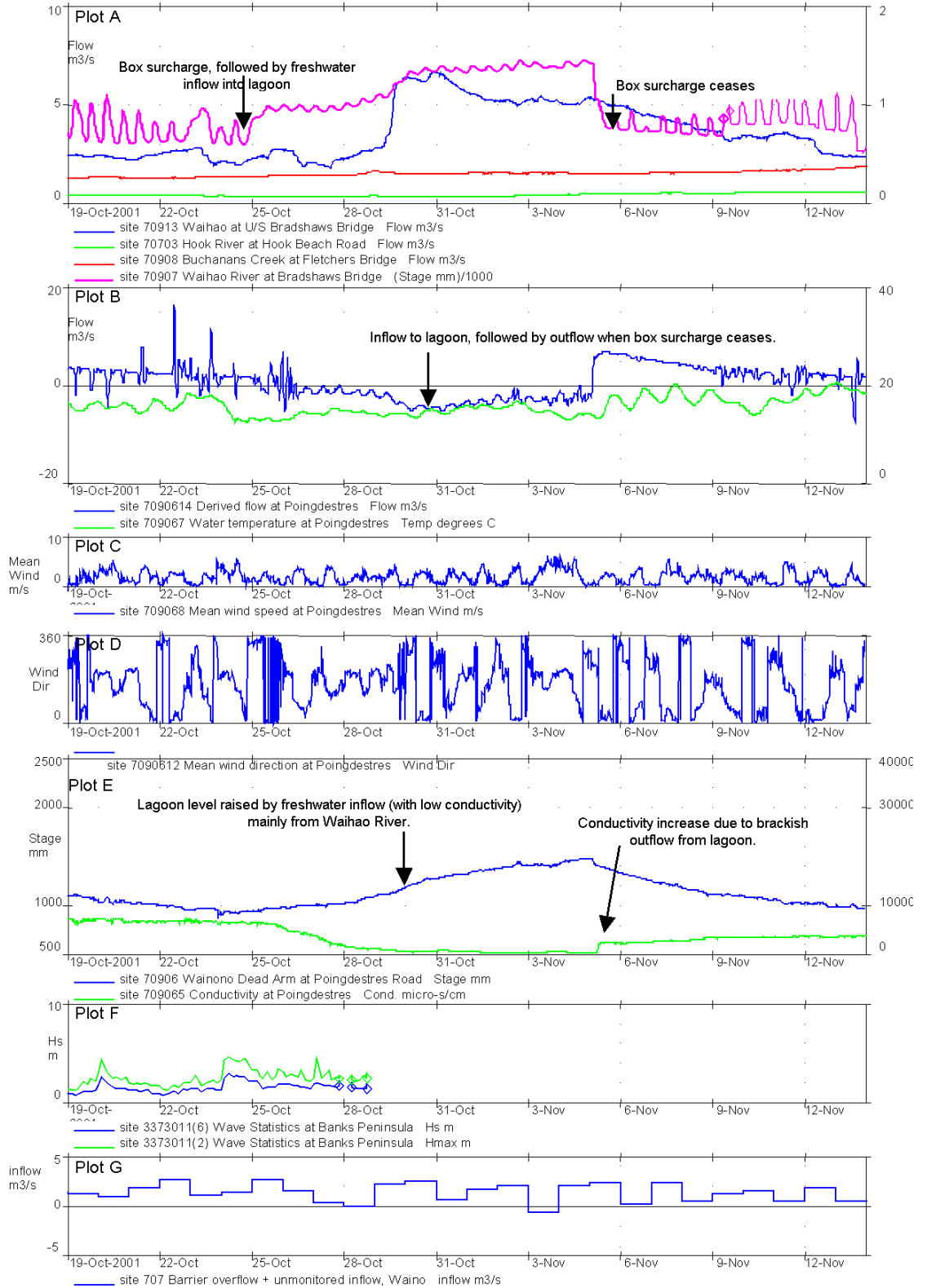
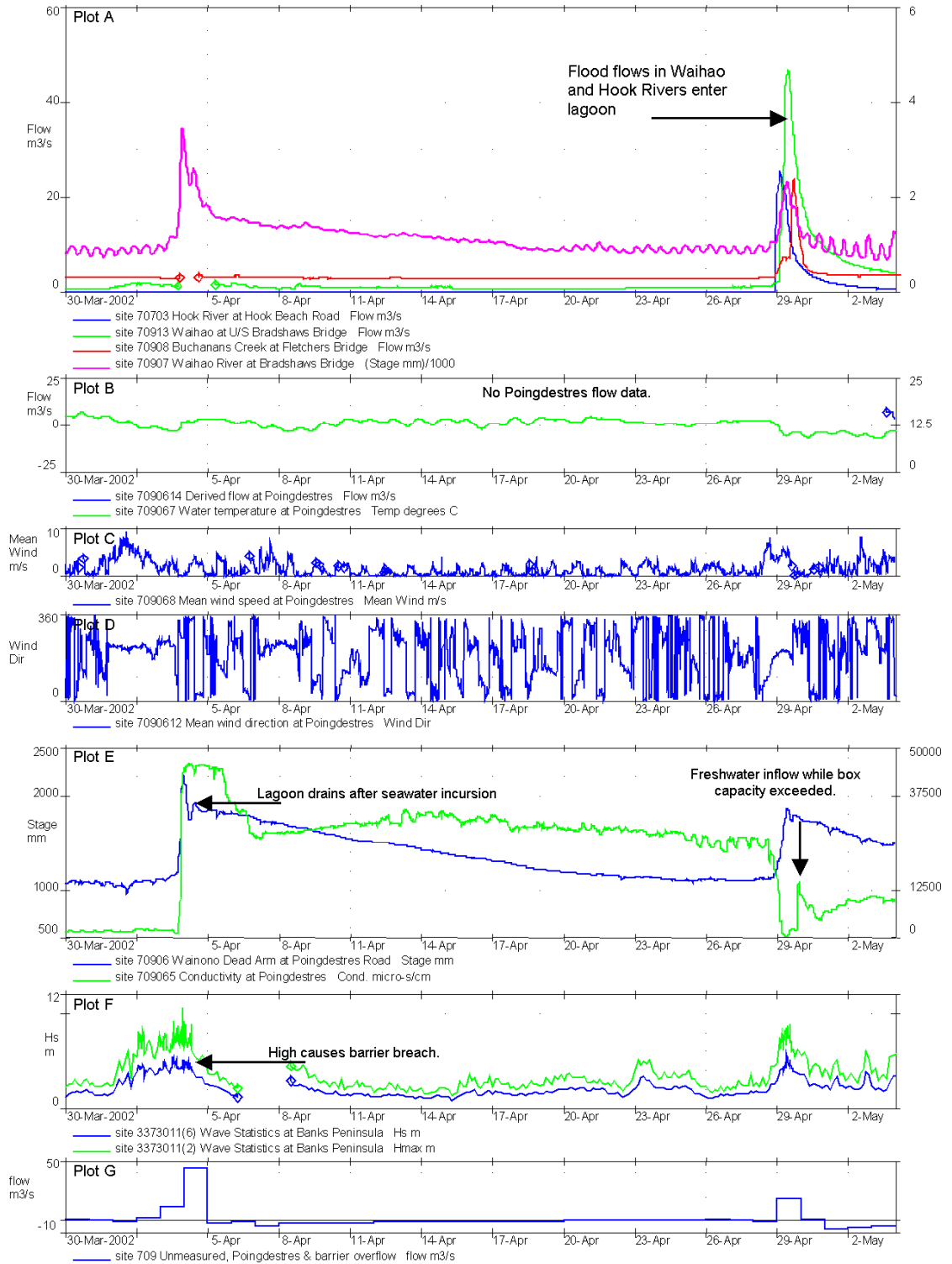


Figure 5.11 Wainono Lagoon data for 19 October – 13 November 2001



**Figure 5.12 Wainono Lagoon data for 30 March to 3 May 2002**

With the absence of Poingdestres flow data, the quantity in Plot G is  $I_U + I_P - O_P$ .

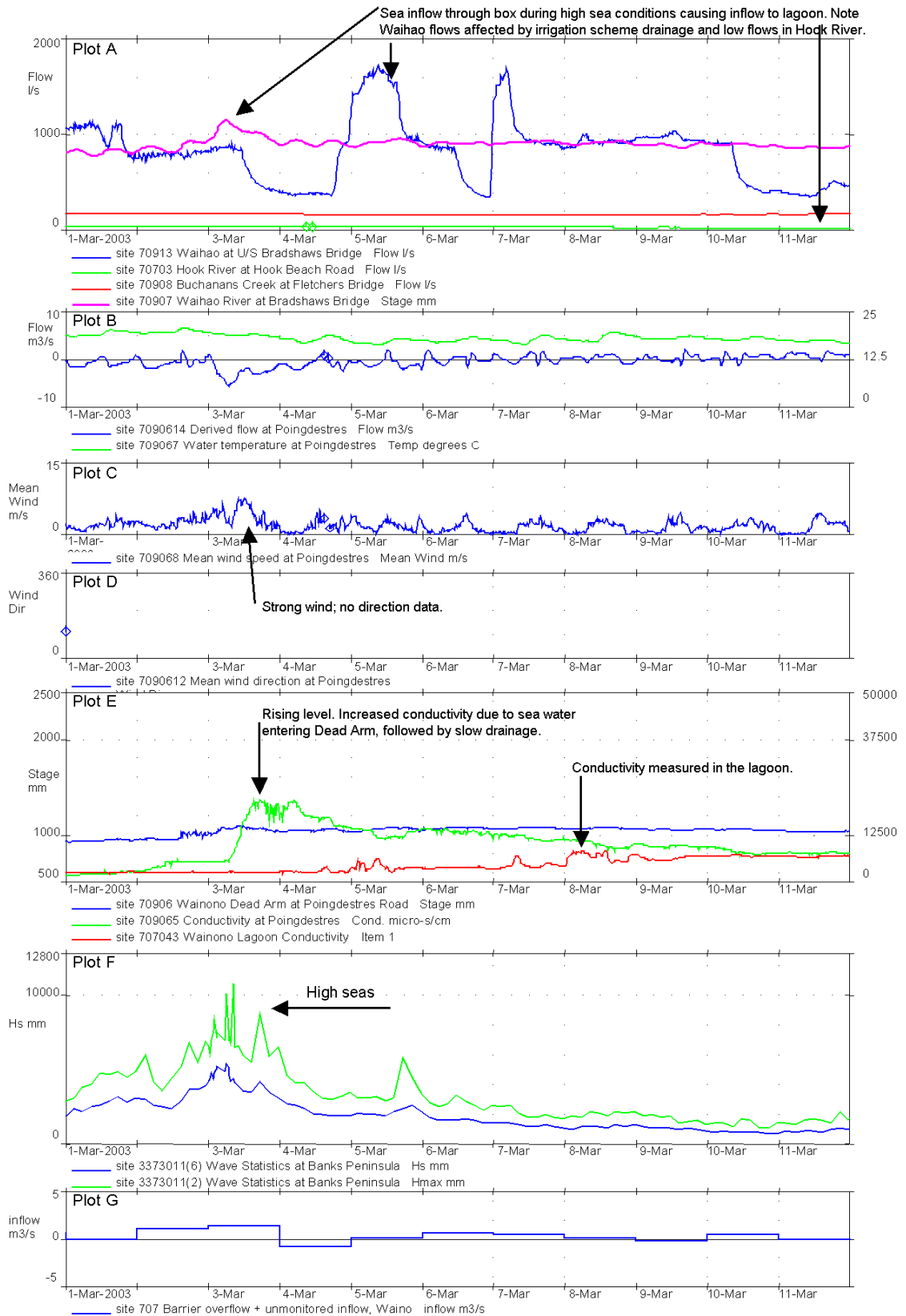


Figure 5.13 Wainono Lagoon data for 1-11 March 2003

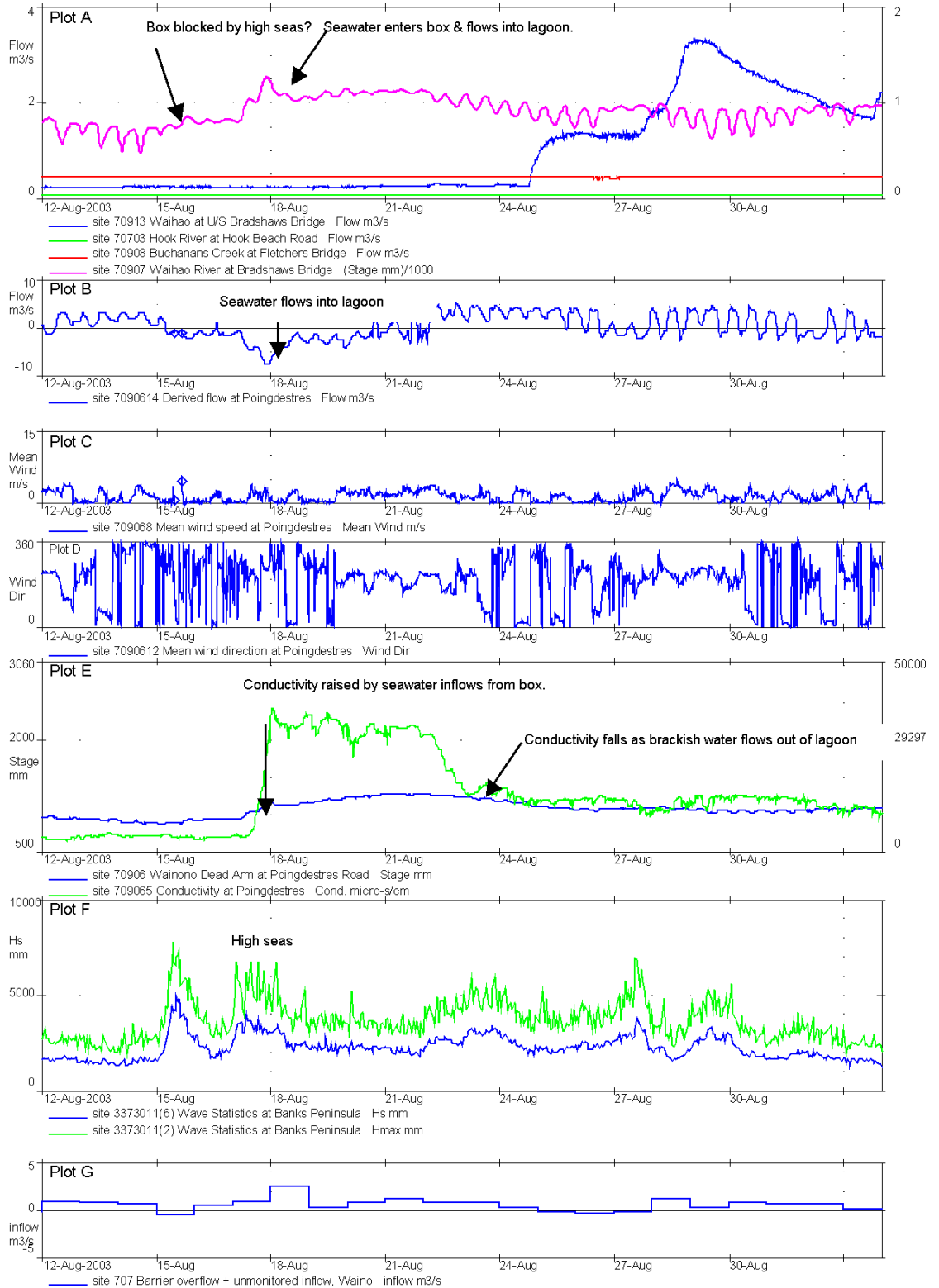


Figure 5.14 Wainono Lagoon data for 12 August to 2 September 2003

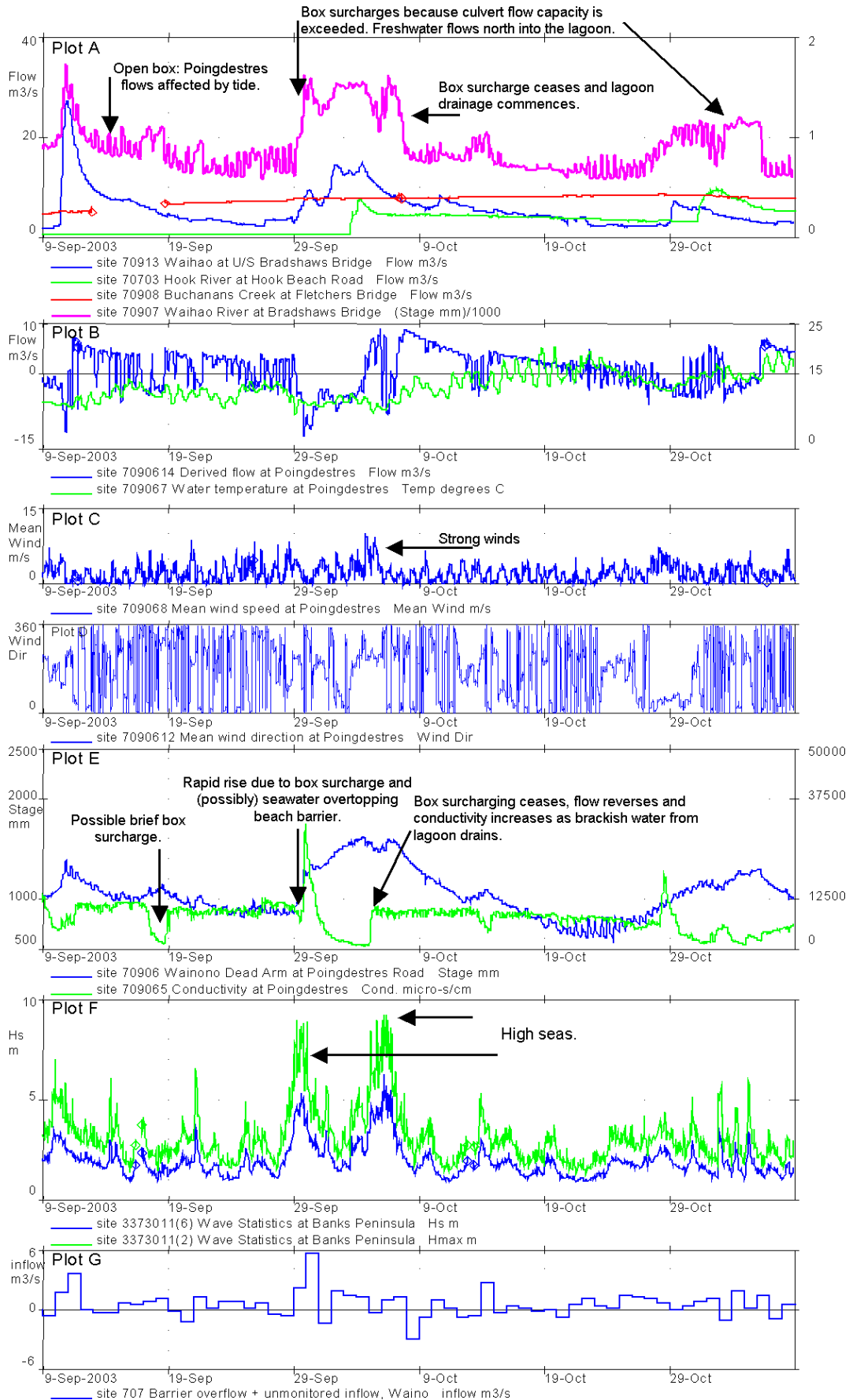


Figure 5.15 Wainono Lagoon data for 9 September to 7 November 2003

## 5.6 Modelling a management option for the Wainono Lagoon (example only)

Below is one example of how the Wainono Lagoon water balance model can be used by stakeholders to investigate the impact of management options on lagoon levels. In this scenario, a flap valve is installed to a height of 1.0 AMSL and is managed so that water from the Dead Arm cannot enter the lagoon whilst outflows from the lagoon can occur until a level of 1.0 AMSL is reached. In addition, if the Dead Arm water level measured at Bradshaw is higher than the lagoon level, no inflow can occur (despite a high Lagoon level). The data between 13<sup>th</sup> June 2001 and the 14<sup>th</sup> of December 2004 were used to construct a daily water balance model in MSEXcel.

The resulting time series is compared to the measured levels and is shown in Figure 5.16 and the frequency distribution in Figure 5.17. This plot shows that the main change occurs in the level up to 1.25 AMSL, which in the modeled scenario is exceeded in 5% (100-95) of the time instead of 15%. It also shows that low levels become slightly less frequent but the extreme high levels (>2 m) are still occurring but at about half the frequency (0.6% instead of 1.23%). It means that extreme high levels cannot be avoided by a structure because of barrier breaches by the sea.

For more details of the model, see Appendix 45.

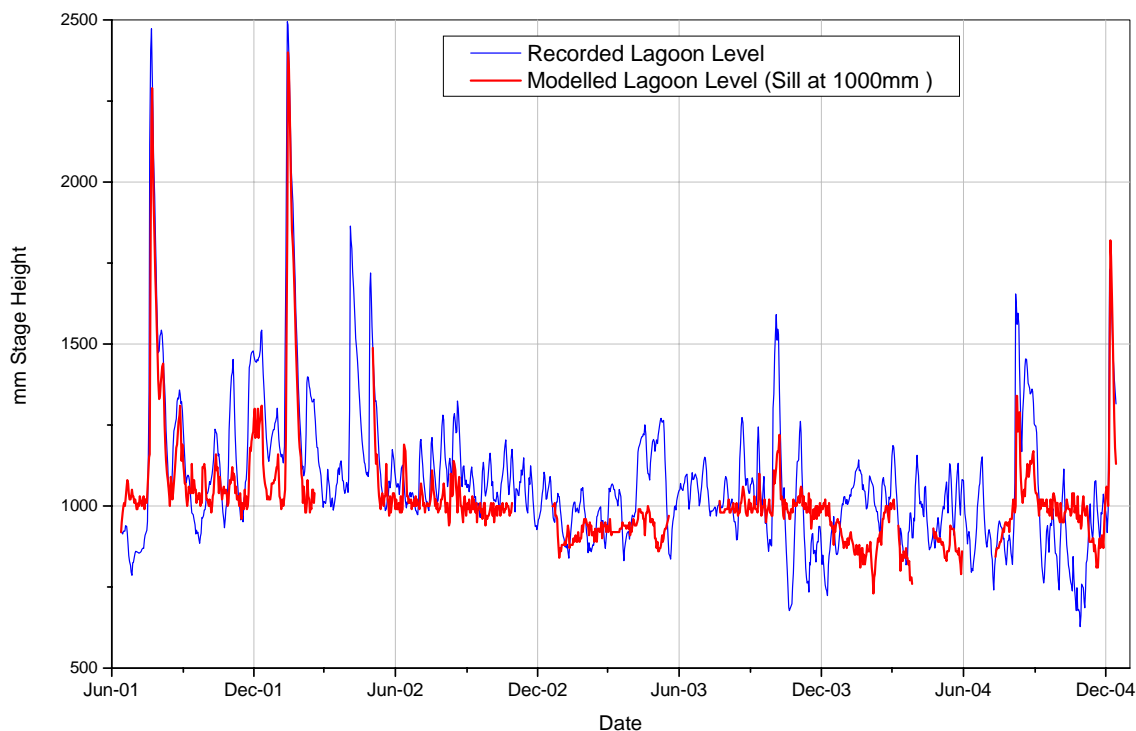


Figure 5.16 Modelled Wainono Lagoon levels

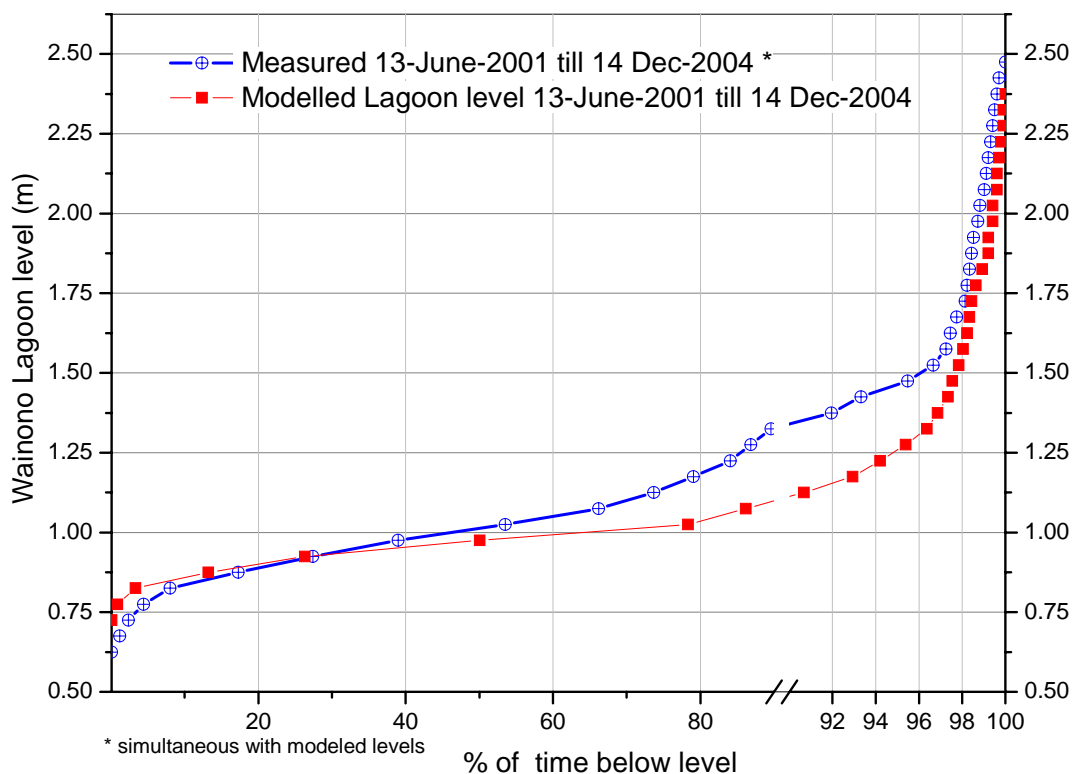


Figure 5.17 Distribution of modelled and measured lagoon levels

## 5.7 Discussion

### 5.7.1 Sea water overtopping the beach barrier

The data examined in 5.5.1 and 5.5.2 show two clear episodes of sea water entering the lagoon directly by overtopping the beach barrier, in July 2001 (Figure 5.9) and April 2002 (Figure 5.12). Further episodes possibly occurred in August & September 2003 (Figure 5.14-5.15-5.16). The daily water balance calculations are convincing for July 2001 and indicate substantial sea water entering the lagoon.

Calculations of inflows for the events in April 2002, which include Poingdestres flows, show a maximum daily value of  $43 \text{ m}^3/\text{s}$  and must include overtopping as well. Some inflows may also have come from the smaller unmonitored catchments such as Waituna Creek.

The other episodes of high measured conductivities at Poingdestres and high sea states coincide with Poingdestres flows into the lagoon and low values of  $I_U$  from the water balance (Figure 5.9, 5.12, 5.16) indicating that the sea water entered the system either through the box, or across the barrier between Poingdestres and the box.

The most notable of these events in terms of significant wave height and rate of rise within the lagoon occurs over the period 29 September to 6 October 2003 (Figure 5.15). The largest discrepancy in the daily water balance for the year occurred of  $5.6 \text{ m}^3/\text{s}$ , on September 30<sup>th</sup>. There are several days that year when the difference exceeds  $2.0 \text{ m}^3/\text{s}$ . The relatively low conductivity data after the lagoon started draining on about 6 October suggests that little sea water overtopping occurred, but poor mixing of sea water in the shallow lagoon

complicates this assertion. The complexity of the situation is compounded by a fresh in the Waihao River causing a rapid rise in the Bradshaws levels, suggesting surcharging of the box and flows north through Poingdestres into the lagoon.

### 5.7.2 Uncertainties in the water balance

Major changes ( $\pm 100\%$ ) to some variables identified in Table 5.2 and in particular Hook River inflows  $I_H$ , Rainfall  $I_R$ , groundwater seepage  $I_G$ , Poingdestres flow ( $I_P - O_P$ ) and evaporation  $O_E$ , have little influence on the water balance. The quantity of the Hook River flows is confirmed by current-meter gaugings in the data archives. The recorded Poingdestres rainfall for 2003 was only 388 mm, but even doubling this quantity would have only a minor influence. The groundwater inflow estimate is difficult to confirm. The Poingdestres flow data have been reviewed above and an adjustment applied. The reliability of the flow data of Poingdestres was less than desirable but given the difficulty in collecting data for a two-way flow site, it provided very useful information. The Timaru Airport open water evaporation estimates were considered above and were confirmed by open pan estimates.

The largest identified quantity in the water balance is the barrier outflow seepage (392 L/s). The “unmeasured inflow/error” is almost the same at 380 L/s. There are considerable uncertainties in this estimate by NIWA (NIWA, 2003). In particular, the analysis assumes that the depth to the impervious layer (0.466 m below mean sea level), which was assessed from measurements in one pit, is constant along the barrier length of nearly 5 km. From borelogs around the lagoon area, we know that the lagoon is likely underlain by a thick silt layer, described as a 3-10m thick clay layer (see Appendix 49).

Ongoing research work at the University of Canterbury has investigated the composition of the beach barrier and early results indicated that the depth to a silty-gravel substrate layer is quite variable. However, this material is permeable and is 1.5 to 2.5 m above the impermeable layer (Appendix 43).

## 5.8 Conclusions

1. A tentative water balance for the lagoon has been estimated, but is subject to considerable uncertainty, much of which appears to be associated with the magnitude of the outflowing barrier seepage and the sea water incursion and sea water seepage into the lagoon.
2. The water balance model provides a method of displaying ‘what if’ scenarios.
3. When developing the model, insights into the water levels at Bradshaw’s, Hook River and Waihao flows, sea incursions, hydraulic behaviour at the box allowed this knowledge to be included when running the model.
4. A lagoon level control structure somewhere in the Dead Arm would avoid high lagoon levels caused by the Waihao River floods.
5. The storm of July 2001 showed that high lagoon levels can also be caused by barrier breaches and a control structure would not prevent these events.
6. The Hook River can raise the level of the lagoon significantly as well; an example is January 2002 (see Figure 5.10). Although the Waihao River was in flood as well during that period, bringing water to the lagoon, the amount of flow from the Hook River (with additions from smaller streams) was large enough to raise the Lagoon level another 0.5 m. Because the flows in the Hook and Waihao will often occur at similar times, the high flows from the Hook will be ‘held up’ in the lagoon until the Waihao has receded again.

7. A control structure would 'force' the Waihao box to open more often during river floods by creating short term higher levels at the box, with a possible reduction in the long term average levels.
8. A control structure could also raise flood levels in the Dead Arm, potentially causing additional problems with slightly higher water levels around the box and the lower Waihao River for short periods.
9. A control structure will affect the water quality in the lagoon by keeping out
  - a. fresh water from Waihao floods
  - b. saltwater when the Waihao box is open.

## 5.9 Recommendations

1. The definition of the beach barrier dimensions, specifically the depth to the impermeable layer, is one source of uncertainty. It could be reduced if the depth to the impermeable layer could be better defined; ground-penetrating radar is an alternative technology to excavating pits that may be more cost-effective. (Appendix 43).
2. The development of a seasonally varying groundwater contribution could improve the water balance (see appendix 44).
3. Investigation of the barrier through-flow by installing a piezometer array across the barrier, possibly in a few locations. This would facilitate investigation of the phreatic groundwater surface in the barrier and would allow proper small-scale aquifer tests to be conducted so the accuracy of the transmissivity value derived from the test on the pit (Goring 2003) can be improved. More importantly, it would provide data on the groundwater level at the seaward side of the barrier. This level is a result of the local sea level, tides, wave setup and wave run up and these factors were too difficult to measure. The wave run up has not been included in the barrier through-flow model but is investigated further in Goring (2006). Measuring the seaward groundwater level gives an input parameter that can be used in the (simple) through-flow model directly rather than using modeled values (see Figure 5.18). This would not directly measure the amount of overtopping though.
4. The daily water balance model should be refined by using calm lagoon level readings with the aid of the wind record to better determine the components of the water balance.
5. Further refinement could be explored using the evaporation values, which could be calculated from climate measurements at nearby Bleekers property and the results compared to the Timaru Airport values. This could provide a correction factor for local evaporation conditions.
6. A flood protection engineering and a water quality study may need to be undertaken to resolve issues raised in the lagoon level management modelling.

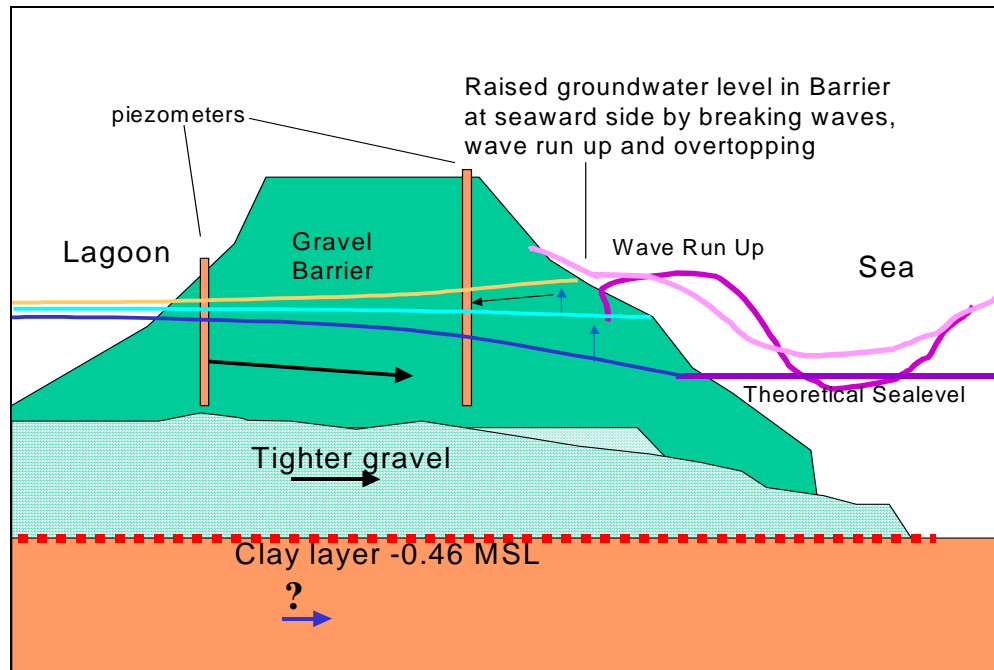


Figure 5.18 Conceptual barrier through-flow model

## 6 Groundwater resources

### 6.1 Previous work

Water level and well information was collected by the New Zealand Geological Survey for the 1940's through until 1979 when this function was taken over by the South Canterbury Catchment Board. Brown and Somerville (1980) compiled well details, water level hydrographs and well logs. The water levels were collected from selected wells on a three monthly basis. Piezometric surveys of the Pareora valley were undertaken in 1969 and 1981, and of the area from Pareora to Waitaki in 1978-79. These surveys did not extend inland along the Otaio, Makikihi and Hook Rivers, or inland as far as Waimate, as there were insufficient wells to permit contouring.

Walsh (1981) wrote a draft report on the surface water resources from the Pareora – Waihao, summarising rainfall, and flow information. Only brief mention of the groundwater resource is made.

Waugh (1987) compiled a water and soil report on the Pareora catchment. This report details the shallow and deep artesian groundwater resource, the geology, water level fluctuations and flow patterns. Collected water quality data indicated groundwater to the south of the river had components of recharge via seepage from the Southburn and Gordons Valleys.

Royds Garden Ltd (1987) detailed an investigation on two deep non-flowing artesian bores used by the PPCS meatworks. The report details the geology and recharge source of the aquifer, and a series of aquifer tests performed on the bores. Sea water intrusion and aquifer reliability were considered, and concluded that abstractions from the two wells would be sustainable.

Issues in the Waihao River-Wainono Lagoon area are summarised in Environmental Consultancy Services (1995). Issues include the Morven Glenavy Irrigation Scheme discharge, enhancement of Wainono Lagoon, and irrigation extractions. The history of investigation and development in the area is included.

A review of existing groundwater information and a proposal for further work (to meet the aims of this report) are outlined in Aitchison-Earl (2000).

Aquifer testing and the hydrogeology of the Pareora River Valley shallow aquifer are reported in Aitchison-Earl (2001). Results from the aquifer test indicated hydraulic connection of shallow groundwater to the Pareora River.

Henshaw, et al (2003) report on an aquifer test in the Studholme area including a summary of the hydrogeology.

Water use patterns for surface and groundwater sources from the 2000-2002 season in the Pareora-Waihao catchments are summarised in Aitchison-Earl (2003).

Forsyth (2004) reports on classification of well logs into geological units, which is expanded by Aitchison-Earl (2005) to describe deeper aquifer units in the Timaru – Waitaki River region.

## 6.2 Groundwater occurrence

### 6.2.1 Geological Aquifer Units

Aquifers are found within a wide variety of geological units, ranging from Quaternary alluvium to marine Tertiary sandstones. The range of aquifer types found makes the Pareora-Waihao catchment areas unique in the Canterbury setting, where most aquifers are in alluvial plains underlain by glacial/fluvial greywacke gravel sand and silt deposits. The diversity of utilised aquifers in this area is largely due to older Pliocene-Pleistocene Gravels and Tertiary Units being within economic drilling distance of the surface.

There are four major aquifer units currently utilised in the study area. These include (youngest to oldest): Quaternary Alluvium which mainly occurs in river valleys; older Pliocene-Pleistocene Cannington Gravels; the Tertiary marine based Southburn Sands of the Otakau Group; and the terrestrial quartz gravel, clays and lignites of the Taratu Formation which overlie basement greywacke. Interpretation of the three older aquifer units was detailed in Aitchison-Earl (2005), assisted by Forsyth (2004). Descriptions given in this report are sourced from these references. Each aquifer is summarised in Table 6.1, and detailed in the sections below. Figure 6.1 is a selected cross-section from Aitchison-Earl (2005) through the Pareora Valley, which indicates the relationship of the different aquifer formations in this area. The location of the cross-section and further cross-sections are provided in Appendix 32.

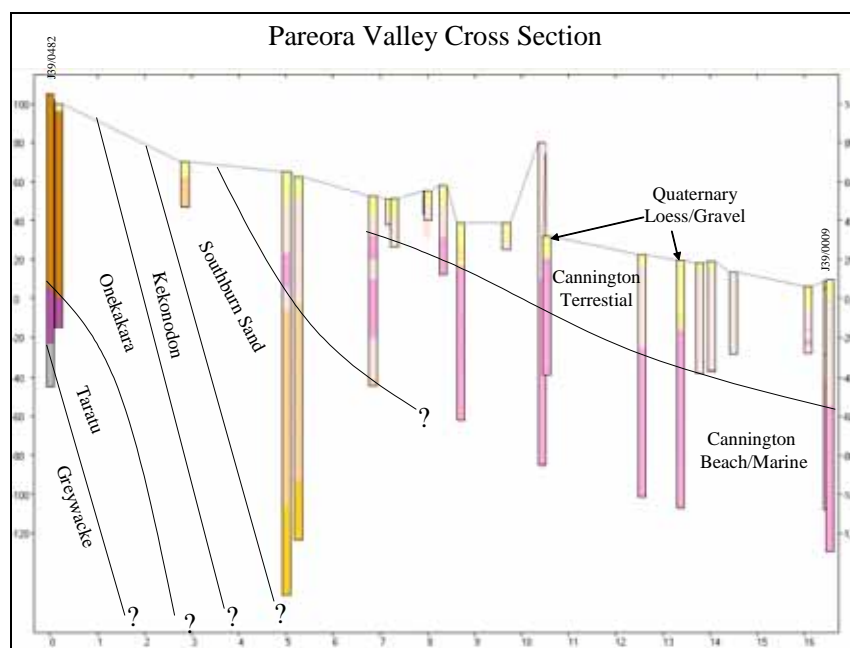


Figure 6.1 Cross-section through the Pareora Valley, Gorge to the coast

**Table 6.1 Aquifer units of the Pareora-Waihao catchments**

Aquifer	Sub-Unit/Area	Average Yield (L/s)	Yield Range (L/s)	Average Specific Capacity (L/s/m)	Typical Description
Quaternary Alluvium <sup>1</sup>	Pareora	14.4	0.1 – 30.4	17.8	Sandy gravels with varying quantities of silty/clay. May be overlain by silty deposits near the coast.
	Otaio	4.9	0.01 – 30	4.3	
	Makikihi	5.6	0.07 – 49	6.4	
	Hook	9.2	0.05 – 32	9.2	
	Waimate	2.4	0.06 – 15	4.0	
	Waihao	13.4	0.1 - 57	8.4	
Cannington Gravels <sup>2</sup>	Cannington Terrestrial	12.5	0.16-56.8	3.6	Yellow-orange/brown rusty or weathered claybound gravels and sands.
	Cannington Beach/Marine	27.4	1.43-62	7.44	Blue-grey well rounded gravels and sands with seashells present in many deposits. Higher yielding aquifers occur in the more gravel dominated layers. Aquifers can be interbedded with swampy deposits of green-blue silts, clays and sands.
Southburn Sand <sup>3</sup>		8.46	0.3 – 21.2	0.2	Grey running sand (occasional gravels) and shells.
Taratu Formation <sup>3</sup>		11.2	0.4 – 16.7	0.93	Small quartz gravels, shells and sand with silt. The presence of lignite is indicative of Taratu Formation.

<sup>1</sup> Refer to Figure 5.2 for location of Quaternary Alluvium aquifers. There was not enough data to obtain yield and specific capacities for the Kohika sub area

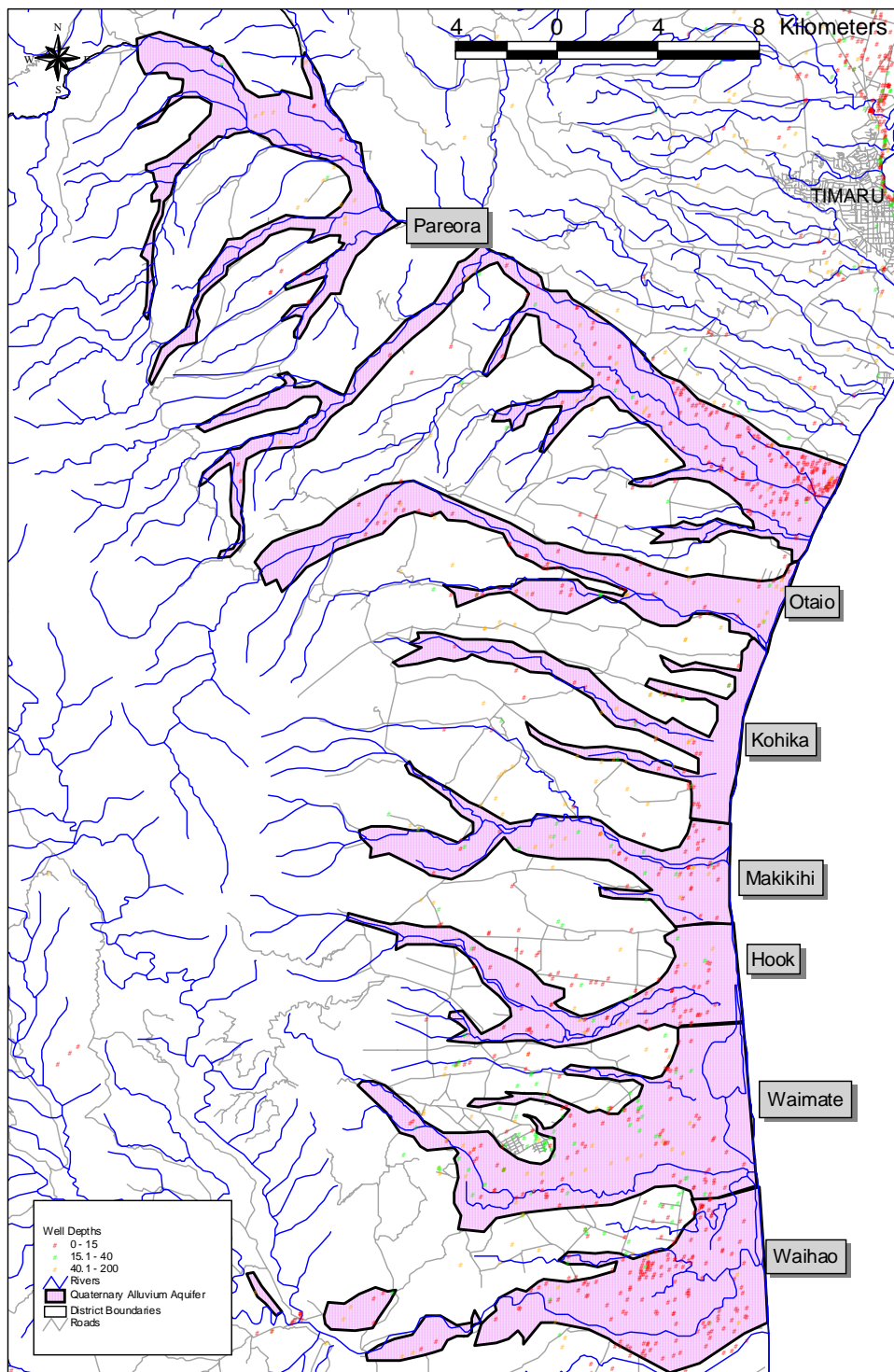
<sup>2</sup> Refer to Figure 5.3 for location of Cannington Gravel aquifers.

<sup>3</sup> Refer to Figure 5.4 for location of Southburn Sand and Taratu Formation aquifers

#### 6.2.1.1 Quaternary Alluvium

Quaternary alluvium overlies much of the study area (refer to Chapter 3 and Figure 3.1), within the river valleys. Shallow aquifers are generally encountered in higher permeability sandy gravel deposits, which are often relic channels of the modern day rivers, within the river valleys. The extent of the resource is limited by the extent of the river valleys bounded by terraces, and the aquifer gravels are typically only 2-20m thick. Interspersed with the sandy gravel channels are silt and claybound gravels, which have lower permeabilities, but still may yield sufficient water for domestic or stock supply. Finer grained coastal sediments up to a few metres thick overlie the alluvium in the area east of the old coastal cliff (Section 3.1). The river valleys within which the Quaternary alluvium occurs are detailed Figure 6.2. Well depths are overplotted in this figure to illustrate how the majority of shallow wells (<15m depth – coloured red) occur in the Quaternary alluvium associated with each river valley.

Older Quaternary gravels exist over most of the downlands areas, and are generally capped by loess often greater than 3m thick. Scattered shallow wells exist in the area south of Timaru and around Waimate, but it is difficult to distinguish the older Quaternary gravels from the underlying Cannington Gravels of the Kowai Formation.



**Figure 6.2 Extent of Quaternary Alluvium aquifer in the Pareora-Waihao catchments**

**6.2.1.2 Cannington Gravels**

‘Cannington Gravels’ are the South Canterbury equivalent of the Kowai Formation in North Canterbury. They comprise of ‘weathered red, orange and brown gravel, sand and muds...commonly cemented by clay and iron oxides’ (Forsyth, 2001). The lowest part of the Cannington Gravels are marine containing abundant shells which outcrop at Timaru and Makikihi. Blue gravels, which signify reducing conditions are generally found lower down the sequence. The thickness may exceed 180m (Timaru) to 230m (Waimate), but may vary geographically (Forsyth, 2004). Aquifers occur both within the terrestrial gravel deposits, and

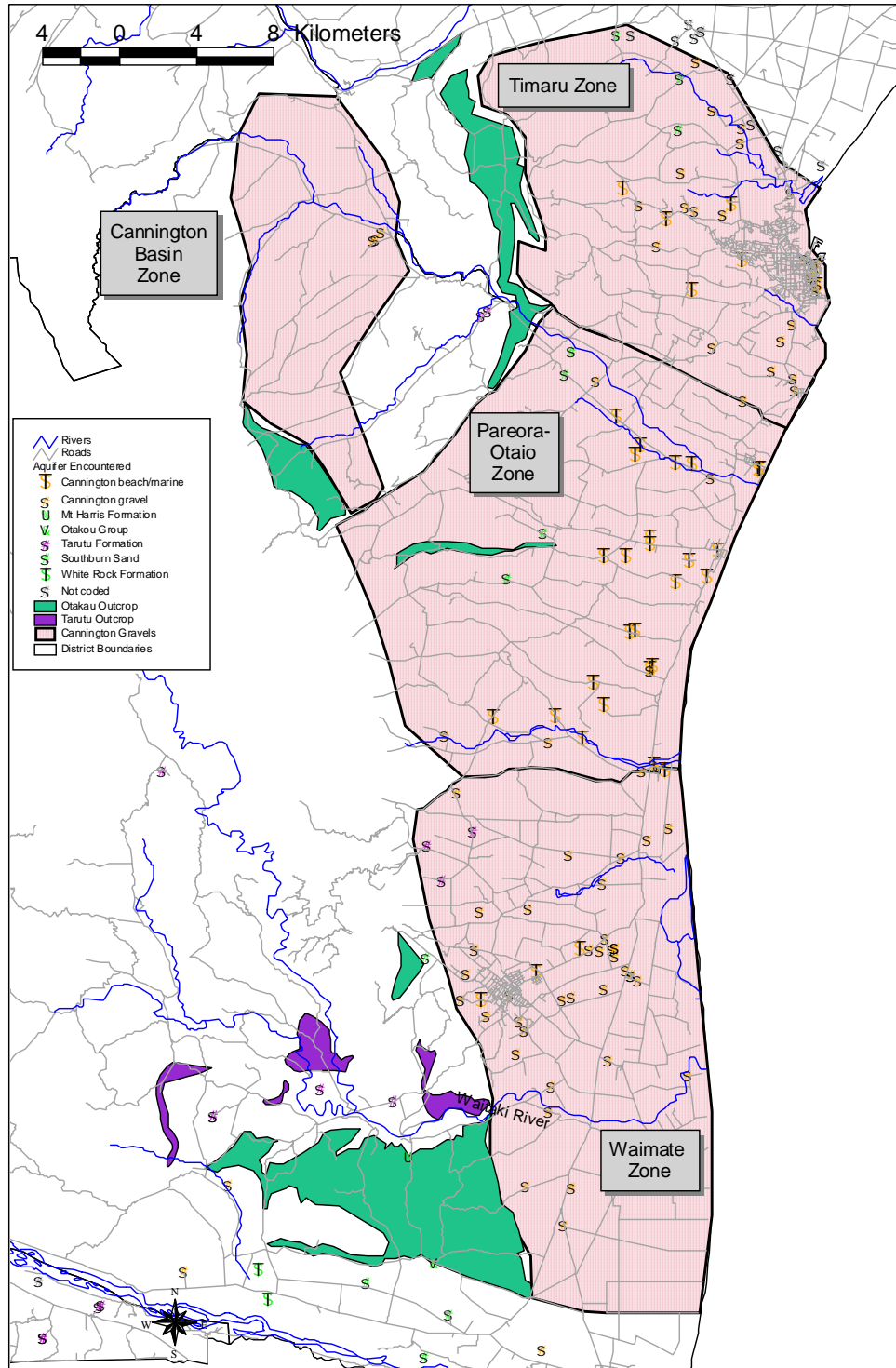
marine/beach environments. These have been separated into 'Cannington Terrestrial aquifers' and 'Cannington Beach/Marine aquifers' (Aitchison-Earl, 2005).

In the Cannington Terrestrial gravels aquifer yields range from 0.16 – 56.8 L/s (Table 6.2). The wells are often screened over ten's of metres to achieve higher yields. Cannington Gravels are present from Timaru to the Waitaki River, but are most highly developed in the Waimate area, where the thickness is greater than 239m adjacent to the Hunter Hills (Aitchison-Earl, 2005).

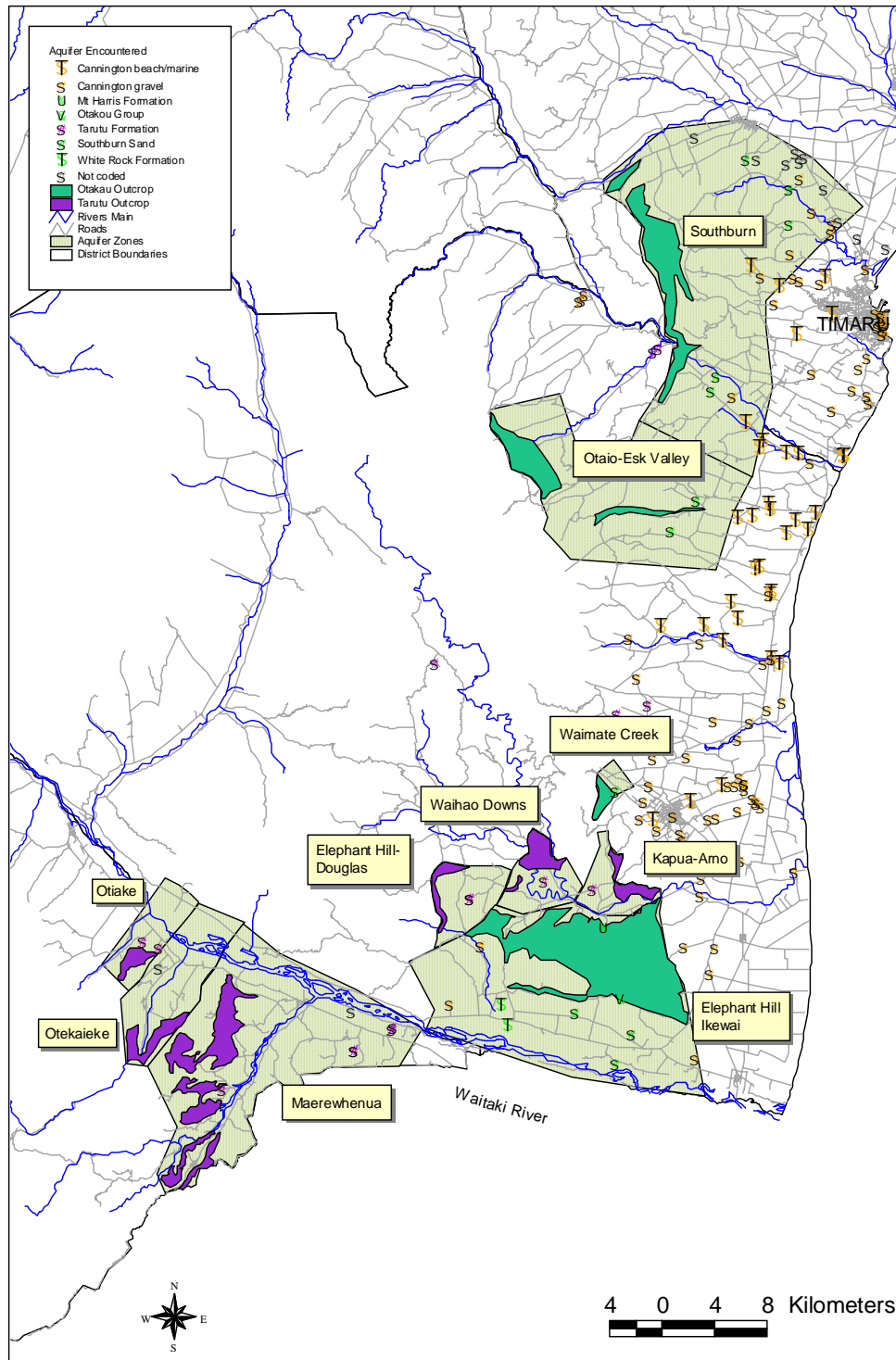
Aquifers within Cannington Beach/Marine deposits are generally better yielding with an average yield of 27.4 L/s, and specific capacity of 7.4 L/s/m compared to 3.6 L/s/m in the Terrestrial gravels (Table 6.2). The aquifer is present in blue/grey sands and well-rounded small-large gravels, often with seashells. The higher yielding layers appear to be gravel dominated (often interpreted as 'beach gravels' in Forsyth, (2004)). The aquifer layers are interspersed with green-blue silts-clays and fine sands, which may be from a swampy environment, and may act as confining layers. Geographically Cannington Beach/Marine aquifers occur from Timaru (Gair, 1961) to at least Makikihi (where it outcrops). Deeper (>100m) wells near Waimate have recorded shells within gravel units, and may indicate the Cannington Beach/Marine sequence extends further south than Makikihi. The depth that the marine deposits occur ranges from 40-180m below ground at different localities (Aitchison-Earl, 2005).

The location of wells penetrating aquifers in Cannington Gravels is shown in Figure 6.3, with wells penetrating the gravels shown by the orange circles (Cannington Terrestrial) and triangles (Cannington Beach/Marine). Four hydrogeological sub-zones are shown on the map as follows:

- Timaru Zone: Cannington Gravels are overlain by the Timaru Basalt and loess, which may impede potential recharge. At greater depths the marine sequence of Cannington gravels is encountered.
- Cannington Basin Zone: Cannington Gravels outcrop extensively at the surface, and are separated from the downstream Pareora-Otaio zone by upthrown fault blocks.
- Pareora-Otaio Zone: Cannington gravels are overlain by Quaternary alluvial and loess deposits. At greater depths the Cannington Marine sequence of shelly blue sands, silts and gravels is encountered.
- Waimate Zone: The Cannington Gravels are extremely thick in this zone, especially in the Waimate area. Most wells are within the terrestrial sequence, characterised by claybound rusty gravels, and numerous thick clay layers.



**Figure 6.3 Cannington Gravel aquifers approximate extent, and sub-zones**  
 NB Outcrops of Tertiary Otakou and Tarutu/Broken River Formation shown for comparison



**Figure 6.4 Location of Southburn Sand (Otakou Group) and Taratu Formation aquifers (Source: Aitchison-Earl, 2005)**

**6.2.1.3 Southburn Sand**

The Otakou Group is predominantly marine and fossiliferous, with mid-shelf sandstone and siltstone (Mt Harris Formation) succeeded by a shallow marine sandstone (Southburn Sand) and quartz sandstone, carbonaceous mudstone and lignite (White Rock Coal Measures) (Forsyth, 2001). Groundwater is found predominantly in the Southburn Sands, although there are a few wells in other parts of the Otakou Group.

The Southburn Sand is a blue-grey sandstone with shelly concretions. Drillers' logs report the aquifer as grey-blue silty sand with shells. The extremely sandy nature of the deposits creates problems with screening the aquifers to avoid sand being sucked into pumps, leading to a lot of time spent developing the wells. Yields range from 0.3 – 21.2 L/s with an average of 8.46 L/s, however the average specific capacity is low, indicating that there are large drawdowns associated with pumping. Figure 6.4 illustrates wells penetrating the aquifer (green symbols), the outcrop areas of the Southburn Sand (green shading), and the associated aquifer zones (from Aitchison-Earl, 2005). The eastwards dip of the Southburn Sands means that wells may penetrate it at economic drilling depths only in the western areas of the downlands, as is illustrated by the occurrence of wells in Figure 6.5.

#### 6.2.1.4 *Taratu formation*

The Taratu Formation (which is locally referred to as the Broken River Formation) is part of the Onekakara Group and unconformably overlies basement greywacke. In North Otago the aquifer is referred to as the 'Papakaio Formation'. The formation is of variable thickness, and can be absent locally. The lowermost beds of this unit consist of quartz conglomerate, sandstone, mudstone and coal. Drillers' logs describe the aquifer as quartz grits to gravels often underlying lignite or coal. The aquifer can contain silts, sands and shells. Well yields range from 0.4 – 16.7 L/s, with an average of 11.2 L/s (Table 6.2). Figure 6.4 illustrates wells penetrating the Taratu Formation aquifer (purple symbols), the outcrop areas of the Taratu Formation (purple shading), and associated aquifer zones (from Aitchison-Earl, 2005). Aquifer zones for the Taratu Formation are mainly based on fault separations.

### 6.2.2 **Aquifer parameters**

There is considerable variability in aquifer parameters for each of the distinct aquifers of the Pareora-Waihao regions. Table 6.2 summarises aquifer yields, specific capacities, estimated transmissivity and storativity. Aquifer test locations and a summary of results are included as Appendix 33. There are only six wells with available aquifer test data; hence, the parameters within Table 6.2 are based on specific capacity data and hydrogeological understanding of each aquifer. Each aquifer is discussed in more detail below.

**Table 6.2 Aquifer parameters Pareora-Waihao River catchment groundwater**

Aquifer Zone		Yield Range (L/s)	Average Specific Capacity (L/s/m)	Estimated Transmissivity Range <sup>1</sup> (m <sup>2</sup> /day)	Aquifer thickness (m)	Storativity
Quaternary Alluvium	Pareora	0.1 – 30.4	17.7	<100 – 10,000 (2500)	1 – 17m	0.01 – 0.3
	Otaio	0.1 - 30	5	no data	1.8 – 13m	0.01 – 0.3
	Makikihi	0.1 – 49.4	5.8	50 – 1200	7 – 25m	0.01 – 0.3
	Hook	0.05 - 32	9.1	< 100 – 10,000	5 – 15m	0.01 – 0.3
	Waimate	0.1 - 15	3.8	< 100 - 1600	10 – 25m	0.01 – 0.3
	Waihao-Wainono	0.1 – 56.9	8.4	500 – 10,000 (1600)	10 – 20m	0.01 – 0.3
Cannington Gravels	Cannington Terrestrial	0.1 – 56.8	3.64	20 - >5000 (2130)	20 - >240m	0.00001 – 0.1
	Cannington Marine	1.3 - 62	7.44	180 - >5000 (3310)		0.00001 – 0.01
Southburn Sands		0.3 - 21	0.19	30 - 300	<50 – 200m+	0.00001 – 0.1
Tarutu Formation		0.3 – 16.7	0.93	5 - 1000	< 50 – 120m <sup>2</sup>	0.00001 – 0.1

<sup>1</sup> Estimated Transmissivity values are taken from conversion of specific capacity data from wells in the aquifer using the Bal (1996) formula. Italics in brackets indicates values from actual aquifer testing (individual tests).

<sup>2</sup> From Forsyth, (2001)

#### 6.2.2.1 Quaternary alluvium

A lack of geological well logs makes interpretation of aquifer thickness difficult. It is assumed that all of the shallow river aquifers thin towards the Hunter Hills, with gravels only a few metres thick in the upper river reaches. The thickness of the more recent river gravels compared to the underlying Cannington Gravels is difficult to distinguish in many well logs. The average thickness in the river valleys is between 5 and 15m. In the coastal area, well logs show greater thicknesses of gravels, interspersed with silt/clay layers to the east of an old sea cliff (Section 3.1).

Aquifer tests have been conducted in the Pareora (Aitchison-Earl, 2001 – well J39/0146) and Studholme areas (Henshaw et. al, 2003 – well J40/0049). These tests yielded transmissivity values of 2500 and 1600 m<sup>2</sup>/day respectively. Both tests were on irrigation wells, which are more likely to be located in areas of higher transmissivity. Slug testing on ECan monitor well J39/0358 at Pareora Railway Bridge indicated moderate values of hydraulic conductivity (< 100m/day). These results are indicative of permeable highly transmissive old river channels of gravels and sand adjacent to less permeable more clay/silt bound gravels (possibly overbank deposits).

The results from the aquifer test on J39/0146 indicated that the Pareora River at 600m distance was acting as a recharge boundary. Similar behaviour would be expected from any of the shallow river aquifers, given the proximity of the rivers in the narrow valleys.

Storativity values were typical for unconfined to semi-confined aquifers. The Pareora aquifer test obtained a value of 0.07 (unconfined), whereas the Waihao North aquifer test obtained a value of 0.00027, typical of a leaky semi-confined aquifer (with the aquifer overlain by up to 5m of silts). The coastal area east of the sea-cliffs is more likely to be semi-confined by coastal sediments from the last sea level rise, and more inland areas to be unconfined, with alluvial silts providing less extensive semi-confining layers.

#### 6.2.2.2 *Cannington gravels*

Cannington Gravels vary in thickness geographically. In general the gravels will increase in thickness towards the coast, as they overlie gently eastwards dipping tertiary sediments. In the upper Pareora River valley, the total thickness of the Cannington Gravels can be ascertained from well logs as around 60m. In the upper Hook it appears to be around 120m thick. The thickest sequence is at Waimate, adjacent to the Hunter Hills where the gravels are greater than 240m thick (J40/0632). This may be related to the downthrow of a fault along the Hunter Hills, allowing a greater thickness of gravels to accumulate. Towards the coast the Cannington Gravel sequence may be several hundred metres thick (based on the eastwards dip of the exposed tertiary sequences inland), and no well log penetrates the full thickness. At Timaru, bore holes penetrate in excess of 160m of Cannington Gravels (J39/0193, J39/0494). Higher transmissivity values would be expected in the marine sequence of the Cannington Gravels, with beach gravel and sand deposits displaying high yields.

Aquifer tests have only been undertaken on artesian wells within the Cannington Gravel Marine sequence at the PPCS Freezing Works at Pareora (J39/0009 and J39/0010). These displayed a distinct tidal cycle in water pressures making analysis difficult. Tidal efficiency was calculated at 0.45, transmissivity at around 3310 m<sup>2</sup>/day and storativity to be typical of semi-confined (0.001 – 0.0008).

An aquifer test on the Cannington Terrestrial was undertaken at Hook (ECS, 2005) on 77 m deep bore J40/0153. This derived a transmissivity of 2130 m<sup>2</sup>/day and storativity of 0.00069. The test data indicated a confined aquifer with leakage assumed to be very small.

Aquifer storativity is therefore typically semi-confined, although it may become unconfined where Cannington Gravels outcrop (i.e. Cannington Basin). It is certainly semi-confined to confined underlying the Timaru Basalt.

#### 6.2.2.3 *Southburn sands*

The Southburn Sands are part of the Otakau group, which also includes the units White Rock Coal Measures and Mt Harris Formation. The White Rock Coal Measures have a few wells tapping aquifers (Aitchison-Earl, 2005), but the Mt Harris Formation is not an aquifer, and could act as an aquitard. On the geological map the three units are mapped as one together, making it difficult to determine the thickness of the Southburn Sands. Wells drilled in the Pareora to Pleasant Point areas indicate thicknesses in excess of 200m in some locations. Transmissivity values are estimated from well specific capacities at 30 – 300 m<sup>2</sup>/day. If the aquifer is estimated to be 200m thick (for example) the hydraulic conductivities would be 0.15 – 1.65m/day, equivalent to that expected for a silty sand/fine sand (Fetter, 2001). The aquifers are likely to be semi-confined, but may be unconfined at outcrop.

#### 6.2.2.4 *Taratu Formation*

The Taratu (Broken River) Formation consists of coal/peats/silts/quartz gravels and sands. The aquifer occurs within the quartz gravel and sand units, which are often toward the bottom of the Taratu Formation, overlying the basement rock. These quartz gravels and sands were formed from the lag deposits of deep weathering of a Cretaceous peneplane. Fluvial processes subsequently sorted the deposits repeatedly. As a fluvial environment, there are gravels, sands, silts and swamp (carbonaceous) deposits within the Taratu Formation. Hydraulic conductivities are thus expected to vary, with higher values in gravels and sands, and lower in peats and silts. There are no aquifer tests recorded on ECan databases but within the Taratu Formation in North Otago (referred to as the Papakaio Aquifer) transmissivities of between 70 – 450 m<sup>2</sup>/day are recorded, with an average value of 195 m<sup>2</sup>/day (ORC, 2004). The aquifer may be unconfined in outcrop to semi-confined to confined where overlain by less permeable younger Tertiary sediments.

### 6.2.3 Groundwater movement

Groundwater movement can be estimated regionally from piezometric contours, and knowledge of the underlying geology.

Piezometric surveys of shallow groundwater were undertaken in 1969 and 1981 in the Pareora Valley, and of the area from Pareora to Waitaki in 1978-79. These surveys did not extend inland along the Otaio, Makikihi and Hook Rivers, or inland as far as Waimate, as there were insufficient wells to permit contouring. Subsequent more extensive surveys of shallow groundwater have been undertaken by Environment Canterbury for the Pareora (2000), Otaio (2001) and Makikihi-Waihao areas (2002 and 2003). Maps of the piezometric surveys are included in Appendix 34. Piezometric contours are not available for deeper aquifers. Groundwater movement is discussed for each catchment below.

#### 6.2.3.1 Pareora Valley

The piezometric contours indicate that the upper Pareora River loses water to groundwater in the reaches below Holme Station Bridge. Groundwater flows parallel to the river down the incised valley, and in the lower reaches flows towards the Pareora River mouth. The profile of flow losses and gains is confirmed by gauging data (Section 4.3). In the Springbrook area (to the south of the river near the coast) inputs from Springbrook Creek cause the piezometric contours to curve with groundwater flowing eastwards towards the river and the coast. There is little difference in piezometric head between the 1969, 1985 and 2000 surveys, with water levels slightly lower in 2000.

Groundwater sourced from the Southburn and Gordon's Valleys (on the south side of the main channel) is postulated as an additional source of recharge in Waugh (1987), based on water chemistry data indicating a greater proportion of surface drainage than is seen on the north side of the river. There are however not enough wells around the confluence of the valleys with the Pareora to show this in the piezometric contours.

#### 6.2.3.2 Otaio Valley

Piezometric contours in the Otaio Valley are fairly coarse, with a limited number of wells/water holes to measure. The contours constructed indicate flow parallel to the river down the river valley, with some indication of additional groundwater flow from the Esk Valley.

#### 6.2.3.3 Makikihi

Only the lower part of the Makikihi has enough wells to create piezometric contours. These indicate groundwater flowing parallel to the river, with recharge from the groundwater system towards the river on the north bank near State Highway One.

#### 6.2.3.4 Wainono Lagoon Tributaries

The piezometric map, especially from 2002 and 2003 clearly show groundwater flowing towards Wainono Lagoon, and the Dead Arm of the Waihao River. Piezometric contours indicate a groundwater divide towards the Coast at Hook, with part of the groundwater flowing north-west, and part of the groundwater flowing south-west towards Wainono Lagoon. Water is shown as being lost from the Hook River in its mid-reaches (part of which is intercepted as springs feeding Merrys Stream).

Around Waimate township, groundwater flows eastwards, but towards Wainono Lagoon the direction shifts to the north-west (to flow towards the Lagoon)

Groundwater is sourced from the upper-mid reaches of the Waihao River, and flows to the north of the River towards the coast in a nor-east-easterly direction, feeding the springs of Buchanans and Sir Charles Creek. On the south bank groundwater flows parallel to the river, and there are indications of recharge from groundwater in the south from the Morven Glenavy Irrigation Scheme (MGIS).

#### 6.2.3.5 *Deeper groundwater*

Groundwater flow directions in deeper aquifers, including the Cannington Gravels, Southburn Sands and Taratu Formation are unknown. There are no piezometric surveys, and little water level information for these aquifers. From geological mapping, the Tertiary sediments and overlying Pleistocene Cannington Gravels are known to dip gently towards the coast. It is therefore assumed that regional groundwater flow direction will be parallel to this dip.

#### 6.2.4 **Groundwater levels**

Groundwater levels in the Pareora-Waihao River catchments have been measured by a variety of agencies since the 1940's. The first measurements were taken by the New Zealand Geological Survey, which monitored wells at 3 monthly intervals until 1979. Subsequent monitoring was undertaken by the SCCB, and then Environment Canterbury. There are 200 wells with more than 5 groundwater level measurements, and 173 with more than 10 measurements between Pig Hunting Creek and Barnettts/Ryans Road (South of the Waihao River). Figure 6.5 illustrates the locations of the wells that have been monitored, and indicates which organisation began the monitoring (in some cases, a well has been measured by several organisations). The wells shown in green are currently monitored by ECan, and summarised in Table 6.3. It can be seen from Figure 6.5 that the first monitoring by NZGS covered much of the shallow aquifer areas, including river valleys and intervening downlands. Monitoring by the SCCB concentrated on the Pareora River Valley, and the Waihao River system, where large amounts of data are available from 1969 – 1975. Wells monitored by ECan include those measured specifically for water levels, and those with water levels monitored as part of water quality sampling. The current ECan network has a broad geographical coverage of shallow aquifer levels, but until recently did not have coverage of deeper aquifers. A field well inspection project was completed in 2005 (Eggleton, 2005), which led to the inclusion of seven deeper wells within the monitoring network. Well hydrographs for selected monitoring sites (along with a location map) are included in Appendix 35.

Long term water levels from wells J40/0050 (recharged by the Waihao River) J40/0047 (rainfall recharged inland from Wainono Lagoon) and J40/0055 (rainfall recharge downlands area near Nukuroa) are illustrated in Figure 6.6. The hydrograph for J40/0055 and J40/0047 both show a typical rainfall recharge pattern of highs and lows, whereas J40/0050 has a typical river recharge pattern, with fairly constant high values, and water levels only falling in times of low/dry river flows. Well J40/0047 with a record since 1950 shows a period of lows in the late 1960's to early 1970's, and a period of higher groundwater levels in the late 1970's. There have been periods of low groundwater levels since 2001, as well as the 1968 and 1971 years. J40/0055 displays the same high groundwater levels in the late 1970's, and low levels which occur more frequently since 1998 (the well going dry in the years 1973, 1985, 1989, 1998, 1999, 2001 and 2002). Groundwater levels in J40/0050 are low in 1972, 1988 and 1998, coinciding with extended periods of low flow in the Waihao River.

Analysis of water levels has been completed in file notes Aitchison-Earl (2004b, 2004c, 2004d) for the Pareora, Otaio and Waihao River systems, focussing specifically on ground-surface water interaction. These analyses are detailed in Section 6.2.5 and Appendix 35.

**Table 6.3 Current groundwater level monitoring network**

Well number	Depth	Reading Start	Number of readings	Type of Site	History and Reason for Monitoring
J39/0006	11	8/7/85	957	Recorder	Installed by SCCB as a recorder site to allow correlation of groundwater levels and Pareora River Flow
J39/0020	72.5	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Cannington Beach/Marine.
J39/0070	?	6/1/70	139	Monthly	Initially measured by SCCB until stopped in 1978, resumed in 2001 by ECan to replace filled in well J39/0058 for areal network distribution in the mid- Pareora Valley
J39/0091	57.2	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Cannington Beach/Marine.
J39/0145	129.1	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Cannington Beach/Marine.
J39/0150	2.6	22/12/98	73	Monthly	Measured since 1998 by ECan for areal distribution in the lower Otaio
J39/0239	5.5	12/10/99	129	Recorder	Installed by ECan in 1999 to correlate with Otaio flow
J39/0255	6	12/10/99	191	Recorder	Installed by ECan in 1999 to correlate with Otaio flow
J39/0258	3.8	1/8/69	129	Monthly	Measured by SCCB until 1981, picked up by ECan in 2000 for areal distribution in the south bank, Pareora Valley.
J39/0358	10	7/12/00	178	Recorder	Installed by ECan to correlate to flow recorder site at Railway Bridge (since dismantled).
J39/0473	126.7	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Cannington Beach/Marine.
J39/0485	96.5	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Cannington Beach/Marine.
J39/0492	217	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Southburn Sand
J40/0044	9.5	29/9/78	206	Monthly	First monitored by SCCB to measure effect of MGIS scheme on groundwater levels.
J40/0045	4	8/10/69	300	Monthly	First monitored by SCCB to measure effect of MGIS scheme on groundwater levels, and the adjacent Waihao River.
J40/0047	9.6	14/9/50	271	Monthly	Measured by NZGS, then SCCB and ECan. Monitors rainfall fed groundwater on Wainono Lagoon margin
J40/0050	4.4	3/10/69	290	Monthly	First measured by SCCB, monitors groundwater flow towards Buchanans Creek.
J40/0051	4.8	29/9/69	313	Monthly	First measured by SCCB, monitors water levels adjacent to Waihao River.
J40/0054	31	16/2/84	205	Monthly	First monitored by SCCB. Measures a deeper rainfall fed semi-confined aquifer (Cannington Gravel), with irrigation takes in the vicinity
J40/0055	10.8	9/3/67	289	Monthly	First measured by SCCB, records rainfall recharged area of groundwater.
J40/0056	9	26/9/69	313	Monthly	First measured by SCCB, monitors water levels adjacent to Waihao River.
J40/0057	5.3	10/9/84	196	Monthly	First measured by SCCB, monitors water levels adjacent to Waihao River.
J40/0058	5.4	22/2/63	383	Monthly	First measured by SCCB, monitors water levels near Willowbridge township.
J40/0059	?	18/9/69	212	Monthly	First measured by SCCB, monitors water levels adjacent to Waihao River.
J40/0071	9.4	26/7/89	712	Recorder	Purpose drilled recorder site by SCCB, measured groundwater levels upstream of Willowbridge township, and Buchanans Creek, and correlates to Waihao River flow.
J40/0095	9.5	14/6/94	125	Monthly	First measured from 1994 to monitor groundwater levels associated with Wainono Lagoon.
J40/0237	6.5	11/4/2000	47	Monthly	First monitored by ECan to record groundwater levels in vicinity of spring source of Merrys Stream.
J40/0238	11.7	4/3/65	119	Monthly	Measured by NZGS, then ECan. Monitors rainfall fed groundwater on Wainono Lagoon margin
J40/0294	5.4	15/12/99	61	Monthly	First measured by ECan as well is adjacent to J40/0054, and measured adjacent shallow water table.
J40/0356	7	14/4/99	68	Monthly	First monitored by ECan for Makikihi River groundwater.
J40/0837	16	29/8/2003	16	Monthly	Purpose drilled by ECan to monitor water levels adjacent to Wainono Lagoon.
J40/0839	230.8	July 2005	1	Monthly	Deep well to be added to network in July 2005 – screened in Taratu Formation

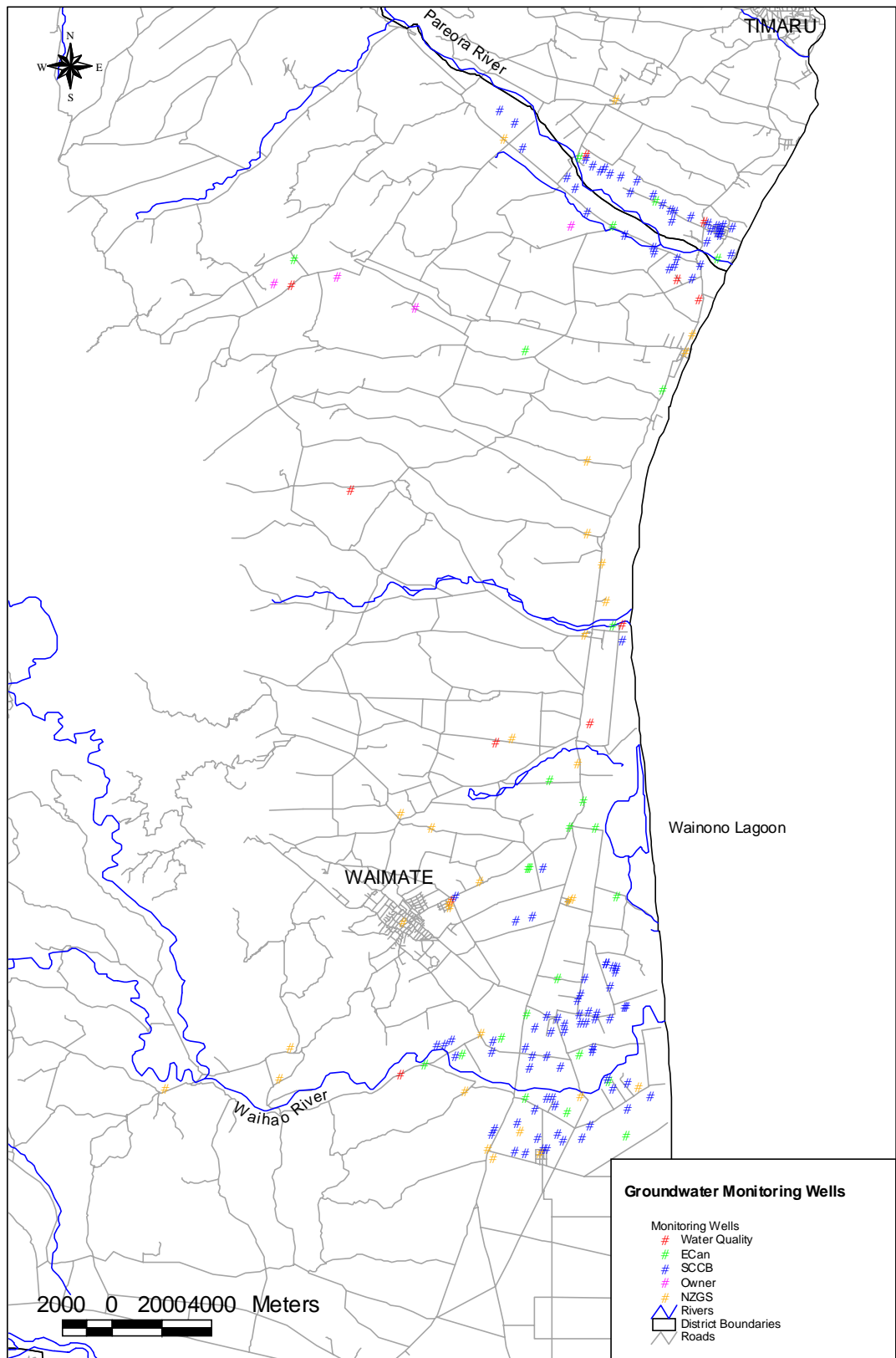
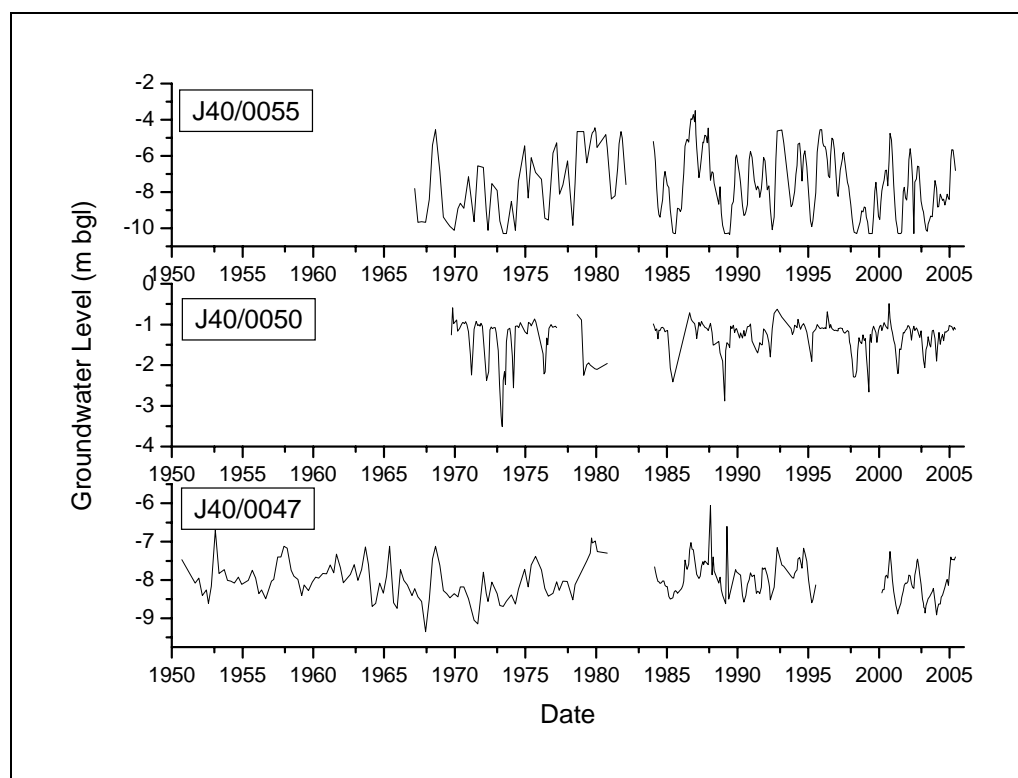


Figure 6.5 Monitoring well locations, Pareora-Waihao (for wells with > 10 measurements)



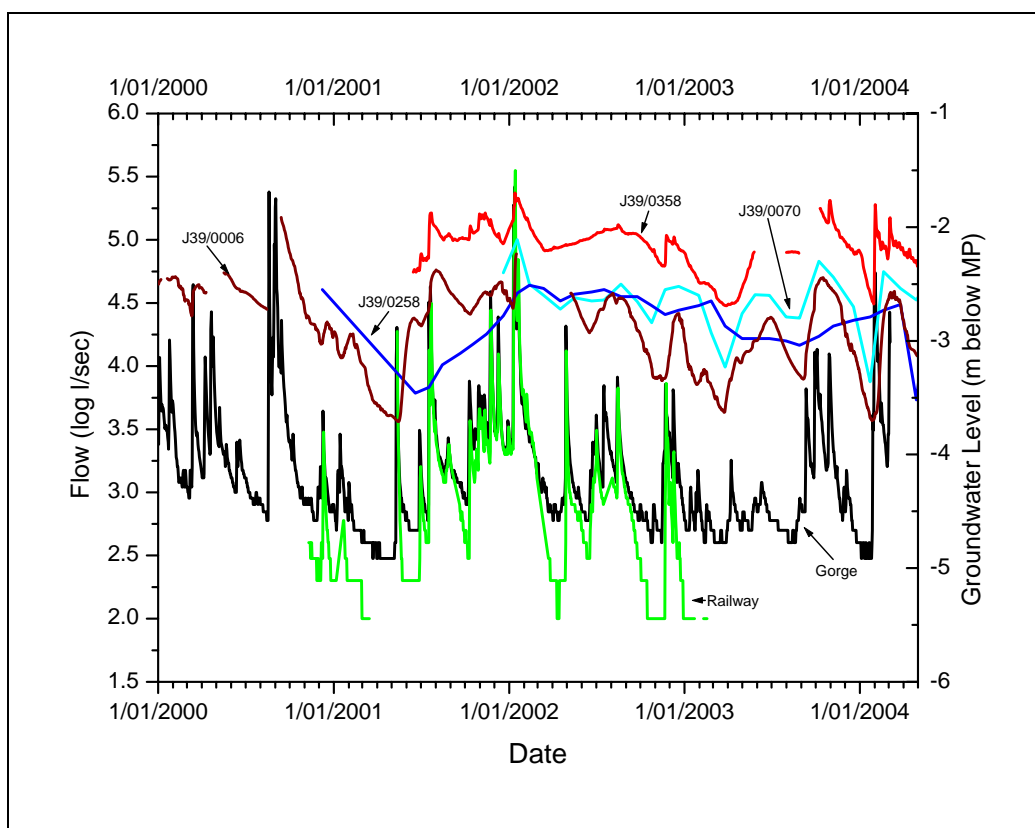
**Figure 6.6 Long term water levels at wells J40/0050, J40/0055 and J40/0047**  
 (Location of wells in Appendix 35)

## 6.2.5 Surface-groundwater interaction

### 6.2.5.1 Pareora

The Pareora River Valley shallow groundwater system (downstream of the Pareora Gorge and located within terraces) is highly interconnected to surface water flows. The range of flows recorded at Pareora Huts and Railway Bridge, and measured groundwater levels at selected sites, since January 2000 are shown in Figure 6.5 (location of sites in Appendix 35). There is an obvious correlation between surface flow and groundwater levels, with increasing rapid increased in groundwater levels in response to high flow events.

