The Water Resources of the Waikouaiti River

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Foreword

Rivers and streams are a major feature of any Otago landscape. 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. This report on the water resources of the Waikouaiti River is one of an occasional series describing Otago river catchments.

The Waikouaiti River in north-eastern Otago drains both high and low producing grasslands. Although surface water is not used extensively for irrigation at this stage, it is essential to fully understand the natural hydrology of an area before effective and efficient sustainable management decisions can be made for the future. This report has drawn together historical hydrological information, along with a recent series of low flow gaugings to help in that decision-making process.

Executive summary

The Waikouaiti River Catchment in eastern Otago covers an area of 425 km^2, but the river yields little water under normal conditions due to the low and sporadic rainfall. The predominant land use within the catchment is sheep and beef farming followed by areas of native vegetation, and some areas of dairying in the lower catchment. Landforms range from flat floodplains close to sea level, to plateau areas, steeplands and dissected hills inland with a maximum elevation of 700 m. The river supports a variety of fish, both trout and a range of threatened native species. Consumptive use of river water is limited with four water takes in the catchment totalling 0.129 m^3/s as well as the undefined takes associated with mining at Macraes Flat.

Rainfall across the catchment is distributed relatively evenly throughout the year. Inland areas experience larger totals in December from summer thunderstorms and slightly lower rainfall occurs in late autumn/winter in some areas. A large variation in monthly rainfall totals between years indicates the sporadic and unreliable nature of rainfall in the catchment. Average annual rainfall varies from 500 mm at Macraes Flat to over 1100 mm in the Silverpeaks.

The river has two branches of relatively different character. The north branch has a mean flow of 1.96 m^3/s, with much higher flows in the winter season than the irrigation season. The south branch has a mean flow of 0.850 m^3/s and little difference between irrigation season and winter flow regimes. While it has a catchment area less than a third of the north branch, the south branch flows at a similar rate to the north branch under normal conditions due to the higher rainfall. Normal monthly flows are highest in the winter months and lowest in autumn. Specific discharge (the flow per unit catchment area) during both normal and low-flow conditions is lower in the north branch, reflecting the lower rainfall and lower relief.

The two branches converge approximately 8 km upstream of the outlet and the lower 5 km of the river through the Karitane estuary are under tidal influence.

Both branches produce large floods at irregular intervals, with some years having two or more large floods and some none.

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1. Introduction

The Waikouaiti River is one of Otago's three major rivers draining to the coast north of Dunedin. While it has a large catchment area, the river yields little water under normal conditions because of the low and sporadic rainfall the catchment receives. The modest summer flows experienced in the lower reaches do support some abstraction for community water supply and irrigation, but for the most part the river is unused. The river also supports a variety of aquatic life, with significant habitat for native and introduced species.

The purpose of this report is to summarise the historical flow and rainfall records in the catchment and to provide a description of the water resources. Estimates of flood and low flow discharges are presented, as is the contribution of water from various areas of the catchment to the overall flow.

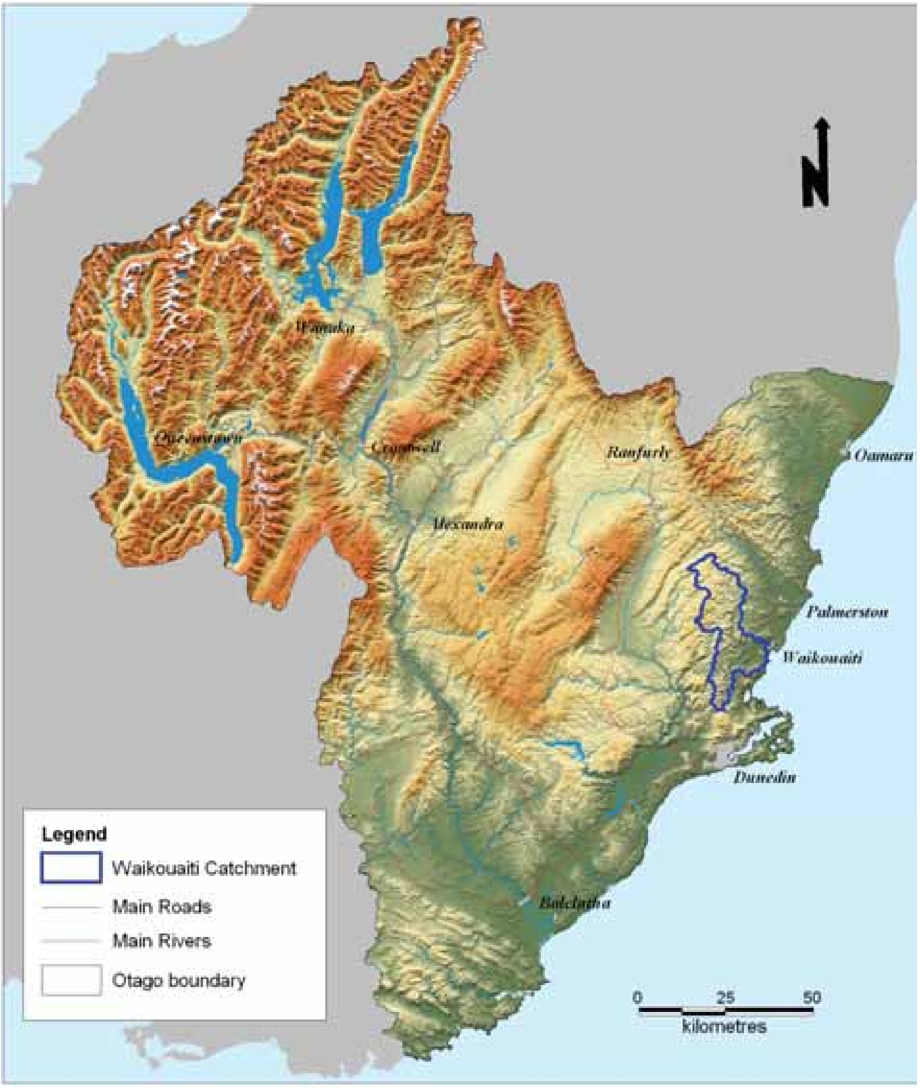

Figure 1.1 Location of the Waikouaiti Catchment in eastern Otago

2. Catchment description

Figure 2.1 The Waikouaiti River Catchment

2.1 Area

The Waikouaiti River is the third largest catchment in Otago that drains to the coast north of Dunedin, with a total area of 425 km^2. Two branches run roughly north-south and vice versa before converging approximately 8 km upstream of the outlet as shown in Figure 2.1. The north branch covers a much larger area of 283 km^2 than the south branch at 86 km^2.

