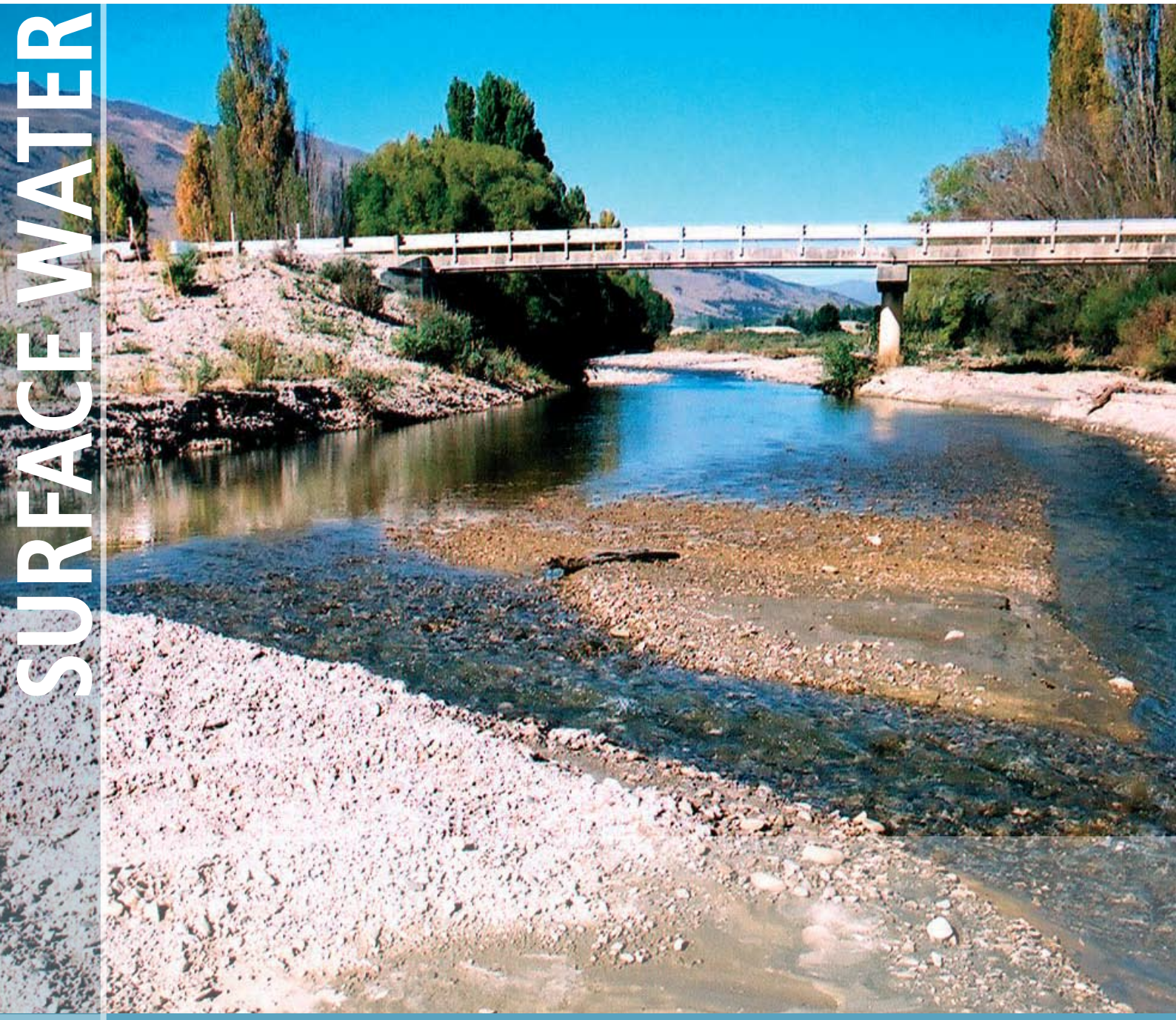
SURFACE WATER

The Water Resources of the Cardrona River



Otago Regional Council

The Water Resources of the Cardrona River

January 2007

1-877265-52-7

Foreword

Otago's rivers and streams are a major feature of any Otago landscape and help make the region what it is. The clean waters provide a rich ecological environment, serve rural and urban communities, and act as a tourist attraction. In many parts of the region, surface waters are also vital for irrigation water, which enables or enhances primary production during the dry summer months.

The Cardrona River is in the upper Clutha Valley and drains from a typical Otago high country landscape. Tussock and low producing grassland dominates the higher catchment areas, while high producing exotic grassland dominates the lower catchment. The principal activity on the tussock is sheep and beef farming; deer are also farmed in the lower regions. Tourism is also very important in the area.

It is essential to fully understand the natural hydrology of an area before effective and efficient sustainable management decisions can be made. This report has drawn together the currently available hydrological information for the Cardrona River Catchment to help in that decision making process.

Executive summary

The Cardrona River has a total catchment area of 337 km^2 and flows northwest for 40km down the steep narrow Cardrona Valley into the Clutha River/Mata-Au at Albert Town. The catchment is contained by the Crown Range to the south and west, dividing it from the Wakatipu basin, and the Criffel Range to the east.

The median annual rainfall ranges from 650-700mm on the lower catchment flats, to 1250-1500mm on the tops of the Crown and Criffel Ranges. A severe rainfall deficit occurs during summer, with typical January - February rainfall totals approximately half of the potential evapotranspiration rate during this period. This summer moisture deficit leads to a high demand for irrigation water, and the Cardrona River has a large number of consented irrigation takes, with a maximum consented take of 2784 l/s as at June 2006.

There have been two long-term hydrological monitoring sites on the Cardrona River; Mt Barker and Albert Town. The Mt Barker site is further upstream, with a smaller catchment area. Despite this, it has a greater average flow, specific yield (average flow / catchment area), and mean annual low flow than the downstream Albert Town site. This is because the Cardrona River downstream of Mt Barker loses water to groundwater recharge and abstractions for irrigation, and in most years the Cardrona dries up along parts of its lower reach during summer. There is some recovery of flow by the time the river reaches Albert Town, however, as groundwater and excess irrigation water re-enters the river. The imbalance in flow rate between Mt Barker and Albert Town is accentuated during the summer irrigation season.

There have also been a number of low flow gauging runs undertaken in the Cardrona. These gaugings have revealed two distinct patterns, with summer flows in the lower catchment considerably lower than those recorded during spring. In the upper catchment, the increase in flow between Cardrona township and Mt Barker was approximately 1300 l/s on the spring gauging runs. During summer however, the increase in flow was considerably less, ranging from 400 to 500 l/s.

A brief analysis of flow gauging runs down Bullock Creek was also undertaken. The creek has a base flow of less than 100 l/s in its upper reaches, which is probably sourced from rainfall in the Mt Alpha area. There was very little variation in flows measured in the upper catchment. Below SH89, Bullock Creek flow gradually increases due to the large number of springs and seeps in the area. It reaches approximately 300 l/s by the time it reaches Helwick Street, and then the rate of increase slows as the creek approaches Lake Wanaka.

This report is restricted to an analysis of the water resource of the Cardrona Catchment. A summary of a water quality monitoring program in the Cardrona is the subject of a separate report (ORC, 2006).

Table of contents

List of figures

List of tables

1. Introduction

Continuous hydrological information has been collected by the Otago Regional Council and the National Institute of Water and Atmosphere (NIWA) in the Cardrona Catchment since the mid 1970s. The purpose of this report is to summarise the flow record from the two permanent sites – Mt Barker and Albert Town, as well as to examine data collected from flow gaugings at other locations within the catchment. Rainfall data from a number of sites, both in the Cardrona Catchment and nearby, is analysed for long-term trends and compared with recent changes in annual average flow rates. Bullock Creek, although not strictly part of the Cardrona Catchment, is believed to obtain some of its flow from the Cardrona, and this study also examines the pattern of flow down this small stream.

2. Cardrona Catchment description

The Cardrona River has a total catchment area of 337 km^2 and flows northwest for 40km down the steep narrow Cardrona Valley into the Clutha River/Mata-Au at Albert Town (Figure 2.1). The catchment is contained by the Crown Range to the south and west, dividing it from the Wakatipu basin, and the Criffel Range to the east.

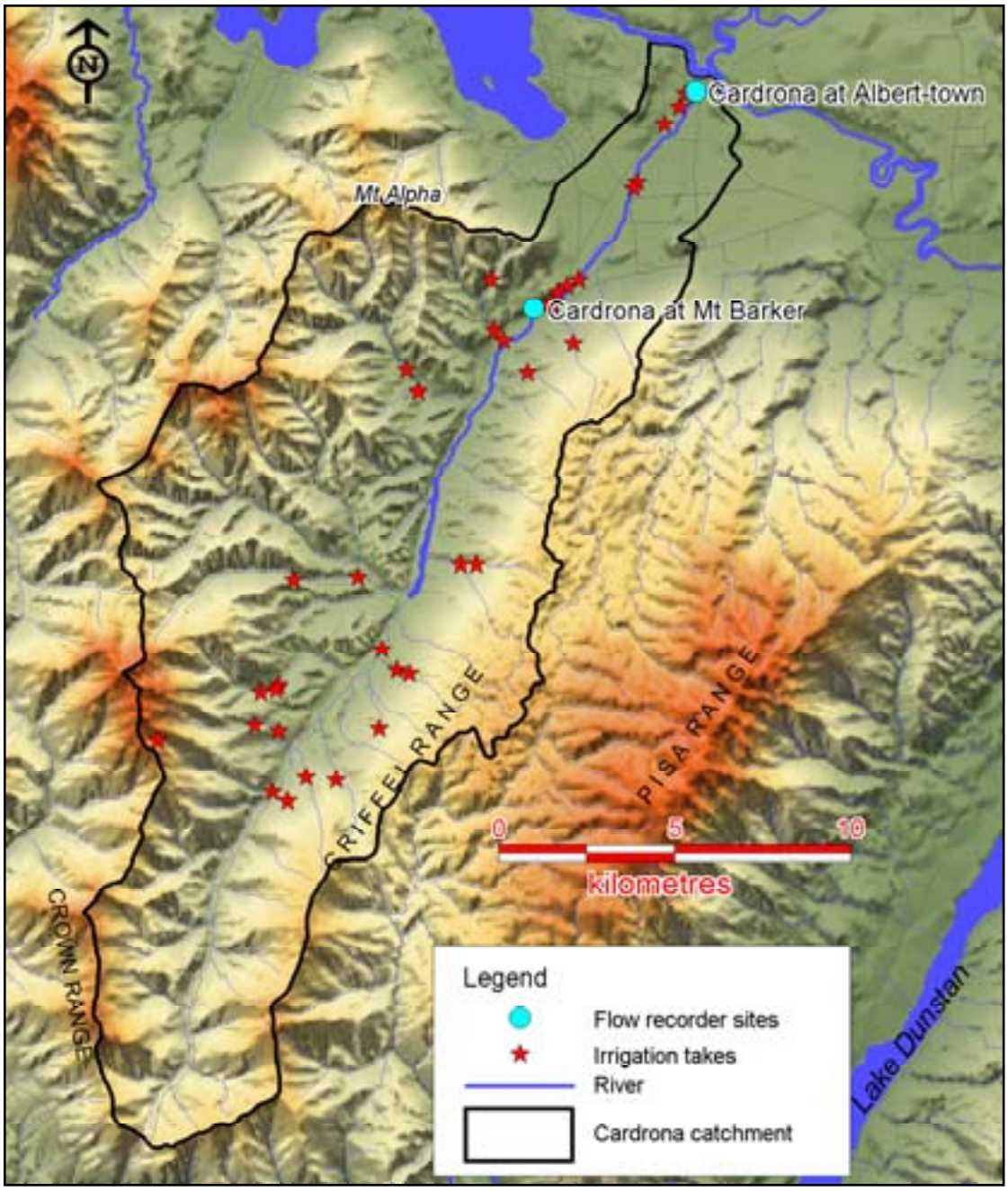


Figure 2.1 Cardrona Catchment, showing flow recorder sites and consented irrigation takes

The catchment consists of a steep river valley at an elevation of between 300m at the confluence with the Clutha/Mata-Au River and 1000m at the top of the Crown Range. Tussock and low producing grassland is prevalent in the higher catchment, while in

the lower catchment, high producing exotic grassland predominates. The catchment is dominated by sheep and beef farming on tussock, with the high producing grasslands in the lower catchment supporting some deer farming.

The median annual rainfall ranges from 650-700mm on the lower catchment flats, to 1250-1500mm on the tops of the Crown and Criffel Ranges (Figure 2.2). A severe rainfall deficit occurs during summer, with January - February rainfall totals generally ranging from 80 to 120mm. Potential Evapotranspiration during this period is considerably higher however, ranging from 206 to 210mm (ORC, 2004). This summer moisture deficit leads to a high demand for irrigation water, and the Cardrona River has a large number of consumptive takes (Figure 2.1), with a maximum consented take of 2784 l/s as at June 2006.