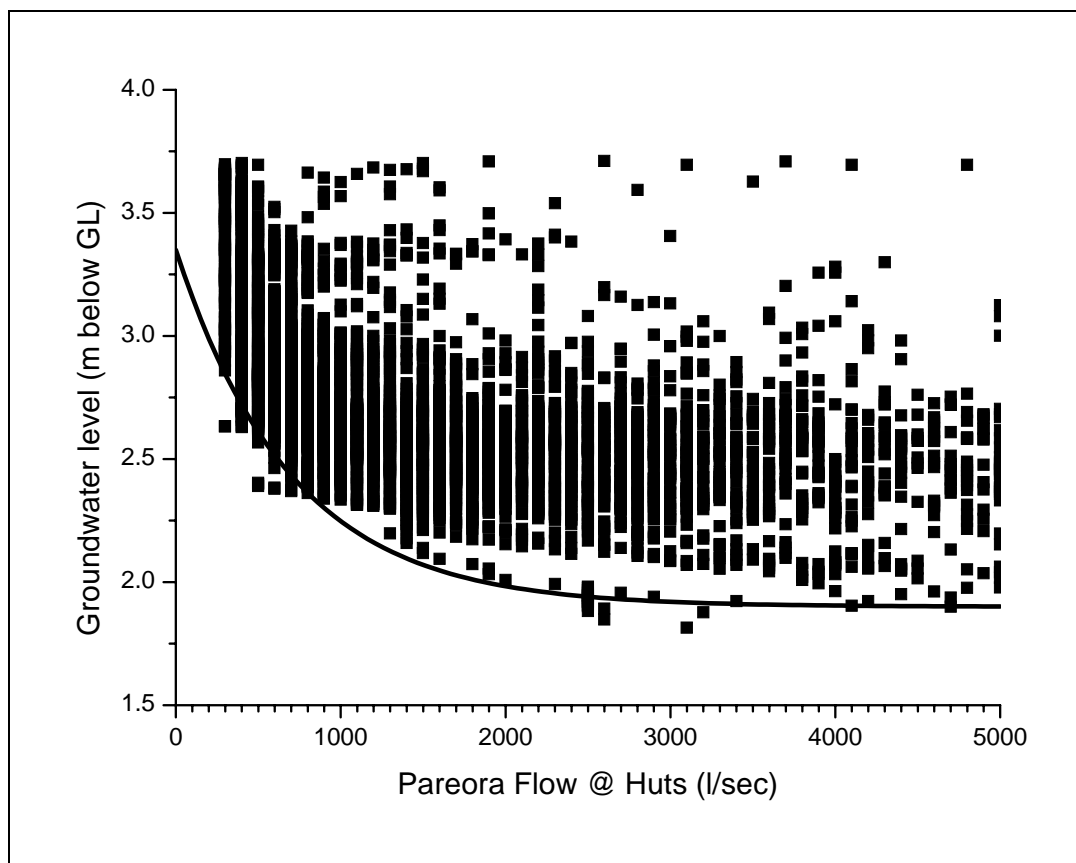
Comparison of river flow and groundwater levels (Appendix 36) has shown that the shallow aquifer is full when flow at Huts is around 1000 L/s. This is illustrated in Figure 6.8, which shows the relationship between Pareora flow at Huts, and groundwater levels in recorder well J39/0006 (points above the fit line indicate the aquifer is still filling).



**Figure 6.7 Pareora River flow and groundwater levels**

The profile of losses and gains in the main channel of the Pareora is consistent with groundwater flow information. Piezometric contours (Appendix 33) indicate that water is lost to groundwater downstream of Huts. This occurs mostly to the south side between Holme Station and Brassels Bridge, as the north side is bounded by a terrace (Waugh, 1987), and mostly to the north side downstream of Brassels Bridge, through what may be old channels (Waugh, 1987). Groundwater re-emerges downstream of Midgeleys from the north and south sides.

A small creek that crossed the Highway, and enters the Pareora upstream of the Railway Bridge arises from springs upstream of State Highway One on the north side of the river. Anecdotal evidence from a landowner (B Yates, pers. comm., 2000) indicates that this creek used to flow all year, and it is only in recent times (last 5-10 years) that the creek has become dry.



**Figure 6.8 Relationship of Groundwater Level at J39/0006 and flow in Pareora River at Huts**

$$\text{(where GWL} = 1.9 + 1.45 * e^{(-x/700)})$$

There are no groundwater level monitoring sites in the Cannington Basin, or Pareora South Branch to compare to river flows.

#### 6.2.5.2 Otaio surface-groundwater interaction

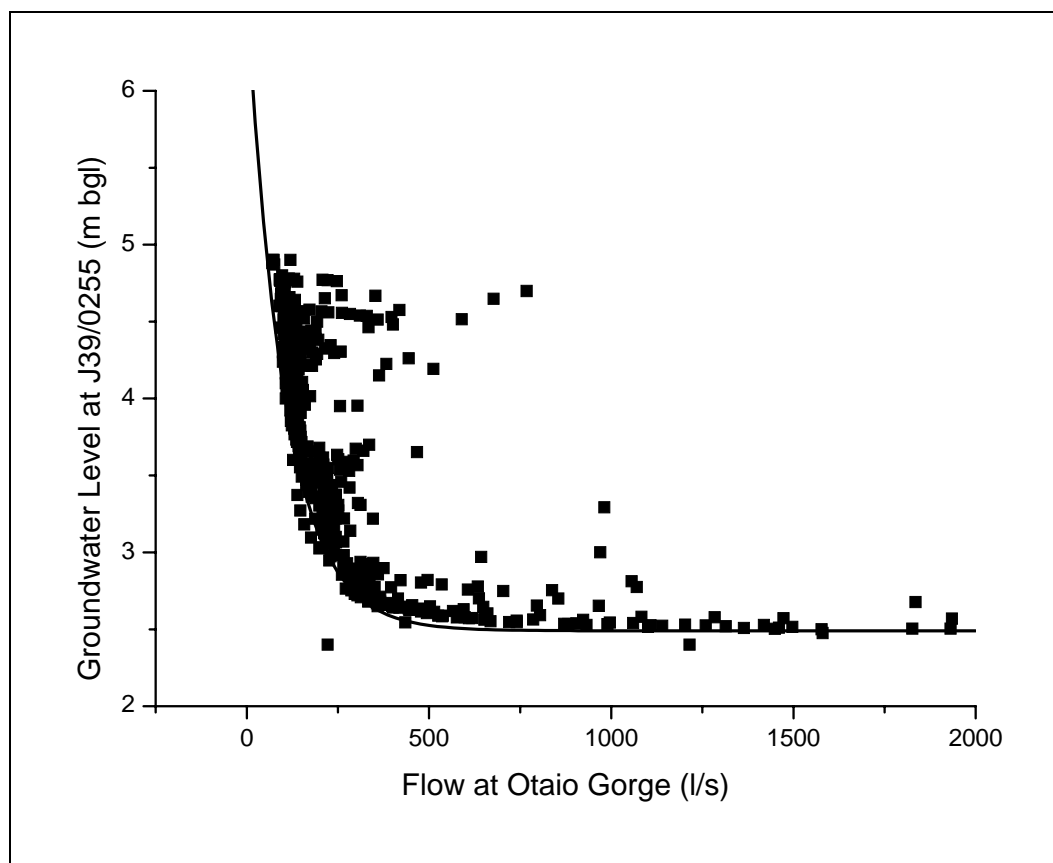
The Otaio River Valley groundwater system is highly connected with surface water flows. Apart from local rainfall, the Otaio River (and its tributary the Esk Valley Stream) is the main source of recharge to the shallow groundwater aquifer. At the Otaio Gorge, flow enters the Otaio River Valley flowing directly over the tertiary siltstone deposits of the Otakau Group (Forsyth, 2001). Downstream the gravel of the riverbed and surrounding land becomes slightly thicker. Bore logs from wells upstream of Drinnans Bridge indicate gravel depths of between 5 and 15m, and trenching (by Waimate District Council) across the river bed between Bluecliffs Crossing and McAlwees crossing encountered the siltstone at a very shallow depth. Further down river, anecdotal evidence (G Johnson, Pers. Comm.) indicates that 'clay' layers force the river to rise to the surface around Grays Crossing. A clay base was encountered in ECan monitoring well J39/0239 (location in Appendix 35), at 3m below the gravels of the river bed.

The variable thickness and width of the gravels containing the shallow groundwater resource influences the profile of flows measured in the Otaio River. As detailed in Section 4.5.3, the Otaio loses water between the Gorge and McAlwees Crossing. This corresponds with an area where gravels become thicker, and water may be lost to storage in the groundwater system. Gains in flow are observed between McAlwees Crossing and Drinnans Bridge. In this area, the gravels become thinner again (note the 'Blue Cliffs' evident to the north of the Otaio in this reach which indicate that the gravels of the river bed are likely to be very thin), forcing groundwater to the surface leading to the increase in flow. In this reach, a spring-fed creek (which often flows when the river bed is dry) also intercepts some of the groundwater,

which feeds into the Otaio River again downstream of Esk Bank Ford. The existence of this creek may explain the apparent losses in flow from Drinnans Bridge to Esk Bank Ford. Downstream of Esk Bank Ford, further gains in flow are observed. The gain to Grays Crossing Road may be influenced by the shallower thickness of gravels in this area (as described in the paragraph above). The gain between Grays Crossing Road and State Highway One will be due to the re-emergence of groundwater towards the coast, as the groundwater level approaches sea level, observed in most rivers in Canterbury.

A number of shallow wells have been monitored in the Otaio Valley. Comparison of the levels with flow in the Otaio River at the Gorge displays a relationship, best achieved using an exponential decay model. Figure 6.9 illustrates an example of flow at the Gorge, and water levels in J39/0255 (the remaining analyses are included in Appendix 36). The exponential decay model is most appropriate, as the groundwater behaviour showed that once the aquifer was full, increased river flows would not lead to any further increases in groundwater level. As detailed in Appendix 36 the relationship between flow and groundwater level can be used to estimate the flow required at the gorge to 'fill' the aquifer, which varies at each location between 160 and 450 L/s. At a 7 day MALF of 125 L/s, aquifer storage will not be full, leading to lower groundwater levels (as observed by abstractors).

Springs occur in three main areas (Appendix 37). One spring feeds a creek arising on the south side of the Otaio downstream of McAlwees Crossing that feeds into the River at Esk Bank Ford. A second area of springs arises upstream of Church Hill Ford, on the north bank, and enters the Otaio River upstream of Grays Crossing. A third spring area occurs on the north side between Grays Crossing and State Highway One.



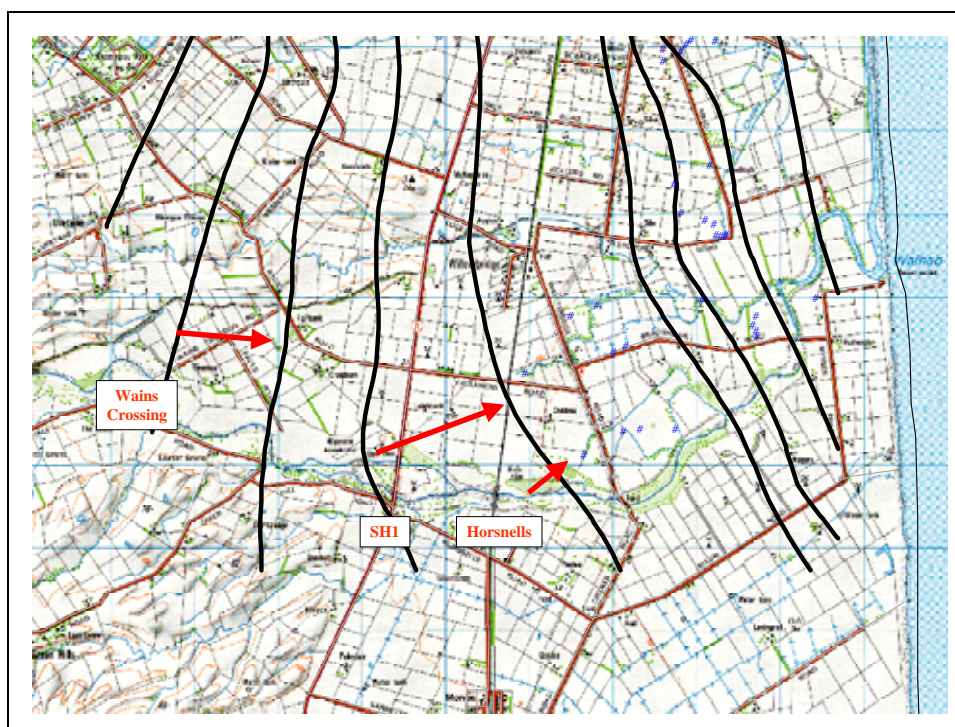
**Figure 6.9 Relationship between Otaio Gorge flow and well J39/0255 (McAlwees Crossing)**

where:  $GWL = 2.49 + 4.1e^{(-x/105)}$ .

### 6.2.5.3 Waihao surface-groundwater interaction

The Waihao River Valley groundwater system is highly connected with surface water flows. Apart from local rainfall, the Waihao River is a dominant source of recharge to the shallow groundwater aquifer (combined with significant summer recharge caused by irrigation from the Morven-Glenavy Irrigation Scheme (MGIS) on the south side of the Waihao). In the upper Waihao, the shallow groundwater is contained within terraces, but towards the coast, (east of SH1) the boundary between the Waihao river aquifer, and Waimate Creek area aquifers to the north, and Waitaki River deposits to the south is uncertain.

The pattern of gains and losses in the Waihao below McCulloughs Bridge (Section 4.4.4) shows losses between Elliotts and State Highway One. Piezometric contours (Figure 6.10) indicate that losses are likely to occur in the Wains Crossing area to an old Waihao Channel, which runs underneath a terrace towards Willowbridge township. Additional losses occur in the area downstream of State Highway One, towards the spring-fed Buchanans and Maroma e kia Creeks.

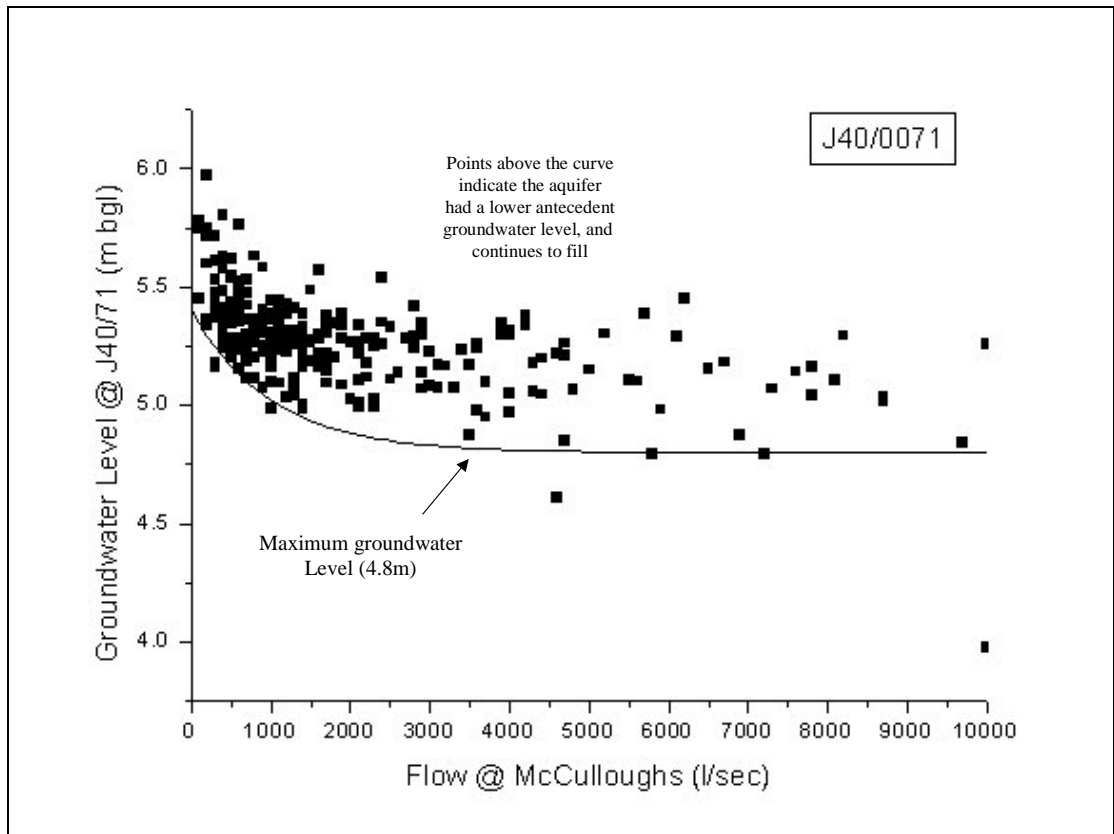


**Figure 6.10 Groundwater flow in the Waihao Shallow Aquifer**

(Black lines are piezometric contours, red arrows indicate losses to groundwater, and blue dots indicate springs)

There is an obvious correlation between surface flow, groundwater levels, and outflow from the spring-fed Buchanans Creek (as detailed earlier in Section 4.4.5), with increasing river flow leading to peaks in groundwater level.

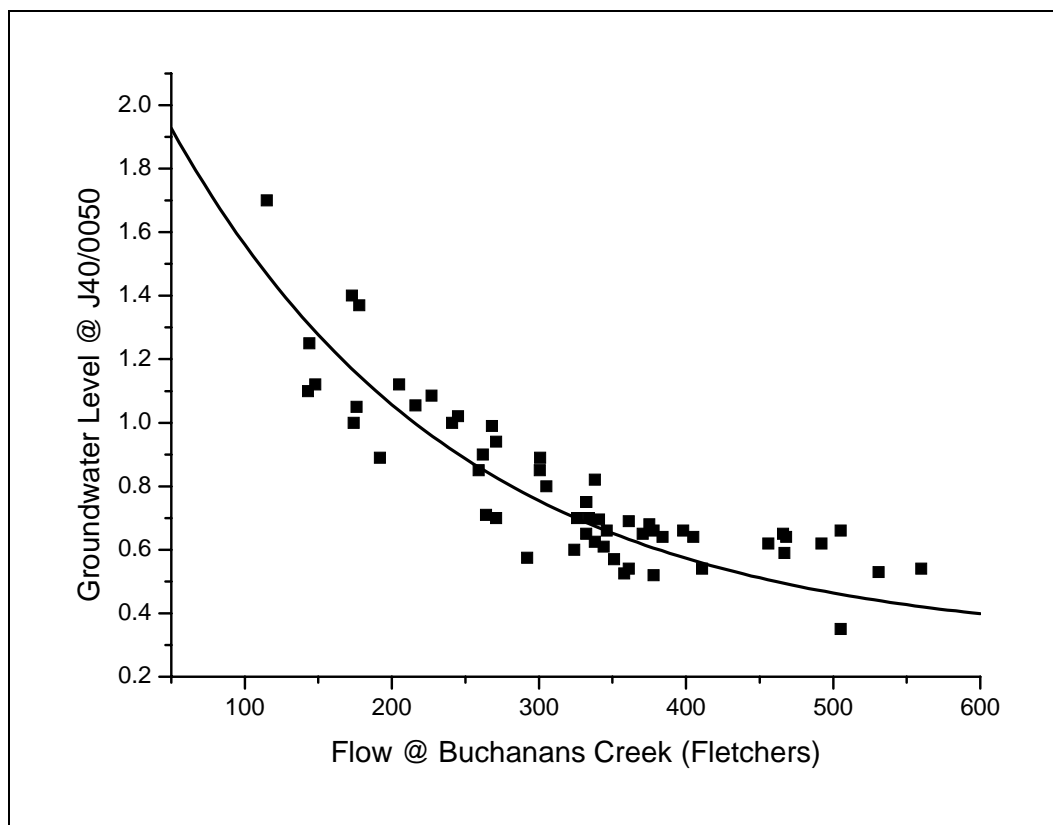
A number of shallow wells have been monitored in the Waihao River area as illustrated in Appendix 35. Comparison of the levels with flow in the Waihao River at McCulloughs displays an exponential correlation, illustrated in Figure 6.11 for well J40/0071 (the remaining analyses are included in Appendix 36).



**Figure 6.11 Relationship of Waihao @ McCulloughs flow and well J40/0071 (Ruddenklaus)**

(where:  $GWL = 4.8 + 0.6e^{(-x/1000)}$ ).

Maximum groundwater levels in all wells generally occur at flows in excess of 1000-2000 L/s. Comparisons of groundwater levels and flow in Buchanans creek were also undertaken (Appendix 36). Well J40/0050, located immediately adjacent to Buchanans Creek, also displayed an exponential relationship (Figure 6.12). Given the historical range (1969 - present) of J40/0050 from ground level to 3 m below ground, flow in Buchanans Creek may have ranged from > 1000 L/s to < 150 L/s.



**Figure 6.12 Comparison of flow at Buchanans Creek and groundwater levels in J40/0050**

where:  $gwl = 0.3 + 2.1e^{(-x/196)}$  hence flow =  $-196(\log_{2.718}(y-0.3/2.1))$ .

## 6.3 Groundwater inputs and outputs

A water balance for the Pareora-Waihao groundwater system can be estimated by assessing inputs and outputs from the system. Inputs include: rainfall, recharge from irrigation, losses from irrigation scheme races, and river flow. Outputs include discharges to spring-fed streams and the lower reaches of rivers, offshore leakage and abstractions. As well as the inputs and outputs to the whole groundwater system, there are inputs and outputs between shallow and deeper groundwater systems.

### 6.3.1 Inputs

#### 6.3.1.1 Land-surface recharge

Land-surface recharge is a term used in the Canterbury Strategic Water Study (Morgan, et. al., 2002) to describe drainage from rainfall and irrigation water from land overlying an aquifer, and has subsequently been used in the NRRP.

##### 6.3.1.1.1 Rainfall

Recharge via precipitation is dependent on:

- The soil water holding capacity (profile available water -PAW)
- Potential evapotranspiration (PET)
- Antecedent soil moisture conditions
- Vegetative cover
- Intensity and duration of rainfall

Recharge will occur when rainfall infiltrates the soil profile so that it exceeds its water holding capacity and allows flow through to the underlying groundwater system. Recharge is therefore more likely to occur under shallower soils or soils with lower PAW, and when the soil profile is already at or near capacity due to antecedent conditions. Recharge is also more likely to occur during months with a lower PET (winter) as the soil profile remains fuller. The climatic conditions of the Pareora-Waihao River catchments are discussed in Section 2.

A large proportion ( $\approx 60\%$ ) of the Pareora-Waihao groundwater allocation zones are comprised of gently rolling loess covered downlands (Section 3.1). Loess thicknesses are generally  $> 8\text{m}$  thick on the higher terraces (dark yellow on Figure 3.1) and can be up to  $17\text{m}$  thick (Forsyth, 2001). There are also patchy loess coverings on younger terraces (annotated as 'Q4' on Figure 3.1).

The physiography of the downlands has two important influences on groundwater recharge. Firstly, the gentle slope of the downlands compared to the plains means there will be greater runoff, hence decreasing the volume of water available for groundwater recharge. Secondly the thick loess covering on the downlands will impede groundwater recharge as loess has a high porosity but low permeability (i.e. holds moisture well, but does not allow much through flow). The loess also contains fragipan layers (Forsyth, 2001), which may act as water restrictive horizons for groundwater recharge.

The combination of a thick, dry loess with a gentle slope makes it likely that much of the rainfall will become runoff, be lost to EVT, or be absorbed by the loess, with little percolating through to groundwater recharge.

An experimental catchment, Adair Farm, located 3-4km south-west of Timaru was set up by the Ministry of Works in the 1970's to measure surface runoff, interflow and soil moisture of a loess covered catchment (Watt, 1972). Results were hampered by lack of flow, and equipment problems. However the limited results indicated that the soil fragipan appeared to be impervious, with soil moisture measurements the same before and after the winter. It could be expected that areas with such a fragipan may restrict groundwater recharge (M Duncan, pers. comm., 2004). International literature indicates that loess deposits severely retard groundwater recharge, although the exact amount of recharge though the loess is often unknown, and can only be resolved through experimental studies, such as the use of environmental tracers. In addition, recharge may occur via preferential flow paths (i.e. cracks in the loess) further complicating estimates of recharge (McDaniel, 1999; O'Geen et al, 2002, 2003).

#### 6.3.1.1.2 Irrigation recharge

As well as rainfall, recharge to groundwater systems can occur with additional water added to the soil profile via irrigation. This mainly occurs over late spring – early autumn when PET is elevated. Irrigation increases the water held in the soil profile. The irrigation, if excessive, may lead to direct recharge where the application exceeds the soil profile available water (PAW), or irrigation may maintain the soil PAW levels such that a rainfall event which would have only partly filled the PAW in a dryland situation, may actually lead to drainage to groundwater and recharge in an irrigated situation.

Irrigation in the Pareora-Waihao area occurs from three sources: Waitaki River water from the MGIS; surface water from the foothills rivers; and groundwater.

#### 6.3.1.1.3 Calculation of land-surface recharge.

Scott (2004) modelled rainfall recharge under dryland and irrigated conditions for much of the groundwater areas of Canterbury. This model used daily estimates of rainfall and PET for the 1972-2003 period on a  $0.05^\circ$  latitude-longitude grid supplied by NIWA, and soil moisture data (PAW). Irrigation inputs from surface water schemes and groundwater based irrigation were also considered.

For the Pareora-Waihao River catchment areas, land-surface recharge was calculated on the basis of Groundwater Allocation Zones (Aitchison-Earl et. al, 2004) being the Pareora, Otaio, Makikihi and Waihao-Wainono zones. Table 6.4 summarises the outputs detailed in Table 3.3 of Scott, (2004). Surface water scheme irrigation is only considered for the Waihao-Wainono zone, which part of the MGIS scheme falls within.

The calculations within Scott (2004) do not consider irrigation recharge from individual surface water irrigators, although groundwater irrigators are considered. Of the 160 (as of February 2005) consents in the area, 59 are irrigating from surface water resources, usually from takes directly out of the main rivers. The total consented land area to be irrigated by these surface takes is around 3200 ha. Not considering this irrigation recharge means that the total land-surface recharge contribution from irrigation may be underestimated.

The Scott model was primarily created to estimate recharge on the Canterbury Plains and assumes that runoff could be neglected (i.e. soil infiltration capacity is not a factor). This may not be appropriate for the rolling loess covered downlands. For the Pareora-Waihao groundwater allocation zones, the soils overlying the loess tend to have average PAW values of < 100mm, whereas the soils in the river valleys (excluding the river bed) have PAW values on average higher than 100mm. This means that under the Scott model, there will be more recharge under the loess areas (due to the lower PAW) than in the river valleys. In reality the opposite is more likely to be true (as per results from Adair Farm, discussed in Section 6.3.1.1.1). A revised recharge model that incorporates a soil infiltration capacity into the soil moisture model may be appropriate. However the necessary runoff and soil infiltration capacity parameters from the loess covered downlands are unknown. The loess may result in higher recharge in the river valleys (due to more runoff) or the runoff may be contained within the drainage network of the downlands. At present there are not enough surface water gaugings on downlands streams (gaugings are primarily in river valleys) to understand the influence that the loess soils may have on runoff. However as an initial estimation, groundwater recharge has been considered assigning the average recharge from Scott, (2004), to the river valleys, and two scenarios: 25% and 10% of the average recharge to the downlands areas. The resulting recharge estimates are compared Table 6.5.

**Table 6.4 Land-surface recharge calculations for Pareora-Waihao River aquifers**

	<b>Pareora</b>	<b>Otaio</b>	<b>Makikihi</b>	<b>Waihao-Wainono</b>
Area (ha)	14160	9023	17528	24656
<b>Rainfall Component</b>				
Mean annual rainfall (mm)	577	600	604	602
Rainfall Recharge (m <sup>3</sup> /yr x 10 <sup>6</sup> )	22.9	15.7	30.8	43.7
Equivalent depth increment (mm)	161	174	176	177
Dryland recharge as % of total rainfall	25.4%	26.4%	26.4%	26.7%
<b>Groundwater Irrigation Component</b>				
Groundwater consented irrigation area (ha)	970	471	904	1345
Assessed groundwater irrigation area (ha)	631	306	588	874
Recharge increment (m <sup>3</sup> /yr x 10 <sup>6</sup> )	1.0	0.5	0.9	1.4
Equivalent depth increment (mm)	162	171	158	155
<b>Surface Water Scheme Irrigation Component</b>				
Surface water scheme supplied area (ha)	0	0	0	1885
Recharge increment (m <sup>3</sup> /yr x 10 <sup>6</sup> )	0	0	0	1.9
Equivalent depth increment (mm)	N/a	N/a	N/a	103
<b>Total land-surface recharge (m<sup>3</sup>/yr x 10<sup>6</sup>)</b>	<b>23.9</b>	<b>16.3</b>	<b>31.7</b>	<b>47.0</b>

Amended from Scott (2003) Table 3-3

**Table 6.5 Comparison of groundwater recharge estimates**

<b>Groundwater Allocation Zone</b>	<b>% area of land in downlands</b>	<b>Recharge estimates from Scott (2004) (m<sup>3</sup>/yr x 10<sup>6</sup>)</b>	<b>Recharge Scenario 1 (Downlands 25% of average recharge) (m<sup>3</sup>/yr x 10<sup>6</sup>)</b>	<b>Recharge Scenario 2 (Downlands 10% of average recharge) (m<sup>3</sup>/yr x 10<sup>6</sup>)</b>
Pareora	64.8	23.9	11.8	9.6
Otaio	60.2	16.3	8.5	7.1
Makikihi	64.8	31.7	14.2	11.5
Waihao-Wainono	43.9	47	25.6	23.1
<b>Total</b>		118.9	60.1	51.3

6.3.1.2 River flow

Analyses of flow regimes in this report provide reliable estimates of intermittent stream contributions. In particular, the discharge from groundwater to spring-fed streams and the coastal reaches of the main rivers has been considered, so that only the stream water totally lost to the groundwater system is included (Table 6.6). Recharge from intermittent streams is reported under mean flow conditions, as other estimates of groundwater recharge, such as rainfall and irrigation losses are based on average annual volumes. Recharge to groundwater is only accounted for in the Pareora River (256 L/s), Makikihi River (561 L/s) and Waimate Creek (128 L/s). For the Otaio and Waihao Rivers, outflows balance (or exceed) inflows in the main stem, hence there is no net loss to groundwater.

**Table 6.6 Estimates of intermittent stream flow contribution to groundwater**

Groundwater Zone	Intermittent Stream	Inflow	Outflow	Net loss from surface water to Groundwater
Pareora	Pareora River	4001 L/s (mean flow at Huts)	3745 L/s (mean flow at Railway Bridge)	256 L/s
Otaio	Otaio River	741 L/s (mean flow at Otaio Gorge)	892 L/s (mean flow at SH1)	Zero <sup>1</sup>
Makikihi	Teschemakers Creek	172 L/s (mean flow u/s of confluence)	Dry at SH1	561 L/s
	Makikihi River	389 L/s (mean flow u/s of confluence)		
Waihao-Wainono	Hook River	156 L/s (mean flow u/s intake)	522 L/s (mean flow @ Hook Beach Road)	Zero <sup>2</sup>
	Waimate Creek	128 L/s (mean flow u/s of Kelceys Bush intake)	Dry at SH1 (some ponding of water in lower reaches towards Wainono Lagoon)	128 L/s
	Waihao River	3775 L/s (Mean flow at McCulloughs)	3206 L/s (mean flow u/s Bradshaws Bridge) 355 L/s (mean flow of Buchanans Creek @ Fletchers) 244 L/s (mean of gaugings, Sir Charles Creek @ Haymans)	Zero <sup>3</sup>

<sup>1</sup> Flow is higher at SH1 than the gorge at mean flow, as more run-off is contributed to the catchment downstream of the gorge. At median flow and MALF, the inflow and outflow approximately balance indicating no net loss to groundwater

<sup>2</sup> There is actually a net gain from groundwater to the Hook River, especially in the lower reaches near Wainono Lagoon, hence the net loss is zero

<sup>3</sup> Summed outflow from Waihao @ Bradshaws and spring-fed creeks Buchanans and Sir Charles exceed losses in the Waihao at mean flow. Inputs and outputs are close to balancing at median and surface water is lost to groundwater at MALF. The inclusion of Sir Charles Creek could be debated, as it is probably fed by a mixture of Waihao River losses and general groundwater – to retain a more conservative estimate of total river recharge it has remained included in this assessment.

### 6.3.1.3 *Recharge to deeper aquifers*

Recharge of the Southburn Sand and Taratu Formation aquifers may occur via the following mechanisms:

- Rainfall recharge at aquifer outcrop
- River recharge at aquifer outcrop
- Recharge from overlying layers
- Recharge via fault systems

Rainfall recharge at aquifer outcrop (see Figure 6.4 for location of outcrops) is estimated in Aitchison-Earl (2005), at 10% of rainfall. This figure is based on Otago Regional Council (1993) estimates of recharge in the Maerewhenua Hills of between 8 and 15% of rainfall. ORC chose 10% as a conservative estimate, given the hilly topography leading to greater run-off, and the drainage impeding loess that covers much of the area.

Direct recharge may occur where rivers and streams cross outcrops of these formations, however there is not enough detailed gauging information to determine losses. For example Southburn Sands outcrop in the Esk Valley, but the Esk Valley Stream is usually dry at the gauging site at the confluence of the Otaio River. Hence potential losses are unknown. Some areas have gauging information, like for the outcrop of Southburn Sand between Pareora@ Huts and Purves Crossing, however it is unknown how much of the losses measured (188 L/s at median flow) infiltrate to the underlying Southburn Sands, and how much remains in the thin layer of overlying Quaternary Gravels. Due to the inherent uncertainties in estimating river contributions, it has been ignored as a source of recharge.

Recharge from overlying layers is likely to occur, but cannot be estimated without knowledge of aquifer permeability and hydraulic heads. The occurrence of two artesian flowing wells in the Taratu Formation, South Branch Pareora, where there are no outcrops of Taratu Formation mapped (Figure 6.4) confirms that recharge from overlying layers must be taking place.

Recharge via fault systems may also occur, however the permeability of fault zones is unknown, and there is often little surface expression of faulting. One area that faulting may provide a direct recharge path is in the Upper Otaio Valley, where a fault is projected to run under the river bed between Bluecliffs and McAlwees Crossing (Figure 3.1). No overall loss of Otaio River flow is observed in gauging data between the Gorge and State Highway One (Table 4.12), hence it seems unlikely that any significant river losses will occur to underlying deeper aquifers via this fault.

Estimates of recharge to deeper aquifers have been undertaken in Aitchison-Earl (2005) based only on 10% of average annual rainfall (there is unlikely to be irrigation based recharge in these areas), and is outlined in Table 6.7 and Table 6.8.

**Table 6.7 Outcrop areas and recharge for Otakou Group Aquifers** (adapted from Aitchison-Earl, 2005)

Zone (as shown in Figure 6.4)	Area of outcrop (m <sup>2</sup> )	Average annual rainfall	Recharge estimate (m <sup>3</sup> /year)	Comments
Southburn-Sutherlands	24,350,164	600mm	1,461,009	The extent of the Otakou Group has been approximated in the Sutherlands area from NZGS Sheet 20 'Mt Cook'. The northern cut-off of the zone at the Tengawai River is for convenience (with wells north of this not included in this report).
Otaio/Esk Valleys	14,402,968	700mm	1,008,207	The presence of a fault in the upper Otaio Valley has caused large offset of geological units, and likely separated aquifers in the Otaio/Esk Valleys from the Cannington Basin.
Waimate Creek	2,536,786	800mm	202,942	Fault shown on map, unknown how connected outcrop is. Only well (J40/0869) in outcrop, which has very poor yield
Elephant Hill/Ikawai	69,784,286	600mm	4,187,057	Complicated by faulting, may be recharge via overlying Kowai formation.

**Table 6.8 Outcrop areas and recharge for Taratu Formation aquifers** (adapted from Aitchison-Earl, 2005)

Zone	Area of outcrop (m <sup>2</sup> )	Average annual rainfall	Recharge estimate (m <sup>3</sup> /year)
Kapua-Arno	3,982,775	700mm	278,794
Waihao Downs	6,217,235	650mm	404,120
Elephant Hill-Douglas	3,127,974	600mm	187,678

### 6.3.2 Outputs

#### 6.3.2.1 Gaining river reaches and spring-fed streams

All the foothills rivers draining the Hunter Hills flow intermittently in that they go dry in their middle reaches during periods of low flows, with surface water being lost to the overlying gravels of the adjacent groundwater system (losing reach). For most of the rivers, flow resumes in the lower reaches towards the sea as groundwater discharges to the river bed (gaining reach).

As well as direct groundwater discharge to the river beds, there are also spring-fed streams sourced from shallow groundwater, most of which flow towards the coastal reaches of the major rivers.

Spring locations are mapped and described in Appendix 25.

#### 6.3.2.2 Discharge to Wainono Lagoon

Piezometric contour data (Section 6.2.3) indicates groundwater flow towards Wainono Lagoon with piezometric pressures at or above sea level. This, together with the presence of

some artesian springs in the Wainono Lagoon area means that discharge of groundwater to the lagoon can be expected.

Sparse well logs indicate a shallow sandy gravel aquifer (up to 20 m thick) exists around the lagoon, overlain by yellow clays and silts of between 2 and 6 m thickness (Aitchison-Earl, 2004a). The clay layer appears to be thinner to the south of the lagoon, along the Waihao Dead Arm. Underlying this aquifer is a deeper semi-confined aquifer (Cannington Gravels – Section 6.2) that is likely to discharge off-shore.

Piezometric contours for April and September 2002 were used to estimate a hydraulic gradient of 0.002-0.0025 (Figure 6.13).

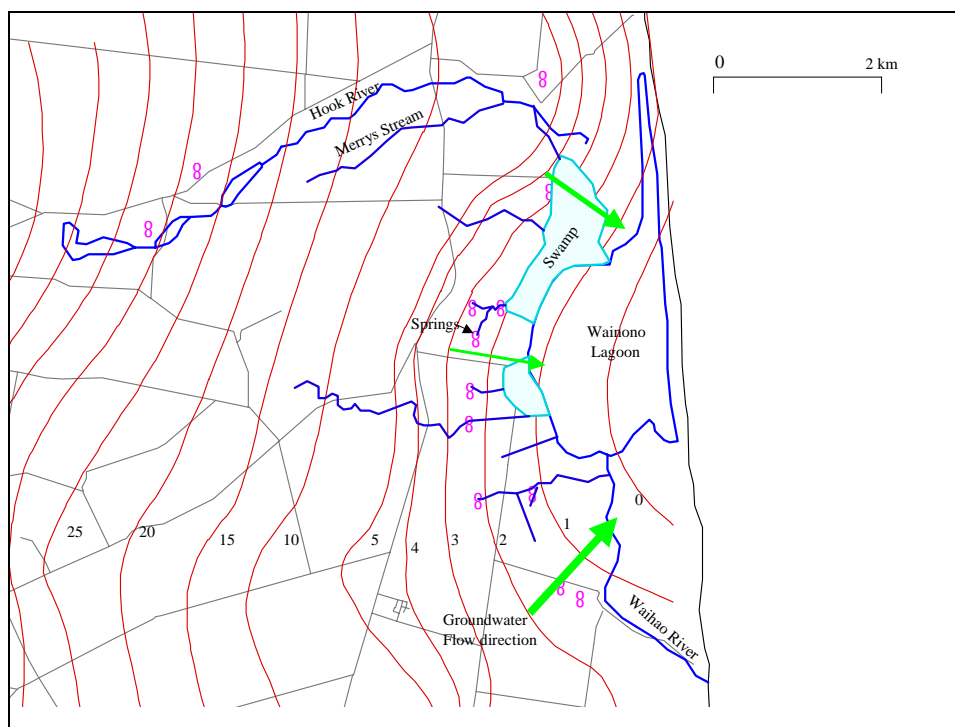
Darcy's Law was used to calculate outflow into the lagoon (Table 6.9) assuming a seepage face of 3000 m (length of 0 m piezometric contour in the lagoon). This indicated flows of between 3900-12,000 m<sup>3</sup>/day (45-139 L/s) assume that the full aquifer thickness is discharging into Wainono Lagoon, and that no groundwater is continuing to flow under the lagoon and discharging offshore. This assumption is very likely to be false, as there are thicknesses of clays of between 2 and 6 m overlying the shallow aquifer, which would impede groundwater discharge into the lagoon. Discharge is likely to be small, slow and diffuse, or to occur via weaknesses in the overlying clay layer as springs.

**Table 6.9 Comparison of estimates of aquifer inflow to Wainono Lagoon using differing parameters.**

		Hydraulic Gradient	
		0.002	0.0025
Transmissivity ( m <sup>2</sup> /day)	650	3900 m <sup>3</sup> /day	4875 m <sup>3</sup> /day
	1600	9600 m <sup>3</sup> /day	12,000 m <sup>3</sup> /day

Given the hydrogeology of the area the discharge/seepage will not be uniform around the lagoon margin. Figure 6.13 outlines two swampy areas (in light blue) and some indicative groundwater flow directions based on piezometric contours. Groundwater is sourced preferentially from the Hook River/Merrys stream area, the Waituna Stream area, and the Waihao Dead Arm, with a much lower contribution from the downlands.

There is likely to be a seasonal fluctuation to groundwater discharge, with lower groundwater levels leading to a smaller aquifer saturated thickness and hence less discharge. Groundwater levels in the April 2003 survey (at the end of the summer irrigation season) are around 1 m lower than in the September 2003 survey (spring after winter recharge). Assuming a 20 m thick aquifer, a 1m change in storage will have a minimal (around 5%) effect on estimated outflows. However, a 1 m drop in aquifer level may be enough to stop springs flowing, and hence significantly decrease outflow to the Lagoon.



**Figure 6.13 Groundwater seepage directions into Wainono Lagoon**

There may also be an unknown contribution from up welling deeper groundwater. Deeper aquifers exist at the coast, and the limited water level information available suggests that an upwards-hydraulic gradient is likely. Without more detailed water levels from deep and shallow aquifers, this gradient remains unknown. Currently there are no deep wells in the immediate vicinity of the lagoon.

#### 6.3.2.3 Offshore Leakage

Some groundwater is assumed to continue to flow underground the coast, and discharge as offshore leakage. The actual amount of offshore leakage cannot be directly measured, and the best estimates are based on the residuals from a groundwater balance (Table 6.10).

#### 6.3.2.4 Abstractions

Abstraction of groundwater occurs through wells, galleries and water holes, which are used for irrigation, domestic, stockwater, public supply and commercial purposes (PPCS Pareora, Makikihi Fries and Food Processors Ltd). Under the current Transitional Regional Plan (TRP) abstractions less than 20 m<sup>3</sup>/day (for a property < 20 ha) and less than 100m<sup>3</sup>/day (for a property > 20 ha) have been categorised as permitted activities, and have not needed a consent. Under the notified NRRP, permitted activities are only for takes < 10m<sup>3</sup>/day per property. All takes exceeding the permitted activity guidelines have been given resource consent to abstract and use water, and the relevant details including rates and volumes of take are recorded in the ECan Consents Database. Currently (March 2005) the consents database indicates that 41.3 x 10<sup>6</sup> m<sup>3</sup>/year is allocated to groundwater consents in the Pareora, Otaio, Makikihi and Waihao Wainono Groundwater Allocation Zones. Further discussion of allocation of groundwater is provided in Section 6.

A schematic water balance is presented in Figure 6.14 and Table 6.10 accounting for all the inputs and outputs to the groundwater system.

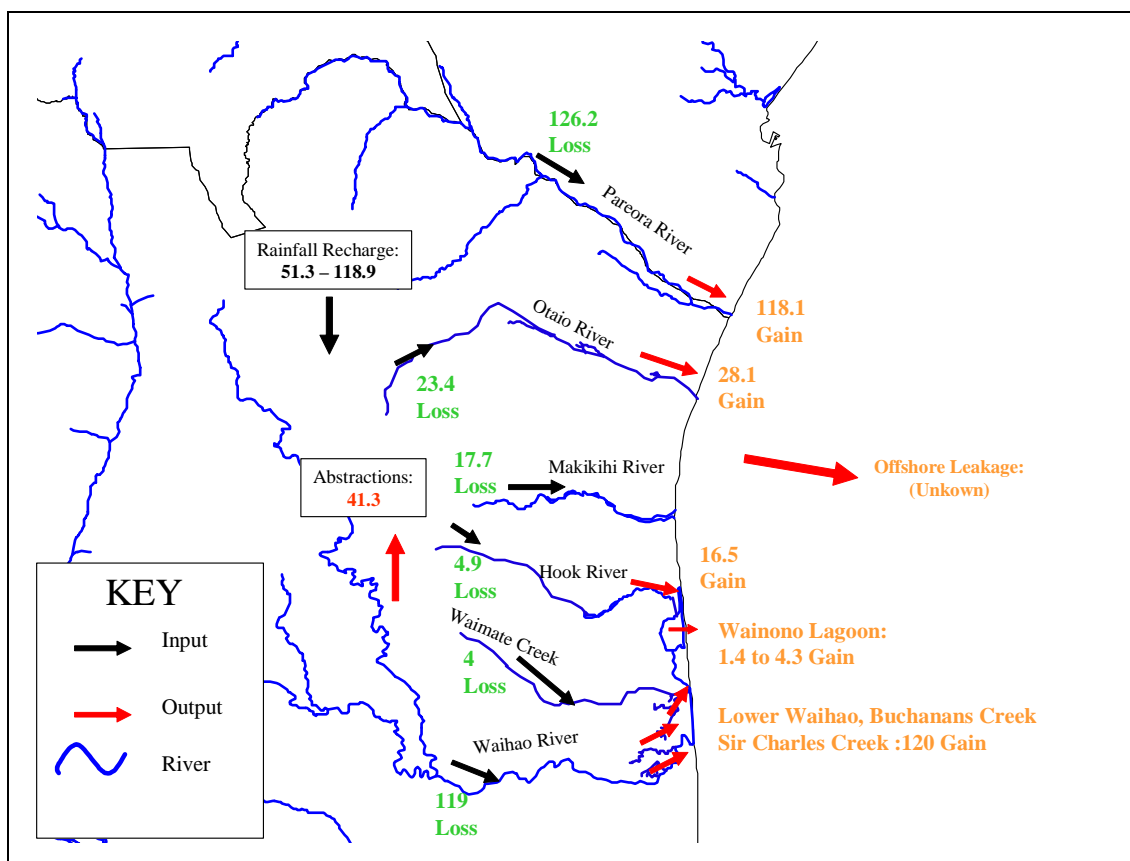


Figure 6.14 Water balance for the Pareora-Waihao groundwater system (figures x10<sup>6</sup> m<sup>3</sup>/year)

Table 6.10 Water balance for the Pareora-Waihao groundwater system

Input	Quantity (10 <sup>6</sup> m <sup>3</sup> /year)	Output	Quantity (million m <sup>3</sup> /year)
Land-Based Recharge (rainfall and irrigation)	51.3 (to 118.9 <sup>1</sup> )	Spring-fed streams/ emergent river reaches	282.7
Losing river reaches	295.2	Abstractions	41.3
		Wainono Lagoon inflow	1.4 – 4.3
		Offshore Leakage	?
<b>TOTAL</b>	<b>346.5</b>	<b>TOTAL</b>	<b>346.5</b>

<sup>1</sup> Refer to Table 6-5

## 6.4 Groundwater quality

A groundwater quality investigation programme was carried out in the area south of Timaru between 1996 and 2000. The programme involved locating wells, and then selecting appropriate wells for sampling. A number of wells have subsequently been included in a monthly or quarterly sampling programme. The resulting data sets have never been formally reported on, but are discussed in internal Performance Measure reports (Smith, 1996, Hayward, 1999).

Most wells sampled were from shallow unconfined aquifers, and results indicated that approximately two thirds suffered from faecal coliform contamination. In addition, there were high iron and manganese concentrations in some wells indicating reducing conditions in the

aquifer. Nitrate-nitrogen concentrations varied from low adjacent to rivers such as the Waitaki, to higher in areas such as Morven (which could possibly be attributed to increased numbers of septic tanks). The water quality and chemistry of the shallow aquifers reflects their vulnerability to contamination, with a combination of unconfined aquifers and poor well head protection providing a direct route for contaminants to the groundwater.

There is data available on water quality for a limited number of wells (12) in the Cannington Gravels and Cannington Marine aquifers, of which five have ongoing monitoring. No analysis or comparison to the shallow aquifer water quality and chemistry has been made. The marine nature of parts of the Cannington sequence may have impacts on water chemistry.

In the deeper Tertiary aquifer, there is little data on water quality or chemistry. The deeper depths and the longer recharge paths to these aquifers increase the likelihood of groundwater containing increasing amounts of dissolved material from the host aquifer, compared to typical Canterbury gravel aquifers. There is no data available for aquifers in the Southburn Sands. Data is available for three wells screened within the Taratu Formation, in the Pareora South Branch (J39/0481 and J39/0482) and Kapua (J40/0706 - upper Waihao<sup>1</sup>) areas (provided by R de Joux, Environmental Consultancy Services). The results indicate high levels of dissolved solids, and elevated levels of many determinants such as chloride, sulphate, and magnesium. Irrigation of the water from J39/0481 and J39/0482 has led to impacts on soil structure (R de Joux, pers. comm., 2005). The owner of J40/0706 requested chemistry sampling to determine the suitability of the water for irrigation – which the results suggest is poor.

The Taratu formation is the geological equivalent of the Papakaio Formation aquifer of North Otago. Water quality/chemistry sampling the Papakaio indicates variable pH, and a high content of iron and sulphate. The relative concentrations of the iron and sulphate are related to the proximity to the recharge source (i.e. shallow unconfined have lower values, compared to deeper confined parts of the formation), and hence age of the groundwater. The iron and sulphate are thought to be derived from the pyrite cement found within the Papakaio Formation (ORC, 1993).

Analysis of existing water quality/chemistry data together with age determination (via isotope sampling) would greatly enhance our knowledge of the source of recharge water to the aquifers.

## 7 Resource use

### 7.1 Use over time

Water use in the Pareora-Waihao has changed over time, with an increasing reliance on groundwater use. Figure 7.1 illustrates cumulative use of the surface and groundwater resource over time (based on records in the ECan consents database, summarised in Appendix 38). Surface water was initially the dominant water use, and increased in the early-mid 1980's. Since this time, surface water use has gradually increased at an average of 2800 m<sup>3</sup>/day/year. Groundwater development occurred at a steady pace since 1979, and rapidly accelerated after 1999 (27,000 m<sup>3</sup>/day/year), so that the majority of consented water use is now from groundwater (as of June 2005, 69% of a total of 412,924 m<sup>3</sup>/day is from groundwater).

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<sup>1</sup> Water sample taken during drilling, so may represent water quality of Taratu or overlying Onekakara group.

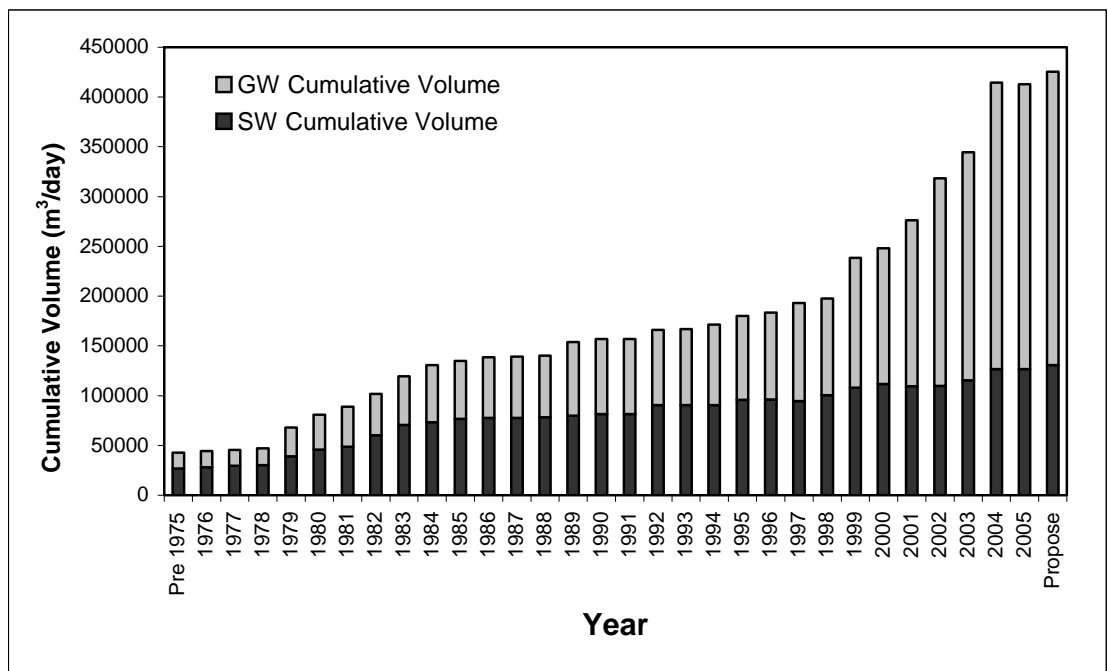


Figure 7.1 Water use patterns over time

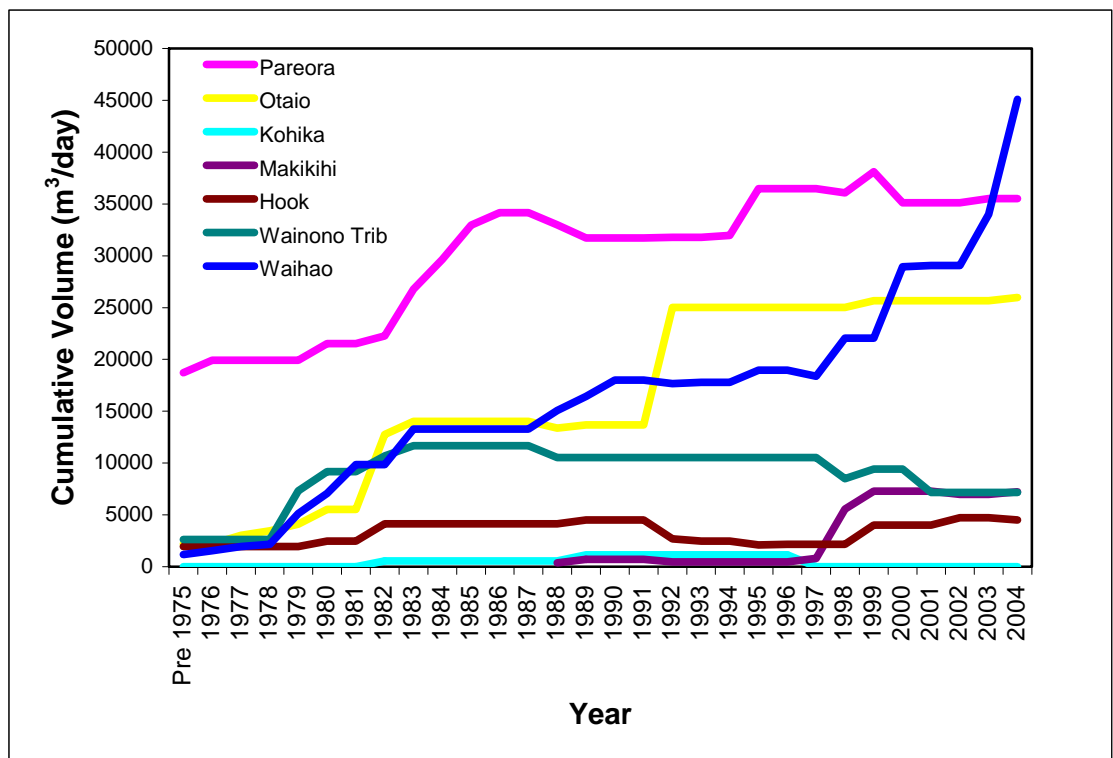


Figure 7.2 Surface water allocation by catchment over time

For individual surface water catchments, trends in use over time are illustrated in Figure 7.2. The highest use is in the Pareora and Waihao Catchments. While surface water use has reached a plateau in recent times, use in the Waihao Catchment has continued to increase. Trends in surface water allocation for the period 1990 to 2000 are described in Chater (2002).

For groundwater, the majority of use pre-2000 has been from shallow Quaternary gravel aquifers (Figure 7.3). Since 2000, there has been increasing allocation from Cannington Gravel aquifers, to the extent that allocation is currently greater than from Quaternary gravels. Abstractions from the Taratu and Southburn Sand aquifers have also begun in the last 5 years. The pattern shown in allocation by aquifers indicates that the recent increase in overall groundwater abstractions (Figure 7.3) has been almost exclusively from allocation from Cannington Gravel aquifers.

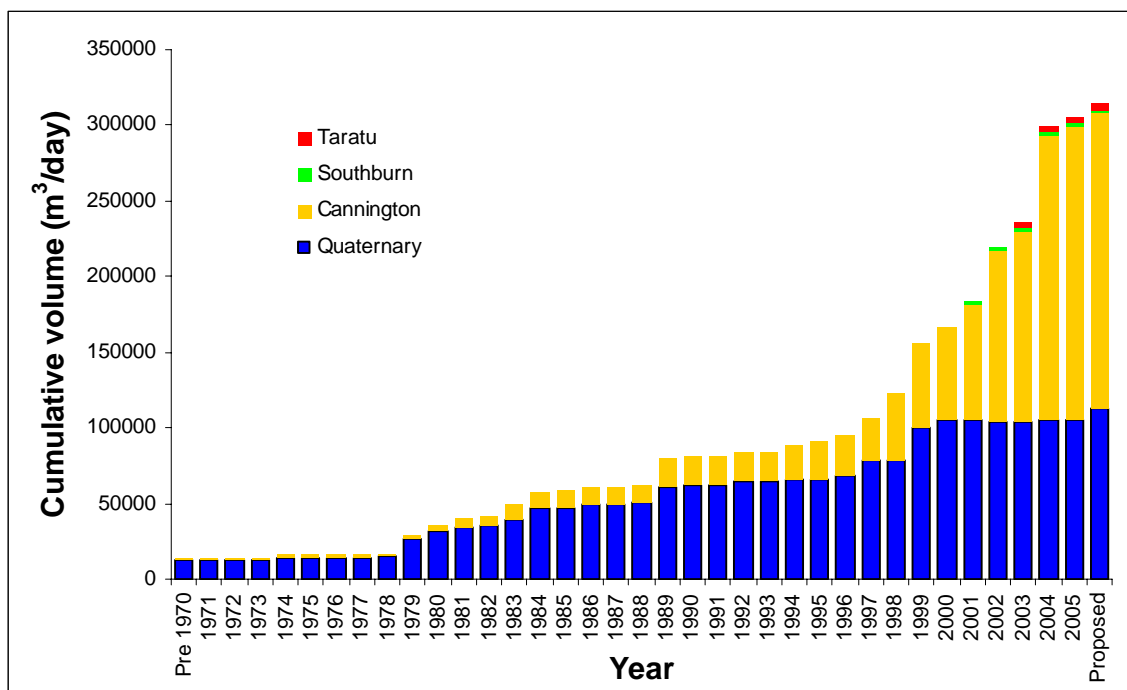


Figure 7.3 Allocation from aquifers by geological classification

## 7.2 Current consented water use

### 7.2.1 Surface water

Current allocation of the surface water resource (including hydraulically connected groundwater – refer to Appendix 38) on a catchment-by-catchment basis compared to the 7-day mean annual low flow (7DMALF) is presented in. The surface water allocated from the main branch of the river and the sub-catchments with current surface water takes are listed. The 7DMALF figure is derived either from the regression analyses given in Sections 4.3 to 4.6, or from integration of the 7DMALF map (Figure 4.20). Therefore, for the 7DMALF value, only the surface water contribution to flows is given.

Note that the allocation figures given are the quantity granted by resource consent, not the actual or estimated quantity used.

**Table 7.1 Current surface water resource use (as of 20 June 2005)**

Catchment	Takes from:	Surface water allocation (L/s)	Hydraulically connected Groundwater Allocation (L/s)	Total allocation (L/s)	7DMALF (L/s)
Pareora	Cannington Stream	1.5		1.5	13.0
	Nimrod Stream	5.5		5.5	23.0
	South Branch Pareora	39.0		39.0	171.0
	Southburn Creek		39.3	39.3	-
	Pareora River main branch	520.0	421.6	941.6	See total
	<b>TOTAL</b>			<b>1026.9</b>	<b>648.0</b>
Otaio	Otaio River	423.0	27.3	<b>450.3</b>	<b>124.0</b>
Makikihi	Makikihi River	64.5	1.15	<b>65.65</b>	<b>26.0</b> <sup>1</sup>
Wainono Lagoon	Wainono Lagoon	800.0 (wetland control)		800.0	-
	Hook River	61.1	38.41	99.51	59.0
	Merrys Stream		4.19	4.19	-
	<b>TOTAL</b>			<b>903.7</b>	-
Waimate Creek	Waimate Creek	44.0	27.7	71.7	23.0
	Sir Charles Creek	118.0	38.9	156.9	-
	<b>TOTAL</b>			<b>228.6</b>	-
Waihao River	North Branch Waihao	91.3		91.3	305.0
	South Branch Waihao	163.0		163.0	31.0
	Waihaorunga Stream	40.4		40.4	-
	Waihao River main branch	324.0	96.8	420.8	See total
	Buchanans Creek		34.9	<b>34.9</b>	- <sup>2</sup>
	<b>TOTAL</b>			<b>750.4</b>	<b>354</b>

Notes:

1 – Flow in the Makikihi River is likely augmented by spring flows. Only the contribution from surface water runoff is given here.

2 – All water in Buchanans Creek at low flows is re-emergent groundwater originating from the Waihao River.

## 7.2.2 Groundwater

Effective allocation of groundwater compared to current and proposed groundwater allocation limits (Section 8) is summarised in Figure 7.2 below. Effective allocation for irrigation takes has been calculated using the methodology described in NRRP Policy WQN14.

**Table 7.2 Current groundwater resource use (as of 13 March 2006)**

Groundwater Allocation Zone	Aquifer	Consented Daily Volume (m <sup>3</sup> /day)	Effective Allocation (m <sup>3</sup> /year) <sup>1</sup>	Estimated Maximum Use <sup>2</sup> (m <sup>3</sup> /year)	Current Groundwater Allocation Zone Limit <sup>3</sup> (m <sup>3</sup> /year)	Alternative Groundwater Allocation Zone Limit <sup>4</sup> (m <sup>3</sup> /year)
<b>Pareora</b>	Quaternary Gravels	52,619	9,591,379	5,569,823	<b>19,700,000</b>	<b>9,940,000</b>
	Cannington Gravels	26,430	4,771,225	4,399,146		
	<b>Total</b>	<b>79,049</b>	<b>14,362,604</b>	<b>9,968,969</b>		
<b>Otaio</b>	Quaternary Gravels	2,880	378,536	183,600	<b>10,400,000</b>	<b>4,250,000</b>
	Cannington Gravels	24,267	2,509,853	1,547,009		
	Southburn Sand	2,070	304,272	131,693		
	<b>Total</b>	<b>29,217</b>	<b>3,192,661</b>	<b>1,862,302</b>		
<b>Makikihi</b>	Quaternary Gravels	2,765	336,578	228,333	<b>15,900,000</b>	<b>15,950,000</b>
	Cannington Gravels	79,691	10,263,952	5,080,299		
	Southburn Sand	6,221	474,862	396,580		
	<b>Total</b>	<b>88,677</b>	<b>11,075,392</b>	<b>5,705,212</b>		
<b>Waihao-Wainono</b>	Quaternary Gravels	30,732	3,599,208	2,190,467	<b>25,600,000</b>	<b>12,800,000</b>
	Cannington Gravels	62,684	9,844,267	5,358,809		
	Taratu Formation	864	164,851	55,080		
	<b>Total</b>	<b>94,280</b>	<b>13,608,326</b>	<b>7,604,356</b>		

<sup>1</sup> Effective allocation for irrigation takes has been calculated using the methodology described in NRRP Policy WQN14.

<sup>2</sup> Based on Section 6.3, 42.5% of average daily volume over 150 day period for irrigation takes, 100% over 150 day period (for seasonal uses) or 100% over 365 days for water supply purposes.

<sup>3</sup> Groundwater allocation limits are based on the '2<sup>nd</sup> Order' approach of 50% of land-based recharge plus intermittent streams (refer to Section 7 and Table 7-1)

<sup>4</sup> Proposed groundwater allocation limit based on revised estimate of land-surface recharge to account for loess soils, and revised intermittent stream contribution (refer to Section 7.2 and Table 7-6).

### 7.3 Actual water use

Water use is usually less than what is consented; hence, any analysis of potential water use based solely on what is recorded in the Consents Database will be erroneous. To attempt to gain a better understanding of water use patterns a condition requiring monitoring of water use on many water take consents in the Pareora-Waihao catchments was enforced in 2001. In addition, monitoring visits of consents were conducted between 2001 and 2003 where a pump calibration was carried out using portable ultrasonic flow meters. A full description of the monitoring and results is given in Aitchison-Earl, (2003). The exercise resulted in water use returns from 33% (2000/2001) and 44% (2001/2002) of all consent holders. Water use was generally estimated through recording the hours pumped and pumping rate. Comparison of the estimated rate and measured rate (through in-line flow meters) indicated they were generally similar (Aitchison-Earl, 2003).

Water use figures provided indicated a different pattern of use over the two irrigations seasons. The 2000/01 year (Figure 7.4) displayed a pattern of high and consistent use, decreasing slightly (particularly for horticulture) as the season neared an end. The 2001/02 season had a different pattern with three main peaks in usage, related to soil moisture deficits and high rainfall events. Table 7.3 summarises water use for each main land use over both irrigation seasons.

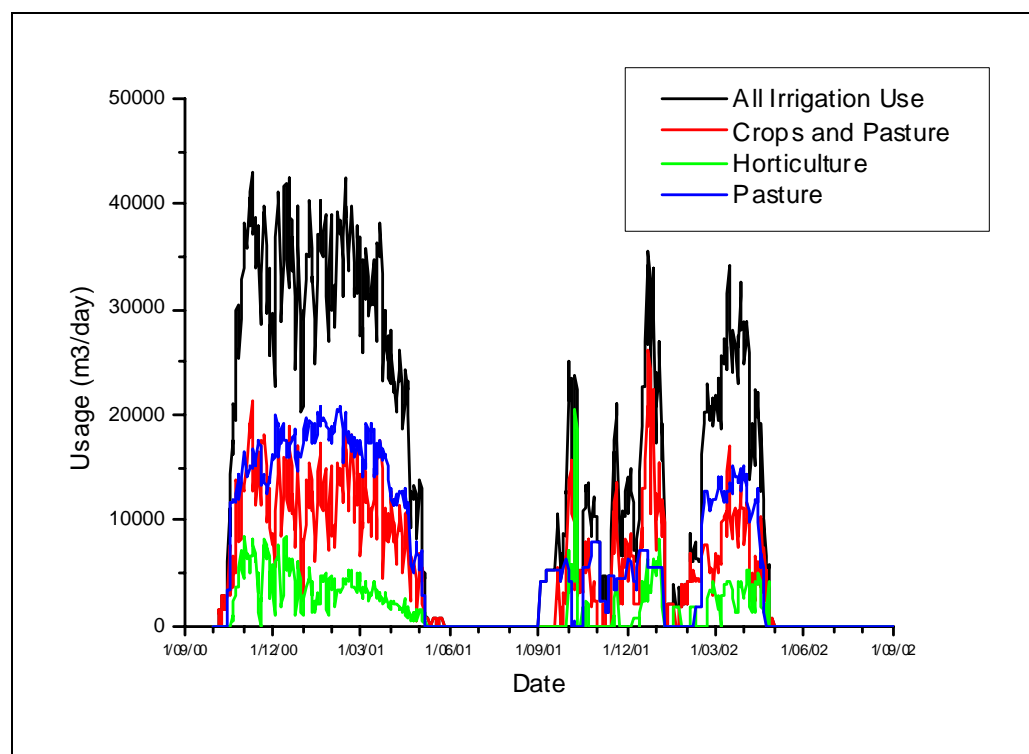
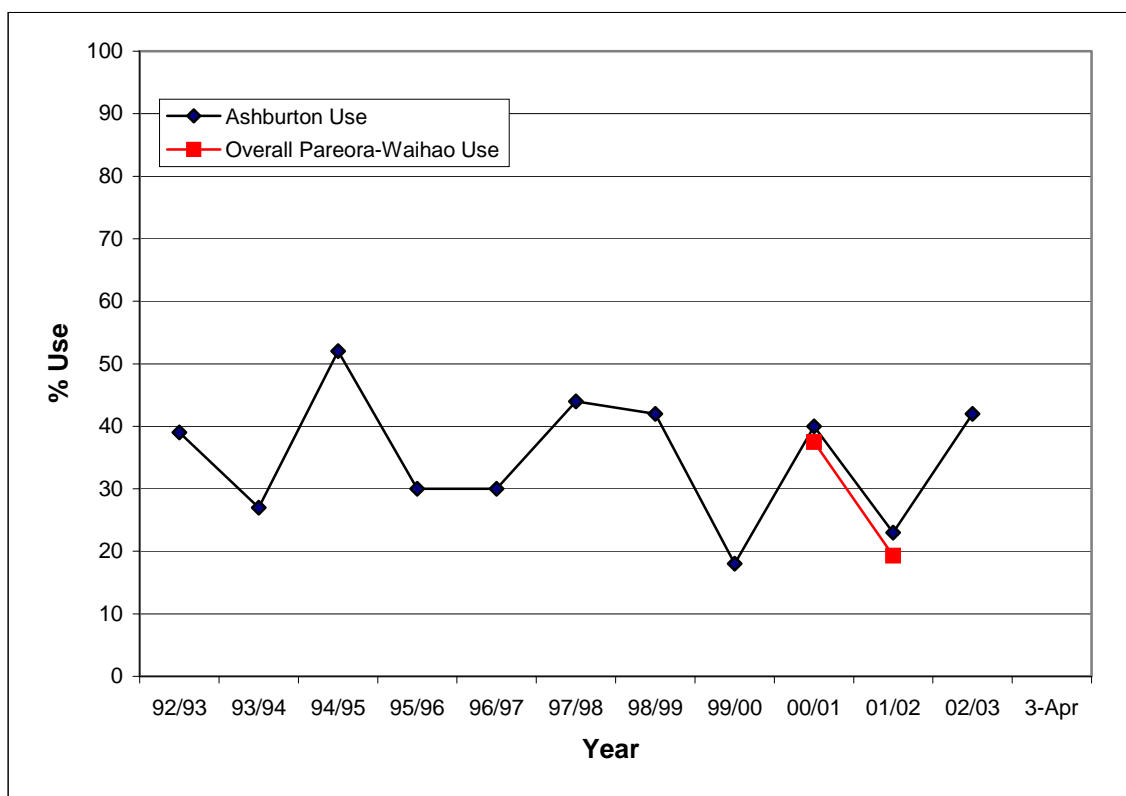


Figure 7.4 Irrigation water usage 2000-2002

**Table 7.3 Percentage use compared to consented daily volume (over a 150 day season)**

Land Use	2000/01	2001/02
Crops and Pasture	31.6%	20.8%
Pasture	42.2%	18.7%
Horticulture	46.0%	14.9%
<b>Average Use</b>	<b>38.0%</b>	<b>19.0%</b>

Sanders (2003) has undertaken an irrigation water use survey since 1994 where power consumption data along with limited water metering has been used to estimate seasonal use. In Figure 7.5 the estimated volumes for the Ashburton District from this survey are compared to the data collected for the Pareora- Waihao catchments for the 2000/01 and 2001/02 years. It shows that for the limited amount of data collected the water use pattern has been similar. If the relationship is similar in other years, then usage in the 1997/98 year (a dry, high use year in some parts of the region) in the Pareora-Waihao area would be around 42.5% of consented daily volume.



**Figure 7.5 Comparison of percentage use of consented volume over a 150 day season for the Ashburton District and Pareora-Waihao**

Public and commercial use was much higher, at an average of 75% (ranging from 21-135%) of the consented rate. Returns provided represent peak use (only summer months) and it could be expected that use would decrease in winter months.

Compared to estimates of effective allocation (Table 7.2), which under NRRP policy WQN14 allows for water to meet a 1 in 5 dry year, estimated maximum use in a dry year (1997/98) is less than effectively allocated for all zones. However, it is expected that existing consents will become more fully utilised over time.

## 8 Recommendations

### 8.1 Limits to water resources (allocation limits/minimum flows)

#### 8.1.1 Surface water allocation limits

The process of surface water allocation is outlined in Environment Canterbury's Proposed NRRP.

In the case of the lower Pareora where the groundwater and surface water is closely linked, as is typical of the rivers in the region, a possible scheme for using levels from an observation well to indicate residual flows is described below.

##### 8.1.1.1 *Methods of management to retain flow regime and environmental values in lower Pareora River (east of SH1)*

###### 8.1.1.1.1 The issue:

Currently surface water and hydraulically connected groundwater consented abstractions are tied to a minimum flow for the Pareora River at Huts. The current minimum flow conditions are:

- (a) The taking of water in terms of this permit shall cease whenever the flow in the Pareora River at the Mount Horrible recorder site (at or about map reference NZMS 260 J39:553-423), as estimated by the Canterbury Regional Council, falls below 300 litres per second.
- (b) The taking of water in terms of this permit shall be reduced to one half of the weekly allocation, noted in condition (1) above, whenever the flow in the Pareora River at the Mount Horrible recorder site (at or about map reference NZMS 260 J39:553-423), as estimated by the Canterbury Regional Council falls below 400 litres per second.

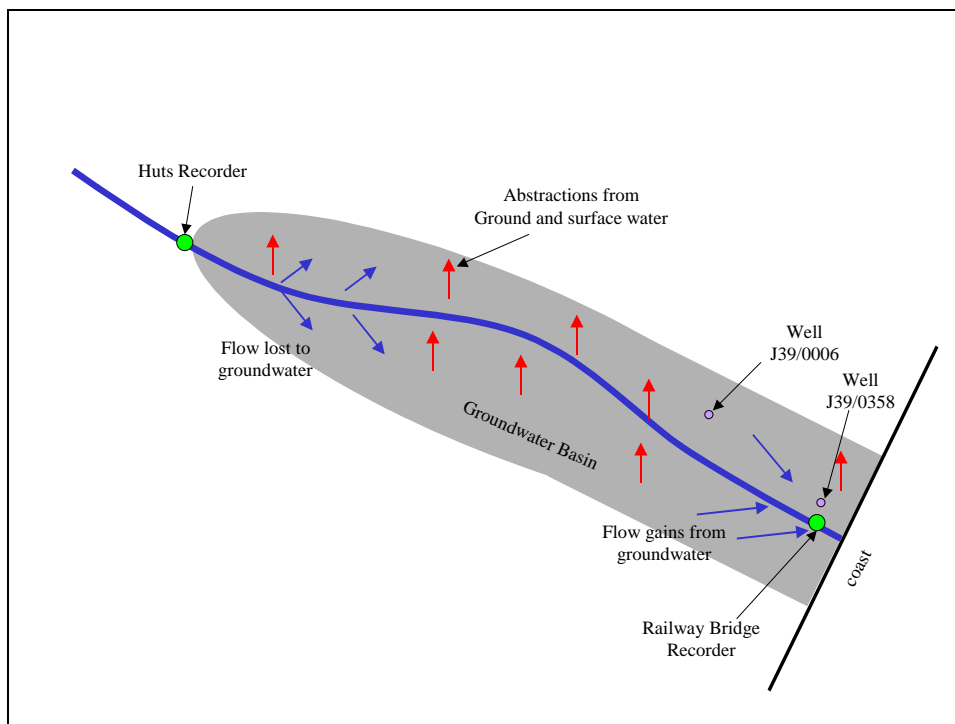
PROVIDED THAT Whenever the Canterbury Regional Council, in consultation with the Water Users Committee representing all water users who are subject to the same Pareora River minimum flow restriction, has determined a water sharing regime which restricts abstraction from the Pareora River to that available above the minimum flow of part (a) of this condition, then the taking of water in accordance with that determination shall be deemed to be in compliance with part (b) of this condition.

Questions have been raised about the suitability of a minimum flow site at Pareora Huts to maintain environmental values for the coastal reaches of the river.

The NRRP review of minimum flows for the Pareora Catchment will identify the values for this reach.

Figure 8.1 schematically describes the Pareora surface and shallow groundwater system. Water is lost from the Pareora into the gravels of the river valley (which can be imagined as a 'groundwater basin') in the upper reaches, while the river often disappears into groundwater in the middle reaches (Section 4.3.4). In the lower reaches emergent groundwater increases the river flow.

A surface water recorder was installed at the Railway Bridge (November 2000 to March 2003) in an attempt to monitor flow conditions in this reach. Periodic sea encroachment meant that this site could not be continued on a long-term basis, and it is therefore not suitable as a minimum flow site.



**Figure 8.1 Schematic diagram of Pareora surface/shallow groundwater resource**

#### 8.1.1.1.2 Options for management

There are several options for managing the surface and shallow groundwater resource:

- a) Maintain status quo with the existing minimum flow at Huts
- b) Use minimum groundwater levels in the lower Pareora as trigger levels as opposed to flow at Huts, specifically to manage abstractions below the Huts.
- c) Revise minimum flow at Huts based on regression with Railway Bridge, to obtain a Huts flow that maintains an appropriate environmental flow regime at Railway Bridge

These options are considered below:

#### 1. Maintain status quo with existing minimum flow at Huts

The original minimum flow was set in the late 1970's to restrict the Timaru District Council from having too large an influence on the low flows of the Pareora River. At that time only a few consents existed for water abstraction.

Today the existing minimum flow equates to a flow of zero at Railway Bridge for the 300 L/s cut off and also zero at the 50% reduction of 400 L/s. This is caused by the ability of abstractors to reduce the groundwater resource so that the emergent water in the lower reaches is considerably reduced. The estimated natural 7DMALF at Railway Bridge is 353 L/s. Therefore the status quo is not appropriate if a flow is required in the lower reaches.

2. Use minimum groundwater levels in the lower Pareora as trigger levels as opposed to flow at Huts

To investigate this option, groundwater levels recorded at well J39/0006 and the Pareora flows recorded at the Railway Bridge over the period of record (November 2000 to March 2003) are plotted in Figure 8.2, with the Huts flows included for completeness. A logarithmic scale is used for the flows to emphasize the low flows. Note that there is a long period of no well record between January and May 2002.

Rises in the well levels show a damped and delayed response to rises in the river flows. On the other hand, during periods of recession in the flows, the well level rate of recession is comparable with the rate of recession of the logarithms of the Railway Bridge flows – see for example the period September to November 2002. To derive a predictive relationship between the well levels and flows, data for periods of recession were extracted and are presented as a log-linear plot in Figure 8.3 with a flow range between 10 and 1000 L/s.

A best-fitting line on this plot has the equation:

$$\text{Railway Bridge flow (L/s)} = 10^{(0.001772 * \text{Well level (mm)} + 7.590)}$$

The resulting Railway Bridge flows for a range of groundwater percentile levels are evaluated in Table 8.1. Percentiles for the levels are evaluated over the complete well level record for nearly 20 years – July 1985 to March 2005.

**Table 8.1 Estimated Railway Bridge flows for a range of well levels**

Level BGL (mm)	Percent of time GW level is above stated value	Estimated Railway Bridge flow (L/s)
-2630	50	1165
-2875	80	442
-3095	90	185
-3299	95	82

Although the equation above is crude, it provides a basis for determining when takes from the lower Pareora and the hydraulically connected groundwater should be reduced to maintain a residual flow in the lower river. The Railway Bridge environmental flow based upon values such as instream needs or reliability of supply will be considered through the NRRP process.

Revise minimum flow at Huts based on regression with Railway Bridge, to obtain a Huts flow that maintains an appropriate environmental flow regime at Railway Bridge  
 There appears to be two water resource systems to manage, one is the river flows to the Huts, and the second is the shallow ground water resource downstream and the emerging water near the coast. Raising the minimum flow at Huts specifically to manage downstream irrigators would unfairly disadvantage the abstractors upstream (of the Huts). This is seen as an unfair method of management.