The catchment has indistinct boundaries for the most part, with no dividing ranges between it and neighbouring catchments. To the west, it is bordered by the Nenthorn Stream Catchment, Three O'clock Stream Catchment and various other small catchments that drain to the lower Taieri River. To the north and east, it shares headwaters with the Shag and Pleasant Rivers. To the south, it is bordered by the Silverpeaks.

2.2 Relief and geology

The catchment is of lower relief than other east coast rivers with the peaks of 400-700 m asl around the catchment edges. The terrain of the catchment can be divided into four broad geomorphic areas:

- Western plateau
- Central area of dissected hill and steeplands
- Coastal hills and downs
- Terraces, river flats and sand dunes.

The western plateau is an area of relatively flat land at high elevation (500 - 700 m) in the headwaters of the north branch around Macraes Flat and extending to the south along the western boundary of the catchment. The central area of the catchment above the confluence of the two branches is, for the most part, severely cut up with tight gullies and heavily dissected landscape. Downstream of the confluence and near to the main stem of the river is a flood plain and estuarine system, with mostly low-lying land and areas of sand dunes and river terraces. The small area of coastal hills and downs downstream of the confluence are more rolling in character and less dissected than those further inland, due to a difference in rock type.

The inland areas are underlain by mainly schistose rocks, while in the coastal downs and flood plain area, more recent sedimentary and volcanic deposits make up the underlying surface geology.

2.3 Soils

The diversity of geologic and environmental factors within the Waikouaiti Catchment makes for a wide range of soils (ORC, 1992). A majority of the catchment is yellow-brown earths, these being the predominate soil in the inland hill and steeplands. Most of the remainder of the catchment is yellow – grey earths and intergrades between yellow-grey and yellow-brown earths in the coastal hills and downs. Some podzolised yellow-brown earths exist on the western plateau area and some recent and gley soils have formed on the low-lying and wet areas of the flood plains. Some redzina soils have formed on the areas of exposed sandstone on the coast.

2.4 Vegetation cover/land use

Vegetation in the catchment has been considerably modified over the last 150 years. Extensive forest and tussock areas have been replaced by a mixture of high and low-producing grasslands with scattered areas of remnant broadleaf and native and exotic forest. In the uplands beyond the confluence, the pasture is mostly low-producing with both native kanuka/ manuka and introduced scrub in gullies. In the Silverpeaks in the headwaters of the south branch, some native manuka/ kanuka and broadleaved indigenous hardwood forest/scrub remains. High producing pastures predominate in the hills and downs and river flat areas in the lower catchment below the confluence. Throughout the catchment, the pasture lands support mainly sheep and beef farming, though some dairy production is occurring in the lower catchment aided by irrigation from the main stem of the river.

2.5 Regional Plan values

The Waikouaiti River is identified within Schedule 1A of the Regional Plan: Water (the Water Plan) which lists any natural and ecosystem values that may be associated with certain rivers in Otago. In the Waikouaiti River, these include significant habitat for both trout and a range of threatened native species. The specific values determined to be significant are detailed in Table 2.1:

Table 2.1 Ecosystem values of the Waikouaiti River

Waikouaiti River (excluding south branch)	• Indigenous fish species threatened with extinction. • Habitat for flathead galaxiid, hybrid galaxiid, banded kokopu and koaro. • Inanga spawning in the lower reaches of the main stem upstream of the SH1 bridge. • Rare invertebrates in headwaters. • Spawning areas for trout. • Areas for the development of juvenile fish. • Presence of eel and trout. • Large water body. • Access within the main stem of the river unimpeded by artificial means.
Waikouaiti River (south branch)	• Indigenous fish species threatened with extinction. • Habitat for koaro. • A range of indigenous fish. • Spawning areas for trout. • Areas for the development of juvenile fish. • Presence of trout. • Riparian vegetation. • Access within the main stem of the river unimpeded by artificial means.
Merton Stream	• Indigenous fish species threatened with extinction. • A range of indigenous fish. • Habitat for lamprey.

In addition, the headwaters of the south branch within the scenic reserve are listed as having a high degree of naturalness.

The Water Plan also lists the water takes for public water supply purposes. Both the Waikouaiti community take in the main stem and the Mt Pleasant/Stoneburn rural water supply take in the north branch (see section 2.7) are included in this schedule. A rule in the plan allows these consents to be controlled activities to provide certainty for the communities.

Both branches of the Waikouaiti River are also included in Schedule 1D, which lists the spiritual and cultural beliefs, values and uses of significance to Kai Tahu.

2.6 Water quality

Water quality in the river is monitored bi-monthly at Orbells Crossing, 3 km below the confluence of the two main branches, as part of the State of the Environment (SoE) reporting programme. This programme aims to capture the spatial variation and long-term trends in water across the region. Water quality is also monitored at Bucklands Crossing in the north branch once a week during the summer as part of the contact recreation monitoring programme.

Between 2000 and 2006, the water quality at Orbells Crossing was classified as very good under the Water Quality Index [WQI] (ORC, 2007). This index uses the compliance with guideline values for a number of important factors such as the level of *E. coli*, dissolved oxygen, turbidity and various nutrients in the water as a basis to classify the water quality. Very good here means that the median (average) values of all factors were under the guideline levels.

Trend analysis of water quality data from 1995 to 2006 at Orbells Crossing showed improvements in suspended solids and the nutrients Ammoniacal Nitrogen, Total Nitrogen and Total Phosphorus as shown by Table 2.2. The only declining trend was that of conductivity.

Table 2.2 Water quality trends in the Waikouaiti River. Statistically significant (p>0.2) trends are depicted in blue for improving water quality and red for declining water quality

	Change	*Significance (p)*
Ammoniacal Nitrogen	Improving	<0.05
Conductivity	Declining	<0.2
Escherichia coli	None	NS
Nitrite/Nitrate Nitrogen	None	NS
Suspended solids	Improving	<0.05
Total Nitrogen	Improving	<0.1
Total Phosphorus	Improving	<0.1
Turbidity	None	NS

After heavy rainfall, levels of *E. coli* can be raised above guideline values for contact recreation, which is typical in catchments with largely agricultural land use.

In addition, summer water temperatures over 20°C have been recorded in the lower reaches, which are stressful conditions for aquatic species.