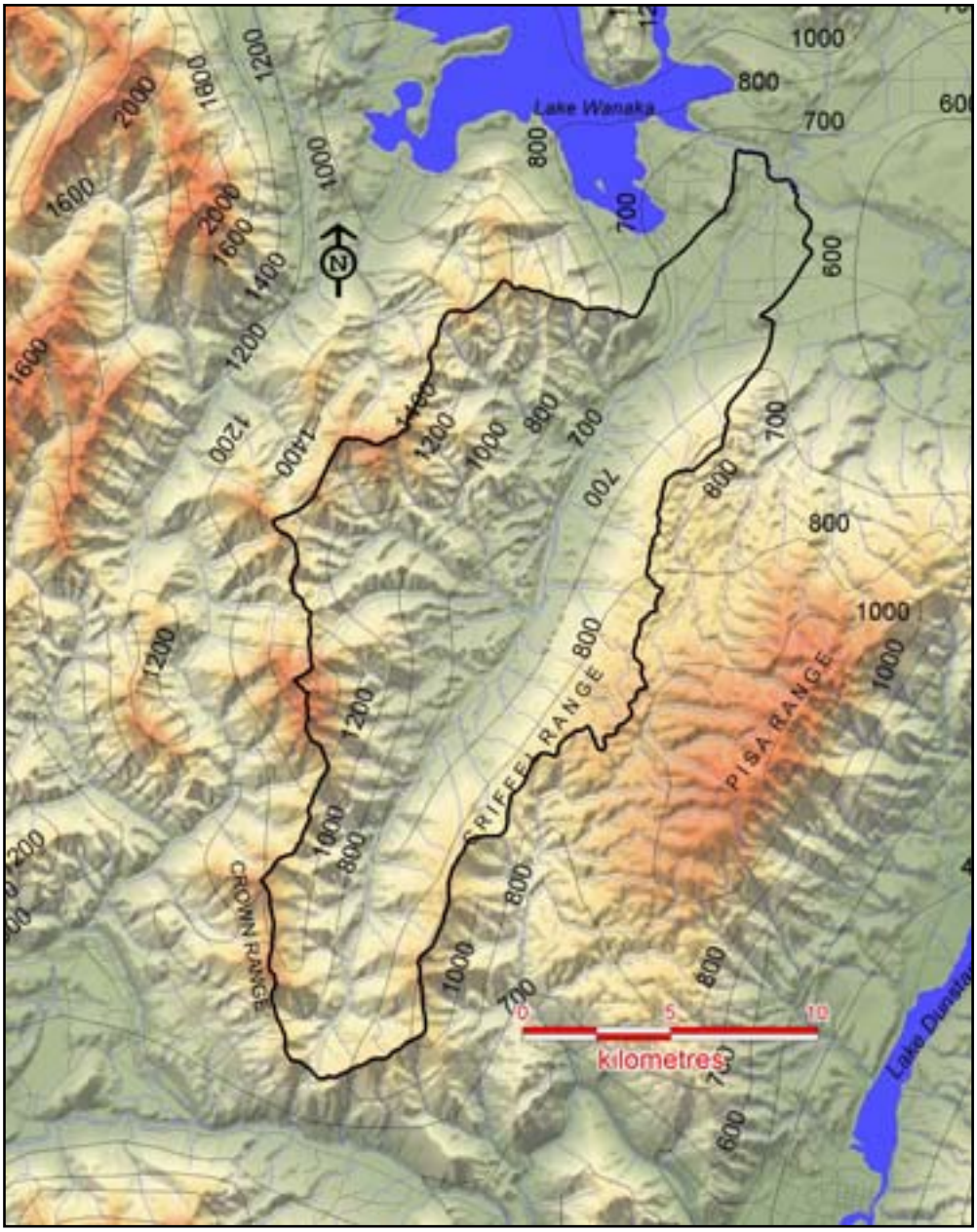


Figure 2.2 Average annual rainfall contours (mm) in the Cardrona Catchment and surrounding area

3. Cardrona Catchment hydrology

Table 3.1 summarises hydrological parameters for the two long-term sites on the Cardrona River; Mt Barker and Albert Town. The Albert Town site was operated by NIWA from 1978 until 2002. Mt Barker was operated by the Otago Regional Council from 1976 to 1988, was then closed for several years, before being re-opened in February 2001. It should be noted that there are a large number of gaps in the early Mt Barker record, most of which occurred during summer. These gaps comprise less than 1% of the record however, and should therefore have only a minor effect on summer low flow calculations. Appendix 1 lists these gaps, along with those from Albert Town.

Despite being further upstream, with a smaller catchment area, the Mt Barker site has a greater average flow, specific yield (average flow/catchment area), and mean annual low flow (MALF). This is because the Cardrona River downstream of Mt Barker is subject to losses due to groundwater recharge and abstractions for irrigation, and in most years, the Cardrona dries up along parts of its lower reach during summer. As at June 2006, 52% of the volume of the consented irrigation takes in the Cardrona Catchment were below Mt Barker (1438 l/s). There is some recovery of flow by the time the river reaches Albert Town, as groundwater and excess irrigation water re-enters the river. Table 3.1 shows that the Albert Town recorder, which operated from 1978 to 2002, did not record any periods of zero flow during this period.

The 7 day low flow in any year is the lowest average flow over a consecutive 7 day period. When this is done for every year of record, the MALF can be determined by adding the lowest 7 day low flows for every year of record and dividing by the number of years in the record.

Table 3.1 Summary of hydrological parameters for Cardrona River

	Mt Barker	**Albert Town**
Record begins	2 Dec, 1976	28 Sept, 1978
Record ends	Still operating, gap from Oct 1988 to Feb 2001.	9 Jan, 2002
Three lowest recorded flows	308 l/s (1980) 388 l/s (2006) 679 l/s (2005)	74 l/s (2000) 85 l/s (1979) 223 l/s (2001)
Average flow	3354 l/s	2908 l/s
Catchment area	293 km^2	346 km^2
Specific yield	11.44 l/km^2	8.4 l/km^2
Median flow	2502 l/s	2027 l/s
Mean Annual Low Flow (MALF)	980 l/s	461 l/s
Lowest 7 day low flow	383 l/s (1978)	102 l/s (1978)

3.1 Distribution of flow

The annual distribution of flow at both recorder sites is shown in Figure 3.1. This shows the percentage of time that the river is equal to, or exceeds a certain flow. Figure 3.1 also shows that, despite being further upstream, the distribution of flow at Mt Barker below approximately 6000 l/s is greater than at Albert Town. For example, the river at Mt Barker flows at 2000 l/s or more for 62% of the time, while the same flow at Albert Town was equaled or exceeded only 50% of the time.

This trend is accentuated during the summer irrigation season, and Figure 3.2 shows flow distribution plots for the two Cardrona sites using only data from September to April. In this case, the river at Mt Barker still flows at 2000 l/s or more for 60% of the time. However, downstream at Albert Town, a 2000 l/s flow was equalled or exceeded only 42% of the time.

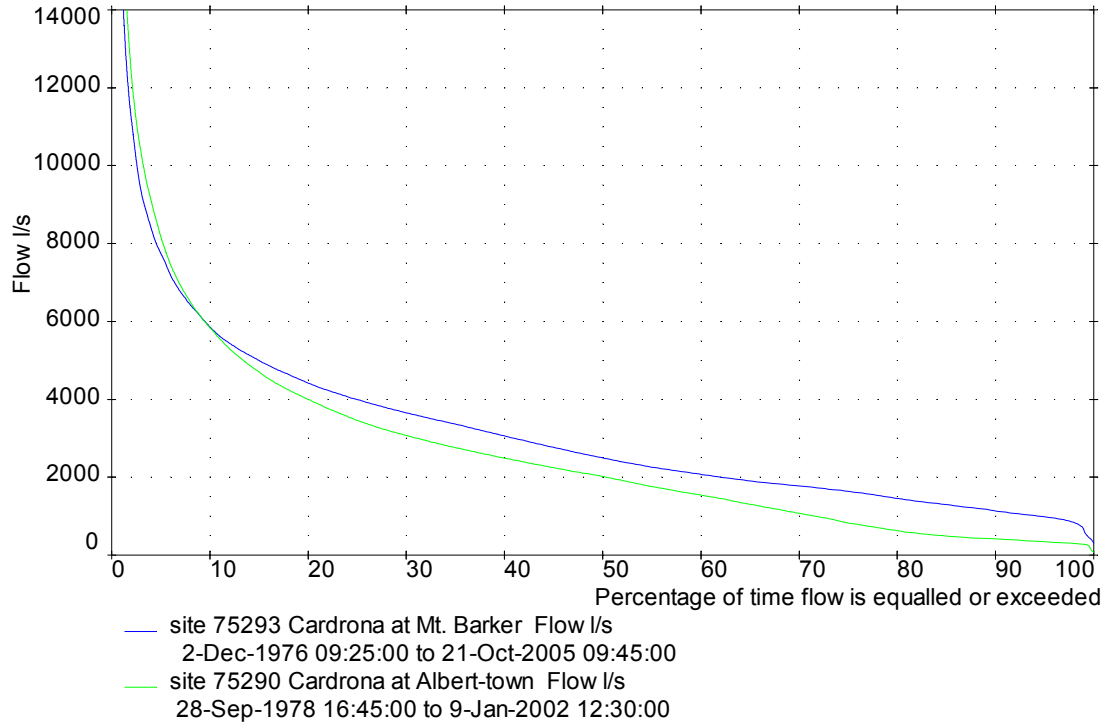


Figure 3.1 Annual distribution of flows at Mt Barker and Albert Town

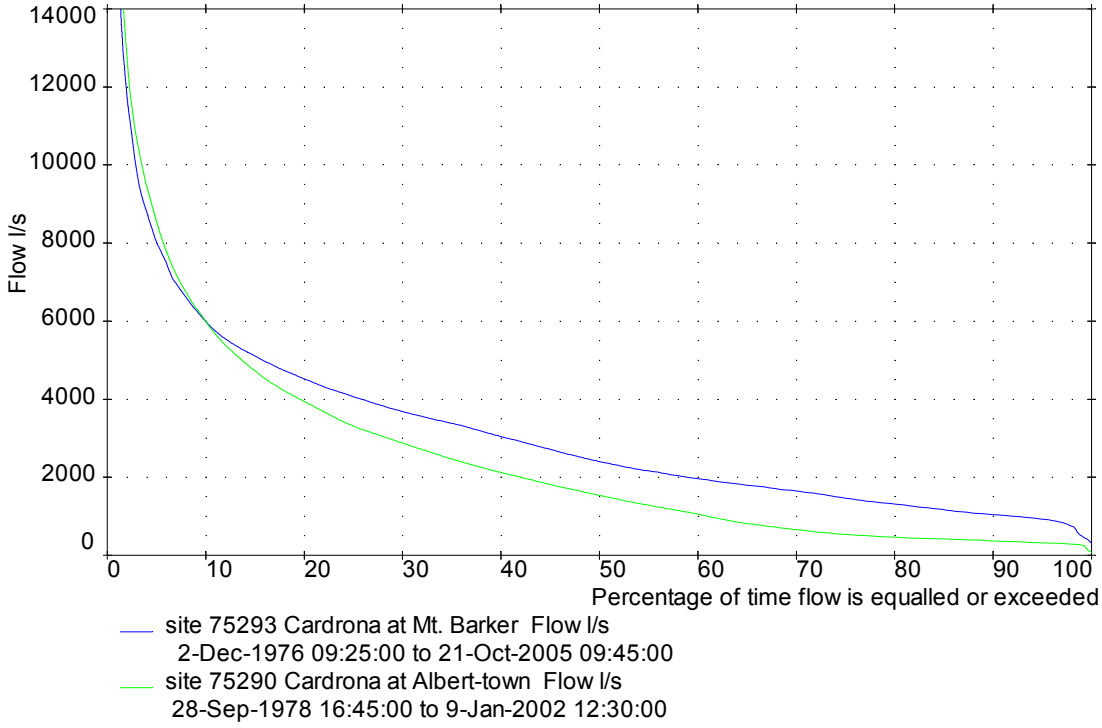


Figure 3.2 Distribution of flows at Mt Barker and Albert Town – irrigation season only

Figure 3.3 shows the distribution of flow during the winter months only (May to August). Winter flows in the Cardrona River at Albert Town are generally slightly lower than those recorded at Mt Barker, although not to the same extent as during the summer months. This suggests that even when there is very little abstraction, a proportion of the flow from the Cardrona is lost to groundwater.

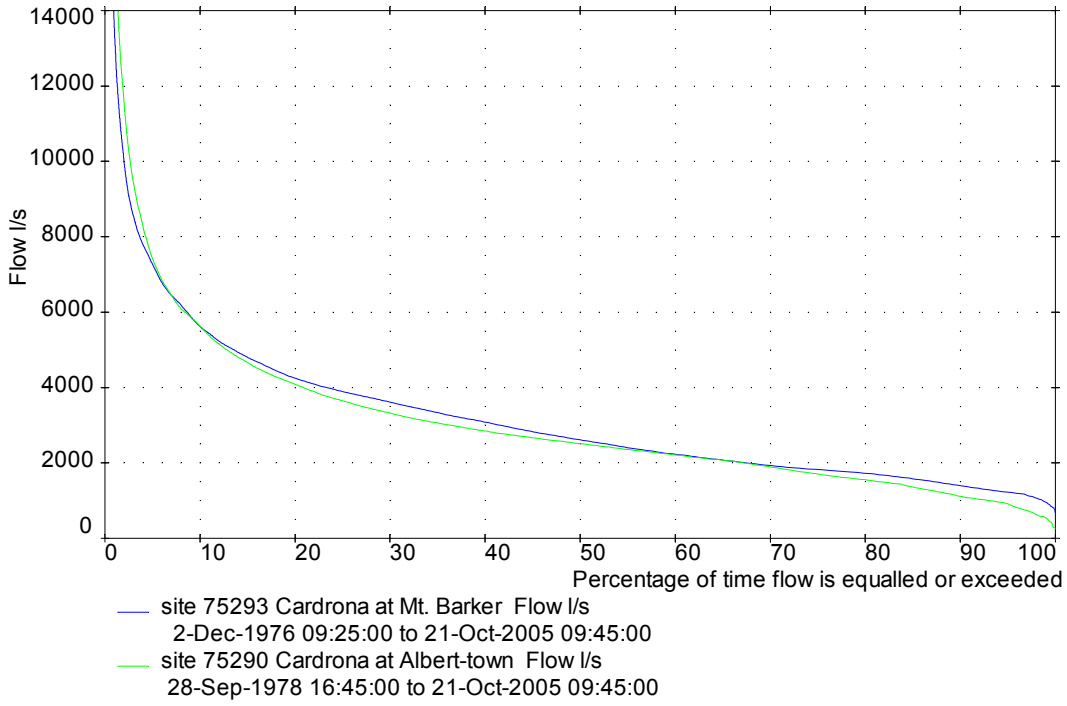


Figure 3.3 Distribution of flows at Mt Barker and Albert Town – winter only

3.2 Temporal variability of flow

3.2.1 Long-term changes in annual average flow

Figure 3.4 and Figure 3.5 show the average annual flow at the Mt Barker and Albert Town sites over the full length of record. At Mt Barker, average flow has ranged from 2000 to 6500 l/s, while at Albert Town, the range is 1000 to 5200 l/s. No discernible trend over time is shown at Albert Town, while at Mt Barker 2003 and 2005 were very dry years, suggesting there has possibly been a decline in average annual flow since the site was reinstalled in 2001. This is discussed further in Section 3.2.4.