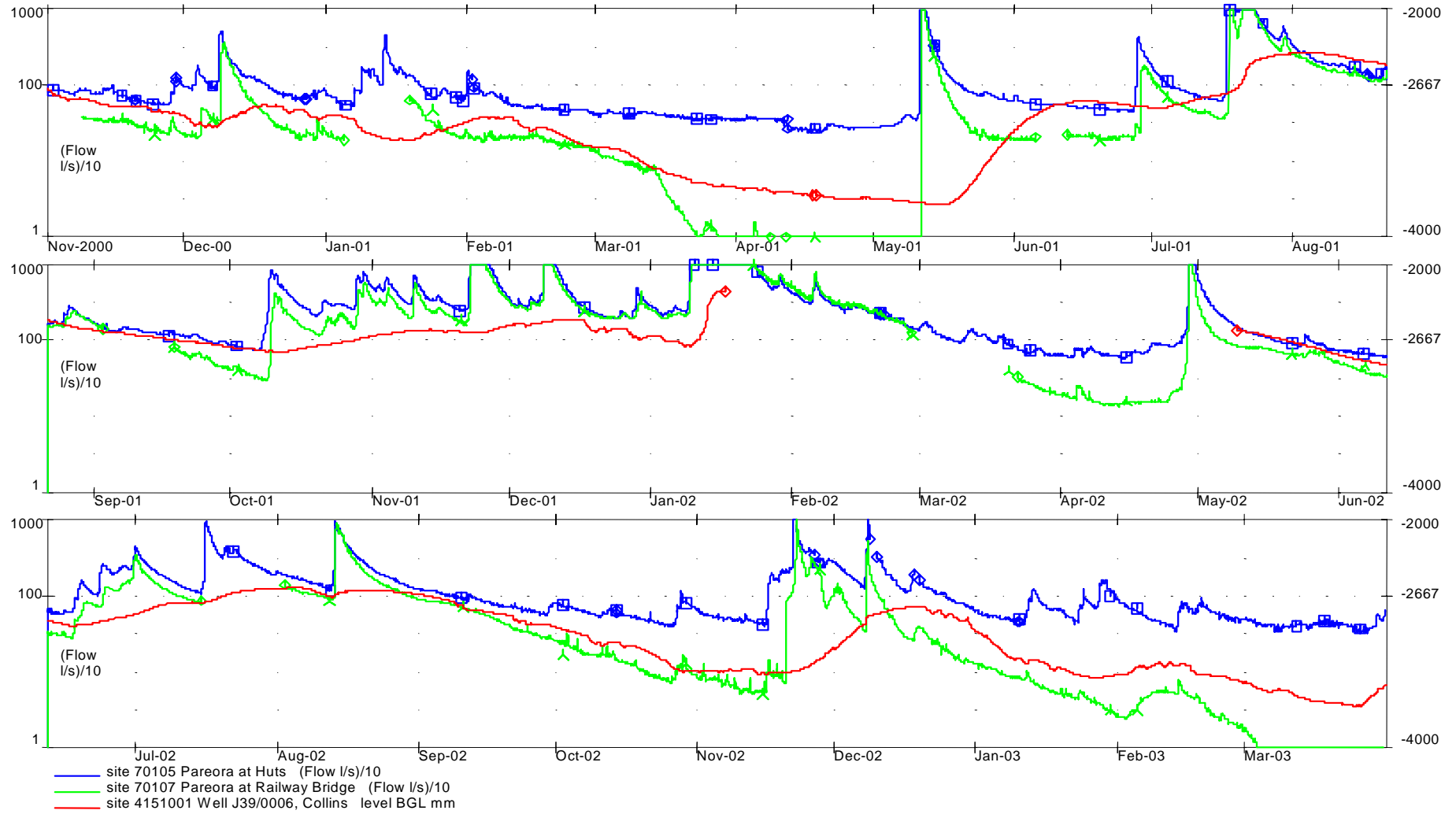
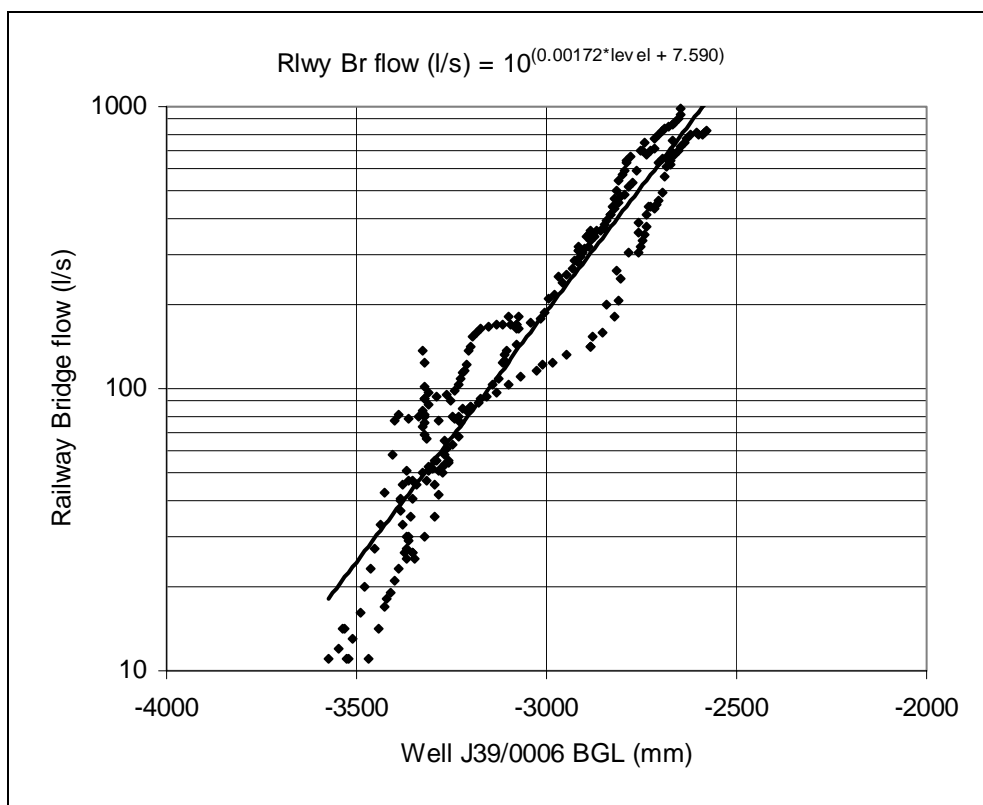


Figure 8.2 Plot of Pareora recorded flows at Huts and Railway Bridge (left hand scales, logarithmic) and well levels for J39/0006 (right hand scales)



**Figure 8.3 Log-linear relationship between recession flows at Railway Bridge and levels for well J39/006.**

### 8.1.2 Groundwater allocation limits

Environment Canterbury's Proposed NRRP Schedule WQN4 details methods for determining interim allocation regimes for groundwater in Canterbury.

The schedule specifies an interim allocatable volume for a groundwater allocation block can be determined as 50% of the annual average land-surface recharge including the recharge component contributed by intermittent streams. For the groundwater allocation zones in the Pareora-Waihao area (Pareora, Otaio, Makikihi and Waihao-Wainono – refer to Figure 8.4 for location), estimates of land-based recharge have already been made (Scott, 2004, and refer to Section 5.3.1.1), as has an estimate of the contribution from intermittent streams to the groundwater allocation zones using data available at the time (Aitchison-Earl, et. al, 2004).

summarises the land-based recharge and intermittent stream contribution currently used by ECan to define the interim allocation regime.

**Table 8.2 Current groundwater allocation limits**

Groundwater Zone	Land-based recharge (million m <sup>3</sup> /year)	Intermittent Stream recharge (million m <sup>3</sup> /year)		Interim allocation limit (million m <sup>3</sup> /year)
		Number	Source	
Pareora	23.9	15.55	Assumes total loss of 7 day MALF (490L/s)	19.7
Otaio	16.3	4.4	Assumes total loss of 7 day MALF (139 L/s)	10.4
Makikihi	31.7	-	-	15.9
Waihao-Wainono	47	4.2	Gauging loss minimum of 0.133m <sup>3</sup> /s	25.6

The groundwater allocation zone approach under Schedule WQN4 of the NRRP is based on dividing areas into groundwater zones, where all aquifers under that area are considered as part of the same groundwater resource. This approach is not as applicable to the Pareora-Waihao aquifers, as the Quaternary Alluvium, Cannington Gravel and deeper Tertiary aquifers are subject to quite different recharge and discharge mechanisms.

As discussed in Section 5.3.1.1 the original estimates of land-based recharge do not properly account for the unique properties of the loess soils on the downlands areas, where recharge may be less than that estimated in Scott (2004). In addition, analysis of flow regimes in this report provides more reliable estimates of intermittent stream contributions as detailed in Table 6.6.

Managing groundwater allocation in these aquifers could either be by treating them as one interconnected groundwater resource (status quo), or by setting individual sub-aquifer allocation limits within the overall groundwater zone allocation limit. These options are outlined below, and summarised in Table 8.3.

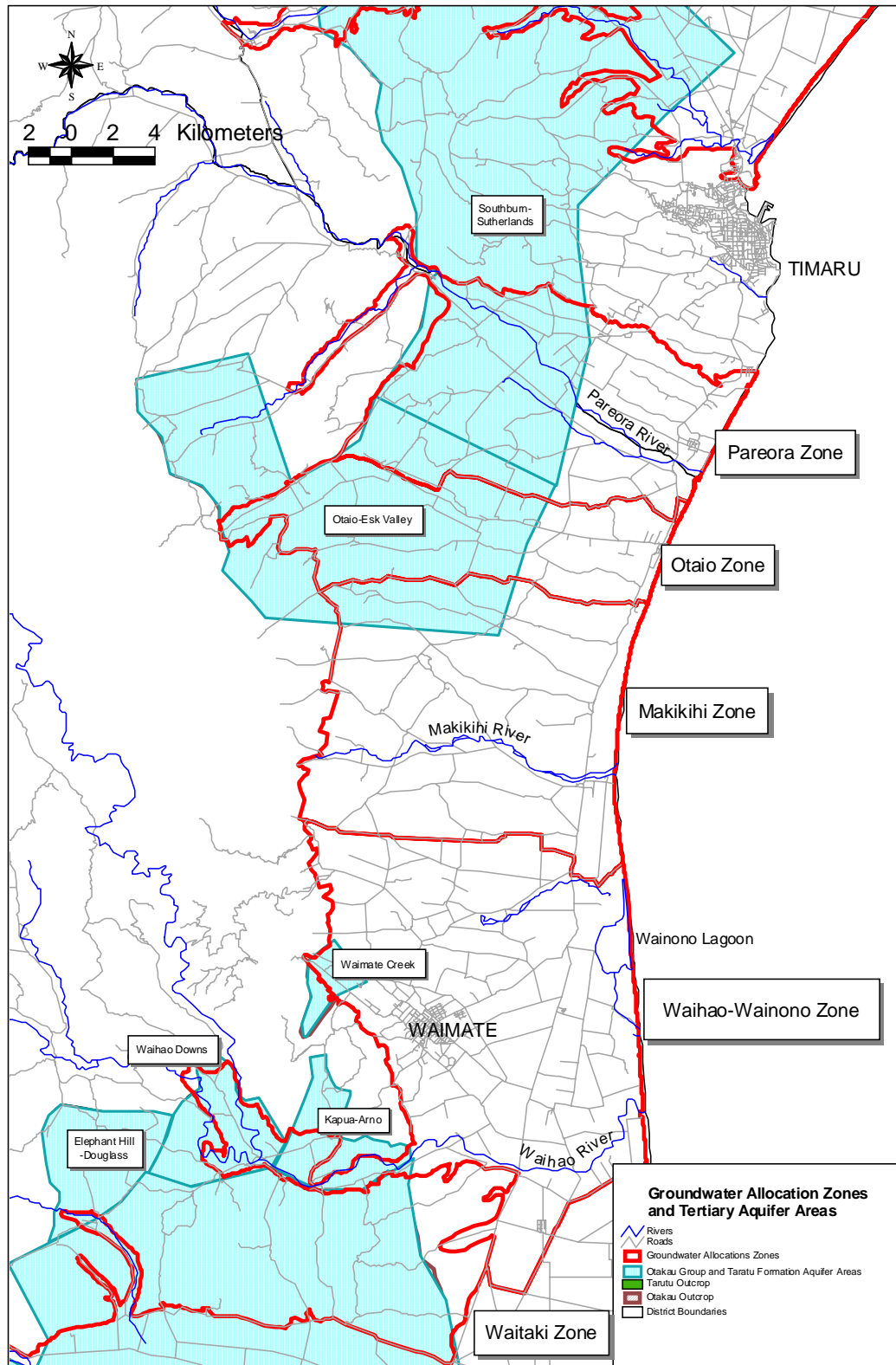


Figure 8.4 Groundwater allocation zones and tertiary aquifer areas

**Table 8.3 Options for allocation limits for Pareora-Waihao groundwater (figures are million m<sup>3</sup>/year)**

Groundwater Allocation Zone	Effective allocation <sup>1</sup>	Option 1: Limit for all aquifers based on existing LSR <sup>2</sup> and revised intermittent stream contribution		Option 2				Refer to Table 8.5
				Option 2a: Revised LSR (based on 25% of average recharge to loess-covered downlands) and revised intermittent stream contribution		Option 2b: Allocation limit for non-Quaternary deep aquifers only, based on LSR only (intermittent recharge assumed to feed shallow aquifer only)		
		Allocation Limit <sup>3</sup>	% Allocated	Allocation Limit <sup>4</sup>	% Allocated	Deep aquifer Allocation Limit	% Allocated	
Pareora	14.36 (9.59 Quaternary + 4.77 non-Quaternary)	15.99 (50% of 23.9 + 8.07)	89.8	9.94 (50% of 11.8 + 8.07)	144.5	5.9 (50% of 11.8)	80.8	
Otaio	3.19 (0.38 Quaternary + 2.81 non-Quaternary)	8.15 (50% of 16.3 + 0)	39.1	4.25 (50% of 8.5 + 0)	75.1	4.25 (50% of 8.5)	66.1	
Makikihi	11.07 (0.336 Quaternary + 10.739 non-Quaternary)	24.70 (50% of 31.7 + 17.69)	44.8	15.95 (50% of 14.2 + 17.69)	69.4	7.1 (50% of 14.2)	146.2	
Waihao-Wainono	13.61 (3.599 Quaternary + 10.01 non-Quaternary)	23.5 (50% of 47 + 0)	57.9	12.8 (50% of 25.6 + 0)	106.3	12.8 (50% of 25.6)	78.2	

<sup>1</sup> Effective allocation derived from Table 7.2: Current Groundwater Resource Use

<sup>2</sup> LSR : Land-surface recharge

<sup>3</sup> Allocation limit is derived from 50 % of land surface recharge (first figure in brackets) and intermittent stream contribution (2<sup>nd</sup> figure in brackets)

<sup>4</sup> Refer to Table 8.4

**8.1.2.1 Option 1**

Maintain the current land-surface recharge estimates, and update the intermittent stream contribution. The allocation limit will not differentiate between aquifers.

Consequences:

This option will still allow further groundwater allocation in all groundwater zones (which are all currently less than 100% allocated). Shallow groundwater would still be subject to the relevant minimum flows and surface water allocation blocks if hydraulically connected.

**8.1.2.2 Option 2**

Under Option 2, the land-surface recharge estimates are updated assuming less recharge under loess-covered downlands. Due to the lack of information on recharge through loess, and the need to be cautious in allocating an unknown resource, a conservative estimate is recommended. Scenario 1 (Table 6.5), using 25% of the average recharge in downland areas is considered an appropriate precautionary estimate. This estimate should be updated when more information on recharge through loess is available. Updated intermittent stream contribution estimates are applied as in Option 1.

There are three sub-categories of Option 2, 2a involves continuing to treat all aquifers as one resource, 2b and 2c separate out the deeper Cannington, and Tertiary aquifers from the shallow Quaternary gravels. It is possible to apply options 2a, b and c as criteria to any single application to take groundwater. If the application exceeds any one of the relevant limits, its sustainability should be examined.

**8.1.2.2.1 Option 2a:**

Treat aquifers as one resource, with updated land-surface recharge and intermittent stream contributions (Table 8.4).

Consequences

Under this option, the Pareora groundwater allocation zone would be fully allocated (148%) and the Waihao-Wainono Zone close to 100% allocation (91.3%). This would mean further groundwater allocation could only occur in the Otaio and Makikihi zones, and to a limited extent in Waihao-Wainono.

**Table 8.4 Proposed groundwater allocation limits**

<b>Groundwater Zone</b>	<b>Land-based recharge<sup>1</sup> (million m<sup>3</sup>/year)</b>	<b>Intermittent Stream recharge<sup>2</sup> (million m<sup>3</sup>/year)</b>	<b>Interim allocation limit<sup>3</sup> (million m<sup>3</sup>/year)</b>
Pareora	11.8	8.07	9.94
Otaio	8.5	0	4.25
Makikihi	14.2	17.69	15.95
Waihao-Wainono	25.6	0	12.8

<sup>1</sup> Land-based recharge from Table 5.5 under Scenario 1, 25% of average recharge under the loess covered downlands

<sup>2</sup> Intermittent stream recharge from Table 5.6

<sup>3</sup> Interim allocation limit is 50% of land-based and intermittent stream recharge

#### 8.1.2.2.2 Option 2b

Due to uncertainty in the role river recharge plays in recharging the deeper aquifers, in this option, the river recharge would be reserved for the shallow Quaternary aquifer only. The same land-surface recharge estimates as in Option 2a would be used, however further allocation from deeper aquifers would not be allowed when the land-surface recharge component of the allocation limit is exceeded.

#### Consequences

Under this option, no further allocation from deeper aquifers would be allowed from the Makikihi zone. Even though the Pareora deep aquifers are less than 100% allocated, the total groundwater resource is > 100 % allocation (from Option 2a), hence no more allocation would be allowed from this zone.

Further deep aquifer allocation is available in the Otaio and Waihao-Wainono zones.

#### 8.1.2.2.3 Option 2c

This option involves setting separate sub-aquifer allocation limits within a groundwater zone, based on recharge at aquifer outcrop (refer to Table 8.5). This is only possible for the Tertiary Southburn Sand and Taratu Formation aquifers, where distinct outcrop areas can be identified. The Southburn Sand is a unit of the Otakou Group, which outcrops (Figure 6.4) in the Pareora Gorge area, in the Esk Valley Stream and in the Waihao Downs area. As discussed in Section 6.3.1.3 it is estimated that around 10% of rainfall on outcrop becomes recharge to the aquifer. Following NRRP Policy WQN14 and Schedule WQN4, 50% of the estimated land-based recharge may be allocated. Recommended allocation limits for these aquifers are outlined in Table 8.5 (the details of each consent are included in Appendix 38). It should be noted that some outcrops are already included in Groundwater Allocation Zones (i.e. the Esk Valley Southburn Sands are part of the Otaio Groundwater Allocation Zone), hence rainfall has already been included in land-based recharge estimates for these zones. Because of this, allocations from Southburn Sand and Taratu aquifers should still be accounted for in the greater Groundwater Allocation Zones, and the allocation zones and limits referred to in Table 8.5 should be considered as sub-zones. Under this option, the allocation limit for the whole zone, set under Option 2a, would remain, hence allocation could not be allowed from a sub-zone if the whole zone was already greater than 100% allocated.

**Table 8.5 Estimated allocation available in Otakou Group and Taratu Formation aquifers**

Aquifer	Sub-Area	Estimated Allocation Limit <sup>1</sup> (m <sup>3</sup> /yr)	Effective Allocation (m <sup>3</sup> /yr)	% allocated
Otakou Group	Southburn-Sutherlands	730,504	386,391	53%
	Otaio/Esk Valleys	504,103	779,134	154%
	Waimate Creek	101,471	0	0%
	Elephant Hill/Ikawai	2,093,528	1,132,040	54%
Taratu Formation	Kapua-Arno <sup>2</sup>	139,397	164,851	118%
	Waihao Downs	202,060	0	0%
	Elephant Hill-Douglas <sup>2</sup>	93,839	332,775	354%

<sup>1</sup> Estimated allocation limit is 50% of the recharge estimate from Table 5.7

<sup>2</sup> NB – there is only one abstraction in each of these zones.

### Consequences

Table 8.3 outlines the current allocation from these aquifer sub-areas. The limiting factor will be the total allocation limit for the zone, which if already deemed to be greater than 100% under Option 2a or 2b, will mean that no further allocation should be allowed from the Tertiary aquifers. This would mean development of deep aquifers in the Pareora or Makikihi Zones would likely be restricted.

#### *8.1.2.3 Analysis of options*

Option 1, involving an updated intermittent stream contribution, but existing land-surface recharge estimates is not considered appropriate, as land-surface recharge may be overestimated (refer to Section 6.3.1.1). Utilising the combination of the Options 2a, b and c (depending on which aquifer a proposed take is within) is more appropriate as a precautionary approach, especially for the deep aquifers which have only been recently developed and for which we have little knowledge of the consequence of long term abstractions.

For all wells in deeper aquifers within the Pareora-Waihao areas, the long term viability of abstractions is unknown, and should be carefully assessed through monitoring of aquifer pressures and chemistry. Investigations are proposed in Section 8.3 Further work.

Recommendations for each aquifer are as follows, and summarised in Table 8.6 compared to current effective allocation.

#### 8.1.2.3.1 Quaternary Alluvium

Groundwater allocation limits should take both land-surface recharge and intermittent stream flow into account as per Option 2a. As the majority of Quaternary Alluvium takes are located adjacent to and hydraulically connected to the major rivers (Figure 6.2), they will also be controlled through NRRP Policy WQN14 through minimum flows and surface water allocation blocks. As current allocation of surface water exceeds 7-day MALF in many catchments (Table 7.1), limits on the surface water resource may have a greater bearing on water use than groundwater allocation limits.

#### 8.1.2.3.2 Cannington Gravels

The Cannington Gravels are extensive over most of the area, and underlie the Quaternary alluvial aquifers where present. The connection between the two aquifers is poorly understood, but it is assumed that land-surface and river recharge may percolate through the extensive gravel thicknesses from the shallow Quaternary alluvium to the deeper Cannington Gravels. Due to the lack of certainty regarding connection, recharge to the two aquifers from land-surface and intermittent stream flow cannot be apportioned. To be conservative, it is recommended that intermittent stream recharge only be included as part of an allocation limit for the shallow Quaternary Alluvium aquifer, as per Option 2b (Table 8.3), hence only rainfall recharge is considered for the Cannington Gravels aquifers.

#### 8.1.2.3.3 Tertiary aquifers (Southburn Sand and Taratu Formation)

With the lack of information on recharge sources, age of water, and sustainability of these aquifers, a conservative approach to allocation should be taken. Allocation limits for each aquifer based on out-crop area as detailed in Table 8.5 indicate more water can be allocated, however the overall zone groundwater allocations under options 2a and 2b indicate that at least in the Pareora and Makikihi Zones, the limits of sustainability may be being reached. If either limit (Option 2a, b or c) is exceeded, no further allocation should occur.

Three wells abstract from the Taratu Formation in areas where there is no known outcrop, two in the Pareora South Branch (J39/0481 and 482) and one in the upper Hook River (J40/0641 -although the identification of this well as Taratu Formation is tentative (Forsyth, 2004)). These wells should thus be managed under Option 2b.

For all wells in the Tertiary aquifers, the long term viability of abstractions is unknown, and should be carefully monitored through monitoring of aquifer pressures and chemistry.

#### 8.1.2.4 *Summary*

If Options 2 a, b and c are accepted, Table 8.6 details in which areas further groundwater allocation would still be possible, and which would be considered already fully allocated.

***The adoption of any of these options is a planning and policy decision, which has not yet been decided by Council.***

**Table 8.6 Summary of Proposed Groundwater Allocation Status (figures in 10<sup>6</sup> m<sup>3</sup>/year)**

Zone	Aquifer	Allocation Option	Allocation Limit	Effective Allocation	Percentage allocated	Consequences
<b>Pareora</b>	<b>All aquifers limit</b>		<b>9.94</b>	<b>14.36</b>	<b>144%</b>	No more allocation from any aquifer in the Pareora Zone, as all aquifer limits exceeded
	Quaternary Alluvium	2a	9.94	9.59	96.5%	
	Cannington Gravels	2b	5.9	4.77	80.8%	
<b>Otaio</b>	<b>All aquifers limit</b>		<b>4.25</b>	<b>3.19</b>	<b>75%</b>	Allocation available in Quaternary (subject to the availability of the surface water block for hydraulically connected groundwater) and Cannington aquifers
	Quaternary Alluvium	2a	4.25	0.38	8.9%	
	Cannington Gravels	2b	4.25	2.51	59.1%	
	Southburn Sands	2c	0.504 <sup>1</sup>	0.30 (plus 0.47 in Makikihi Zone)	154%	
<b>Makikihi</b>	<b>All aquifers limit</b>		<b>15.95</b>	<b>11.08</b>	<b>69.5%</b>	Allocation available in Quaternary alluvium.
	Quaternary Alluvium	2a	15.95	0.34	2.1%	
	Cannington Gravels	2b	7.1	10.74 (10.26 Cannington and 0.47 Southburn)	151%	
	Southburn Sands	2b <sup>2</sup>				
<b>Waihao-Wainono</b>	<b>All aquifers limit</b>		<b>12.8</b>	<b>13.6</b>	<b>106%</b>	No more allocation from any aquifer in the Waihao-Wainono Zone, as all aquifer limits exceeded
	Quaternary Alluvium	2a	12.8	3.60	28.1%	
	Cannington Gravels	2b	12.8	9.84	76.9%	
	Taratu Formation a) Kapua-Arno b) Waihao Downs	2c	0.14 0.20	0.16 0	118% 0%	

<sup>1</sup> From Table 7-5, Otaio/Esk Valley sub-area of Otakaou Group aquifer, covers Otaio and Makikihi zones

<sup>2</sup> No Southburn Sand outcrop in this area, hence allocation limit unable to be set via option 2c – reverts to combined allocation with Cannington gravel

## 8.2 Groundwater quality

In the deeper aquifers, particularly those in marine-derived sediments, the quality of the groundwater may not be suitable for drinking or for irrigation use.

As discussed in Section 6.4, there is very little data currently available on the quality and chemistry of the deeper aquifers, although there is a significant as yet unreported on data set for shallow aquifers. An incident reported near the South Branch Pareora has indicated that the water derived from wells within the Taratu Formation has had adverse impacts on the soil structure.

The Otago Regional Council Regional Water plan (ORC, 2004) specifically details issues regarding degradation of soil resources due to poor quality groundwater especially for the Papakaio and Waiareka Volcanics aquifers (Issue 9.2.5, 9.3.5, 9.4.23), and addresses them via rules and information requirements for resource consents. Information Requirement: 16.3.1 (7) for resource consent requires '*In the case of the taking of groundwater for irrigation purposes, a description of the quality of the groundwater where there is likely to be any adverse effect on soils*'.

It is therefore recommended that any consent applications to abstract groundwater from the Cannington Marine, Southburn Sands or Taratu Formation aquifers be required to undertake testing the aquifer chemistry to determine the suitability of the water for the proposed use.

## 8.3 Further work

- Further river flow gaugings carried out as recommended in Section 4.8.
- Examination of soil infiltration capacity for loess covered downlands to determine appropriate values for a land-surface recharge model.
- Investigate Cannington Gravel, Southburn Sand and Taratu Formation aquifers to determine sustainable yield through:
  - Long-term water level monitoring to determine trends
  - Water chemistry and isotope sampling to determine recharge source and residence time
  - Aquifer testing to determine aquifer parameters and connection between aquifers
- Sampling and description of groundwater quality and chemistry from shallow and deeper aquifers to describe current state, and trends over time. This would assist in determining potential limitations of water quality for use.

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## Appendix 1: Analysis of Pareora at Huts 7-day annual low flows and derivation of naturalised flows

It is assumed that the irrigation season runs from 1 October to 30 April and that only 50% of irrigation abstractions are used. "Full irrigation" takes occur when recorded flows at the Pareora at Huts site exceed 400 l/s. "Half restriction" occurs when recorded flows lie between 400 l/s and 300 l/s and consent holders are then only authorised to use half their consented abstraction rate. "Full restriction" applies when the recorded flow is less than 300 l/s and consent holders must cease abstraction. Units for all the flow data are litres per second (l/s). "S&D" refers to "Stock and Domestic" usage. The "TDC cor'n" is calculated based on the equation given in section 4.3.1.

Year ending 30-June-	Date of low flow	Recorded low flow (l/s)	TDC cor'n	Other S&D	Irrigation cor'n	Naturalised low flow (l/s)
1983	2/03/1983	370	126	9	9	513
1984	14/04/1984	599	171	9	18	797
1985	28/03/1985	313	114	9	26	462
1986	5/07/1985	415	135	9	0	558
1987	<b>5/01/1987</b>	<b>377</b>	<b>127</b>	9	26	<b>539</b>
1988	10/05/1988	429	137	9	0	575
1989	30/10/1988	278	108	9	17	412
1990	28/11/1989	428	137	9	54	629
1991	<b>11/02/1991</b>	<b>450</b>	<b>142</b>	9	54	<b>655</b>
1992	19/03/1992	356	123	9	35	523
1993	30/06/1993	619	175	9	0	803
1994	28/08/1993	377	127	11	0	516
1995	18/03/1995	557	163	10	54	783
1996	30/03/1996	957	200	9	54	1220
1997	17/05/1997	808	200	9	0	1017
1998	11/02/1989	304	113	9	35	461
1999	21/02/1999	498	151	9	54	712
2000	28/09/1999	596	170	9	0	775
2001	12/04/2001	263	105	9	0	377
2002	10/06/2002	609	173	9	0	791
2003	22/03/2003	382	128	9	35	554
2004	12/01/2004	317	115	9	35	476
7DMALF		468				643
Normalised 7DMALF						659

**Missing record during time of suspected lowest flow - low flow estimated and should be used with caution.**

## Appendix 2: Details of estimated surface water and groundwater takes from the Pareora catchment as calculated from resource consents

PAREORA CATCHMENT SURFACE WATER CONSENTS

Irrigation

Public and Stockwater/Rural Supply

Water rights:	Reg No. 3169	Reg No. 2863	Reg No. 2903 Reg No. 2492	Reg No. 1456 Reg No. 2619 Reg No. 2913	Reg No. 2018 Reg No. 2906	Reg No. 2020 Reg No. 2888	Reg No. 2880	Reg No. 3400	Reg No. 3403												
<b>Original consent:</b>	scy690641	scy650048b	scy630274b	scy760105	scy820175	scy820351	scy880032	crc950103	scy750028	scy800097	crc921501	scy800100	scy840007	scy830256	crc950292	scy850197	crc990880	scy860031	crc950386	crc990820	
Commenced:	1940	11/04/1985	8/11/1983	14/06/1989	9/09/1982	11/02/1976	14/12/1988	7/09/1994	14/02/1985	14/05/1980	2/10/1992	14/05/1980	12/04/1984	13/09/1989	14/10/1994	12/12/1985	1/05/2000	15/05/1986	17/03/1995	6/12/1999	
Expired:	2/04/2003	1/06/1999	1/06/1999	1/06/2009	1/05/2000	1/05/2000	19/12/1995	31/08/1929	1/06/1994	1/06/1999	1/06/2004	1/05/2000	1/05/2000	1/06/1994	5/10/2029	1/06/1999	27/04/2015	1/06/1994	15/03/1930	5/11/2014	
<b>Replacement:</b>	crc011399	crc000183	crc990342			crc991286					crc032086	crc991282				crc992192			crc950390		
Commenced:	2/04/2003	14/02/2002	19/10/1998			1/05/2000					3/10/2003	1/05/2000				1/05/2000			17/03/1995		
Expires:	5/11/2024	27/04/2015	15/10/1993			27/04/2015					3/10/1938	27/04/2015				27/04/2015			15/03/1930		
<b>Year</b>	<b>Average Daily Rate to be added back (l/s)</b>																				
1940	200																				
1941	200																				
1942	200																				
1943	200																				
1944	200																				
1945	200																				
1946	200																				
1947	200																				
1948	200																				
1949	200																				
1950	200																				
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1968	200																				
1969	200																				
1970	200																				
1971	200																				
1972	200																				
1973	200																				
1974	200																				
1975	200																				
1976	200				5.9		5.89		1.6												
1977	200				5.9		5.89		1.6												
1978	200				5.9		5.89		1.6												
1979	200				5.9		4.15		1.6												
1980	200				5.9		4.15		1.6	0.375			9.3								
1981	200				5.9		4.15		1.6	0.375			9.3								
1982	200				5.9	4.15	4.15		1.6	0.375			9.3								
1983	200			1.5	5.9	13.65	4.15		1.6	0.375			9.3		4.15						
1984	200			1.5	5.9	13.65	4.15		1.6	0.375			9.3	16.75	4.15						
1985	200	16.5		1.5	5.9	13.65	4.15		1.6	0.375			9.3	16.75	4.15		2.5				
1986	200	16.5		1.5	5.9	13.65	4.15		1.6	0.375			9.3	16.75	4.15		2.5		20.65		
1987	200	16.5		1.5	5.9	13.65	4.15		1.6	0.375			9.3	16.75	4.15		2.5		20.65		
1988	200	16.5		1.5	5.9	13.65	4.15		1.6	0.375			9.3	16.75	4.15		2.5		20.65		
1989	200	16.5		1.5	5.9	14.2	22.5	0.8	1.6	0.375			15	15	4.15		2.5		12.4		
1990	200	16.5		1.5	5.9	14.2	22.5	0.8	1.6	0.375			15	15	4.15		2.5		12.4		
1991	200	16.5		1.5	5.9	14.2	22.5	0.8	1.6	0.375			15	15	4.15		2.5		12.4		
1992	200	16.5		1.5	5.9	14.2	22.5	0.8	1.6	0.375	0.4		15	15	4.15		2.5		12.4		
1993	200	16.5		1.5	5.9	14.2	22.5	0.8	1.6	0.375	0.4		15	15	4.15		2.5		12.4		
1994	200	16.5		1.5	5.9	14.2	22.5	0.8	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4		
1995	200	16.5		1.5	5.9	14.2	22.5	0.8	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4	26.5	
1996	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4	26.5	
1997	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4	26.5	
1998	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4	26.5	
1999	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5		12.4	26.5	
2000	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8
2001	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8
2002	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8
2003	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8
2004	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8
2005	200	16.5		1.5	5.9	14.2	22.5	2	2	1.6	0.375	0.4	15	15	4.15	10	2.5	10.2	12.4	26.5	11.8

Takes above Pareora at Huts recorder site

Takes from Pareora South Branch

Low flow condition?

Original consent:	Y	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	Y	N	Y	N	Y	Y
			4l/s below discharge point	Conditions of managment plan	Conditions of managment plan	Conditions of managment plan				Conditions of managment plan	Cease <300l/s 1/2 <400l/s at Huts.	Conditions of managment plan	Conditions of managment plan		Cease <300l/s at Huts.		Cease <300l/s at Huts.		Cease <300l/s at Huts.	Cease <300l/s at Huts.
Replacement:	Y	N	Y			Y				Y	Y	Y	Y		Y		Y		Y	
	30l/s below dam		4l/s below discharge point			Cease <300l/s 1/2 <400l/s at Huts.				Cease <300l/s 1/2 <400l/s at Huts.	Cease <300l/s 1/2 <400l/s at Huts.				Cease <300l/s at Huts.		Cease <300l/s at Huts.		Cease <300l/s at Huts.	
<b>Add back to:</b>	Pareora site 1866 and below. See Section 4.3.7.	Pareora site 1866 and below.	Pareora site 1866 and below.	White Rock site 2065 and below. Pareora site 1856 and below.	Pareora site 1856 and below.	Pareora site 70106 and below.	Sth Branch site 170102 and below. Pareora site 1853 and below.	Sth Branch site 170102 and below. Pareora site 1853 and below.	Sth Branch site 170102 and below. Pareora site 1853 and below.	Sth Branch site 2252 and below. Pareora site 1853 and below.	Sth Branch site 2274 and below. Pareora site 1853 and below.	Pareora site 1853 and below.	Pareora site 1851 and below.	Pareora site 1851 and below.	Pareora site 1852 and below.	Pareora site 170101 and below.	Pareora site 1858 and below.	Pareora site 1858 and below.	Pareora site 1858 and below.	Sites on Pareora Trib below take and Pareora site 170103 and below.

WHOLE CATCHMENT TOTAL SW TAKE:

ABOVE HUTS TOTAL SW TAKE:

Year	Total S&D	Total irrig.	1/2 restriction	Full restriction	S&D minus	Year	Total S&D	Total irrig.	1/2 restriction	Full restriction	S&D minus
1940	200	0	0	0	0	1940	200	0	0	0	0
1941	200	0	0	0	0	1941	200	0	0	0	0
.	" "	" "	" "	" "	" "	.	" "	" "	" "	" "	" "
.	" "	" "	" "	" "	" "	.	" "	" "	" "	" "	" "
1969	200	0	0	0	0	1969	200	0	0	0	0
1970	200	0	0	0	0	1970	200	0	0	0	0
1971	200	0	0	0	0	1971	200	0	0	0	0
1972	200	0	0	0	0	1972	200	0	0	0	0
1973	200	0	0	0	0	1973	200	0	0	0	0
1974	202	0	0	0	2	1974	200	0	0	0	0
1975	207	6	3	0	7	1975	202	0	0	0	2
1976	207	6	3	0	7	1976	207	6	3	0	7
1977	207	6	3	0	7	1977	207	6	3	0	7
1978	207	4	2	0	7	1978	207	6	3	0	7
1979	207	14	7	0	7	1979	207	4	2	0	7
1980	207	14	7	0	7	1980	207	5	2	0	7
1981	207	18	9	0	7	1981	207	5	2	0	7
1982	209	32	16	4	9	1982	207	9	4	0	7
1983	209	48	24	4	9	1983	209	18	9	0	9
1984	209	67	43	23	9	1984	209	18	9	0	9
1985	209	88	64	44	9	1985	209	35	26	17	9
1986	209	88	64	44	9	1986	209	35	26	17	9
1987	209	88	64	44	9	1987	209	35	26	17	9
1988	209	103	67	36	9	1988	209	35	26	17	9
1989	209	103	67	36	9	1989	209	54	35	17	9
1990	209	103	67	36	9	1990	209	54	35	17	9
1991	209	103	67	36	9	1991	209	54	35	17	9
1992	209	103	67	36	9	1992	209	54	35	17	9
1993	211	113	77	36	11	1993	209	54	35	17	9
1994	210	135	102	31	10	1994	211	54	35	17	11
1995	209	135	102	19	9	1995	210	54	35	17	10
1996	209	135	102	19	9	1996	209	54	35	17	9
1997	209	135	102	19	9	1997	209	54	35	17	9
1998	209	135	102	19	9	1998	209	54	35	17	9
1999	209	141	96	3	9	1999	209	54	35	17	9
2000	209	111	80	0	9	2000	209	37	19	0	9
2001	209	128	97	17	9	2001	209	23	11	0	9
2002	209	128	97	17	9	2002	209	39	28	17	9
2003	209	130	98	17	9	2003	209	39	28	17	9
2004	209	130	98	17	9	2004	209	42	29	17	9
2005	0	0	0	0	-200	2005	209	42	29	17	9

**PAREORA CATCHMENT STREAM DEPLETING GROUNDWATER CONSENTS**  
Data compiled and stream depletion calculated by Philippa Aitchison-Eart

	Irrigation										Public and Stockwater/Rural Supply															
Original consent:	crc990943/1	crc011907	crc971810.2	crc991239/2/1	crc020599	crc980553	crc991400	crc991982	crc991281	crc990697	crc991284	crc990633	crc991384	crc991278	crc991280	scy810084	crc010393	crc991283	crc991682	crc991443	crc991310	crc990818	crc991279	crc010392	scy810083	crc991155
Commenced:	May-2000	Jan-2002	Oct-2004	May-2000	Jan-2002	Dec-1997	May-2000	May-2000	May-2000	May-2000	May-2000	Feb-1999	May-1999	Oct-1999	Oct-1999	Feb-1969	Oct-2000	May-2000	Mar-1999	Jun-1999	May-2000	Dec-1999	May-2000	Oct-2000	Feb-1969	Sep-1999
Expired:	Apr-2015	Apr-2015	Mar-1932	Apr-2015	Apr-2015	Jun-2001	Apr-2015	Apr-2015	Apr-2015	Apr-2015	Jun-2003	Feb-1934	May-1934	Oct-1934	Oct-1934	Nov-2000	Oct-1935	Apr-2015	Mar-1934	Jun-1934	Jun-2004	Jun-2001	Apr-2015	Oct-1935	Nov-2000	Sep-1994
Replacement 1:						crc980553.1					crc991284.1										crc991310.1	crc990818.1				
Commenced:						14/06/2001					19/06/2003										3/06/2004	14/06/2001				
Expires:						5/08/2003					27/04/1935										27/04/2015	5/11/2014				
Replacement 2:						crc980553.2																				
Commenced:						5/08/2003																				
Expires:						10/12/1932																				

Year	Stream depletion rate to be added back (l/s)																										
1969																											
1970																											
1971																											
1972																											
1973																											
1974																											
1975																											
1976																											
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2002																											
2003																											
2004																											
2005																											

Low flow condition?	Above Huts																															
Original consent:	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	N				
Replacement:	Full <300l/s 1/2 <400l/s at Huts.		Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	<1500 l/s at Huts	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Y Full <300l/s 1/2 <400l/s at Huts.								Full <300l/s 1/2 <400l/s at Huts.			Full <300l/s 1/2 <400l/s at Huts.	Y Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.						
Add back to:	Pareora Lowe Gorge and below.	Pareora Purves Crossing and below.	1/2 Pareora Jefcoates Rd and full below.	1/2 Pareora Jefcoates Rd and full below.	Pareora Brassells Bge and below.	Pareora Midgleys Track and below.	Pareora Midgleys Track and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	Pareora SH1 and below.	1/2 to SH1 and 1/2 to Railway Br.	Pareora Railway Br	Pareora Railway Br	Pareora Railway Br	Y Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Full <300l/s 1/2 <400l/s at Huts.	Pareora Railway Br	Pareora Railway Br	Pareora Railway Br	1/2 to Pareora Railway Bge.	

WHOLE CATCHMENT TOTAL GW TAKE:						ABOVE HUTS TOTAL GW TAKE:				
Year	Total S&D	Total irrig.	<1500 l/s at Hut:	1/2 restriction	Full restriction	Year	Total S&D	Total irrig.	1/2 restriction	Full restriction
1969	1	0	0	0	0	1969	0	0	0	0
1970	1	0	0	0	0	1970	0	0	0	0
1971	1	0	0	0	0	1971	0	0	0	0
1972	1	0	0	0	0	1972	0	0	0	0
1973	1	0	0	0	0	1973	0	0	0	0
1974	1	0	0	0	0	1974	0	0	0	0
1975	1	0	0	0	0	1975	0	0	0	0
1976	1	0	0	0	0	1976	0	0	0	0
1977	1	0	0	0	0	1977	0	0	0	0
1978	1	0	0	0	0	1978	0	0	0	0
1979	1	0	0	0	0	1979	0	0	0	0
1980	1	0	0	0	0	1980	0	0	0	0
1981	1	0	0	0	0	1981	0	0	0	0
1982	1	0	0	0	0	1982	0	0	0	0
1983	1	0	0	0	0	1983	0	0	0	0
1984	1	0	0	0	0	1984	0	0	0	0
1985	1	0	0	0	0	1985	0	0	0	0
1986	1	0	0	0	0	1986	0	0	0	0
1987	1	0	0	0	0	1987	0	0	0	0
1988	1	0	0	0	0	1988	0	0	0	0
1989	1	0	0	0	0	1989	0	0	0	0
1990	1	0	0	0	0	1990	0	0	0	0
1991	1	0	0	0	0	1991	0	0	0	0
1992	1	0	0	0	0	1992	0	0	0	0
1993	1	0	0	0	0	1993	0	0	0	0
1994	1	0	0	0	0	1994	0	0	0	0
1995	1	0	0	0	0	1995	0	0	0	0
1996	1	0	0	0	0	1996	0	0	0	0
1997	1	7	7	4	0	1997	0	0	0	0
1998	1	7	7	4	0	1998	0	0	0	0
1999	71	26	26	17	7	1999	0	0	0	0
2000	75	101	101	58	16	2000	0	14	7	0
2001	74	105	105	61	16	2001	0	14	7	0
2002	74	132	127	72	16	2002	0	14	7	0
2003	74	136	132	70	7	2003	0	14	7	0
2004	74	170	165	86	7	2004	0	14	7	0
2005	74	170	165	86	7	2005	0	14	7	0

## Appendix 3: Concurrent gaugings in the Pareora catchment used in analysis (1/5)

Flow (l/s)	White Rock River											Pareora River											Pareora Sth Branch		Sth Brnch Trib	Recorder Sites			
	2130 Elder	2278 Gordons	2227 Matata	2239 Motukaika	2236 Nimrod	2275 Taiko	2382 Unnamed Brasells	2276 W/R 1	2277 W/R 2	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	70106 Evans	1858 Midgleys	1856 Lower Gorge	1857 Upper Gorge	1853 Purves	1851 Holme Stn	1852 Tailbots	1854 Jefcoates	170101 Brasells	170103 SH1	2252 Craignore	170102 Timaunga	1876 Golf Links	2274 Gorge Rd	2253 Back Line	70107 Railway Br	70105 Huts
4/04/1973												374	Dry			386		5	6		Dry				220			17	
18/04/1973												321				443		89	75						168				
15/05/1973												4338	5605									5608			1486				
29/05/1973																977	977												
4/07/1973												322													157				
13/07/1973												296					173								172				
5/10/1973												677	360			779			700		554	361 / 366			290			605	
12/11/1973												1111													411				
7/01/1974												829													345				
1/02/1974												443													203				
4/02/1974	109		32	79	37				73	181	196				270												17		
27/03/1974														1037 / 1254 / 1038					1380		1255	1346 / 1374			476				
19/04/1974												113000																	
6/12/1974												406													185				
6/01/1975												149													113				
23/12/1975												391													198				
7/01/1976												276													283				
12/03/1976												388													233				
22/03/1976												299	30				106	noflow			3				156				
13/04/1976	55			46	14				33			284													157				
7/07/1976												373													233				
9/11/1976												825 / 1536																	
25/01/1977												3699													1301				
4/04/1977												339													210				
4/10/1977												2188													860				
5/01/1978												642													253				
15/02/1978	101		26	60	21				47		86	284													163				
23/02/1978												221					78								160				
6/03/1978												244													158				
10/03/1978																													
15/03/1978	71		12	44	18				36	132	65	219		Dry			Dry												

## Concurrent gaugings in the Pareora catchment used in analysis (2/5)

Flow (l/s)	White Rock River										Pareora River							Pareora Sth Branch			Sth Brnch Trib	Recorder Sites									
	2130 Elder	2278 Gordons	2227 Matata	2239 Motukaika	2236 Nimrod	2275 Taiko	2382 Unnamed Brasells	2276 W/R 1	2277 W/R 2	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	70106 Evans	1858 Midgleys	1856 Lower Gorge	1857 Upper Gorge	1853 Purves	1851 Holme Stn	1852 Talbots	1854 Jefcoates	170101 Brasells	170103 SH1	2252 Craigmore	170102 Timaunga	1876 Golf Links	2274 Gorge Rd	2253 Back Line	70107 Railway Br	70105 Huts		
Date																															
6/03/1978												244													158						
10/03/1978													Dry					Dry				Dry									
15/03/1978	71		12	44	18				36	132	65	219			107										121						
7/04/1978												463													223						
30/08/1978												4774													1714						
15/10/1978													Dry																		
4/01/1979												1106													633						
12/01/1979												707													488						
23/01/1979												441													316						
31/01/1979												216													94						
7/02/1979												306													188						
15/02/1979												425													179						
23/02/1979												400													197						
15/03/1979												4673													1998				1990/1985		
5/06/1979												2220													869						
18/06/1979												1187													419						
28/06/1979												784													352						
3/07/1979												1333													678						
19/07/1979												671													317						
6/08/1979												3470													1786						
19/09/1979												932													413						
18/12/1979												688													415						
12/02/1980												1459													252						
26/02/1980												1291													445						
29/04/1980																		198150													
26/05/1980												1623																			
3/06/1980												1156													504						
25/06/1980																									532						
9/07/1980												1038													404						
22/07/1980												762													451						
19/08/1980												1322													330						
3/09/1980												1122													335						
29/09/1980												442													158						
7/10/1980												333													147						
21/10/1980												4310													977						

Concurrent gaugings in the Pareora catchment used in analysis (3/5)

Flow (l/s)											Pareora River										Pareora Sth Branch		Sth Brnch Trib	Recorder Sites						
	2130 Elder	2278 Gordons	2227 Matata	2239 Motukaika	2236 Nimrod	2275 Taiko	2382 Unnamed Brasells	2276 W/R 1	2277 W/R 2	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	70106 Evans	1858 Midgley's	1856 Lower Gorge	1857 Upper Gorge	1853 Purves	1851 Holme Stn	1852 Talbots	1854 Jefcoates	170101 Brasells	170103 SH1	2252 Craigmere	170102 Timaunga	1876 Golf Links	2274 Gorge Rd	2253 Back Line	70107 Railway Br	70105 Huils	
Date																														
28/10/1980												864													356					
11/11/1980												3439													1172					
17/12/1980												665													321					
14/01/1981												741													505					
2/02/1981												777													378					
4/02/1981																	731					201								
8/04/1981												793													480					
20/05/1981												831													415					
4/08/1981												2421													665					
7/09/1981												1229													511					
11/12/1981												492																		
21/01/1982												527													392					
5/02/1982																	5247													
18/02/1982												282													285					
13/03/1982																	1114													
29/03/1982												419													283					
22/04/1982												1219													443					1784
24/05/1982												524													298					820
11/10/1982																									198					544
8/11/1982																									436					1871
30/11/1982																									687					3583
15/12/1982																									468					1419
3/01/1983																									720					3015
24/01/1983																									252					838
23/02/1983																									206					389
26/09/1983																														<b>53054</b>
16/07/1985																	93350												4529	4542
19/07/1985													1922									1921							1729	2527
7/08/1985																													514	1089
10/10/1985																													295	864
14/10/1985																	589		333		231							266	812	
7/11/1985																													1487	1893
19/11/1985													879				2283		1548		1396								924	2674

## Concurrent gaugings in the Pareora catchment used in analysis (4/5)

Flow (l/s)											Pareora River										Pareora Sth Branch			Sth Brnch Trib		Recorder Sites				
	2130 Elder	2278 Gordons	2227 Matata	2239 Motukaika	2236 Nimrod	2275 Taiko	2382 Unnamed Brasells	2276 W/R 1	2277 W/R 2	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	70106 Evans	1858 Midgley's	1856 Lower Gorge	1857 Upper Gorge	1853 Purves	1851 Holme Stn	1852 Talbots	1854 Jefcoates	170101 Brasells	170103 SH1	2252 Craigmore	170102 Timaunga	1876 Golf Links	2274 Gorge Rd	2253 Back Line	70107 Railway Br	70105 Huils	
17/01/1986														4188				4557	4523	4372								4913	4883	
30/04/1986														604				576	496	474								667	956	
12/08/1986														70367				68284											68284	
19/01/1987														2				137		1			222							504
5/02/1998													179								Dry	61		70					306	
25/03/1998													493								Dry	71		149					772	
8/04/1998													275								3	124		132					477	
27/10/1998																					1085	966		229					1526	
24/04/1998													368								109	132		169					707	
7/07/1998													1575								1750	544		99					2125	
11/08/1998																					378	454							756	
21/10/1998													2936								3605	3334		524					3742	
15/12/1998																					538	531							2931	
9/02/1999																					186	315							844	
16/03/1999																					392	80		262					1112	
4/05/1999																					2109								2778	
5/05/1999												1698						2334			2051								2536	
6/05/1999																						2016 / 2034							2241	
17/05/1999													716					819			584	670							1036	
31/05/1999													431					482			162	361							691	
16/06/1999													3576					5368			4992 / 4862 / 4736	4756 / 4659							5209	
30/08/1999																		746	577		528	457							1022	
9/09/1999																		698	465		433	324							910	
6/04/2000																					4872								1580	
14/08/2000		Dry				Dry		Dry	5				388	Dry				389			83	348			160		358	616		
25/08/2000		51				127	3	89	108				3912	5233				5557			5631	6701		1485		6043	5745			
24/11/2000		Dry				Dry	NoFlow	Dry	1				381	Dry				215			115	261		196		227	568			
7/12/2000		Dry				Dry	NoFlow	Dry	3				715					530			416	415		230		359	974			
24/01/2001		Dry				Dry	Flowing	Dry	<1				505	28				361			348	345		256		476	765			







Pareora gaugings naturalised – page 3 of 5

Date	Naturalised Flows (l/s)										Pareora River										Sth Br Tib	Pareora Sth Branch			Recorder Sites (9)																
	2130 Elder	2239 Mokuikaika	2275 Taiko	2278 Gordons	2382 Unnamed Brasells	2276 WFR 1	2277 WFR 2	2236 Nimrod	2227 Malata	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	1857/0190 Upper Gorge (1)	2258 Gorge rd br. (2)	Scotts Bend (3)	Camington Br. (3)	Cave Pareora Br. (3)	1856 Lower Gorge (4)	10106 Evans	1853 Purves		1851 Holme Stn	1852 Talbots	1854 Jelfcoates	170101 Brasells	1858 Midgleys	170103 SH1	2253 Back Line	170102 Timaunga	1876 Golf Links	2252 Craigmore (5)	2274 Gorge Rd	70107 Railway Br (6)	Pareora Huts (7)	Rocky Gully (8)	Alt. Rocky Gully	Huts/Recorded	TDC lake *			
19/04/1974																		113200																				200			
6/12/1974																			606																			200			
6/01/1975																			349																			200			
23/12/1975																			591																			200			
7/01/1976																			476																			200			
12/03/1976																			594																			200			
22/03/1976																			505																			200			
13/04/1976	55	46					14		33									490		314		noflo		211		238											200				
7/07/1976																		579																				200			
9/11/1976																		825/1536																				200			
25/01/1977																		3910																				200			
4/04/1977																		550																				200			
4/10/1977																		2399																				200			
5/01/1978																		853																				200			
15/02/1978	101	60					21	26	53		92						495																					200			
23/02/1978																		432			291																	200			
6/03/1978																		455																					200		
10/03/1978																																							200		
15/03/1978	71	44					18	12	42	138	71	107					430			Dry				Dry		Dry												200			
7/04/1978																	674																						200		
30/08/1978																	4980																						200		
15/10/1978																																							200		
4/01/1979																		1317																					200		
12/01/1979																		918																					200		
23/01/1979																		652																						200	
31/01/1979																		427																						200	
7/02/1979																		517																						200	
15/02/1979																		636																						200	
23/02/1979																		611																						200	
15/03/1979																		4884																						200	
5/06/1979																		2426																						200	
18/06/1979																		1393																						200	
28/06/1979																		990																						200	
3/07/1979																		1539																						200	
19/07/1979																		877																						200	
6/08/1979																		3676																						200	
19/09/1979																		1138																						200	
18/12/1979																		899																						200	
12/02/1980																		1670																						200	
26/02/1980																		1502																						200	
29/04/1980																																									200
26/05/1980																																									200
3/06/1980																																									200
25/06/1980																																									200
9/07/1980																																									200
22/07/1980																																									200
19/08/1980																																									200
3/09/1980																																									200
29/09/1980																																									200
7/10/1980																																									200
21/10/1980																																									200
28/10/1980																																									200
11/11/1980																																									200
17/12/1980																																									200
14/01/1981																																									200
2/02/1981																																									200
4/02/1981																																									200
8/04/1981																																									200
20/05/1981																																									200
4/08/1981																																									200
7/09/1981																																									200





- 1) Site above TDC water supply. Gaugings from 1996 from ECS recorder site.
- 2) Also known as Heatherleigh Br. Gaugings from 1996 from ECS.
- 3) ECS Gauging site
- 4) Gaugings from 1996 from ECS.
- 5) Gauging site assumed to be above golf course
- 6) Recorder site between 8/11/00 and 31/3/03.
- 7) Gaugings listed here only for dates of concurrent gaugings in catchment. Full listing of Huts gaugings in 'Pareora at Huts gaugings' sheet.
- 8) Alternative recorder flow if gauged that day, or alternative gauged flow on day before or after.
- 9) **Bolded numbers** are recorded values.

## Consents used for naturalising the Pareora gaugings

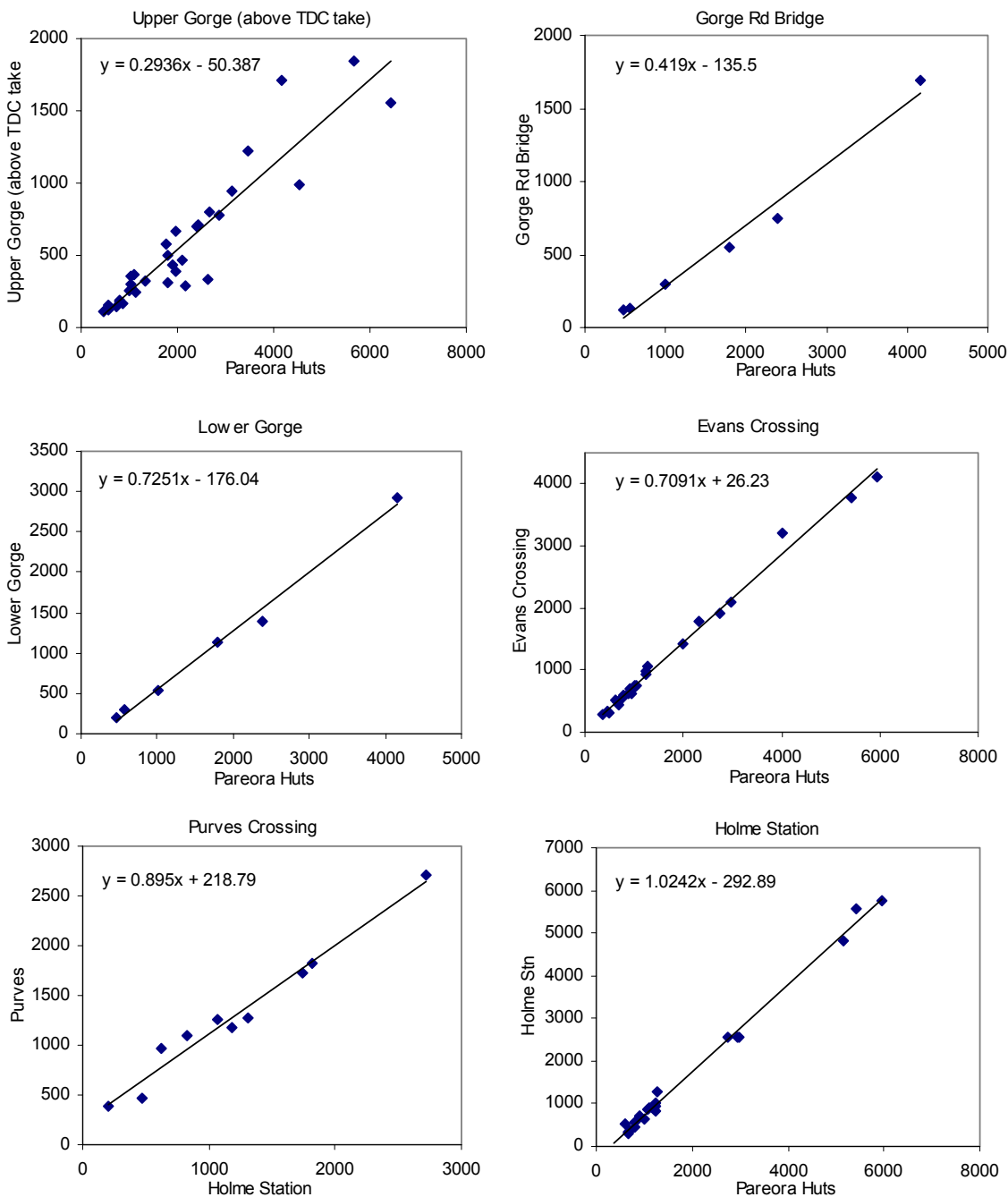
Consent Numbers Included for Naturalising site:	2065 U/S Nimrod	2067 1st Bridge	2068 2nd Bridge	2258 Gorge Rd Br.	Scotts Bend	Cannington Br.	Cave Pareora Br.	1856 Lower Gorge
Consents:	scy760105	scy760105	scy760105	scy690641/crc	scy690641/crc011399	scy690641/crc011399 scy850048b/crc000183 scy830274b/crc990342	scy690641/crc011399 scy850048b/crc000183 scy830274b/crc990342 scy760105 scy820175 crc990943/ 1	scy690641/crc011399 scy850048b/crc000183 scy830274b/crc990342 scy760105 scy820175 crc990943/ 1
<b>Sites without Consents</b>								
2130 Elder								
2239 Motukaika								
2275 Taiko								
2278 Gordons								
2382 Unnamed Brasells								
2276 W/R 1								
2277 W/R 2								
2236 Nimrod								
2227 Matata								
1857/70190 Upper Gorge								
2253 Back Line								
				Surface water				
				Groundwater				
70106 Evans	1853 Purves	1851 Holme Strn	1852 Talbots	1854 Jefcoates	170101 Brasells	1858 Midgleys		
scy690641/crc011399	scy690641/crc011399	scy690641/crc011399	scy690641/crc011399	scy690641/crc011399	scy690641/crc011399	scy690641/crc011399		
scy850048b/crc000183	scy850048b/crc000183	scy850048b/crc000183	scy850048b/crc000183	scy850048b/crc000183	scy850048b/crc000183	scy850048b/crc000183		
scy830274b/crc990342	scy830274b/crc990342	scy830274b/crc990342	scy830274b/crc990342	scy830274b/crc990342	scy830274b/crc990342	scy830274b/crc990342		
scy760105	scy760105	scy760105	scy760105	scy760105	scy760105	scy760105		
scy820175	scy820175	scy820175	scy820175	scy820175	scy820175	scy820175		
scy820351/crc991286	scy820351/crc991286	scy820351/crc991286	scy820351/crc991286	scy820351/crc991286	scy820351/crc991286	scy820351/crc991286		
crc990943/ 1	scy880032	scy880032	scy880032	scy880032	scy880032	scy880032		
	crc950103	crc950103	crc950103	crc950103	crc950103	crc950103		
	scy750028	scy750028	scy750028	scy750028	scy750028	scy750028		
	scy800097	scy800097	scy800097	scy800097	scy800097	scy800097		
	crc921501/crc032086	crc921501/crc032086	crc921501/crc032086	crc921501/crc032086	crc921501/crc032086	crc921501/crc032086		
	scy800100/crc991282	scy800100/crc991282	scy800100/crc991282	scy800100/crc991282	scy800100/crc991282	scy800100/crc991282		
	crc990943/ 1	scy840007	scy840007	scy840007	scy840007	scy840007		
	crc011907	scy830256	scy830256	scy830256	scy830256	scy830256		
		crc990943/ 1	crc950292	crc950292	crc950292	crc950292		
		crc011907	crc990943/ 1	crc990943/ 1	scy850197/crc992192	scy850197/crc992192		
			crc011907	crc011907	crc990943/ 1	crc990880		
				crc971810.2	crc011907	scy860031/crc950390		
				crc991239	crc971810.2	crc950386		
					crc991239	crc990943/ 1		
					crc020599	crc011907		
						crc971810.2		
						crc991239		
						crc020599		
						crc980553/ 1/2		
						crc991400		

Pareora – Waihao River: Water Resource Summary

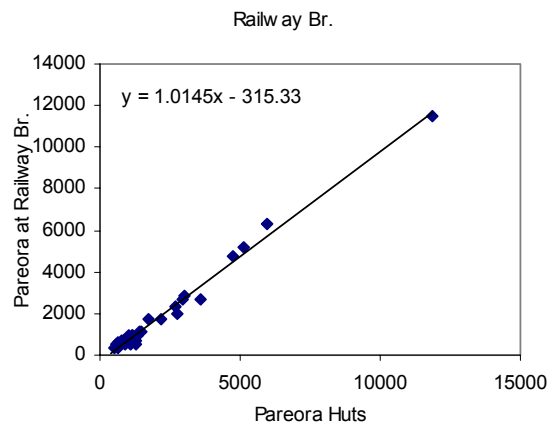
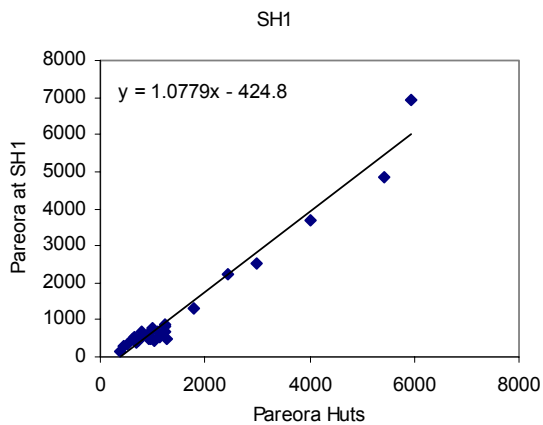
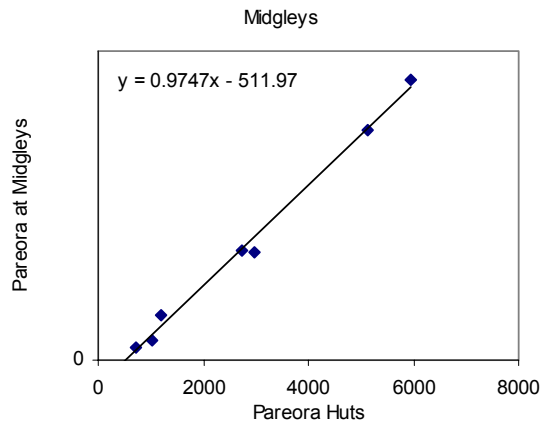
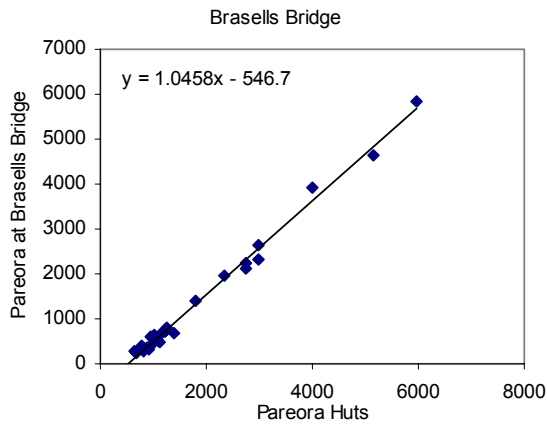
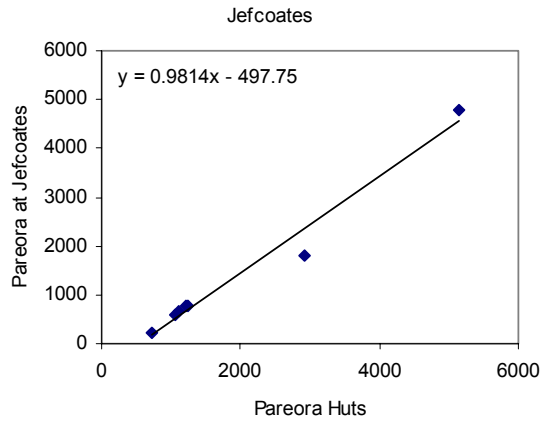
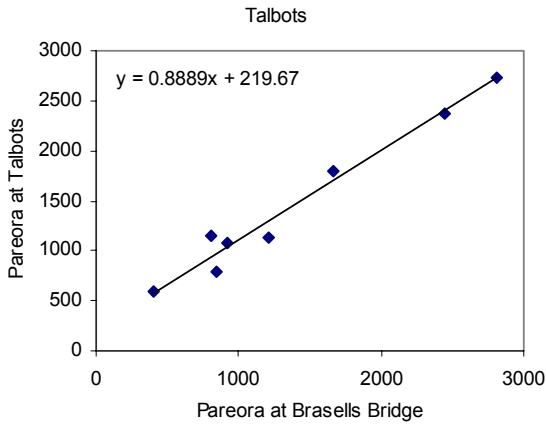
170103 SH1	Pareora Sth Branch				Recorder Sites	
	170102 Timaunga	1876 Golf Links	2252 Craigmore	2274 Gorge Rd	70107 Railway Br	Pareora Huts
scy690641/crc011399	scy880032	scy880032	scy880032	scy880032	scy690641/crc011399	scy690641/crc011399
scy850048b/crc000183	crc950103	crc950103	crc950103	crc950103	scy850048b/crc000183	scy850048b/crc000183
scy830274b/crc990342	scy750028	scy750028	scy750028	scy750028	scy830274b/crc990342	scy830274b/crc990342
scy760105			scy800097	scy800097	scy760105	scy760105
scy820175				crc921501/crc032086	scy820175	scy820175
scy820351/crc991286					scy820351/crc991286	scy820351/crc991286
scy880032					scy880032	scy880032
crc950103					crc950103	crc950103
scy750028					scy750028	scy750028
scy800097					scy800097	scy800097
crc921501/crc032086					crc921501/crc032086	crc921501/crc032086
scy800100/crc991282					scy800100/crc991282	crc990943/.1
scy840007					scy840007	
scy830256					scy830256	
crc950292					crc950292	
scy850197/crc992192					scy850197/crc992192	
crc990880					crc990880	
scy860031/crc950390					scy860031/crc950390	
crc950386					crc950386	crc991384
crc990820					crc990820	crc991278
crc990943/.1					crc990943/.1	crc991280
crc011907					crc011907	scy810084
crc971810.2					crc971810.2	crc010393
crc991239	crc991384				crc991239	crc991283
crc020599	crc991278				crc020599	crc991682
crc980553/.1/.2	crc991280				crc980553/.1/.2	crc991443
crc991400	scy810084				crc991400	crc991310/.1
crc991982	crc010393				crc991982	crc990818/.1
crc991281	crc991283				crc991281	crc991279
crc990697	crc991682				crc990697	crc010392
crc991284/.1					crc991284/.1	scy810083
crc990633					crc990633	crc991155

## Appendix 5: Regression equations fitted to the plots of the tertiary site gaugings with the secondary (or in some cases primary) site for the Pareora catchment.

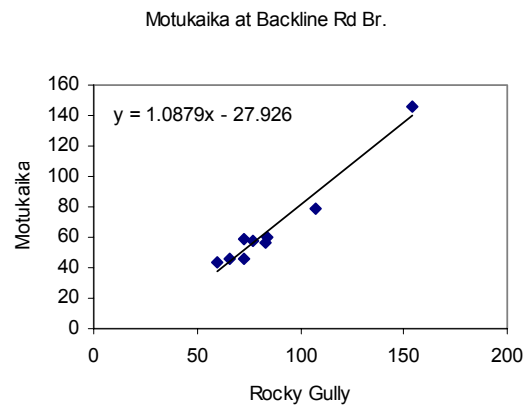
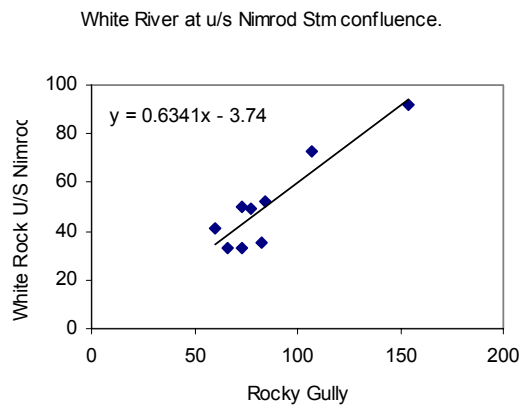
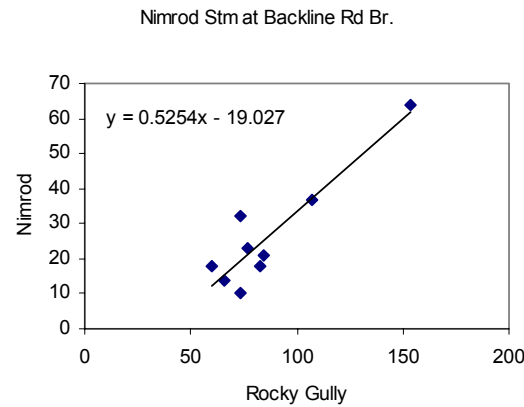
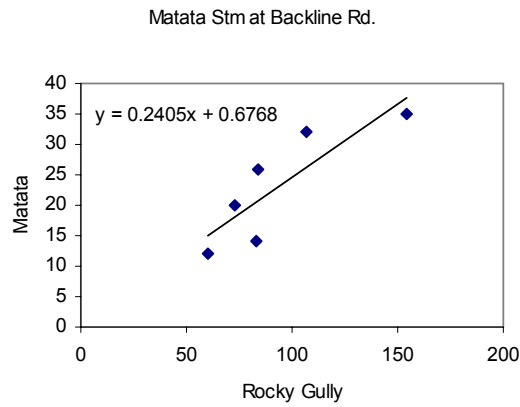
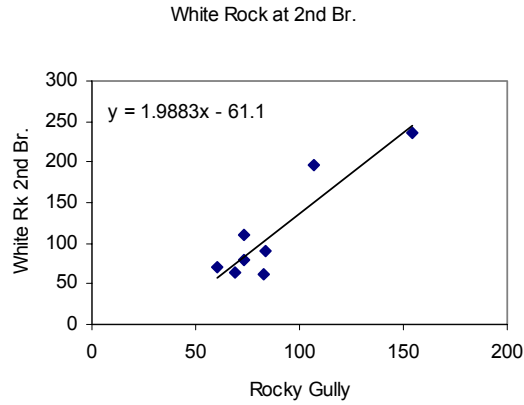
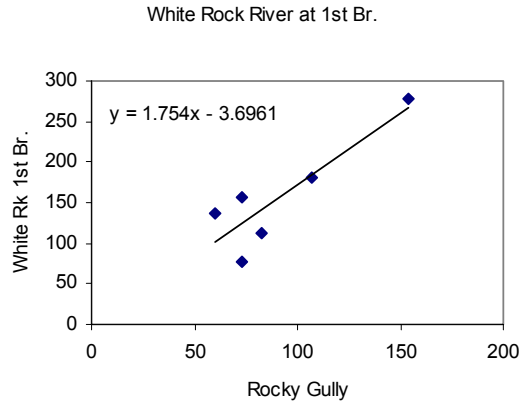
**Regressions for the Pareora River main channel gaugings from the farthest upstream (Upper Gorge) site to Holme Station Bridge.**



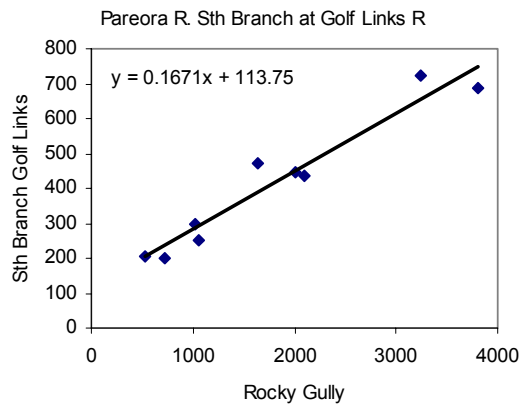
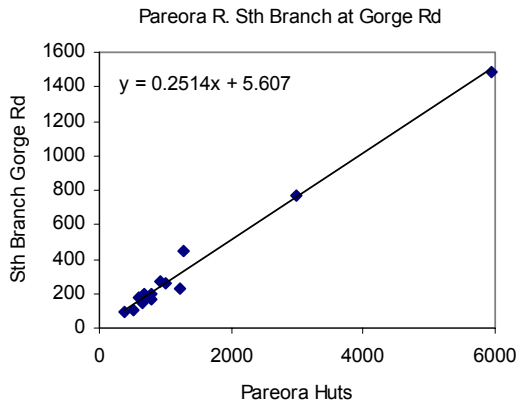
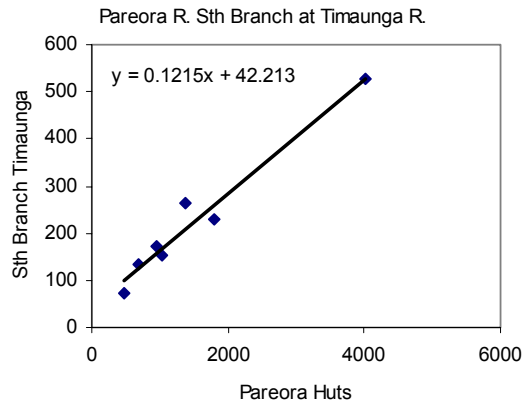
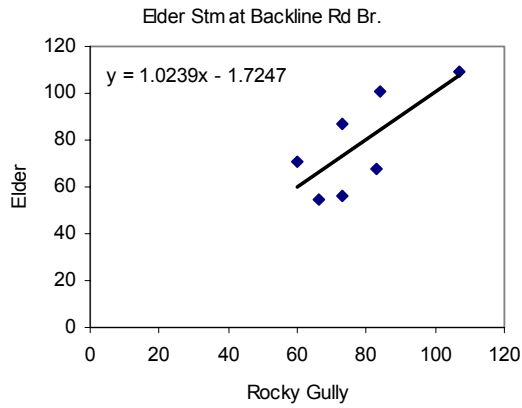
**Regressions for the Pareora River main channel gaugings from Talbots to Railway Bridge (the lowermost site).**



**Regressions for the White Rock & Motukaika Rivers.**



Regressions for the Pareora River South Branch



## Appendix 6: Analysis of Waihao at McCulloughs Bridge 7-day annual low flows and derivation of naturalised flows.

It is assumed that the irrigation season runs from 1 October to 30 April and that only 50% of irrigation abstractions are used. "Full irrigation" takes occur when recorded flows at the Waihao at McCulloughs Bridge site exceed 600 l/s. "Half restriction" applies when recorded flows lie between 600 l/s and 250 l/s and consent holders are then only authorised to use half their consented abstraction rate. "Full restriction" applies when the recorded flow is less than 250 l/s and consent holders must cease abstraction. Units for all the flow data are litres per second (l/s). "S&D" refers to "Stock and Domestic" usage.

Year ending	Date of low flow	Recorded low flow (l/s)	S&D cor'n	Irrigation cor'n	Naturalised low flow (l/s)
30/06/1983	<b>3/03/1983*</b>	<b>290</b>	7	23	<b>320</b>
30/06/1984	26/02/1984	450	7	23	480
30/06/1985	6/03/1985	213	7	7	227
30/06/1986	5/07/1985	348	7	0	355
30/06/1987	15/01/1987	282	7	23	312
30/06/1988	12/05/1988	359	7	0	366
30/06/1989	15/12/1988	188	7	13	208
30/06/1990	10/04/1990	382	7	29	418
30/06/1991	5/02/1991	319	7	29	355
30/06/1992	15/03/1992	231	7	13	251
30/06/1993	18/03/1993	680	7	44	731
30/06/1994	12/11/1993	468	8	27	503
30/06/1995	24/02/1995	300	8	31	339
30/06/1996	22/04/1996	658	8	50	716
30/06/1997	13/12/1996	667	8	50	725
30/06/1998	<b>15/01/1998*</b>	<b>141</b>	8	11	<b>160</b>
30/06/1999	19/02/1999	160	8	7	175
30/06/2000	25/10/1999	372	8	31	411
30/06/2001	12/04/2001	125	8	7	140
30/06/2002	29/03/2002	414	8	28	450
30/06/2003	22/03/2003	166	8	0	174
30/06/2004	2/01/2004	232	8	0	240
	7DMALF	341			368

\* Missing record during time of suspected lowest flow - low flow should be used with caution.

## Appendix 7: Details of estimated surface water takes from the Waihao catchment as calculated from resource consents

WAIHAO CATCHMENT SURFACE WATER CONSENTS								Irrigation			Public and Stockwater /Rural Supply				
Water rights:				Reg No1908											
Original consent	scy770015	scy760079	scy888047	crc982101/1	scy810171B/3B	crc990372	scy730170	crc940263B	crc991829	crc951287	scy790131	scy830134	scy800045	scy790132	
Commenced:	Feb-1977	May-1905	Feb-1989	Jan-2001	Jun-1905	May-2004	May-1905	Nov-1993	May-2000	Jul-1995	Jun-1905	Jun-1905	Jun-1905	Jun-1905	
Expired:	Dec-1993	Sep-2001	Sep-2001	Feb-2010	Dec-1998	May-2014	Dec-2008	Dec-2008	Apr-1935	Jul-1930	Sep-2001	Dec-1998	Jan-2001	Jun-1992	
Replacement	crc940845	crc990390	crc982146								crc981890	crc99014			
Commenced	Feb-1994	Sep-2001	Sep-2001								Sep-2001	Sep-2000			
Expires:	Feb-2029	Feb-2010	Feb-2010								Feb-2010	Feb-2010			
Year	Average Daily Rate to be added back (l/s)														
1973							5.3								
1974					0.6		5.3								
1975					0.6		5.3								
1976		1.15			0.6		5.3								
1977	1.5	1.15			0.6		5.3								
1978	1.5	1.15			0.6		5.3								
1979	1.5	1.15			0.6		5.3				3.15			2.4	
1980	1.5	1.15					5.3				3.15		11.3	2.4	
1981	1.5	1.15			4.25		5.3				3.15		11.3	2.4	
1982	1.5	1.15			4.25		5.3				3.15		11.3	2.4	
1983	1.5	9.1			4.25		5.3				3.15	9.1	11.3	2.4	
1984	1.5	9.1			4.25		5.3				3.15	9.1	11.3	2.4	
1985	1.5	9.1			4.25		5.3				3.15	9.1	11.3	2.4	
1986	1.5	9.1			4.25		5.3				3.15	9.1	11.3	2.4	
1987	1.5	9.1			4.25		5.3				3.15	9.1	11.3	2.4	
1988	1.5	9.15			4.25		5.3				3.15	9.1	11.3	2.05	
1989	1.5	9.15	6.7		4.25		5.3				3.15	9.1	11.3	2.05	
1990	1.5	9.15	6.7		4.25		5.3				3.15	9.1	11.3	2.05	
1991	1.5	9.15	6.7		4.25		5.3				3.15	9.1	11.3	2.05	
1992	1.5	9.15	6.7		4.25		5.3				3.15	9.1	11.3	2.05	
1993	1.5	9.15	6.7		4.25		5.3				3.15	9.1	11.3		
1994	1.6	9.15	6.7		4.25		5.3	1.4			3.15	9.1	11.3		
1995	1.6	9.15	6.7		4.25		5.3	1.4		6.75	3.15	9.1	11.3		
1996	1.6	9.15	6.7		4.25		5.3	1.4		6.75	3.15	9.1	11.3		
1997	1.6	9.15	6.7		4.25		5.3	1.4		6.75	3.15	9.1	11.3		
1998	1.6	9.15	6.7		4.25		5.3	1.4		6.75	3.15	9.1	11.3		
1999	1.6	9.15	6.7				5.3	1.4		6.75	3.15	9.1	11.3		
2000	1.6	9.15	6.7				5.3	1.4	8.5	6.75	3.15	9.1	11.3		
2001	1.6	9.15	6.7	11.55			5.3	1.4	8.5	6.75	3.15	9.1	11.3		
2002	1.6	9.15	7.1	11.55			5.3	1.4	8.5	6.75	3.15	9.1			
2003	1.6	9.15	7.1	11.55			5.3	1.4	8.5	6.75	3.15	9.1			
2004	1.6	9.15	7.1	11.55		8.5	5.3	1.4	8.5	6.75	3.15	9.1			
2005	1.6	9.15	7.1	11.55		8.5	5.3	1.4	8.5	6.75	3.15	9.1			
	Waihao Nth Branch takes				Waihaorunga Str takes				Waihao Sth Branch takes						
	Takes above Waihao at McCulloughs														

### Low flow condition?

Original consent:	N	Y	N	Y	N	Y	N	N	Y	Y	Y	Y	Y	N
		Cease <250l/s 1/2 600l/s McCulloughs.		Cease <250l/s 1/2 600l/s McCulloughs.		Cease <250l/s 1/2 600l/s McCulloughs.			Cease <250l/s 1/2 600l/s McCulloughs.	Cease <250l/s 1/2 600l/s McCulloughs.	Roster <600l/s. Cease <100l/s at Coat Pit Br.	Roster <600l/s. Cease <100l/s Coat Pit Br.	Cease <250l/s 1/2 600l/s McCulloughs.	
Replacement:	N	Y	Y								Y	Y		
		Cease <250l/s 1/2 <600l/s McCulloughs									Cease <250l/s 1/2 <600l/s McCulloughs.			
Add back to:	Waihao Nth Brnch Kaiwarua and <	Waihao Nth Brnch at Waihao Forks and below			Waihao Sth Brnch at Henshaws and below.							Waihao Sth Brnch at Waihao Forks and <	Waihao at McCulloughs and below.	