2.7 Water takes /Present water use

Few consented water takes exist in the Waikouaiti Catchment at present as shown by Figure 2.2. In the lower catchment, three separate takes draw a maximum of 0.125 m^3/s from the main stem of the river as shown by Table 2.3. The largest of these is for community water supply. The other two are for irrigation and stock drinking water on the flood plains near Waikouaiti township. In the upper catchment, a number of surface water takes exist for dewatering of mine pits at Macraes Flat. The impact of the Macraes Mine takes on the flow regime of the river is thought to be minimal though essentially the mine removes an area of catchment above the take of around 6 km^2, with little to none of the water removed being released back into the river. A small take of 0.004 m^3/s also exists in the north branch to supply the communities of Stoneburn and Mt Pleasant.

Table 2.3 Consumptive water takes in the Waikouaiti Catchment

Consent No.	Consent Holder	Location	Purpose	Maximum Rate (m^3/s)	Volume (m^3/month)
96810	Oceana Gold	Macraes Flat	Mine pit dewatering	None	None
96813	Oceana Gold	Macraes Flat	Mine pit dewatering	None	None
2004.100	Oceana Gold	Macraes Flat	Mine pit dewatering	None	None
2007.522	Oceana Gold	Stoneburn	Mine pit dewatering	None	*(300 m^3/day)**
97427	Waitaki District Council	Stoneburn	Stoneburn rural supply	0.004	11,160 (360 m^3/day)*
2006.075 & 2006.002	Dunedin City Council	Waikouaiti	Waikouaiti town supply	0.060	108,500 (3,500 m^3/day)*
2003.823	McAra Family Trust	Waikouaiti	Irrigation	0.019	45,965
2001.783	Pacific View Ltd.	Orbells Crossing Bridge, Waikouaiti	Irrigation and stockwater	0.046	108,000
Existing Total Primary Allocation				0.129	273,625

* (bracketed) daily volumes consented. Monthly volume = daily volume x 31.

All the existing consents have residual or minimum flows attached to them that allow for the protection of the life supporting capacities of aquatic ecosystems in the river.

No surface water discharge permits now exist in the lower catchment as both the previous treated sewerage discharges are now discharged to land.

2.7.1 Water allocation

The primary allocation limit for the catchment is currently at 0.170 m^3/s, measured in the main stem of the river at the upstream Health Intake site (see Figure 3.3). As the existing primary allocation is currently 0.129 m^3/s, the remaining primary allocation stands at 0.041 m^3/s, although further supplementary allocation is also available. Supplementary allocation enables access to water at moderate flows, while maintaining aquatic ecosystem and natural character values. It is allocated in blocks of water; for a river the size of the Waikouaiti the block size is 0.5 m^3/s. From each block, 50% is made available for abstraction with the other 50% remaining instream. The following formula is used to derive the supplementary minimum flow:

Supplementary minimum flow = primary allocation limit (**0.170 m^3/s**) + supplementary allocation remaining instream (**0.250 m^3/s**)
= **0.420 m^3/s**

Permits in the first block of supplementary allocation would be able to use their water permits when the flow is over this supplementary minimum flow.

Further supplementary allocation (flood harvesting) is available when flows are above mean flow without any restriction on quantity or rate of take, though storage is required to hold this harvested water to be used during times of low rainfall.

Figure 2.2 Consented surface water takes in the Waikouaiti Catchment

3. Rainfall

The climate of the catchment is considered mild and dry inland, but each of the two branches has different characteristics. The south branch is similar to other streams originating in the Silverpeaks such as the Waitati River, Water of Leith and Silver Stream Catchments. Here annual rainfall is much higher, ranging between 700 and 1,200 mm and consequently specific discharge (the amount of water flowing into the river per unit of land area) is higher under normal conditions. The north branch, on the other hand, has a climate similar to other rivers on the North Otago coast such as the Shag and Kakanui, with low specific discharge under normal conditions and annual rainfall between 400 mm and 800 mm. Here the rainfall is more irregular. Annual rainfall across the catchment generally follows a north-south gradient being highest in the high elevation areas in the southwest and lowest in the inland area around Macraes Flat as shown by Figure 3.1. Average annual rainfall in the coastal hill and floodplains is between 600 and 800 mm.

The annual rainfall total maps were derived during the growOtago climate project (ORC, 2004). Median annual and quarterly rainfall layers for the entire Otago region were built from long-term records of daily rainfall at numerous sites that were interpolated with an elevation factor added in.

3.1.1 Annual rainfall distribution

There are a number of daily rainfall stations in and around the catchment that give a good record of monthly variation in rainfall in different parts of the catchment. Figure 3.3 shows the location of these rainfall stations.

Average monthly rainfall totals across the catchment are generally even throughout the year as shown by the solid blue bars in Figure 3.2. In the headwaters to the north (Nenthorn, Glendale and Stoneburn), average rainfall is around 50 mm per month with a trend toward higher rainfall during December-January which is likely to be associated with thunderstorms. Lower rainfall occurs in autumn-winter and September. More notable is the great variation between the maximum and minimum monthly totals recorded, which in some years is close to zero and in others is over 200 mm. In these inland sites there also seems to be less variation in rainfall totals during spring with large rainfall totals absent from the record.

Sullivan's Dam, near the headwaters of the south branch, shows much larger and consistent average monthly rainfall totals, but a trend toward higher maximum totals during the autumn and winter. Lower monthly totals are possible during early summer.

The large variation in monthly totals shows that, while on average rainfall is consistent throughout the year, there is inherent insecurity in the rainfall in any given month, regardless of the time of the year.

Rainfall in the lower catchment appears to be similar to the northern part of the catchment with monthly averages around 50 mm. However, the larger average rainfall in December is absent and the lowest averages occur in August-September. Large rainfall totals are absent from August through to December. The highest averages occur here in January and March.