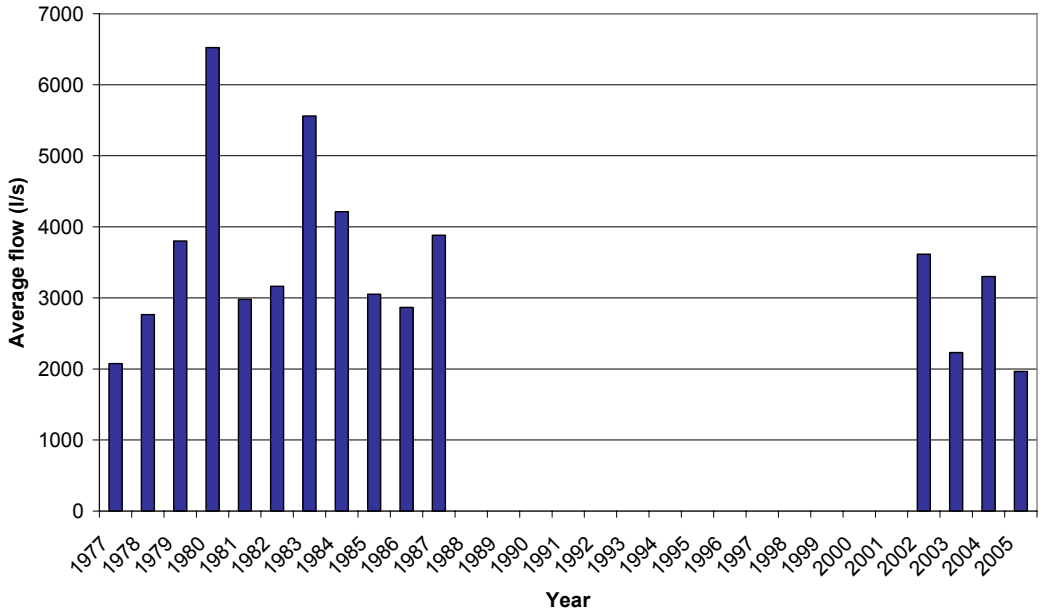


Figure 3.4 Annual average flow in the Cardrona River at Mt Barker

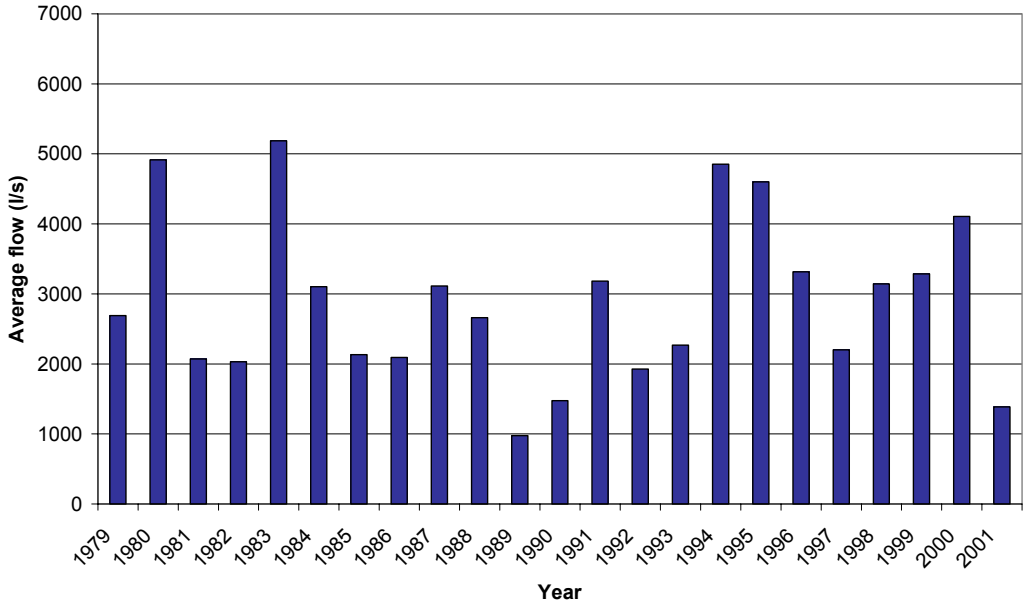


Figure 3.5 Annual average flow in the Cardrona River at Albert Town

3.2.2 Long-term changes in 7-day low flow

Figure 3.6 and Figure 3.7 show the seven day low flow for each year of record at the two Cardrona sites. The seven day low flow is the lowest average flow over any consecutive seven day period in any year. While the difference in annual average flows between the two sites is minimal (as shown in Figure 3.4 and Figure 3.5), the difference between typical seven day low flows is significant. At Mt Barker, the range is generally between 800 and 1600 l/s, while at Albert Town, the range is normally between 250 and 750 l/s.

The Albert Town site does not show any discernible trend in the seven day low flow value since records began, while at Mt Barker, the seven day low flow figures appears to have become more consistent at approximately 800 to 900 l/s.

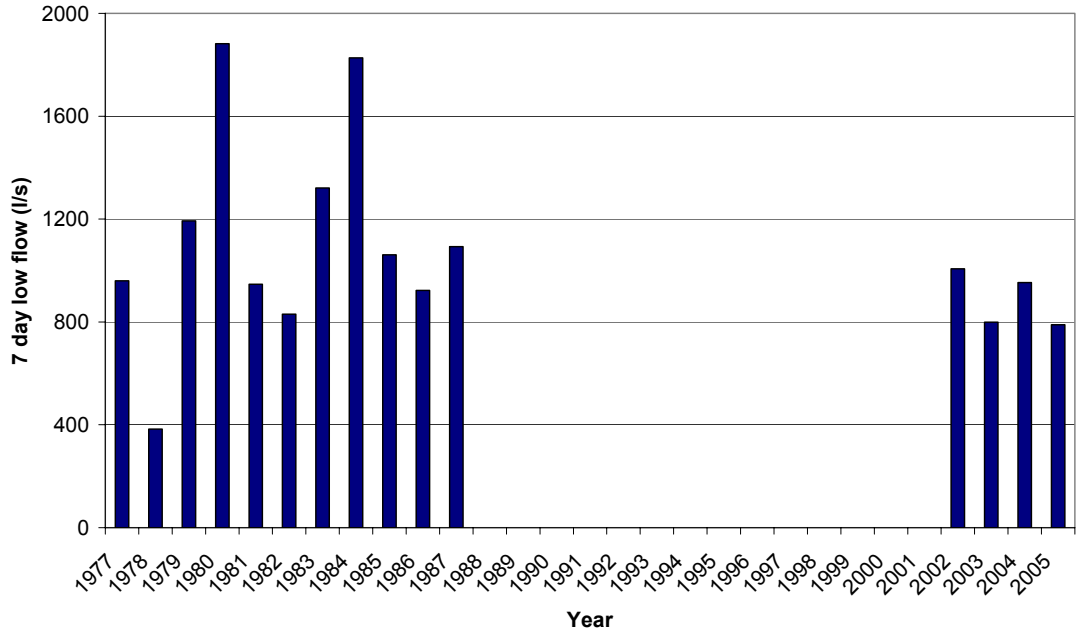


Figure 3.6 7 Day low flow in the Cardrona River at Mt Barker

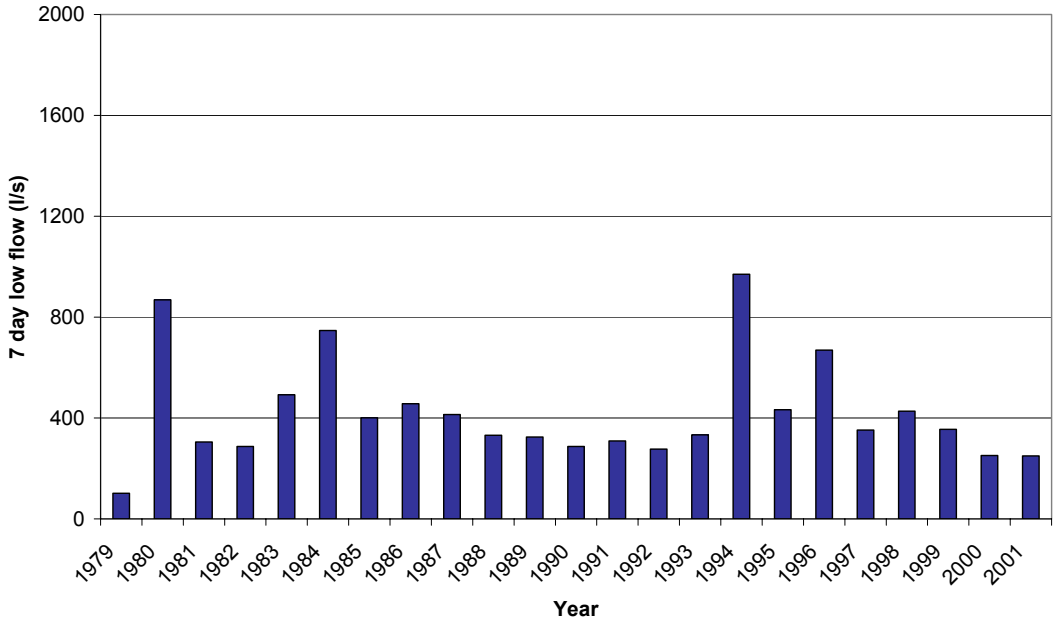


Figure 3.7 7 Day low flow in the Cardrona River at Albert Town

3.2.3 Average monthly flows

Figure 3.8 and Figure 3.9 show minimum, maximum and average monthly flows at the two Cardrona River recorder sites. A similar pattern is shown at both locations, with the lowest flows occurring in February as natural river flow falls away and irrigation demand reaches its peak. The highest flows generally occur in September and October due to snow melt from the upper catchment. The greatest variation between minimum and maximum recorded monthly flows occurs in the spring at Mt Barker and on into early summer downstream at Albert Town.

The particularly high maximum monthly flow at Albert Town for November was recorded in 1999, due to the largest flood on record occuring in that month. The Mt Barker site was not operating at that time.