Details of estimated surface water and groundwater takes from the Waihao catchment as calculated from resource consents (Continued)

WAIHAO CATCHMENT SURFACE WATER CONSENTS					Irrigation		Public and Stockwater/Rural Supply				
Original consent:	scy780200	scy790164	scy770122	scy790115/.1	crc990296	crc905131	scy810034	crc990382	scy810160	crc972243	scy790015
Commenced	May-1905	Jun-1905	May-1905	Jun-1905	Sep-2000	Jul-1990	Jun-1905	Dec-2003	Jun-1905	Nov-1998	Jun-1905
Expired:	Dec-1998	Feb-2000	Apr-1997	Jun-2000	Feb-2010	Sep-2000	Oct-2004	Dec-2013	Dec-2003	Oct-2008	Dec-2003
Replacement		crc990365/.1		crc990361			crc990389		crc990379		crc990381
Commenced		Feb-2000		Mar-2022			Oct-2004		Dec-2003		Dec-2003
Expires:		Feb-2001		Feb-2010			Feb-2010		Dec-2013		Dec-2013
Year											
1977											
1978			1.65								
1979	1.25		1.65								
1980	1.25	0.85	1.65	11.65							2
1981	1.25	0.85	1.65	11.65							2
1982	1.25	0.85	1.65	11.65			16.1		6.35		2
1983	1.25	0.85	1.65	11.65			16.1		6.35		2
1984	1.25	0.85	1.65	11.65			16.1		6.35		2
1985	1.25	0.85	3.3	11.65			16.1		6.35		2
1986	1.25	0.85	3.3	11.65			16.1		6.35		2
1987	1.25	0.85	3.3	11.65			16.1		6.35		2
1988	1.25	0.85	3.3	11.65			16.1		6.35		2
1989	1.25	0.85	3.3	11.65			16.1		6.35		2
1990	1.25	2.05	3.3	11.65			5.35		6.35		2
1991	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1992	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1993	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1994	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1995	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1996	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1997	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1998	1.25	2.05	3.3	11.65		9.2	5.35		6.35		2
1999	1.25	2.05		11.65		9.2	5.35		6.35		2
2000		2.05		11.65		9.2	5.35		6.35	22.5	2
2001		2.05		11.65	9.35	9.2	5.35		6.35	22.5	2
2002		2.05		11.65	9.35		5.35		6.35	22.5	2
2003		2.05		11.65	9.35		5.35		6.35	22.5	2
2004		2.05		11.65	9.35		5.35	8.5	6.35	22.5	2
2005		2.05		11.65	9.35		5.35	8.5	16	22.5	25.5
		2.05		11.65	9.35		16	8.5	16	22.5	25.5
Low flow condition?											
original consent	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N
	Cease <250l/s Roster <600l/s McCulloughs.	Cease <250l/s Roster <600l/s McCulloughs.		Cease <250l/s Roster <600l/s McCulloughs.	Cease <250l/s 1/2 <600l/s McCulloughs.	Cease <250l/s 1/2 <600l/s McCulloughs.	Cease <250l/s Roster <600l/s McCulloughs.	Cease <100l/s at Bradshaws.		Cease <112l/s at Buchanans at Fletchers	
Replacement		Y		Y			Y		Y		Y
		Cease <250l/s 1/2 <600l/s at McCulloughs.		Cease <250l/s 1/2 <600l/s at McCulloughs.			Cease <250l/s 1/2 <600l/s at McCulloughs.		Cease <100l/s at Bradshaws.		
Add back to:											
	Waihao at D/S McCulloughs and <	Waihao at Elliots and below.	Waihao at Elliots and below.	Waihao at Elliots and below.	Waihao at Wains Xing and <	Waihao at Wains Xing and <	Waihao at Wains Xing and <.	Waihao at U/S Bradshaws and <	Waihao at U/S Bradshaws and <		

Details of estimated groundwater takes from the Waihao catchment as calculated from resource consents

**WAIHAO CATCHMENT STREAM DEPLETING GROUNDWATER CONSENTS**

Data compiled and stream depletion calculated by Philippa Aitchison-Earl							Irrigation (groundwater)		Public and Stockwater/Rural Supply (none)			
Original consent:	crc991213	scy810146	scy790261	crc051084	scy790156	scy790156	scy800073	crc031115	crc950626	scy800115	scy700570	crc972242
		12/11/1981	1/12/1979	5/01/2005	12/09/1979	13/09/1979	9/04/1980	2/04/2003	22/12/1994	11/06/1980	8/07/1970	1/08/1997
Expired:	1/02/2010	12/07/2000	1/12/1998	23/12/2039	1/12/1998	1/12/1998	9/03/1999	31/03/2038	15/12/2029	Contin.	1/10/2001	30/07/2032
Replacement		crc981942	crc990759		crc000848	crc000848	crc982138/1					
Commenced:		12/07/2000	26/04/2000		12/03/2001	12/03/2001	3/09/1999					
Expires:		1/02/2010	20/04/2010		1/02/2010	1/02/2010	4/03/2034					

Year	Stream depletion rate to be added back (l/s)											
1970												2.15
1971												2.15
1972												2.15
1973												2.15
1974												2.15
1975												2.15
1976												2.15
1977												2.15
1978												2.15
1979			2.15		3.55	3.45						2.15
1980			2.15		3.55	3.45	1.5			4.9		2.15
1981		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1982		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1983		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1984		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1985		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1986		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1987		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1988		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1989		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1990		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1991		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1992		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1993		8.5	2.15		3.55	3.45	1.5			4.9		2.15
1994		8.5	2.15		3.55	3.45	1.5		1.7	4.9		2.15
1995		8.5	2.15		3.55	3.45	1.5		1.7	4.9		2.15
1996		8.5	2.15		3.55	3.45	1.5		1.7	4.9		2.15
1997		8.5	2.15		3.55	3.45	1.5		1.7	4.9	2.15	2.55
1998		8.5	2.15		3.55	3.45	1.5		1.7	4.9	2.15	2.55
1999		8.5					1.5		1.7	4.9	2.15	2.55
2000	8.8	6.5	2.15				2.35		1.7	4.9	2.15	2.55
2001	8.8	6.5	2.15		3.55	3.45	2.35		1.7	4.9	2.15	2.55
2002	8.8	6.5	2.15		3.55	3.45	2.35		1.7	4.9		2.55
2003	8.8	6.5	2.15		3.55	3.45	2.35	7.15	1.7	4.9		2.55
2004	8.8	6.5	2.15		3.55	3.45	2.35	7.15	1.7	4.9		2.55
2005	8.8	6.5	2.15	2.05	3.55	3.45	2.35	7.15	1.7	4.9		2.55

**Low flow condition?**

Original consent:	Y	N	N	N	N	N	N	Y	N	N	N	N
	Cease <250l/s 1/2 <600l/s at McCulloughs.							Cease <100 l/s at Bradshaws				
Replacement		N	N		Y	Y	N					
					Cease 112l/s at uchanans	Cease <112l/s at Buchanan						
Add back to:	Waihao at Wains Xing and below.	Waihao at SH1 and below	Waihao at SH1 and below	Waihao at Crowes Rd Ford and below	Buchanans at Willowbr. and elow.	Waihao at U/S Bradshaws and below.	Waihao at U/S Bradshaws below	Waihao at U/SBadshaws and below.	Buchanans at fletchers Rd and below	Buchanans at Fetchers Farm & below.	Buchanans at Fetchers Farm & below.	Buchanans at Fetchers Farm & below.

Details of estimated surface water and groundwater takes from the Waihao catchment as calculated from resource consents (Resulting Totals)

Year	Whole catchment Total gw take:				Above McCulloughs Total Groundwater Take:				Whole catchment Total Surface Water take:				Above McCulloughs Total Surface water Take:			
	Total S&D	Total irrig.	1/2 restriction	Full restriction	Total S&D	Total irrig.	1/2 restriction	Full restriction	Total S&D	Total irrig.	1/2 restriction	Full restriction	Total S&D	Total irrig.	1/2 restriction	Full restriction
1970	0	2	2	2	0	0	0	0								
1971	0	2	2	2	0	0	0	0								
1972	0	2	2	2	0	0	0	0								
1973	0	2	2	2	0	0	0	0	5	0	0	0	5	0	0	0
1974	0	2	2	2	0	0	0	0	5	1	1	1	5	1	1	1
1975	0	2	2	2	0	0	0	0	5	1	1	1	5	1	1	1
1976	0	2	2	2	0	0	0	0	5	2	1	1	5	2	1	1
1977	0	2	2	2	0	0	0	0	7	3	3	2	7	2	1	1
1978	0	2	2	2	0	0	0	0	7	5	3	2	7	2	1	1
1979	0	11	11	11	0	0	0	0	7	25	16	7	7	7	5	3
1980	0	18	18	18	0	0	0	0	7	35	21	6	7	18	10	2
1981	0	26	26	26	0	0	0	0	7	62	39	17	7	22	14	7
1982	0	26	26	26	0	0	0	0	7	62	39	17	7	22	14	7
1983	0	26	26	26	0	0	0	0	7	79	48	17	7	39	23	7
1984	0	26	26	26	0	0	0	0	7	81	50	18	7	39	23	7
1985	0	26	26	26	0	0	0	0	7	81	50	18	7	39	23	7
1986	0	26	26	26	0	0	0	0	7	81	50	18	7	39	23	7
1987	0	26	26	26	0	0	0	0	7	81	50	18	7	39	23	7
1988	0	26	26	26	0	0	0	0	7	81	49	18	7	39	23	6
1989	0	26	26	26	0	0	0	0	7	78	51	25	7	46	29	13
1990	0	26	26	26	0	0	0	0	7	87	56	25	7	46	29	13
1991	0	26	26	26	0	0	0	0	7	87	56	25	7	46	29	13
1992	0	26	26	26	0	0	0	0	7	87	56	25	7	46	29	13
1993	0	26	26	26	0	0	0	0	7	85	54	23	7	44	27	11
1994	0	28	28	28	0	0	0	0	8	85	54	23	8	44	27	11
1995	0	28	28	28	0	0	0	0	8	92	57	23	8	50	31	11
1996	0	28	28	28	0	0	0	0	8	92	57	23	8	50	31	11
1997	0	30	30	30	0	0	0	0	8	92	57	23	8	50	31	11
1998	0	30	30	30	0	0	0	0	8	88	54	19	8	50	31	11
1999	0	21	21	21	0	0	0	0	8	105	71	15	8	46	26	7
2000	0	31	27	22	0	0	0	0	8	123	80	15	8	55	31	7
2001	0	38	34	22	0	0	0	0	8	125	82	15	8	66	36	7
2002	0	36	32	20	0	0	0	0	8	115	73	8	8	55	28	0
2003	0	43	39	20	0	0	0	0	8	123	73	8	8	55	28	0
2004	0	43	39	20	0	0	0	0	8	165	85	0	8	64	32	0
2005	0	45	41	22	0	0	0	0	8	175	124	0	8	64	32	0

## Appendix 8: Concurrent gaugings in the Waihao catchment used in analysis

Flow l/s Date	Waihao Nth Br.		Waihao Sth Branch					Waihao River					Recorder Sites			
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliotts	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes	70907 Bradshaws	70913 U/S Bradshaws	70902 McCulloughs
3/10/1956														145646		
10/12/1957														2118		
15/10/1958											317					
15/11/1958														174		
20/01/1959														194		
11/03/1960											0					
13/05/1964		219					150									
8/01/1965		3048					129									
14/05/1965		966					458									
15/12/1965		444														
21/04/1966		612					284									
4/11/1966		668					280									
4/11/1969														96		
6/10/1970														5369		
12/11/1970														903		
7/12/1970														151		
3/02/1971														61		
4/03/1971														33		
5/04/1971														87		
26/04/1971		599		59/332/248	488											
27/04/1971	327															
14/06/1971														4842		
22/07/1971														1935		
6/09/1971														2148		
5/10/1971														439		
8/11/1971														1382		
8/12/1971														288		
24/01/1972														96		
8/02/1972				50												
8/03/1972		193	32		47									29		
19/04/1972														10		
8/06/1972														1129		
29/06/1972														1056		
27/07/1972														4498		
31/08/1972														558		
29/09/1972														181		
8/11/1972														532		
6/12/1972														107		
25/01/1973														38		
8/02/1973	122	174	27	24	7											
19/02/1973							6									
2/03/1973														8		
8/03/1973	94															
11/04/1973														33		
18/04/1973										Dry						
14/05/1973														38		
29/05/1973														32		
2/10/1973										1375	654	405		529		
29/11/1973									505					143		
31/01/1974	157	264	29	48	32		8									
½/1974										47						
6/12/1974														193		

Concurrent gaugings in the Waihao catchment used in analysis  
Continued (1)

Flow I/s	Waihao Nth Br.		Waihao Sth Branch				Waihao River					Recorder Sites				
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliots	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes	70907 Bradshaws	70913 U/S Bradshaws	70902 McCulloughs
15/03/1976	159	272	34	68		47				160						
7/07/1976										343						
30/07/1976			78													
24/03/1977												162				
9/08/1977			416				235									
13/03/1978							8									
14/03/1978	114		35	39	9											
4/01/1979										1610				4116		
12/01/1979												338		1987		
23/01/1979												232		744		
7/02/1979												535		1242		
15/02/1979												62		1937		
23/02/1979												111		1003		
14/03/1979		169														
15/03/1979													160	938		
5/06/1979														3616		
18/06/1979														1490		
28/06/1979														778		
3/07/1979														1850		
18/07/1979														671		
19/09/1979														1702		
18/12/1979														2157		
12/02/1980														3023		
26/02/1980														2594		
3/06/1980														707		
25/06/1980														2492		
9/07/1980														1673		
22/07/1980														1175		
19/08/1980														1987		
3/09/1980														2277		
29/09/1980														2155		
7/10/1980														2006		
14/10/1980														1922		
21/10/1980														3640		
28/10/1980														2127		
4/11/1980														2670		
11/11/1980														7432		
26/11/1980														5745		
9/12/1980														2493		
17/12/1980														2248		
14/01/1981														1539		
2/02/1981																
4/02/1981														1137		
8/04/1981														2010		
4/08/1981														8088		
7/09/1981														2782		
11/12/1981														2771		
21/01/1982														1947		
18/02/1982														1563		
6/05/1983		2079														3196
16/05/1983		1876							2614	2167	1798					2571
21/06/1983									2903	2459	1968					2795
8/12/1983									1167	963	197					1125
9/01/1984									1314	1113	336					1151
25/01/1984									687	498	60					636

Concurrent gaugings in the Waihao catchment used in analysis  
Continued (2)

Flow I/s	Waihao Nth Br.		Waihao Sth Branch					Waihao River					Recorder Sites			
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliotts	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes	70907 Bradshaws	70913 U/S Bradshaws	70902 McCulloughs
7/11/1985										412						1274
24/01/1986									1230	1370						2289
11/06/1987										1156				1548		1978
9/07/1987														3160		3593
24/07/1987										5987						<b>26021</b>
29/07/1987								7270	6766					6886		<b>6446</b>
1/09/1987														2494		3011
17/09/1987														3140		3513
14/10/1987														2805		2201
12/11/1987											57			1721		1040
9/12/1987														1519		585
8/01/1988														1053		679
10/02/1988										Dry				1492		683
10/03/1988														794		558
17/12/1990														1435		913
5/02/1998		131		32		4		121								?
25/03/1998	169	212		36		17		247								<b>425</b>
8/04/1998	134	152		38		8										<b>192</b>
24/04/1998	190	358		45		70										<b>600</b>
7/07/1998	732	1105		336		573										<b>1724</b>
21/10/1998	1636	2570		490		803		3337								<b>2802</b>
27/10/1998	723			192		332										<b>1291</b>
16/03/1999	520	651		103		138										<b>931</b>
6/05/1999								558	1346	920		1102	1591			1766
20/05/1999								296	1237	18		66	322			<b>719</b>
4/06/1999								262	183	Dry		20	239			502
16/06/1999								5455	5328	4401		3838	3724			<b>5802</b>
23/07/1999	3110	5126		1032		2777			8288	91						<b>7826</b>
23/11/2000								480			Dry	Dry	1412		1499	468
14/12/2000								807		335	No flow	Dry	354		766	808
25/01/2001								371		Dry	Dry	Dry	211		956	427
23/02/2001								218		Dry	Dry	Dry	31		595	229
29/03/2001								129		Dry		Dry	2		709	173
19/04/2001													2		?	<b>136</b>
20/04/2001								113		Dry	Dry	Dry			697	133
20/06/2001								509		84	Dry		Dry		203	585
1/08/2002								2060		1964	1495	1356	1374		1547	2124
5/09/2002								1504	1573	980	763	631	1084		1580	1394
14/11/2002								437	509	Dry	Dry	Dry	176		642	498
4/02/2004								3505	3798	2635	2759	2301	2845		4431	3816

## Appendix 9: Waihao naturalised flows

Flow l/s	Waihao Nth Branch		Waihao Sth Branch				Waihao River							Recorder Sites		
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliotts	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes (1)	70902 McCulloughs (2)	70913 U/S Brad-shaws (3)	70907 Bradshaws (4)
Date																
3/10/1956																145646
10/12/1957																2118
15/10/1958											317					
15/11/1958																174
20/01/1959																194
11/03/1960											0					
13/05/1964		219				150										
8/01/1965		3048				129										
14/05/1965		966				458										
15/12/1965		444														
21/04/1966		612				284										
4/11/1966		668				280										
4/11/1969																96
6/10/1970																5369
12/11/1970																903
7/12/1970																151
3/02/1971																61
4/03/1971																33
5/04/1971																87
26/04/1971		599		59/332/248	488											
27/04/1971	327															
14/06/1971																4842
22/07/1971																1935
6/09/1971																2148
5/10/1971																439
8/11/1971																1382
8/12/1971																288
24/01/1972																96
8/02/1972				50												
8/03/1972		193	32		47											29
19/04/1972																10
8/06/1972																1129
29/06/1972																1056
27/07/1972																4498
31/08/1972																558
29/09/1972																181
8/11/1972																532
6/12/1972																107
25/01/1973																43
8/02/1973	122	174	27	24	12											
19/02/1973							6									
2/03/1973																13
8/03/1973	94															
11/04/1973																38
18/04/1973										Dry						
14/05/1973																43
29/05/1973																37
2/10/1973									1380	659		410				534
29/11/1973									510							148
31/01/1974	157	264	29	48	38		8									
1/2/1974										53						
6/12/1974																499
15/03/1976	159	273	34	68		53				167						
7/07/1976										348						
30/07/1976			78													
24/03/1977												472				
9/08/1977			416				235									
13/03/1978							8									

continued>

Flow I/s	Nth Branch		Waihao Sth Branch				Waihao River							Recorder Sites		
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliots	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes (1)	70902 McCulloughs (2)	70913 U/S Bradshaws (3)	70907 Bradshaws (4)
Date																
14/03/1978	116		35	39	15											
4/01/1979										1640						4146
12/01/1979													368			2017
23/01/1979													262			774
7/02/1979													565			4272
15/02/1979													92			4967
23/02/1979													441			4033
14/03/1979		172														
15/03/1979													490			968
5/06/1979																3623
18/06/1979																1497
28/06/1979																785
3/07/1979																1857
18/07/1979																678
19/09/1979																4709
18/12/1979																2193
12/02/1980																3069
26/02/1980																2640
3/06/1980																714
25/06/1980																2499
9/07/1980																1680
22/07/1980																1182
19/08/1980																1994
3/09/1980																2284
29/09/1980																2162
7/10/1980																2054
14/10/1980																4970
21/10/1980																3688
28/10/1980																2175
4/11/1980																2718

Continued next page with naturalised flows

- 1) Flows have outfall flows of the MGIS at Horsnells subtracted to give the natural flow in the Waihao at Crowes Rd Ford. Some gaugings not to be used because no MGIS data available for the period of the gauging.
- 2) Gaugings listed here only for dates of concurrent gaugings in catchment. Full listing of McCulloughs gaugings in 'WaihaoGaugings' workbook, 'Waihao McCulloughs gaugings' sheet.
- 3) Flows have outfall flows of the MGIS at Horsnells and Crowes subtracted to give the natural flow in the Waihao at U/S Bradshaws. Gaugings listed here only for dates of concurrent gaugings in catchment. Full listing of U/S Bradshaws gaugings in 'Waihao US Bradshaws gaugings' sheet.
- 4) Flows have outfall flows of the MGIS at Horsnells and Crowes subtracted to give the natural flow in the Waihao at Bradshaws. Some gaugings not to be used because no MGIS data available for the period of the gauging. All Waihao at Bradshaws gaugings listed here. Waihao at Bradshaws is a stage only site.

On next page>

- 5) Waihao at Crowes Rd Ford is usually gauged upstream of the Crowes Rd MGIS outfall, therefore only the Horsnells outfall needs to be subtracted to give the natural flow. Because the MGIS flows can vary over the day, the value to be subtracted is that which corresponds to the time of the gauging, taking into consideration 1000m travel time, based on the mean velocity of the gauged flow.
- 6) Subtract MGIS Crowes and Horsnells outfalls from Waihao at U/S Bradshaws, according to the time of the gauging and the time of travel.

**MGIS at Horsnells and Crowes outfall flows to be subtracted from d/stm sites**

Flow l/s	Nth Branch		Sth Branch		Waihao River							Recorders			MGIS at Horsnells and Crowes outfall flows to be subtracted from d/stm sites		
	170901 Kaiaua	170905 Forks	170902 Pentland	170903 Forks	70912 D/S McCull.	170904 Elliots	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes (1)	70902 McCulloughs (2)	70913 U/S Brad-shaws (3)	70907 Bradshaws (4)	MGIS flow?	Subtract from 70911 Crowes (5)	Subtract from 70913 U/S Brads (6)	Subtract from 70907 Brads:
Date																	
11/11/1980												4850					2630
26/11/1980												3593					2200
9/12/1980												1031					1510
17/12/1980												596					1700
14/01/1981												1614	?			?	
2/02/1981								Dry									
4/02/1981												712	?				500+?
8/04/1981												3465	?				?+1380
4/08/1981												8095					0
7/09/1981												2789	?				?
11/12/1981												2854	?				?
21/01/1982												2030	?				?
18/02/1982												1646	?				?
6/05/1983		2081									3203						
16/05/1983		1878									2578						
21/06/1983						2621	2174	1805			2802						
8/12/1983						2910	2466	1975			1171						
9/01/1984						1229	1041	286			1197						
25/01/1984						1377	1193	426			682						
7/11/1985						750	578	150			1320						
24/01/1986								502			2335						
11/06/1987							1310	1460			1985	1555					0
9/07/1987								1163			3600	3167					0
24/07/1987								5994			26028						
29/07/1987						7277	6773				6453	6893					0
1/09/1987											3018	2501					0
17/09/1987											3520	3147					0
14/10/1987											2247	1032					1875
12/11/1987								147			1086	253					1570
9/12/1987											615	660					930
8/01/1988											725	504					650
10/02/1988								Dry			729	233					1360
10/03/1988											588	494					370
17/12/1990											966	431					1110
5/02/1998		149	32	34		195					?						
25/03/1998	171	225	36	38		294					464						
8/04/1998	136	160	38	22							215						
24/04/1998	192	376	45	100							659						
7/07/1998	734	1107	336	580							1732						
21/10/1998	1638	2587	490	833		3411					2861						
27/10/1998	725		192	362							1350						
16/03/1999	522	669	103	168							986						
6/05/1999					566		1354	928	610	1774		869		500			730
20/05/1999					304		1245	26	74	727		330		0			0
4/06/1999					270		191	Dry	28	510		247		0			0
16/06/1999					5463		5336	4409	3846	5810		3732		0			0
23/07/1999	3112	5128	1032	2784		8296	99			7834							
23/11/2000					515			Dry	Dry	-41	503	-25		1520	1600		
14/12/2000					862		431	no flow	Dry	154	863	335		310	550		
25/01/2001					406		Dry	Dry	Dry	-227	462	-239		500	1270		
23/02/2001					236		Dry	Dry	Dry	-222	247	-299		280	930		
29/03/2001					147		Dry		Dry	-281	191	-55		310	800		
19/04/2001										-536	154	?		565			
20/04/2001					131		Dry	Dry	Dry	151	-127				860		
20/06/2001					517		92	Dry		Dry	593	211		0	0		
1/08/2002					2068		1972	1503	1364	1382	2132	1555		0	0		
5/09/2002					1512	1581	988	771	639	647	1402	1148		445	440		
14/11/2002					469	548	Dry	Dry	Dry	-195	530	114		430	600		
4/02/2004					3569	3876	2736	2869	2411	2717	3880	3309		295	1270		

5), 6) see previous page

Consents Numbers for Naturalisation

Date	Waihao Nth		Waihao Sth Branch				Waihao River						Recorder Sites			
	170901 Kaiwarua	170905 Forks	1822 Kaiwarua	170902 Pentland	1815 Henshaws	170903 Forks	2228 Meyers	70912 D/S McCull.	170904 Elliots	70910 Wains	70909 SH1	2381 U/S Horsnells	70911 Crowes (1)	70902 McCulloughs (2)	70913 U/S Brad-shaws (3)	70907 Bradshaws (4)
Surface water	scy770015/crc940825	scy770015/crc940825			scy810171B/3B	scy810171B/3B	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825	scy770015/crc940825
Ground water		scy760079/crc990390			crc990372	crc990372	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390	scy760079/crc990390
		scy888047/crc982146			scy730170	scy730170	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146	scy888047/crc982146
		crc982101/.1			crc940263B	crc940263B	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1	crc982101/.1
					crc991829	crc991829	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B	scy810171B/3B
					crc951287	crc951287	crc990372	crc990372	crc990372	crc990372	crc990372	crc990372	crc990372	crc990372	crc990372	crc990372
					scy790131/crc981890	scy790131/crc981890	scy730170	scy730170	scy730170	scy730170	scy730170	scy730170	scy730170	scy730170	scy730170	scy730170
					scy830134/crc990014	scy830134/crc990014	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B	crc940263B
							crc991829	crc991829	crc991829	crc991829	crc991829	crc991829	crc991829	crc991829	crc991829	crc991829
					crc951287	crc951287										
					scy790131/crc981890	scy790131/crc981890										
					scy830134/crc990014	scy830134/crc990014										
					scy800045	scy800045										
					scy790132	scy790132										
					scy780200	scy780200										
							scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365	scy790164/crc990365
							scy770122	scy770122	scy770122	scy770122	scy770122	scy770122	scy770122	scy770122	scy770122	scy770122
							scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361	scy790115/crc990361
							crc990296	crc990296	crc990296	crc990296	crc990296	crc990296	crc990296	crc990296	crc990296	crc990296
							crc905131	crc905131	crc905131	crc905131	crc905131	crc905131	crc905131	crc905131	crc905131	crc905131
							scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389	scy810034/crc990389
							crc991213	crc991213	crc991213	crc991213	crc991213	crc991213	crc991213	crc991213	crc991213	crc991213
							scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379	scy810160/crc990379
							scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759
							scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942	scy810146/crc981942
							scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759	scy790261/crc990759
							scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848	scy790156/crc000848
							scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138	scy800073/crc982138
							crc031115	crc031115	crc031115	crc031115	crc031115	crc031115	crc031115	crc031115	crc031115	crc031115

**Buchanans gaugings and naturalised flows**

Buchanans catchment gaugings			
Flow l/s			Recorder site:
Date	1575 Willowbridge	1576 Fletchers Rd	70908 Fletchers Farm
10/12/1996	113	511	
20/01/1997	75	543	
17/02/1997	57	538	
17/03/1997	95	532	
14/04/1997	73	556	
19/05/1997	117	531	
9/06/1997	77	453	
14/07/1997	39	417	
12/08/1997	49	417	
15/09/1997	76	426	
13/10/1997	53	482	
10/11/1997	44	400	
15/12/1997	Dry	260	
12/01/1998	Dry	208	
9/02/1998	Dry	161	
9/03/1998	Dry	107	
6/04/1998	Dry	104	
11/05/1998	Dry	134	
8/06/1998	Dry	170	
5/05/1999	Dry	Dry	275 #
20/05/1999	Dry	Dry	312
4/06/1999	Dry	Dry	360
16/06/1999	Dry	Dry	294
23/11/2000	Dry	Dry	321
14/12/2000	126	Dry	254/258
25/01/2001	46		184
23/02/2001	20	Dry	160
29/03/2001	Dry	Dry	134
20/04/2001	Dry	Dry	141
20/06/2001	Dry		186
1/08/2002	Dry		457
5/09/2002	228		450
14/11/2002	70	Dry	307
4/02/2004	Dry		162

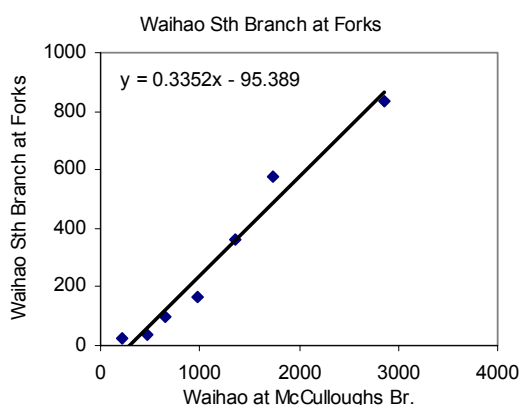
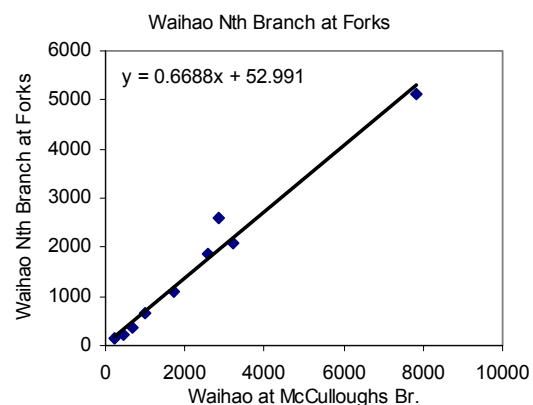
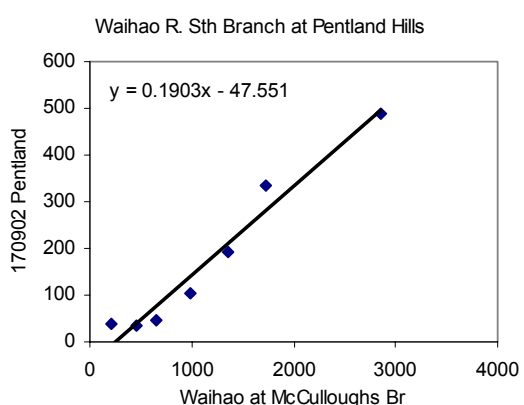
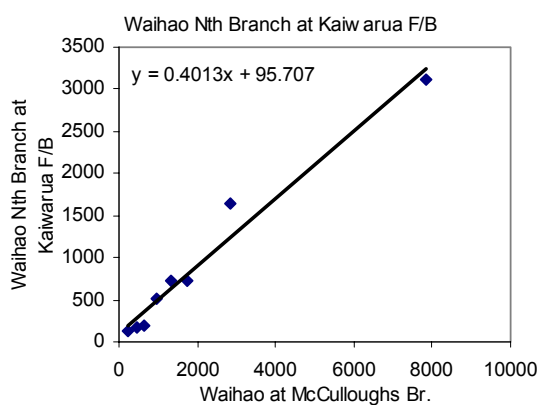
#Gauged 6/5/99.

Buchanans Creek naturalised gaugings			
Flow l/s			Recorder site:
Date	1575 Willowbridge	1576 Fletchers Rd	70908 Fletchers Farm
10/12/1996	117		522
20/01/1997	79		554
17/02/1997	61		549
17/03/1997	99		543
14/04/1997	77		567
19/05/1997	121		533
9/06/1997	81		455
14/07/1997	43		419
12/08/1997	53		419
15/09/1997	80		428
13/10/1997	57		495
10/11/1997	48		413
15/12/1997	Dry		273
12/01/1998	Dry		221
9/02/1998	Dry		174
9/03/1998	Dry		120
6/04/1998	Dry		117
11/05/1998	Dry		136
8/06/1998	Dry		172
5/05/1999	Dry	Dry	286
20/05/1999	Dry	Dry	323
4/06/1999	Dry	Dry	371
16/06/1999	Dry	Dry	305
23/11/2000	Dry	Dry	332
14/12/2000	126	Dry	265
25/01/2001	46		195
23/02/2001	20	Dry	171
29/03/2001	Dry	Dry	145
20/04/2001	Dry	Dry	152
20/06/2001	Dry		197
1/08/2002	Dry		466
5/09/2002	232		459
14/11/2002	74	Dry	316
4/02/2004	Dry		171
<b>Consents:</b>			
Surface water	scy790156	crc950626	crc950626
Groundwater	crc000848		scy800115
			scy700570
			scr972242

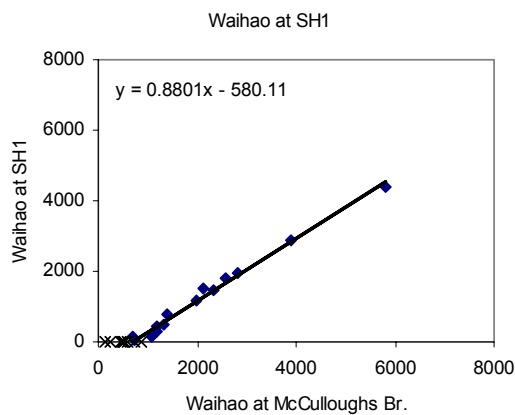
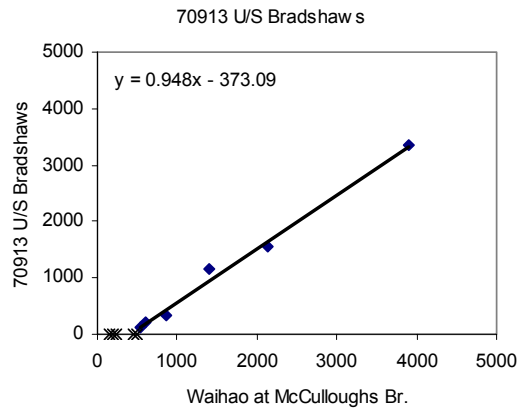
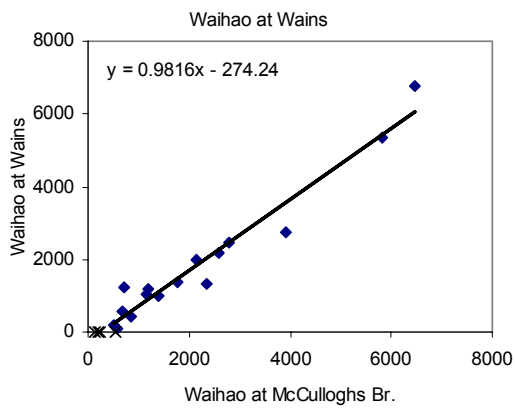
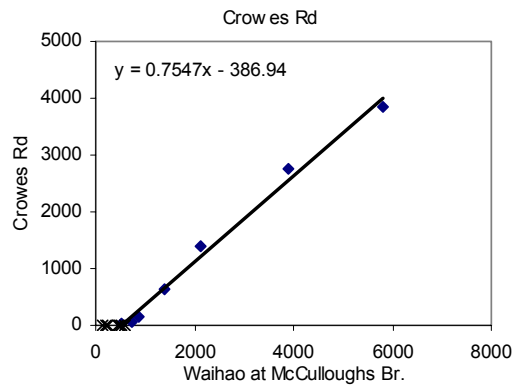
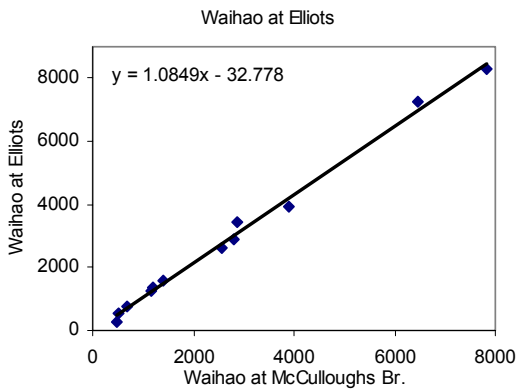
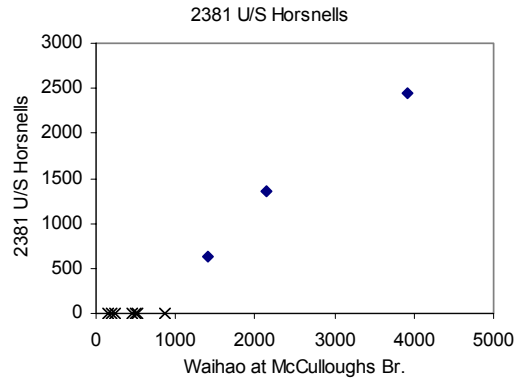
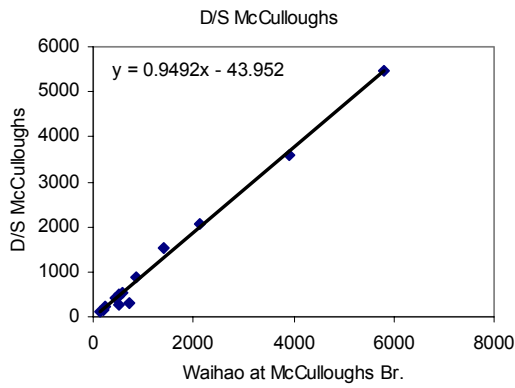
## Appendix 10: Regression equations for sites on the Waihao River

**Regression equations fitted to the plots of the tertiary site gaugings with the secondary Waihao River at McCulloughs Bridge site for the Waihao catchment.**

**Regressions for the Waihao River tributary sites upstream of the Waihao Forks.**



**Regression for sites on the main stem of the Waihao River downstream from the Waihao Forks.**



## Appendix 11: Gaugings conducted in the Otaio catchment

Flow l/s	Otaio River								Recorder sites (recorder data in bold):			
	1860 Bluedcliffs	1861 McAlwees	1862 Drinnans	1866 Esk Bank	1867 Church	1868 Grays	70301 SH1	2033 Otaio Trib	1869 Esk Valley	70303 Otaio Gorge	Hakataramea MHB	Rocky Gully
15/02/1968	142		95		109	204	402				<b>3404</b>	<b>179</b>
27/08/1968	652		725		608	768	1144			775	<b>6393</b>	182
29/05/1969							55			167	<b>2619</b>	<b>150</b>
5/06/1969							46			151	<b>1960</b>	<b>108</b>
8/10/1970							1042			842	<b>9495</b>	<b>340</b>
16/11/1970							158			214	<b>3876</b>	<b>277</b>
8/12/1970							85			153	<b>1528</b>	
5/02/1971							36			161	<b>1130</b>	<b>276</b>
5/03/1971							45			112	<b>1155</b>	<b>132</b>
5/04/1971							43			212	<b>3065</b>	<b>170</b>
15/06/1971							706			645	<b>9028</b>	<b>315</b>
22/07/1971							501			415	<b>4749</b>	<b>212</b>
3/09/1971							564				<b>5039</b>	<b>176</b>
6/10/1971							286			227	<b>6220</b>	<b>293</b>
8/11/1971							485			342	<b>5206</b>	<b>283</b>
10/12/1971							212				<b>2814</b>	<b>153</b>
23/02/1972							58				<b>890</b>	<b>100</b>
19/04/1972							43			117	<b>1150</b>	<b>115</b>
14/06/1972							234				<b>5370</b>	<b>178</b>
7/07/1972							1138			989	<b>4901</b>	<b>232</b>
31/07/1972							530			370	<b>6608</b>	<b>237</b>
1/09/1972							234				3664	<b>187</b>
2/10/1972							86			156	<b>4357</b>	<b>172</b>
8/11/1972							226			263	4573	<b>172</b>
7/12/1972							121			234	<b>6705</b>	<b>389</b>
26/01/1973							31			131	<b>1348</b>	<b>84</b>
5/03/1973							0				<b>733</b>	<b>82</b>
4/02/1981							84				<b>1238</b>	<b>105</b>
17/01/1991							86				<b>1029</b>	<b>117</b>
22/01/1991							41				<b>1193</b>	<b>145</b>
5/02/1998							0			70	<b>695</b>	<b>58</b>
25/03/1998							0				<b>1068</b>	<b>110</b>
24/04/1998							0				<b>1106</b>	<b>84</b>
7/07/1998							143				<b>4666</b>	
21/10/1998							789				<b>10025</b>	<b>484</b>
7/05/1999	137	11	95				41			284	<b>2414</b>	<b>197</b>
19/05/1999			40	103		46	90			161	<b>1803</b>	<b>109</b>
2/06/1999			15	45	27	34	157			127	<b>1398</b>	<b>83</b>
18/06/1999	716		711	573	430	411	601			813	<b>4465</b>	<b>338</b>
24/11/2000	No Flow	Dry	No Flow	Dry	Dry	Dry	58		No Flow	155	<b>2078</b>	
7/12/2000	Dry	Dry	Dry	Dry	Dry	Dry	34		Dry	136	<b>3660</b>	
24/01/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	115	<b>2011</b>	<b>125</b>
22/02/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	92	<b>1024</b>	<b>66</b>
26/03/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	75	<b>910</b>	<b>53</b>
18/04/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry		Dry	68	<b>885</b>	<b>51</b>
19/06/2001	Dry	Dry	No Flow	Dry	Dry	No Flow	134	No Flow	Dry	109	<b>1299</b>	<b>79</b>
5/03/2004	888	658	910	613	764	780	1239	226	Dry	1019	<b>7887</b>	<b>478</b>
2/12/2004	350	106	244	63	150	278	433	278	Dry	549	<b>4271</b>	<b>171</b>
25/01/2005	269	63	249	61	175	323	494	242	6	331	<b>4977</b>	<b>156</b>

From telemetry

## Appendix 12: Details of estimated surface water and groundwater takes from the Otaio catchment as calculated from resource consents.

**OTAIO CATCHMENT SURFACE WATER CONSENTS**

Irrigation

Public and Stockwater/Rural

Original consent:	crc981876	scy880064	crc920659	crc920906	scy820338	crc920910	scy820086
Commenced:	26/04/1999	11/10/1989	12/11/1992	12/11/1992	9/12/1982	12/11/1992	1979
Expired:	12/05/2004	1/06/1992	1/06/2027	1/06/2027	1/06/1992	1/06/2027	1/06/1992
Replacement :	crc981876.1						
Commenced:	12/05/2004						
Expires:	22/04/1934						
<b>Year</b>	<b>Average Daily Rate to be added back (l/s)</b>						
1973							
1974							
1975							
1976							
1977							
1978							
1979							3.8
1980							3.8
1981							3.8
1982					6.2		3.8
1983					6.2		3.8
1984					6.2		3.8
1985					6.2		3.8
1986					6.2		3.8
1987					6.2		3.8
1988					6.2		3.8
1989		3			6.2		3.8
1990		3			6.2		3.8
1991		3			6.2		3.8
1992		3	11.45	9.1	6.2	25	3.8
1993		5m3/day	11.45	9.1		25	
1994		stock and	11.45	9.1		25	
1995		domestic	11.45	9.1		25	
1996		after this:	11.45	9.1		25	
1997		0.1 l/s	11.45	9.1		25	
1998			11.45	9.1		25	
1999	7.4		11.45	9.1		25	
2000	7.4		11.45	9.1		25	
2001	7.4		11.45	9.1		25	
2002	7.4		11.45	9.1		25	
2003	7.4		11.45	9.1		25	
2004	10.7		11.45	9.1		25	
2005	10.7		11.45	9.1		25	

**Low flow condition?**

Original consent:	N	N	N	N	N	N	N
Replacement :	N						
Add back to:	Otaio at Bluecliffs and below.	Otaio at McAlwees and below.	Otaio at McAlwees and below.	Otaio at Church Hill and below.	Otaio at Church Hill and below.	Otaio at Grays Xing and below.	Otaio at Grays Xing and below.

**Details of estimated surface water and groundwater takes from the Otaio at SH1 as calculated from resource consents.**

OTAIO CATCHMENT SURFACE WATER CONSENTS					Irrigation	Public and Stockwater/Rural Supply				
Original consent:	crc920874	crc920689	scy820092	crc921001b	scy770013	scy800137	scy820017	crc921001c	scy820019	scy820133
Commenced:	Nov-92	Nov-92	Nov-78	Nov-92	1977	1973	1982	Nov-92	1982	1982
Expired:	Jun-27	Jun-27	Jun-92	Jun-27	June-92	June-92	June-92	June-27	June-92	June-92
<b>Replacement :</b>			crc920866		crc920905					
Commenced:			Nov-92		Nov-92					
Expires:			Jun-27		Jun-27					
<b>Year</b>										
1973						11.1				
1974						11.1				
1975						12.65				
1976						12.65				
1977					5.0	12.65				
1978			2.5		5.0	12.65				
1979			2.5		5.0	12.65				
1980			2.5		5.0	20.65				
1981			2.5		5.0	20.65				
1982			7.6		5.0	20.65	3.6		3.85	28.2
1983			7.6		12.4	20.65	3.6		3.85	28.2
1984			7.6		12.4	20.65	3.6		3.85	28.2
1985			7.6		12.4	20.65	3.6		3.85	28.2
1986			7.6		12.4	20.65	3.6		3.85	28.2
1987			7.6		12.4	20.65	3.6		3.85	28.2
1988			7.6		12.4	20.65	3.6		3.85	28.2
1989			7.6		12.4	20.65	3.6		3.85	28.2
1990			7.6		12.4	20.65	3.6		3.85	28.2
1991			7.6		12.4	20.65	3.6		3.85	28.2
1992	26.85	28.85	8.25	22.9	12.4	20.65	3.6	20.65	3.85	28.2
1993	26.85	28.85	8.25	22.9	12.4			20.65		
1994	26.85	28.85	8.25	22.9	12.4			20.65		
1995	26.85	28.85	8.25	22.9	12.4			20.65		
1996	26.85	28.85	8.25	22.9	12.4			20.65		
1997	26.85	28.85	8.25	22.9	12.4			20.65		
1998	26.85	28.85	8.25	22.9	12.4			20.65		
1999	26.85	28.85	8.25	22.9	12.4			20.65		
2000	26.85	28.85	8.25	22.9	12.4			20.65		
2001	26.85	28.85	8.25	22.9	12.4			20.65		
2002	26.85	28.85	8.25	22.9	12.4			20.65		
2003	26.85	28.85	8.25	22.9	12.4			20.65		
2004	26.85	28.85	8.25	22.9	12.4			20.65		
2005	26.85	28.85	8.25	22.9	12.4			20.65		

**Low flow condition?**

Original consent:	N	N	N	N	N	N	N	N	N	N
Replacement :					N					
<b>Add back to:</b>	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.	Otaio at SH1.

**OTAIO CATCHMENT STREAM DEPLETING GROUNDWATER CONSENTS**  
 Data compiled and stream depletion calculated by Philippa Aitchison-Earl

Irrigation  
 Public and Stockwater/Rural Supply

<b>Original consent:</b>	crc980527	crc981407	crc021383/.1	scy820075
Commenced:	26/10/1999	26/10/1999	18/03/2002	1982
Expired:	26/10/2009	26/10/2009	14/03/1937	1/06/1992
<b>Replacement :</b>				crc920668/.1/.2
Commenced:				22/05/1992
Expires:				1/06/2002
<b>Replacement 2 :</b>				
Commenced:				
Expires:				

Year	Stream depletion rate to be added back (l/s)			
1982				0.1
1983				0.1
1984				0.1
1985				0.1
1986				0.1
1987				0.1
1988				0.1
1989				0.1
1990				0.1
1991				0.1
1992				0.1
1993				0.1
1994				0.1
1995				0.1
1996				0.1
1997				0.1
1998				0.1
1999	8.35	4.35		0.1
2000	8.35	4.35		0.1
2001	8.35	4.35		0.1
2002	8.35	4.35	0.05	0.1
2003	8.35	4.35	0.05	0.1
2004	8.35	4.35	0.05	0.1
2005	8.35	4.35	0.05	0.1

**Low flow condition?**

Original consent:	N	N	N	N
Replacement:				

<b>Add back to:</b>	Otaio at Drinnans Br and below.	Otaio at Church Hill and below.	Half to Otaio at SH1.	Half to Otaio at SH1.
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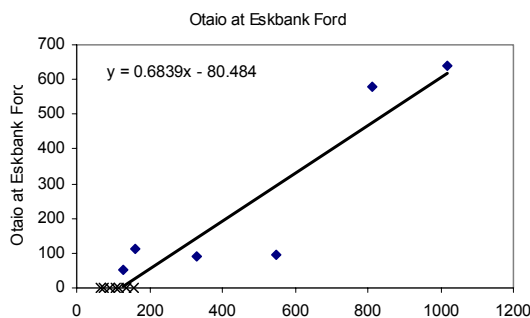
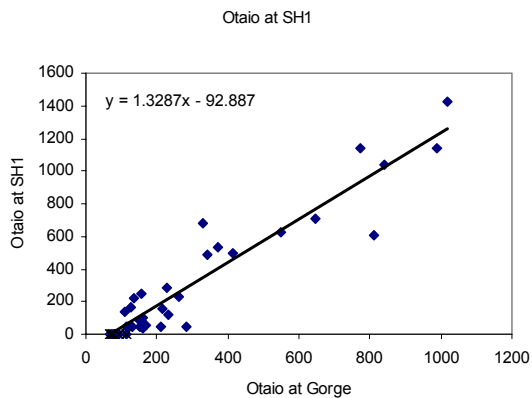
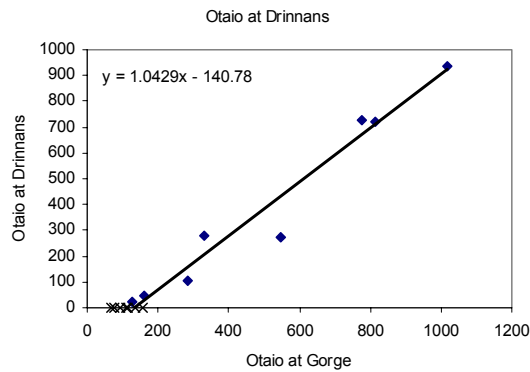
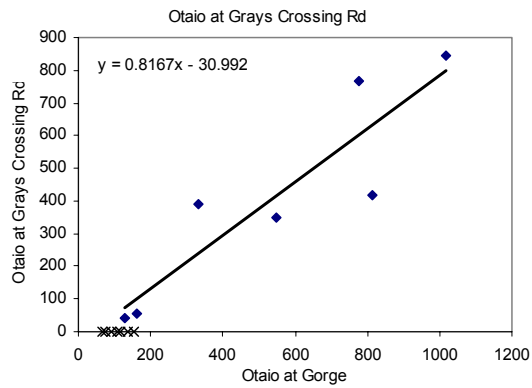
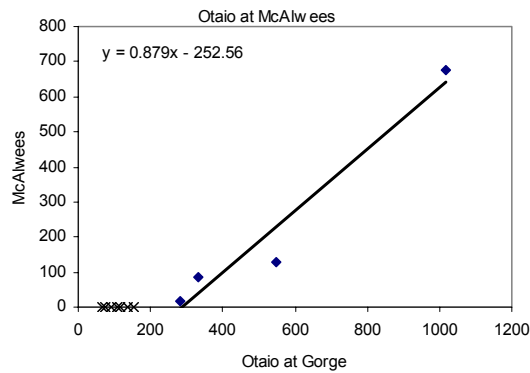
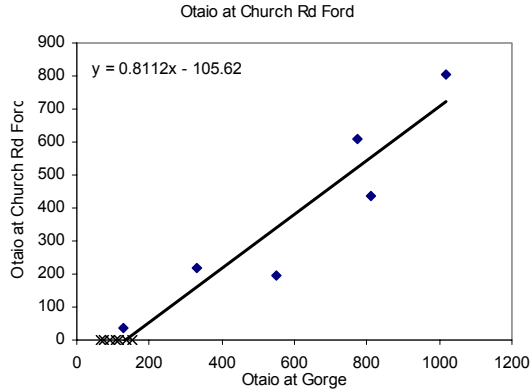
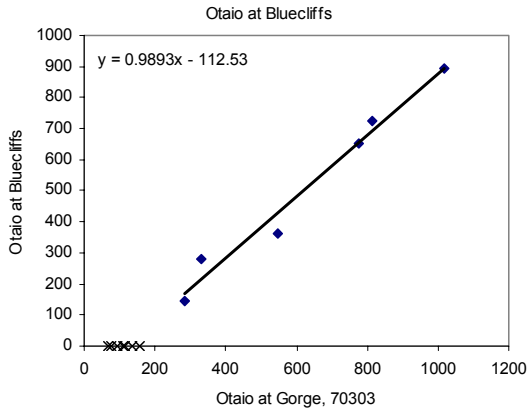
# Appendix 13: Otaio gaugings naturalised

Flow l/s	Otaio River							Recorder site (recorder data in bold):					
	1860 Bluecliffs	1861 McAlwees	1862 Drinnans	1866 Esk Bank	1867 Church	1868 Grays	70301 SH1	2033 Otaio Trib	1869 Esk Valley	70303 Otaio Gorge	Hakataramea MHB	Rocky Gully	
15/02/1968	142		95		109	204	402				<b>3404</b>	<b>179</b>	
27/08/1968	652		725		608	768	1144			775	<b>6393</b>	182	
29/05/1969							55			167	<b>2619</b>	<b>150</b>	
5/06/1969							46			151	<b>1960</b>	<b>108</b>	
8/10/1970							1042			842	<b>9495</b>	<b>340</b>	
16/11/1970							158			214	<b>3876</b>	<b>277</b>	
8/12/1970							85			153	<b>1528</b>		
5/02/1971							36			161	<b>1130</b>	<b>276</b>	
5/03/1971							45			112	<b>1155</b>	<b>132</b>	
5/04/1971							43			212	<b>3065</b>	<b>170</b>	
15/06/1971							706			645	<b>9028</b>	<b>315</b>	
22/07/1971							501			415	<b>4749</b>	<b>212</b>	
3/09/1971							564				<b>5039</b>	<b>176</b>	
6/10/1971							286			227	<b>6220</b>	<b>293</b>	
8/11/1971							485			342	<b>5206</b>	<b>283</b>	
10/12/1971							212				<b>2814</b>	<b>153</b>	
23/02/1972							58				<b>890</b>	<b>100</b>	
19/04/1972							43			117	<b>1150</b>	<b>115</b>	
14/06/1972							234				<b>5370</b>	<b>178</b>	
7/07/1972							1138			989	<b>4901</b>	<b>232</b>	
31/07/1972							530			370	<b>6608</b>	<b>237</b>	
1/09/1972							234				3664	<b>187</b>	
2/10/1972							86			156	<b>4357</b>	<b>172</b>	
8/11/1972							226			263	<b>4573</b>	<b>172</b>	
7/12/1972							121			234	<b>6705</b>	<b>389</b>	
26/01/1973							42.1			131	<b>1348</b>	<b>84</b>	
5/03/1973							0				<b>733</b>	<b>82</b>	
4/02/1981							116				<b>1238</b>	<b>105</b>	
17/01/1991							172.4				<b>1029</b>	<b>117</b>	
22/01/1991							127.4				<b>1193</b>	<b>145</b>	
5/02/1998							0			70	<b>695</b>	<b>58</b>	
25/03/1998							0				<b>1068</b>	<b>110</b>	
24/04/1998							0				<b>1106</b>	<b>84</b>	
7/07/1998							143				<b>4666</b>		
21/10/1998							954.7				<b>10025</b>	<b>484</b>	
7/05/1999	144.4	18.4	102.4				48.4			284	<b>2414</b>	<b>197</b>	
19/05/1999			47.4	110.4			53.4	97.4		161	<b>1803</b>	<b>109</b>	
2/06/1999			22.4	52.4	34.4		41.4	164.4		127	<b>1398</b>	<b>83</b>	
18/06/1999	723.4		718.4	580.4	437.4		418.4	608.4		813	<b>4465</b>	<b>338</b>	
24/11/2000	No Flow	Dry	No Flow	Dry	Dry	Dry		243.9		No Flow	155	<b>2078</b>	
7/12/2000	Dry	Dry	Dry	Dry	Dry	Dry		219.9		Dry	136	<b>3660</b>	
24/01/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	115	<b>2011</b>	<b>125</b>
22/02/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	92	<b>1024</b>	<b>66</b>
26/03/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	75	<b>910</b>	<b>53</b>
18/04/2001	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	68	<b>885</b>	<b>51</b>
19/06/2001	Dry	Dry	No Flow	Dry	Dry	No Flow		141.4	No Flow	Dry	109	<b>1299</b>	<b>79</b>
5/03/2004	895.4	676.9	937.3	640.3	804.8	845.8	1424.9		226	Dry	1019	<b>7887</b>	<b>478</b>
2/12/2004	360.7	128.2	274.6	93.6	194.1	347.1	622.2		278	Dry	549	<b>4271</b>	<b>171</b>
25/01/2005	279.7	85.2	279.6	91.6	219.1	392.1	683.2		242	6	331	<b>4977</b>	<b>156</b>

Consents:		From telemetry											
Surface water	crc981876/.1	crc981876/.1	crc981876/.1	crc981876/.1	crc981876/.1	crc981876/.1	SH1	all	crc921001b				
Groundwater	scy880064	scy880064	scy880064	scy880064	scy880064	scy880064	scy880064	in box	scy770013/crc920905				
	crc920659	crc920659	crc920659	crc920659	crc920659	crc920659	in box		scy800137				
		crc980527	crc980527	crc920906	crc920906	crc920906			scy820017				
				scy820338	scy820338	scy820338			crc921001c				
				crc980527	crc920910	crc920910			scy820019				
				crc981407	scy820086	scy820086			scy820133				
					crc980527	crc920874			crc980527				
					crc981407	scy920689			crc981407				
						scy820092/crc920866							

# Appendix 14: Regression equations fitted to the plots of the tertiary site gaugings with the secondary Otaio River at Gorge site for the Otaio catchment



## Appendix 15: Gaugings conducted in the Kohika Stream catchment

### Surface Water Take:

	From	To	Max Rate	Max quantity	Usage days	Average daily rate
WR2508	1982	8/02/1989		4000	7	6.6
SCY820193	8/02/1989	1/06/1997	27	8000	7	13.2

KOHIKA AT SH1:		HOOK BEACH RD:	
Date	Flow (l/s)	Naturalised flow (l/s)	
24/11/2000	10	170.2	
7/12/2000	5	141.2	
24/01/2001	1	96.2	
22/02/2001	1	<b>83.2</b>	
26/03/2001	1	<b>70.2</b>	
18/04/2001	1	<b>63.2</b>	
20/06/2001	1	52.6	
5/03/2004Dry		<b>485.8</b>	
2/12/2004	10	<b>403.8</b>	
25/01/2005	25	<b>411.1</b>	

No takes within period of gaugings therefore no need to naturalise.

## Appendix 16: Gaugings conducted in the Makikihi River catchment

### Flow l/s

Date	1864 Teschemaker	1863 Makikihi Tesch.	1865 Makikihi SH1
16/02/1968		243	
4/02/1981		35	
5/05/1999		105	
17/05/1999		52	
31/05/1999		36	
15/06/1999	44	658	
23/11/2000	22	59	Dry
7/12/2000	23	58	Dry
24/01/2001	10	30	Dry
22/02/2001	9	20	Dry
26/03/2001	8	10	Dry
18/04/2001	3	1	Dry
19/06/2001	14	29	No flow
2/02/2004	866	3233	3909
4/02/2004	242	751	455

### Feb. 1968 Concurrent Gauging Run:

Site	16/02/1968	17/02/1968
2212 Peters Gorge	24	
2215 Peters BackLine		25
2209 Peters Pakihi	39	
2211 Makikihi Gorge	39	
2216 Makikihi Milnes		59
2210 Makikihi Pakihi	95	
2214 Makikihi Peters		75
2213 Makikihi Buss.	120	
1863 Makikihi Tesch.	243	
2217 Makikihi Trib.		62

# Appendix 17: Details of estimated surface water and groundwater takes from the Makikihi catchment as calculated from resource consents

**MAKIKIHI CATCHMENT SURFACE AND GROUNDWATER CONSENTS**

Irrigation  
Public and Stockwater/Rural Supply

						GW Consent
<b>Original consent:</b>	crc915077	crc992781/.1	scy880041	crc041333	crc990059	crc980271
Commenced:	28/01/1992	3/08/1999	8/02/1989	25/02/2004	1/08/1997	18/09/1997
Expired:	1/09/1992	30/07/1934	1/09/1992	24/02/1939	30/10/1998	19/09/1932
<b>Replacement 1:</b>	crc920983		crc921573		crc990059.1	
Commenced:	2/07/1992		2/10/2002		30/10/1998	
Expires:	1/09/2002		1/06/2002		20/07/1932	
<b>Replacement 2:</b>	crc021287					
Commenced:	14/02/2002					
Expires:	13/02/1937					
<b>Year</b>	<b>Average Daily Rate to be added back (l/s)</b>					
1989			2.05			
1990			2.05			
1991			2.05			
1992	0.65		2.05			
1993	0.65		2.05			
1994	0.65		2.05			
1995	0.65		2.05			
1996	0.65		2.05			
1997	0.65		2.05		1.9	1.15
1998	0.65		2.05		1.9	1.15
1999	0.65	10	2.05		27.5	1.15
2000	0.65	10	2.05		27.5	1.15
2001	0.65	10	2.05		27.5	1.15
2002	0.95	10	2.05		27.5	1.15
2003	0.95	10			27.5	1.15
2004	0.95	10		1.5	27.5	1.15
2005	0.95	10		1.5	27.5	1.15
<b>Low flow condition?</b>						
Original consent:	N	20 l/s maintained below the take.	N	N	N	N
Replacement :	N		N		N	
<b>Add back to:</b>						
	Makikihi at Teschemaker and below.	Teschemaker Ck & Makikihi at SH1.	Teschemaker Ck & Makikihi at SH1.	Teschemaker Ck & Makikihi at SH1.	Makikihi at SH1.	Nowhere.

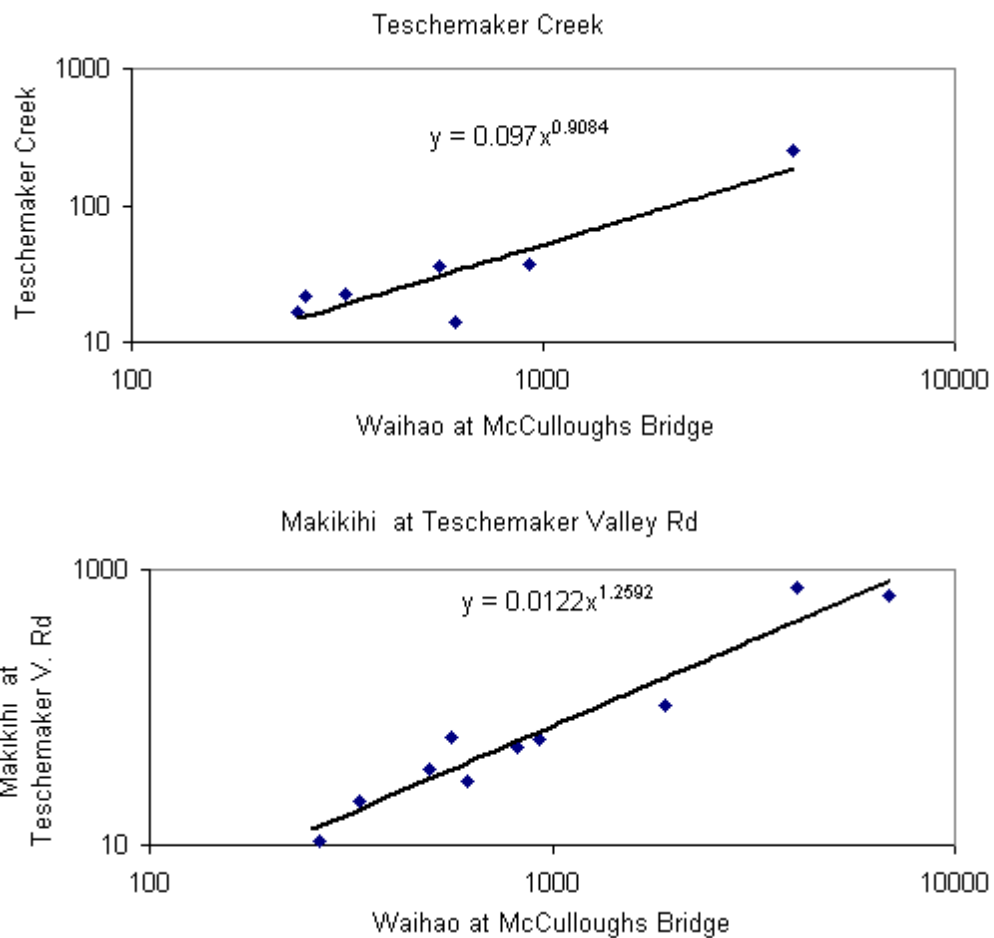
## Appendix 18: Makikihi gaugings naturalised

Flow l/s	Primary sites (recorder data in bold):					
Date	1864 Teschemaker	1863 Makikihi Tesch.	1865 Makikihi SH1	Otaio at Gorge	Waihao at McCulloughs	Hook at Beach Rd
16/02/1968		243				
4/02/1981		35				
5/05/1999		105			1897	
17/05/1999		52			819	
31/05/1999		36			497	
15/06/1999	44	658			6879	
23/11/2000	35.6	59.7	Dry		560	170
7/12/2000	36.6	58.7	Dry		926	141
24/01/2001	23.6	30.7	Dry			96
22/02/2001	22.6	20.7	Dry		332	<b>83</b>
26/03/2001	21.6	10.7	Dry		263	<b>70</b>
18/04/2001	16.6	1.7	Dry	68	253	<b>63</b>
19/06/2001	14	29	No flow	109	613	<b>52</b>
2/02/2004	879.6	3233.7	3950.8	<b>4324</b>	11462	<b>3020</b>
4/02/2004	255.6	751.7	496.8	<b>1290</b>	4039	463

**Consents:**

Surface water	crc992781/.1	crc915077/920983/021287	crc915077/920983/021287
Groundwater	scy880041/crc921573		crc992781/.1
	crc041333		scy880041/crc921573
			crc041333
			crc990059/.1

## Appendix 19: Regression equations fitted to the plots of the tertiary site gaugings in the Makikihi catchment with the secondary Waihao at McCulloughs site



## Appendix 20: Gaugings for small streams between the Makikihi River and Hook River

### COASTAL CREEKS MAKIKIHI TO HOOK

NO SITES AFFECTED BY TAKES.

Date	2366 Hook Drn at Hook Swamp Rd	1835 Hook Drn Spring Fed at Hook Swamp Rd	170704 Hook Drn at Swamp Rd	1580 Hook Drn at Douglas Rd	Recorder sites:		Hook takes added back
					Otaio at Gorge	Hook at Hook Beach Rd	
5/05/1999			0				
20/05/1999			0				
4/06/1999			0				
16/06/1999			0				
23/11/2000	39		No flow			170.2	52.2
14/12/2000			Dry	31		127.2	52.2
25/01/2001			No flow	30		96.2	52.2
23/02/2001			No flow	7		85.2	52.2
29/03/2001			Dry	No flow		69.2	52.2
20/04/2001			Dry	No flow	67	62.2	52.2
20/06/2001		5	No flow	1	102	52.6	26.6
1/08/2002		25		67	428	284.6	26.6
5/09/2002		15	15	69	249	248.6	26.6
14/11/2002		22	Dry	17	108	116.2	52.2
4/02/2004	No flow	23		No flow	1290	462.8	48.8

## Appendix 21: Gaugings conducted in the Hook River catchment

Flow l/s	Recorder site:			
	Date	70702 Hook Trib	70701 Hook U/S Intake	70703 Hook Beach Rd
	20/02/1968	48		
	2/03/1973		21	
	23/03/1973		25	
	11/04/1973		17	
	14/05/1973		120	
	1/02/1974		31	
	4/01/1979		120	
	23/01/1979		75	
	7/02/1979		43	
	15/02/1979		61	
	23/02/1979		39	
	15/03/1979		295	
	5/06/1979		134	
	18/06/1979		126	
	28/06/1979		91	
	3/07/1979		110	
	18/07/1979		69	
	6/08/1979		383	
	19/09/1979		71	
	18/12/1979		63	
	12/02/1980		64	
	26/02/1980		95	
	3/06/1980		107	
	25/06/1980		102	
	9/07/1980		76	
	22/07/1980		92	
	19/08/1980		82	
	3/09/1980		55	
	29/09/1980		26	
	7/10/1980		36	
	21/10/1980		121	
	28/10/1980		50	
	11/11/1980		202	
	17/12/1980		51	
	14/01/1981		78	
	8/04/1981		102	
	4/08/1981		199	
	7/09/1981		107	
	18/02/1982		42	
	29/03/1982		43	
	11/10/1982		26	
	8/11/1982		86	
	30/11/1982		120	
	15/12/1982		122	
	3/01/1983		124	
	24/01/1983		60	
	23/02/1983		39	
	5/02/1998		25	
	6/05/1999	70	8	
	20/05/1999	13		
	4/06/1999	8	2	
	16/06/1999	20	25	
	23/11/2000	23	41	118
	14/12/2000	24	52	75
	25/01/2001	18	41	44
	23/02/2001	13	23	33
	29/03/2001	6	10	17
	20/04/2001	7	10	10
	20/06/2001	12	18	26
	1/08/2002	37	78	258
	5/09/2002	24		222
	14/11/2002	20	39	64
	4/02/2004		455	414

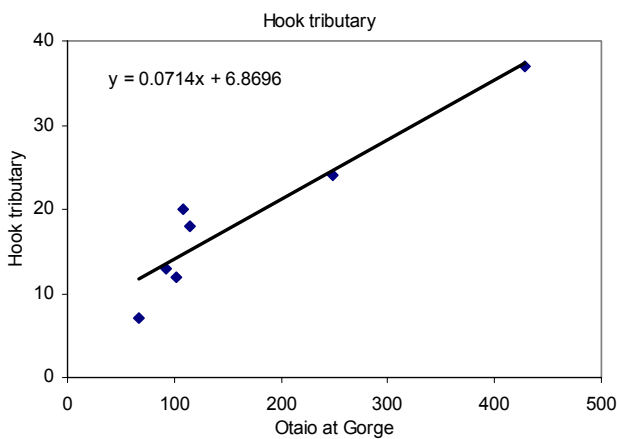
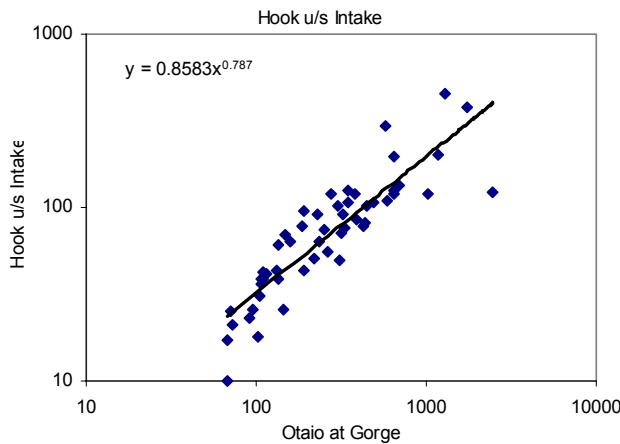
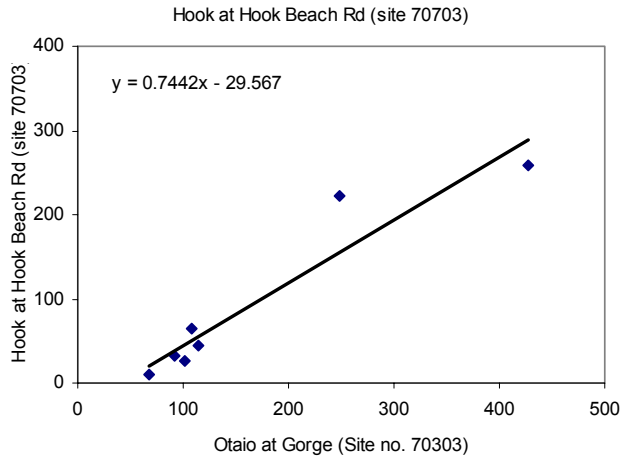
## Appendix 22: Details of estimated surface water and groundwater takes from the Hook catchment as calculated from resource consents

HOOK CATCHMENT SURFACE AND GROUNDWATER CONSUMPTION													
Irrigation													
Surface Water													
Public and Stockwater/Ru Groundwater													
Original consent:	scy 850075/6	scy 700021	crc 970696	scy 820353	crc 991525	scy 880058	crc 960785/1/2	crc 820165	crc 980998	crc 980998	crc 970579	crc 970579	crc 991430/1
Started:	Aug-70	Feb-70	Nov-96	May-89	Mar-99	Jun-89	Nov-96	Jun-05	Jan-99	Jan-99	Oct-96	Oct-96	Mar-99
Expired:	Sep-97	Aug-03	Nov-31	Sep-92	Mar-04	Sep-92	Oct-31	May-91	Jan-34	Jan-34	Oct-31	Oct-31	Mar-04
Replacement 1:	crc980386			crc921570		crc921523							crc032212
Commenced:	May-99			Oct-92		Jan-93							Nov-03
Expires:	Mar-04			Jun-02		Jun-02							Nov-38
Year													
1970	15.3	6											
1971	15.3	6											
1972	15.3	6											
1973	15.3	6											
1974	15.3	6											
1975	15.3	6											
1976	15.3	6											
1977	15.3	6											
1978	15.3	6											
1979	15.3	6											
1980	15.3	6											
1981	15.3	6											
1982	15.3	6						4.15					
1983	15.3	6						4.15					
1984	15.3	6						4.15					
1985	15.3	6						4.15					
1986	15.3	6						4.15					
1987	15.3	6						4.15					
1988	15.3	6						4.15					
1989	15.3	6		4.15		2.05		4.15					
1990	15.3	6		4.15		2.05		4.15					
1991	15.3	6		4.15		2.05		4.15					
1992	15.3	6		4.15		2.05							
1993	15.3	6		2.1		1.25							
1994	15.3	6		2.1		1.25							
1995	15.3	6		2.1		1.25							
1996	15.3	6	0.6	2.1		1.25	6.95			1.8	0.3		
1997	15.3	6	0.6	2.1		1.25	6.95			1.8	0.3		
1998	15.3	6	0.6	2.1		1.25	6.95			1.8	0.3		
1999	20	6	0.6	2.1	7.5	1.25	6.95		2.4	1	1.8	0.3	2.25
2000	20	6	0.6	2.1	7.5	1.25	6.95		2.4	1	1.8	0.3	2.25
2001	20	6	0.6	2.1	7.5	1.25	6.95		2.4	1	1.8	0.3	2.25
2002	20	6	0.6	2.1	7.5	1.25	6.95		2.4	1	1.8	0.3	2.25
2003	20	6	0.6		7.5		6.95		2.4	1	1.8	0.3	2.25
2004	20	6	0.6		7.5		6.95		2.4	1	1.8	0.3	2.25
2005	20	6	0.6				6.95		2.4	1	1.8	0.3	2.25
Low flow condition?													
Original consent	N	N	N	N	N	N	N	N	N	N	N	N	N
Replacement 1	Y			N		N							
<30l/s u/s intake, drop to 16l/s take.													
All Sites Added Back to Hook at Hook / Beack Rd													

## Appendix 23: Hook gaugings naturalised

Flow l/s		Recorder site (recorder data in bold):			
Date	70702 Hook Trib	70701 Hook U/S Intake	70703 Hook Beach Rd	Otaio at Gorge	Waihao at McCulloughs
20/02/1968	48				
2/03/1973		21		72	
23/03/1973		25			
11/04/1973		17		68	
14/05/1973		120		274	
1/02/1974		31		105	
4/01/1979		120		650	
23/01/1979		75		253	
7/02/1979		43		190	
15/02/1979		61		135	
23/02/1979		39		110	
15/03/1979		295		570	
5/06/1979		134		694	
18/06/1979		126		350	
28/06/1979		91		229	
3/07/1979		110		589	
18/07/1979		69		148	
6/08/1979		383		1728	
19/09/1979		71		314	
18/12/1979		63		233	
12/02/1980		64		157	
26/02/1980		95		190	
3/06/1980		107		347	
25/06/1980		102		443	
9/07/1980		76		328	
22/07/1980		92		327	
19/08/1980		82		433	
3/09/1980		55		261	
29/09/1980		26		144	
7/10/1980		36		108	
21/10/1980		121		1028	
28/10/1980		50		311	
11/11/1980		202		1182	
17/12/1980		51		221	
14/01/1981		78		186	
8/04/1981		102		299	
4/08/1981		199		648	
7/09/1981		107		487	
18/02/1982		42		110	
29/03/1982		43		132	
11/10/1982		26		96	685
8/11/1982		86		390	2417
30/11/1982		120		378	2183
15/12/1982		122		2477	1689
3/01/1983		124		651	2102
24/01/1983		60		310	1602
23/02/1983		39		136	511
5/02/1998		25		70 ?	
6/05/1999	70	8			1696
20/05/1999	13				727
4/06/1999	8	2			510
16/06/1999	20	25			5810
23/11/2000	23	41	118		542
14/12/2000	24	52	75		902
25/01/2001	18	41	44	115	507
23/02/2001	13	23	33	92	244
29/03/2001	6	10	17		188
20/04/2001	7	10	10	67	148
20/06/2001	12	18	26	102	593
1/08/2002	37	78	258	428	2132
5/09/2002	24		222	249	1402
14/11/2002	20	39	64	108	569
4/02/2004		455	414	1290	3970

## Appendix 24: Regression equations fitted to the plots of the sites in the Hook catchment with the Otaio River at Gorge recorder site.



## Appendix 25: Gaugings for small streams flowing into Wainono Lagoon

**Flow l/s**

Date	1881 Unnamed Stream (Wainono) at Hannaton Road	70809 Unnamed Stream Middle Wainono at Kingsburys Road	70811 Unnamed Stream North Wainono at SH1	2380 Unnamed Stream South Wainono at SH1	70810 Waituna Stream at SH1 Bridge
23/11/2000		Dry	No Flow	Dry	No Flow
14/12/2000		Dry	No Flow	Dry	No Flow
25/01/2001		Dry	No Flow	Dry	No Flow
23/02/2001		Dry	No Flow	Dry	No Flow
29/03/2001		Dry	No Flow	Dry	No Flow
20/04/2001		Dry	Dry	Dry	No Flow
20/06/2001	1	No Flow	No Flow	Dry	Dry
1/08/2002		Dry	No Flow	Dry	No Flow
5/09/2002	0	Dry			No Flow
14/11/2002	2	Dry			Ponding
4/02/2004	3	Dry			No flow

## Appendix 26: Gaugings conducted in the Waimate Creek catchment

**Flow l/s**

Date	70806 Kelseys U/S Intake	70807 Kelseys Carpark	70805 Gorge	70808 SH1	70803 Recorder House	2379 Meyers Rd
17/07/1954					587	
28/09/1956					7068	
3/10/1956					38799	
19/05/1957					56125	
29/05/1961					11185	
2/08/1961					35764	
28/02/1968	31					
28/02/1968	31					
5/08/1969	18					
9/10/1970			165			
12/11/1970			28			
8/12/1970			29			
3/02/1971			38			
4/03/1971			10			
5/04/1971			95			
14/06/1971			149			
22/07/1971			70			
3/09/1971			113			
5/10/1971			26			
8/11/1971			56			
8/12/1971			32			
24/01/1972			9			
19/04/1972			85			
8/06/1972			37			
29/06/1972			45			
31/07/1972			89			
31/08/1972			20			
29/09/1972			11			
8/11/1972			107			
6/12/1972			69			
25/01/1973			8			
23/03/1973	18					
11/04/1973	13					
14/05/1973	60					
13/07/1973	0					
1/02/1974	24					
13/04/1976	21					
4/10/1977	147					
6/03/1978	12					
4/01/1979	204					
12/01/1979	96					
23/01/1979	36					
7/02/1979	22					
15/02/1979	20					
23/02/1979	26					
15/03/1979	159					
5/06/1979	104					
18/06/1979	59					
28/06/1979	51					
3/07/1979	105					
18/07/1979	58					
6/08/1979	488					
19/09/1979	64					
12/02/1980	43					
26/02/1980	74					
3/06/1980	29					
25/06/1980	63					
9/07/1980	44					
22/07/1980	49					
19/08/1980	47					

Pareora – Waihao River: Water Resource Summary

Flow l/s						
Date	70806 Kelseys U/S Intake	70807 Kelseys Carpark	70805 Gorge	70808 SH1	70803 Recorder House	2379 Meyers Rd
7/09/1981	80					
21/01/1982	56					
18/02/1982	29					
30/11/1982	97					
15/12/1982	65					
24/01/1983	42					
13/03/1986			50000		115000	
5/02/1998	15					
25/03/1998	0					
8/04/1998	0					
22/09/1998	27					
15/10/1998	288					
24/10/1998	98					
23/11/1998	56					
13/01/1999	33					
9/02/1999	18					
5/03/1999	16					
9/04/1999	29					
5/05/1999				0		
6/05/1999	57	41				
20/05/1999		20		0		
4/06/1999	20	12		0		
16/06/1999		30		0		
6/07/1999	104					
6/08/1999	104					
9/09/1999	86					
5/10/1999	37					
11/11/1999	63					
9/12/1999	94					
13/01/2000	134					
18/02/2000	55					
16/03/2000	448					
26/04/2000	201					
30/05/2000	42					
29/06/2000	37					
19/07/2000	21					
13/10/2000	22					
10/11/2000	77					
23/11/2000	25					No Flow
14/12/2000	41					No Flow
25/01/2001	21					No Flow
23/02/2001	15					Dry
29/03/2001	11					No Flow
19/04/2001						Dry
20/04/2001	13					
20/06/2001	15					Dry
14/08/2001	49					
12/10/2001	227					
14/12/2001	139					
22/02/2002	59					
7/05/2002	72					
1/08/2002	47					No Flow
5/09/2002	32					1.5
14/11/2002	28					Dry
14/01/2003	34					
4/02/2004	336					2 l/s or No Flow

## Appendix 27: Details of estimated surface water and groundwater takes from the Waimate catchment as calculated from resource consents

### WAIMATE CATCHMENT SURFACE AND GROUNDWATER CONSENTS

Irrigation  
Public and Stockwater/Rural Supply

Original consent:	Surface Water				Groundwater
	scy690429	crc961089	scy798146	scy800040	scy690696
Commenced:	13/08/1969	24/01/1996	1979	1980	5/11/1969
Expired:	1/10/2001	24/01/2031	1/09/1998	1/09/1998	1/10/2001
<b>Replacement 1:</b>			crc981312		
Commenced:			10/06/1998		
Expires:			10/06/2033		
1969	26.3				2.7
1970	26.3			5.25	2.7
1971	26.3			5.25	2.7
1972	26.3			5.25	2.7
1973	26.3			5.25	2.7
1974	26.3			5.25	2.7
1975	26.3			5.25	2.7
1976	26.3			5.25	2.7
1977	26.3			5.25	2.7
1978	26.3			5.25	2.7
1979	26.3		13.25	5.25	2.7
1980	26.3		13.25	2.9	2.7
1981	26.3		13.25	2.9	2.7
1982	26.3		13.25	2.9	2.7
1983	26.3		19	2.9	2.7
1984	26.3		19	2.9	2.7
1985	26.3		19	2.9	2.7
1986	26.3		19	2.9	2.7
1987	26.3		19	2.9	2.7
1988	26.3		19	2.9	2.7
1989	26.3		19	2.9	2.7
1990	26.3		19	2.9	2.7
1991	26.3		19	2.9	2.7
1992	26.3		19	2.9	2.7
1993	26.3		19	2.9	2.7
1994	26.3		19	2.9	2.7
1995	26.3		19	2.9	2.7
1996	26.3	0.2	19	2.9	2.7
1997	26.3	0.2	19	2.9	2.7
1998	26.3	0.2	19	2.9	2.7
1999	26.3	0.2	19.5	2.9	2.7
2000	26.3	0.2	19.5	2.9	2.7
2001	26.3	0.2	19.5	2.9	2.7
2002		0.2	19.5	2.9	
2003		0.2	19.5	2.9	
2004		0.2	19.5	2.9	
2005		0.2	19.5	2.9	
<b>Low flow condition?</b>					
Original consent:	N	N	N	N	N
Replacement :			15l/s d/s of intake.		
<b>Add back to:</b>					
	Waimate at Kelceys Bush Carpark and below.	Waimate at Recorder House and below.	Waimate at Recorder House and below.	Waimate at Recorder House and below.	Waimate at Recorder House and below.