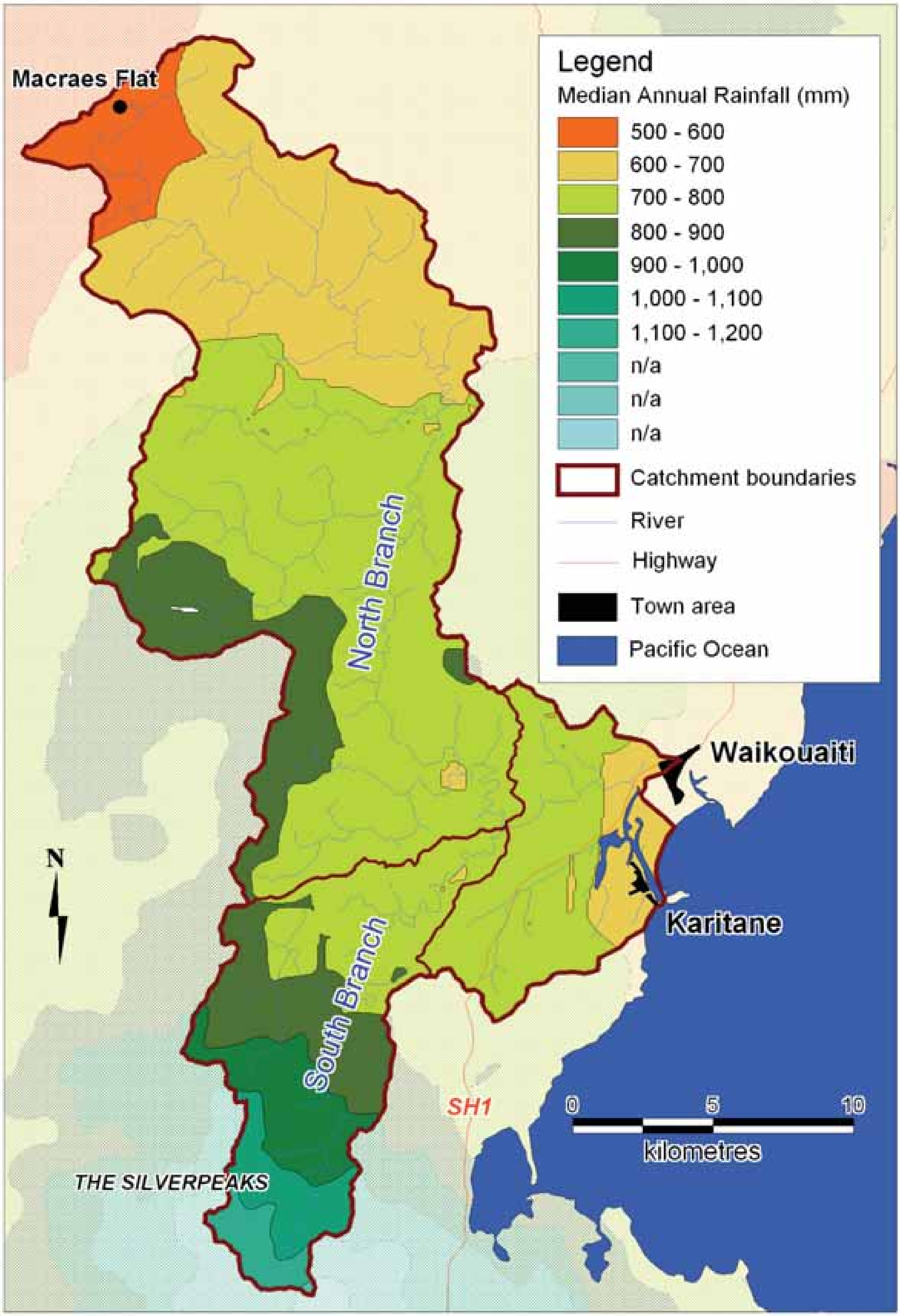

Figure 3.1 Median annual rainfall over the Waikouaiti Catchment (from growOtago)

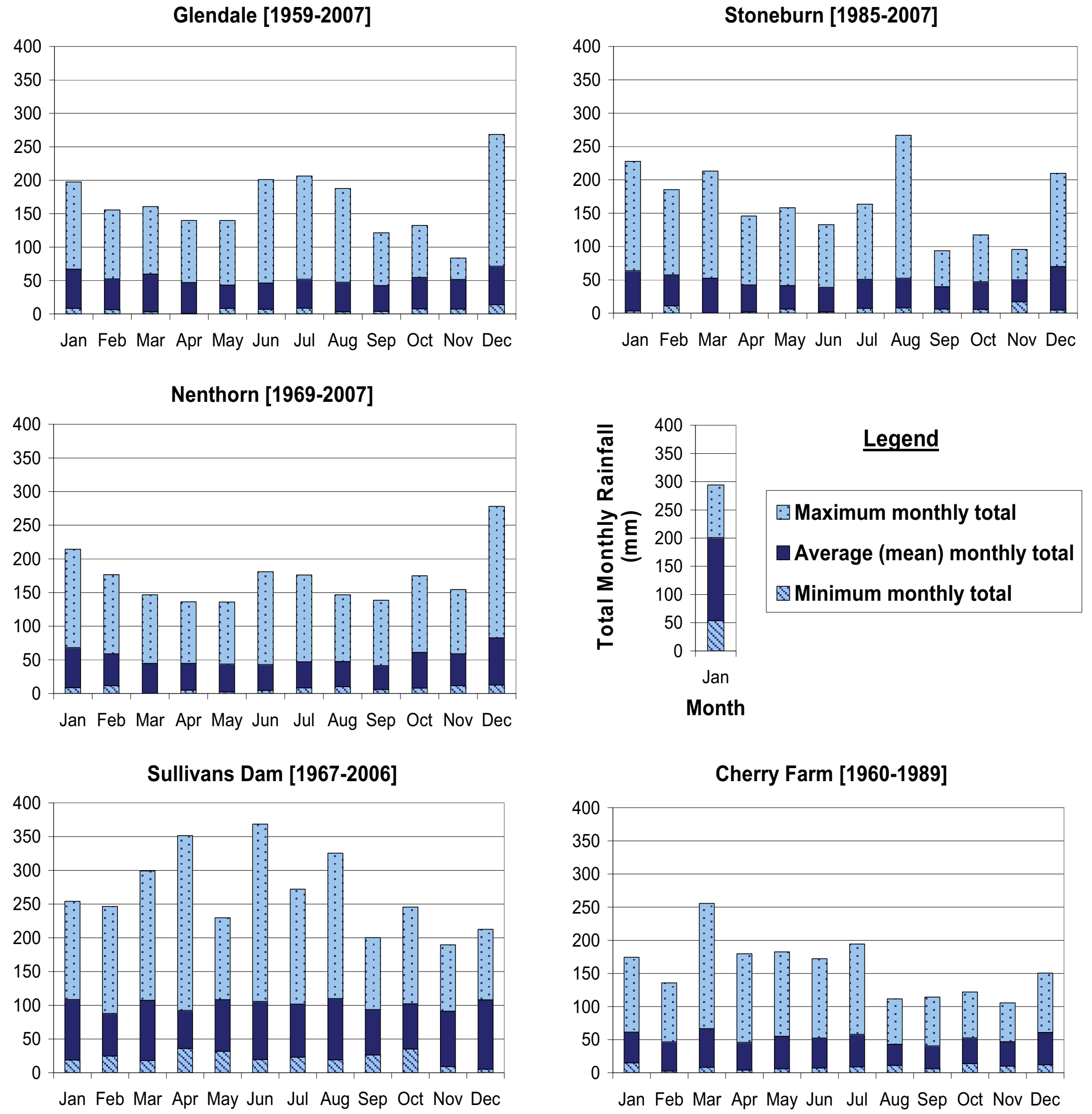

Figure 3.2 Monthly rainfall trends for the Waikouaiti Catchment. See note on August totals*

* Cause of large August totals at Stoneburn - August 2000 - 135 mm over 3 days - >200 m^3/s in the Shag River @ the Grange.