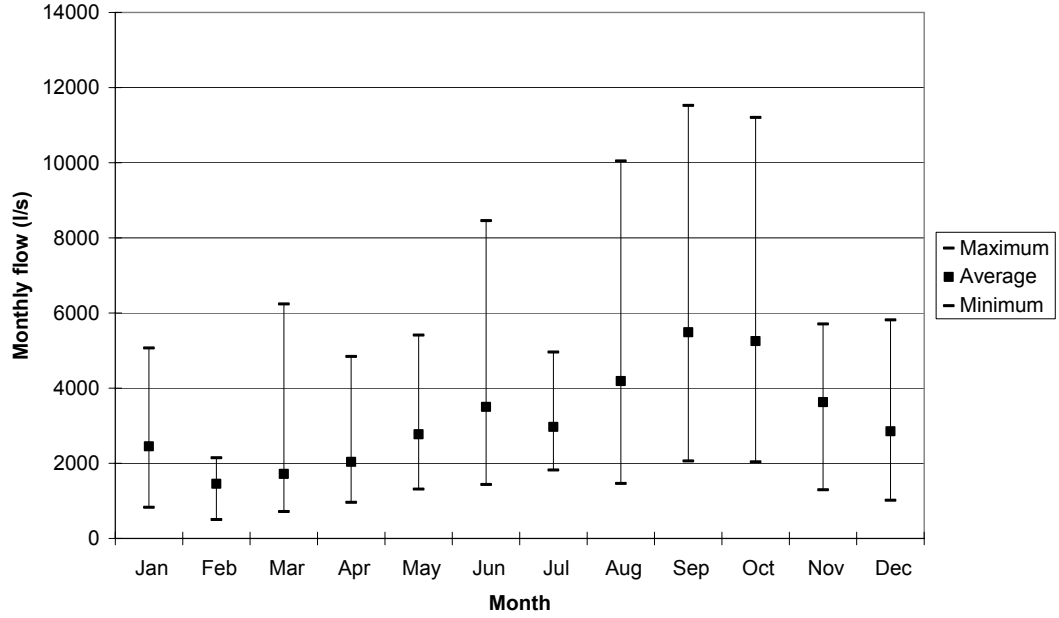


Figure 3.8 Monthly flows in the Cardrona River at Mt Barker

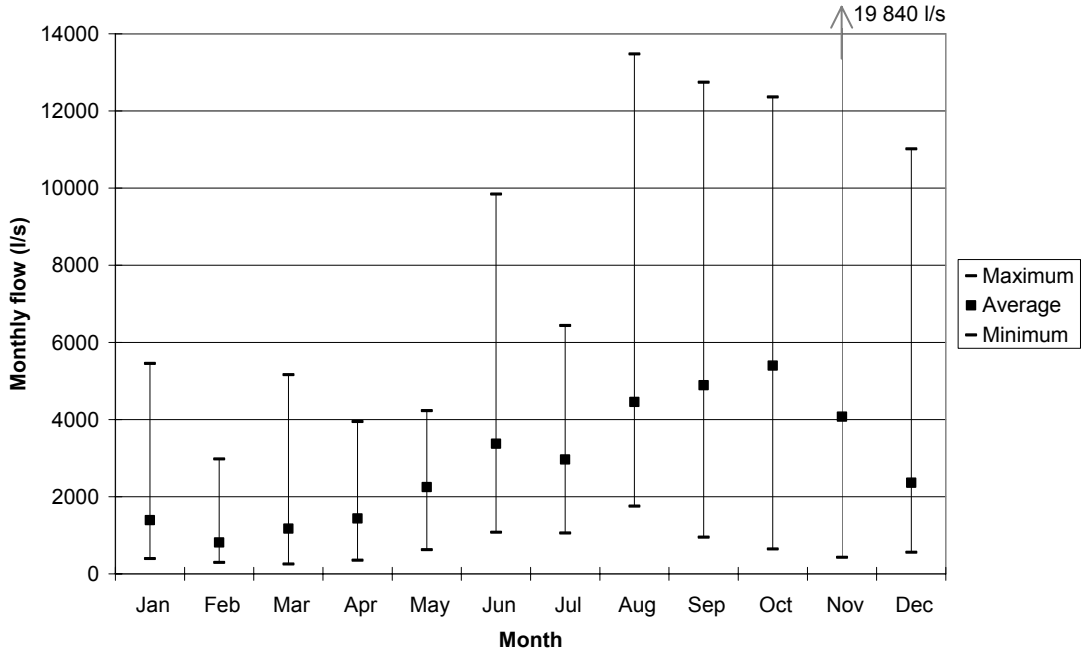


Figure 3.9 Monthly flows in the Cardrona River at Albert Town

3.2.4 Long-term changes in average monthly flow

A series of graphs in Appendix 2 show long-term trends in monthly average flow at Mt Barker and Albert Town over the full period of record. With the exception of January and February, average monthly flows have generally been lower at Mt Barker since the site was re-opened in 2001. May and August in particular have seen a significant decline, with average flows dropping by approximately 1500 l/s between 1977 and 2006. Table 3.2 shows the average monthly flow for May and August for

the first period of record at Mt Barker (1977-88) and the latest period since the site was re-installed (2001-06).

Table 3.2 Average monthly flow for May and August at Cardrona at Mt Barker, 1977-88 and 2001-06

Month	1977-88	2001-06	% change
May	3135	1683	-46%
August	4700	2933	-36%

By comparison, there was little change in average monthly flows at Albert Town between 1978 and 2001. The only month to show any significant trend was May, which has declined by approximately 1000 l/s. It should be noted that the approximately 20 years of record at these two sites is still a relatively short period to try and define any long-term trends. However, the data presented in Appendix 2 does give a reasonably accurate summary of what has happened in the Cardrona River since continuous monitoring began.

A possible reason for a decrease in flow rates in the Cardrona is a decline in rainfall over the last few years. This is discussed further in Section 3.3.

3.3 Long-term changes in rainfall

There are relatively few long-term rain gauge sites in the Cardrona Catchment. Figure 3.10 shows all available data from the Cardrona township site, which dates back to 1928. There have been a number of years since 1998 with periods of missing record however, making it hard to determine any recent trends in annual rainfall totals. There is a reasonably good correlation between rainfall totals at Cardrona and Queenstown, however, and an annual total for 2004 and 2005 was able to be estimated using this technique.

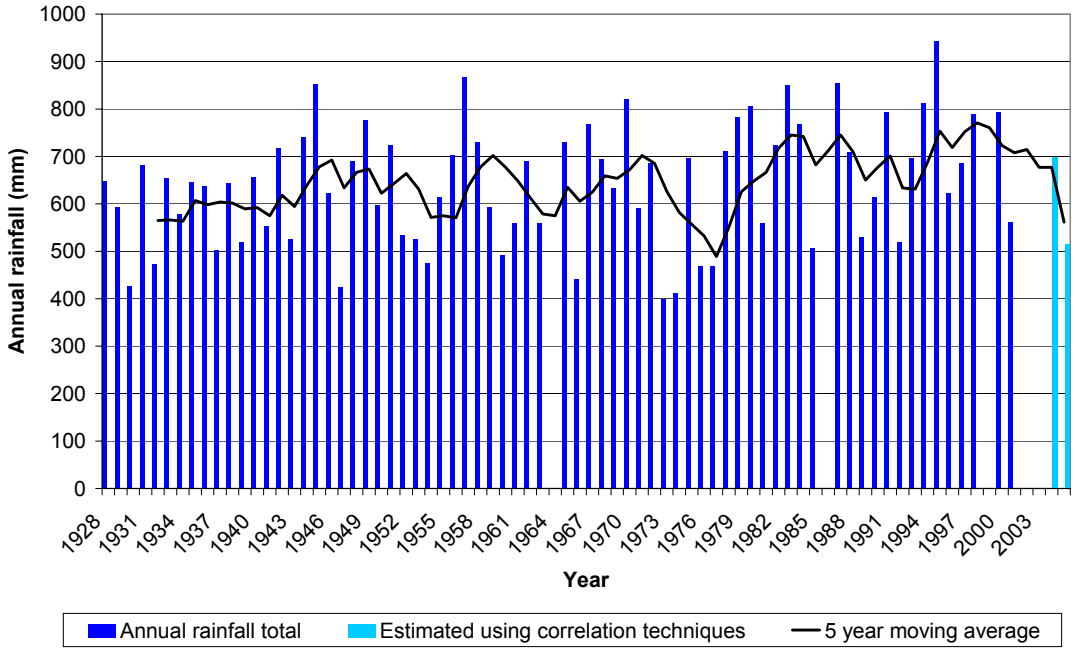


Figure 3.10 Annual rainfall totals at Cardrona, 1928 - 2005

Figure 3.11 shows data from the Matukituki at West Wanaka site, which dates back to 1961. This is the nearest site to the lower Cardrona valley with a reasonably long record that is still operational.

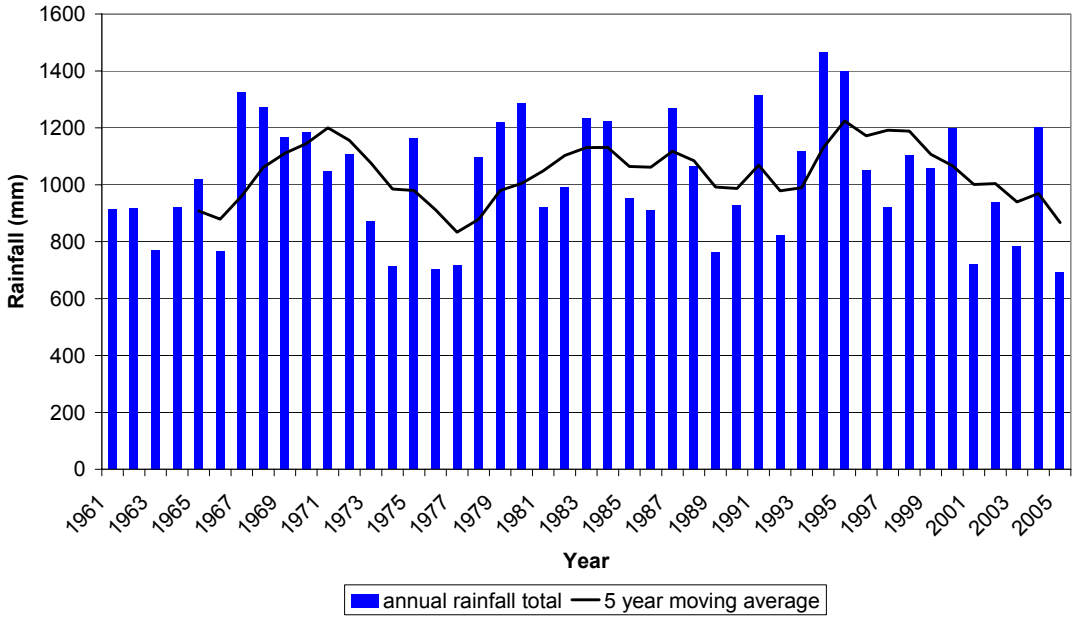


Figure 3.11 Annual rainfall totals at Matukituki at West Wanaka, 1961 – 2005

There is also a long-term record from Wanaka township, which unfortunately ends in 1990. This is shown in Appendix 3, along with more recent records from the Wanaka DOC office, and rainfall data from Queenstown, which dates back to 1890. The Wanaka Airport gauge (Figure 3.12) has been operational since 1993, and although not strictly within the Cardrona Catchment, does give a reasonably good indication of rainfall in the lower catchment.

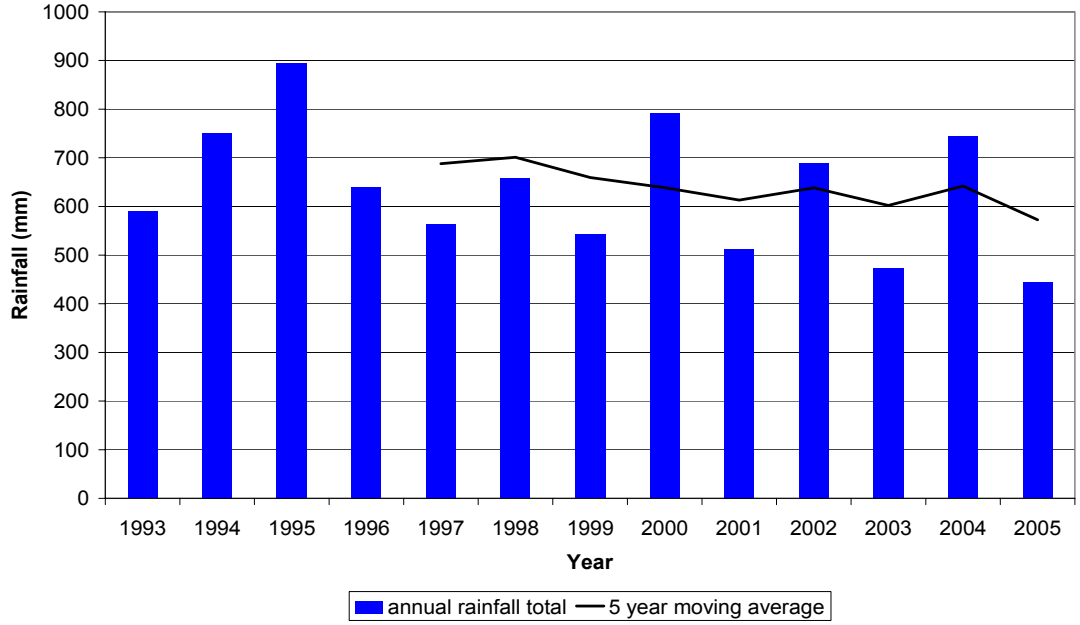


Figure 3.12 Annual rainfall figures at Wanaka Airport, 1993 – 2005

The Cardrona township, West Wanaka and Wanaka Airport gauges all show a downward trend in annual rainfall totals since the late 1990s. The five-year moving average at West Wanaka has declined approximately 300mm since 1995, while the moving average at the airport site has dropped 120mm since 1998. Further west, annual rainfall totals at Queenstown increased from approximately 600mm in 1890 to over 1000mm in the late 1990's (Appendix 3). Since then there have been a number of dry years, with average annual rainfall dropping away to about 800mm.

The decline in Cardrona River flows at Mt Barker as shown in Figure 3.4, Figure 3.6 and Table 3.2, since the site was re-installed in 2001, is likely to be partly due to the lower than average rainfall over the last decade.

4. Cardrona low flow gaugings

In addition to the information available from the two permanent recording stations, a number of low flow gauging runs have been undertaken in the Cardrona. Figure 4.1 shows the location of these gauging sites, along with the location of the permanent flow recorder sites.