## Appendix 28: Waimate Creek naturalised gaugings 1954 – Oct 1980

Flow l/s							RECORDER SITES:		
Date	70806 Kelseys U/S Intake	70807 Kelseys Carpark	70805 Gorge	70803 Recorder House	2379 Meyers Rd	70808 SH1	Otaio Gorge	Hook Beach Rd	Waihao McCulloughs
17/07/1954					587				
28/09/1956					7068				
3/10/1956					38799				
19/05/1957					56425				
29/05/1961					44485				
2/08/1961					35764				
28/02/1968	31								
28/02/1968	31								
5/08/1969	18								
9/10/1970			191.3						
12/11/1970			54.3						
8/12/1970			55.3						
3/02/1971			64.3						
4/03/1971			36.3						
5/04/1971			121.3						
14/06/1971			175.3						
22/07/1971			96.3						
3/09/1971			139.3						
5/10/1971			52.3						
8/11/1971			82.3						
8/12/1971			58.3						
24/01/1972			35.3						
19/04/1972			111.3						
8/06/1972			63.3						
29/06/1972			71.3						
31/07/1972			115.3						
31/08/1972			46.3						
29/09/1972			37.3						
8/11/1972			133.3						
6/12/1972			95.3						
25/01/1973			34.3						
23/03/1973	18								
11/04/1973	13								
14/05/1973	60								
13/07/1973	0								
1/02/1974	24								
13/04/1976	21								
4/10/1977	147								
6/03/1978	12								
4/01/1979	204								
12/01/1979	96								
23/01/1979	36								
7/02/1979	22								
15/02/1979	20								
23/02/1979	26								
15/03/1979	159								
5/06/1979	104								
18/06/1979	59								
28/06/1979	51								
3/07/1979	105								
18/07/1979	58								
6/08/1979	488								
19/09/1979	64								
12/02/1980	43								
26/02/1980	74								
3/06/1980	29								
25/06/1980	63								
9/07/1980	44								
22/07/1980	49								
19/08/1980	47								
3/09/1980	29								
29/09/1980	18								
7/10/1980	18								

Pareora – Waihao River: Water Resource Summary

Flow l/s Date	70806 Kelseys U/S Intake	70807 Kelseys Carpark	70805 Gorge	70803 Recorder House	2379 Meyers Rd	70808 SH1	RECORDER SITES:		
							Otaio Gorge	Hook Beach Rd	Waihao McCulloughs
14/10/1980	16								
21/10/1980	33								
28/10/1980	19								
11/11/1980	136								
17/12/1980	25								
14/01/1981	27								
8/04/1981	76								
4/08/1981	107								
7/09/1981	80								
21/01/1982	56								
18/02/1982	29								
30/11/1982	97								2183
15/12/1982	65								1690
24/01/1983	42								1602
13/03/1986			50026.3	115026.3					1250000
5/02/1998	15								?
25/03/1998	0								319
8/04/1998	0								211
22/09/1998	27								498
15/10/1998	288								2353
24/10/1998	98								1994
23/11/1998	56								708
13/01/1999	33								310
9/02/1999	18								260
5/03/1999	16								231
9/04/1999	29								689
5/05/1999						0			1774
6/05/1999	57	67.3							1696
20/05/1999		46.3				0			727
4/06/1999	20	38.3				0			510
16/06/1999		56.3				0			5810
6/07/1999	104								2942
6/08/1999	104								4309
9/09/1999	86								1228
5/10/1999	37								603
11/11/1999	63								1190
9/12/1999	94								1230
13/01/2000	134								3568
18/02/2000	55								1290
16/03/2000	448								7492
26/04/2000	201								7298
30/05/2000	42								1459
29/06/2000	37								1695
19/07/2000	21								891
13/10/2000	22								2086
10/11/2000	77								961
23/11/2000	25				No Flow				542
14/12/2000	41				No Flow				902
25/01/2001	21				No Flow				501
23/02/2001	15				Dry			85.2	244
29/03/2001	11				No Flow			69.2	188
19/04/2001					Dry			63.2	151
20/04/2001	13							62.2	148
20/06/2001	15				Dry		102 ?		593
14/08/2001	49						366	231.6	2620
12/10/2001	227						778	150.2	3375
14/12/2001	139						711	373.2	2896
22/02/2002	59						303	308.2	1471
7/05/2002	72						489	390.6	1967
1/08/2002	47				No Flow		428	284.6	2132
5/09/2002	32				1.5		249	248.6	1402
14/11/2002	28				Dry		108	116.2	569
14/01/2003	34						146	135.8	903
4/02/2004	336				24.4		107	462.8	3970

## Appendix 29: Gaugings conducted in the Sir Charles Creek catchment

Flow l/s				
Date	70813 Trib 1	70812 Trib 2	1581 Trib 3	70801 Haymans
4/11/1969				216
6/10/1970				222
7/10/1970		83		
12/11/1970		21		178
7/12/1970		127		285
3/02/1971		61		160
5/03/1971		24		169
5/04/1971		35		105
15/06/1971		83		202
22/07/1971		55		289
6/09/1971		82		266
5/10/1971		86		235
8/11/1971		74		264
10/12/1971		69		243
24/01/1972		67		242
19/04/1972		29		144
8/06/1972		66		170
29/06/1972		108		191
31/07/1972		73		324
31/08/1972		119		325
29/09/1972		105		343
8/11/1972		111		558
6/12/1972		61		270
25/01/1973		37		209
2/03/1973		8		64
11/04/1973		6		
14/05/1973		11		
29/05/1973		11		
2/10/1973		55		286
29/11/1973		88		356
10/12/1996	48	4	101	247
20/01/1997	33	No flow	76	137
17/02/1997	43	No flow	73	200
17/03/1997	80	Minimal flow	93	331
14/04/1997	88	Minimal flow	79	226
19/05/1997	96	7	88	Ungaugable
9/06/1997	98	10	84	
14/07/1997	96	8	86	
12/08/1997	79		84	
13/10/1997	40		86	
10/11/1997	48		64	
15/09/1997	57		81	
15/12/1997	33		54	
12/01/1998	25		42	
9/02/1998	14		31	
9/03/1998	7		18	
6/04/1998	2		13	
11/05/1998	4		32	
8/06/1998	6		39	
5/05/1999	10	3		
6/05/1999				214
20/05/1999	10	5		288
4/06/1999	15	3		165
16/06/1999	18	4		222
23/11/2000	108	43	11	318
14/12/2000	48	80	12	Ungaugable
24/01/2001			1	
25/01/2001	13	28		
23/02/2001	25	20	Dry	Ungaugable
29/03/2001	12	5	1	Ungaugable
19/04/2001	10	3	Dry	Ungaugable
20/06/2001	22	3	1	
1/08/2002				310
5/09/2002				292
14/11/2002				211
4/02/2004	47	2	No flow	

# Appendix 30: Details of estimated surface water and groundwater takes from the Waimate catchment as calculated from resource consents

**SIR CHARLES CATCHMENT SURFACE AND GROUNDWATER CONSENTS**

Irrigation

Public and Stockwater/Rural Supply

	Surface Water				Groundwater	
Original consent:	scy820008	crc981741	crc000652	scy790023	scy700570	crc981424
Commenced:	1982	27/05/1998	22/12/1999	1979	8/07/1970	1/02/2000
Expired:	1/09/1998	27/05/2033	22/12/2009	1/09/1998	1/10/2001	22/12/2009
<b>Replacement 1:</b>					crc972242	
Commenced:					1/08/1997	
Expires:					30/07/2032	
<b>Replacement 2:</b>						
Commenced:						
Expires:						
<b>Year</b>						
1970					3.85	
1971					3.85	
1972					3.85	
1973					3.85	
1974					3.85	
1975					3.85	
1976					3.85	
1977					3.85	
1978					3.85	
1979				13.9	3.85	
1980				13.9	3.85	
1981				13.9	3.85	
1982	8.7			13.9	3.85	
1983	8.7			13.9	3.85	
1984	8.7			13.9	3.85	
1985	8.7			13.9	3.85	
1986	8.7			13.9	3.85	
1987	8.7			13.9	3.85	
1988	8.7			13.9	3.85	
1989	8.7			13.9	3.85	
1990	8.7			13.9	3.85	
1991	8.7			13.9	3.85	
1992	8.7			13.9	3.85	
1993	8.7			13.9	3.85	
1994	8.7			13.9	3.85	
1995	8.7			13.9	3.85	
1996	8.7			13.9	3.85	
1997	8.7			13.9	4.45	
1998	8.7	13.15		13.9	4.45	
1999		13.15	5.45		4.45	
2000		13.15	5.45		4.45	3.25
2001		13.15	5.45		4.45	3.25
2002		13.15	5.45		4.45	3.25
2003		13.15	5.45		4.45	3.25
2004		13.15	5.45		4.45	3.25
2005		13.15	5.45		4.45	3.25
<b>Low flow condition?</b>						
Original consent:	N	Cease <100 l/s at Haymans Rd	Cease depth 0.75m at Haymans (box open), 0.85m (box closed).	N	N	N
Replacement :					N	Same as crc000652.
<b>Add back to:</b>	Sir Charles Ck at Haymans Rd.	Mobile pump. Add back 1/2 (6.6 l/s) to Haymans Rd	Drain is u/s of Haymans. Add back to Haymans.	-	Sir Charles Ck Trib 3 at Lindsays Rd and below.	Sir Charles Ck at Haymans Rd.

# Appendix 31: Sir Charles Creek naturalised gaugings

Date	Flow l/s				Recorder sites:		
	70813 Trib 1	70812 Trib 2	1581 Trib 3	70801 Haymans	Hook Beach Rd	Waihao McCulloughs	
4/11/1969				216			
6/10/1970				225.9			
7/10/1970		83					
12/11/1970		21		181.9			
7/12/1970		127		288.9			
3/02/1971		61		163.9			
5/03/1971		24		172.9			
5/04/1971		35		108.9			
15/06/1971		83		202			
22/07/1971		55		289			
6/09/1971		82		266			
5/10/1971		86		238.9			
8/11/1971		74		267.9			
10/12/1971		69		246.9			
24/01/1972		67		245.9			
19/04/1972		29		147.9			
8/06/1972		66		170			
29/06/1972		108		191			
31/07/1972		73		324			
31/08/1972		119		325			
29/09/1972		105		343			
8/11/1972		111		561.9			
6/12/1972		61		273.9			
25/01/1973		37		212.9			
2/03/1973		8		67.9			
11/04/1973		6					
14/05/1973		11					
29/05/1973		11					
2/10/1973		55		289.9			
29/11/1973		88		359.9			
10/12/1996	48	4	105	255.7			831
20/01/1997	33	No flow	80	137			1699
17/02/1997	43	No flow	77	208.7			3166
17/03/1997	80	Minimal flow	97	339.7			1340
14/04/1997	88	Minimal flow	83	234.7			251
19/05/1997	96	7	88	Ungaugable			1137
9/06/1997	98	10	84				1346
14/07/1997	96	8	86				1917
12/08/1997	79		84				1251
15/09/1997	57		81				2405
13/10/1997	40		91				1260
10/11/1997	48		69				796
15/12/1997	33		59				350
12/01/1998	25		47				172
9/02/1998	14		36			?	
9/03/1998	7		23				721
6/04/1998	2		18				193
11/05/1998	4		32				419
8/06/1998	6		39				601
5/05/1999	10	3					1774
6/05/1999				214			1696
20/05/1999	10	5		288			727
4/06/1999	15	3		165			510
16/06/1999	18	4		222			5810
23/11/2000	108	43	15.5	333.4	170		542
14/12/2000	48	80	16.5	Ungaugable	127		902
24/01/2001			5.5		?	?	
25/01/2001	13	28			96		507
23/02/2001	25	20	Dry	Ungaugable	85		244
29/03/2001	12	5	5.5	Ungaugable	69		188
19/04/2001	10	3	Dry	Ungaugable	63		151
20/06/2001	22	3	1		53		593
1/08/2002				310	285		2132
5/09/2002				292	249		1402
14/11/2002				226.4	116		569
4/02/2004	47	2	No flow		463		3970

Consents:

Surface Water  
Groundwater

scy700570/crc972242  
scy820008  
crc981741  
crc000652  
scy700570/crc972242

# Appendix 32: Geological cross-sections

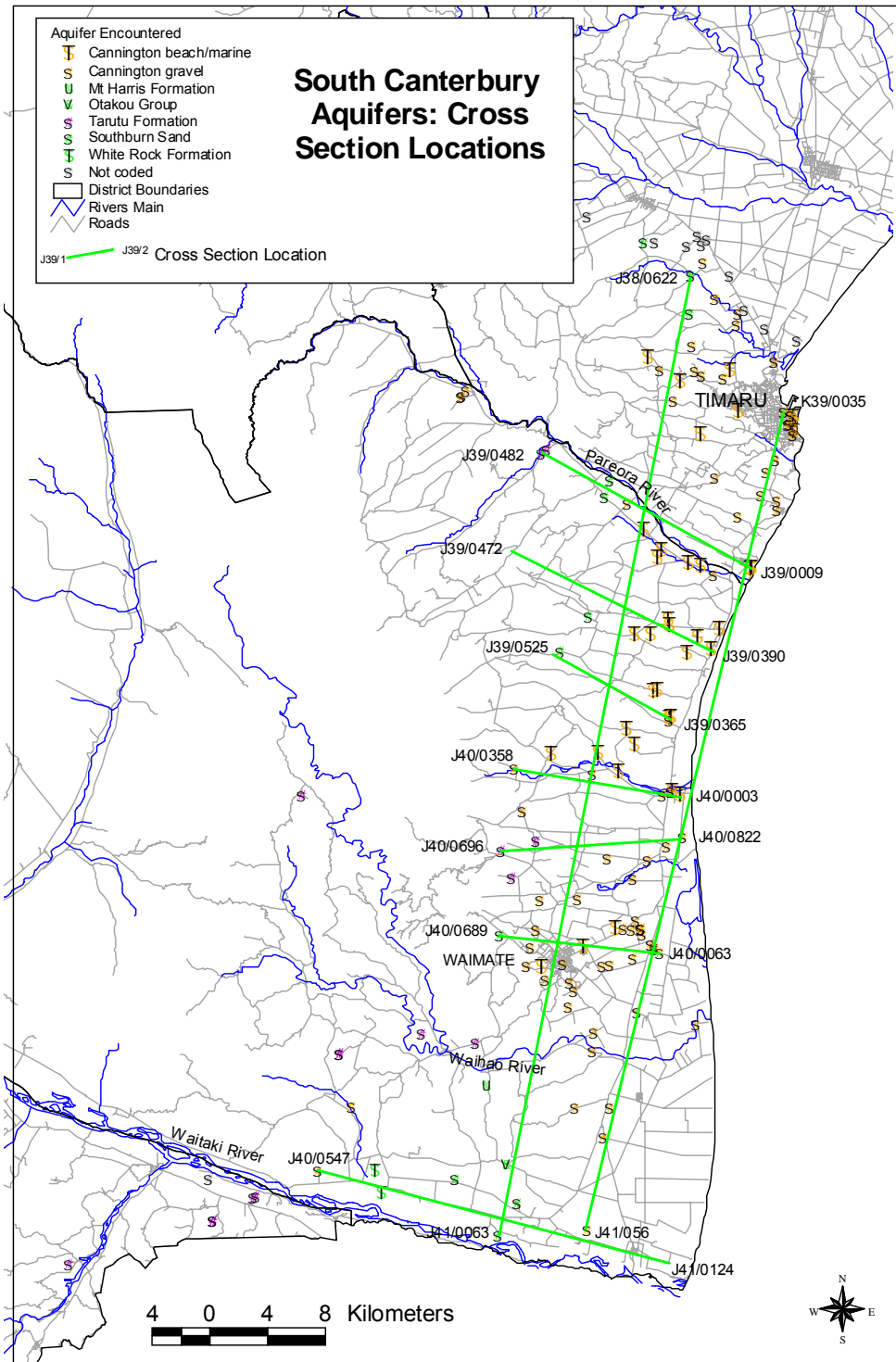


Figure 32.1 Pareora Valley Cross Section, J39/0482 – J39/0009  
(NB horizontal scale in km, vertical scale in m)

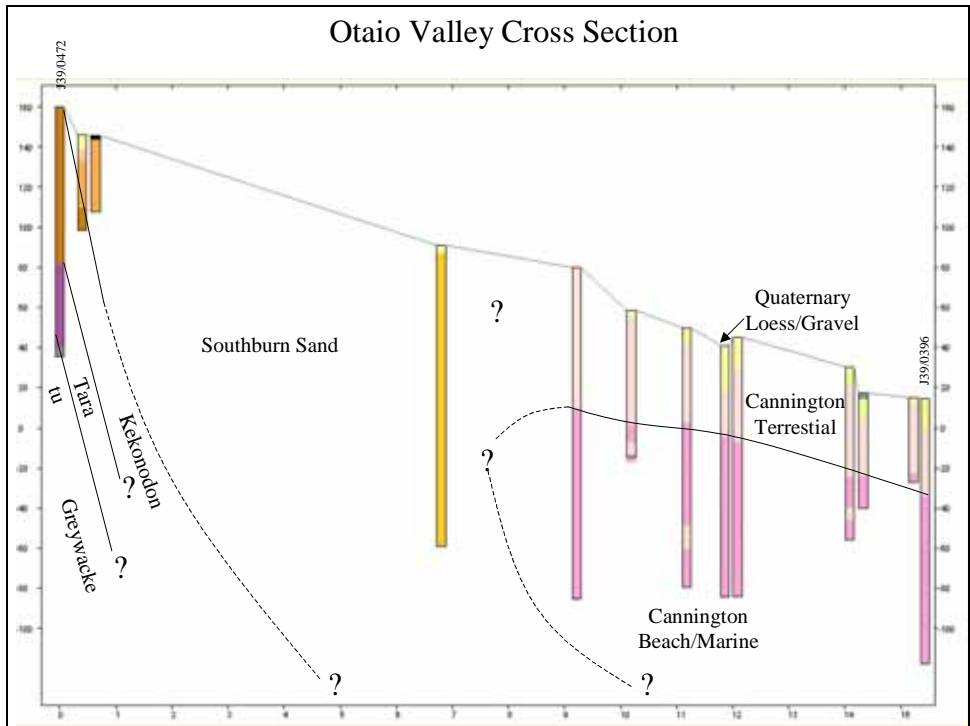


Figure 32.2 Otaio Valley Cross Section, J39/0472 – J39/0396

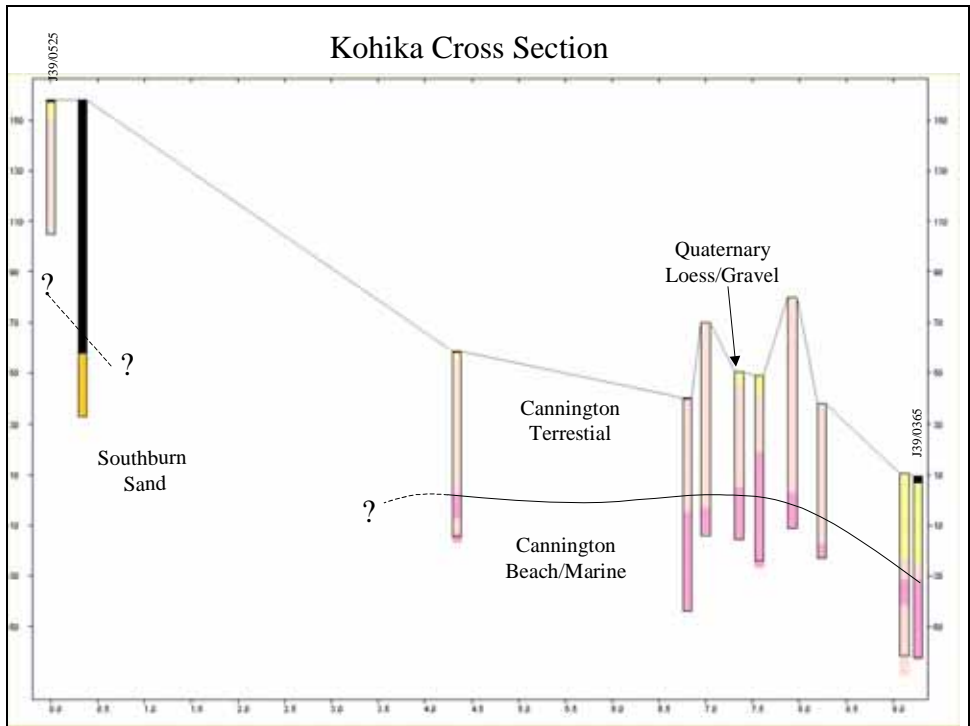


Figure 32.3 Kohika Cross Section, J39/0525 – J39/0365

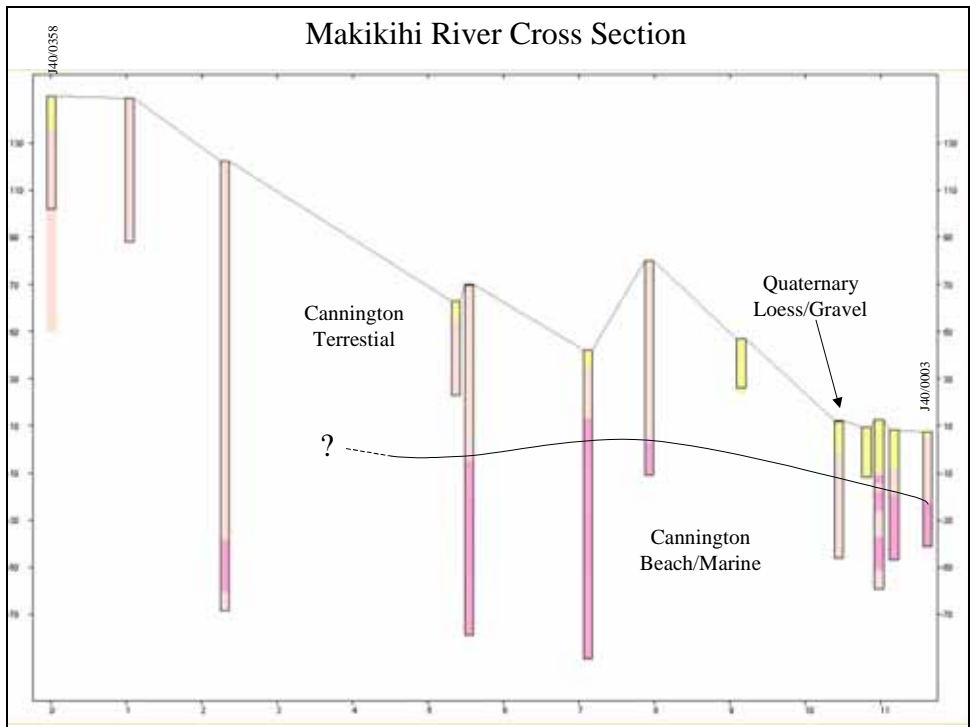


Figure 32.4 Makikihi River Cross Section, J40/0358 – J40/0003

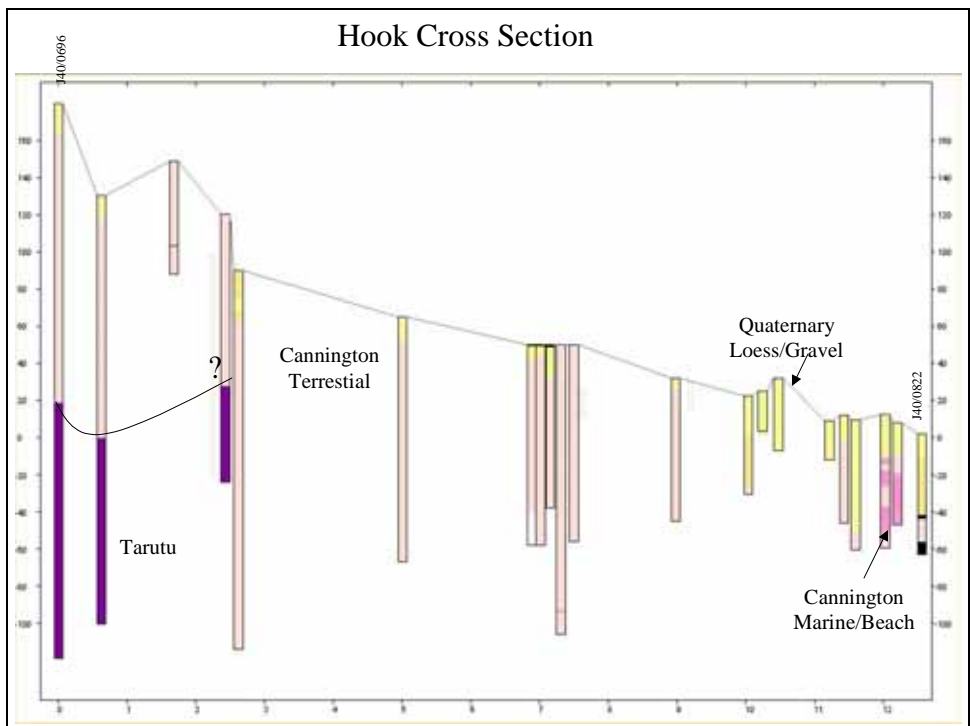


Figure 32.5 Hook Cross Section, J39/0696 – J40/0822

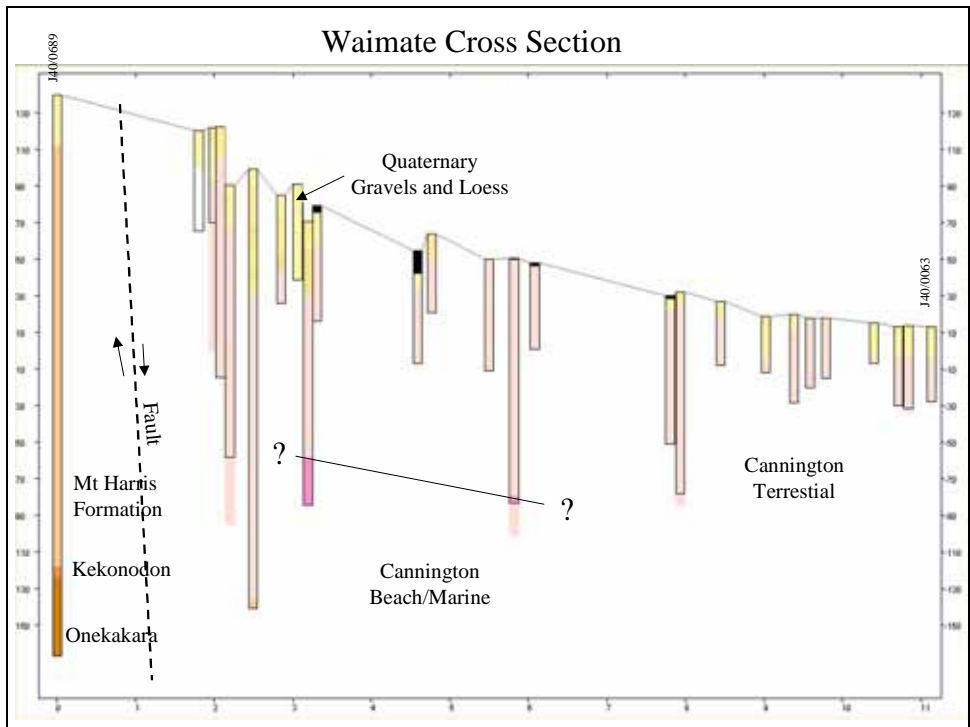


Figure 32.6 Waimate Cross Section, J40/0689 – J40/0063

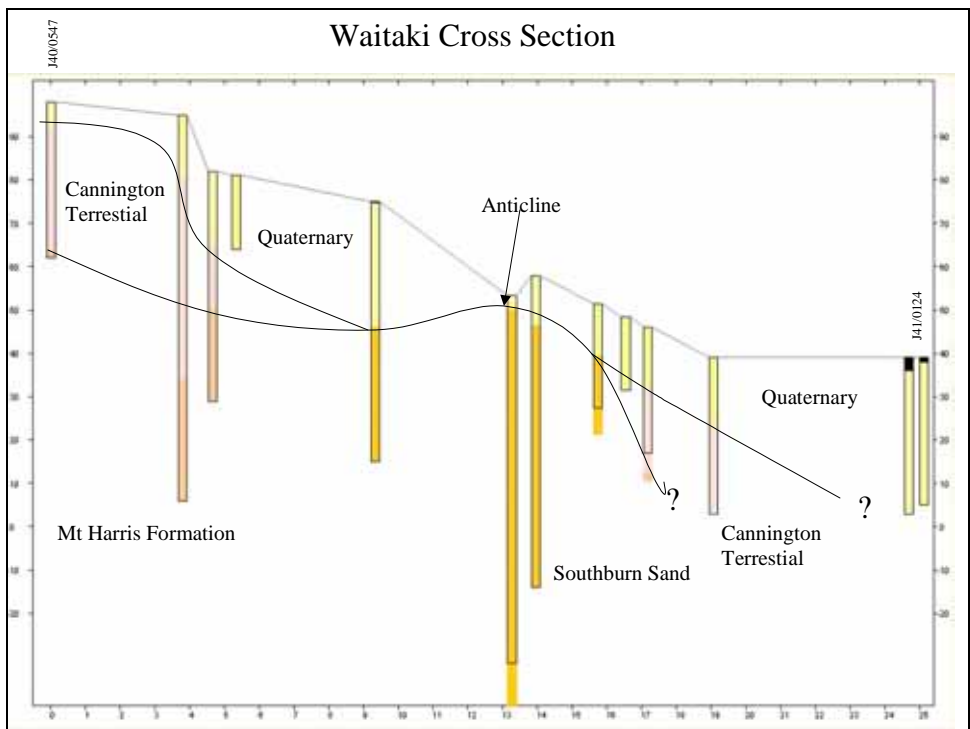


Figure 32.7 Waitaki Cross Section, J40/0547 – J41/0124

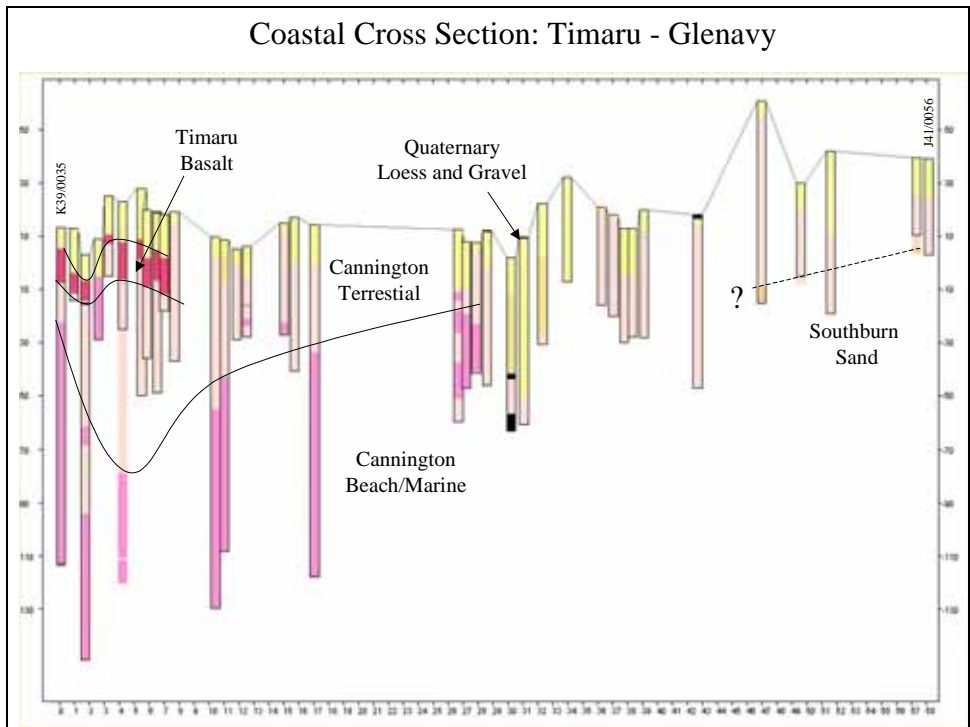


Figure 32.8 Coastal Cross-Section: Timaru-Glenavy, K39/0035 – J41/0056

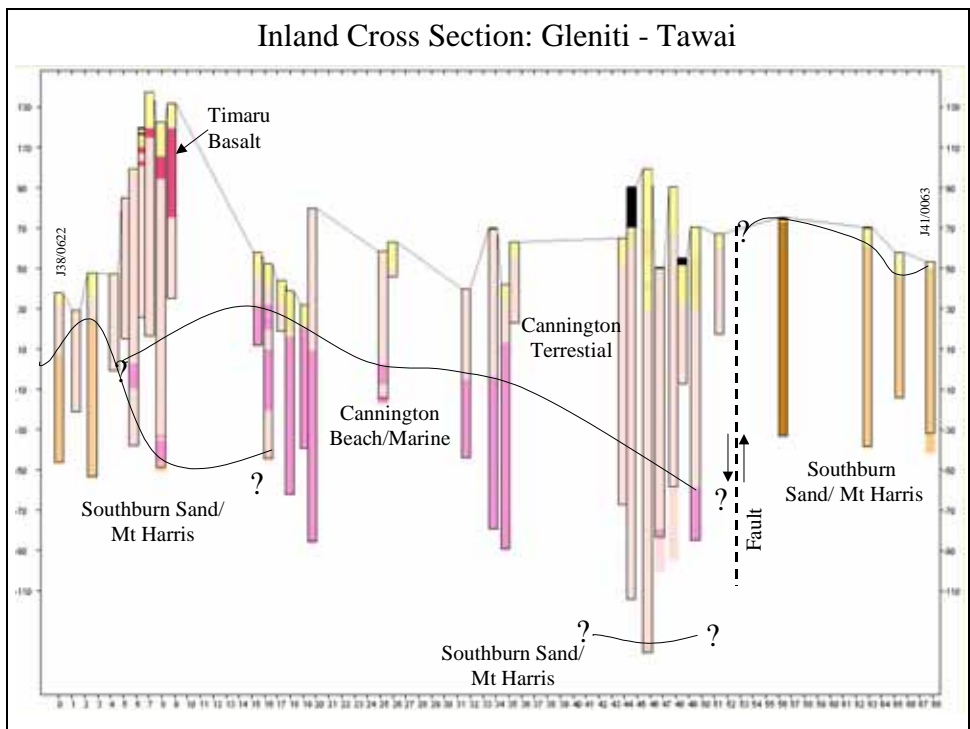


Figure 32.9 Inland Cross Section: Gleniti-Tawai, J38/0622 – J41/0063

## Appendix 33: Aquifer Test Summary

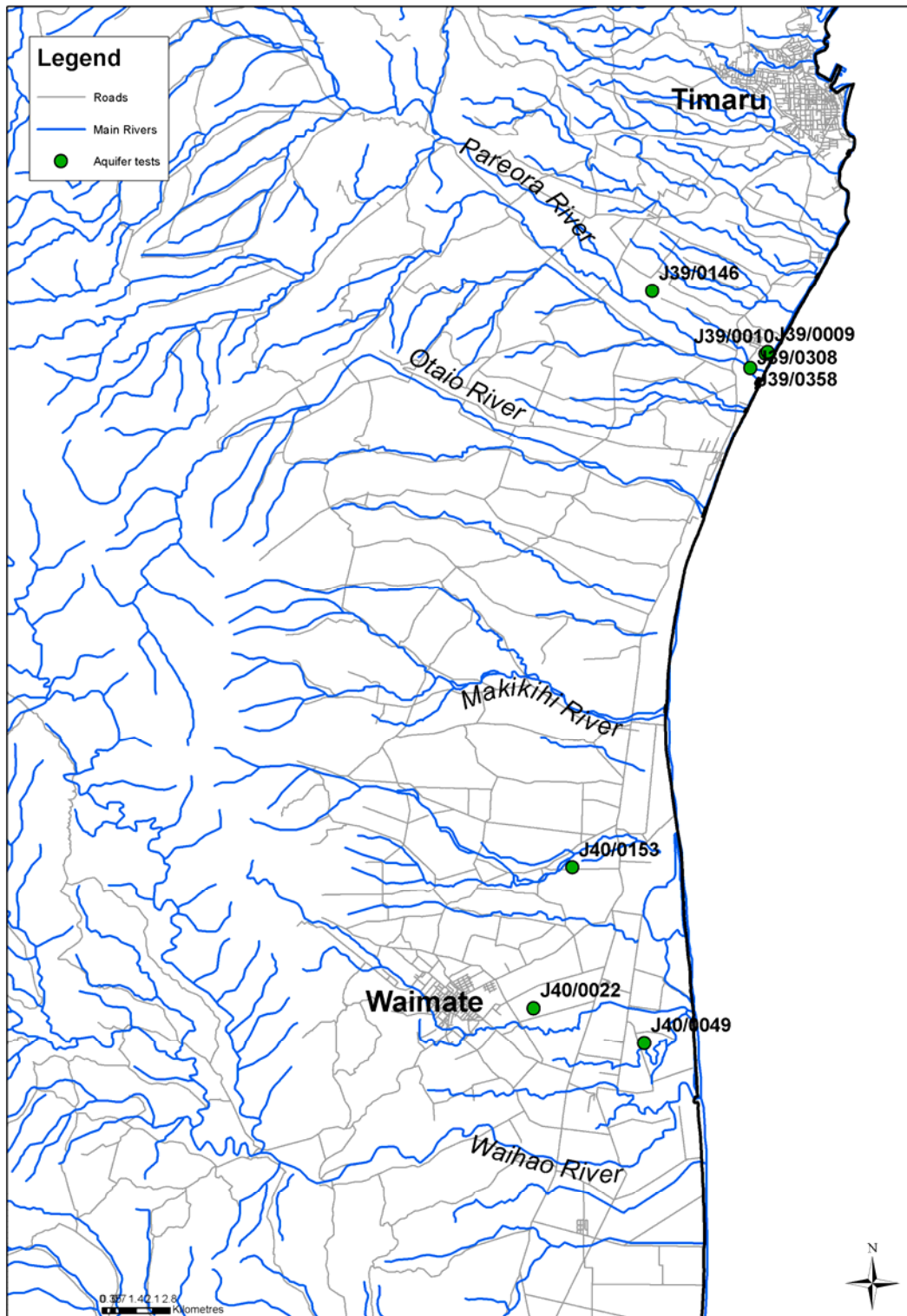
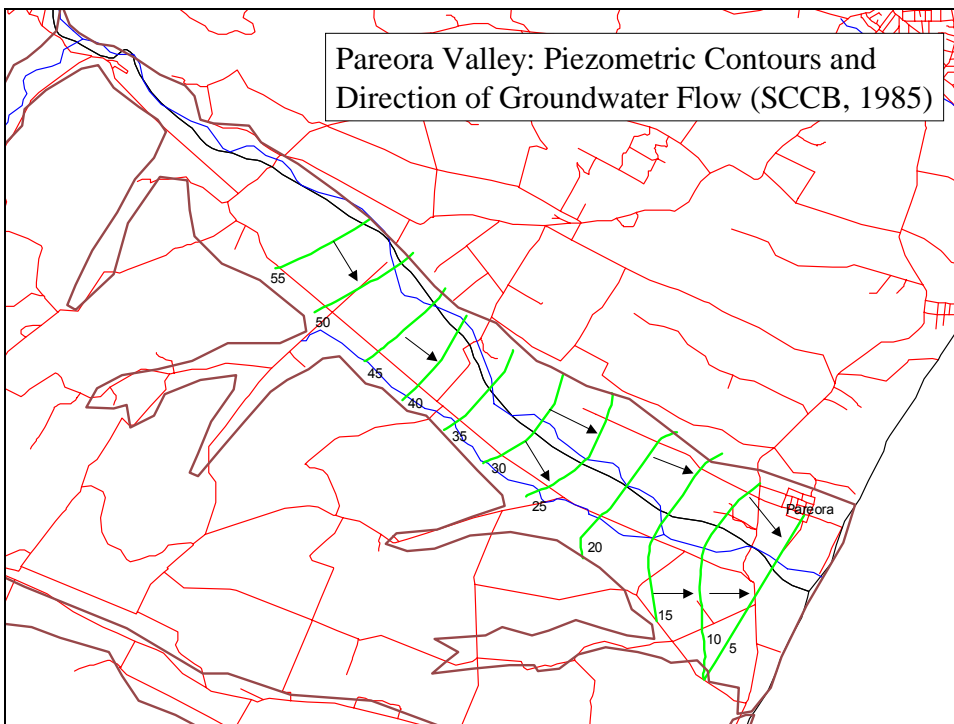
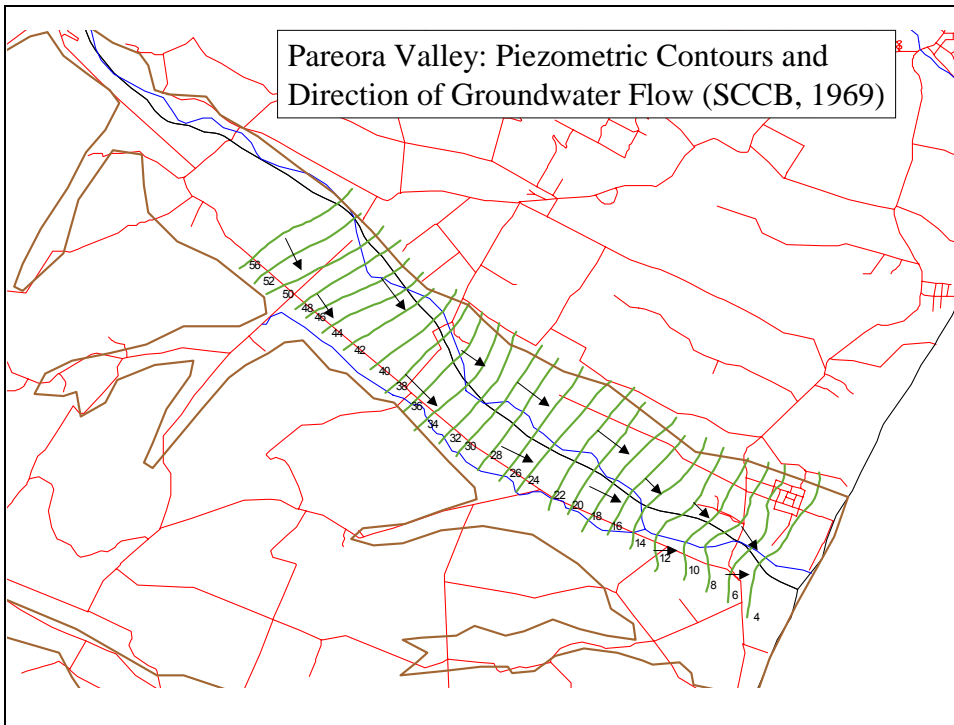


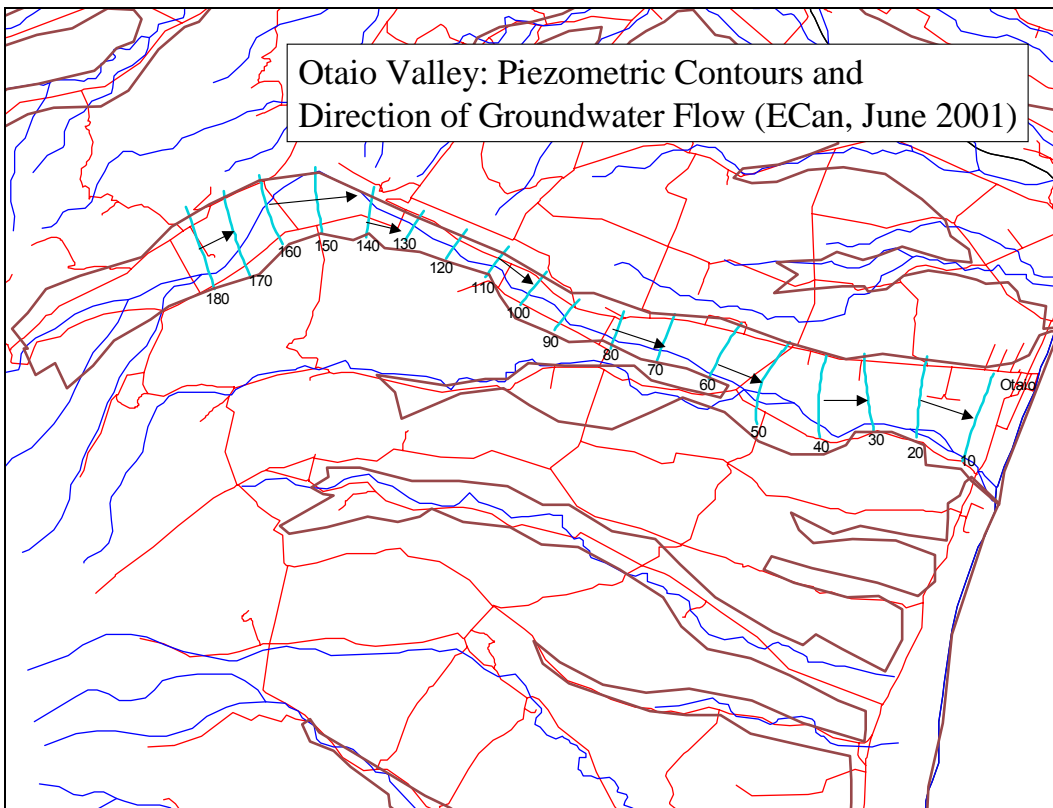
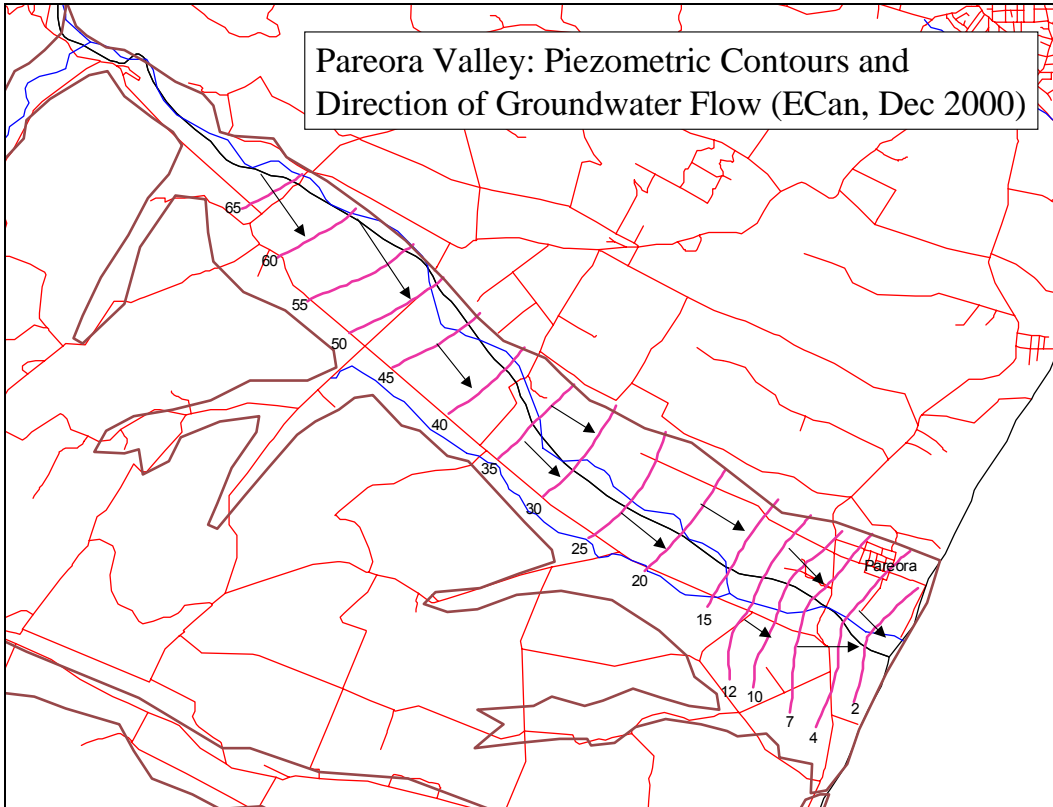
Figure A33.1: Location of aquifer tests in the Pareora-Waihao Area

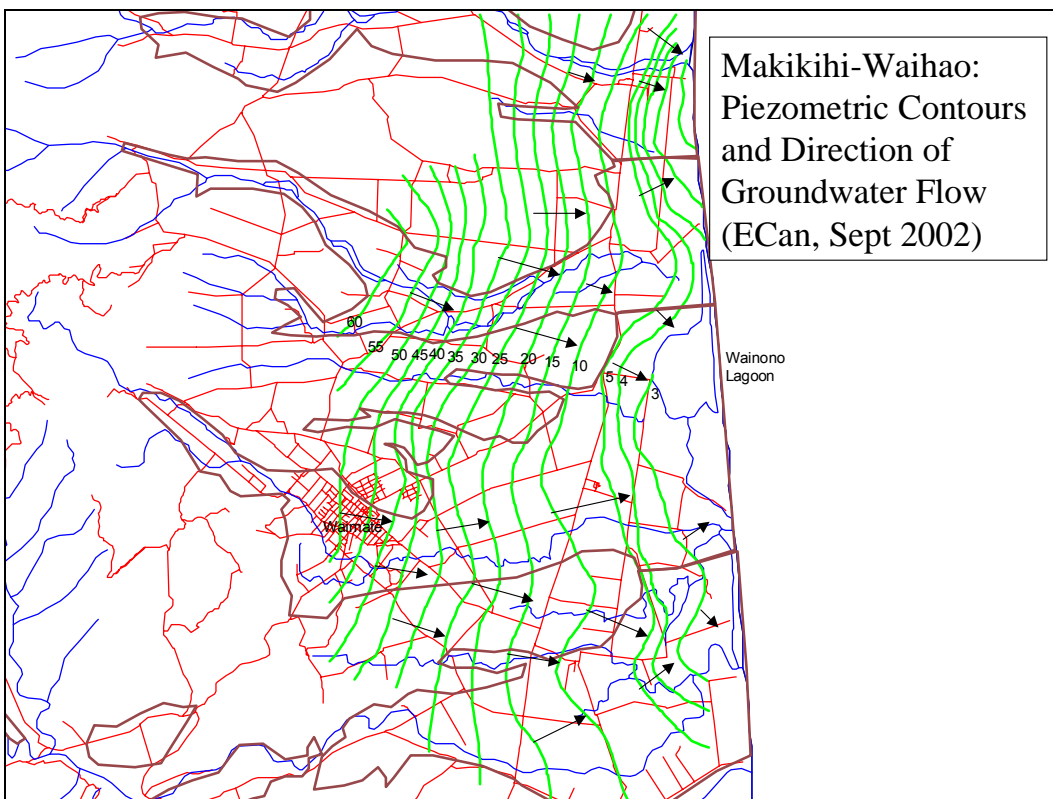
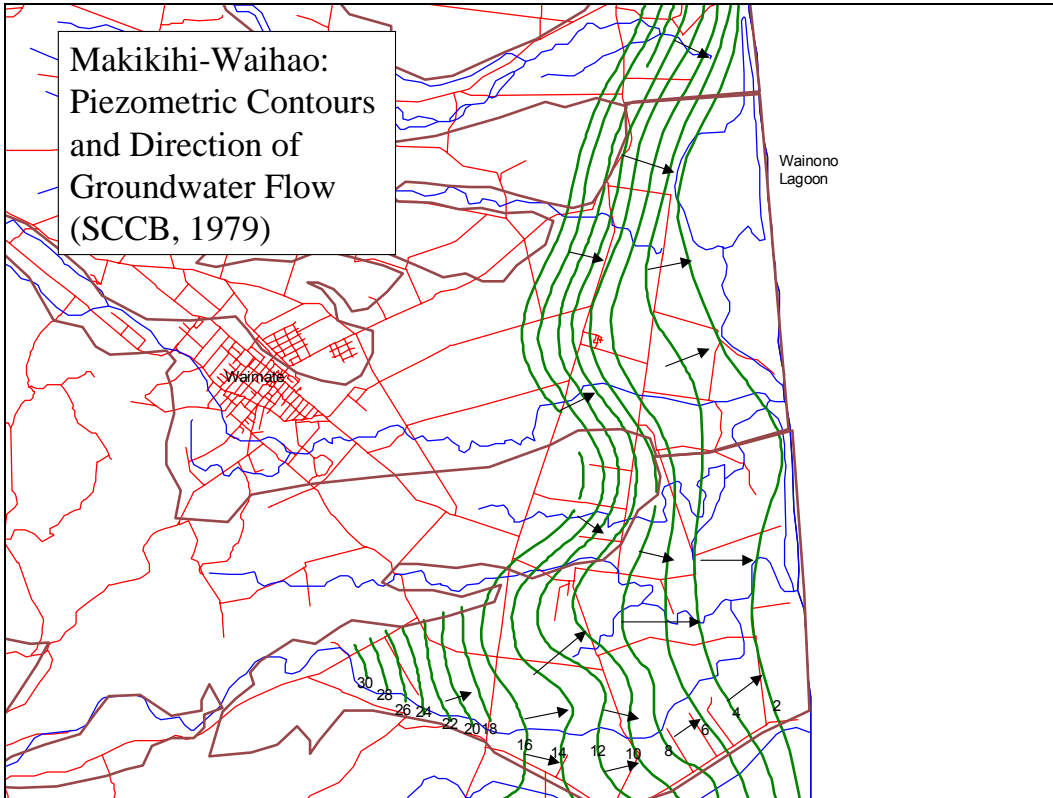
**Table A33.1: Summary of Aquifer Test information in the Pareora-Waihao Catchments.**

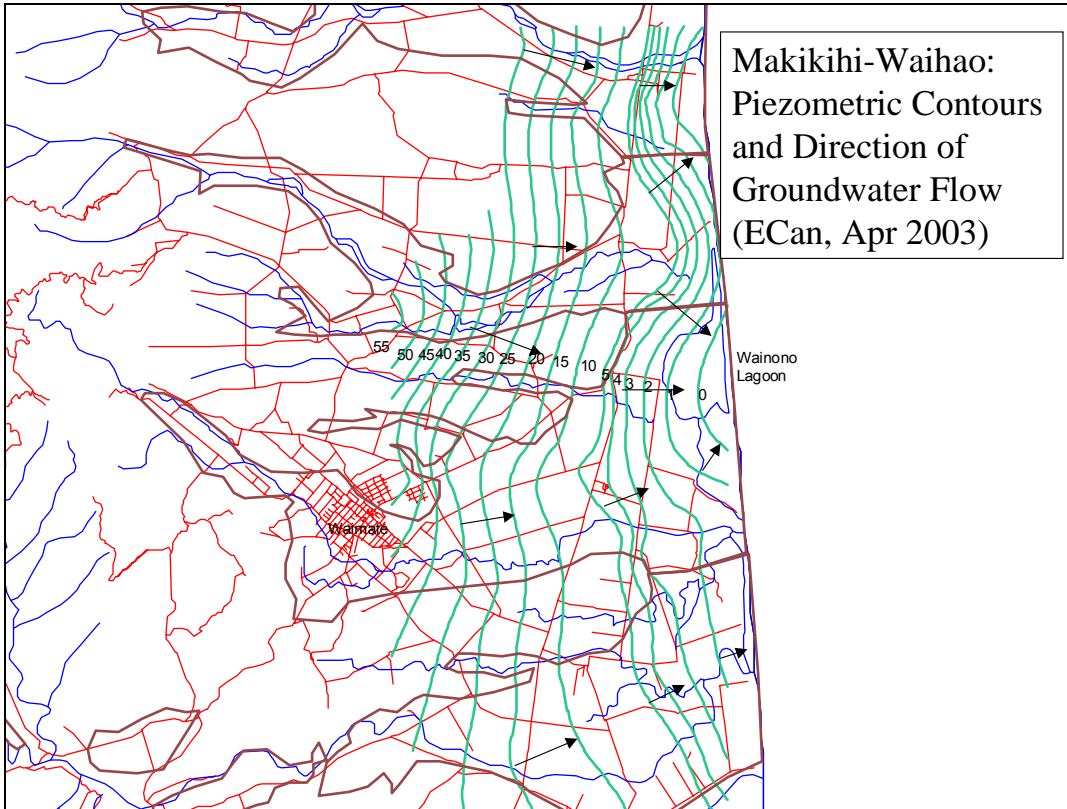
Well Number (pumping well first)	Location	Aquifer	Well Depth	Test Type	Test Date + Duration	Analysis Method	Max Pump Rate (l/s)	Parameters T (m <sup>2</sup> /d) S L (m)	Comments
J39/0146 J40/0053 J40/0054, Piezo	Pareora Valley	Quaternary Gravels	4.8	Constant discharge	25/10/00 1102 min	Hantush Jacob and Hunt (2002)	29.5	T 2500 S 0.07 L 530	A recharge boundary caused by the Pareora River was evident in recovery data, indicating stream depletion may occur.
J39/0358	Pareora Coast	Quaternary Gravels	10	Slug Test	28/10/01		-	K 60-100 m/d	Conducted as a slug test as well was pumped dry.
J39/0308	Pareora Coast	Quaternary Gravels	5.2	Slug Test	28/10/01		-	K 15-20 m/d	
J39/0009	Pareora Coast	Cannington beach/marine	13.9	Step	18/6/85 175 min		35.6	-	Original drillers test, 7 steps 7.9 – 35.6 l/s
J39/0009	Pareora Coast	Cannington beach/marine	13.9	Step	28/6/85 60 min		22.7	-	Test undertaken to obtain drawdowns at reduced pumping rates
J39/0009	Pareora Coast	Cannington beach/marine	13.9	Constant discharge	21/6/85 350min	Jacob straight line	35.6	T 3308	21 minutes of recovery data. Tidal efficiency calculated at 0.46
J39/0009	Pareora Coast	Cannington beach/marine	13.9	Constant discharge	25/6/85 5600 min	Jacob straight line	35.6	T 2000-5600	900 minutes of recovery data. Tidal efficiency calculated at 0.46
J39/0009 J39/0010	Pareora Coast	Cannington beach/marine	13.9	Constant discharge	29/9/86 15 days(?)	Jacob straight line	53	T 4407 S 0.0008	Change in slope in time-drawdown graph which may be related to tidal effects.
J39/0010	Pareora Coast	Cannington beach/marine	11.6.6	Step	7/11/86		100	-	Original drillers test, 5 steps 75 – 100 l/s
J39/0010 J39/0009	Pareora Coast	Cannington beach/marine	11.6.6	Constant discharge	17/1/87 9 days	Jacob straight line	60	T 3060 S 0.001	Data quality affected by flow rate changes
J40/0022 J40/0004	Waimate	Cannington Gravels	81.4	Constant discharge	2/8/88		-	T 156	Observation bore had 2mm drawdown and 16mm recovery, may be in different aquifer (59m deep)
J40/0049 J40/0048 J40/0613 J40/0745 J40/0799 J40/0800 J40/0801	Studholme	Quaternary Gravels	7.2	Variable rate	17/7/02 3137 min	Hantush-Jacobs	30.8	T 1600 S 0.00027 L 2800	Weir installed in Pratts Creek to measure stream depletion, none measured in time of test.
J40/0153	Hook	Cannington Gravels	77.2	Variable rate	23/9/2005	Theis	32.4	T 2130 S 0.00069	Test conducted by Environmental Consultancy Services. Very good fit of data to Theis curve, little leakage.

## Appendix 34: Piezometric contours

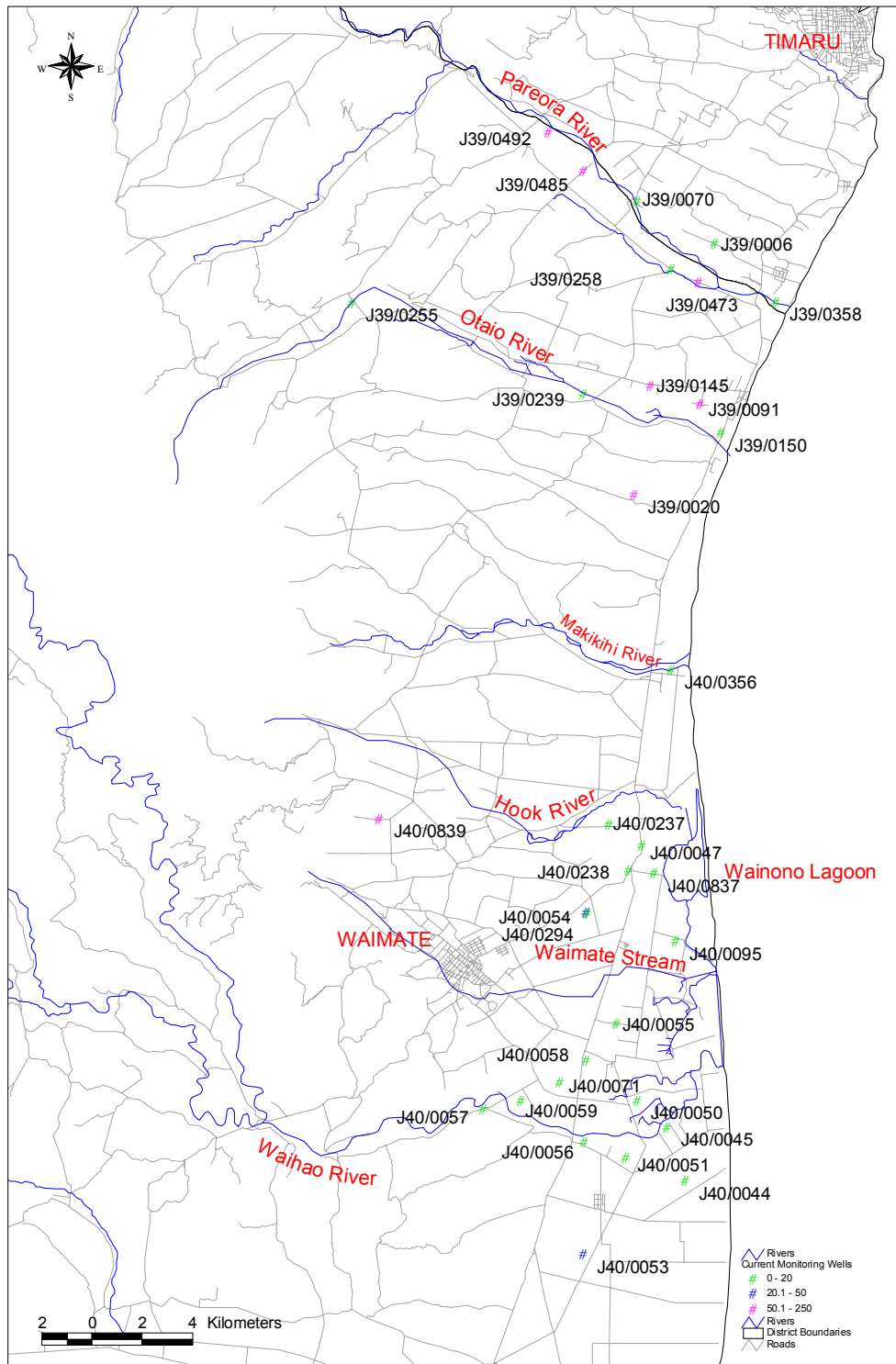




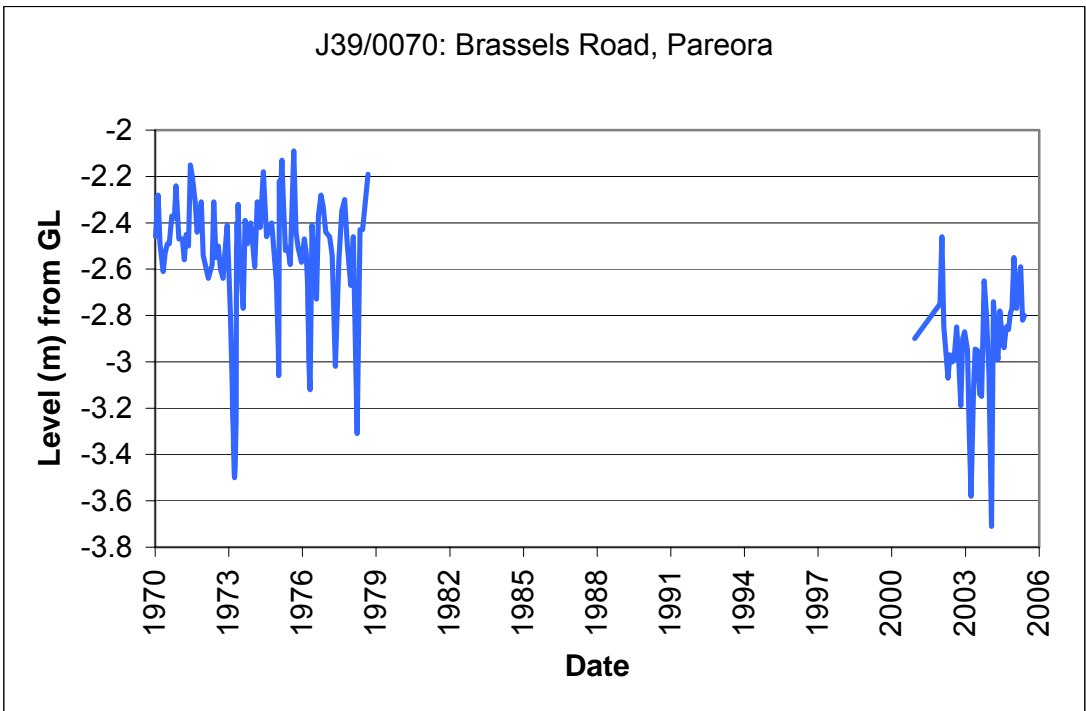
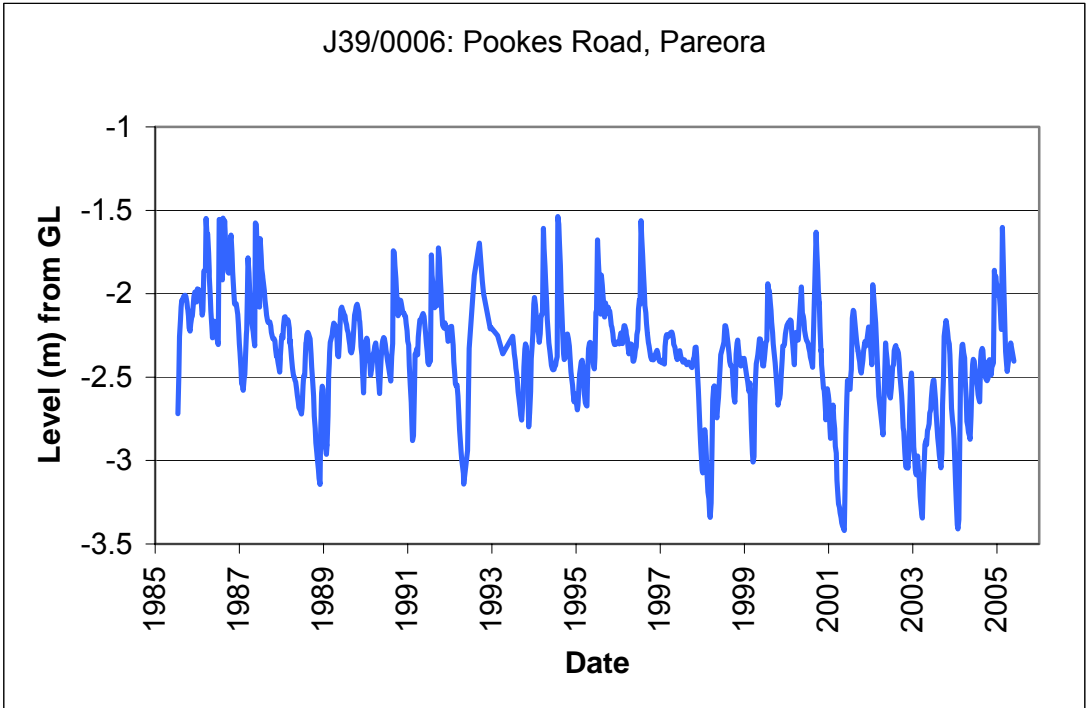


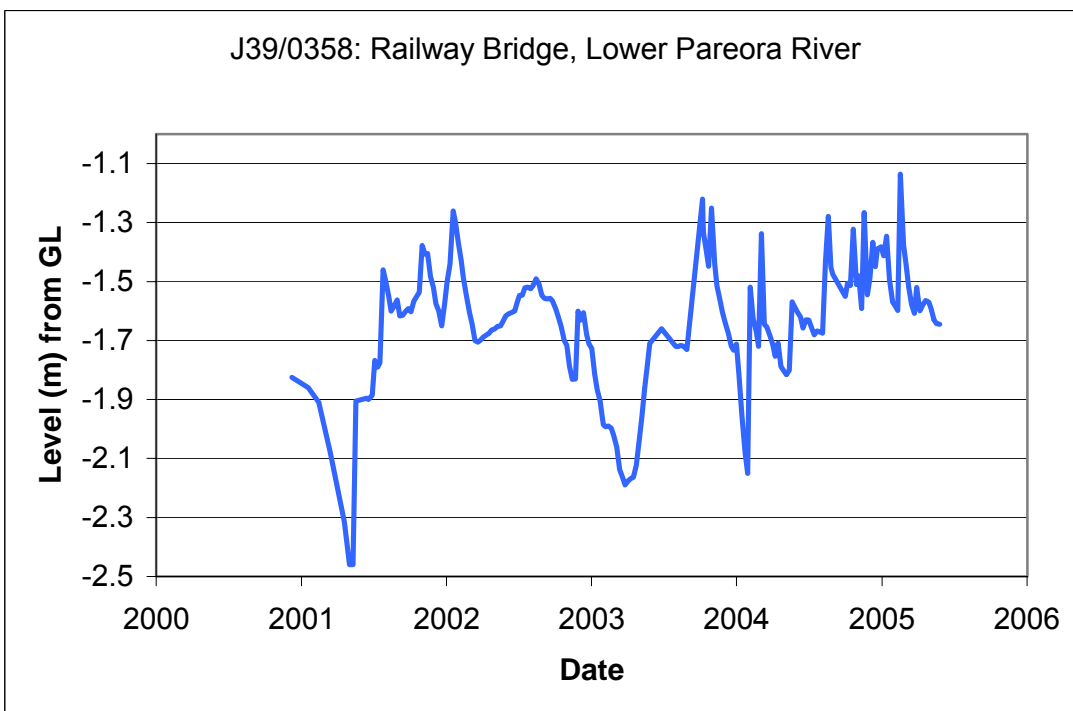
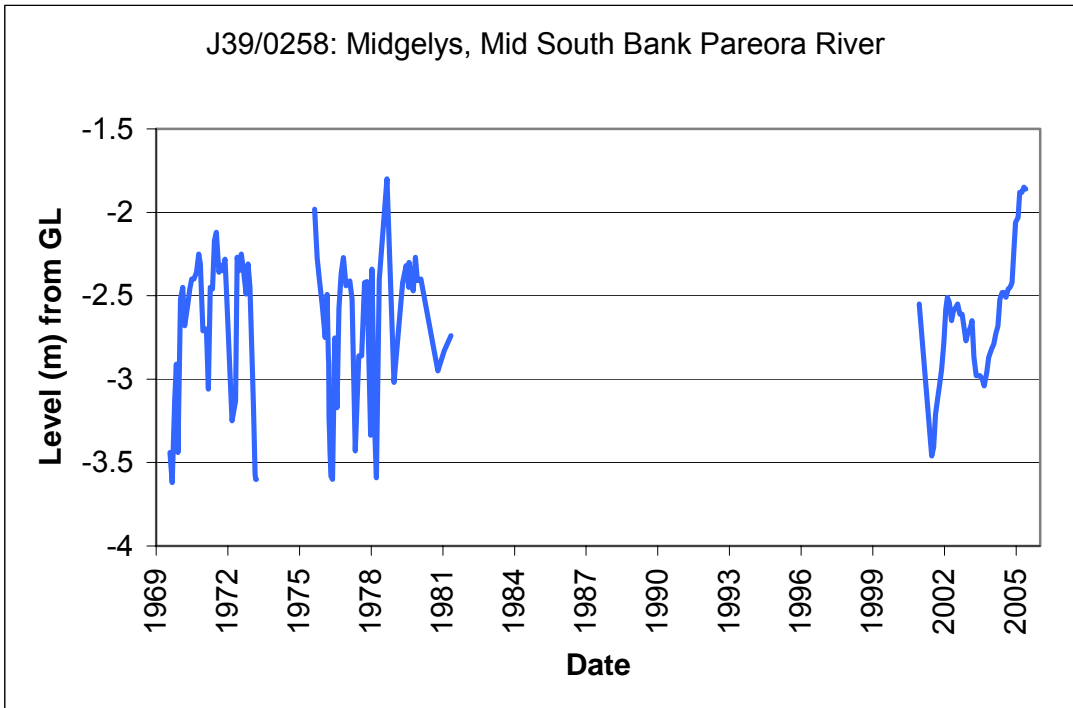


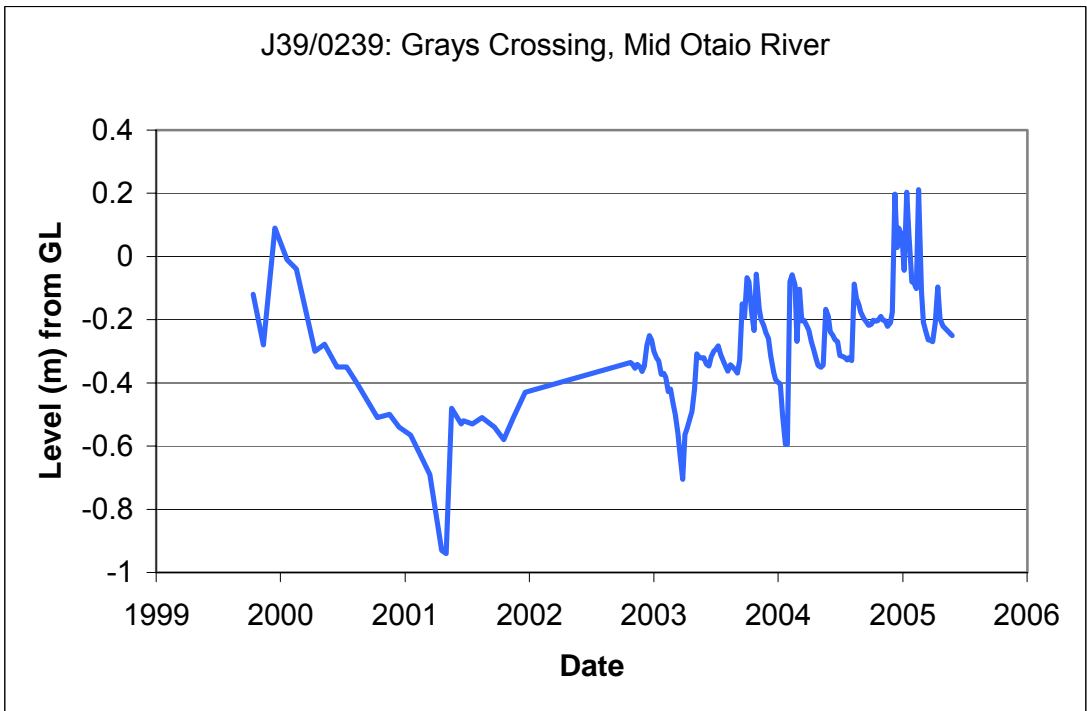
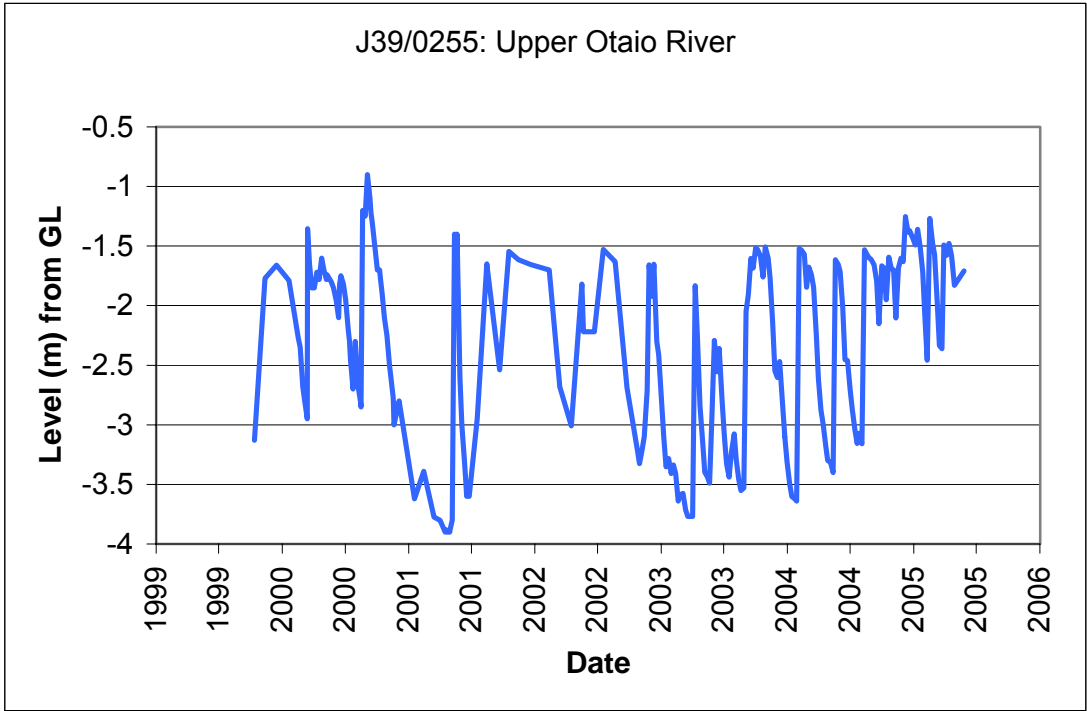
# Appendix 35: Well hydrographs

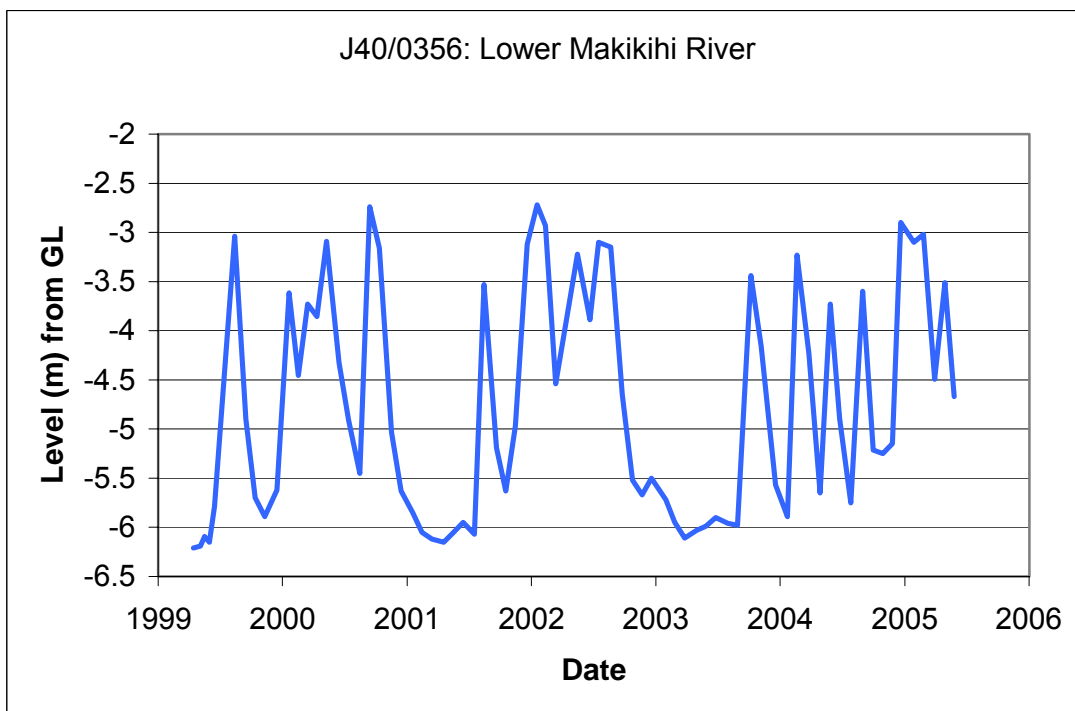
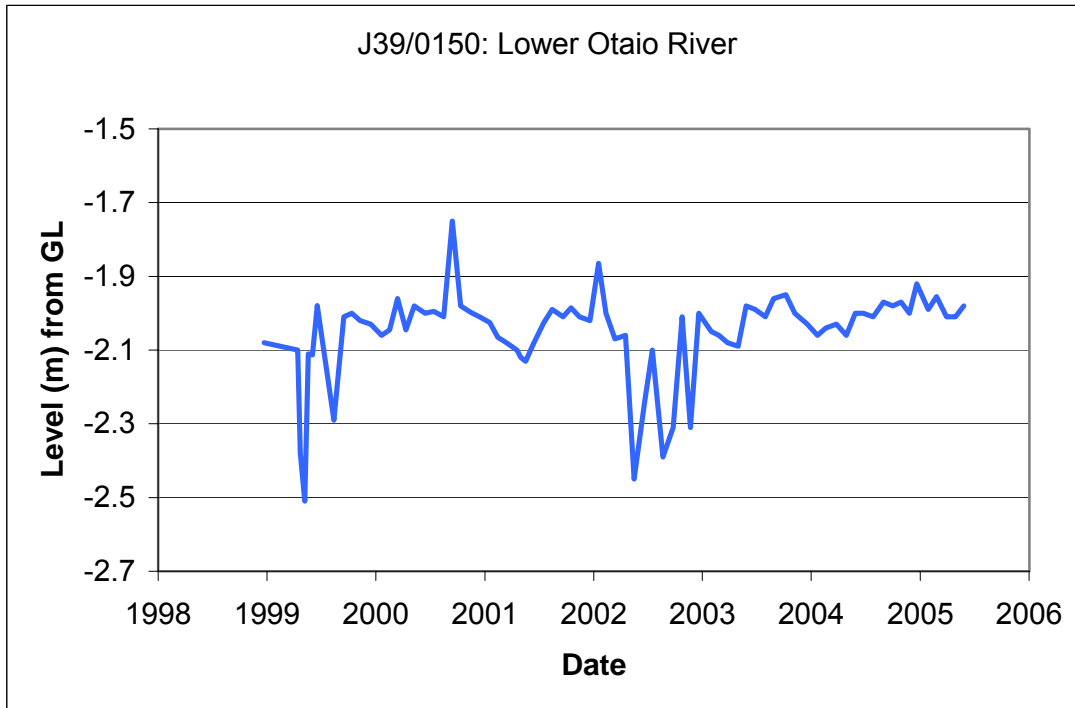