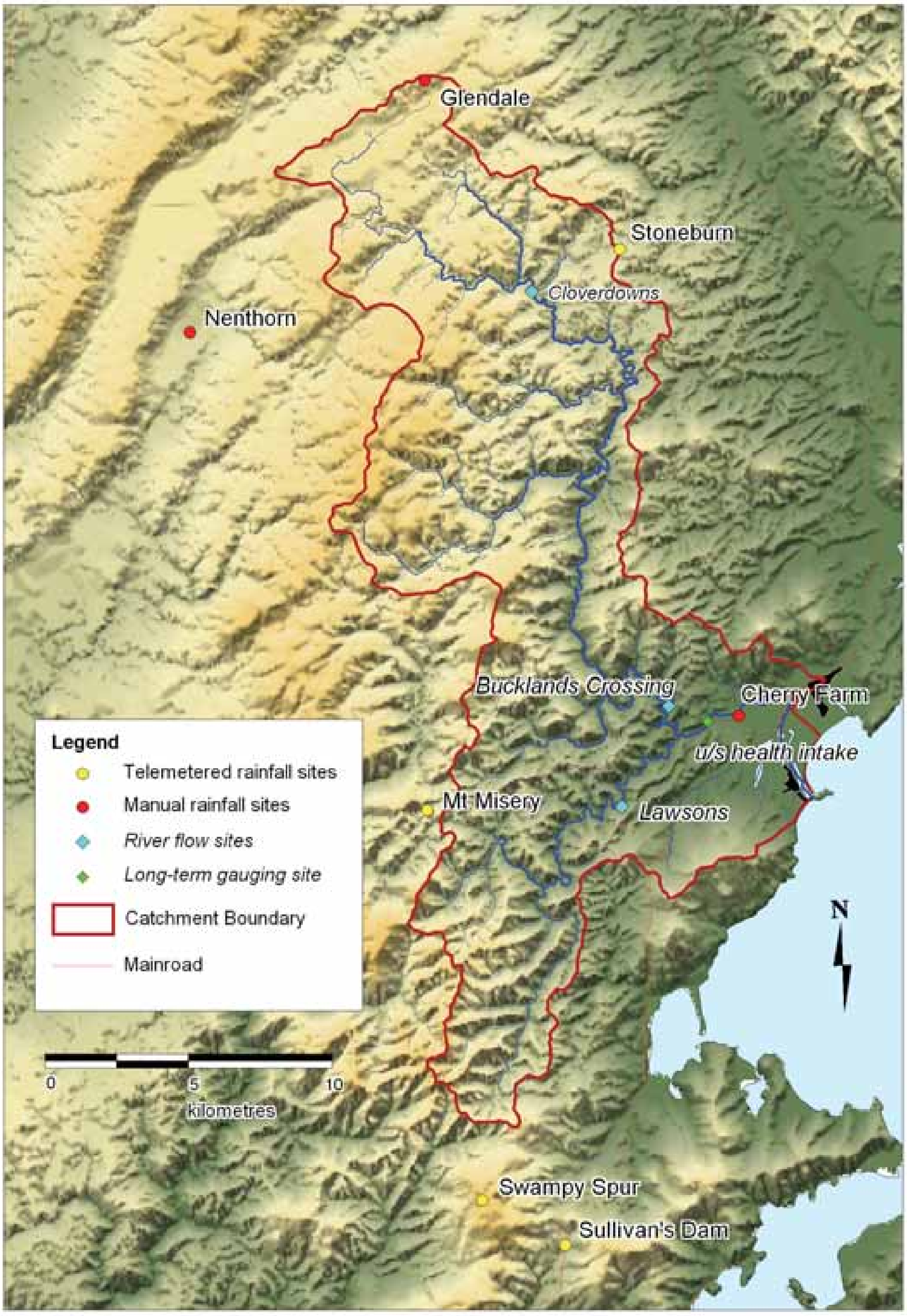

Figure 3.3 Rainfall and river flow monitoring sites in and around the Waikouaiti Catchment

4. Hydrology

Continuous flow recorders were installed on the two main branches of the Waikouaiti River in 1991. These give a good picture of the variation in flow through different seasons and over different years. The north branch recorder was located at Bucklands Crossing, 2 km above the confluence of the two branches and captured 98% of the catchment area as shown by Figure 3.3. It was decommissioned in 1999. The south branch recorder is located at Lawsons, 5 km above the confluence and captures 92% of the catchment area. It is currently (March 2008) still in operation though it is planned to move the equipment from this site to one on the main stem just below the confluence. The new site will provide more useful information for the lower catchment during floods and summer low flows.

This section provides a description of the flow recorded at each site including general flow statistics, annual flow distribution, and flow duration curves. Flooding in the catchment is discussed and flood frequency estimates made. The frequency of low flows is discussed and estimates of the 7-day mean annual low flow (MALF) are made. Finally, results from concurrent gauging in the north branch, south branch and main stem are discussed. Table 4.1 provides an explanation of the hydrological terms used in this report.

Table 4.1 Glossary of hydrological terms

Term	Definition	Units
Flow	The rate of water flowing down a river	Cubic metres per second – m^3/s (cumecs) and also litres per second – l/s 1000 l/s equals 1 m^3/s
Specific discharge or (specific yield)	The amount of flow in a river divided by the area upstream of that point i.e. how much water comes to the river from each unit of land. Can be reported at any flow but usually at the mean flow, flood flows and 7-day low flows.	Flow per unit area $m^3/s /km^2$
7-day low flow	The mean (average) flow over 7 days	m^3/s
7-day MALF (or MALF)	The average of the lowest 7-day low flows from each year of record	m^3/s
Median flow	The middle value if all the flow values are lined up i.e. half the time the flow is above the median flow, half the time below.	m^3/s
Mean flow	The total of all the flows added up then divided by the length of record. This is the most common average, but is greatly affected by floods.	m^3/s

4.1 Flow statistics

Flow at both stations is generally natural, though there is one small water take in the headwaters of the north branch for rural water supply. The character of flow in each branch is relatively similar, though the north branch has a much greater variation in flow due to the large area and more variable and inconsistent rainfall. The south branch, while it has an area 28% the size of the north branch, has a median flow over 70% of that in the north branch and a higher MALF as shown by Table 4.2. It is interesting to note that subsequent to 1999, there has been a significant reduction in the annual median flow and a non-significant reduction in the mean annual flow of the south branch (ORC, 2008). Using a record of the same period to that in the north branch gives a mean flow of 0.886 m^3/s, a median flow of 0.480 m^3/s and a much higher MALF of 0.203 m^3/s. The statistics for the north branch, using this earlier period of record, are therefore likely to be biased toward higher flows.