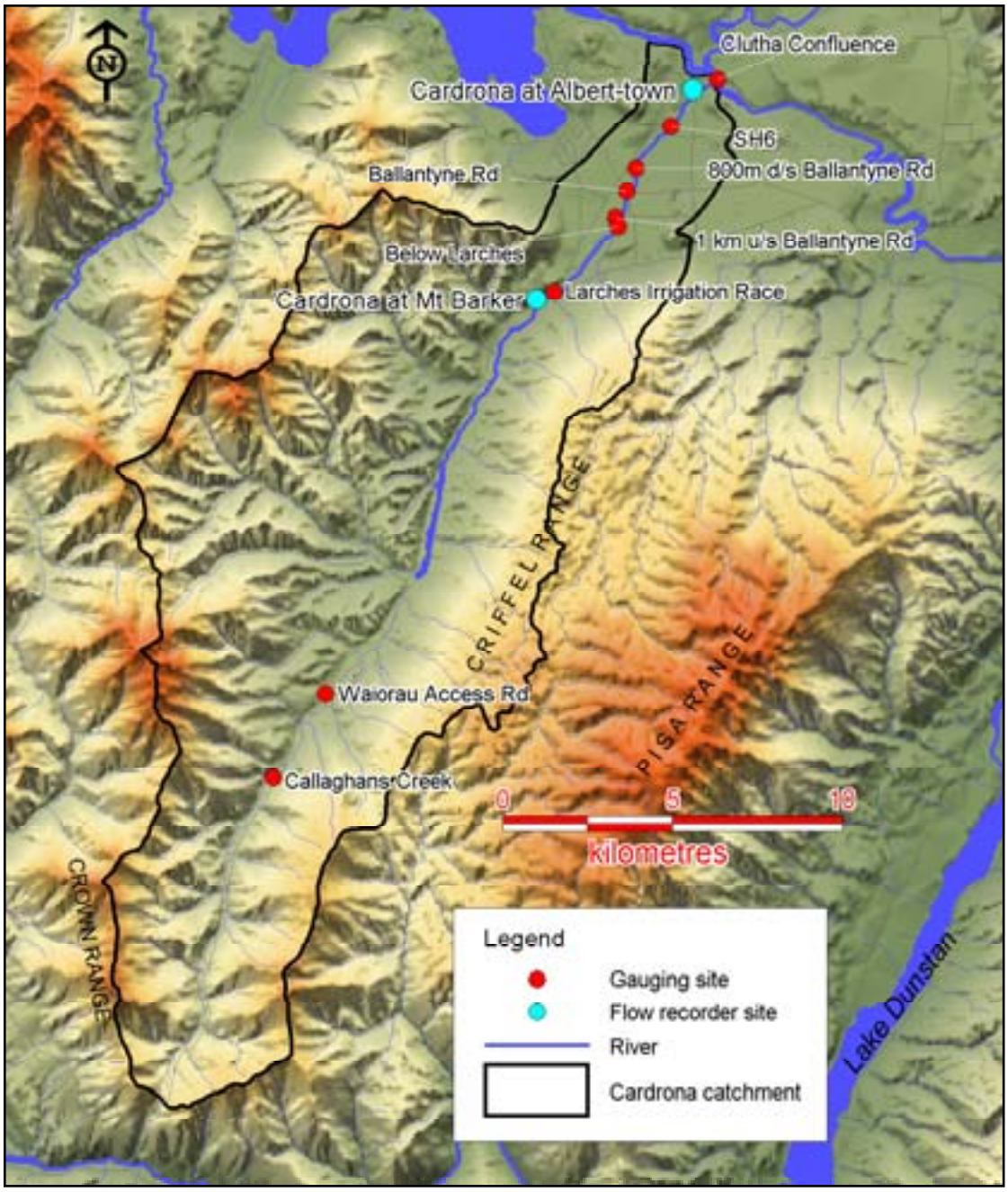


Figure 4.1 Low flow gauging and permanent flow sites in the Cardrona Catchment

Figure 4.2 shows the results from six gauging runs down the Cardrona River between October 2001 and April 2006. Unfortunately, not all sites were gauged during each run. In some cases, for ease of presentation, an estimate of flow has been made for

intermediary sites where gaugings were not taken (for example, no gauging was taken at Albert Town on 26/1/2004, although one was done at the nearby Clutha confluence site). The most complete set of gaugings was the run on 26/1/2004. The actual flow values for each gauging are shown in Appendix 4.

In addition to gaugings taken in the main stem of the river, gaugings were also taken in the irrigation race which abstracts water from the Cardrona between Mt Barker and The Larches Station on two occasions. This is described further in Section 4.3.

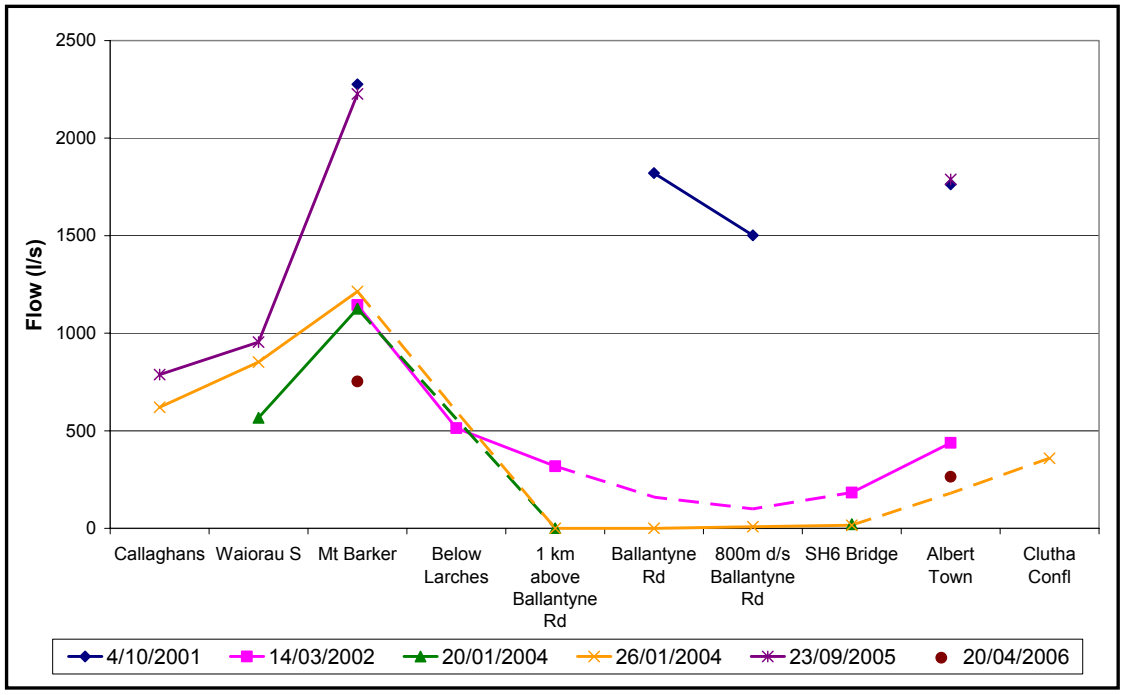


Figure 4.2 Results of six flow gauging runs in the Cardrona River

Despite the paucity of data on some of the gauging runs down the Cardrona, two distinct patterns emerge, with summer flows in the lower catchment considerably lower than those recorded during spring. The increase in flow between Waiorau and Mt Barker was approximately 1300 l/s on the spring gauging runs. During summer however, the increase in flow was considerably less, ranging from 400 to 500 l/s.

Downstream of Mt Barker, the difference between spring and summer gauging runs is even more pronounced, with the summer gaugings showing a rapid decline in flow below this point. The section between Ballantyne Road and SH6 often runs dry during the summer months, and the January 2004 gauging runs measured as little as 16 l/s at the SH6 site.

4.1 Spring flow gaugings

Two gauging runs were completed early in the irrigation season (4/10/2001 and 23/9/2005). The flow at Mt Barker on both of these gauging runs was approximately 2250 l/s, while at Albert Town a flow of approximately 1800 l/s was recorded on both days. Both gauging runs show that river flow declined below Mt Barker (Figure 4.2)

and suggest that the river is losing water up until at least 800 metres downstream of Ballantyne Road, and then gains water again towards the mouth.

Figure 4.3 and Figure 4.4 show the continuous flow record from the Mt Barker site for the weeks preceeding and following the gauging runs on 4/10/2001 and 23/9/2005. These hydrographs show that river flow was reasonably steady and at a moderate level (above 2000 l/s) for a considerable period before the gauging runs were done. This is important as it means all gauged reaches of the river are in a reasonably steady state, rather than falling or climbing rapidly.

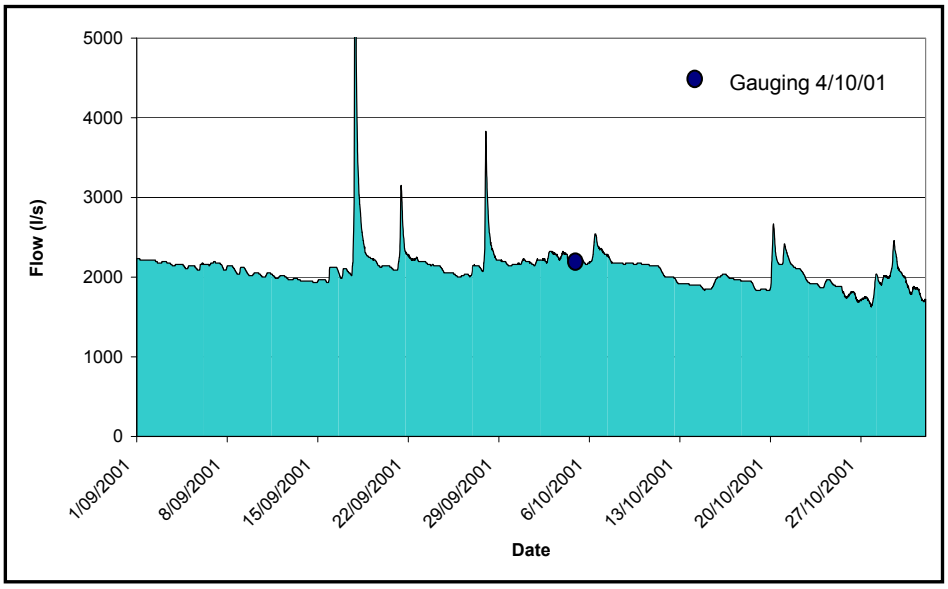


Figure 4.3 Hydrograph of Cardrona River at Mt Barker for Sept-Oct 2001

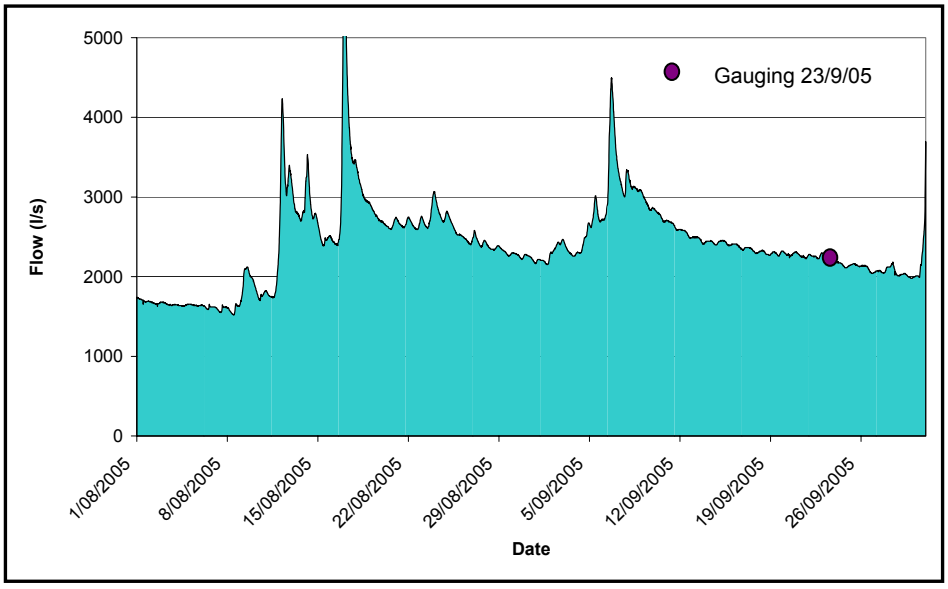


Figure 4.4 Hydrograph of Cardrona River at Mt Barker for Aug-Sept 2005

4.2 Summer flow gaugings

Figure 4.5, Figure 4.6 and Figure 4.7 show the flow at Mt Barker for the weeks preceeding and following the gauging runs on 14/3/2002, 20/1/2004 and 26/1/2004 and 20/4/2006. Compared to the flows shown in the preceeding Section, the Cardrona at Mt Barker was considerably lower in the period leading up to these gauging runs, and most of these summer low flow gaugings were done during periods of stable low flows.