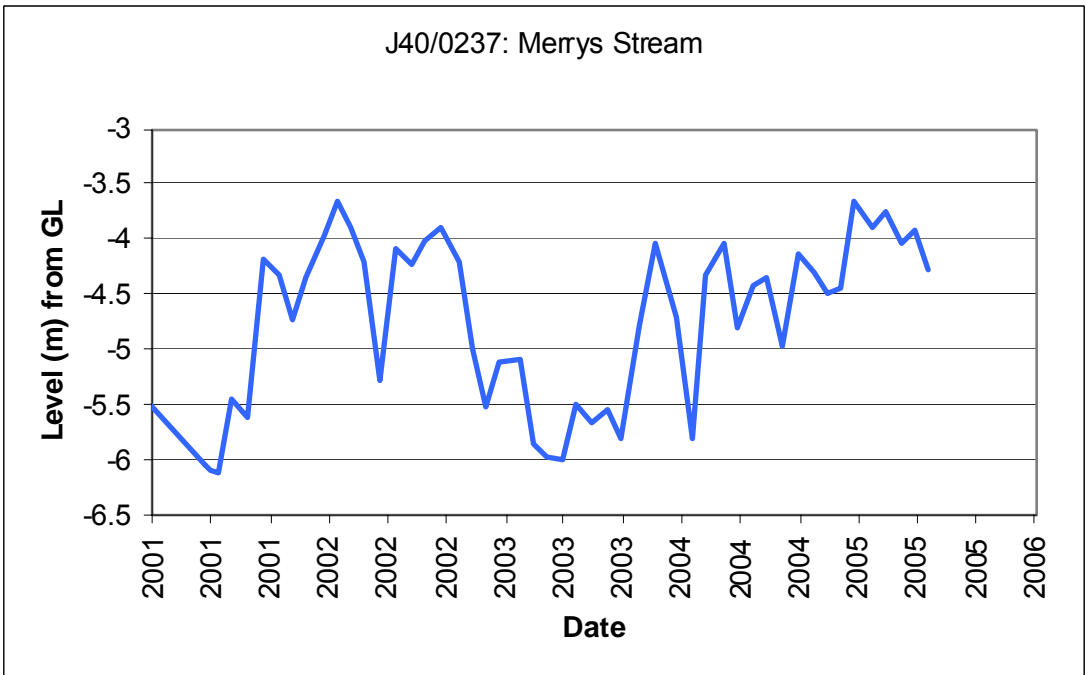
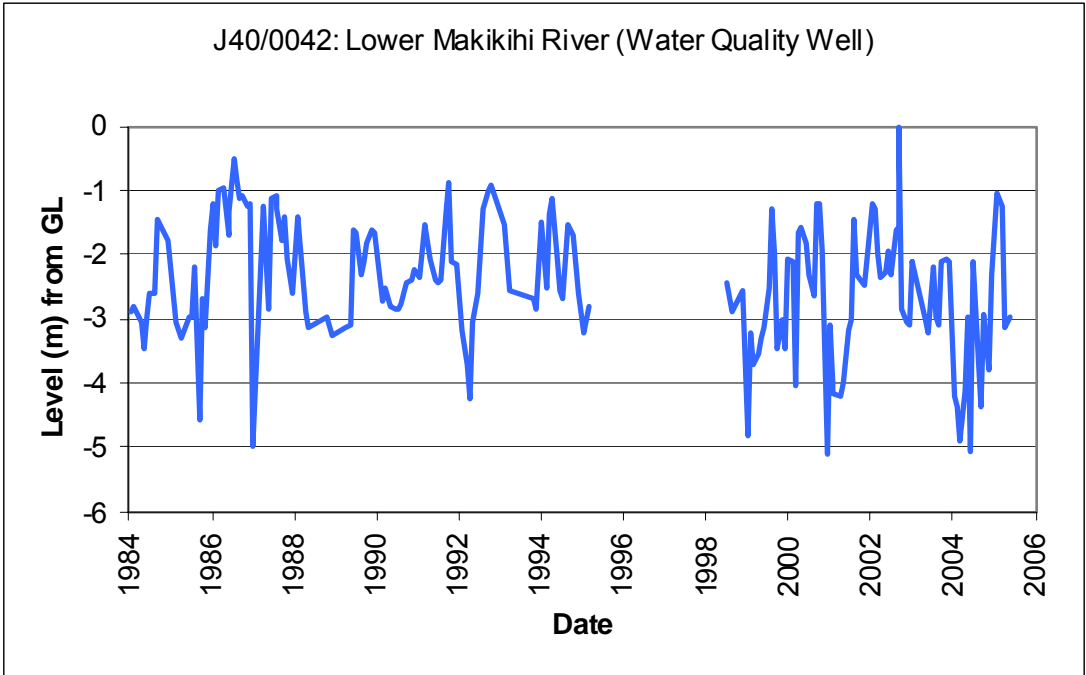
(NB, wells with pink dots are deep wells where monitoring only started in June 2005, hence no water level plots are presented for these)

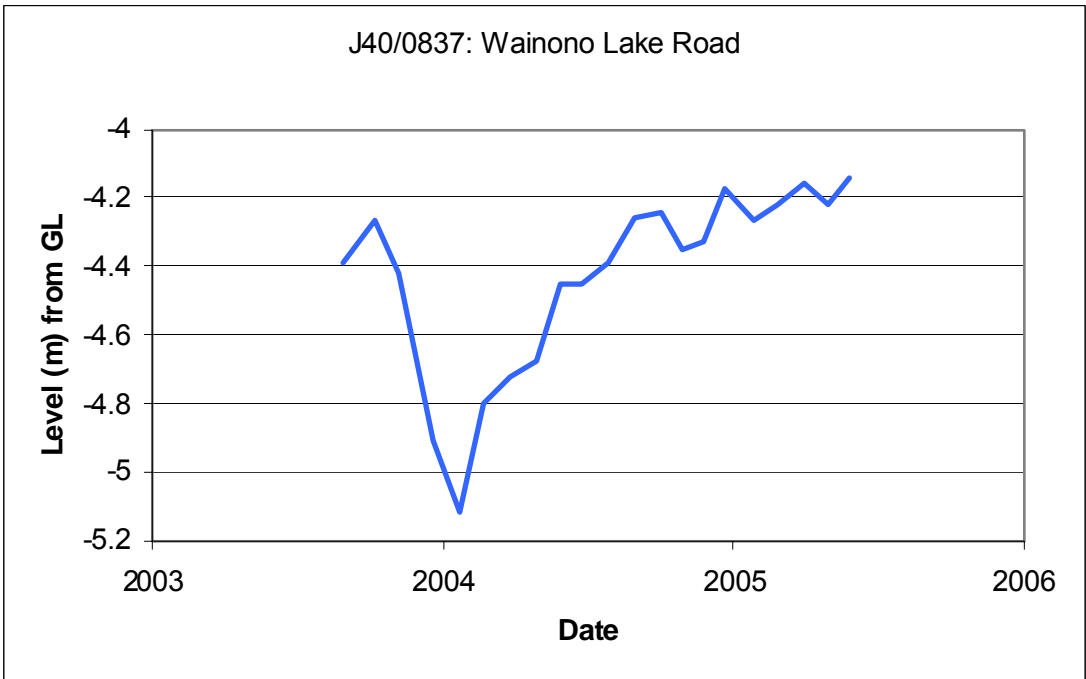
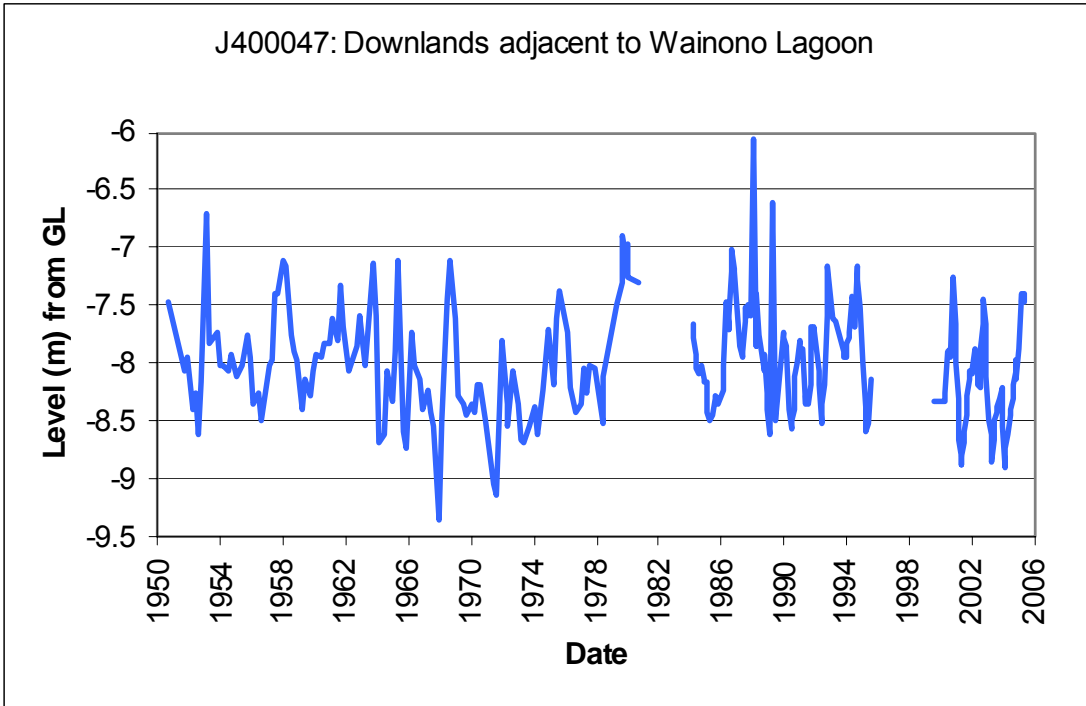


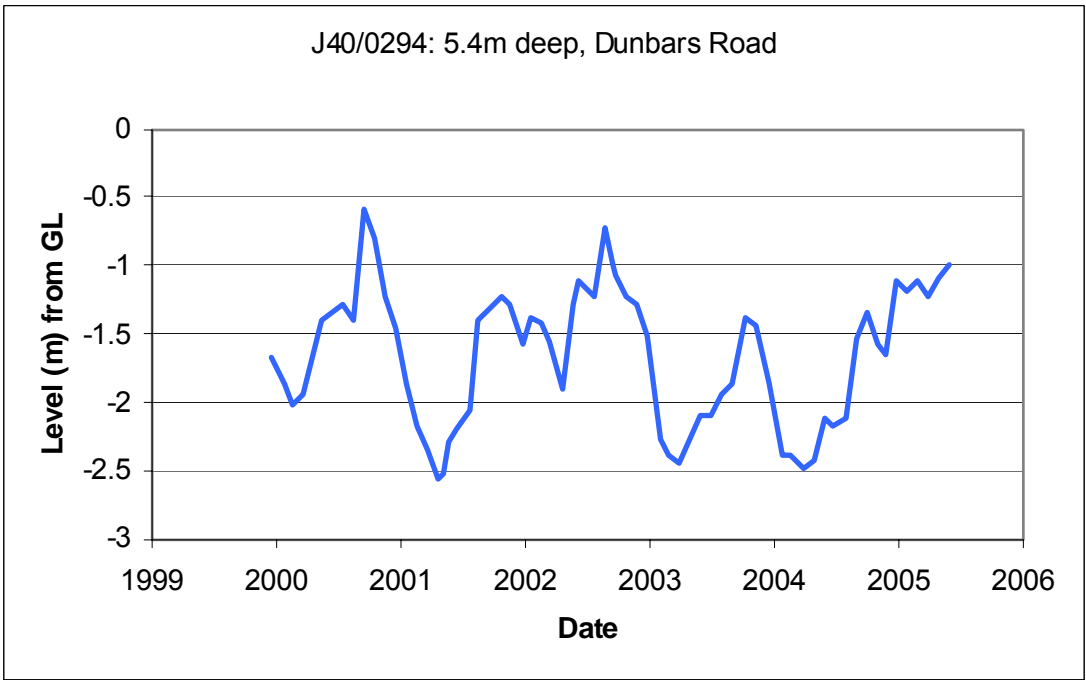
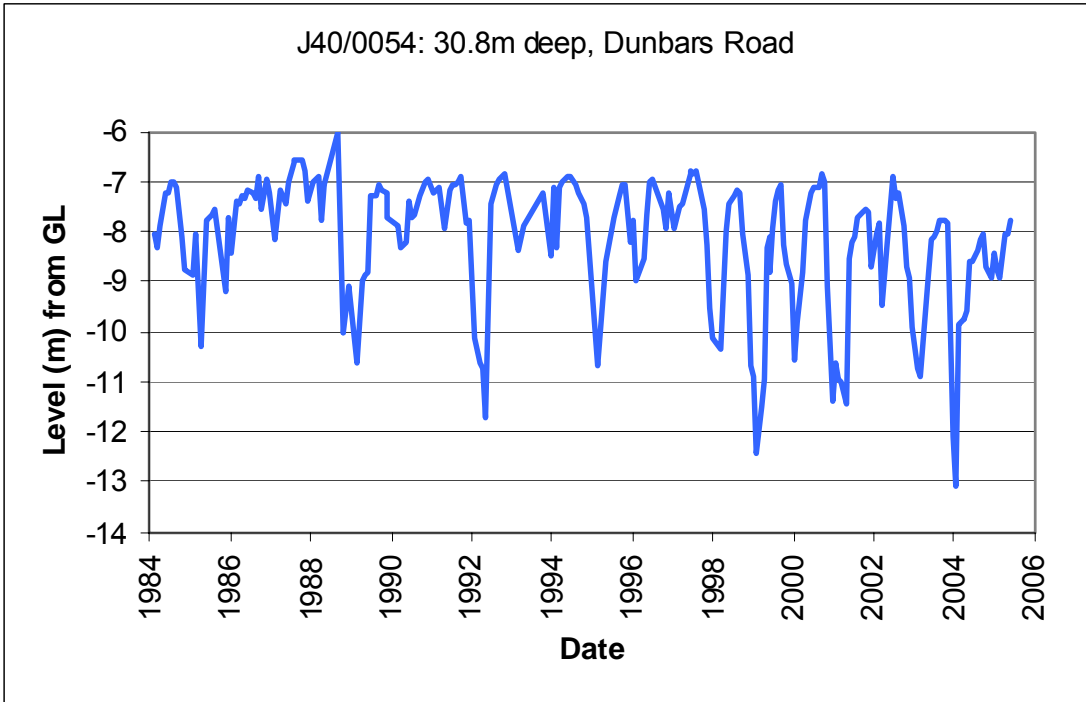


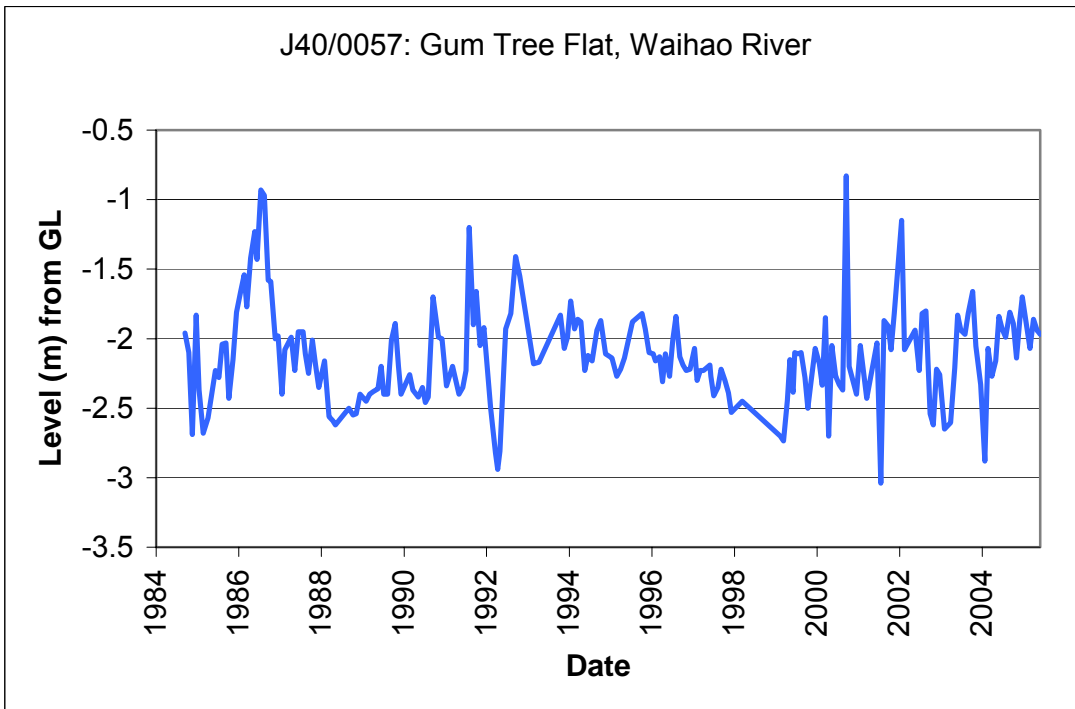
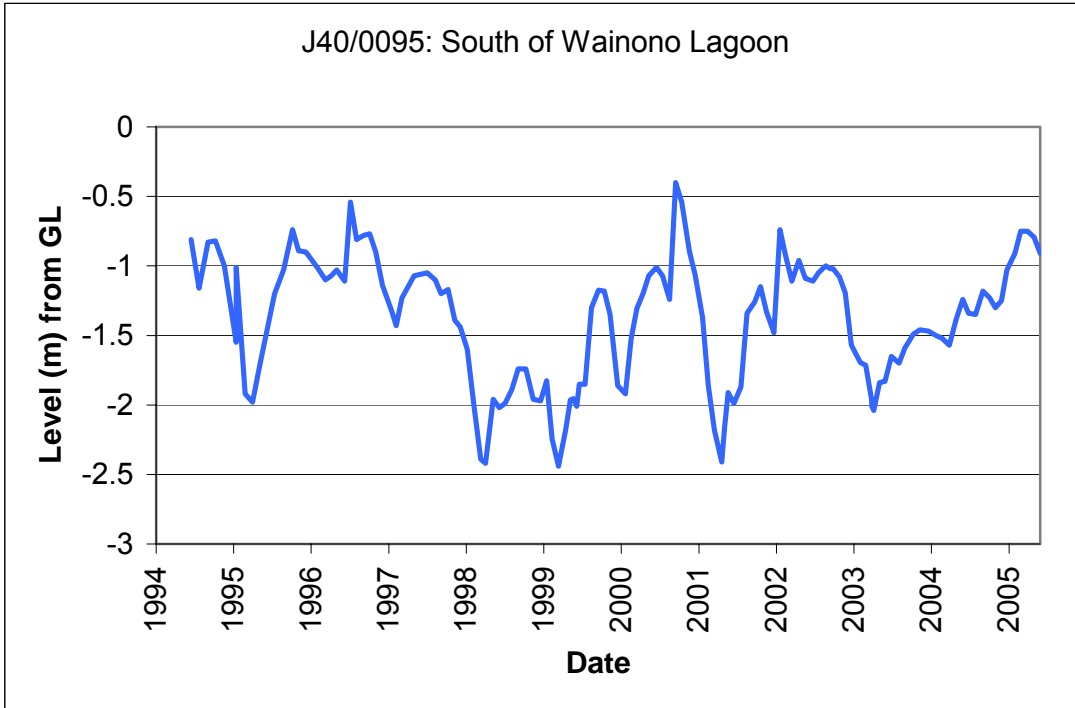


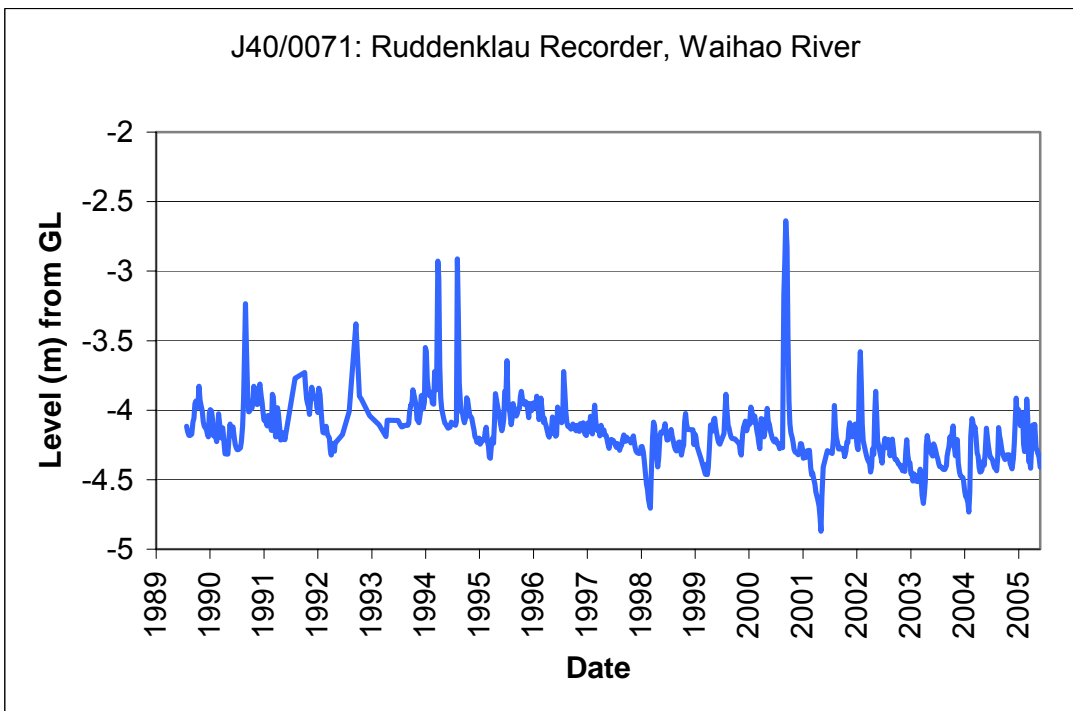
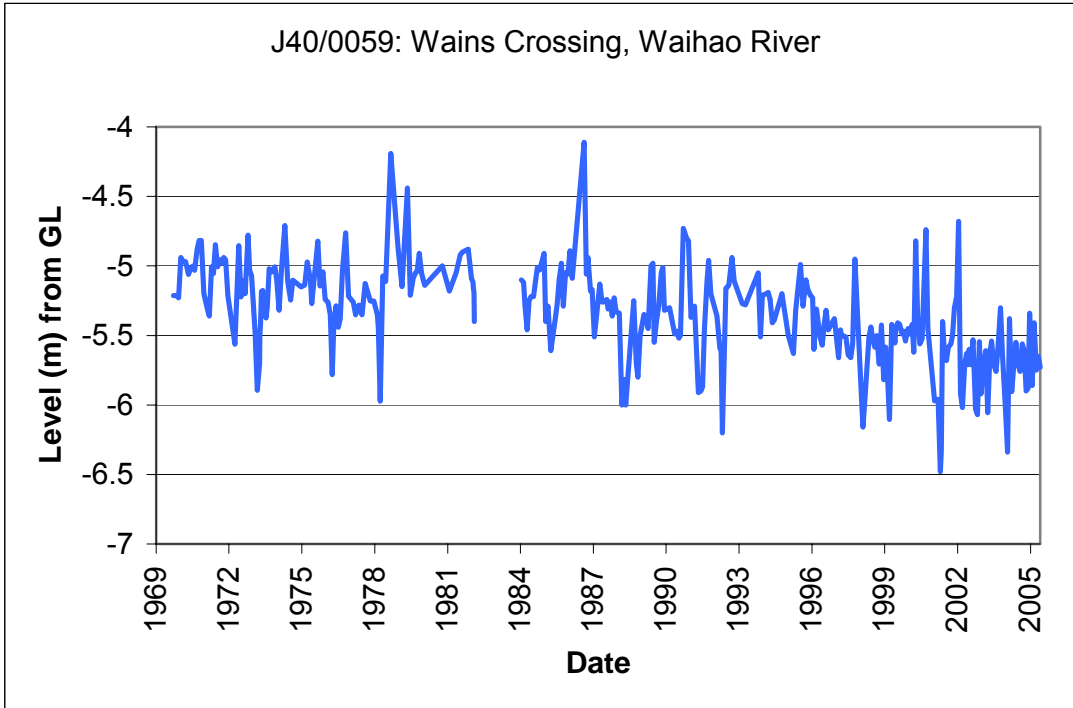


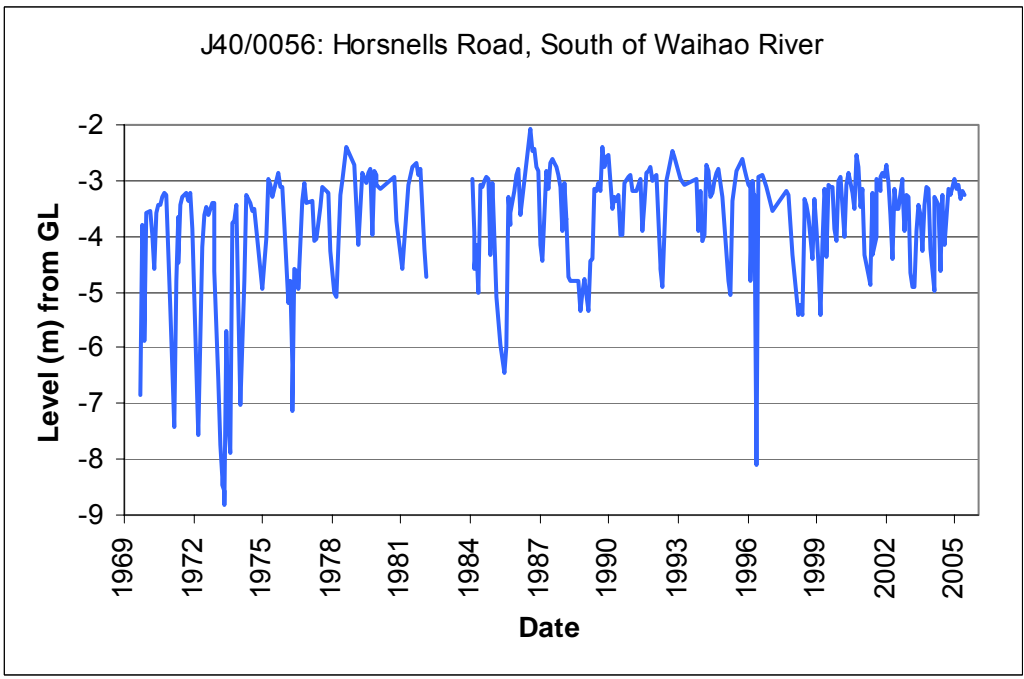
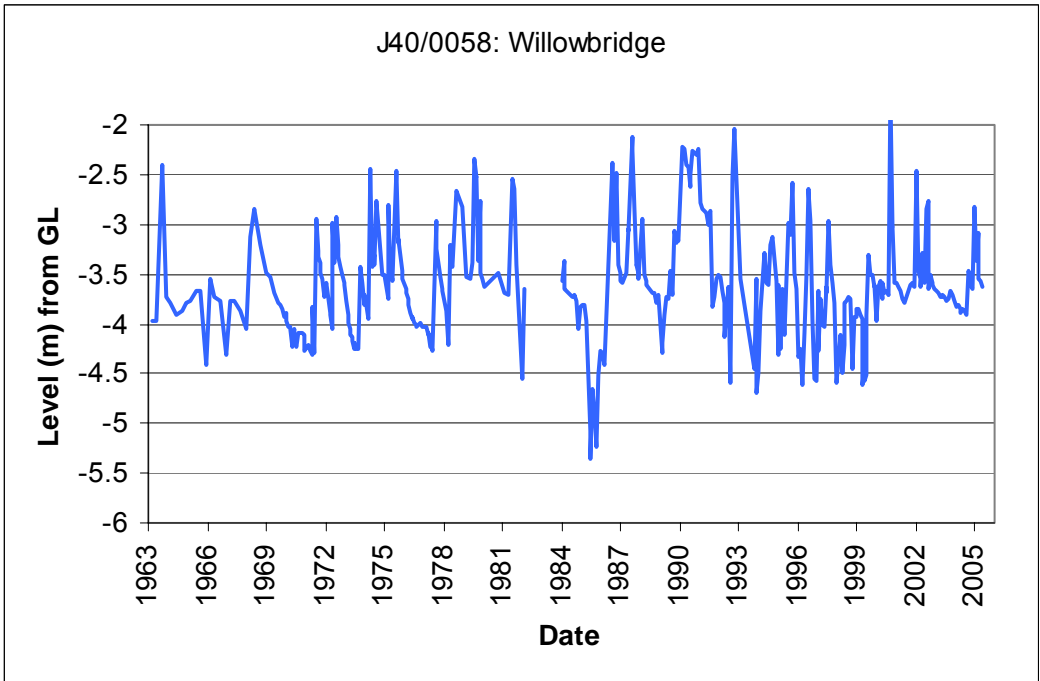


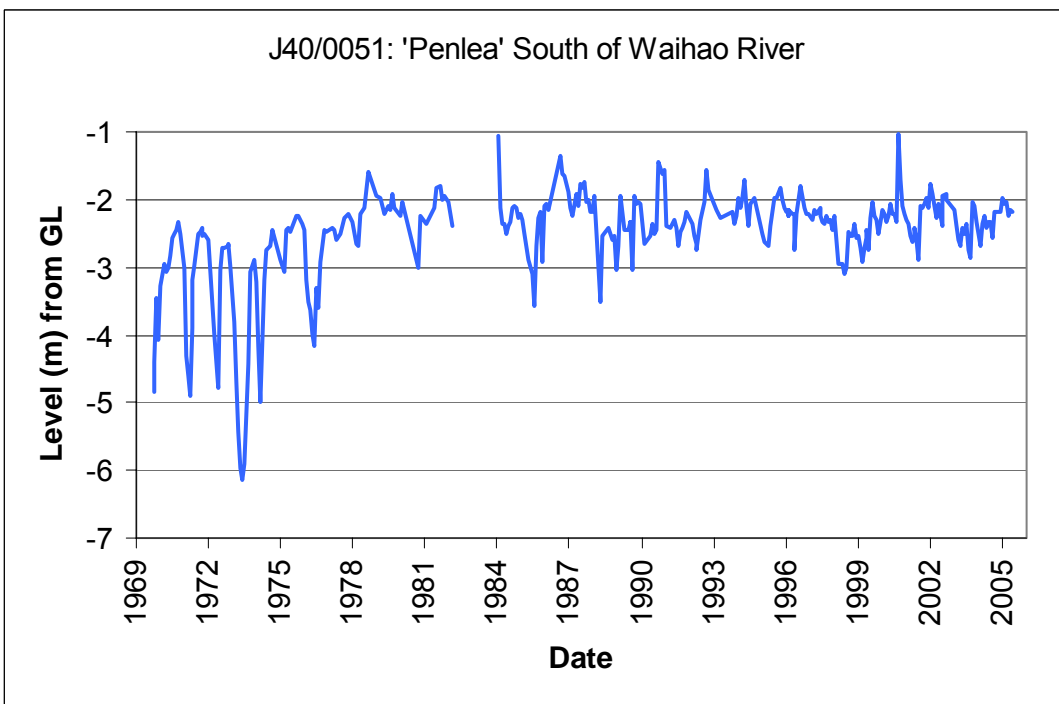
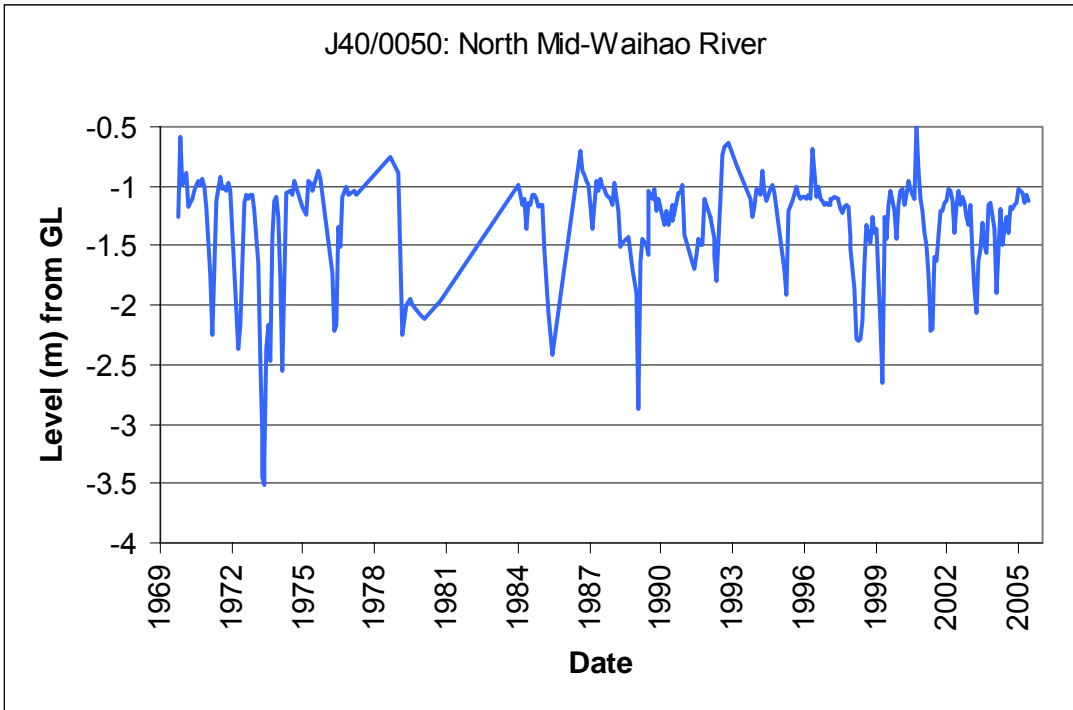


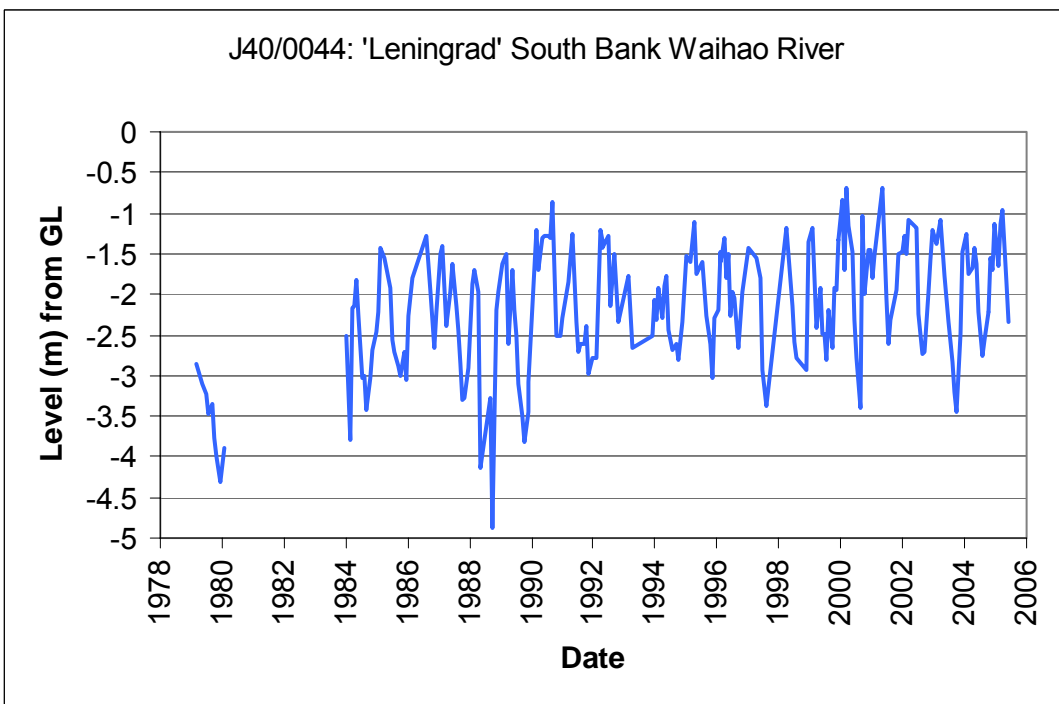
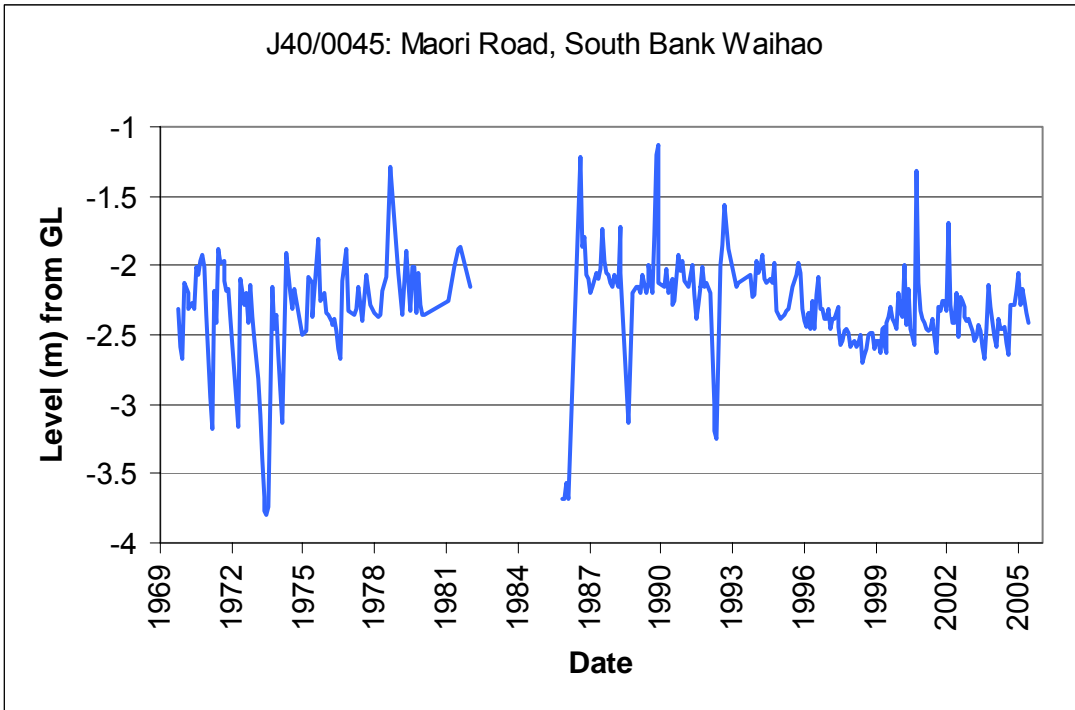










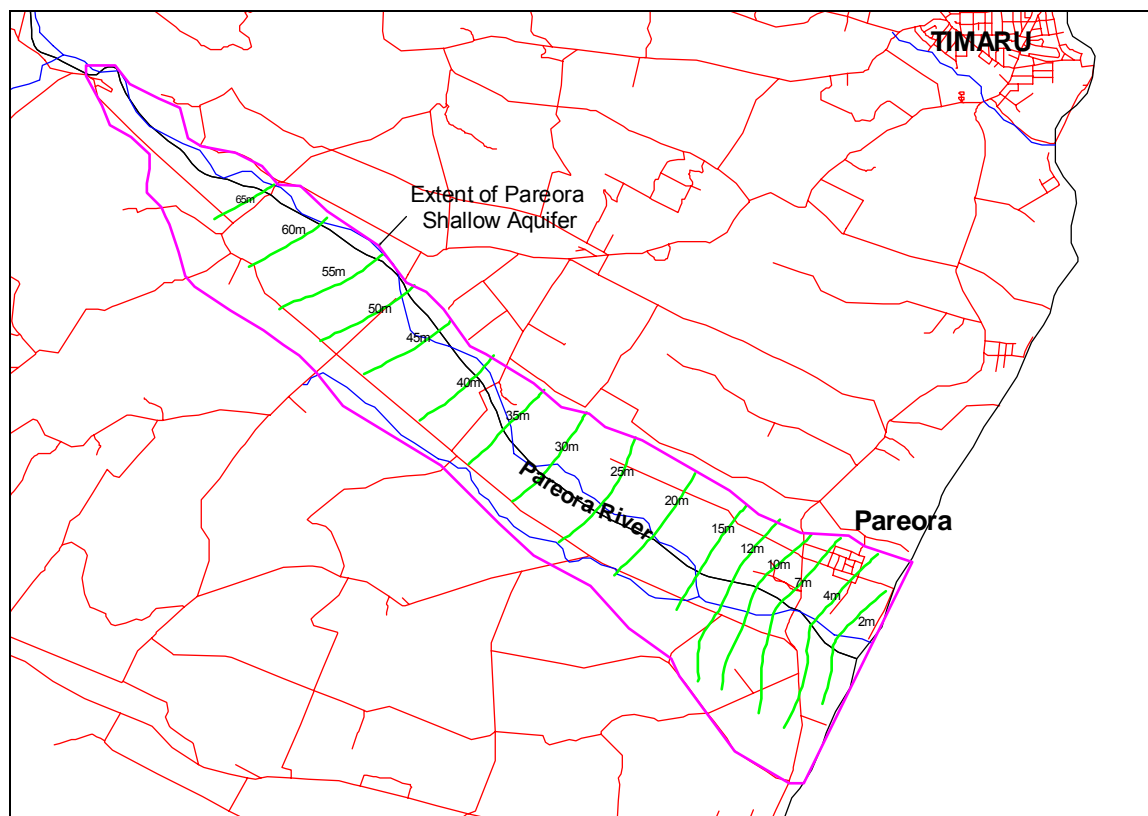


## Appendix 36: Surface-groundwater interaction analyses

### Pareora Valley

#### 1. Introduction

Apart from local rainfall, the Pareora River is the main source of recharge to the shallow groundwater aquifer. Figure 1 shows the approximate extent of the shallow groundwater contained within terraces incised into the downlands of South Canterbury.



**Figure 1: Pareora River Valley shallow aquifer extent and piezometric contours**

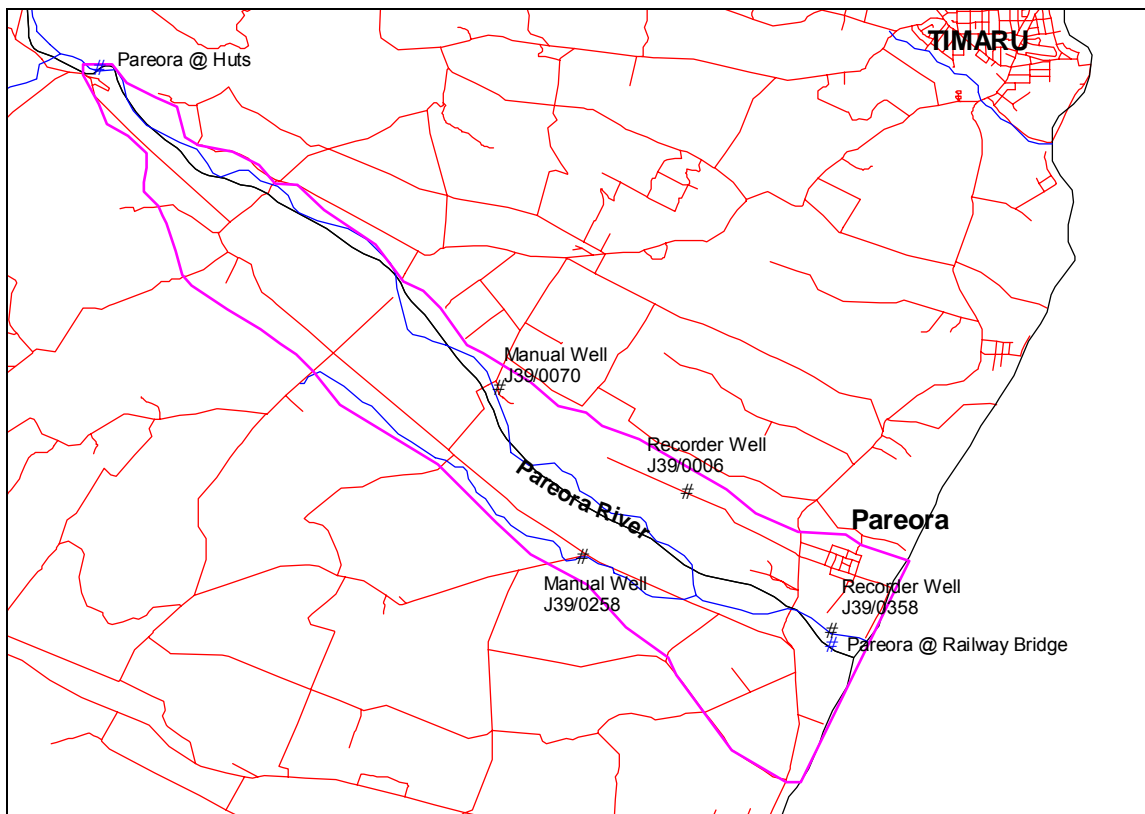
#### 2. Available data sets

In the Pareora River Valley, a surface water recorder has been installed at the gorge (Pareora Huts) since April 1982, with a mean flow of 3666 l/sec and a daily range from 300-570,000 l/sec, and a 7 day mean annual low flow (7-day MALF) of 781 l/sec (S. Facer, pers. comm.)

An additional recorder site was installed at the Railway Bridge (the coastal side of State Highway One) in November 2000, however difficulties maintaining the site led to its closure in March 2002. This site in the period of operation had an average daily flow range of 0 - 353,300 l/sec, and a mean flow of 2768 l/sec.

Manual groundwater level monitoring has been undertaken at several wells since 1969, however all sites were discontinued in a network review in 1995, leaving just purpose drilled recorder well J39/0006 (installed 1985) operating. Since 1995, monitoring has been undertaken manually at wells J39/0070, J39/0258, and

an additional recorder well was installed in October 2000 adjacent to the Railway Bridge surface water recorder site<sup>1</sup>. The locations of all monitoring sites are shown in Figure 2.



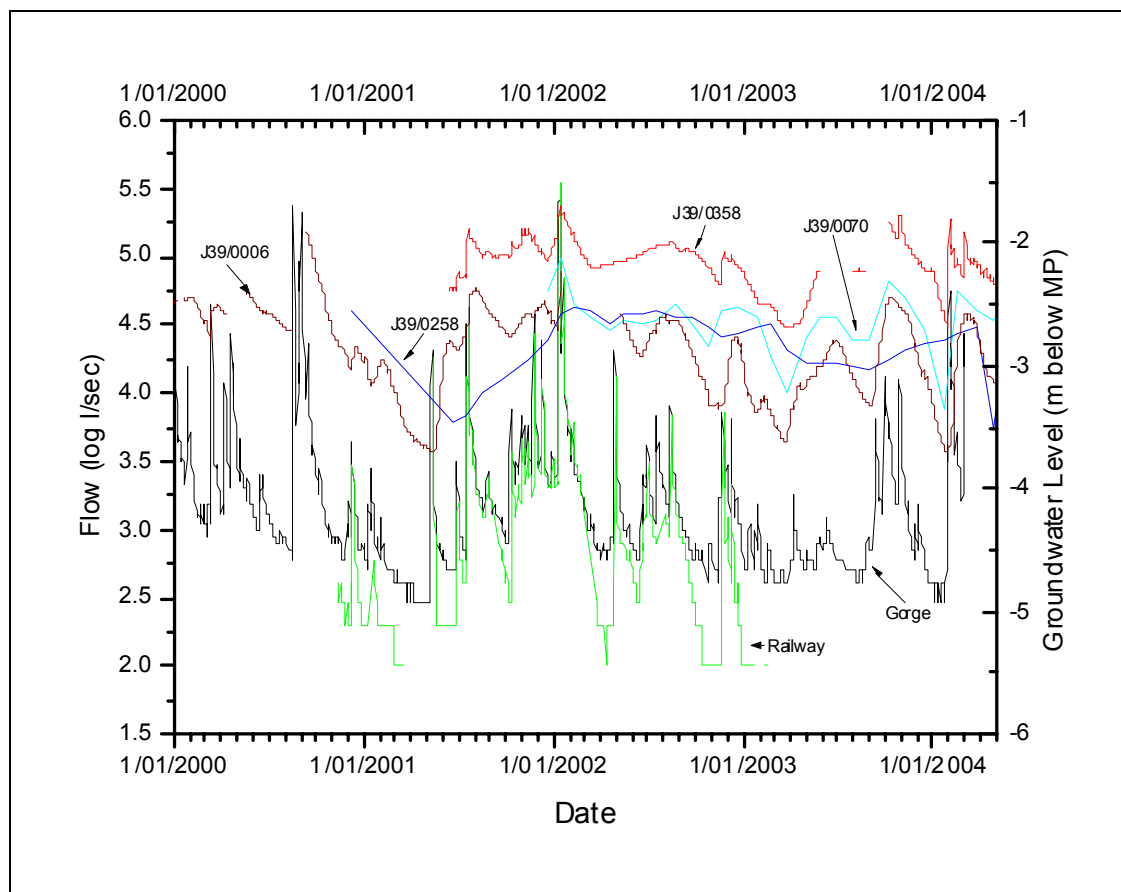
**Figure 2: Location of surface and groundwater monitoring sites in the Pareora Valley.**

### 3. Data analysis

The range of flows recorded at Pareora Huts and Railway Bridge, and the measured groundwater levels since January 2000 are shown in Figure 3. There is an obvious correlation between surface flow and groundwater levels, with increasing river flow leading to peaks in groundwater level.

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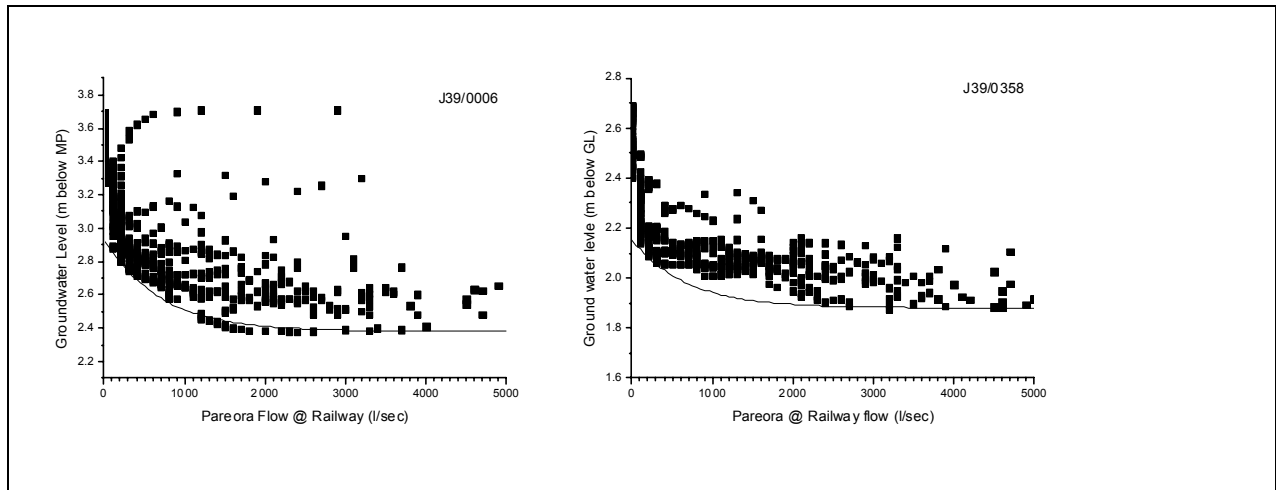
<sup>1</sup> This was intended to allow a relationship between groundwater level and surface flow to be ascertained, with a view to removing the surface water recorder once this was obtained. The surface recorder site was however removed early due to difficulties maintaining the site.



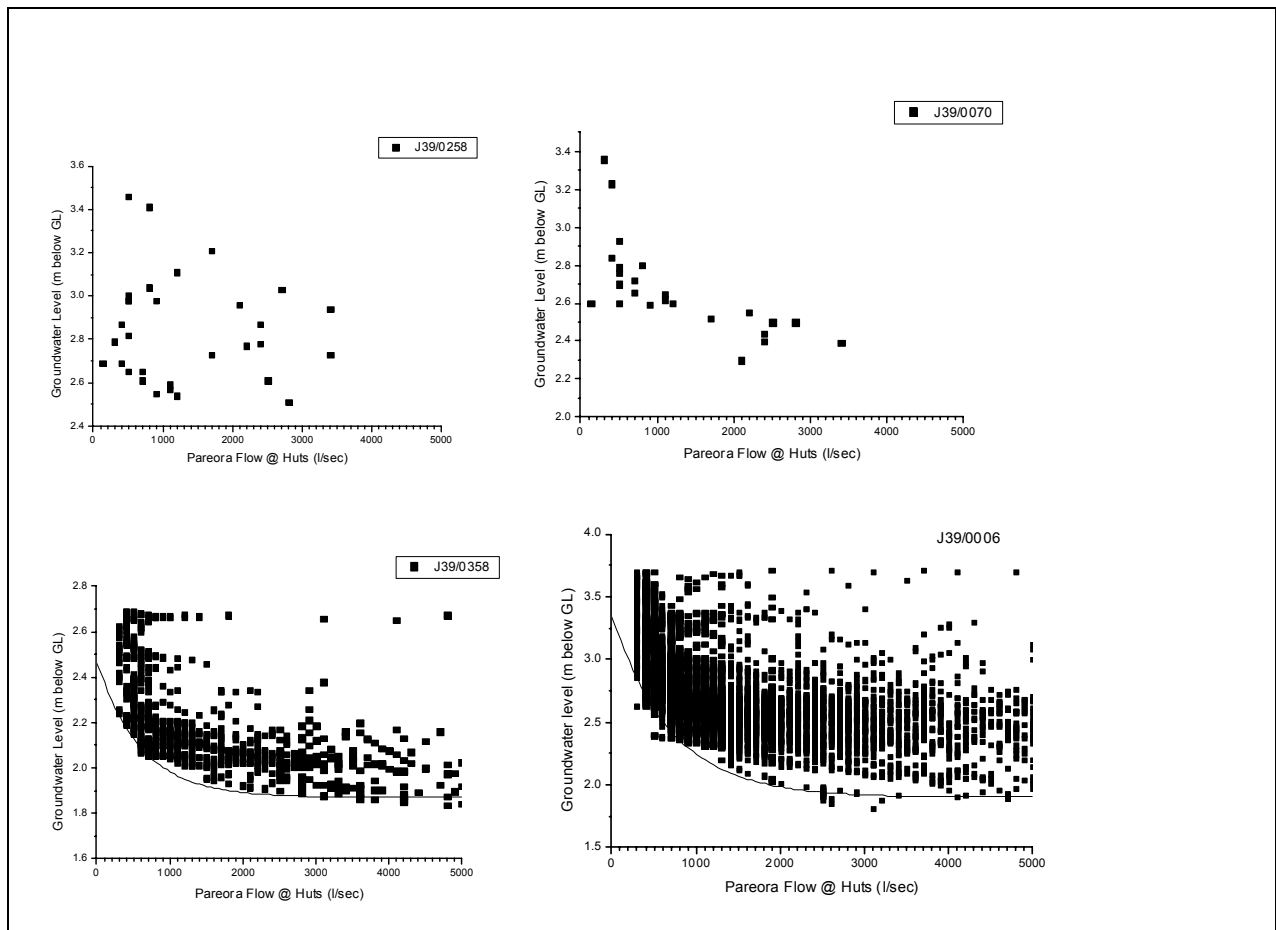
**Figure 3: Pareora River flow and Groundwater Levels.**

To better analyse this relationship, scatter-plots of monitoring wells and flow sites were created. Figure 4 shows the relationship between Pareora flow at the Railway Bridge, and groundwater levels at adjacent well J39/0358, and in well J39/0006. Figure 5 shows the relationship between Pareora Flow at Huts, and groundwater levels in wells J39/0358, J39/0006, J39/0070 and J39/0258.

When flow at the Railway Bridge is greater than 2000 l/sec, groundwater levels at J39/0358 and J39/0006 seem to be up to maximum (i.e aquifer storage is full) (Figure 4). When flow was 0, groundwater levels at J39/0358 were between 2.43m and 2.7m below ground. For J39/0006, the lowest groundwater level when the Railway Bridge was dry was between 3.26 and 3.7m below ground.



**Figure 4: Groundwater levels at J39/0358 and J39/0006 and Pareora Flow at Railway Bridge (for flow up to 5000 l/s) Exponential decay curve fitted.**



**Figure 5: Groundwater levels at J39/0258, J39/0070, J39/0358 and J39/0006 and Pareora Flow at Huts (for flow < 5000 l/s). Exponential decay curve fitted to recorder wells only.**

When compared to Pareora flow at Huts, groundwater levels at J39/0258 seem to have little relationship to flow (Figure 5). Levels at J39/0006, J39/0070, and J39/0358 show a relationship, with maximum groundwater levels generally occurring at flows around 1000 l/sec. Exponential decay relationships were fitted to recorder well data (refer Figure 4 and Figure 6 for curves). Table 1 outlines the obtained input values for the fit equation:

$$\text{GWL} = y_0 + A_1 * e^{(-x/t_1)}$$

Where  $y_0$  is effectively the maximum groundwater level at each well,  $A_1$  controls the 'empty level' and  $t_1$  the curvature of the line.

**Table 1: Function correlation inputs**

	Well Number	y0	A1	t <sub>1</sub>
<b>Railway Bridge</b>	J39/0006	2.38	0.55	700
	J39/0358	1.88	0.272	680
<b>Huts</b>	J39/0006	1.9	1.45	700
	J39/0358	1.87	0.6	600

From this relationship expected maximum groundwater levels at different flows for the Pareora can be ascertained (Table 2).

**Table 2: Maximum Groundwater levels estimated from flow at Huts**

Well Number	Huts @ 300 l/sec <sup>1</sup>	Huts @ 400 l/s <sup>2</sup>	Huts @ MALF (781 l/sec)	Huts @ Mean (3665 l/sec)
J39/0006	-2.84	-2.72	-2.37	-1.91
<b>J39/0358</b>	-2.23	-2.18	-2.03	-1.87

<sup>1</sup>Pareora on full irrigation restrictions

<sup>2</sup>Pareora on partial irrigation restriction.

## Analysis of surface water and groundwater interaction in the Otaio Valley

### 1. Introduction

The Otaio River Valley groundwater system is highly interconnected to the surface water flows. Apart from local rainfall, the Otaio River (and its tributary the Esk Valley Stream) are the main source of recharge to the shallow groundwater aquifer. Figure 1 shows the approximate extent of the shallow groundwater contained within terraces incised into the downlands of South Canterbury. At the Otaio Gorge, flow enters the Otaio River Valley flowing directly over the tertiary siltstone deposits of the Otakau Group (Forsyth, 2001). Downstream the gravel of the river bed and surrounding land becomes slightly thicker, although trenching across the river bed between Bluecliffs Crossing and McAlwees crossing (around the 170m piezometric contour on Figure 1) was found to encounter the siltstone at very shallow depths. Further down river, anecdotal evidence from farmers indicates that 'clay' layers forcing the river to rise to the surface around Grays Crossing, (around the 50-60m piezometric contour on Figure 1). Bore logs also indicate a near-surface clay layer in much of the upper Valley. Hence the Otaio River Valley aquifer has a variable thickness and width, which will influence the range of groundwater levels and storage.

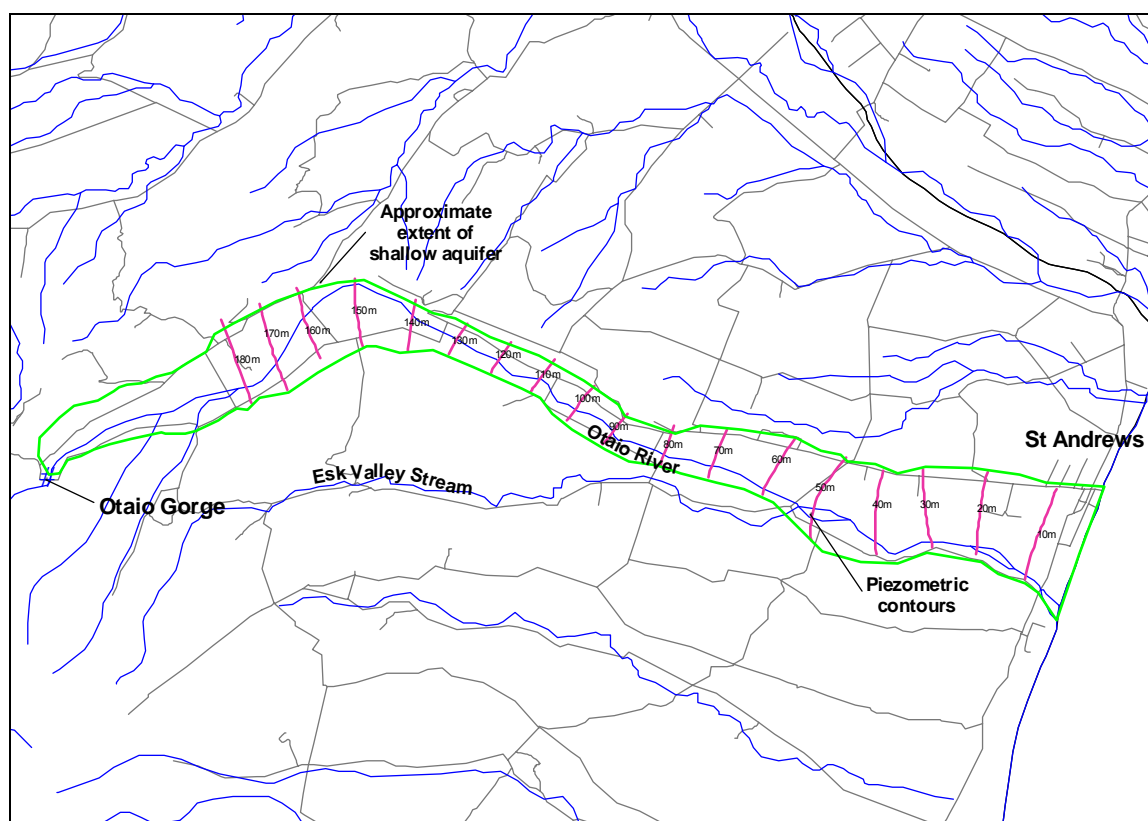
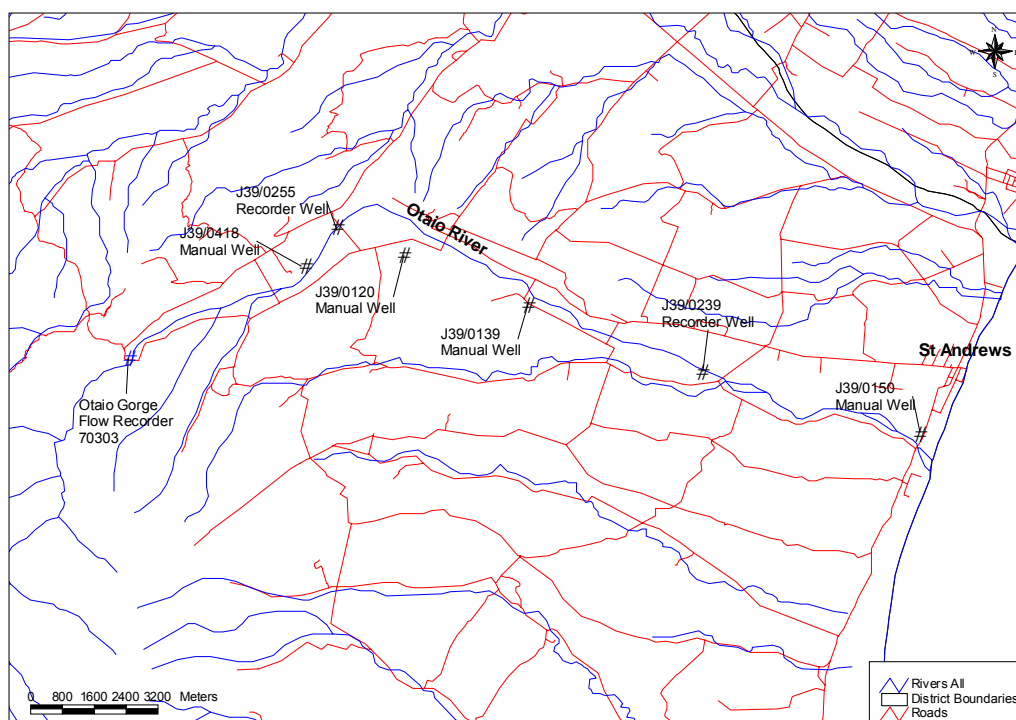


Figure 1: Otaio River Valley shallow aquifer extent and piezometric contours

### 2. Available data sets

In the Otaio River Valley, a surface water recorder has been installed at the Gorge since April 2001, with a mean flow of 724 l/sec and a daily range from 64 l/sec to 31895 l/sec, and a 7 day mean annual low flow (7-day MALF) of 139 l/sec (E Smith pers. comm.). Two purpose drilled monitoring wells; J39/0239 and J39/0255 were installed in September 1999, with recorders installed from September 2002. In addition, Environment Canterbury (ECan) manually monitors well J39/0150, and local farmers have provided measurements from wells J39/0418, J39/0120 and J39/0139. The locations of all monitoring sites are shown in Figure 2.



### 3. Data analysis

The range of flows recorded at Otaio Gorge is shown in Figure 3, and Figure 4 shows the measured groundwater levels. There is an obvious correlation between surface flow and groundwater levels, with increasing river flow leading to peaks in groundwater level. To better analyse this relationship, scatter-plots of each monitoring well compared to the log of daily Otaio flow at the gorge were produced, and exponential decay relationships fitted to each (note that the graphs appear to be increasing instead of decaying due to the negative nature of groundwater levels). The log of flow was chosen to flatten out the peaks in flow. These relationships are shown in Figure 5. An exponential decay was chosen, as the groundwater behaviour showed that once a certain maximum groundwater level was hit, the aquifer was full, and increased river flows would not increase this maximum (the flattening out of the curve at the top). Table 1 lists the variables of the function fitted to each plot, with the function form:  $f(x) = y_0 + A1e^{-x/t_1}$ , where  $y_0$  is effectively the maximum groundwater level at each well,  $A1$  controls the 'empty level', and  $t_1$  the curvature of the line.

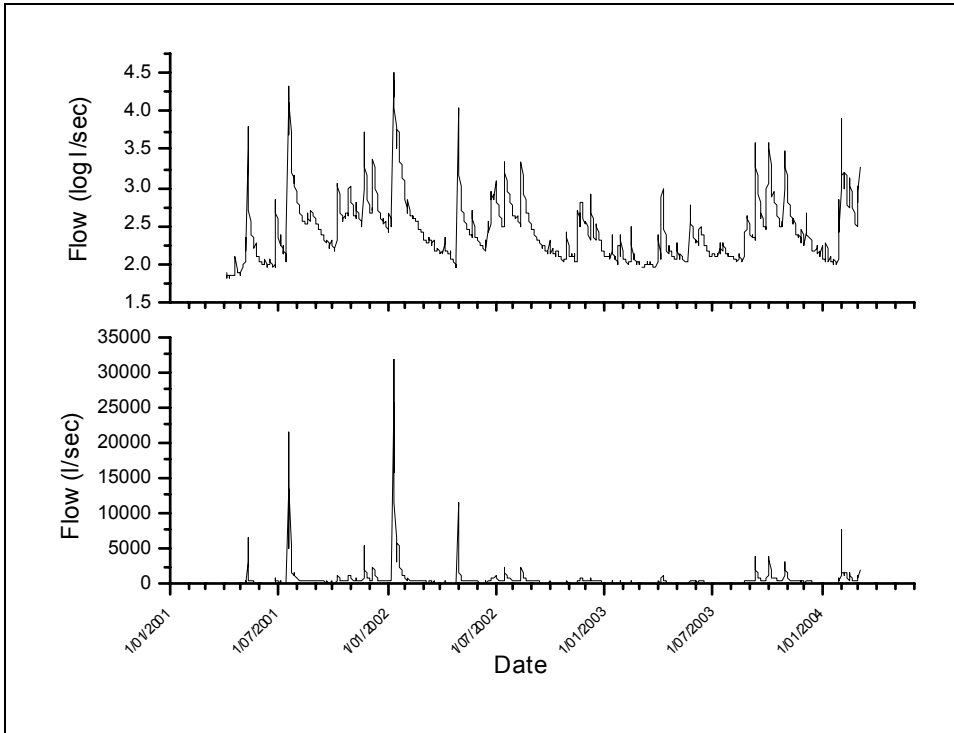


Figure 3: Flow at the Otaio Gorge, plotted as normal and log.

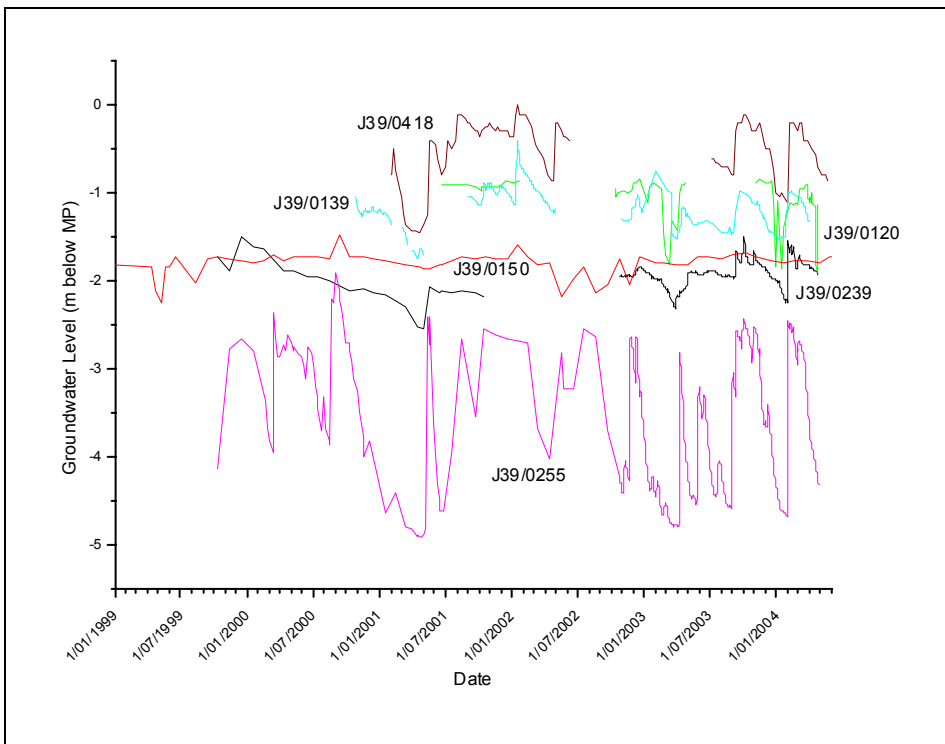


Figure 4: Groundwater levels at Otaio Valley wells

Table 1: Function correlation inputs

Well Number	y0	A1	t <sub>1</sub>
J39/0418	-0.09	-385	0.31
J39/0255	-2.38	-1500	0.3
J39/0120	-0.8	-90	0.3
J39/0139	-0.6	-40	0.5
J39/0239	-1.81	-110000	0.15
J39/0120	-0.8	-90	0.3
J39/0150	-1.65	-3.5	0.6

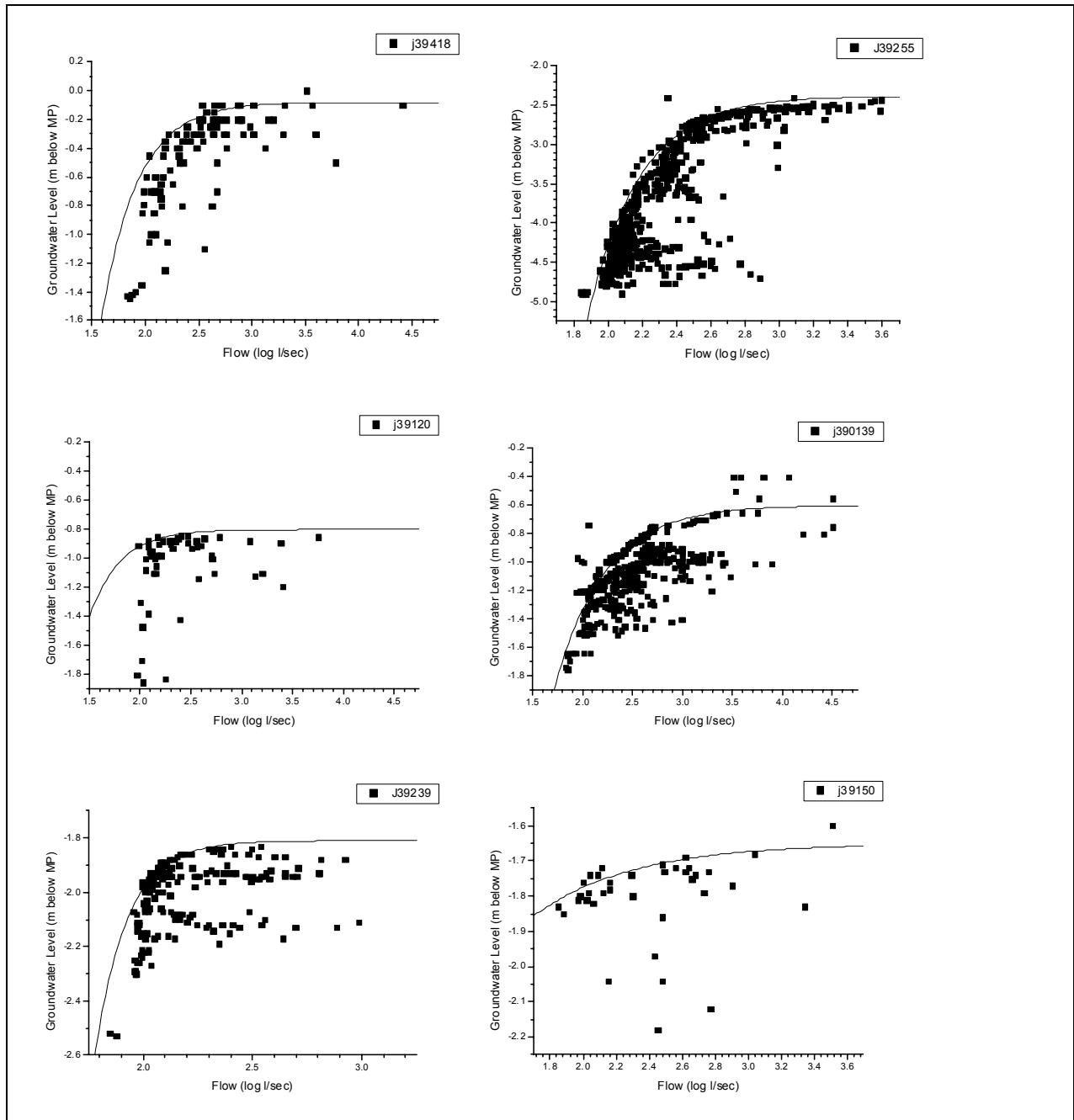


Figure 5: Correlations of Otaio Gorge flow to groundwater wells

The maximum level the line is fitted to relates to the maximum level the aquifer can fill to at a certain flow, the scatter of points evident below the best fit line is due to the aquifer filling to the maximum. Hence a high flow event can occur when antecedent groundwater levels are low, and the level recorded will be lower than if the event had occurred while levels were higher (i.e more storage filled in the aquifer).

The relationship is best for the recorder well J39/0255, and worst for J39/0120 and J39/0150. For J39/0150 this is probably because this is the most coastal well, and measurable responses from each river flow event may not reach this far. For J39/0120, there are less data points, and groundwater levels may be affected by pumping from the water hole.

Using these graphs, it can be estimated what groundwater levels would be given a certain gorge flow. Table 2 details the maximum and minimum water levels expected if 7-day MALF or mean flow is assumed (the lesser groundwater level is from the fit of the line, the minimum the lowest measured level below this (i.e as the aquifer is still filling)). Similarly, the flow required at the gorge to maintain each well at its maximum level (i.e aquifer storage is 100%) can be ascertained, and is also shown in Table 2.

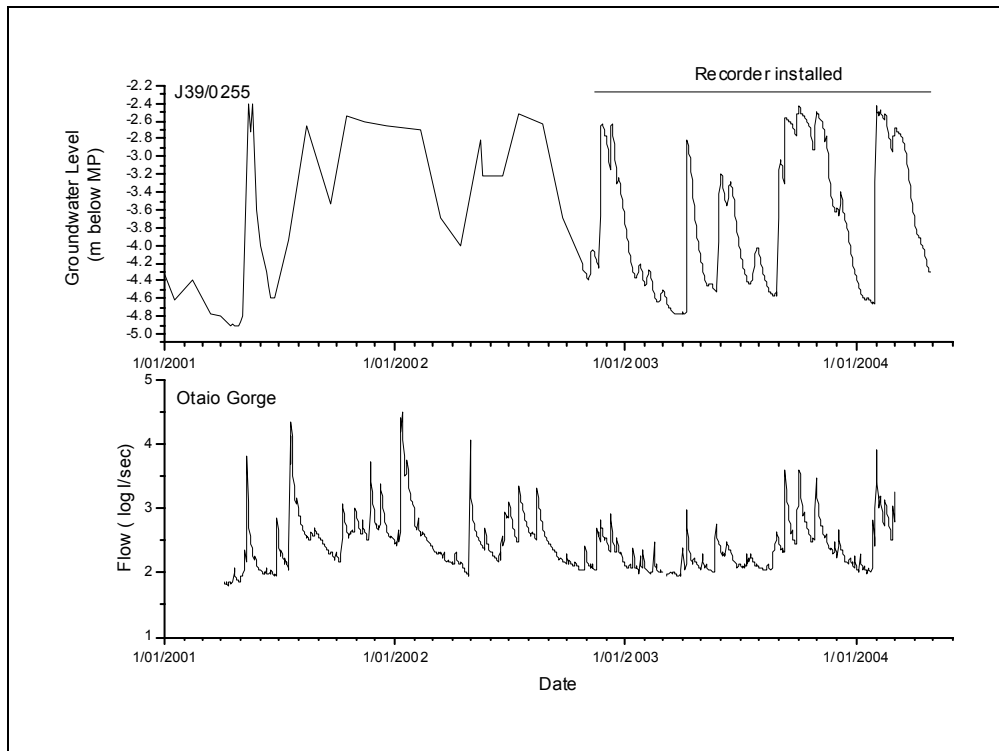
Well Number	7-day MALF (139 l/sec) GWL		Mean flow (734 l/sec) GWL		Flow at gorge required to fill aquifer storage (l/sec)
	Max	Min	Max	Min	
J39/0418	-0.48	-1.28	-0.13	-0.4	320
J39/0255	-3.58	-4.8	-2.49	4.7	350
J39/0120	-0.87	-1.9	-0.81	-1.2	450
J39/0139	-1.15	-1.52	-0.73	-1.45	500
J39/0239	-1.88	-2.2	-1.81	-2.15	160
J39/0150	-1.75	-2.05	-1.68	-1.84	160

**Table 2: Groundwater levels estimated from gorge flows**

The range of required gorge flows is probably due to the different aquifer thicknesses and hence available storage at each well site.

The record for the closest recorder well J39/0255 was compared to the gorge flow, as shown in Figure 6, and indicated the following broad qualitative observations:

- A large gorge flow leads to less time delay in the response at J39/0255
- A large gorge flow leads to a larger magnitude of rise at J39/0255
- A lower antecedent level at J39/0255 leads to a larger rise at J39/0255 in response to a gorge flow event
- A lower antecedent level at J39/0255 leads to a larger time delay in response at J39/0255.

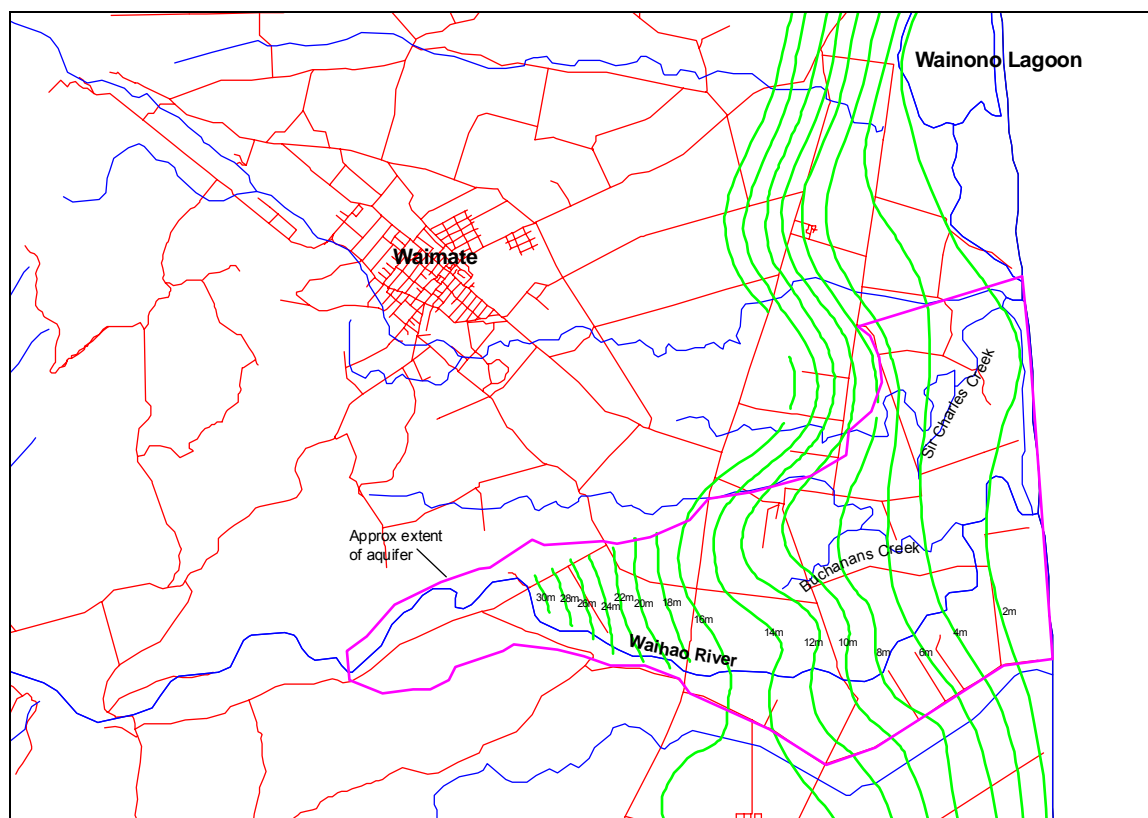


**Figure 6: Relationship of Otaio Gorge flow and recorder well J39/0255  
(approx 6km downstream)**

## Analysis of surface water and groundwater interaction in the Waihao River Shallow Aquifer

### 1. Introduction

The Waihao River Valley groundwater system is highly connected to the surface water flows. Apart from local rainfall, the Waihao River is a dominant source of recharge to the shallow groundwater aquifer. On the south side of the Waihao, significant summer recharge is caused by irrigation from the Morven-Glenavy Irrigation Scheme (MGIS). Figure 1 shows the approximate extent of the shallow groundwater aquifer. In the upper area, it is contained within terraces of the Waihao River. Towards the coast, the boundary between the Waihao river aquifer, and shallow aquifer to the north is uncertain, as is the southern boundary with Waitaki River deposits.



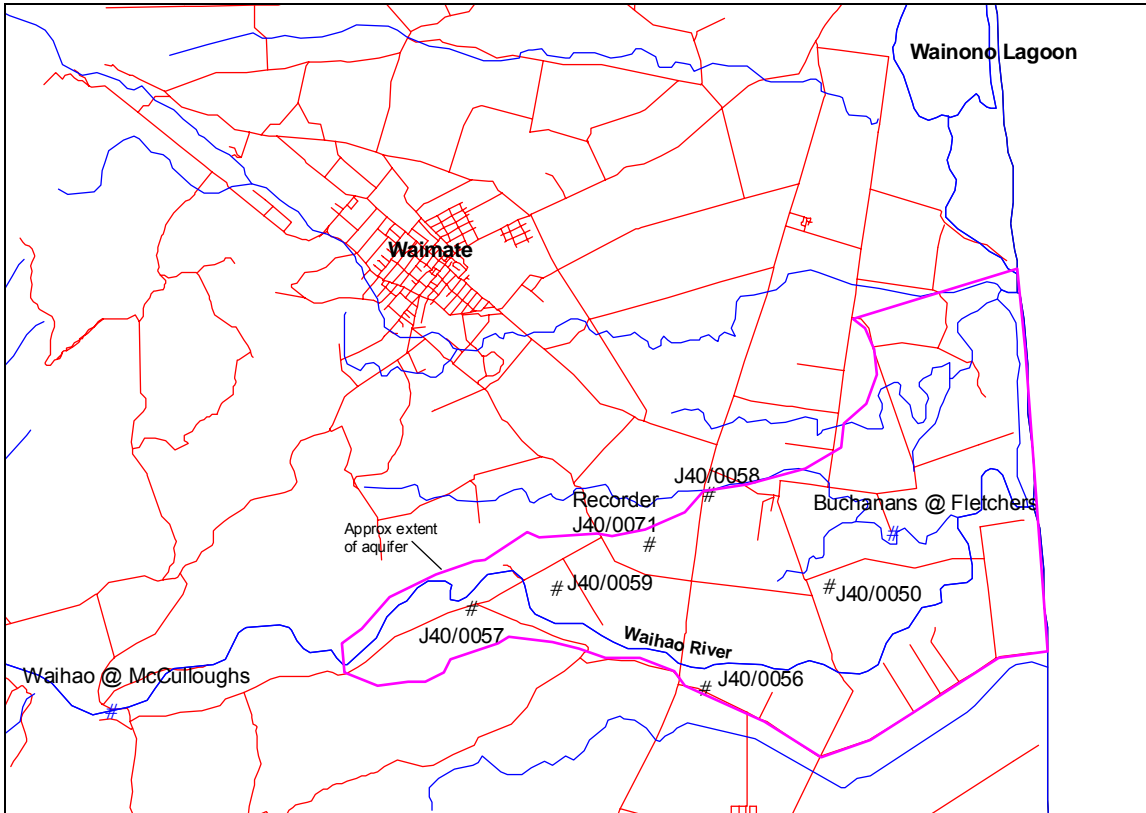
**Figure 1: Waihao River shallow aquifer extent and piezometric contours**

### 2. Available data sets

In the Waihao River, a surface water recorder has been installed at the McCulloughs Bridge since September 1982, with a mean flow of 3713 l/sec and a daily range from 100-478,700 l/sec, and a 7 day mean annual low flow (7-day MALF) of 391 l/sec (S. Facer, pers. comm.)