Table 4.2 General flow statistics for the Waikouaiti River

	North branch @ Bucklands Crossing	South branch @ Lawsons
Period of continuous record	Jan 1991 – Aug 1999	Feb 1991 – current[A]
Catchment area (km^2)	279	79
Mean flow (m^3/s)	1.963	0.850
Median flow (m^3/s)	0.594	0.425
Specific discharge [yield] at mean flow ($m^3/s/km^2$)	0.007	0.0108
Mean annual flood (m^3/s)	108	50
Specific discharge [yield] at mean annual flood ($m^3/s/km^2$)	0.386	0.634
3 highest flows (m^3/s)	549 [Dec 1993] 470 [Jul 1994] 452[Jan 2002][B]	151 [Jan 2002] 135 [Jul 2007] 86 [Jul 1994]
7-day MALF	0.172 (0.151)	0.182
Specific discharge [yield] at MALF ($m^3/s/km^2$)	0.000616 (0.000541)	0.002304
Lowest 7-day low flow (m^3/s)	0.013 [Feb 1999]	0.101 [Apr 1999]

[A]Flow statistics for the south branch are calculated with data to 30 April 2008.
[B]Gauging data.

In times of low flow, the south branch provides most of the flow to the main stem. This is most likely due the origin of the south branch in the Silverpeaks, which has higher and more dependable rainfall. During the 1999 drought, the north branch had a 7-day low flow of 0.013 m^3/s, but the south branch remained at a substantially higher flow, with a 7-day low flow of 0.101 m^3/s. When the surface area of the branches is taken into account, the contribution of the south branch is higher still, with the specific discharge (or yield) at MALF being around four times higher in the south branch than the north.

While the north branch produces larger floods, they are similar per unit of surface area. The specific discharge during the largest recorded flood is similar (~2 m^3/s per km^2), but is higher in the south branch than the north for a mean annual flood.

4.1.1 Annual flow distribution

In order to examine the variation in flow on average through the year, an average flow for each month of the year was calculated based on the frequency of occurrence of a given flow. To do this, average (mean) flows were computed for every complete month of record and then the mid-point of these, the median, was defined as the average. The median value is used as an average here as this represents the middle value from all the years recorded (i.e. in half the years the flow was higher and in half the years the flow was lower). This makes it less susceptible to being affected by large flows in one year that are not representative of the normal conditions. Table 4.3 shows the maximum, minimum, mean and median values of the monthly average flows for each year of record.

Table 4.3 Summary statistics of monthly mean flows in the Waikouaiti River. All flows are in m^3/s

South branch at Lawsons (Feb 1991- April 2008)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	0.46	0.35	0.25	0.43	0.37	0.47	0.81	0.94	0.58	0.54	0.55	0.68
Min.	0.16	0.14	0.16	0.15	0.15	0.21	0.22	0.18	0.33	0.26	0.24	0.24
Mean	1.21	0.68	0.54	0.56	0.48	0.74	1.44	1.39	1.26	0.78	0.67	0.80
Max.	9.06	3.08	2.78	1.67	0.96	3.13	5.62	5.33	6.45	1.95	1.87	2.24

North branch at Bucklands (Jan 1991 – Aug 1999)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	0.40	0.30	0.26	0.37	0.74	1.19	2.36	2.06	1.12	0.81	0.81	0.65
Min.	0.06	0.02	0.09	0.17	0.14	0.64	0.22	0.16	0.35	0.42	0.38	0.17
Mean	0.52	1.13	0.36	0.76	0.76	2.36	4.39	2.57	2.73	1.92	1.21	4.18
Max.	1.27	4.76	1.17	3.07	1.28	7.81	21.13	9.25	8.36	5.20	3.15	28.38

Table 4.3 also shows the very low flows the north branch can experience in the summer months with the lowest monthly mean flow in the north branch of 0.02 m^3/s in February 1999, during the drought experienced through the region at this time.

Figure 4.1 and Figure 4.2 show the average flow near the bottom of each branch for every month of the year. Both the branches show a similar pattern of variation, with the highest average flows in the winter and the lowest average flows at the end of summer/early autumn. This variation is largely due to changes in evapotranspiration (ET) as rainfall is relatively consistent throughout the year; in winter ET is lower and therefore more of the rain that falls makes its way into the river. In late summer-early autumn, soil moisture is depleted from the summer months and river flows remain low until sufficient rain soaks the ground and recharges the subsurface contribution to the stream flow.

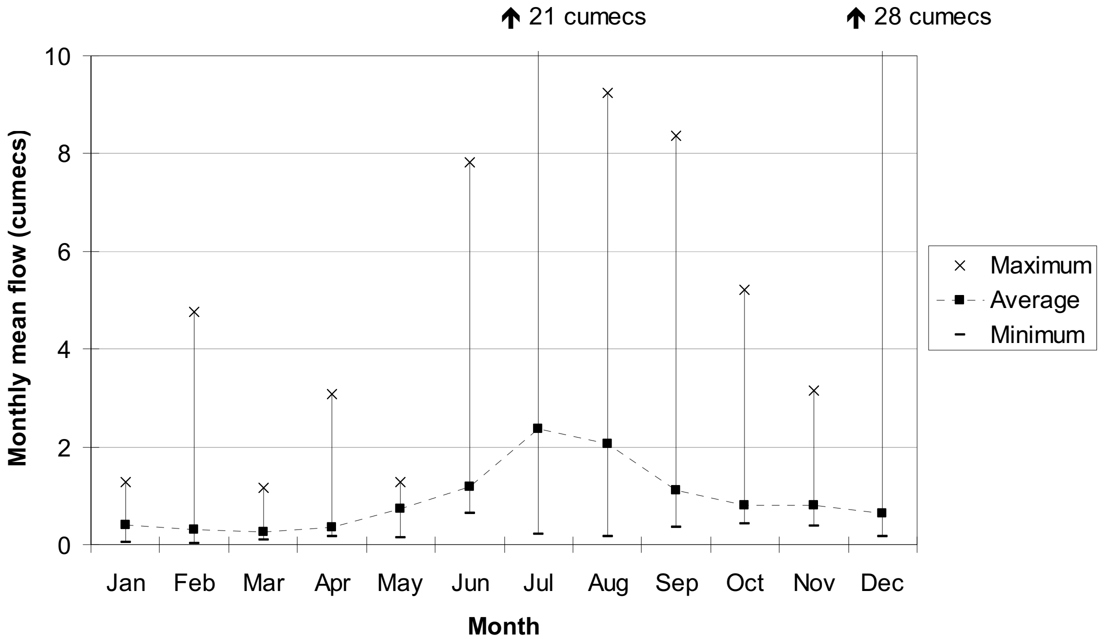

Figure 4.1 Monthly flows in the Waikouaiti River (north branch) at Bucklands Crossing (1991-1999). The average used is the median