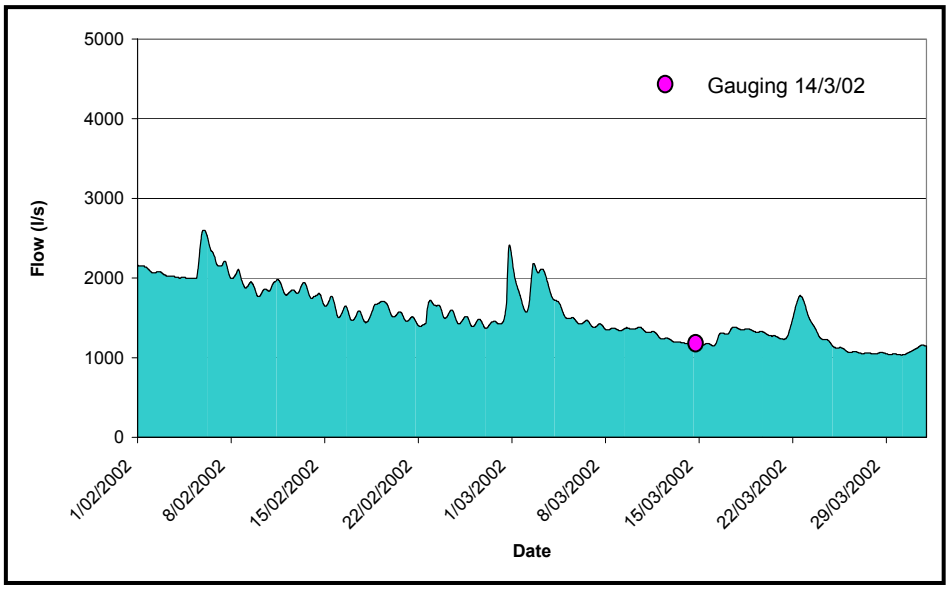


Figure 4.5 Hydrograph of Cardrona River at Mt Barker for Feb-Mar 2002

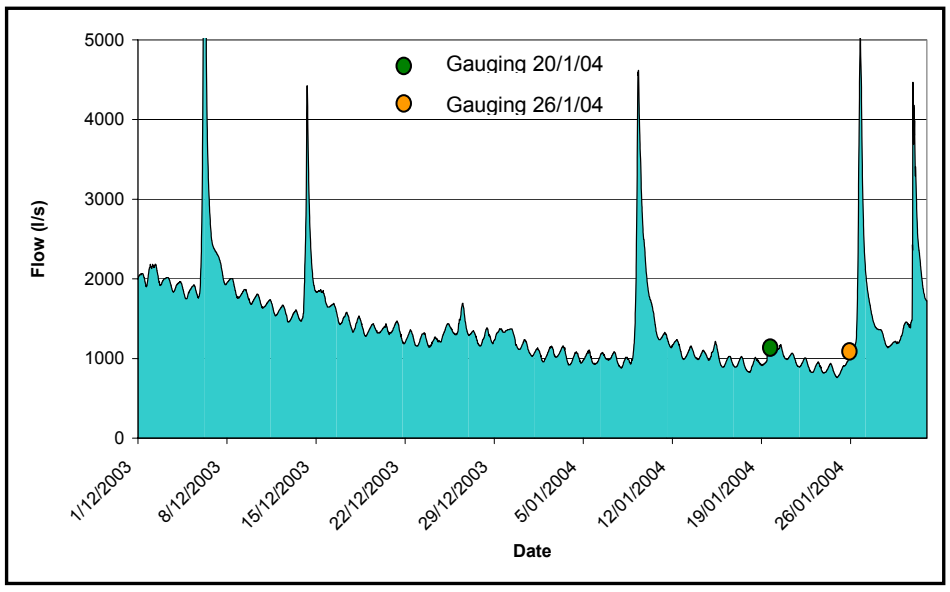


Figure 4.6 Hydrograph of Cardrona River at Mt Barker for Dec 2003-Jan 2004

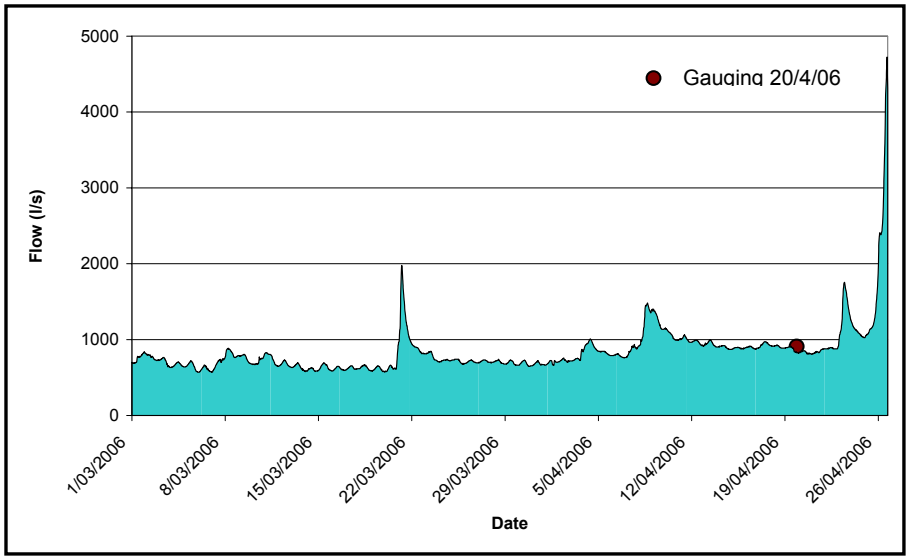


Figure 4.7 Hydrograph of Cardrona River at Mt Barker for Mar-Apr 2006

4.3 Effect of the Larches irrigation race

The Cardrona River is used as a major source of water for irrigation schemes in the Wanaka Basin. A take of up to 500 l/s from the river at the Larches area (Figure 4.8) is transported via an open race network to the greater Wanaka Basin. This is the largest single consented take from the Cardrona River. Irrigation water not used is either returned to the Cardrona River or by-washed into a small creek in the lower Mt Alpha area, which then flows to Lake Wanaka (ORC, 2003).

Figure 4.8 Irrigation water (to the right) being diverted from the Cardrona River at The Larches, February 2002

The Otago Regional Council has three recorded flow gaugings on this irrigation race. On 20 January 2004, the Cardrona River upstream of the race was flowing at 1126 l/s (Mt Barker site). The flow in the race was measured at 471 l/s on the same day. Losses to groundwater and other irrigation abstractions had reduced the remaining flow in the Cardrona River to zero approximately 3km downstream of the race (1km upstream Ballantyne Road site). A very similar situation was measured five days later on 26 January (Appendix 4).

The only other flow measurement from the irrigation race was late in the irrigation season on 20 April 2006, when 72 l/s was recorded. The upstream flow on this day was 753 l/s at Mt Barker. Unfortunately, there were no other gaugings done in the Cardrona River downstream of the race, apart from well downstream at Albert Town.

The gauging runs on 20 and 26 January 2004 were towards the end of a severe drought in Otago. The cumulative effect on the Cardrona River of water being diverted into the Larches irrigation race (as well as other smaller takes) during this period was significant, with the river running dry not far downstream. It is possible that due to groundwater losses, the Cardrona River may have still run dry further downstream if these takes had not been active. Further research is required to accurately define the net water loss to groundwater in the lower Cardrona, but it has been previously estimated at between 660 l/s and 900 l/s (ORC, 2003).

5. Bullock Creek

The springs in the Wanaka township known as Bullock Creek are effectively drainage points for groundwater from the Wanaka Basin Aquifer, a proportion of which is thought to be sourced from the Cardrona River (ORC, 2003). Bullock Creek (Figure 5.1) emerges in the lower Mt Alpha area as small seeps, which then flow past the Wanaka Fish Hatchery, gaining flow as it proceeds along the base of the moraine area. Further down there are several prominent springs and numerous smaller springs that contribute to the total flow. The creek flows through Wanaka and enters the Lake at Roy's Bay.

Bullock Creek Flows have been measured intermittently from March 1983 to April 2006 and total outflow to Lake Wanaka during base flow conditions generally range from 300 l/s to 630 l/s (ORC 2003). A one-off gauging of 1465 l/s at Mt Aspiring Road was recorded during heavy rainfall in January 2004. Figure 5.1 shows the location of flow gauging sites on Bullock Creek and the flow gauging results are shown in Figure 5.2 and Appendix 4.

Figure 5.1 Location of flow measurement sites in Bullock Creek

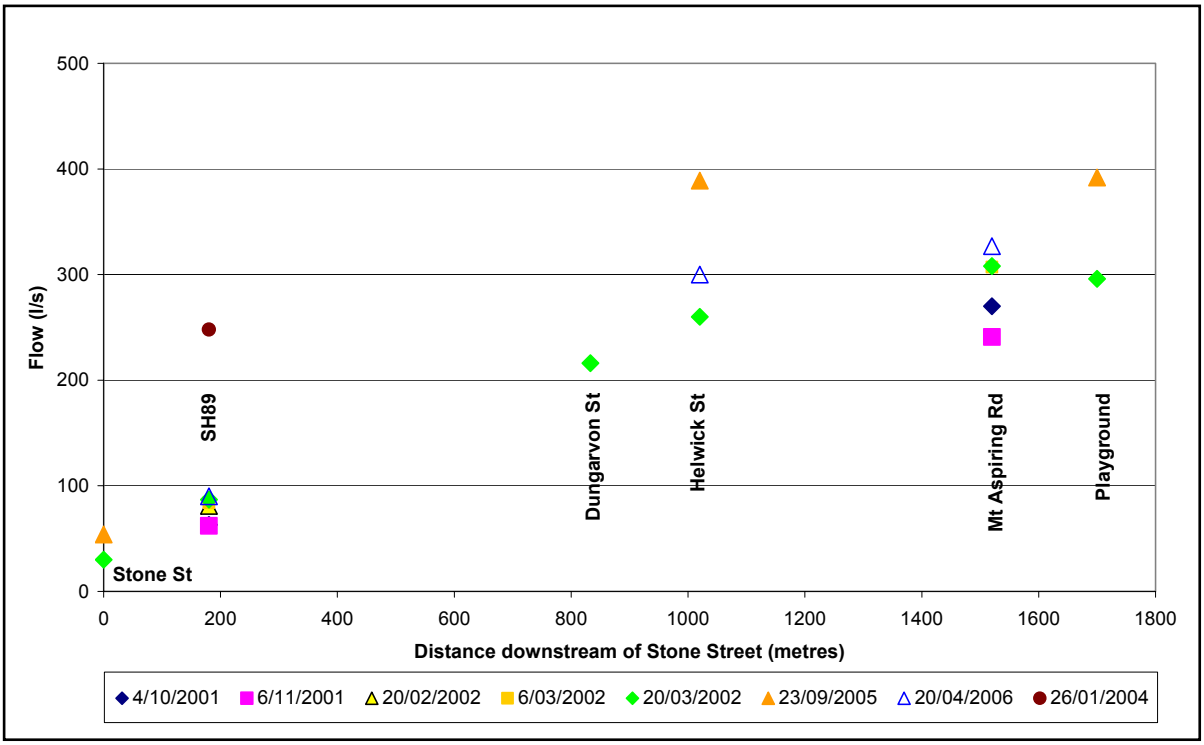


Figure 5.2 Flow gaugings on Bullock Creek, 2001 to 2006.

5.1 Relationship between Cardrona River and Bullock Creek flows

A base flow of less than 100 l/s in Bullock Creek above Stone Street is probably sourced from rainfall in the Mt Alpha area (Figure 2.1). Flow gaugings at Stone Street and SH89 between 2001 and 2006 show very little variation in flow (Figure 5.2), with the exception of 26/1/2004, when it was raining heavily. Below SH89, Bullock Creek flow gradually increases to reach approximately 300 l/s by the time it reaches Helwick Street. The rate of increase then slows as the creek approaches Lake Wanaka.

In the downstream reaches there are several prominent springs, as well as numerous smaller springs and seeps that all contribute to Bullock Creek flows. A previous study by the Otago Regional Council indicates that some of the water from these springs may originate from the Cardrona River. Earlier work carried out in the Wanaka Basin by the Otago Regional Council and Institute of Geological and Nuclear Sciences (IGNS, 1997) included isotopic measurements from Bullock Creek and the Cardrona River. Results showed that Bullock Creek flow was directly related to Cardrona River losses. This was also confirmed by piezometric survey and subsequent water balance equations (ORC, 2003).

6. Conclusions

The Cardrona River is in the upper Clutha Valley and drains from a typical Otago high country landscape. Tussock and low producing grassland dominates the higher catchment areas, while high producing exotic grassland dominates the lower catchment.

The annual average rainfall ranges from 600-750mm on the flats in the lower catchment area between Cardrona township and Wanaka Airport. A severe rainfall deficit occurs during summer, with January - February rainfall totals generally ranging from 80 to 120mm. Potential Evapotranspiration during this period is considerably higher, however, ranging from 206 to 210mm. This summer moisture deficit leads to a high demand for irrigation water.

The cumulative effect of consumptive takes downstream of Mt Barker means that the river has considerably more flow at this point than further down the catchment at Albert Town, particularly during the summer months. In addition, there appears to have been a reduction in both annual average flow and seven day low flow values at Mt Barker since the site was reinstalled in 2001. The months of May and August have seen the most significant decline in average flow. The decline in flow is not as pronounced at Albert Town, although there has been no continuous flow record from this site since 2001. Additional information is required to determine whether flow rates have declined significantly since that time.

A study of rainfall patterns at rain-gauge sites in and around the Cardrona Catchment shows there has been a decline in annual average rainfall since the late 1990s and this is likely to have contributed to the reduced flow rates at Mt Barker. Any increase in the demand for irrigation water will also have a detrimental effect on flows in the Cardrona River.

A number of gauging runs in the Cardrona Catchment have provided additional information on changes in flow rates as the river moves downstream. A gradual reduction in flow below Mt Barker was also well documented by this study and the river is shown to often run dry during the summer months in the section between Ballantyne Road and SH6. Gaugings on The Larches irrigation race below Mt Barker confirmed that it was taking up to 500 l/s during the particularly dry summer of 2003-2004, with the river running dry approximately 3km downstream of the race. Other irrigation takes were not monitored as part of this study.

The final section of this report summarised flow information collected from Bullock Creek, which flows through Wanaka. Bullock Creek has been shown to obtain some of its flow from the Cardrona River, in the form of a number of springs and seeps in its lower reaches. Flow rates in this creek are generally fairly constant due to a large percentage of its flow coming from groundwater. Measured flows range from less than 100 l/s in the upper reaches to as much as 400 l/s at the mouth.

7. Future considerations

This report has summarised the currently available hydrological information in the Cardrona Catchment. For management purposes, more specific work may be necessary in the future to supplement the understanding of the water resource. Some future considerations are given below.

7.1 Albert Town gaugings

A series of gaugings over a range of different flows at the old Albert Town flow recorder site would help determine whether the recent decline in average flow rates at Mt Barker is also occurring downstream.

7.2 Intensive gauging program

Gauging un-modified flows in the catchment would provide valuable information on the yield of water that could be expected from the Cardrona under natural conditions. In addition, a more extensive series of flow measurements of both the main stem of the river and consumptive takes along the lower Cardrona would better define losses to groundwater.

Such a gauging program would be best undertaken during a prolonged dry period to ensure that flows were stable.

7.3 Monitoring of water takes

In addition to the work suggested in section 7.2, it would be useful to have additional information on how much water is being extracted from the Cardrona at any one time. This would help to manage the water resource more efficiently and ensure fairness among water users. This can be achieved by installing flow loggers on pumps and flow monitoring sites on major irrigation races. Such schemes have already been installed in other water short areas such as the Kakanui Catchment in North Otago.

8. References

Institute of Geological and Nuclear Sciences Ltd, 1997. Groundwater quality of the Wanaka and Wakatipu Basins, Central Otago, New Zealand.

NIWA, Otago Regional Council, 2001. The Climate of Otago: Patterns of Variation and Change.