An additional recorder site was installed on spring-fed Buchanan's Creek in July 1999. This site has an average daily flow range of 100 - 6700 l/sec, and a mean flow of 352 l/sec.

Manual groundwater level monitoring has been undertaken at several wells since 1969, including J40/0059, J40/0058, J40/0056, J40/0049 and J40/0057. A purpose drilled recorder well J40/0071 was installed in July 1989. The locations of all monitoring sites are shown in Figure 2.



**Figure 2: Location of surface and groundwater monitoring sites in the Waihao Shallow Aquifer**

### 3. Data analysis

The range of flows recorded at Waihao @ McCulloughs and Buchanans Creek, and the measured groundwater levels since January 2000 are shown in Figure 3. Figure 4 is a smaller scale set from the period 1999-2004. There is an obvious correlation between surface flow and groundwater levels, with increasing river flow leading to peaks in groundwater level. A previous file note (Aitchison-Earl, 2000) has outlined the relationship between flow at McCulloughs Bridge, groundwater levels at J40/0071 and flow in spring-fed Buchanans Creek.

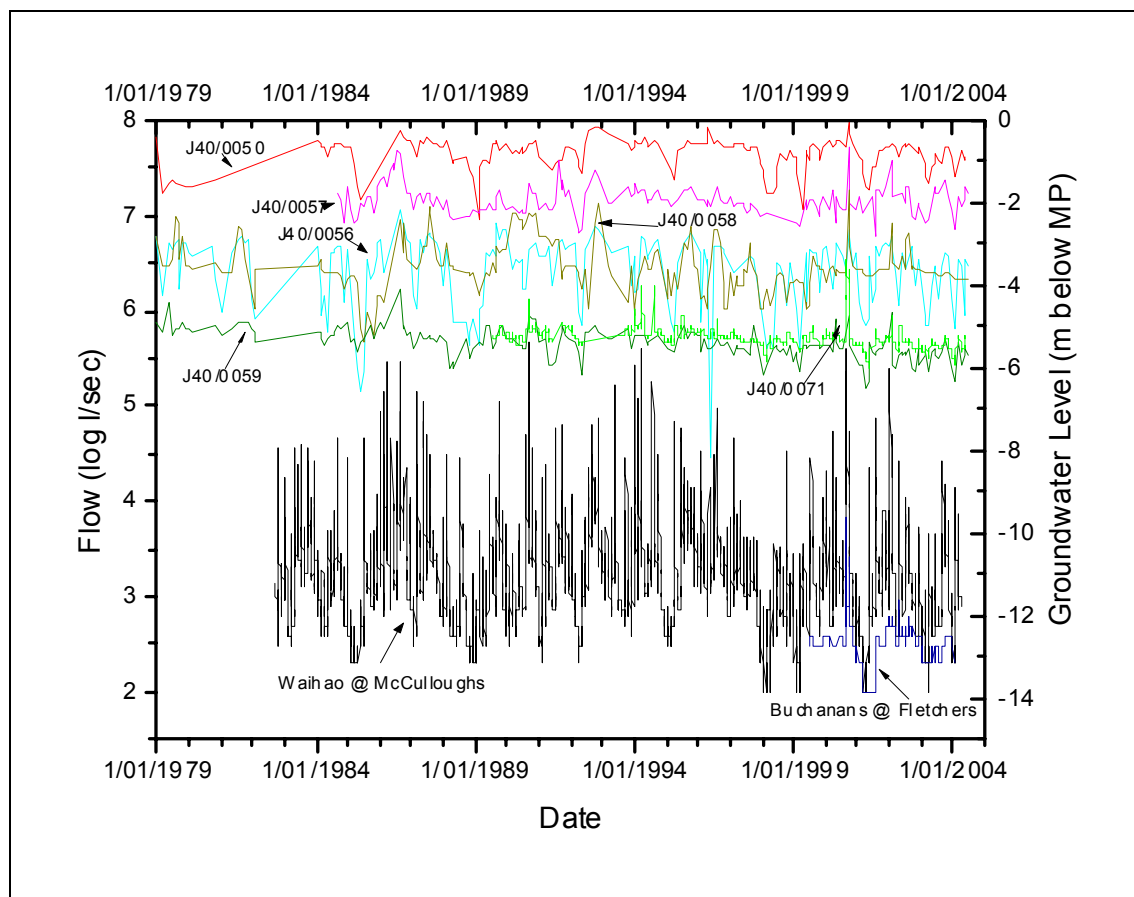
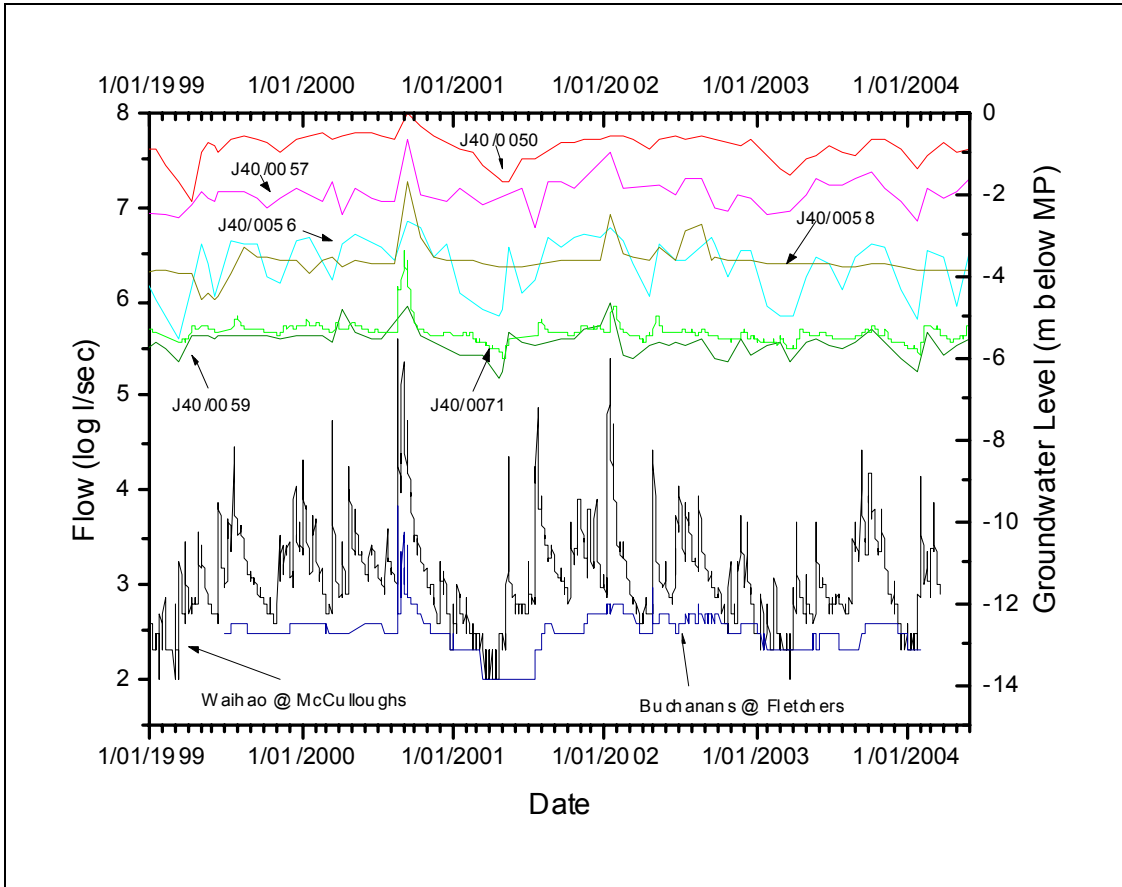


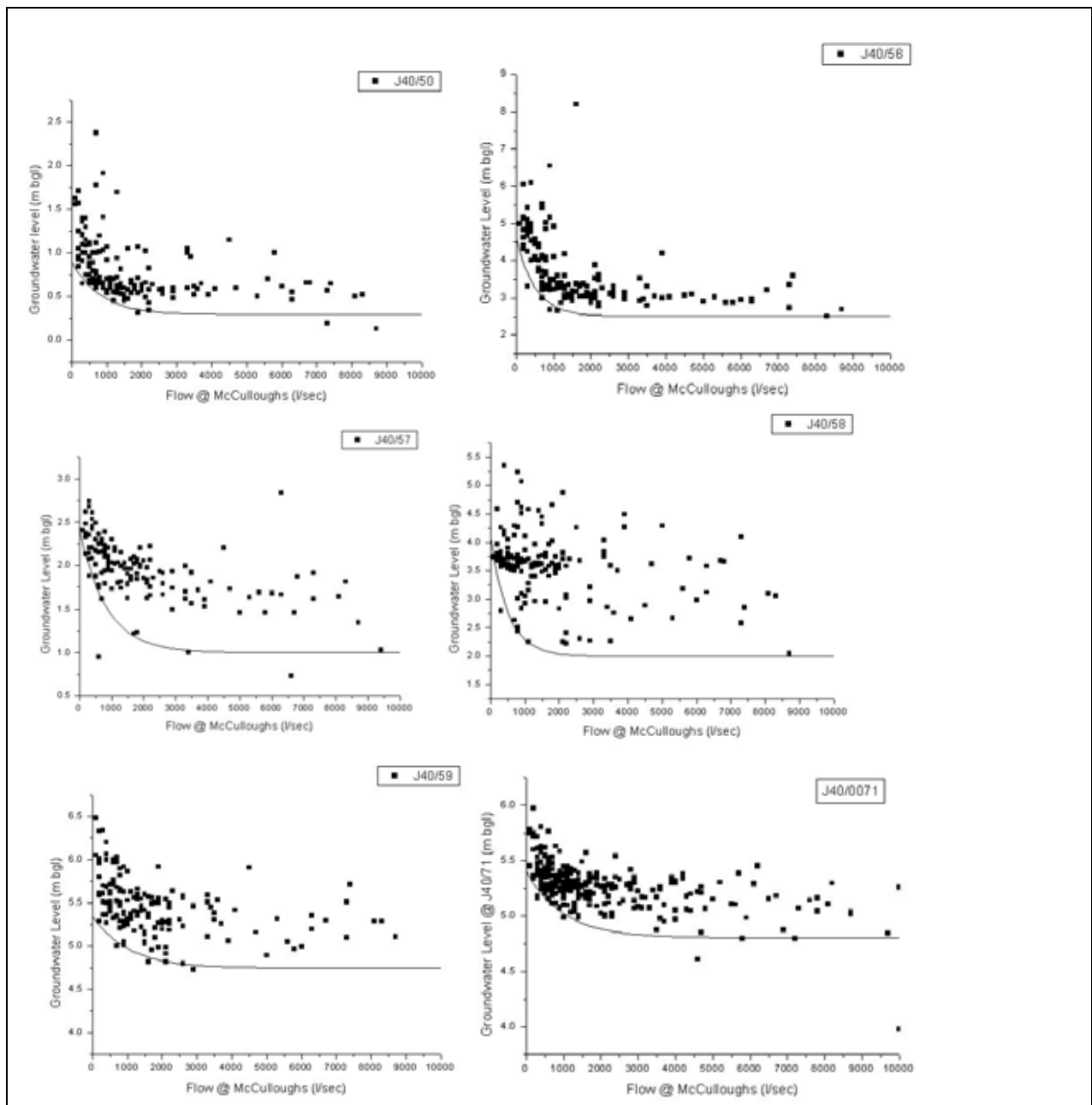
Figure 3: Waihao River flow and Groundwater Levels.



**Figure 4: Waihao River flow and Groundwater Levels, 1999-2004**

To better analyse the available data, scatter-plots of monitoring wells and flow sites were created.

Figure 4 shows the relationship between Waihao flow at the McCulloughs Bridge, and groundwater levels. Figure 5 shows the relationship between flow in Buchanans Creek and groundwater levels.



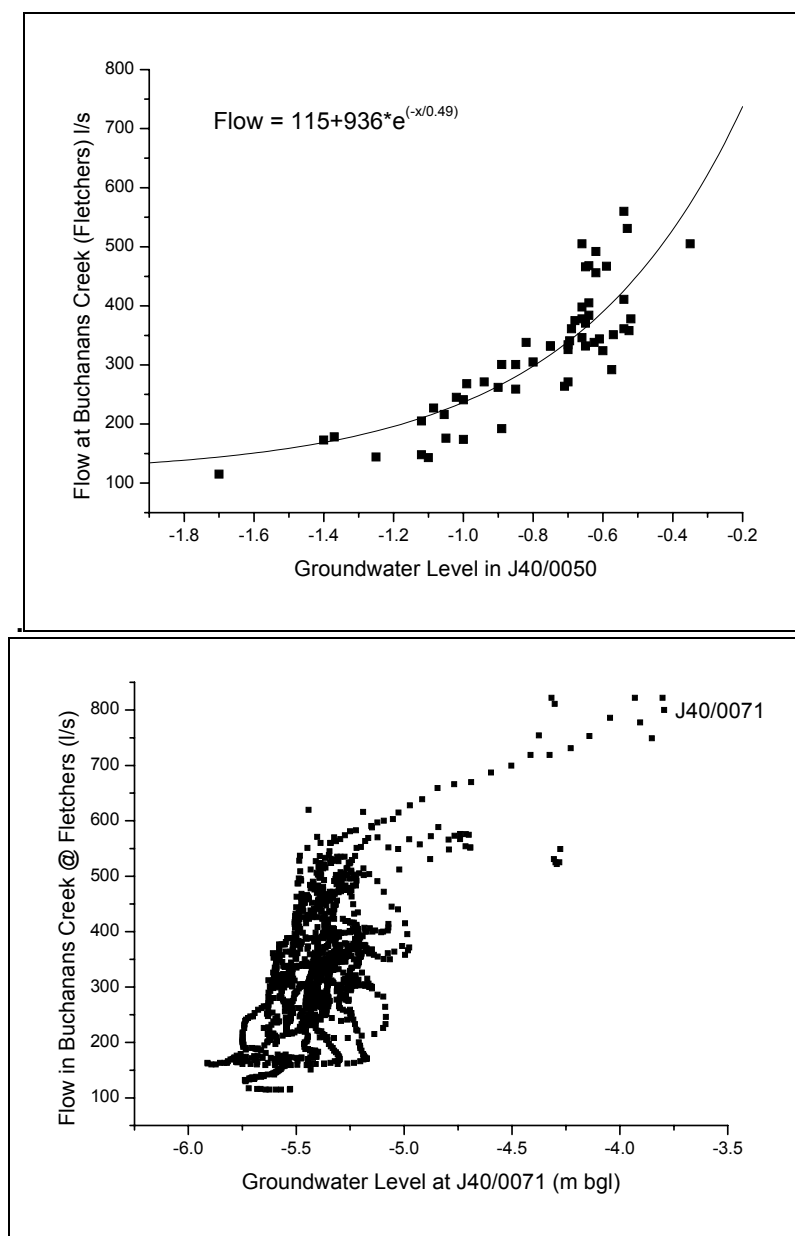
**Figure 4: Groundwater levels at J40/0050, J40/0056, J40/0057, J40/0058, J40/0059 and J40/0071 and Waihao Flow at McCulloughs (for flow < 10000 l/s), with exponential decay curve fitted.**

When compared to Waihao flow at McCulloughs, groundwater levels in show a relationship, with maximum groundwater levels generally occurring at flows around 1000-2000 l/sec. Exponential decay relationships were fitted to well data (refer Figure 4 for curves). Table 1 outlines the obtained input values for the fit equation:

$$GWL = y_0 + A_1 * e^{(-x/t_1)}$$

where  $y_0$  is effectively the maximum groundwater level at each well,  $A_1$  controls the 'empty level', and  $t_1$  the curvature of the line.

The data shows a better relationship for low flows (<2000 l/sec).



**Figure 5: Groundwater levels at J40/0050, and J40/0071 and Buchanan's Creek Flow (for flow < 900 l/s).**

There is also a relationship between groundwater levels and the spring-fed Buchanan's Creek, as displayed in Figure 5 for a well located adjacent to the source of the creek.

**Table 1: Function correlation inputs for Waihao @ McCulloughs**

Well	y0	A1	t <sub>1</sub>
J40/0050	0.3	0.6	800
J40/0056	2.5	2.1	500
J40/0057	1	1.4	850
J40/0058	2	2.1	500
J40/0059	4.75	0.6	1000
J40/0071	4.8	0.6	1000

From these relationships expected maximum groundwater levels at different flows for the Waihao can be ascertained (Table 3). The relationship is best at flows of <2000 l/sec, and should not be used to predict levels at higher flows. Similarly the flow in Buchanans Creek can be predicted using groundwater levels at J40/0050.

**Table 3: Maximum Groundwater levels estimated from flow at Huts (shaded wells have less confidence in relationship (refer to fit lines in Figure 4)**

Well Number	McCulloughs @ 250 l/sec <sup>1</sup>	McCulloughs @ 600 l/s <sup>2</sup>	McCulloughs @ MALF (391 l/sec)
<b>J40/0050</b>	0.74	0.58	0.67
<b>J40/0056</b>	3.77	3.13	3.46
<b>J40/0057</b>	2.04	1.69	1.88
<b>J40/0058</b>	3.27	2.63	2.96
<b>J40/0059</b>	5.22	5.08	5.16
<b>J40/0071</b>	5.27	5.13	5.21

<sup>1</sup>Waihao on full irrigation restrictions

<sup>2</sup>Waihao on partial irrigation restriction.

## References

Aitchison-Earl, P.L., 2002, 'Preliminary comparison of rainfall, Waihao River flow, groundwater levels and spring flow in Buchanans' Creek' File note IN6C-0049, June 2000.

## Appendix 37: Spring Locations



**Table: Spring Details (1)**

Spring Number	Spring Type	Morphology	Variability	Geology	QAR Cod	Location	Locality	Grid Reference	Use
J40/0378				Other	4		Kapua	J40:495-009	IR
J39/0207			Intermittent		3	Head of spring creek	St Andrew	J39:5074-3043	IR
J39/0175		Seepage	Permanent	Limestone	3	60m north of pump shed in front paddock	Rota puna station	J39:5135-3463	DO
J39/0132					3	Gully past yard	Hunter	J39:5141-2412	DO
J39/0195		Point	Permanent	Gravel	3	Below terrace	Otaio	J39:5224-3218	ST
J39/0127					3	In gully behind house	Hunter	J39:5512-2393	NO
J39/0128					3	Paddock after bridge	Hunter	J39:5542-2320	NO
J40/0332		Seepage	Intermittent		3	In marshy area	Hook	J40:5551-1356	NO
J40/0227					4		Waimate	J40:559-125	
J39/0204					3	Head of creek at base of trc	st Andrew	J39:5602-3180	
J39/0213					3	North of river	st Andrew	J39:5706-3061	
J39/0214					3		st Andrew	J39:5721-3054	
J39/0205					4	Seepage north of pump	st Andrew	J39:573-308	
J39/0167			Permanent	Gravel	2	Beside pumpshed behind stopbanks	Southburn	J39:5845-3982	IR
J40/0337					3	Among trees, in paddock left of house	Hook	J40:5859-1172	NO
J40/0304					3	Paddock opposite round shed	Makikihi	J40:5865-1965	DO
J40/0338					3	In swampy area beside shed	Hook	J40:5916-1240	NO
J39/0203					4	Headwaters of stream	St Andrew	J39:592-304	
J39/0202			Intermittent		4		St Andrew	J39:597-302	
J39/0164			Permanent	Gravel	2	Beside pumpshed behind stopbank	Southburn	J39:5966-3887	IR
J40/0389	Depres.	Point	Permanent	Gravel	3	Channel behind old house	Morven	J40:6215-0040	IR
J39/0197			Permanent		3	In swampy area	St Andrew	J39:6230-2854	IR
J39/0414		Point	Intermittent	Sand	2	Half way down terrace below house.	Brassels bridge	J39:62335-37174	DO
J40/0402	Depres.	Seepage	Permanent	Gravel	3	Drain into maroma-hua-kia stram	Willowbridge	J40:6235-0042	IR
J40/0713		Point	Intermittent	Gravel	3	Foot of terrace pond	Studholme	J40:6260-0523	
J39/0199					3		St Andrew	J39:6263-2845	IR
J39/0198					3		St Andrew	J39:6269-2870	IR
J40/0403	Depres.	Point	Permanent	Gravel	3		Willowbridge	J40:6277-0043	IR
J39/0200					3		St Andrew	J39:6280-2844	IR
J40/0341			UN		3	Under shed in swampy area	Hook	J40:6320-1348	DO
J39/0201					3	Springs in river bed	St Andrew	J39:6329-2833	
J40/0633		Point	Permanent		3	At corner in road	Willowbridge	J40:6337-0272	
J39/0416			Intermittent	Soil	3	Head of springbrook creek	Springbrook	J39:6341-3403	
J39/0381	Depres.	Seepage	Intermittent	Soil	3	Gully behind recorder well	Pareora	J39:6505-3530	
J39/0380	Depres.				3		Pareora	J39:6568-3428	
J39/0367	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6622-3444	
J39/0368	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6645-3415	
J39/0369	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6647-3413	
J39/0370	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6648-3411	
J39/0371	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6651-3407	
J39/0372	Depres.	Point	Permanent	Gravel	3	In sands creek	Pareora	J39:6657-3402	
J39/0461	Contact	Point	Permanent	Gravel	4		Hunter	J39:484-235	DO
J40/0721		Point	Permanent	Sand	2		Nukuroa	J40:63176-03586	
J40/0722	Depres.		Permanent	Sand	3		Nukuroa	J40:6276-0335	
J40/0723		Point	Permanent	Soil	3		Nukuroa	J40:6283-0301	
J40/0724	Depres.	Point	Permanent	Soil	3		Nukuroa	J40:6313-0292	
J40/0725	Depres.	Point	Permanent	Soil	3		Nukuroa	J40:6323-0287	

Table: Spring Details (continued)

Spring Number	Spring Type	Morphology	Variability	Geology	QAR	Location	Locality	Grid Reference	Use Cod
J40/0726	Depres.	Point	Permanent	Soil	3		Nukuroa	J40:6326-0274	
J40/0727		Point	Permanent	Soil	3		Nukuroa	J40:6331-0273	
J40/0728	Depres.	Point	Permanent	Soil	3		Nukuroa	J40:6338-0274	
J40/0729	Depres.	Seepage	Permanent	Soil	3		Willowbridge	J40:6375-0154	
J40/0730	Depres.	Seepage	Permanent	Soil	3		Willowbridge	J40"6373-0159	
J40/0731	Depres.	Seepage	Permanent	Soil	3		Willowbridge	J40:6369-0167	
J40/0732	Depres.	Seepage	Permanent	Soil	3		Willowbridge	J40:6374-0177	
J40/0733	Depres.	Point	Permanent	Gravel	2		Willowbridge	J40:63091-01957	
J40/0734	Depres.	Point	Intermittent	Gravel	2		Willowbridge	J40:60970-01083	
J40/0735	Depres.	Seepage	Intermittent	Soil	2		Willowbridge	J40:62026-01341	
J40/0736	Depres.	Point	Permanent	Gravel	3	Downstream side of flume	Willowbridge	J40:6183-0191	
J40/0738	Depres.	Seepage	Permanent	Soil	3		Willowbridge	J40:6218-0141	
J40/0739		Point	Intermittent	Gravel	2		Nukuroa	J40:62622-04976	
J40/0740		Point	Intermittent	Gravel	2		Nukuroa	J40:62628-04831	
J40/0747	Artesian	Point	Intermittent	Soil	2		Studholme	J40:63408-07541	
J40/0748	Artesian	Point	Intermittent	Soil	2		Studholme	J40:63630-07409	
J40/0749	Depres.	Point	Intermittent	Soil	2		Willowbridge	J40:61673-00111	
J40/0750	Artesian	Point	Intermittent	Sand	2		Studholme	J40:63696-05485	
J40/0751	Artesian	Point	Intermittent	Sand	2		Studholme	J40:63688-05906	
J40/0752	Artesian	Point	Permanent	Soil	2		Studholme	J40:64524-05464	
J40/0753	Artesian	Point	Permanent	Soil	2		Nukuroa	J40:63606-05417	
J40/0754	Artesian	Point	Permanent	Soil	2		Nukuroa	J40:63543-05343	
J40/0756	Artesian	Point	Intermittent	Soil	2		Nukuroa	J40:63508-05776	
J40/0757				Soil	3	In creek bed	Nukuroa	J40:6284-0495	
J40/0758					3		Nukuroa	J40:6290-0503	
J40/0759					3		Nukuroa	J40:6295-0508	
J40/0760					3		Nukuroa	J40:6306-0515	
J40/0761					3		Nukuroa	J40:6325-0507	
J40/0762	Depres.		Permanent	Gravel	3		Willowbridge	J40:6151-0178	
J39/0465	Contact	Horizon	Permanent	Gravel	3	Side of gully downstream of J39/132	Hunter	J39:5161-2424	
J39/0466					3		Hunter	J39:5237-2464	
J39/0467		Point	Permanent	Gravel	4		Hunter	J39:509-238	
J39/0468	Contact	Horizon	Permanent	Gravel	4		Hunter	J39:493-235	DO
J39/0469	Contact	Horizon		Gravel	3		Hunter	J39:4856-2375	
J40/0813					2	Near small terrace, blw shed	Waihao mouth	J40:64444-01990	IR
J40/0819			Permanent		3		Gum tree flat	J40:5144-9912	DO
J40/0820			Permanent		3		Gum tree flat	J40:5073-9929	ST
J40/0846	Depres.	Seepage	Permanent		2	On eastern side of paddock	Wainono	J40:63274-12159	ST
J40/0847	Depres.	Seepage	Permanent		2		Wainono	J40:62700-10799	
J40/0853					3		Wainono	J40:6238-1081	
J40/0854					2		Wainono	J40:62353-10415	
J40/0855					2		Wainono	J40:62557-09798	
J40/0856					2		Wainono	J40:62345-09413	
J40/0857					3		Wainono	J40:6244-0854	
J40/0858					3		Wainono	J40:6308-0862	
J39/0549					4		Otipua	J39:6160-4095	IR
J39/0550					4		Pareora west	J39:5900-4160	IR
J39/0551					4		Timaru	J39:6650-3100	IR
J40/0898					3		Hook	J40:6054-1231	

## Appendix 38: Stream depletion calculations

Stream depletion is estimated using the Jenkins (1977) assessment, which relies on the input variables transmissivity (T, m<sup>2</sup>/day), storativity (S), distance to stream (m), and pump rate (Q l/s)

Pump rates over 7 days and over 150 days are calculated based on the average daily rate from consent conditions (for 7 days) and the rate to deliver the annual volume over 150 days (calculated under NRRP Schedule WQN9), as described in NRRP Policy WQN14.

**Pareora Catchment Current Consent**

**Pareora groundwater Allocation Zone, Closest Stream Pareora River, Transmissivity 2500 m<sup>2</sup>/d, Storativity 0.1**

Well No.	Consent No.	Distance to Pareora (m)	NRRP Annual Volume	NRRP Annual Volume per well	Volume per return period (m <sup>3</sup> )	Return period (days)	Volume per return period (m <sup>3</sup> ) per well	Pumping over 7 days, Q (l/s)	Stream depletion for pumping over 7days, q (l/s)	Degree of hydraulic connection for 7 days pumping, q/Q (%)	Pumping to deliver annual volume over 150 days, Q (l/s)	Stream depletion for pumping over 150 days, q (l/s)	Degree of hydraulic connection for 150 days pumping, q/Q (%)	NRRP Category of Stream Depletion Effect	Pump rate to be taken based on NRRP (l/s)	Amount to be taken into account for Pareora River surface water allocation block (l/s)	Previous estimate provided to surface water February 2005	Difference between Estimates
J39/0135	CRC010392	1123	40500	40500	2100	7	300	3.5	0.2	5.8	3.1	2.1	68.2	Moderate	3.1	2.1	2.13	0.00
J39/0095	CRC010393	294	51300	51300	2660	7	380	4.4	2.7	61.9	4.0	3.6	91.5	Moderate	4.0	3.6	3.62	0.00
J39/0460	CRC011907	115	5824	5824	302	7	43	0.5	0.4	84.6	0.4	0.4	96.7	Moderate	0.4	0.4	0.43	0.00
J39/0228	CRC020599	280	164295	164295	7500	7	1071	12.4	7.9	63.6	12.4	11.4	91.9	Moderate	12.4	11.4	11.02	0.37
J39/0338	CRC971810.2	300	1148515	1148515	8146	1	8146	94.3	57.7	61.2	88.6	80.9	91.3	Moderate	88.6	80.9	80.89	0.00
J39/0506 <sup>1</sup>	CRC980553.2	60	494554	494554	18144	7	2592	30.0	27.6	91.9	30.0	29.5	98.3	High	30.0	30.0	29.48	0.52
J39/0072	CRC990633	745	42897	42897	3320	7	474	5.5	1.1	20.8	3.3	2.6	78.6	Moderate	3.3	2.6	2.60	0.00
J39/0218	CRC990697	525	155988	155988	8640	7	1234	14.3	5.4	37.5	12.0	10.2	84.8	Moderate	12.0	10.2	10.21	0.00
J39/0402 <sup>2</sup>	CRC990818.1	230	1226610	1226610	8164	1	8164	94.5	65.9	69.7	94.5	88.2	93.3	Moderate	94.5	88.2	87.71	0.46
J39/0336	CRC990943.1	10	277200	277200	17186	7	2455	28.4	28.0	98.7	21.4	21.3	99.7	High	28.4	28.4	28.40	0.02
J39/0035 <sup>3</sup>	CRC991155	600	2676856	2676856	7354	1	7354	85.1	26.4	31.0	85.1	70.4	82.7				70.26	-70.26
J39/0338	CRC991239.3	300	416244	416244	15271	7	2182	25.2	15.5	61.2	25.2	23.0	91.3	Moderate	25.2	23.0	22.82	0.23
J39/0067	CRC991278	535	50283	50283	2495	7	356	4.1	1.5	36.6	3.9	3.3	84.5	Moderate	3.9	3.3	3.28	0.00
J39/0337	CRC991279	1070	116856	116856	7020	7	1003	11.6	0.8	7.1	9.0	6.3	69.6	Moderate	9.0	6.3	6.28	0.00
J39/0254	CRC991280	620	50553	50553	2495	7	356	4.1	1.2	29.5	3.9	3.2	82.1	Moderate	3.9	3.2	3.20	0.00
J39/0340	CRC991281	700	502365	502365	22014	7	3145	36.4	8.6	23.7	36.4	29.1	79.8	Moderate	36.4	29.1	28.74	0.32
J39/0154	CRC991283	370	141491	141491	6210	7	887	10.3	5.5	53.2	10.3	9.2	89.3	Moderate	10.3	9.2	8.93	0.24
J39/0339	CRC991284.1	40	301514	301514	16798	7	2400	27.8	26.3	94.6	23.3	23.0	98.8	High	27.8	27.8	27.80	-0.03
J39/0341 <sup>4</sup>	CRC991310.1	730	250221	250221	9180	7	1311	15.2	3.3	21.7	15.2	12.0	79.0	Moderate	15.2	12.0	11.85	0.14
J39/0098	CRC991384	975	27418	27418	2160	10	216	2.5	0.2	9.9	2.1	1.5	72.2	Moderate	2.1	1.5	1.53	0.00
J39/0146 <sup>5</sup>	CRC991400	1030	612014	612014	30845	7	4406	51.0	4.2	8.2	47.2	33.4	70.7	Moderate	47.2	33.4	33.38	0.00
J39/0176	CRC991443	835	187938	187938	985	1	985	11.4	1.8	15.8	11.4	8.7	76.0	Moderate	11.4	8.7	8.36	0.30
J39/0191	CRC991682	1160	17172	17172	1800	20	90	1.0	0.1	5.0	1.0	0.7	67.2	Moderate	1.0	0.7	0.67	0.03
J39/0162	CRC991982	520	125190	125190	6259	7	894	10.3	3.9	37.9	9.7	8.2	84.9	Moderate	9.7	8.2	8.21	0.00

footnotes see next page

### Pareora Catchment Expired Consents

Pareora groundwater Allocation Zone, Closest Stream Pareora River, Transmissivity 2500 m<sup>2</sup>/d, Storativity 0.1

Well No.	Consent No.	Distance to Pareora (m)	NRRP Annual Volume	NRRP Annual Volume per well	Volume per return period (m <sup>3</sup> )	Return period (days)	Volume per return period (m <sup>3</sup> ) per well	Pumping over 7 days, Q (l/s)	Stream depletion for pumping over 7days, q (l/s)	Degree of hydraulic connection for 7 days pumping, q/Q (%)	Pumping to deliver annual volume over 150 days), Q (l/s)	Stream depletion for pumping over 150 days, q (l/s)	Degree of hydraulic connection for 150 days pumping, q/Q (%)	NRRP Category of Stream Depletion Effect	Pump rate to be taken based on NRRP (l/s)	Amount to be taken into account for Pareora River surface water allocation block (l/s)	Previous estimate provided to surface water February 2005	Difference between Estimates
J39/0090	CRC895028	560	30450	30450	60	7	8.57143	0.1	0.0	34.4	0.1	0.1	83.8	Moderate	0.1	0.1	0.08	0.00
J39/0090	CRC895028.1	560	30450	30450	60	7	8.57143	0.1	0.0	34.4	0.1	0.1	83.8	Moderate	0.1	0.1	0.08	0.00
J39/0113	CRC980553	620	222102	222102	2592	1	2592	30.0	8.8	29.5	17.1	14.1	82.1	Moderate	17.1	14.1	14.07	0.00
J39/0058 <sup>6</sup>	CRC980553.1	340	296732	296732	18144	7	2592	30.0	17.0	56.5	22.9	20.6	90.1	Moderate	22.9	20.6	24.02	-3.39
J39/0049	CRC990818	1010	934615	311538	2721	1	907	10.5	0.9	8.8	10.5	7.5	71.2	Moderate	10.5	7.5	22.44	-14.96
J39/0279		1040		311538	2721	1	907	10.5	0.8	7.9	10.5	7.4	70.4	Moderate	10.5	7.4	22.18	-14.79
J39/0280		840		311538	2721	1	907	10.5	1.6	15.6	10.5	8.0	75.9	Moderate	10.5	8.0	23.91	-15.94
J39/0336	CRC990943	10	281104	281104	17186	7	2455.14	28.4	28.0	98.7	21.7	21.6	99.7	High	28.4	28.4	28.34	0.08
J39/0338	CRC991239	300	416244	416244	15271	7	2181.57	25.2	15.5	61.2	25.2	23.0	91.3	Moderate	25.2	23.0	23.05	0.00
J39/0338	CRC991239.2	300	416244	416244	15271	7	2181.57	25.2	15.5	61.2	25.2	23.0	91.3	Moderate	25.2	23.0	23.05	0.00
J39/0334	CRC991284	580	274719	274719	16798	7	2399.71	27.8	9.1	32.7	21.2	17.6	83.2	Moderate	21.2	17.6	19.36	-1.72
J39/0341 <sup>7</sup>	CRC991310	1120	150132	150132	9180	7	1311.43	15.2	0.9	5.8	11.6	7.9	68.3	Moderate	11.6	7.9	10.36	-2.45
J39/0094	SCY810083	675	29893	29893	91	1	91	1.1	0.3	25.4	1.1	0.8	80.5	Moderate	1.1	0.8	0.85	0.00
J39/0095	SCY810084	294	29893	29893	91	1	91	1.1	0.7	61.9	1.1	1.0	91.5	Moderate	1.1	1.0	0.96	0.00

- 1 Consent allows for max rate from 3 bores, J39/0506 is closest to river so taken as worst case scenario.
- 2 Consent allows for max rate from 8 bores, J39/0402 is closest to river so taken as worst case scenario.
- 3 **Consent not considered as closer to coast than to River**
- 4 Consent allows for max rate from 2 bores, J39/0341 is closest to river so taken as worst case scenario.
- 5 Consent allows for max rate from 3 bores, J39/0146 is closest to river so taken as worst case scenario.
- 6 Consent allows for max rate from 4 bores, J39/0058 is closest to river so taken as worst case scenario.
- 7 Consent allows for max rate from 2 bores, J39/0095 is closest to river so taken as worst case scenario.

### Otaio Catchment

Groundwater Allocation Zone Otaio Transmissivity 1000m<sup>2</sup>/d Storativity 0.1

Well No.	Consent No.	Distance to nearest stream (m)	Closest stream	NRRP Annual Volume = per well	Volume per return period (m <sup>3</sup> )	Return period (days)	Volume per return period (m <sup>3</sup> ) per well	Pumping over 7 days, Q (l/s)	Stream depletion for pumping over 7days, q (l/s)	Degree of hydraulic connection for 7 days pumping, q/Q (%)	Pumping to deliver annual volume over 150 days, Q (l/s)	Stream depletion for pumping over 150 days, q (l/s)	Degree of hydraulic connection for 150 days pumping, q/Q (%)	NRRP Category of Stream Depletion Effect	Pump rate to be taken based on NRRP (l/s)	Amount to be taken into account for Otaio River surface water allocation block (l/s)	Previous estimate provided to surface water February 2005	Difference between Estimates
<b>Current Consents</b>																		
J39/0081	<b>CRC021383.1</b>	450	Otaio Main Stem	10712	293	7	42	0.5	0.1	22.9	0.5	0.4	79.5	Mod	0.5	0.4	0.23	0.15
J39/0139	<b>CRC981407</b>	280	Spring-fed Otaio Trib	151596	1440	1	1440	16.7	7.6	45.4	11.7	10.2	87.2	Mod	11.7	10.2	8.72	1.48
J39/0120	<b>CRC981527</b>	0	Spring-fed Otaio Trib	226940	1440	1	1440	16.7	16.7	100.0	16.7	16.7	100.0	High	16.7	16.7	10.00	6.67
<b>Expired Consents</b>																		
J39/0081	<b>CRC920668</b>	470	Otaio Main Stem	6427	510	7	73	0.8	0.2	20.9	0.5	0.4	78.6	Mod	0.5	0.4	0.40	-0.01
J39/0081	<b>CRC920668.1</b>	470	Otaio Main Stem	6427	510	7	73	0.8	0.2	20.9	0.5	0.4	78.6	Mod	0.5	0.4	0.40	-0.01
J39/0081	<b>CRC920668.2</b>	470	Otaio Main Stem	6427	510	7	73	0.8	0.2	20.9	0.5	0.4	78.6	Mod	0.5	0.4	0.40	-0.01
J39/0081	<b>SCY820075</b>	470	Otaio Main Stem	6427	73	1	73	0.8	0.2	20.9	0.5	0.4	78.6	Mod	0.5	0.4	0.40	-0.01
J39/0081	<b>CRC021383</b>	470	Otaio Main Stem	6427	293	7	42	0.5	0.1	20.9	0.5	0.4	78.6	Mod	0.5	0.4	0.23	0.15

### Makikihi Catchment

Groundwater Allocation Zone Otaio, Transmissivity 1200m<sup>2</sup>/d Storativity 0.1 Current consents (only)

J40/0042	<b>CRC012590.1</b>	800	Makikihi River	273658	2592	1	2592	30.0	1.5	5.1	21.1	14.2	67.3	Mod	21.1	14.2	14.22	0.00
J40/0298	<b>CRC980271</b>	100	Makikihi River	62920	1210	7	173	2.0	1.6	80.7	2.0	1.9	95.8	Mod	2.0	1.9	4.65	-2.73

**Waimate-Hook Catchment**  
**Groundwater allocation zone Waihao-Wainono**  
**Storativity 0.1 for all**

Well No.	Consent No.	Distance to nearest stream (m)	Closest stream	Distance to Stream 2	Stream 2	(day <sup>2</sup> /m) T	NRRP Annual Volume	NRRP Annual Volume per well	Volume per return period (m <sup>3</sup> )	Return period (days)	Volume per return period (m <sup>3</sup> ) per well	Pumping over 7 days, Q (l/s)	Stream depletion for pumping over 7 days, q (l/s)	Degree of hydraulic connection for 7 days pumping, q/Q (%)	Pumping to deliver annual volume over 150 days, Q (l/s)	Stream depletion for pumping over 150 days, q (l/s)	Degree of hydraulic connection for 150 days pumping, q/Q (%)	NRRP Category of Stream Depletion Effect	Pump rate to be taken based on NRRP (l/s)	Amount to be taken into account for surface water allocation block	Previous estimate provided to surface water February 2005	Difference between Estimates
<b>Current Applications</b>																						
J40/0380	CRC050336	100	Wainono Lagoon Trib			500			2160	1												
<b>Current Consents</b>																						
J40/0377	CRC032212	275	Hook River			1500	136286	136286	5000	7	714	8.3	4.5	54.8	8.3	7.4	89.7	Moderate	8.3	7.4	4.5	-3.0
J40/0099	CRC960785.2	90	Spring fed Hook Trib			1500	761400	761400	2074	1	2074	24.0	20.3	84.4	24.0	23.2	96.6	Moderate	24.0	23.2	13.9	-9.3
J40/0242	CRC970579 <sup>1</sup>	65	Merrys Stream	410	Hook River	1500	59994	29997	8425	14	602	7.0	6.2	88.7	2.3	2.3	100	Moderate	2.3	2.3	4.2	1.9
J40/0243		100	Merrys Stream			1500		29997	8425	14	602	7.0	5.8	82.7	2.3	2.2	96.2	Moderate	2.3	2.2	3.6	1.4
J40/0082	CRC980998 <sup>2</sup>	125	Hook River Trib.	300	Hook River	1500	63634	63634	4086	7	584	6.8	5.3	78.5	4.9	4.9	100	Moderate	4.9	4.9	6.8	1.8
J40/0897	CRC041958	90	Hook River			1500	35,519	35519	2040	7	291	3.4	2.8	84.4	2.7	2.6	96.6	Moderate	2.7	2.6	2.0	-0.7
<b>Expired/Transferred Consents</b>																						
J40/0377	CRC991430.1	275	Hook River			1500	82426	82426	720	1	720	8.3	4.6	54.8	6.4	5.7	89.7	Moderate	6.4	5.7	12.06	6.4
J40/0380	CRC991488.1	100	Wainono Lagoon Trib			500	61819	61819	540	1	540	6.3	4.4	70.5	4.8	4.5	93.5	Moderate	4.8	4.5	9.23	4.8
J40/0015	SCY690696 <sup>2</sup>	220	Waimate Creek	260	Waimate Crk Trib.	250	44762	44762	391	1	391	4.5	1.1	24.0	3.5	2.8	79.9	Moderate	3.5	2.8	6.22	3.5
J40/0380		CRC040462	100	Wainono Lagoon Trib			500	123638	123638	12960	12	1080	12.5	8.8	70.5	9.5	8.9	93.5	Moderate	9.5	8.9	18.46
J40/0099	SCY820165	90	Spring fed Hook Trib			1500	140696	140696	1229	1	1229	14.2	12.0	84.4	10.9	10.5	96.6	Moderate	10.9	10.5	21.34	10.9
J40/0099	CRC960785	90	Spring fed Hook Trib			1500	761400	761400	2074	1	2074	24.0	20.3	84.4	24.0	23.2	96.6	Moderate	24.0	23.2	47.20	24.0
J40/0377	CRC991430	275	Hook River			1500	82426	82426	720	1	720	8.3	4.6	54.8	6.4	5.7	89.7	Moderate	6.4	5.7	12.06	6.4
J40/0380	CRC991488	100	Wainono Lagoon Trib			500	61819	61819	540	1	540	6.3	4.4	70.5	4.8	4.5	93.5	Moderate	4.8	4.5	9.23	4.8
J40/0099	CRC960785.1	90	Spring fed Hook Trib.			1500	761400	761400	2074	1	2074	24.0	20.3	84.4	24.0	23.2	96.6	Moderate	24.0	23.2	47.20	24.0

1) 1.99 l/s from Merrys Strm and 0.31 l/s from Hook River  
 2) Both in same catchment

**Waihao Catchment Groundwater Allocation Zone: Waihao-Wainono  
Transmissivity 1600 and Storativity 0.1**

Well No.	Consent No.	Distance to nearest stream (m)	Closest stream	Distance to Stream 2	Stream 2	NRRP Annual Volume = per well	Volume per return period (m <sup>3</sup> )	Return period (days)	Volume per return period (m <sup>3</sup> )	Pumping over 7 days, Q (l/s)	Stream depletion for pumping over 7 days, q (l/s)	Degree of hydraulic connection for 7 days pumping, q/Q (%)	Pumping to deliver annual volume over 150 days), Q (l/s)	Stream depletion for pumping over 150 days, q (l/s)	Degree of hydraulic connection for 150 days pumping, q/Q (%)	NRRP Category of Stream Depletion Effect	Pump rate to be taken based on NRRP (l/s)	Amount to be taken into account for Waihao River surface water allocation block (l/s)	Previous estimate provided to surface water February 2005	Difference between Estimates
<b>Current Applications</b>																				
J40/0156	CRC990037	490	Buchanans Creek				39917	14	2851	33.0	9.9	30.1	0.0	0.0						
<b>Current Consents</b>																				
J40/0154 <sup>1</sup>	CRC000848 <sup>1</sup>	600	Buchanans Creek	620	Maroma hua kia	381600	14000	7	2000	23.1	4.7	20.5	23.1	23.1	100.0	Moderate	23.1	23.1	14.0	9.1
J40/0188	CRC031115	470	Waihao Main Stem			282517	44712	18	2484	28.8	9.2	32.1	21.8	18.1	83.0	Moderate	21.8	18.1	14.3	3.8
J40/0815	CRC051084	360	Waihao Main Stem			60734	9564	14	683	7.9	3.5	44.7	4.7	4.1	86.9	Moderate	4.7	4.1	4.1	-0.1
J40/0093	CRC950626	875	Buchanans Creek			88938	713	1	713	8.3	0.5	6.4	6.9	4.7	69.0	Moderate	6.9	4.7	3.4	1.3
J40/0155 <sup>2</sup>	CRC972242 <sup>2</sup>	295	Sir Charles Creek	520	Buchanans Crk	230388	2041	1	2041	23.6	12.6	53.3	17.8	17.8	100.0	Moderate	17.8	17.8	14.0	3.8
J40/0049 <sup>3</sup>	CRC981424 <sup>3</sup>	313	Pratts Creek	880	Sir Charles Crk	330662	25056	7	3579	41.4	21.1	50.8	25.5	25.5	100.0	Moderate	25.5	25.5	25.0	0.5
J40/0095	CRC981449	340	Wainono Dead Arm			403767	2160	1	2160	25.0	11.8	47.3	25.0	21.9	87.7	Moderate	25.0	21.9	13.2	8.8
J40/0405	CRC981471.2	195	Wainono Dead Arm			81324	31104	15	2074	24.0	16.3	68.0	6.3	5.8	92.9	Moderate	6.3	5.8	13.4	-7.5
J40/0362	CRC981942	360	Waihao Main Stem			293547	2160	1	2160	25.0	11.2	44.7	22.7	19.7	86.9	Moderate	22.7	19.7	13.0	6.7
J40/0157	CRC982138.1	710	Waihao Main Stem			148064	12751	14	911	10.5	1.4	13.4	10.5	7.9	74.6	Moderate	10.5	7.9	4.7	3.1
J40/0068	CRC990759	1380	Waihao Main Stem			165287	16200	14	1157	13.4	0.0	0.4	12.8	6.7	52.9	Low	12.8	6.7	4.2	2.5
J40/0465	CRC991213	225	Waihao Main Stem			408505	2765	1	2765	32.0	20.3	63.5	31.5	28.9	91.8	Moderate	31.5	28.9	17.6	11.3
J40/0156	SCY800115	490	Buchanans Creek			222345	12000	7	1714	19.8	6.0	30.1	17.2	14.1	82.3	Moderate	17.2	14.1	9.8	4.3
<b>Expired/Transferred Consents</b>																				
J40/0155	SCY700570	295	Sir Charles Creek	520	Buchanans Crk	199768	1745	1	1745	20.2	10.8	53.3	15.4	15.4	100.0	Moderate	15.4	15.4	12.0	3.4
J40/0154	SCY790156	600	Buchanans Creek	620	Maroma hua kia	228960	14000	7	2000	23.1	4.7	20.5	17.7	17.7	100.0	Moderate	17.7	17.7	14.0	3.7
J40/0068	SCY790261	1380	Waihao Main Stem			132470	8100	7	1157	13.4	0.0	0.4	10.2	5.4	52.9	Low	10.2	5.4	4.2	1.2
J40/0157	SCY800073	710	Waihao Main Stem			65532	4007	7	572	6.6	0.9	13.4	5.1	3.8	74.6	Moderate	5.1	3.8	3.0	0.8
J40/0005	SCY810146	385	Waihao Main Stem			325875	19926	7	2847	32.9	13.7	41.6	25.1	21.6	86.1	Moderate	25.1	21.6	17.0	4.6
J40/0405	CRC981471	195	Wainono Dead Arm			93465	5715	7	816	9.4	6.4	68.0	7.2	6.7	92.9	Moderate	7.2	6.7	5.3	1.4
J40/0157	CRC982138	710	Waihao Main Stem			148064	12751	14	911	10.5	1.4	13.4	10.5	7.9	74.6	Moderate	10.5	7.9	4.7	3.1
J40/0405	CRC981471.1	195	Wainono Dead Arm			81324	5715	7	816	9.4	6.4	68.0	6.3	5.8	92.9	Moderate	6.3	5.8	5.3	0.6

1) 8.9 l/s from Buchanans Creek, 8.8 from Maroma  
3) Both creeks in same catchment

2) 13.4l/s from Sir Charles Creek and 4.4l/s from Buchanans

## Appendix 39: Water re use over time

Year	Surface water Volume		Groundwater Volume		Surface water Area		Groundwater Area		TOTAL Groundwater and Surface water	
	Total for Year (m3/d)	Cumulative (m <sup>3</sup> /d)	Total for Year (m3/d)	Cumulative (m <sup>3</sup> /d)	(ha)	Cumulative (ha)	(ha)	Cumulative (ha)	Total Cumulative Volume	Total Cumulative Area
Pre 1975	26694	26694	15998	15998	215.5	215.5	212	212	42692	427.5
1976	1536	28230	0	15998	105	320.5	0	212	44228	532.5
1977	1273	29503	36	16034	32	352.5	0	212	45537	564.5
1978	642	30145	953	16987	87	439.5	35	247	47132	686.5
1979	8835	38980	12191	29178	379.3	818.8	707	954	68158	1772.8
1980	6811.4	45791.4	5967	35145	188.5	1007.3	318	1272	80936.4	2279.3
1981	2786	48577.4	5321	40466	121	1128.3	176	1448	89043.4	2576.3
1982	11675	60252.4	1142	41608	541.2	1669.5	35	1483	101860.4	3152.5
1983	10203	70455.4	7315	48923	266	1935.5	159	1642	119378.4	3577.5
1984	2893	73348.4	8510	57433	81	2016.5	333	1975	130781.4	3991.5
1985	3285	76633.4	785	58218	45.5	2062	40	2015	134851.4	4077
1986	1214	77847.4	2617	60835	100	2162	76	2091	138682.4	4253
1987	0	77847.4	514	61349	0	2162	15	2106	139196.4	4268
1988	421.4	78268.8	345	61694	-46	2116	5	2111	139962.8	4227
1989	1704	79972.8	12148	73842	-104.6	2011.4	145	2256	153814.8	4267.4
1990	1588	81560.8	1449	75291	64	2075.4	4	2260	156851.8	4335.4
1991		81560.8	0	75291		2075.4	0	2260	156851.8	4335.4
1992	8996	90556.8	307	75598	388.5	2463.9	-7	2253	166154.8	4716.9
1993	-98	90458.8	900	76498	0	2463.9	0	2253	166956.8	4716.9
1994	167	90625.8	4169	80667	-5	2458.9	162	2415	171292.8	4873.9
1995	5314.6	95940.4	3370	84037	209	2667.9	100	2515	179977.4	5182.9
1996	71	96011.4	3536	87573	0	2667.9	33	2548	183584.4	5215.9
1997	-1386	94625.4	11047	98620	-80	2587.9	272	2820	193245.4	5407.9
1998	5995	100620.4	-1808	96812	151.7	2739.6	75	2895	197432.4	5634.6
1999	7221.6	107842	33873	130685	548	3287.6	684.6	3579.6	238527	6867.2
2000	3887	111729	5574	136259	-87	3200.6	161	3740.6	247988	6941.2
2001	-2185	109544	30485	166744	-63.4	3137.2	971	4711.6	276288	7848.8
2002	408	109952	41544	208288	94	3231.2	1230	5941.6	318240	9172.8
2003	5362	115314	21074	229362	148	3379.2	594	6535.6	344676	9914.8
2004	11414	126728	58384	287746	-309	3070.2	1527	8062.6	414474	11132.8
2005		126728	-1550	286196		3070.2	157	8219.6	412924	11289.8
<b>prop.</b>	<b>4082</b>	<b>130810</b>	<b>8402</b>	<b>294598</b>	<b>0</b>	<b>3070.2</b>	<b>260</b>	<b>8479.6</b>	<b>425408</b>	<b>11549.8</b>

**Surface Water Daily Volumes by Catchment (as of 23 June 2005)**

Year	Pareora		Otaio		Kohika		Makikihi		Hook		Wainono		Waihao	
	Annual Volume (m3/day)	Cumulative Annual Volume (m3/day)	Annual Volume (m3/day)	Cumulative Annual Volume (m3/day)	Annual Volume (m3/day)	Cumulative Annual Volume (m3/day)	Annual Volume (m3/day)	Cumulative Annual Volume (m3/day)	Annual Volume (m3/day)	Cumulative Annual Volume (m3/day)	Tributaries Annual Volume (m3/day)	Wainono Tributaries Cumulative Annual Volume (m3/day)	Annual Volume (m3/day)	Waihao Cumulative Annual Volume (m3/day)
Pre 1975	18730	18730	2178	2178		0			1961	1961	2636	2636	1189	1189
1976	-4757	13973		2178		0				1961		2636	6857	8046
1977		13973	857	3035		0				1961		2636	24	8070
1978		13973	428	3463		0				1961		2636	214	8284
1979		13973	657	4120		0				1961	-1849	787	72	8356
1980	0	13973	1393	5513		0			519	2480	-51	736	1954	10310
1981		13973		5513		0				2480		736	2786	13096
1982	-18	13955	6286	11799	571	571			1659	4139	1500	2236		13096
1983	2607	16562	1285	13084		571				4139	995	3231	10314	23410
1984	1285	17847		13084		571				4139		3231		23410
1985	2050	19897		13084		571				4139		3231		23410
1986	5942	25839		13084		571				4139		3231		23410
1987		25839		13084		571				4139		3231		23410
1988	2235	28074	-657	12427		571	356	356		4139	-1141	2090	4082	27492
1989	1610	29684	318	12745	571	1142	356	712	357	4496		2090	0	27492
1990		29684		12745		1142		712		4496		2090	1588	29080
1991		29684		12745		1142		712		4496		2090		29080
1992	1980	31664	4000	16745		1142	5191	5903	-1818	2678		2090	-356	28724
1993		31664		16745		1142		5903	-219	2459		2090	121	28845
1994	9634	41298		16745		1142		5903		2459		2090	7	28852
1995	5710	47008		16745		1142		5903	-360	2099		2090	1166	30018
1996		47008		16745		1142		5903	54	2153		2090		30018
1997		47008		16745	-1142	0	328	6231	0	2153		2090	-571	29447
1998	1571	48579		16745		0	4752	10983		2153	2521	4611	0	29447
1999	-1078	47501	643	17388		0	1728	12711	2766	4919	938	5549		29447
2000	-5549	41952		17388		0		12711		4919		5549	0	29447
2001	571	42523		17388		0		12711	-30	4889	-2273	3276	0	29447
2002	571	43094		17388		0	-2889	9822	4740	9629		3276		29447
2003	-787	42307		17388		0		9822	1857	11486		3276	0	29447
2004		42307	286	17674		0	256	10078	-216	11270		3276	0	29447

**Yearly and Cumulative Groundwater Daily Volumes by Aquifer (as of 23 June 2005).**

	Annual Volume Quaternary (m3/day)	Cumulative Volume Quaternary (m3/day)	Annual Volume Cannington (m3/day)	Cumulative Volume Cannington (m3/day)	Annual Volume Southburn (m3/day)	Cumulative Volume Southburn (m3/day)	Annual Volume Taratu (m3/day)	Cumulative Volume Taratu (m3/day)
Pre 1973	12562	12562	1818	1818	0	0	0	0
1974	1491	14053	0	1818	0	0	0	0
1975	0	14053	237	2055	0	0	0	0
1976	0	14053	0	2055	0	0	0	0
1977	36	14089	0	2055	0	0	0	0
1978	953	15042	0	2055	0	0	0	0
1979	12191	27233	0	2055	0	0	0	0
1980	4796	32029	1171	3226	0	0	0	0
1981	2143	34172	3178	6404	0	0	0	0
1982	1142	35314	0	6404	0	0	0	0
1983	4383	39697	2932	9336	0	0	0	0
1984	7082	46779	1428	10764	0	0	0	0
1985	0	46779	785	11549	0	0	0	0
1986	2617	49396	0	11549	0	0	0	0
1987	514	49910	0	11549	0	0	0	0
1988	353	50263	-8	11541	0	0	0	0
1989	10057	60320	7869	19410	0	0	0	0
1990	1449	61769	0	19410	0	0	0	0
1991	0	61769	0	19410	0	0	0	0
1992	3130	64899	-1177	18233	0	0	0	0
1993	0	64899	900	19133	0	0	0	0
1994	713	65612	3456	22589	0	0	0	0
1995	0	65612	3370	25959	0	0	0	0
1996	2240	67852	1296	27255	0	0	0	0
1997	11046	78898	1	27256	0	0	0	0
1998	-708	78190	17727	44983	0	0	0	0
1999	21579	99769	10854	55837	0	0	0	0
2000	5574	105343	4992	60829	0	0	0	0
2001	0	105343	15228	76057	2070	2070	0	0
2002	-1521	103822	37116	113173	0	2070	864	864
2003	508	104330	12291	125464	0	2070	3456	4320
2004	540	104870	62546	188010	0	2070	0	4320
2005	291	105161	6480	194490	0	2070	0	4320
Proposed	7970	113131	0	194490	0	2070	432	4752

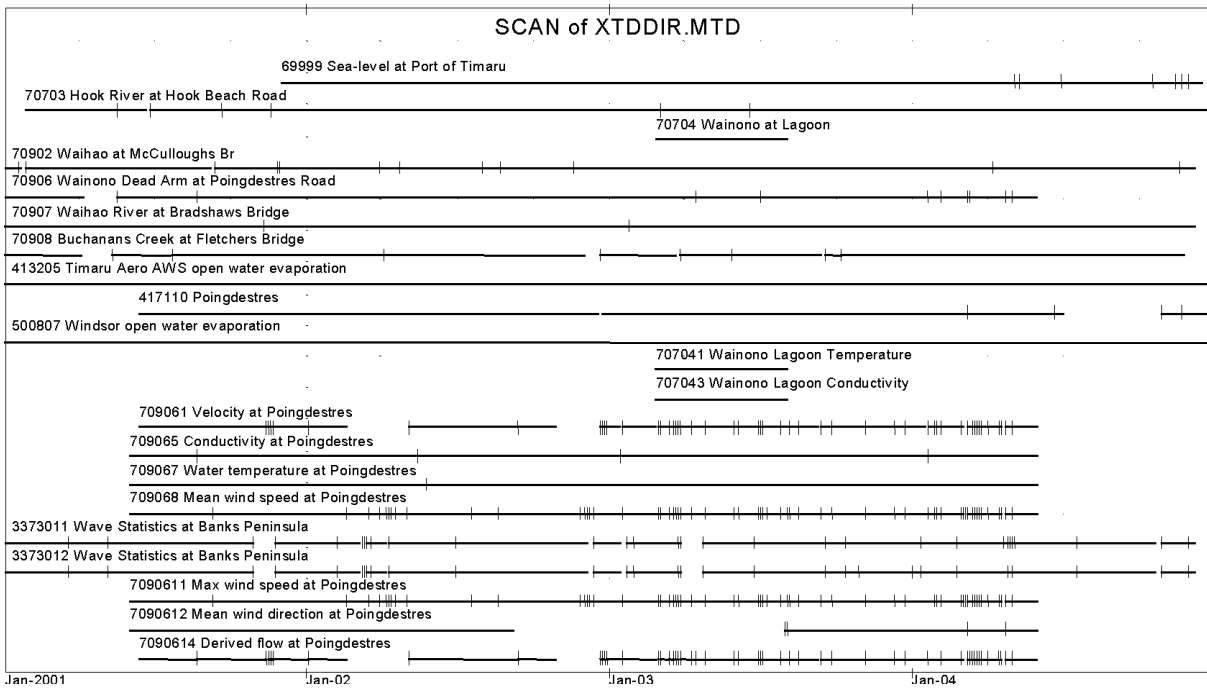
**Groundwater Daily Volumes by Allocation Zone and Aquifer (as of 23 June 2005)**

	Wainono			Pareora			Otaio			Makikihi	
	Quaternary	Taratu	Cannington	Quaternary	Taratu	Cannington	Quaternary	Southburn	Cannington	Quaternary	Cannington
Pre 1973	2799		1818	9763							
1974				1491							
1975			237								
1976											
1977										36	
1978				953							
1979	9753			2365			73				
1980	680		1171	1361						2755	
1981	2143		3178								
1982				1142							
1983	14		2932	4369							
1984	1310		1428	5772							
1985			785								
1986										2617	
1987										514	
1988	353		-8								
1989	-61		790	10118		7079					
1990				9			1440				
1991											
1992	206		-1177				1440			1484	
1993			900								
1994	713										3456
1995			3370								
1996	2240		1296								
1997	296		1	10738						12	
1998			-1808							-708	19535
1999	5159		7411	16420		1931			1512		
2000	1273		4992	4301							
2001			10632					2070	4596		
2002	97	864	7511	1078		7268	-17		18103	-2679	4234
2003	2478		2592		3456	4320				-1970	5379
2004	540		7294			5832					49420
2005	291		6480								
<b>Proposed</b>	6307	432		194			1469				

**Groundwater Consents within Southburn Sand and Taratu Formation (23 June 2005)**

Well No	Consent	Average Daily Rate	Effective Allocation (m <sup>3</sup> /year)	Aquifer	Aquifer Zone
J40/0894/454	CRC001819	3024	332,775	Tarutu	Elephant Hill-Douglass
J41/0063	CRC990438	3110	1,132,040	Southburn Sand	Elephant Hill-Ikewai
J40/0652	CRC030417	864	164851	Tarutu	Kapua-Arno
J40/0641	CRC021531	1728	388435.5	Tarutu?	No Zone (no outcrop)
J39/0481/482	CRC030876	3456	333963	Tarutu	No Zone (no outcrop)
J39/0247	CRC011511.1	2070	304272	Southburn Sand	Otaio-Esk Valley
J39/0531	CRC050890	6221	474862	Southburn Sand	Otaio-Esk Valley
J38/0328	CRC000492	259	49417	Southburn Sand	Southburn-Sutherlands
J38/0571	CRC031343	1383	145800	Otakau?	Southburn-Sutherlands
J38/0593	CRC040052	1728	139968	Southburn Sand	Southburn-Sutherlands
J38/0622	CRC041122	492.5	51206	Southburn Sand	Southburn-Sutherlands

## Appendix 40 Data availability Wainono Lagoon study



Time lines showing the availability of time series data for the Wainono Lagoon.

Note that "417110 Poingdestres" refers to the Poingdestres rainfall record. The Wainono Lagoon temperature and conductivity is recorded at the same location as 70704, Wainono Lagoon level. Locations of the recorders except for 3373011/2 Wave Statistics at Banks Peninsula and 69999 Timaru sea level are shown on Figure 5-1.

## Appendix 41 Flow recorder site Poingdestres Rd



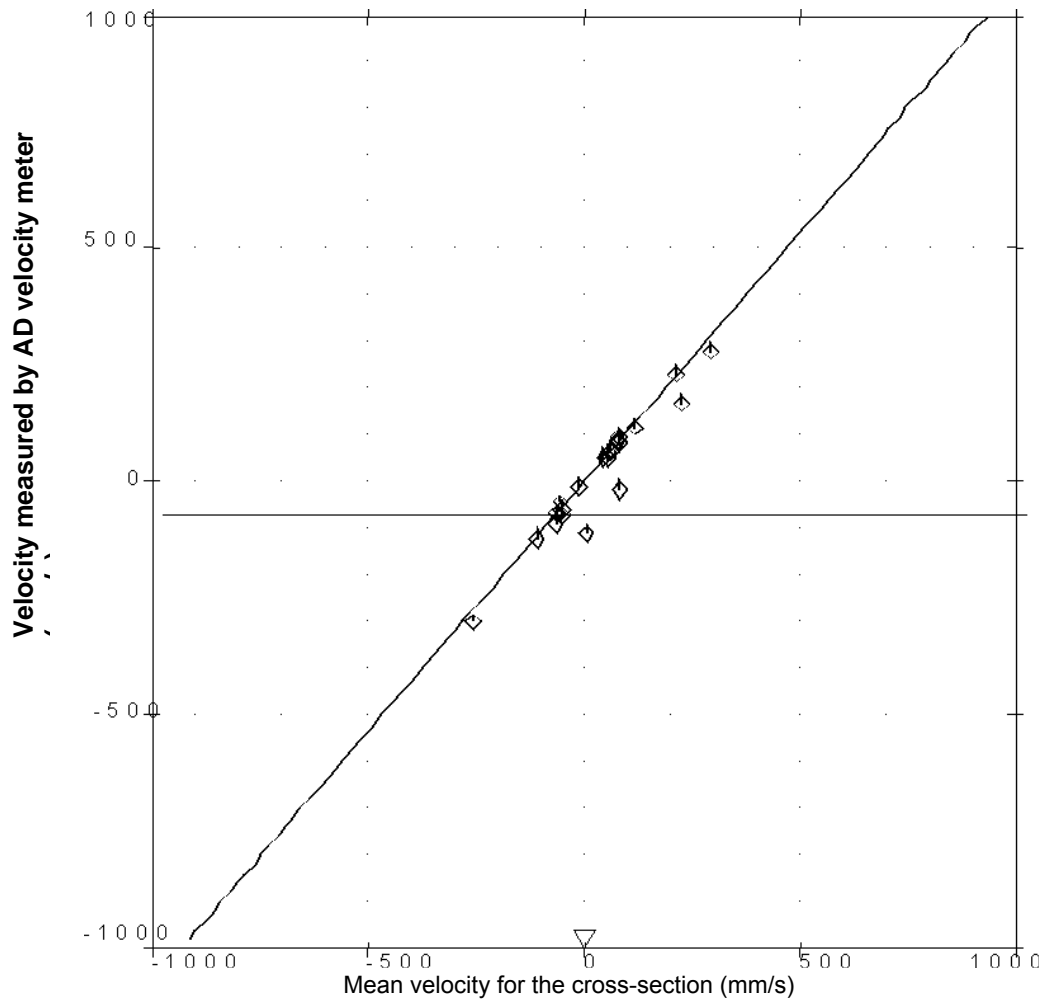
**Figure 1** Picture of the water level recorder on the Dead Arm at Poingdestres Road (station number 79706)

The picture is looking northeast from the bridge. Stakes holding the underwater acoustic Doppler velocity measurement equipment are visible to the right of the staff gauge and in the left foreground. The lagoon is to the left of the picture and the beach barrier forms the distant flat horizon. (*photo: A.I. McKerchar, 30.11.04*) The Poingdestres Road recording site is a particularly challenging for flow measurement because no unique relation exists between level and flow, and flow can reverse several times a day. The solution adopted for measuring discharge at this site has been to install an acoustic-doppler (AD) velocity meter that measures flow velocity across the channel.

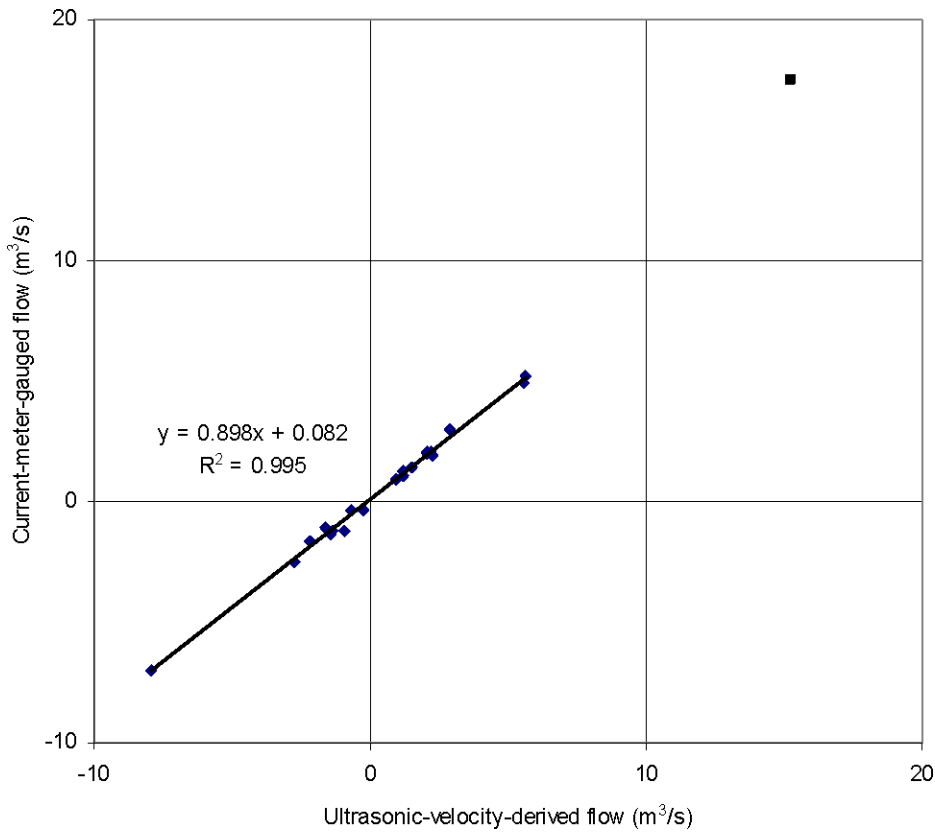
The measurements are scaled to yield estimates of mean velocity in the cross-section. The “rating” curve, used to scale the measured AD velocities to the mean velocity in the cross-section, is presented in Figure 2. From each recorded level, cross-section area is deduced and discharge is taken as the product of mean velocity and cross-section area. Comparison of a series of conventional current meter gaugings for this site with the AD-velocity-derived (rated) discharges at the same times Figure 3 indicates a slight bias in the derived discharge record: apart from the highest gauging at approximately 17 m<sup>3</sup>/s, the absolute values of the current-meter-gauged-flows are somewhat less than the rated flows. To correct for this bias, a straight line fitted by least squares to the gaugings, except the highest, has the equation (Figure 9):

$$Flow_{gauged} = 0.898 * Flow_{rated} + 0.082 \quad (m^3/s)$$

This correction is applied to all the Poingdestres flow data. Note the convention adopted is that negative discharge is flow into the lagoon; positive flow is flow out of the lagoon toward the Waihao Box. The flow duration curves for the filed data and for the data corrected to the current-meter gaugings are presented in Figure 10. Data for percentiles of interest are presented in Table 1. The interesting feature of these data is the range of values between positive and negative flows, even though the mean (0.644 m<sup>3</sup>/s) is quite low. Eighty percent of the time the flow rate is in the range +3 m<sup>3</sup>/s to –2 m<sup>3</sup>/s.

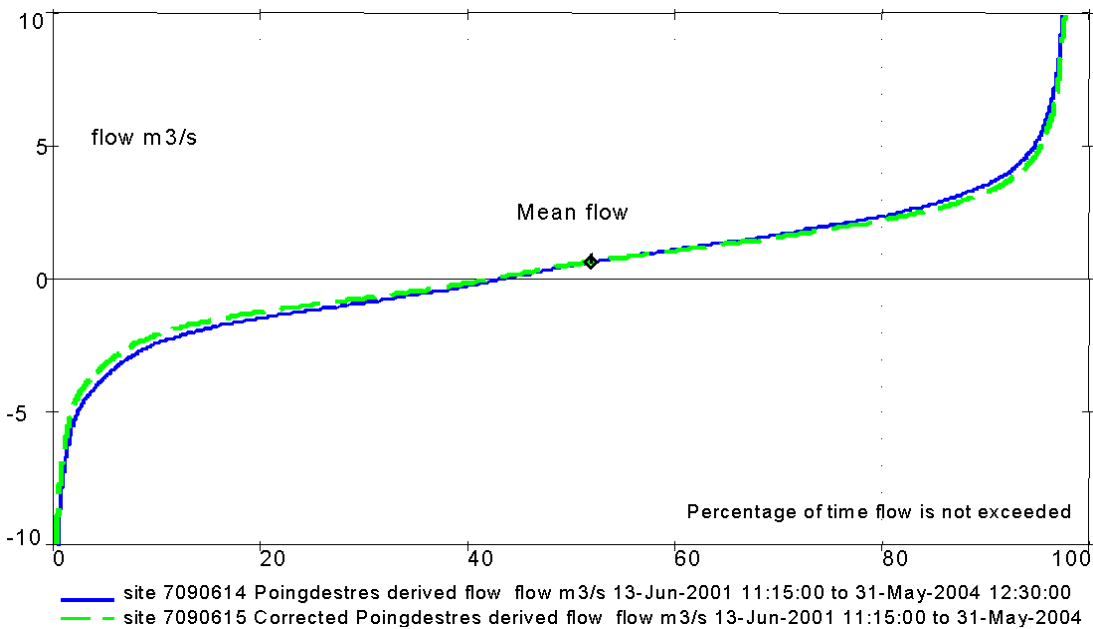


**Figure 2** Rating curve used to convert velocities measured by the FlowTracker acoustic doppler (AD) velocity meter to mean velocities in the cross-section.



**Figure 3: Current-meter-gauged flows at Poingdestres vs AD-velocity-derived flows**

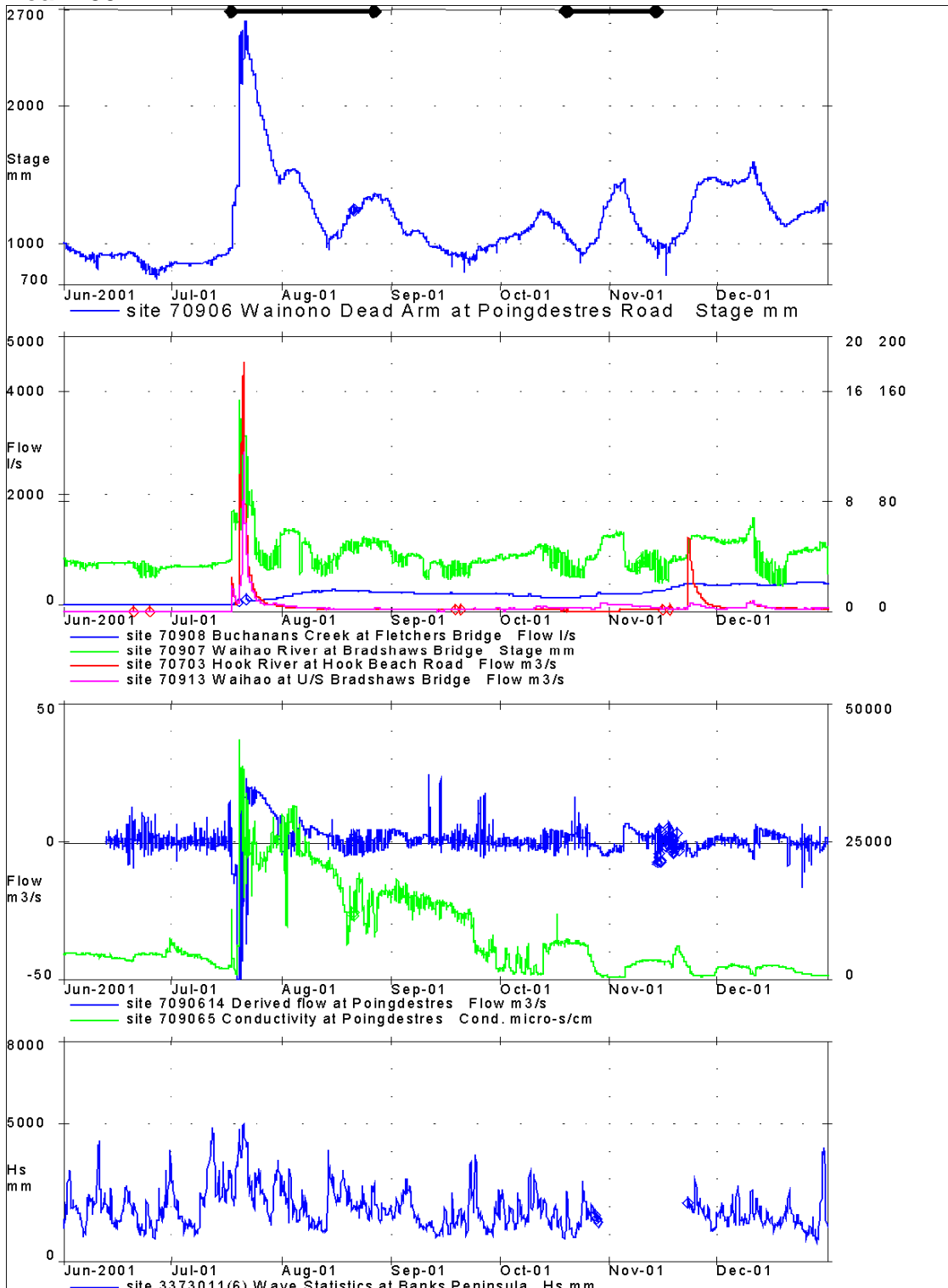
The convention used in the report is that negative discharge is flow into the lagoon; positive flow is flow out of the lagoon toward the Waihao Box.



**Figure 4 Flow duration curve**

Flow duration curve for Poingdestres flow data, as filed (blue), and scaled to current meter gaugings using the best fit line in Figure 3: Current-meter-gauged flows at Poingdestres vs AD-velocity-derived flows (green).

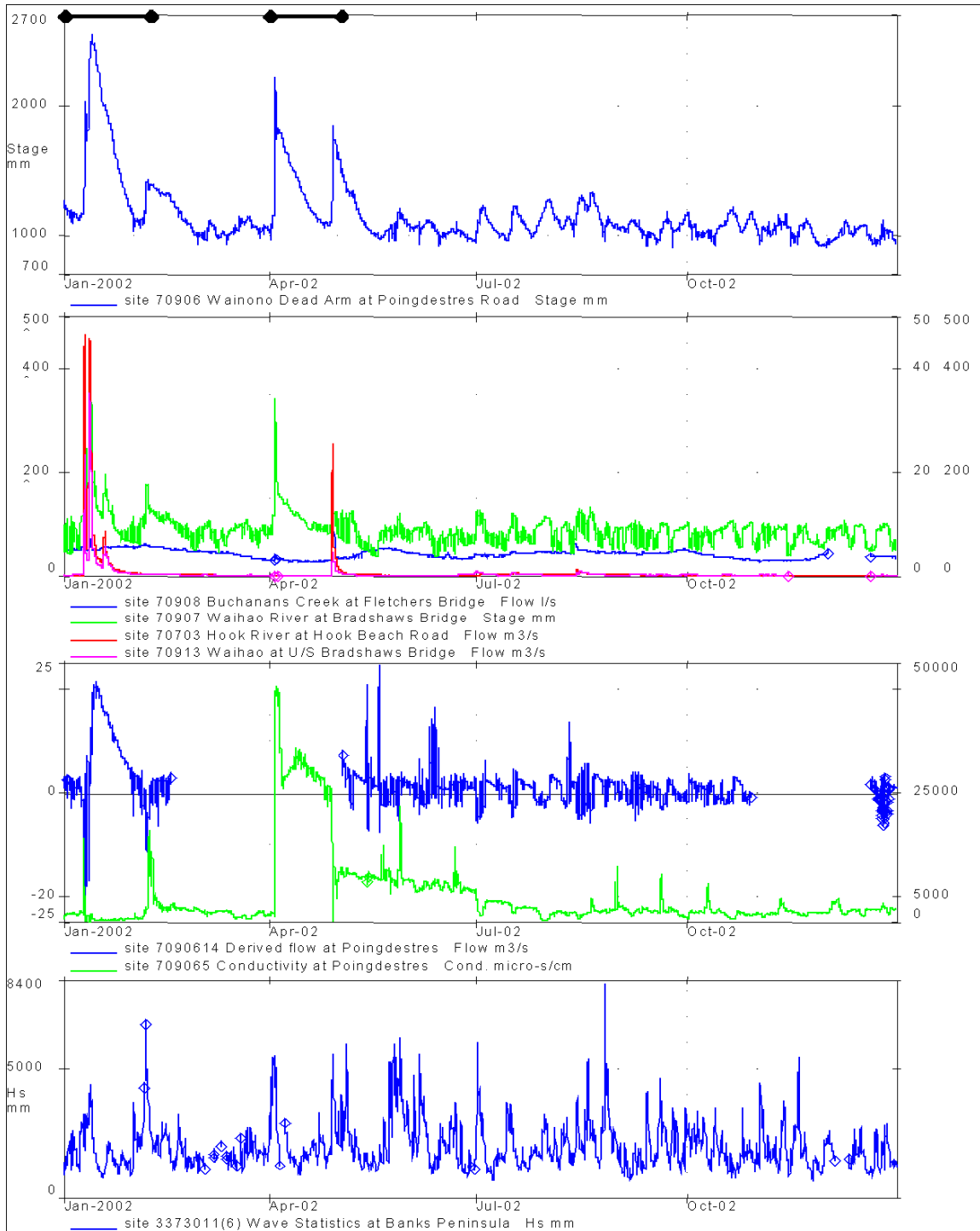
## Appendix 42 Overview Plots Wainono Lagoon Year 2001



**Figure 5 Wainono Lagoon Levels, flows, conductivity and wave data recorded in 2001**

Levels, flows, conductivity and wave data recorded in 2001. Note that in the second panel stage data are shown for the Bradshaws Bridge site. Also, the scales for the Hook and Waihao flows in the second panel, and conductivity in the third panel, are on the right-hand-side. The wave data in the lowest panel are significant wave heights recorded at the Banks Peninsula wave rider buoy. Black bars along the top of the first panel identify periods examined in main report.