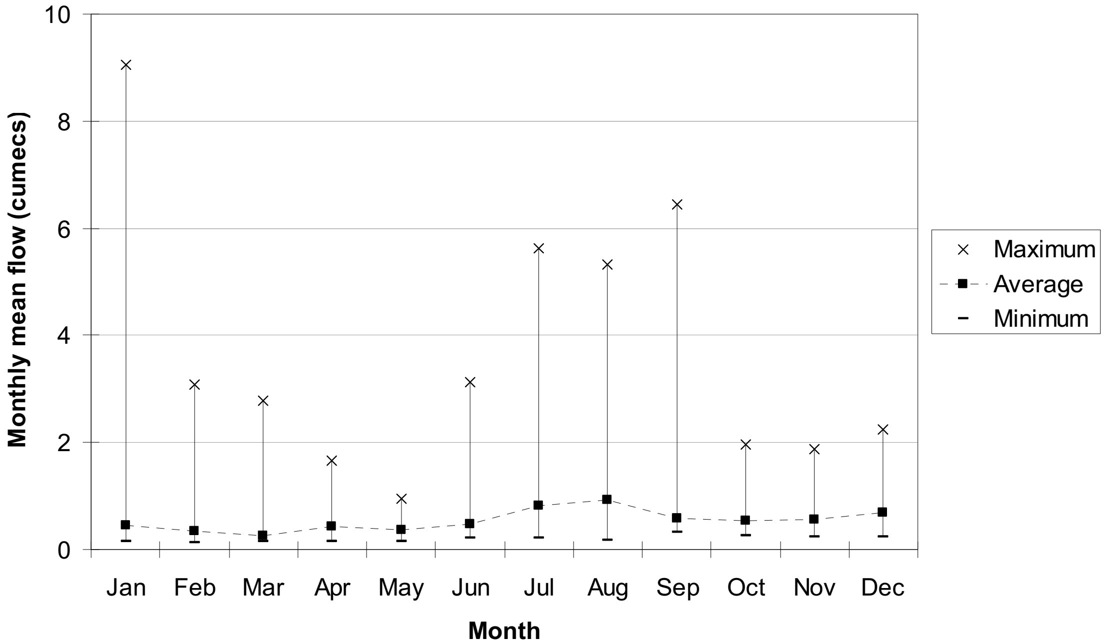

Figure 4.2 Monthly flows in the Waikouaiti River (south branch) at Lawsons (1991-2007). The average used is the median

The north branch at Bucklands shows a greater variation in average flow through the year than the south branch, with an average flow over 2 m^3/s during the winter months and around 0.4 m^3/s in the autumn as shown in Figure 4.1. Average monthly flow in the south branch in comparison varies from 0.94 m^3/s in August to 0.25 m^3/s in March (Figure 4.2).

Both branches, but especially the north branch, can experience a wide range of mean monthly flows from year to year. This is most evident in the winter months when mean flows in the north branch have ranged from 21 m^3/s in July 1994 to 0.16 m^3/s in August 1998, which is linked to the prevailing weather patterns. The catchment can also experience major floods during summer as shown by the large monthly mean flows in December in the north branch and January in the south branch. These are associated with large floods in 1993 and 2002, respectively.

Daily water level records from 1977-87 at Cloverdowns in the headwaters of the north branch show a minimal flow at this point in the catchment as shown by Figure 4.3. Average flow from January through to April is well below 0.2 m^3/s. The pattern here follows the pattern at the other recorder sites; lower in summer and higher during the winter months.

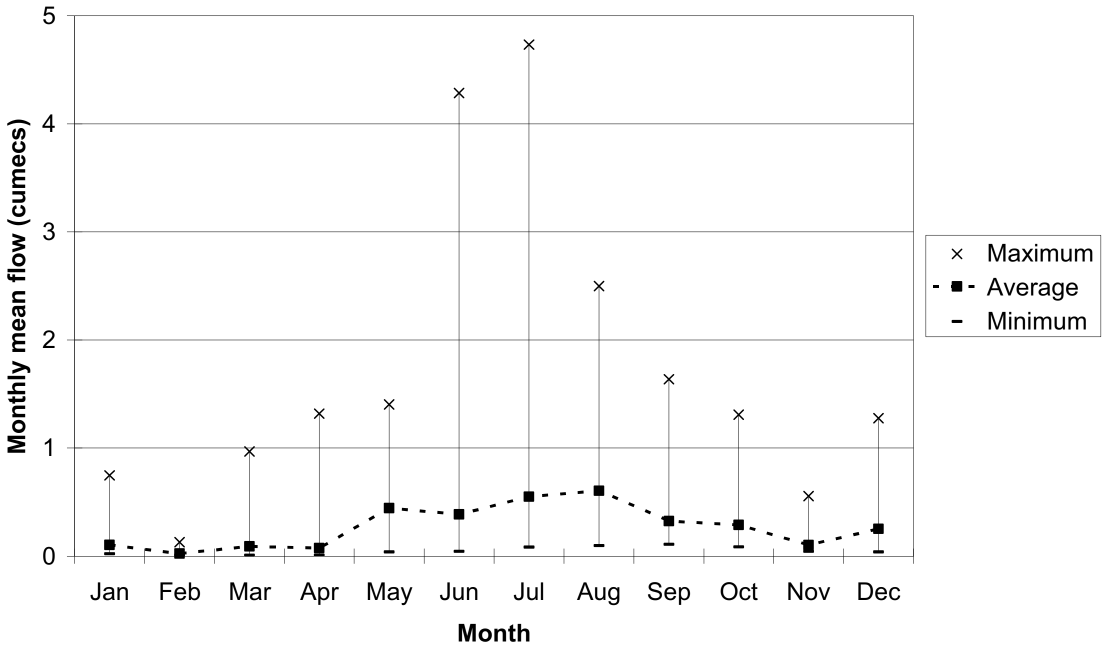

Figure 4.3 Monthly flows in the Waikouaiti River (north branch) at Cloverdowns (1977-1987). The average used is the median

4.1.2 Flow duration curves

Flow duration curves show the percentage of time the river flows at or above a particular flow. Flow duration curves for each branch using data from the entire year are shown in Figure 4.4. The median/average flow is where the curve meets the 50% gridline, in this case around 0.6 m^3/s for the north branch and 0.4 m^3/s for the south branch.