NIWA, Otago Regional Council, Jan – Sept 2006. Otago and Climate Pasture Update (Monthly climate, river flow and rainfall summary).

Otago Regional Council, 2000. Clutha Catchment Monitoring Report.

Otago Regional Council. 2003. Wanaka Basin Groundwater Modelling Report.

Otago Regional Council, 2004. GrowOtago. Climate and Soils Mapping Package.

Otago Regional Council, 2006. Water Quality of the Lindis and Cardrona rivers. Report No. ISBN 1-877265-38-1.

Appendix 1 Gaps in flow record for Cardrona at Mt Barker and Cardrona at Albert Town

Filename: **U:\Certified Data.hts**

Site: **Cardrona at Mt Barker**

Data starts at 2-Dec-1976 09:25:00
- Gap from 23-Mar-1978 11:00:00 to 27-Mar-1978 13:00:00 of 4.08 Days
- Gap from 10-Jan-1979 14:51:00 to 8-Feb-1979 14:25:00 of 28.98 Days
- Gap from 10-Jan-1980 14:05:00 to 15-Feb-1980 10:00:00 of 1.18 Months
- Gap from 28-Feb-1980 10:05:00 to 27-Mar-1980 16:35:00 of 28.27 Days
- Gap from 16-Jan-1981 08:35:00 to 12-Feb-1981 15:00:00 of 27.27 Days
- Gap from 20-Feb-1981 23:02:00 to 23-Feb-1981 16:36:00 of 2.73 Days
- Gap from 7-Mar-1981 22:57:00 to 12-Mar-1981 16:10:00 of 4.72 Days
- Gap from 19-Nov-1981 15:20:00 to 14-Jan-1982 14:45:00 of 1.84 Months
- Gap from 24-Nov-1983 14:50:00 to 8-Mar-1984 19:04:09 of 3.46 Months
- Gap from 17-Jul-1985 17:05:00 to 15-Aug-1985 16:45:00 of 28.99 Days
- Gap from 7-Apr-1988 16:50:00 to 28-Apr-1988 10:20:00 of 20.73 Days
- Gap from 21-Oct-1988 09:30:00 to 23-Feb-2001 14:15:00 of 12.34 Years
- Gap from 25-May-2005 01:15:00 to 25-May-2005 12:00:00 of 10.75 Hours
- Gap from 15-Jun-2005 11:00:00 to 21-Jun-2005 14:00:00 of 6.13 Days
- Gap from 24-Jun-2005 08:00:00 to 27-Jun-2005 13:45:00 of 3.24 Days

Data ends at 4-Apr-2006 15:00:05

Number of gaps: **15**

Filename: **U:\Certified Data.hts**

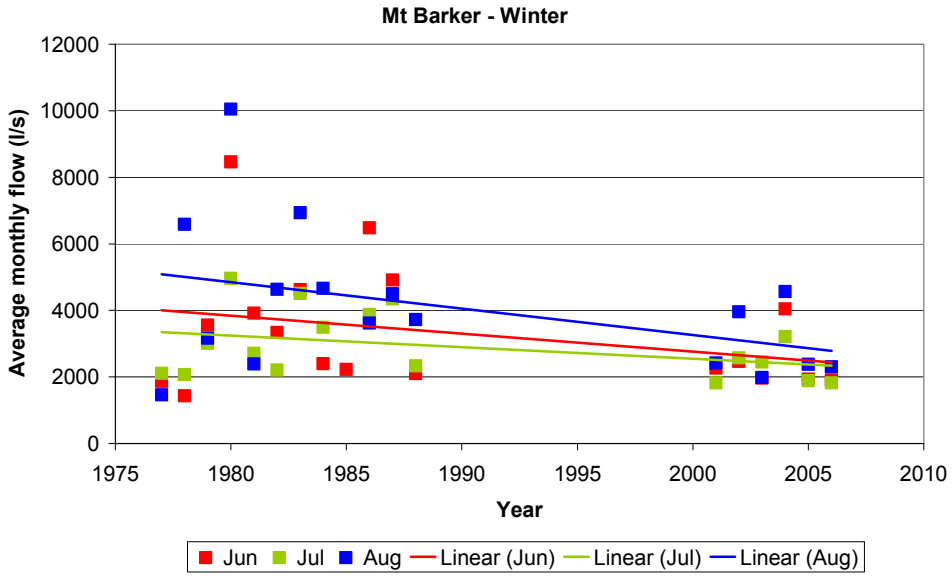
Site: **Cardrona at Albert Town**

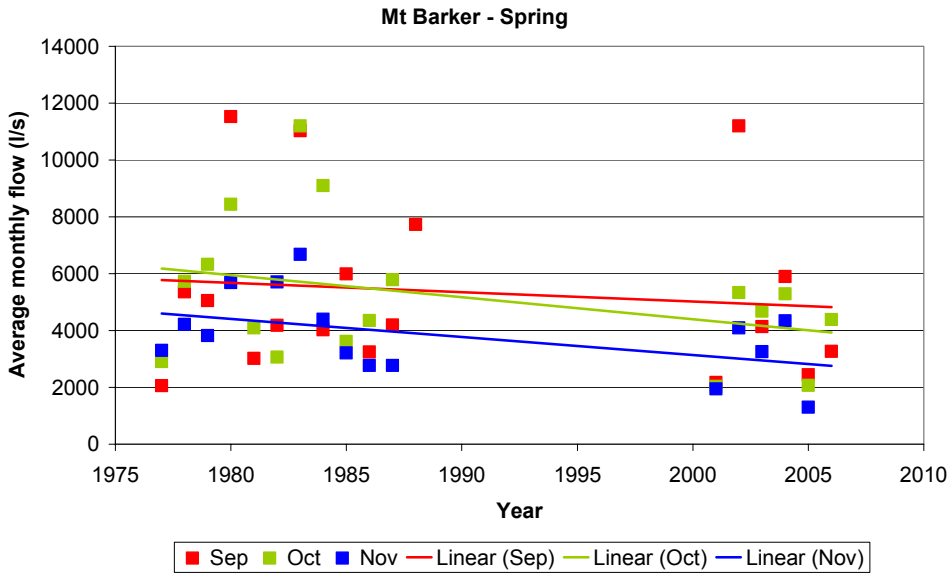
Data starts at 28-Sep-1978 16:45:00
- Gap from 15-Sep-1981 14:15:00 to 24-Sep-1981 14:15:00 of 9.00 Days
- Gap from 29-Dec-1983 18:15:00 to 12-Jan-1984 14:15:00 of 13.83 Days
- Gap from 3-Jul-1993 03:15:00 to 8-Jul-1993 15:15:00 of 5.50 Days
- Gap from 2-Jul-1994 07:15:00 to 7-Jul-1994 15:00:00 of 5.32 Days
- Gap from 12-Aug-1994 13:45:00 to 15-Sep-1994 14:15:00 of 1.12 Months
- Gap from 8-Apr-1997 10:30:00 to 11-Apr-1997 12:15:00 of 3.07 Days

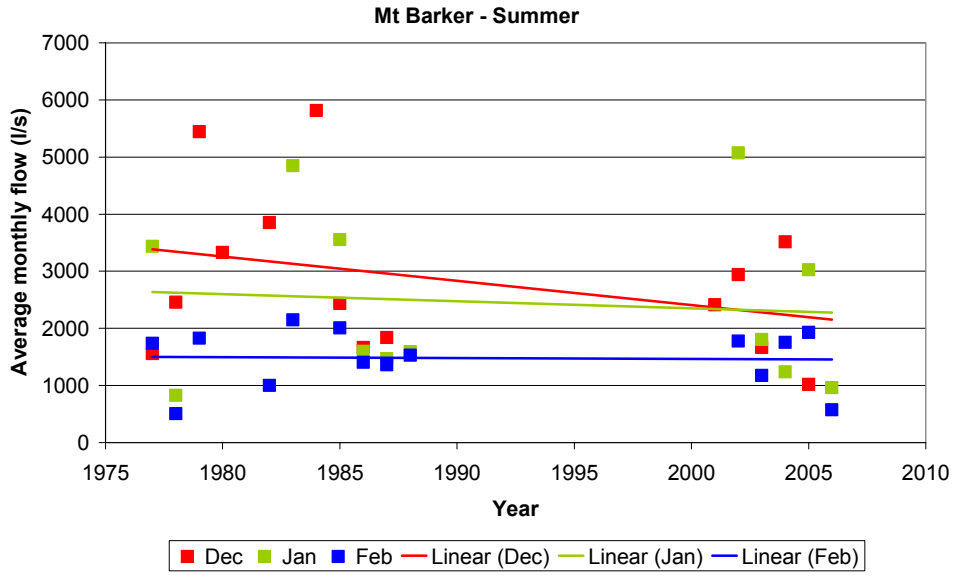
Data ends at 9-Jan-2002 12:30:00

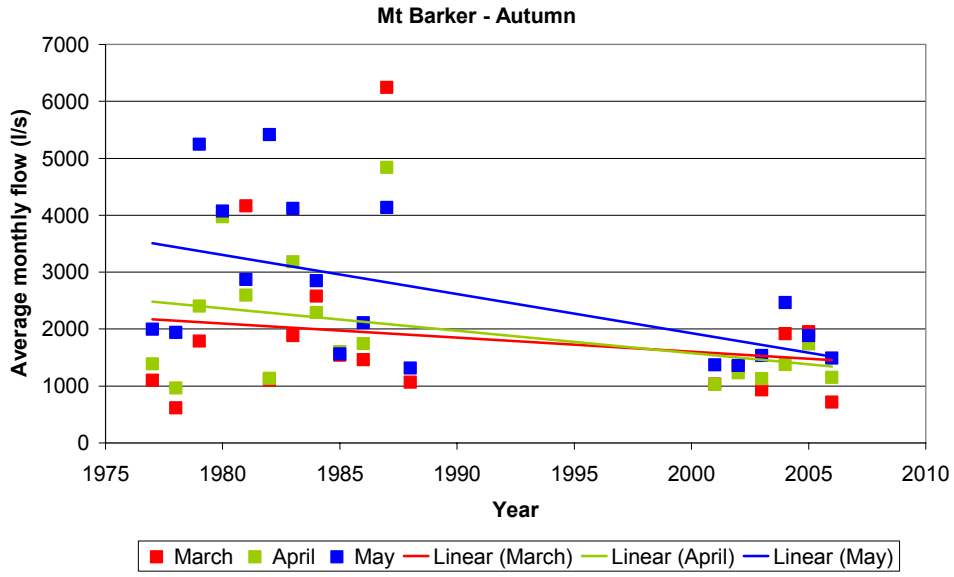
Number of gaps **6**

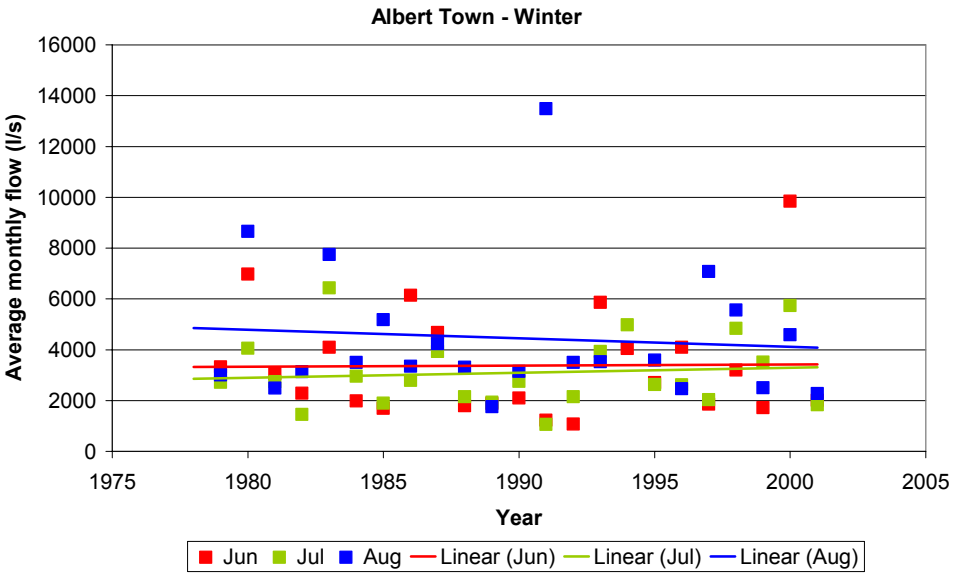
Appendix 2 Monthly average flows at Cardrona at Mt Barker and Cardrona at Albert Town