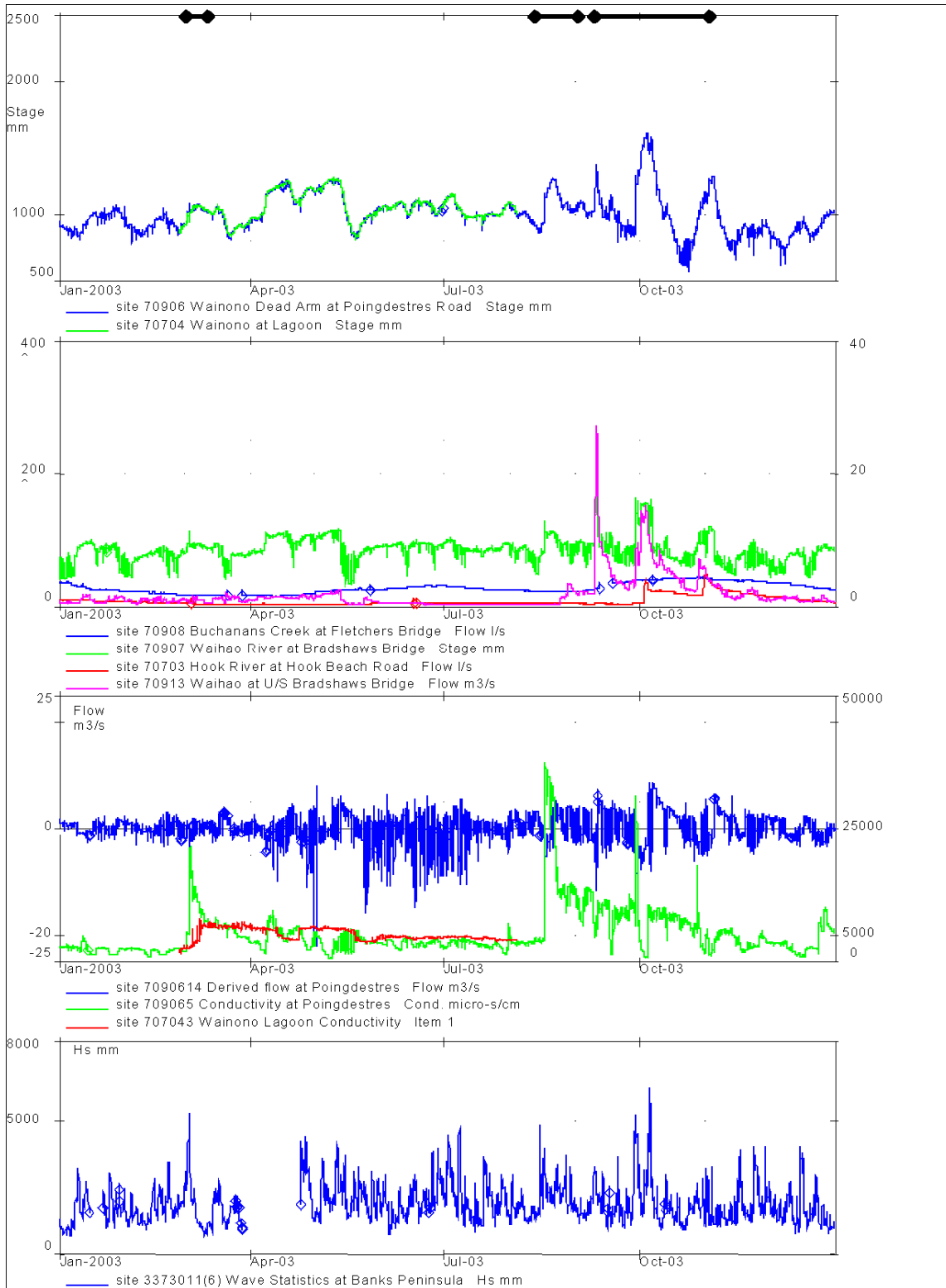
**Year 2002**



**Figure 6 Wainono Lagoon Levels, flows, conductivity and wave data recorded in 2002**

Note that in the second panel stage data are shown for the Bradshaws Bridge site. Also the scales for the Hook and Waihao flows in the second panel, and conductivity in the third panel, are on the right-hand-side. The wave data in the lowest panel are significant wave heights recorded at the Banks Peninsula wave rider buoy. Black bars along the top of the first panel identify periods examined in greater detail in the main report.

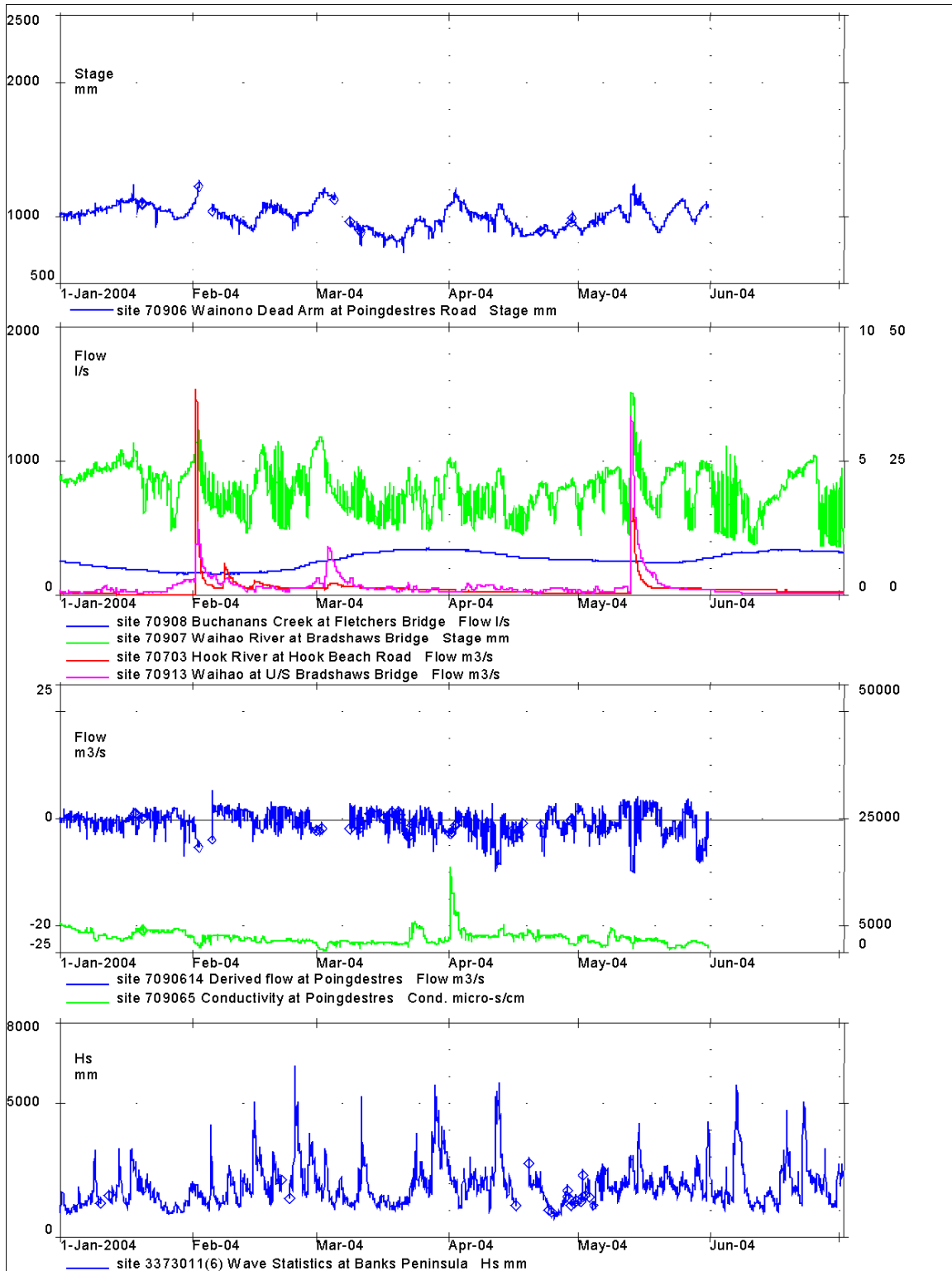
Year 2003



**Figure 7 Wainono Lagoon Levels, flows, conductivity and wave recorded in 2003**

In the top panel the short record of levels measured in the lagoon over plots the levels measured at Poingdestres. Note that in the second panel stage data are shown for the Bradshaws Bridge site. Also, the scales for the Waihao flow in the second panel, and conductivity in the third panel, are on the right-hand-side. The third panel includes a short period of conductivity data measured in the lagoon. The wave data in the lowest panel are significant wave heights recorded at the Banks Peninsula wave rider buoy. Black bars along the top of the first panel identify periods examined in detail in the report.

**Year 2004**



**Figure 8 Levels, flows and conductivity recorded in January to June 2004**

Note that the scales for the Hook and Waihao flows in the second panel, and conductivity in the third panel, are on the right-hand-side. The wave data in the lowest panel are significant wave heights recorded at the Banks Peninsula wave rider buoy.

## Appendix 43: Wainono Lagoon seepage study - Goring



### **Wainono Lagoon Seepage Background**

One of the most important parameters in calculating the seepage from Wainono Lagoon to the sea is the depth of the impermeable layer, for this influences both the permeability and the flow through the berm. Goring & Willsman(2003)<sup>2</sup> found that variations of  $\pm 0.3$  m in the level of the impermeable layer results in errors of  $\pm 30\%$  in the estimate of the total seepage flow. Therefore, any opportunity to refine estimates of the depth of the impermeable layer is worth pursuing.

### **The Project**

DTec Consulting Ltd is assessing the changes to the Wainono berm as a result of hydro development in the Waitaki River for Meridian Energy Ltd. As part of their studies, one of Derek Todd's students dug several pits in the berm and analysed the material dug out. Perhaps this information would help to resolve how the depth of the impermeable layer varies along the berm?

### **Results**

Investigation has revealed that the student stopped digging when they reached the level where silt was encountered. They called this the level of the "substrate" and they mapped how it varied across the berm, essentially following the shape of the armouring on the berm. Unfortunately, this substrate is 1 to 2 m above MSL and 1.5 to 2.5 m above the impermeable layer.

Derek Todd and I have discussed whether the level of the substrate would be indicative of the level of the impermeable layer and we have concluded it would not. We believe the substrate comes from silt in suspension in waves. When the waves break onto the berm the silty seawater percolates down through the porous gravels until the velocity reduces to zero and the silt drops out of suspension, coating the nearby gravel and making the gravel less permeable. Over years, the silty gravel builds up higher and higher. On the other hand, the impermeable layer is much older and probably comes from the bed of the lagoon itself. Indeed, Figure 8 of Goring & Willsman(2003) shows the material in the impermeable layer. It is blue pug, quite unlike the yellow silt that lies above it which can be seen in Figures 5 and 6.

### **Conclusions**

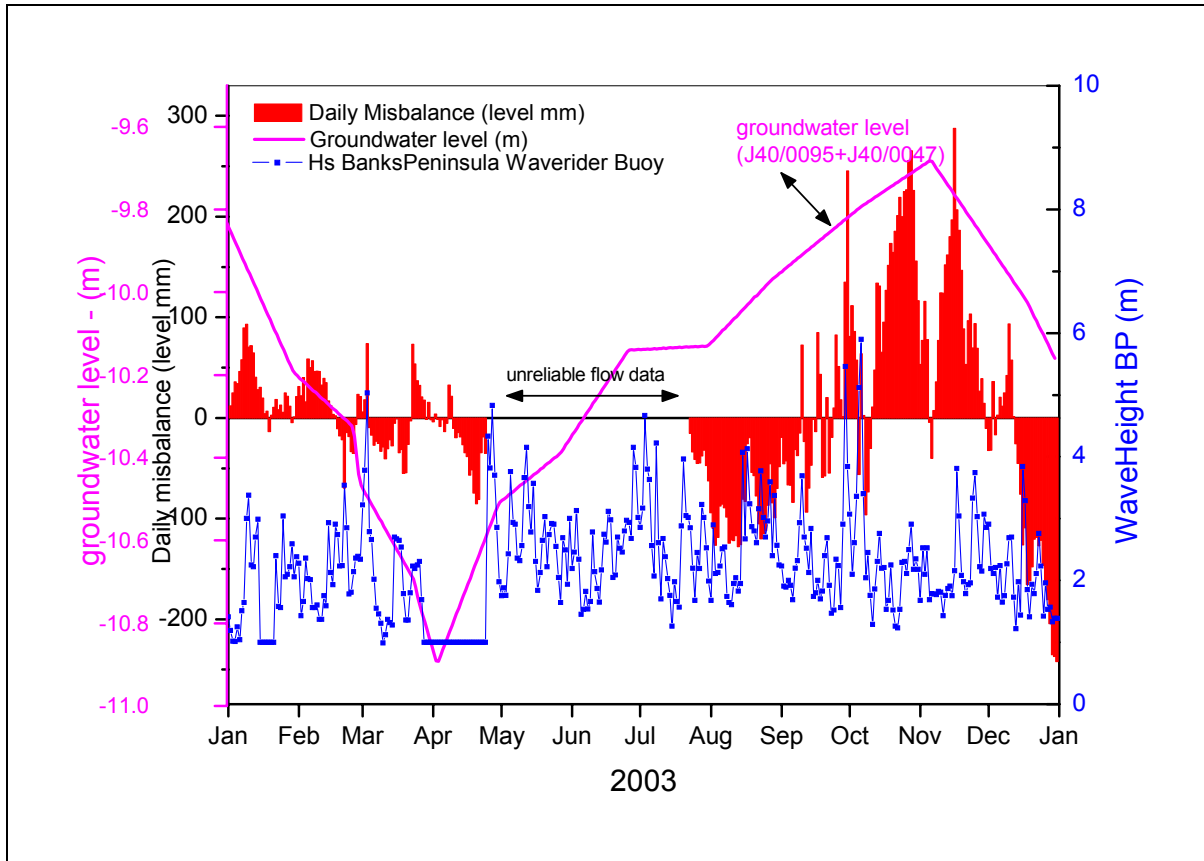
The position of the substrate, or the depth where the gravels become silty, is not indicative of the depth of the impermeable layer under the Wainono berm. To obtain more information about the depth of the impermeable layer, pits need to be dug to at least 0.5 m below MSL, or approximately 5 to 6 m below the top of the berm. This entails digging holes at least 5 to 6 m in diameter, which requires the use of a large hydraulic excavator.

Derek Goring  
Mulgor Consulting Ltd  
Sunday, 1 May 2005

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<sup>2</sup> Goring, D. G.; Willsman, A. 2003: Wainono Lagoon seepage.: Stage 2. NIWA Client Report CHC2003-047, 26 pp.

## Appendix 44 Possible seasonal groundwater input and influence of sea wave height.



Model based on daily inputs / outputs in 2003.

When the known inputs and outputs are compared with the change in level of the lagoon, the water balance appears to close when a constant inflow rate of 400 L/s between 1<sup>st</sup> Jan and the 22<sup>nd</sup> of May 2003 is added to the lagoon and 700l/s between 22<sup>nd</sup> July and the 31<sup>st</sup> of December 2003. From the remaining daily difference it seems that a variable groundwater component could improve the model (high groundwater level in October/November coincides with a shortfall of inflows.)

The wave height also seems to correlate with some of the positive peaks but is of shorter duration (meaning: more water comes in because of wave action). This suggests that improvements to the water balance can be made if some input parameters are considered and refined further.

However, the main focus for improvement should be on the flow through the barrier as this is the largest variable not measured.

## Appendix 45 Wainono Lagoon water balance model

Date	Measur ed level mm	Lake Storage m <sup>3</sup>	Lake Area m <sup>2</sup>	Inflows			1/s										Outflows				Total Out m <sup>3</sup> /d	unmeasur ed	
				Hook m <sup>3</sup> /s	Poingdestre m <sup>3</sup> /s	Total It m <sup>3</sup> /d	G/W Ig m <sup>3</sup> /d	Rain Ir m <sup>3</sup> /d	Total in m <sup>3</sup> /d	Hlagoon m	Hsea m rec	Hsea m AOSL	Barrier s m <sup>3</sup> /s	Barrier Os m <sup>3</sup> /d	Pan Corr	Timaru Openen	Evap Oe mm	Evap Oe m <sup>3</sup> /d					
13-Jun-01	919	1547000	4292	0.02	1.238	-1.22	-105235	12096	0	0	-93139	0.919	1.435	0.000	0.000071	0.34	29317	0.81	16	13	55624	84941	-178081
14-Jun-01	919	1547000	4293	0.021	0.355	-0.33	-28858	12096	0	0	-16762	0.919	1.435	0.000	0.000071	0.34	29317	0.81	17	13.8	59115	88432	-105193
15-Jun-01	914	1547000	4294	0.023	0.267	-0.24	-21082	12096	0	0	-8986	0.914	1.435	0.000	0.000071	0.34	29079	0.81	16	13	55650	84729	-93715
16-Jun-01	923	1582000	4295	0.024	0.417	-0.39	-33955	12096	0.5	2148	-19712	0.923	1.435	0.000	0.000072	0.34	29508	0.81	6	4.86	20874	50382	-105094
17-Jun-01	922	1582000	4296	0.025	0.368	-0.34	-29635	12096	0.5	2148	-15391	0.922	1.435	0.000	0.000072	0.34	29460	0.81	7	5.67	24358	53819	-69210
18-Jun-01	923	1582000	4297	0.025	0.167	-0.14	-12269	12096	1.5	6446	6273	0.923	1.435	0.000	0.000072	0.34	29508	0.81	7	5.67	24364	53872	-47600
19-Jun-01	939	1617000	4298	0.025	2.333	-2.31	-199411	12096	0	0	-187315	0.939	1.435	0.000	0.000074	0.35	30279	0.81	8	6.48	27851	58130	-280445
20-Jun-01	937	1617000	4299	0.026	1.97	-1.94	-167937	12096	0	0	-155841	0.937	1.435	0.000	0.000073	0.35	30182	0.81	6	4.86	20893	51075	-206916
21-Jun-01	916	1547000	4300	0.028	2.211	-2.18	-188648	12096	0	0	-176552	0.916	1.435	0.000	0.000071	0.34	29174	0.81	16	13	55728	84902	-191454

First part of the spreadsheet where the daily ‘unmeasured inflow/outflow’ is calculated.

The change in lagoon storage is calculated from the change in level combined with the bathymetry data of the lagoon (appendix 46). The evaporation total is the Timaru Airport open pan evaporation corrected with monthly factors to from (Hounam 1973) multiplied with the area of the lagoon, which is also derived from the bathymetry data of the lagoon (appendix 47).

Date	Measur ed level mm	Lake Storage m <sup>3</sup>	Lake Area m <sup>2</sup>	Hook m <sup>3</sup> /s	Poingdestre m <sup>3</sup> /s	Total It m <sup>3</sup> /d	G/W Ig m <sup>3</sup> /d	Rain Ir m <sup>3</sup> /d	Total in m <sup>3</sup> /d	Hlagoon m	Hsea m rec	Hsea m AOSL	Barrier s m <sup>3</sup> /s	Barrier Os m <sup>3</sup> /d	Pan Corr	Timaru Openen	Evap Oe mm	Evap Oe m <sup>3</sup> /d	Total Out m <sup>3</sup> /d	unmeasur ed				
																					Stage Brads	Diff Brads	PNG flow	Model ed Level
13-Jun-01	919	1547000	3444	-2061	875	44	1.2	0.000	2	0.000	919	919	1547000	3444	0.020	12096	0	0	13824	1.43509	-29228	12.96	44634	-162675
14-Jun-01	919	1547000	3444	-1218	877	83	0.4	0.000	2	0.000	919	960	1723499	3579	0.021	12096	0	0	13910	1.43509	-27242	13.77	49283	-83153
15-Jun-01	914	1547000	3444	-1085	866	114	0.3	0.000	2	0.000	914	980	1820562	3632	0.023	12096	0	0	14083	1.43509	-26252	12.96	47071	-72896
16-Jun-01	923	1582000	3471	-406	880	130	0.4	0.000	2	0.000	923	1010	1907541	3711	0.024	12096	0.5	1856	16025	1.43509	-24741	4.86	18035	-111800
17-Jun-01	922	1582000	3471	-801	879	161	0.4	-1.736	2	1.736	922	1040	2035366	3788	0.025	12096	0.5	1894	16150	1.43509	-23200	5.67	21478	-70932
18-Jun-01	923	1582000	3471	-551	877	143	0.2	-1.417	2	1.417	923	1020	1972474	3737	0.025	12096	1.5	5606	19862	1.43509	-24231	5.67	21189	-50642
19-Jun-01	939	1617000	3498	-2436	897	113	2.3	-1.258	2	1.258	939	1010	1920522	3711	0.025	12096	0	0	14256	1.43509	-24741	6.48	24047	-281139
20-Jun-01	937	1617000	3498	-2395	889	171	2.0	-2.054	2	2.054	937	1060	2107220	3838	0.026	12096	0	0	14367	1.43509	-22155	4.86	18653	-210418
21-Jun-01	916	1547000	3444	-3836	846	104	2.2	-2.214	2	2.214	916	1070	2154513	3863	0.028	12096	0	0	14479	1.43509	-21627	12.96	50064	-163011

Second part of the spreadsheet

The daily modelled lagoon level is calculated from the measured inflows and outflows AND the daily ‘unmeasured inflow/outflow from part 1, except for the measured Poingdestres outflow, which in the model is calculated from the ‘positive side’ of the rating curve of the lagoon level height and outflow at Poingdestres (Appendix 48). The ‘negative’ rating curve (part for inflow *into* the lagoon) is handled in the model as a structure prevents inflows into the lagoon and only allows outflows. There is also a sill level modeled, e.g. a level where the outflow from the lagoon is prevented when the level drops below 1000 mm (modeled) stage height at Poingdestres. When the difference between Bradshaw’s and the modeled Poingdestres’ stage is negative (Bradshaw’s is higher during flood in the Waihao), the flows are prevented from entering the lagoon but also from leaving the lagoon.

The resulting model levels are plotted in the main text.

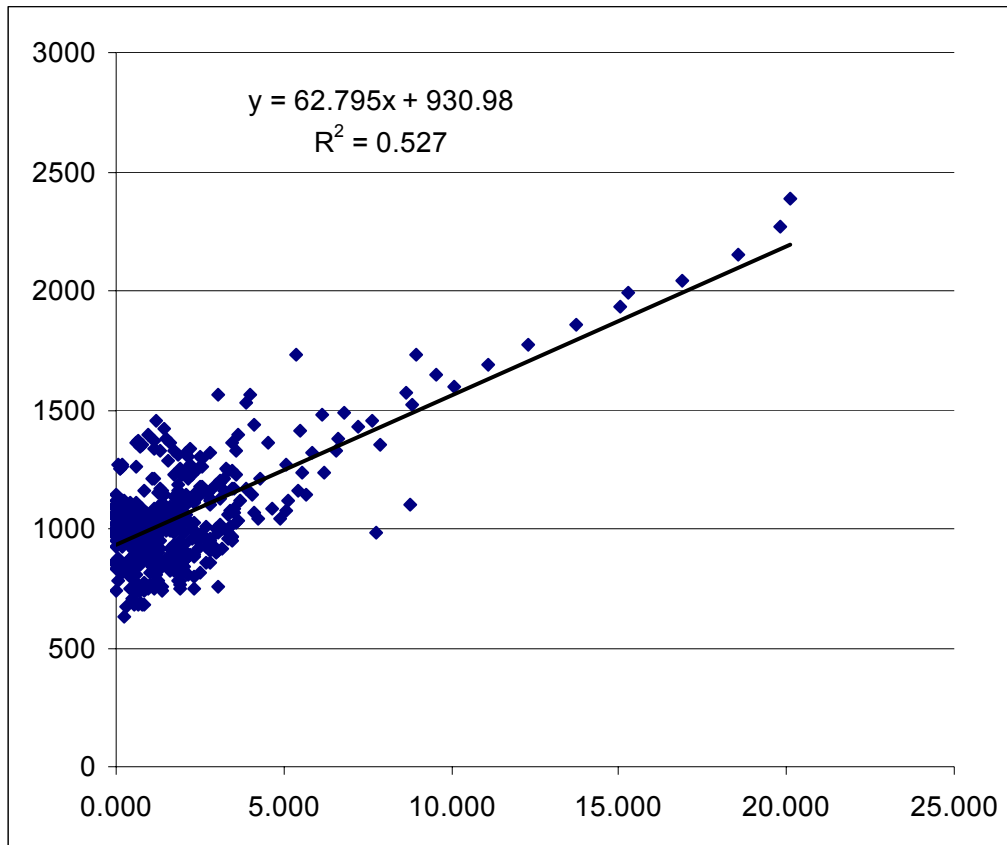
During the construction of the model it appeared that some periods in the Poingdestres flow data was unreliable. If the flow data is incorrect it can create a large “unmeasured in- or outflow” component that causes unrealistic lagoon level changes in the model. Therefore, several periods of flow data were not used and the model ‘restarted’ with measured lagoon levels after the unreliable period.

## Appendix 46 Wainono Lagoon lagoon level and volume (NIWA)

Level mm	Volume m <sup>3</sup> *1000								
		680	829	1290	3061	1900	6891	2510	12658
		690	857	1300	3108	1910	6970	2520	12770
		700	886	1310	3156	1920	7049	2530	12882
100		710	915	1320	3204	1930	7129	2540	12995
110	74	720	944	1330	3253	1940	7209	2550	13109
120	76	730	973	1340	3303	1950	7290	2560	13223
130	77	740	1003	1350	3353	1960	7372	2570	13338
140	78	750	1032	1360	3403	1970	7454	2580	13453
150	80	760	1063	1370	3455	1980	7536	2590	13569
160	81	770	1093	1380	3506	1990	7619	2600	13685
170	83	780	1124	1390	3558	2000	7703	2610	13802
180	85	790	1155	1400	3611	2010	7787	2620	13919
190	86	800	1186	1410	3664	2020	7871	2630	14037
200	88	810	1217	1420	3718	2030	7956	2640	14155
210	91	820	1249	1430	3772	2040	8042	2650	14274
220	94	830	1281	1440	3827	2050	8127	2660	14393
230	98	840	1314	1450	3882	2060	8214	2670	14513
240	102	850	1346	1460	3938	2070	8301	2680	14633
250	106	860	1379	1470	3994	2080	8388	2690	14754
260	111	870	1412	1480	4051	2090	8476	2700	14875
270	116	880	1445	1490	4108	2100	8564	2710	14997
280	121	890	1479	1500	4166	2110	8653	2720	15119
290	126	900	1513	1510	4224	2120	8742	2730	15241
300	132	910	1547	1520	4283	2130	8832	2740	15364
310	138	920	1582	1530	4342	2140	8922	2750	15487
320	144	930	1617	1540	4402	2150	9013	2760	15611
330	150	940	1652	1550	4462	2160	9105	2770	15735
340	157	950	1687	1560	4523	2170	9196	2780	15860
350	164	960	1723	1570	4584	2180	9289	2790	15985
360	171	970	1759	1580	4645	2190	9382	2800	16111
370	178	980	1795	1590	4707	2200	9475	2810	16237
380	186	990	1832	1600	4770	2210	9569	2820	16364
390	194	1000	1869	1610	4833	2220	9664	2830	16491
400	202	1010	1906	1620	4897	2230	9759	2840	16618
410	215	1020	1943	1630	4961	2240	9855	2850	16746
420	229	1030	1981	1640	5026	2250	9951	2860	16875
430	243	1040	2018	1650	5092	2260	10048	2870	17004
440	259	1050	2056	1660	5157	2270	10145	2880	17133
450	276	1060	2095	1670	5224	2280	10243	2890	17263
460	294	1070	2133	1680	5291	2290	10341	2900	17393
470	313	1080	2172	1690	5358	2300	10440	2910	17524
480	334	1090	2211	1700	5426	2310	10540	2920	17655
490	355	1100	2250	1710	5494	2320	10640	2930	17787
500	377	1110	2290	1720	5563	2330	10741	2940	17919
510	398	1120	2329	1730	5633	2340	10843	2950	18051
520	420	1130	2370	1740	5702	2350	10945	2960	18184
530	442	1140	2410	1750	5773	2360	11048	2970	18318
540	465	1150	2451	1760	5844	2370	11152	2980	18452
550	488	1160	2492	1770	5915	2380	11256	2990	18586
560	512	1170	2533	1780	5987	2390	11361	3000	18721
570	537	1180	2574	1790	6059	2400	11466		
580	562	1190	2616	1800	6132	2410	11572		
590	588	1200	2658	1810	6206	2420	11678		
600	615	1210	2701	1820	6280	2430	11785		
610	641	1220	2745	1830	6354	2440	11892		
620	667	1230	2789	1840	6429	2450	12000		
630	693	1240	2833	1850	6505	2460	12108		
640	719	1250	2878	1860	6581	2470	12217		
650	746	1260	2923	1870	6658	2480	12326		
660	774	1270	2969	1880	6735	2490	12436		
670	801	1280	3015	1890	6813	2500	12547		



## Appendix 48 Wainono Lagoon level and outflow at Poingdestress



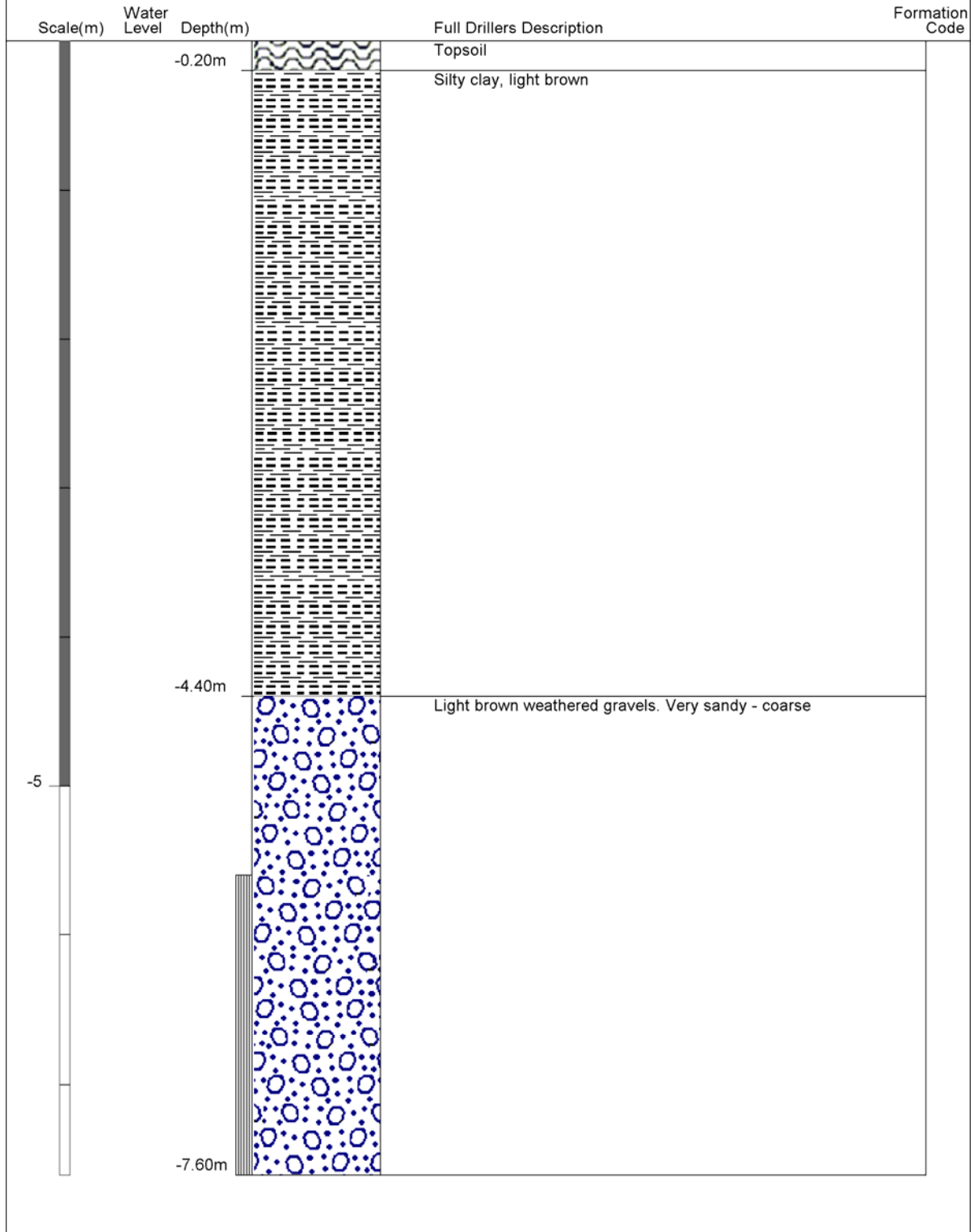
Note: This is the 'positive' side of the flow-level relationship. The **inflow** side is different. Poingdestres has two-way flows influenced by tides, lagoon levels and Waihao and Hook River flows.



**Borelog well on Hook Station Road (just northwest of Lagoon)**

**Borelog for well J40/0708**

Gridref: J40:62582-11995 Accuracy : 3 (1=best, 4=worst)  
 Driller : Washingtons Exploration Ltd  
 Drill Method : Rotary Rig  
 Drill Depth : -7.6m Drill Date :



## Appendix 50 Report Wainono Lagoon: Seawater Incursion by Derek G. Goring

# Wainono Lagoon: Seawater Incursion

**Derek G. Goring**

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consulting **ltd.**

Client Report 2006/3

**May 2006**

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## EXECUTIVE SUMMARY

There is strong evidence that seawater regularly flows into Wainono Lagoon. This study investigated the possible sources of seawater incursion.

For seawater to flow into the lagoon, sea levels must be higher than lagoon levels. However, after careful composition of the sea-level record, allowing for all possible errors, it was found that sea level exceeds lagoon level for only 2.6% of the time on a long-term basis. This is insufficient to explain frequent, substantial incursions of seawater into the lagoon.

Investigation into wave runup found that allowing for this, there is positive head between the ocean and the lagoon for between 60 and 70% of the time and the head exceeds 1 m for 20% of the time. However, wave runup is a probabilistic quantity, being the height that is exceeded by 2% of all incoming waves, so the actual duration when the head is positive is quite small.

Three mechanisms for seawater incursion were found:

- Wave overtopping — this occurs frequently (on average, 4 times per month) at the section of berm that was washed out in July 2002. Estimates of the flow in these events averaged over time have a median of 0.96 cumecs, with there being a 90% probability that flows are greater than 0.08 cumecs, and a 10% probability that they are greater than 4.74 cumecs.
- Seepage — allowing for the more permeable gravels higher in the berm and the narrower width, the seepage flow into the lagoon was estimated to be 0.005 cumecs as a result of wave runup.
- Deadarm flow — flow back through the box and up the deadarm occurs from time to time.

The conclusion is that the source of frequent and substantial incursions of seawater into Wainono Lagoon is waves overtopping the berm at the location of the washout caused by the July 2002 storm. The size of the flows into the lagoon as a result of these events is highly variable, but there is a 50% probability that the long-term average inflow exceeds 0.96 cumecs.

## 1. INTRODUCTION

In earlier work on Wainono Lagoon by the author (Goring, 2003 and Goring & Willsman, 2003), the emphasis was on calculating the seepage flow from the lagoon to sea. Subsequently, however, strong evidence has emerged that seawater regularly flows into the lagoon: (i) the salinity close to the berm is usually much higher than the salinity on the landward side of the lagoon; and (ii) the water balance is negative (i.e., there is insufficient flow into the system). Therefore, in this study, the emphasis is on investigating the possible mechanisms for seawater to flow into the lagoon on a regular basis.

The only way seawater can flow into the lagoon is if sea level is higher than lagoon level. Therefore, a primary objective is to determine accurate sea levels that have the same datum as the lagoon levels. This is the subject of Section 2. The mechanisms for seawater to flow into the lagoon are considered in Section 3.

## 2. SEA-LEVEL RECORD

Unfortunately, no direct measurements of sea level are made near the Wainono Lagoon, and the nearest measurements are at Timaru Port and at The Spit in the entrance to Otago Harbour (Figure 1).

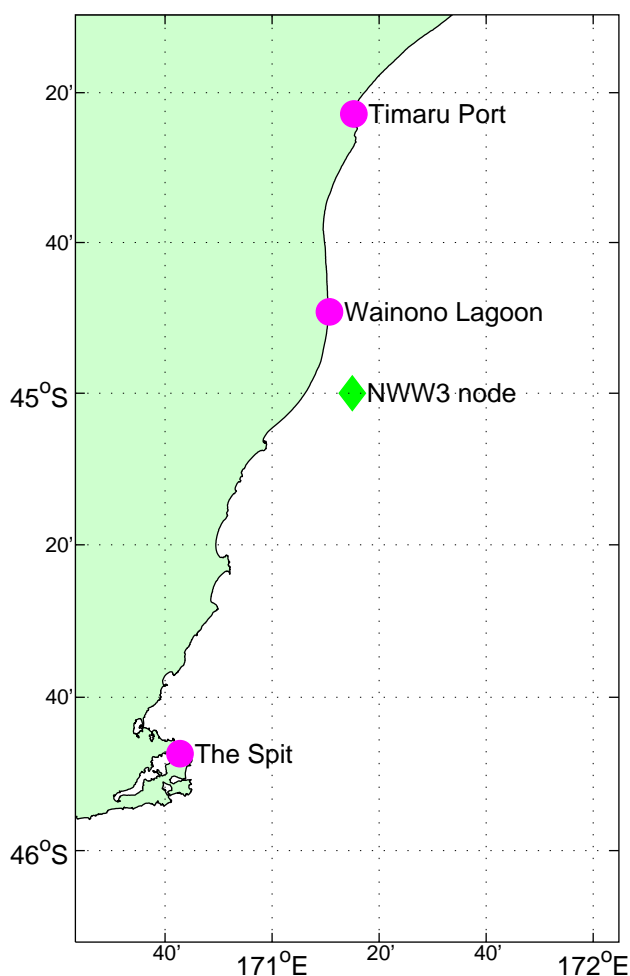


Figure 1. Map showing the location of the lagoon in relation to tide gauges at Timaru and The Spit, and the nearest node of NOAA's NWW3 global wave model.

Sea level has three components: tides, storm surge and MLOS:

- Tides, caused by the gravitational attraction of Sun and Moon on Earth's waters, vary spatially around New Zealand. The NIWA tide model (Walters, et al., 2001) allows tides to be estimated accurately anywhere in the EEZ.
- Storm surge, which is the response of the ocean to varying atmospheric pressure and wind, varies spatially, but not as much as tides. Storm surge measured at Timaru Port is the best estimate of storm surge at Wainono.

- MLOS, or mean level of the sea, is the response of the ocean to long-period effects such as the annual cycle, El Niño/Southern Oscillation, Interdecadal Pacific Oscillation, and, of course, rising sea levels. We expect MLOS to have little spatial variability, so MLOS from Timaru Port is the best estimate of MLOS at Wainono.

**2.1 Tides**

To check the accuracy of the NIWA tide model for Wainono, the tides forecast by the model for Timaru were compared with the measured tide. The results of this comparison are that the forecasts lead the actual tide by 10 minutes and, if this time error accounted for, the 95% confidence interval is  $\pm 0.080$  m. In other words, the tide can be forecast by the model to within  $\pm 0.080$  m for 95% of the time. For Wainono, we apply this time correction to forecasts from the model and assume the same confidence interval.

**2.2 Storm Surge**

Comparison of storm surge at Timaru with storm surge at The Spit (Otago Harbour entrance) for the 18 months of overlapping record gives 95% confidence intervals of  $\pm 0.176$  m about MLOS for Timaru and  $\pm 0.180$  m for The Spit. These results are consistent with variance in atmospheric pressure increasing with latitude. However, the difference is small, so we conclude that Timaru storm surge will be a good indicator of storm surge at Wainono.

**2.3 MLOS**

MLOS at Timaru and Spit are compared in Figure 2, where 0.04 m has been added to Spit MLOS to minimize the difference between the records. For Timaru, MSL is 1.41 m above chart datum, while for Spit it is 1.11 m (from the Nautical Almanac), so these quantities have been subtracted from the calculated MLOS to bring the levels to MSL datum. From a physical point of view, we would expect there to be little difference between MLOS at these two sites, but in fact there are differences as large as 0.07 m at times. The offset of 0.04 m between the two records reflects the difference in the MSL datum of the two sites. The mean MLOS for Timaru is 0.041 m above MSL and MLOS varies by  $\pm 0.08$  m about this from month to month. These numbers give an indication of the errors in sea level that are likely to arise from this portion of the sea-level spectrum.

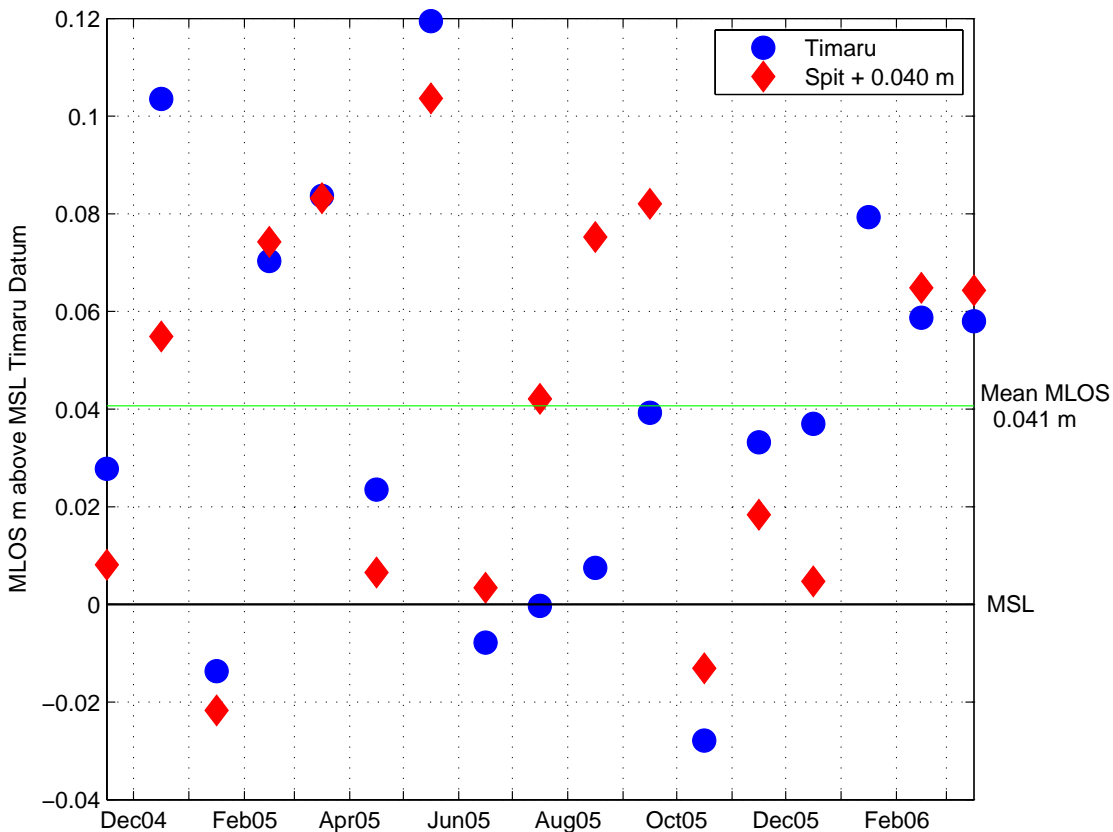


Figure 2. Comparison of monthly MLOS at Timaru and Spit.

## 2.4 Head

The nett head which is what drives any flow from the sea into the lagoon is given by:

$$\text{Head} = \text{Tide} + \text{Storm Surge} + \text{MLOS} - \text{Lagoon Level}$$

Assuming the quantities described in the previous sections are correct, the CDF and statistics of the Head for the period from Dec 2001 to Feb 2006 are presented in Figure 3. The statistical moments indicate that the distribution is close to Gaussian, though the negative kurtosis indicates the extremes are somewhat smaller than would be expected for Gaussian. The figure shows that for 97.4% of the time, lagoon level exceeds sea level, indicating that flow will be predominantly from the lagoon to the sea. However, if the sea level were elevated by 0.5 m, there would be positive head 25% of the time, and if it were elevated by 1 m, there would be positive head for 50% of the time. Examination of the records and interrogation of ECan (Timaru) staff denies the possibility that such large height differences could be errors in datums, yet these are the differences that would be required to explain frequent and substantial flows of sea water into the lagoon. So the question is posed: how could such differences occur?

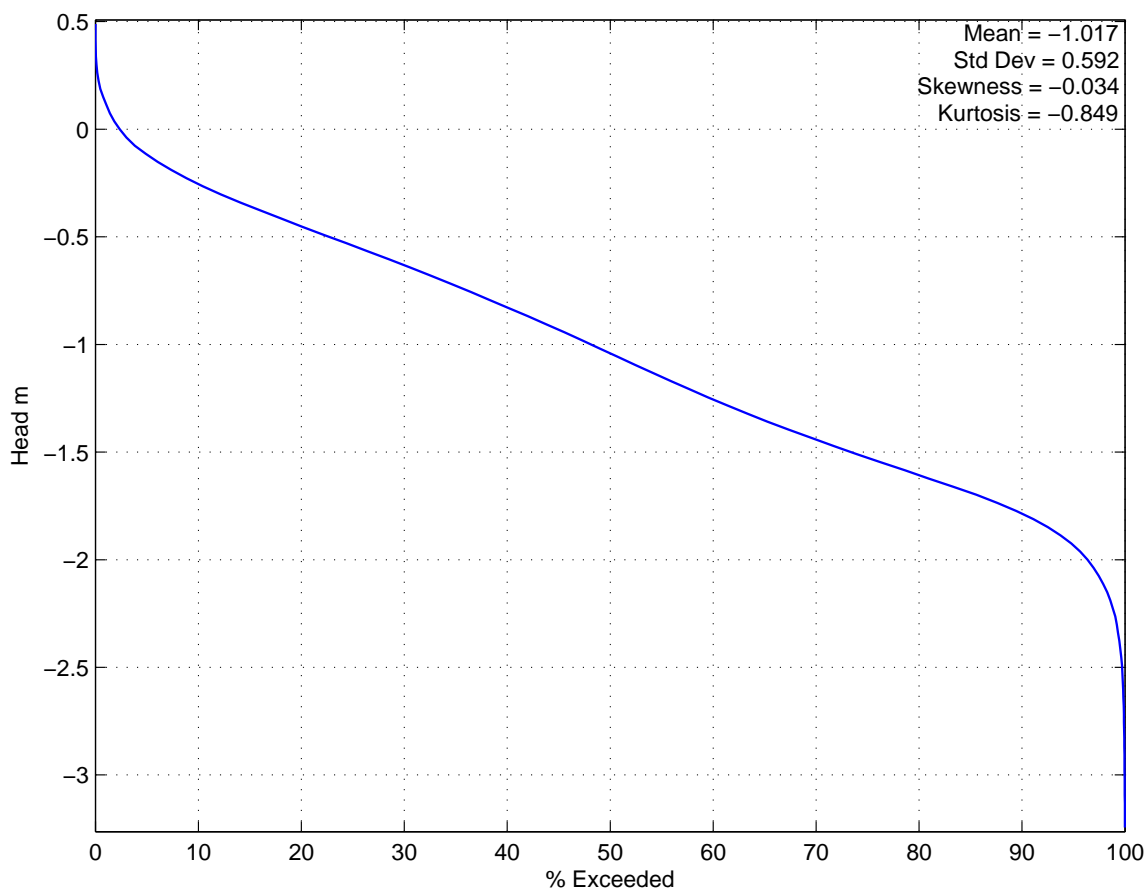


Figure 3. Cumulative distribution function for head (difference between sea level and lagoon level), with statistical moments listed.

## 3 MECHANISMS FOR SEAWATER INFLOW

There are two problems in explaining frequent and substantial flow of seawater into the lagoon: (i) the head (as explained in Section 2.4); and (ii) assuming there is adequate head, what is the mechanism? These points are considered separately in this section.

### 3.1 Generating Enough Head

One factor that was not considered in calculating the head is the effect of ocean waves. Compared to the other quantities under consideration, individual ocean waves have a much smaller time scale (seconds compared to hours and days), and they are oscillatory (i.e., the water flows in, and a few seconds later, it flows out), just like the tide. However, unlike the tide, the positive wave can break on the berm and surge up. The largest waves can surge over the berm. Such action is called “runup” and a great deal of work has been done on calculating runup, especially for extreme conditions on erosive beaches. Ruggiero et al. (2001)

describe laboratory and field measurements applied to the Oregon coast and suggest the following relationship for the 2% runup (i.e., the vertical height that is reached by 2% of waves):

$$R_{2\%} = 0.27 \sqrt{SHL} \quad (1)$$

where  $S$  is the slope of the beach,  $H$  is the deep water wave height, and  $L$  is the deep water wave length. The slope of the beach (i.e.,  $\tan\beta$ ) can be obtained from the profiles (Appendix B) giving a range of from 0.09 to 0.51 over the 15 profiles, with a median of 0.19. This is a very steep beach (the median slope is 4 times the largest slope of the Oregon beaches) and is classified as “reflective”, rather than “dissipative”. The deep water wave height and length can be obtained from the records of the NWW3 model at 6-hourly intervals from Mar 1997 to the present. This allows a time series of runup to be constructed. The CDF for wave runup is shown in Figure 4.

Also shown in Figure 4 is the CDF for an alternative method of calculating runup that is used by Dutch engineers calculating the runup on dikes (van der Meer, 2002). Dikes typically have slopes much steeper than the Wainono berm; however, the method can be applied to dikes with small slopes. The approach here is to first calculate the breaker parameter,  $\xi_0$ :

$$\xi_0 = \frac{\tan \alpha}{\sqrt{H/L}} \quad (2)$$

where in this case the slope  $\tan \alpha$  is the slope from water’s edge to the top of the berm (i.e., not the beach slope that was used earlier), which for Wainono varies between 0.09 and 0.18, and has a median of 0.12. The breaker parameter indicates whether waves will break on the slope or not. For  $\xi_0 > 2.5$ , the waves do not break, but surge up and down the slope. For Wainono,  $\xi_0$  varies between 0.34 and 4.33, with a median of 0.98, indicating that most waves break onto the beach, but some do not. Runup is calculated as:

$$R_{2\%} = 1.65 \gamma_b \gamma_\beta \gamma_f \xi_0 H \quad (3)$$

where:

$\gamma_b$  = berm factor – for Wainono it is 1.

$\gamma_\beta$  = angle of wave attack – for Wainono it is 1.

$\gamma_f$  = slope material factor – for the stony Wainono beach it is 0.85.

The CDFs in Figure 4 are quite similar, but the one based on Netherland dikes which gives larger runup is more likely to be applicable for Wainono because the berm is more like a dike than a dissipative beach. Furthermore, runup in excess of 5 m would be required for the berm to be overtopped, which has happened on occasion, but the Oregon beach method gives maximum runup of only 4.3 m.

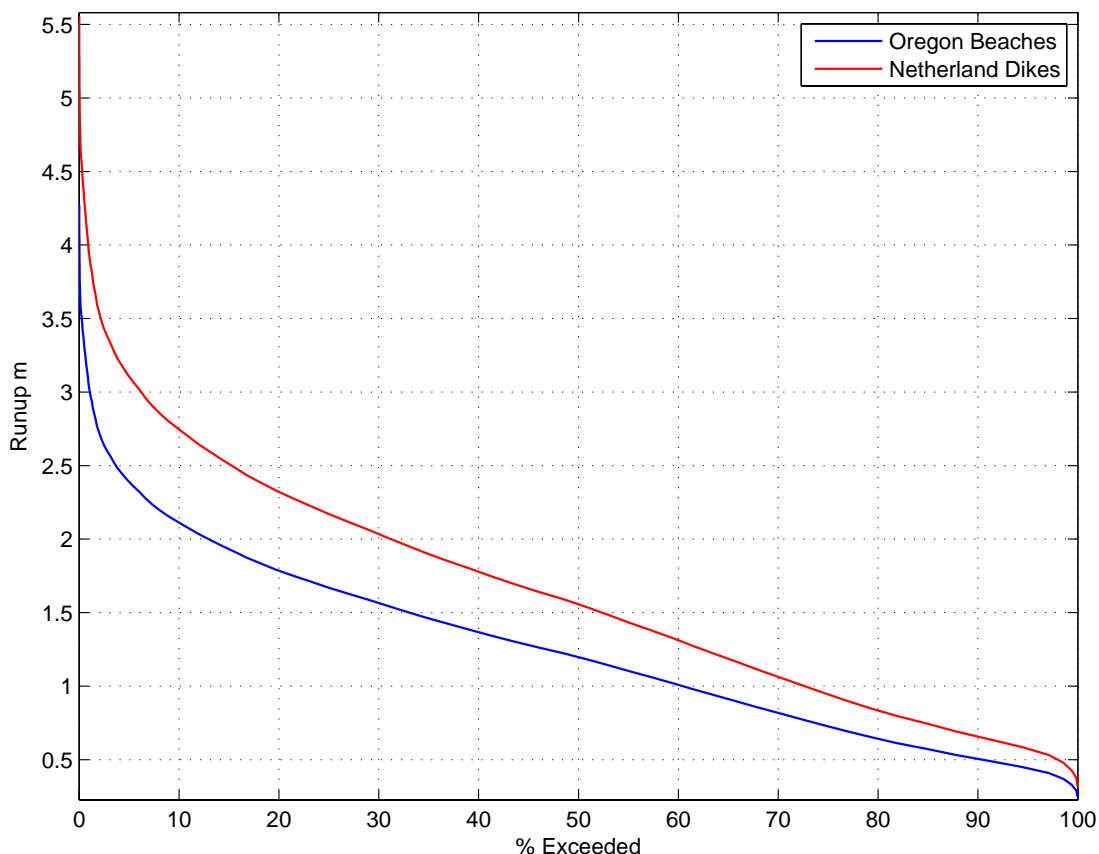


Figure 4. Cumulative distribution functions for runup calculated using two different methods based on (i) dissipative Oregon beaches and (ii) Netherland dikes.

By adding the runup to sea levels and subtracting the lagoon level, we obtain the head, as shown in Figure 5. The figure shows that incorporating runup has increased the likelihood of there being positive head between the ocean and the lagoon to being between 60 and 70%, and the head is likely to be greater than 1 m for at least 20% of the time.

We can also calculate the times when the lowest point in the berm will be overtopped, as shown in Figure 6. Analysis of these data indicate that using the Netherland dikes method for calculating runup, there were 216 overtopping events in the 53 months of record, some of them as short as 1 hour and some as long as 45 hours. However, it must be borne in mind that wave runup is a probabilistic quantity, being the height that is exceeded by 2% of all incoming waves. Thus, for 98% of the time, the head will be less than this.

This section has shown that the extra head required for seawater to flow into the lagoon is provided by the waves, but what is the mechanism for penetration through the berm?

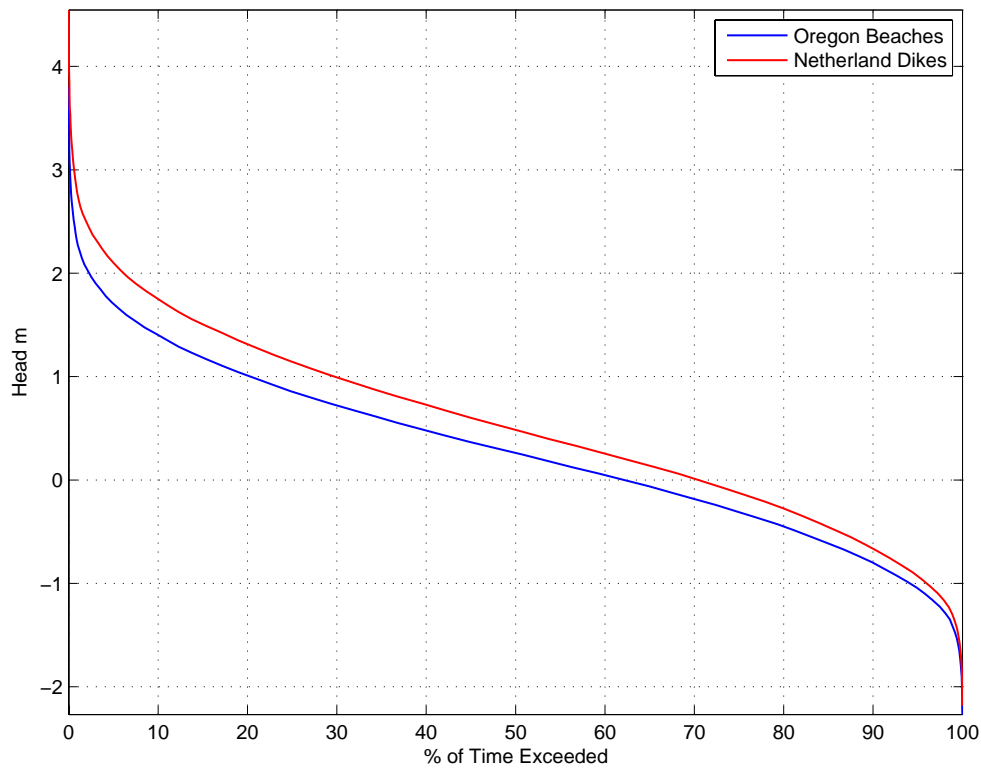


Figure 5. Cumulative distribution functions for head = sea level + runup – lagoon level

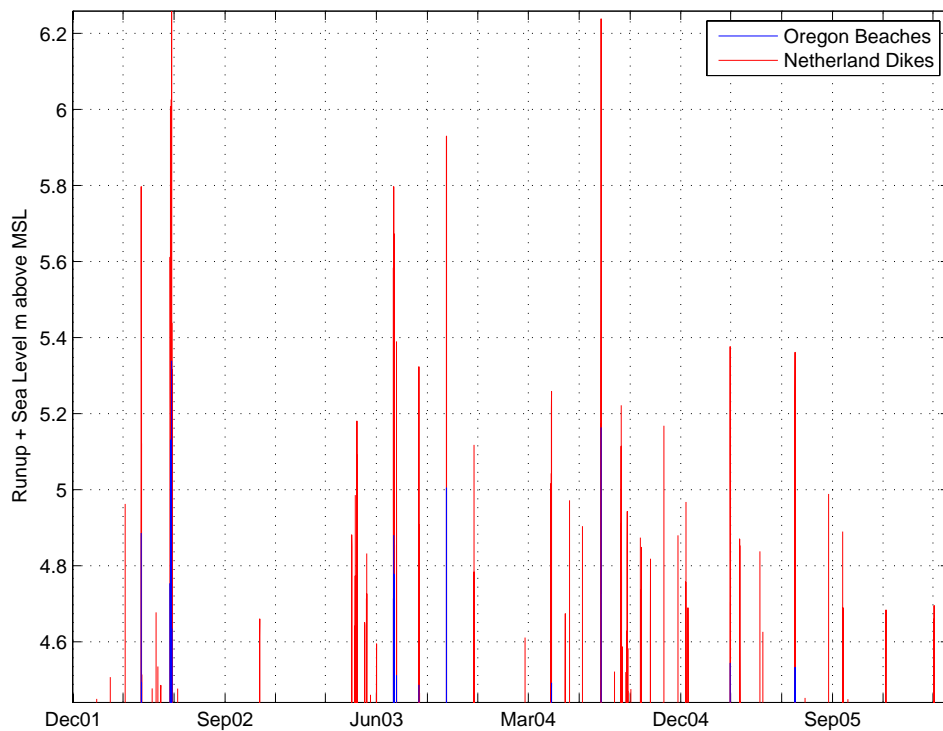


Figure 6. Overtopping events for Profile 3 (Northing 5609.6 km) where the crest level is 4.44 m.

### 3.2 Mechanisms for Seawater Penetration

In the previous section, we showed that for between 60 and 70% of the time, there is positive head between the ocean and the lagoon. In this section, we consider how that head could be transformed into seawater inflow.

### 3.2.1 Wave Overtopping

One obvious means for seawater to penetrate the lagoon is by waves overtopping the berm. Figure 6 shows this is a frequent event occurring on average 4 times per month, though there can be periods of several months when no overtopping occurs.

Van der Meer (2002) provides a method for calculating the volume of seawater that overtops a dike. First, we calculate the flow per wave per unit length of dike,  $q$ :

$$\frac{q}{\sqrt{gH^3}} = \frac{0.067}{\sqrt{\tan \alpha}} \xi_0 \exp \left[ -4.3 \frac{R_c}{H} \frac{1}{\gamma_b \gamma_\beta \gamma_f \xi_0} \right] \quad (4)$$

with a maximum of:

$$\frac{q}{\sqrt{gH^3}} = 0.2 \exp \left[ -2.3 \frac{R_c}{H} \frac{1}{\gamma_b \gamma_\beta \gamma_f} \right] \quad (5)$$

where  $R_c$  is the height of the crest.

To obtain the volume of water that overtops the dike from the average flow per wave per unit length,  $q$ , a probabilistic approach is required that uses the Weibull distribution for flow  $q$  and the Rayleigh distribution for runup  $R_{2\%}$ . The resulting equations are first of all the probability that a particular runup will cause overtopping (Rayleigh distribution):

$$P_{OV} = \exp \left[ - \left( \sqrt{-\ln 0.02} \frac{R_c}{R_{2\%}} \right)^2 \right] \quad (6)$$

and the volume for a given probability  $P_v$  (Weibull distribution):

$$V = \frac{0.84 T_m q}{P_{OV}} [-\ln(1 - P_v)]^{4/3} \quad (7)$$

where  $T_m$  is the mean wave period.

These relationships can be applied to the time series of waves and sea levels for each of the 15 profiles in the Wainono berm using the following steps:

1. From the times series of significant wave height and peak period from the NWW3 model, calculate the breaker parameter,  $\xi_0$ , from Equation (2) and the 2% runup,  $R_{2\%}$ , from Equation (3) using the berm slope for this profile.
2. Calculate a time series of pseudo crest height by subtracting the sea level height from the crest height – this gives the crest height relative to the runup.
3. Using Equations (4) through (7), calculate the volume per wave per unit length for probabilities of 10, 50, and 90%.
4. Calculate the flow per unit length by dividing by the wave period.

The flow over the length of the berm is obtained by integrating using Simpson's rule. The result is three time series of total overtopping flow (over the length of the berm), one for each of the three probabilities. If we now integrate these time series over the total length of time and divide by that time, we get the overtopping flow averaged over time. A summary of the results of this process is presented in Table 2, in which, for example, the flow of 0.08 cumecs for 90% exceedance means that there is a 90% probability that the flow will exceed 0.08 cumecs. Of course these overtopping flows are episodic, as indicated in Figure 6.

Furthermore, for a large proportion of the berm, the crest is more than 5 m high and will never be overtopped. In fact, for 12 of the 15 profiles, the crest is never overtopped, and for the remaining 3 profiles (in the washout region between 5609.3 and 5610.1 km Northing) overtopping occurs for less than 3% of the time.

**Table 2. Overtopping flows (cumecs) for various probabilities of exceedance.**

Parameter	% Exceedance		
	90	50	10
Overtopping Flow, averaged over time	0.08	0.96	4.74
Peak Flow	9.22	114	564

### 3.2.2 Seepage

Previous studies showed that the average seepage flow from the lagoon to the ocean is of the order of 0.4 cumecs (once a factor of 2 error in the original analysis is allowed for). Such flows occur because for 97.5% of the time, the lagoon level is higher than sea level (Figure 3). However, incorporating wave runup changes the head relationship to that shown in Figure 5 where the ocean is higher than the lagoon for between 60 and 70% of the time. The runup we are using here is the runup resulting from the highest 2% of waves, and of course for each of those waves, there is positive runup, then negative rundown. Ostensibly, we would expect that the flow penetrating the loose gravel in the berm on the runup will return to sea in the rundown. However, wave breaking is a highly nonlinear phenomenon and it is conceivable that a large proportion of the penetrating flow in the runup does not return to sea, but flows through the loose gravels near the top of the berm and eventually seeps into the lagoon.

Assuming that this occurs for every 50<sup>th</sup> wave and that the head difference applies only for half of the wave, we can obtain a time series of heads that apply for just 360 s every hour and substitute these into the Dupuit formula:

$$q = \frac{KH^2}{2 \times 86400 L} \quad (8)$$

where  $K$  is the permeability (in m/day),  $H$  is the head,  $L$  is the width of the berm, and  $q$  is the flow per unit length of berm. The permeability for lagoon seepage found by Goring & Willsman (2003) was  $K = 840$  m/day, so a reasonable estimate for the permeability in the looser gravels is  $K = 1000$  m/day. Then, using a berm width of 70 m, and assuming the length of the berm is 4760 m, Equation (8) yields an average flow rate of 0.005 cumecs, which is two orders of magnitude less than the seepage flow from lagoon to ocean seepage flow.

### 3.2.3 Flow up the Deadarm

Another possible source of seawater flow into the lagoon is reverse flow through the box and up the deadarm. However, for this to happen in normal tidal flows, sea level would have to be considerably higher than lagoon level. An example when reverse flow must have occurred is shown in Figure 7. This figure contains a lot of information, so we need to carefully go through it. It shows a 3-month period over the winter of 2003, from 1-Jun to 31-Aug. The lowermost plot shows that the flows in the Waihao River for the 3 month-period were constant at about 1 cumec.

Sea level significantly exceeded lagoon level only once in the period, for a few tides from 14 to 18 June. In response, there was a small but insignificant change in salinity, but the main effect was large negative flows at Poingdestres, indicating flow into the lagoon. The total volume of water flowing into the lagoon past Poingdestres from 14 to 19 Jun was 1.0 m·km<sup>2</sup>. The lagoon responded by increasing its level by 0.15 m, which is a volume of 0.7 m·km<sup>2</sup>, assuming a lake area of 4.3 km<sup>2</sup> (G.Horrell, *pers. comm.*). This lake area may not take account of the reach from Poingdestres to the lagoon, but for the two to match, the area would need to be as large as 6.6 km<sup>2</sup>. The absence of a change in salinity for this event probably indicates the flow was a backwater event, rather than a seawater incursion. The high sea levels caused flow from the Waihao River to flow up the deadarm, rather than through the box. For this event, wave runup was relatively small.

The period from 27 Jun to 3 Jul was another when substantial flow into the lagoon occurred. The total inflow volume was 1.8 m·km<sup>2</sup>, but the response in lagoon level was only 0.17 m, giving a volume of 0.7 m·km<sup>2</sup>, which is less than half what would be expected. Very large runup (> 4 m) occurred on 2 Jul, but there was no apparent effect on the flow at Poingdestres.

The major event of the period occurred on 17 Aug when the flow at Poingdestres dropped to -4 cumecs, the salinity jumped to more than 30 (i.e., pure seawater), and the lake level jumped by 0.2 m in 18 hours, then slowly increased over the next few days to peak at 1.28 m, a total rise of 0.41 m representing a volume increase in the lagoon of 1.8 m·km<sup>2</sup>. The flow past Poingdestres into the lagoon over this period totaled 1.3 m·km<sup>2</sup>. All of this occurred at a time of small tidal range and low sea levels, but wave runup was 3.8 m.

A possible explanation for this curious set of events is that wave runup is a major cause of backflow in the deadarm, either by causing the Waihao to back up or by direct incursion of seawater. However, waves are a highly variable, stochastic phenomenon. Thus, the absence of seawater incursion for the large runup event in late June, but the presence of seawater incursion in the smaller event in August, is explained by

differences in the random wave field that are not encapsulated in the two parameters describing the field (i.e., wave height and period).

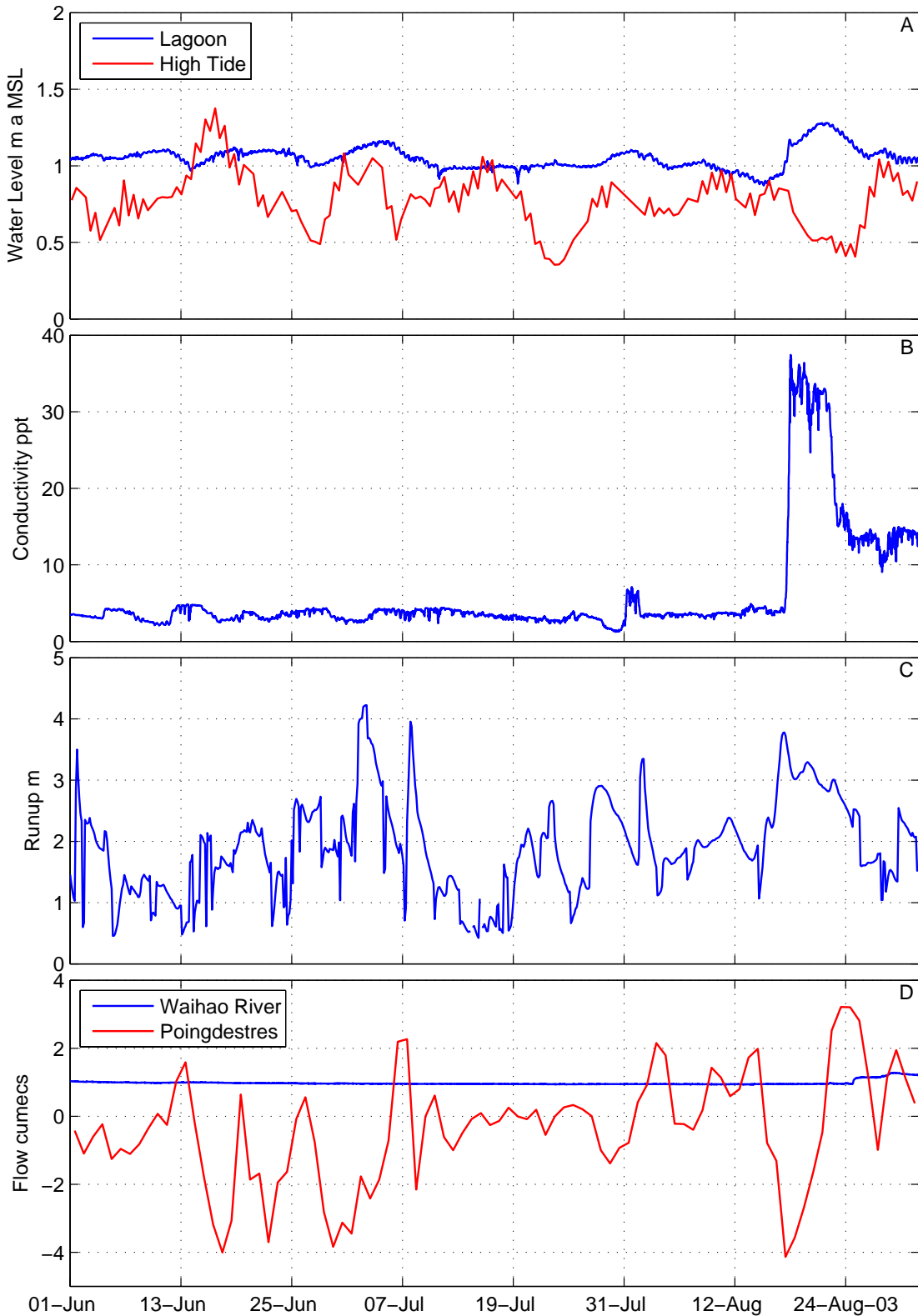


Figure 7. For the Winter of 2003: A. water levels: lagoon (blue) and high tide envelope (red); B. salinity; C. wave runup; and D. river flows.

## CONCLUSIONS

There is strong evidence that seawater regularly flows into Wainono Lagoon. This study investigated the possible sources of seawater incursion.

For seawater to flow into the lagoon, sea levels must be higher than lagoon levels. However, after careful composition of the sea-level record, allowing for all possible errors, it was found that sea level exceeds lagoon level for only 2.6% of the time on a long-term basis. This is insufficient to explain frequent, substantial incursions of seawater into the lagoon.

Investigation into wave runup found that allowing for this, there is positive head between the ocean and the lagoon for between 60 and 70% of the time and the head exceeds 1 m for 20% of the time. However, wave runup is a probabilistic quantity, being the height that is exceeded by 2% of all incoming waves, so the actual duration when the head is positive is quite small.

Three mechanisms for seawater incursion were found:

- Wave overtopping — this occurs frequently (on average, 4 times per month) at the section of berm that was washed out in July 2002. Estimates of the flow in these events averaged over time have a median of 0.96 cumecs, with there being a 90% probability that flows are greater than 0.08 cumecs, and a 10% probability that they are greater than 4.74 cumecs.
- Seepage — allowing for the more permeable gravels higher in the berm and the narrower width, the seepage flow into the lagoon was estimated to be 0.005 cumecs as a result of wave runup.
- Deadarm flow — flow back through the box and up the deadarm occurs from time to time.

The conclusion is that the source of frequent and substantial incursions of seawater into Wainono Lagoon is waves overtopping the berm at the location of the washout caused by the July 2002 storm. The size of the flows into the lagoon as a result of these events is highly variable, but there is a 50% probability that the long-term average inflow exceeds 0.96 cumecs.

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- Goring, D. G.; Willsman, A. 2003: Wainono Lagoon berm seepage: Stage 2. *NIWA Client Report CHC2003-047*, 26 pp.
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- Van der Meer, J. W. 2002: Wave run-up and wave overtopping at dikes. Publication of the Technical Advisory Committee on Flood Defence, The Netherlands, 42 pp (translated from Dutch).

## APPENDIX A: Wave Height Statistics

**Table A.1 Mean significant wave height for the coastal nodes around New Zealand of the NWW3 global wave model.**

<b>Node</b>	<b>Longitude °E</b>	<b>Latitude °N</b>	<b>Mean Height m</b>
Puysegur	166.25	-46.00	3.44
Fiordland	166.25	-45.00	3.25
W Stewart	167.50	-47.00	3.18
Chathams	183.75	-44.00	3.18
3 Kings	172.50	-34.00	2.65
Hokianga	172.50	-36.00	2.64
Jackson Bay	167.50	-44.00	2.56
E Foveaux	168.75	-47.00	2.53
Heaphy	171.25	-41.00	2.49
90 Mile Beach	172.50	-35.00	2.46
Farewell	172.50	-40.00	2.34
Kaipara	173.75	-37.00	2.16
Raglan	173.75	-38.00	2.13
N Cape	173.75	-34.00	2.09
Poverty	178.75	-39.00	2.07
Foulwind	171.25	-42.00	2.03
Harihari	170.00	-43.00	1.97
E Cape	178.75	-38.00	1.93
New Plymouth	173.75	-39.00	1.92
Otago	171.25	-46.00	1.84
Palliser	175.00	-42.00	1.77
Kidnappers	177.50	-40.00	1.71
Bay of Plenty	177.50	-37.00	1.69
Wairarapa	176.25	-41.00	1.63
Bay of Islands	175.00	-35.00	1.58
S Taranaki	173.75	-40.00	1.58
N Canterbury	173.75	-43.00	1.54
E Coromandel	176.25	-37.00	1.38
Hauraki	175.00	-36.00	1.34
<b>Waitaki</b>	<b>171.25</b>	<b>-45.00</b>	<b>1.22</b>
Ellesmere	172.50	-44.00	1.21

**APPENDIX B: Berm Survey**

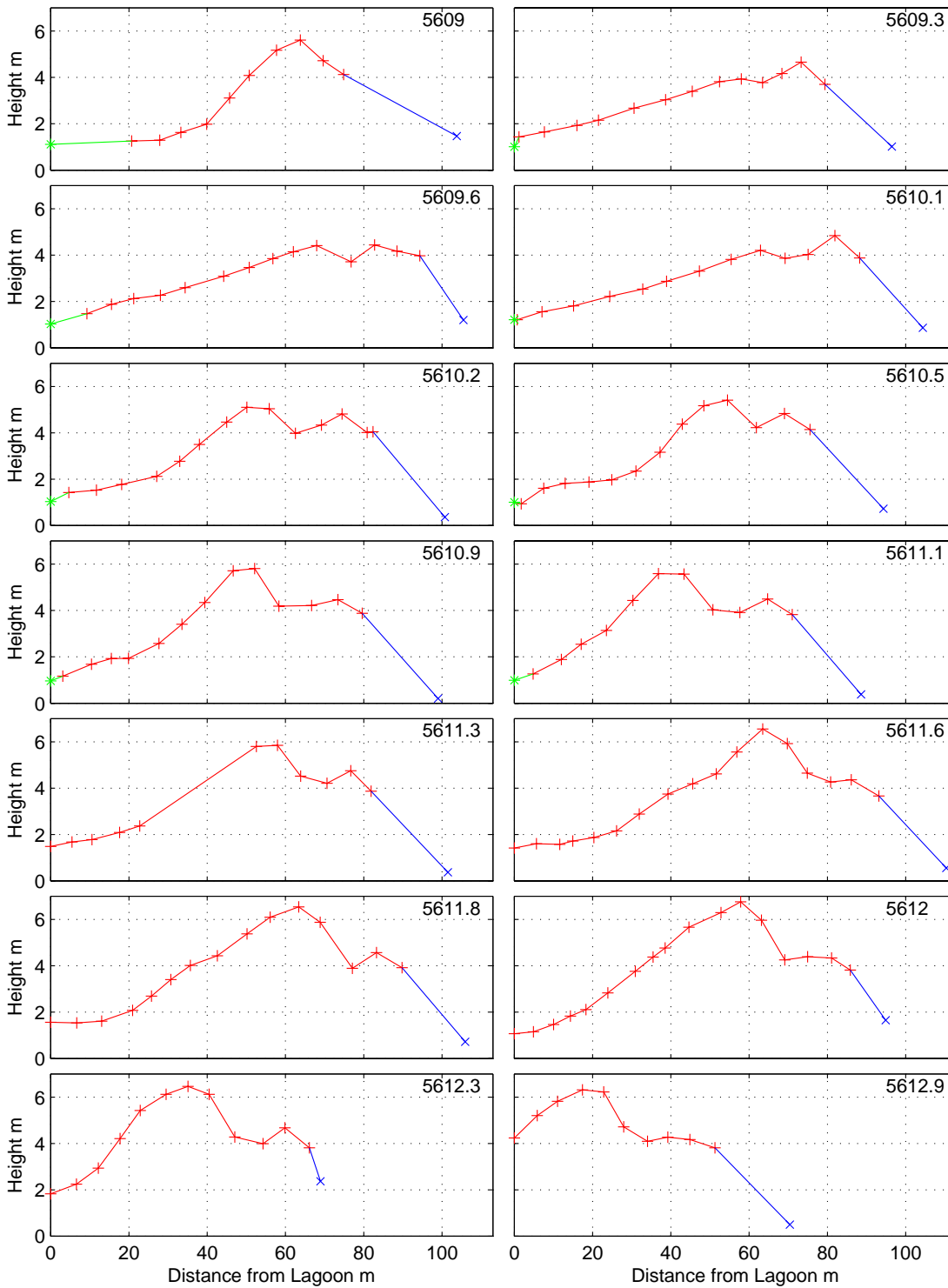
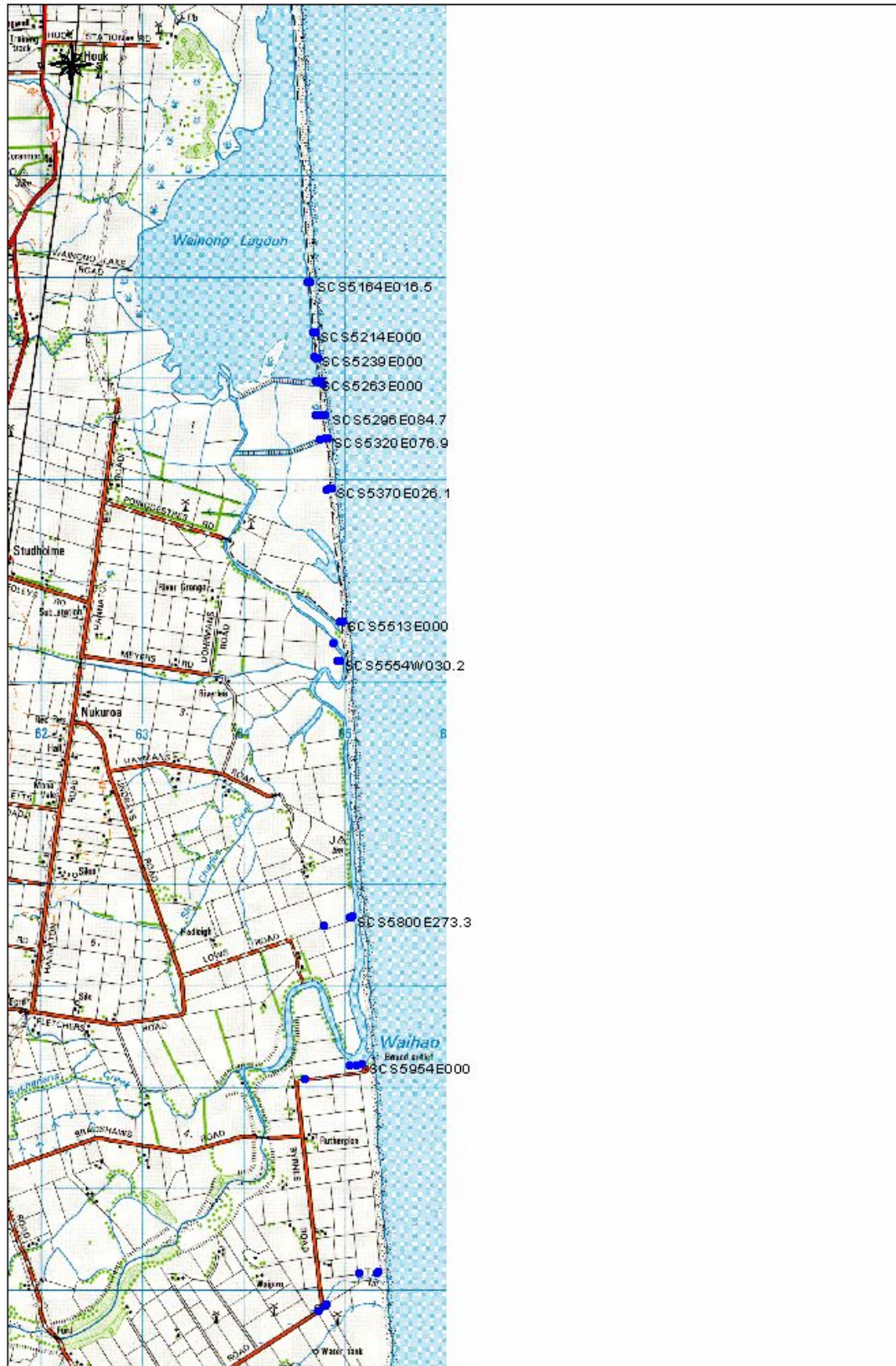
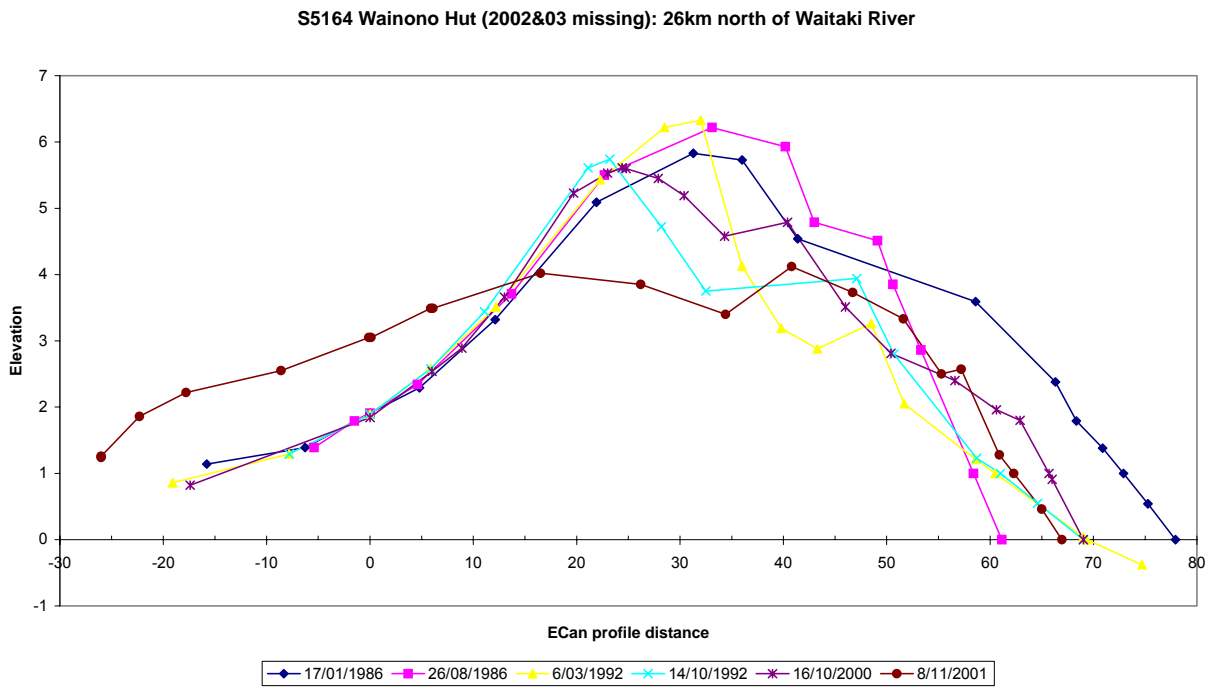


Figure B.1 Berm cross-sections indicated by northing (in km to NZMG), in which green is from the lagoon edge trajectory survey, blue is from the sea side trajectory survey, and red is from the profiles survey (from Goring & Willsman, 2003).

## Appendix 51 Environment Canterbury beach profile locations Wainono Lagoon





**Figure Example Cross Section Beach Barrier Wainono Lagoon.**



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