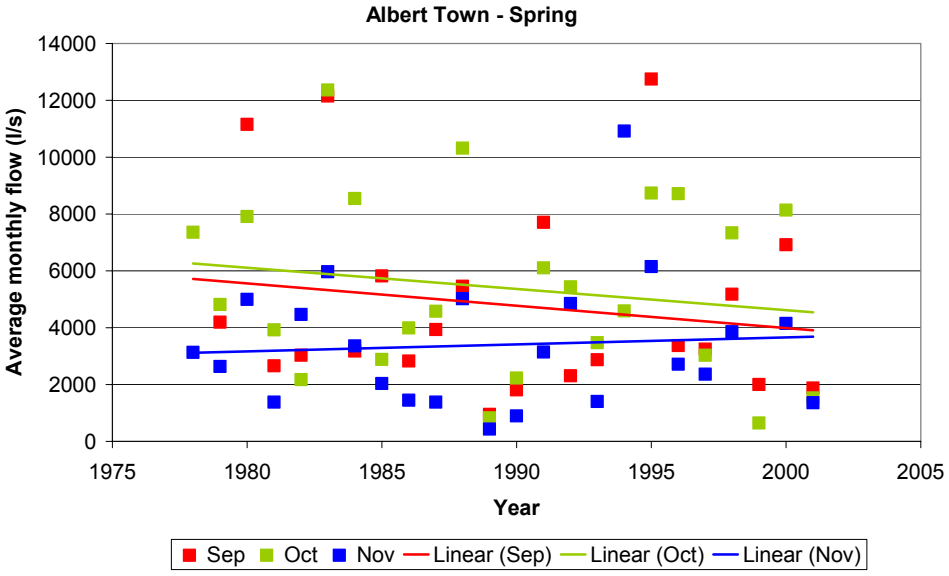


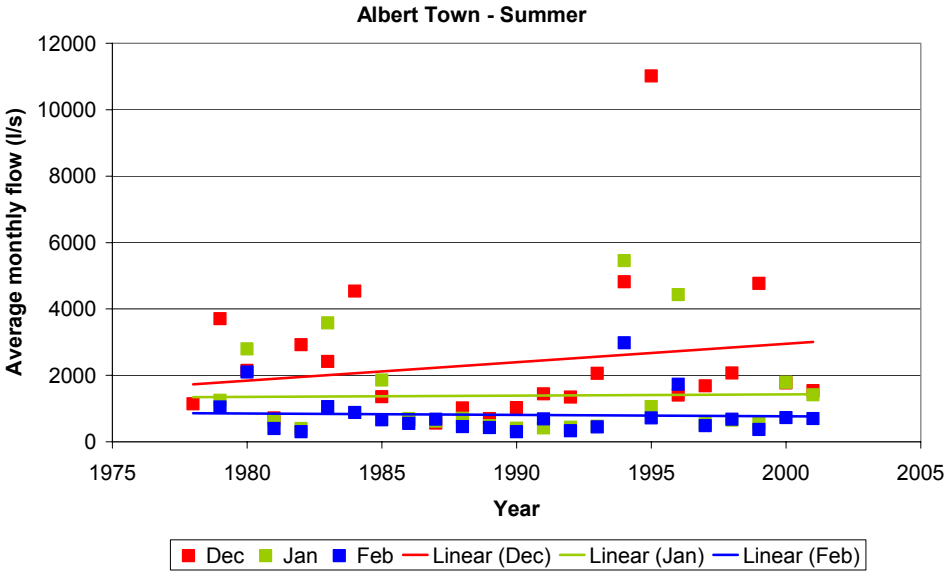


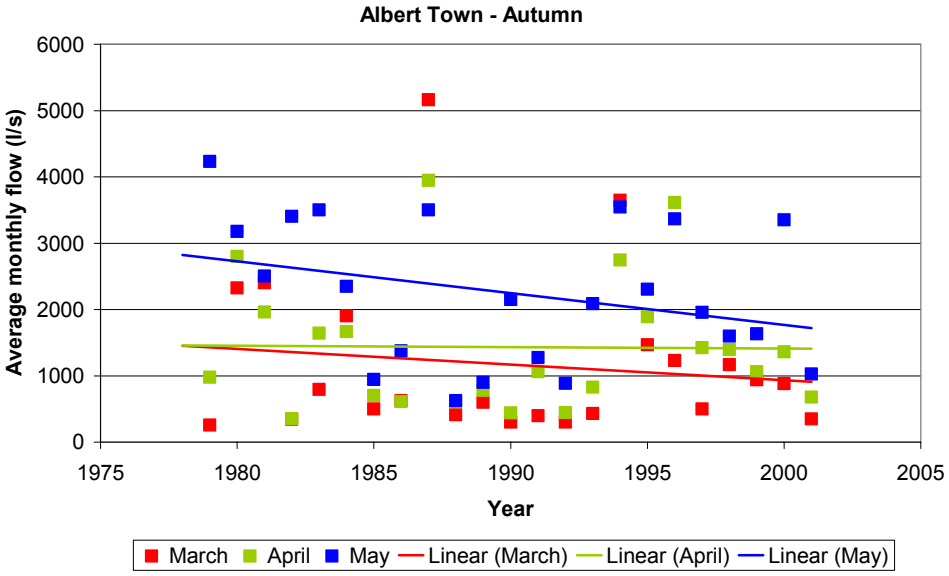

Mt Barker - Summer
Average monthly flow (l/s)
7000
6000
5000
4000
3000
2000
1000
0
1975
1980
1985
1990
1995
2000
2005
2010
Year
Dec
Jan
Feb
Linear (Dec)
Linear (Jan)
Linear (Feb)


Mt Barker - Autumn
Average monthly flow (l/s)
7000
6000
5000
4000
3000
2000
1000
0
1975
1980
1985
1990
1995
2000
2005
2010
Year
March
April
May
Linear (March)
Linear (April)
Linear (May)

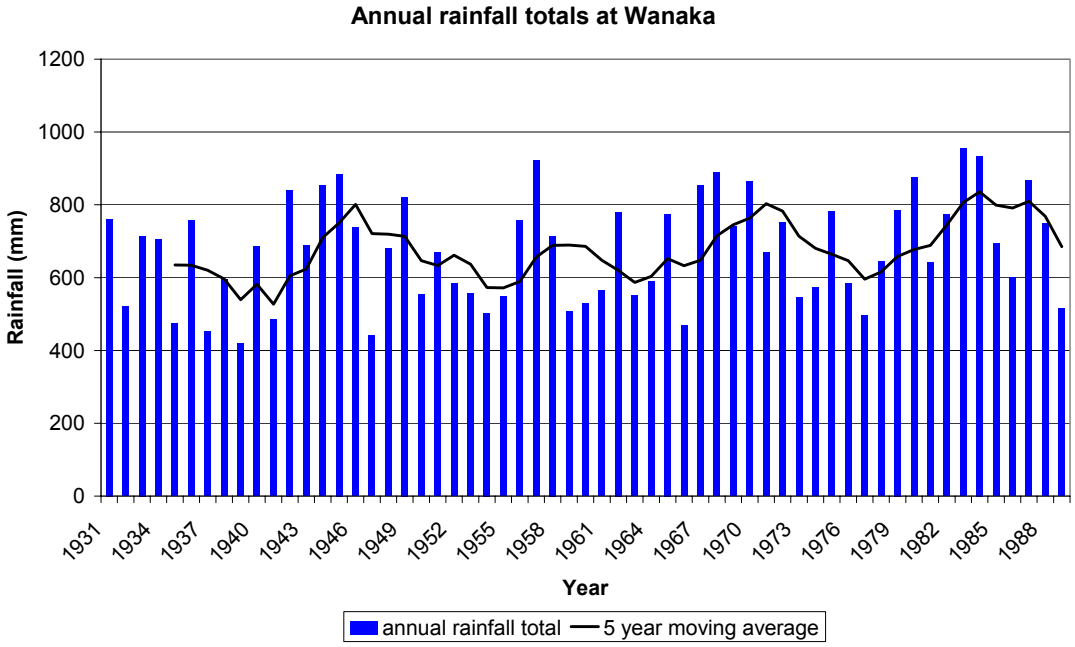

Albert Town - Winter
Average monthly flow (l/s)
16000
14000
12000
10000
8000
6000
4000
2000
0
1975
1980
1985
1990
1995
2000
2005
Year
Jun
Jul
Aug
Linear (Jun)
Linear (Jul)
Linear (Aug)

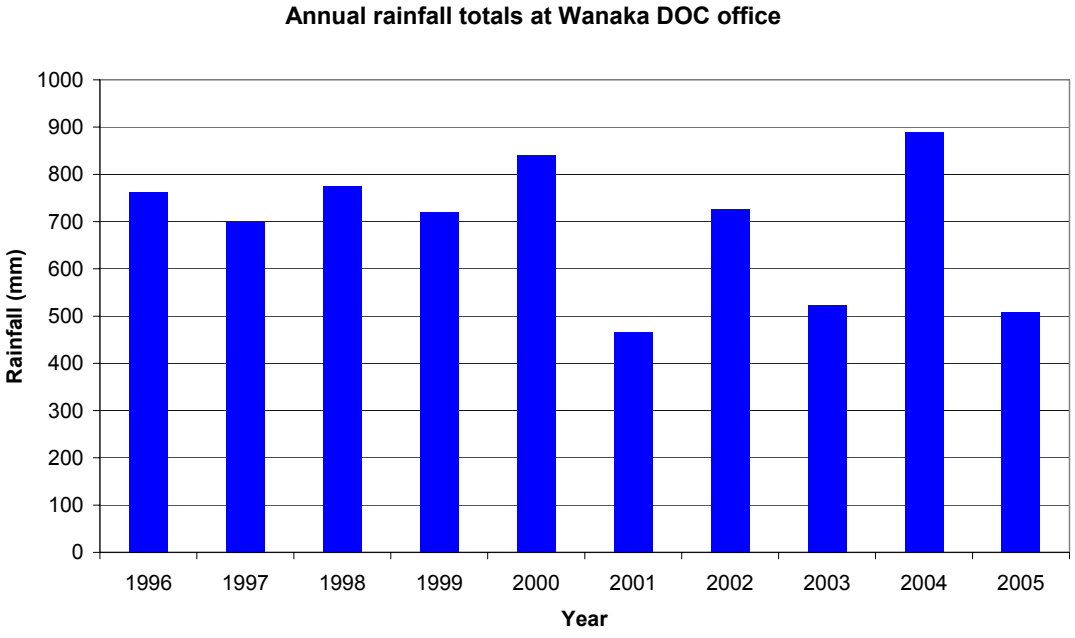

Albert Town - Spring
Average monthly flow (l/s)
14000
12000
10000
8000
6000
4000
2000
0
1975
1980
1985
1990
1995
2000
2005
Year
Sep
Oct
Nov
Linear (Sep)
Linear (Oct)
Linear (Nov)

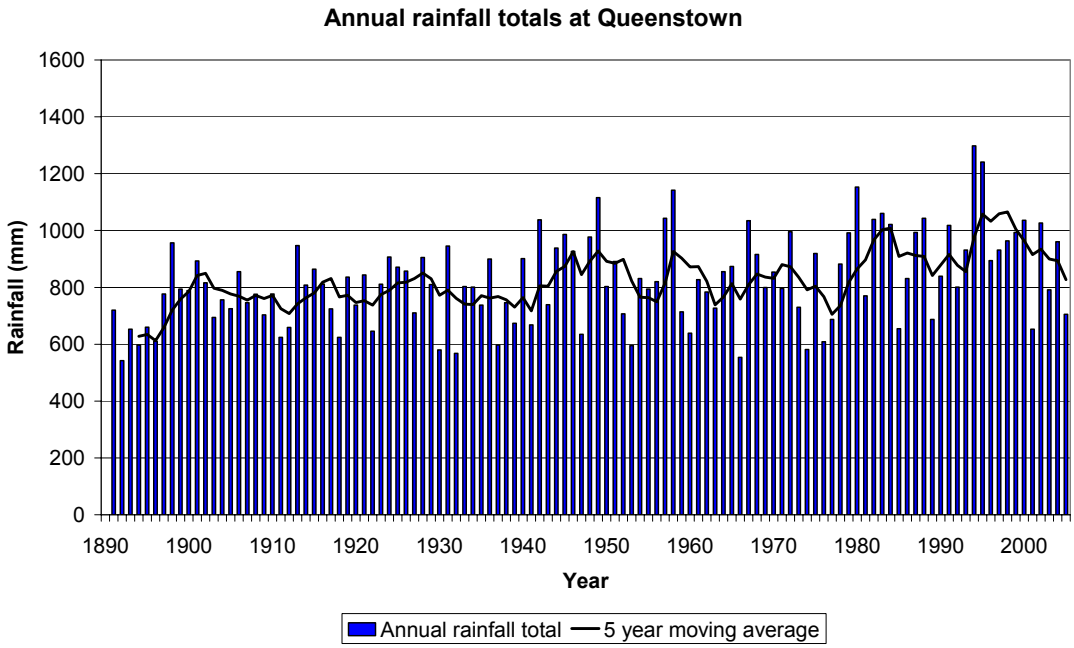

Albert Town - Summer
Average monthly flow (l/s)
12000
10000
8000
6000
4000
2000
0
1975
1980
1985
1990
1995
2000
2005
Year
Dec
Jan
Feb
Linear (Dec)
Linear (Jan)
Linear (Feb)


Albert Town - Autumn
Average monthly flow (l/s)
6000
5000
4000
3000
2000
1000
0
1975
1980
1985
1990
1995
2000
2005
Year
March
April
May
Linear (March)
Linear (April)
Linear (May)

Appendix 3 Rainfall records from Wanaka and Queenstown






Annual rainfall totals at Queenstown
Rainfall (mm)
1600
1400
1200
1000
800
600
400
200
0
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Annual rainfall total
5 year moving average

Appendix 4 Gauging results from Cardrona River, 2001 - 2006

	Date					
Site	4/10/01	14/3/02	20/1/04	26/1/04*	23/9/05	20/4/06
Callaghans				621	788	
Waoirau Stn			567	852	955	
Mt Barker	2276	1144	1126	1214	2226	753
Water race at Larches			471	477		72
Below Larches		514				
1km above Ballantyne Rd		318	0	0		
Ballantyne Rd	1821			0		
800m below Ballantyne Rd	1502					
SH6 Bridge		183	21	16		
Albert Town		438			1788	264
Clutha Confl.				359		

* Heavy rain late in the day on 26/1/04

Appendix 5 Gauging results from Bullock Creek, 2001 - 2006

	Date							
Site	4/10/01	6/11/01	20/2/02	6/3/02	20/3/02	26/1/04*	23/9/05	20/4/06
Stone St					30		54	
SH89	63	62	81	84	87	248		90
Dungarvon					216			
Helwick					260		389	300
Mt Aspiring	270	241		307	308	1465		327
Playground					296		392	

* Heavy rain late in the day on 26/1/04