The dramatic curves show that the river most often has minimal flow, but at times can reach much higher flows. Flows of over 1.0 m^3/s are experienced approximately 30% of the time in the north branch, but only 15% of the time in the south branch. The curves show that the north branch usually flows greater than the south branch as would be expected from the much larger area of the catchment. However, very low flows are less common in the south branch, with flows in the lowest 20% being higher in the south branch.

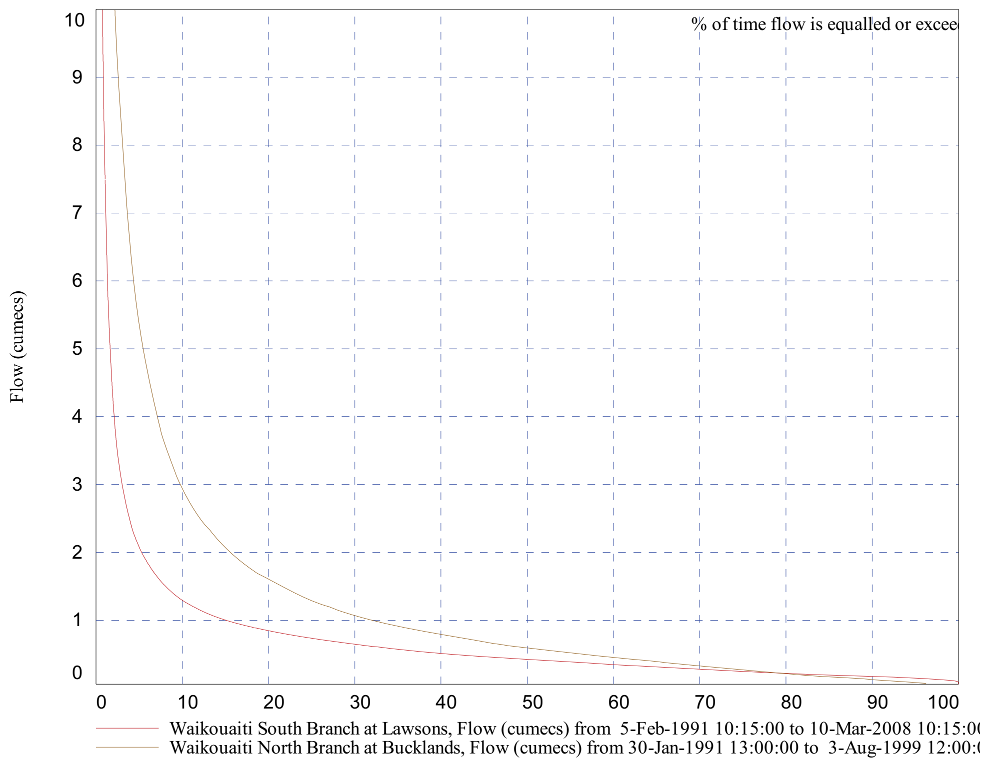

Figure 4.4 Flow duration curves for the Waikouaiti River

The irrigation season

Figure 4.5 shows that in the south branch there is minimal difference in the flow between the irrigation season (September to April) and the winter season (May to August). The north branch, however, shows a much greater difference between winter and irrigation season flows (Figure 4.6). Median flow is under 0.5 m^3/s during the summer, but closer to 1.0 m^3/s in the winter season. During the irrigation season, flow is under 1.0 m^3/s around 80% of the time.

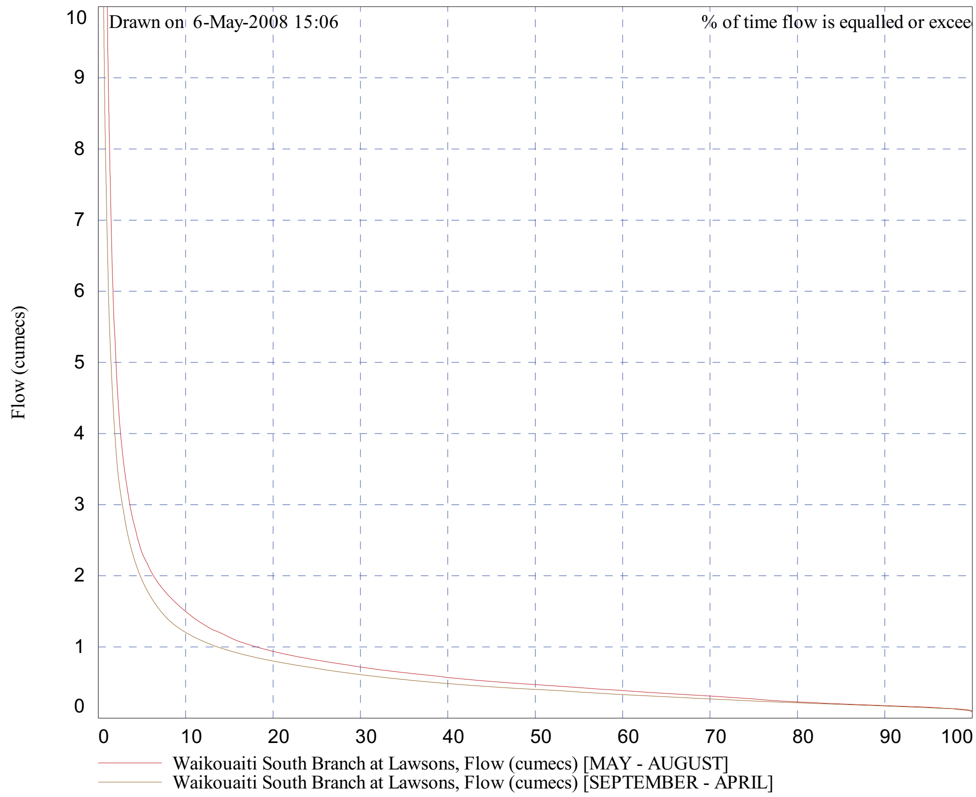

Figure 4.5 Flow duration curve for the Waikouaiti River (south branch) during irrigation season (September-April) and winter season (May - August)

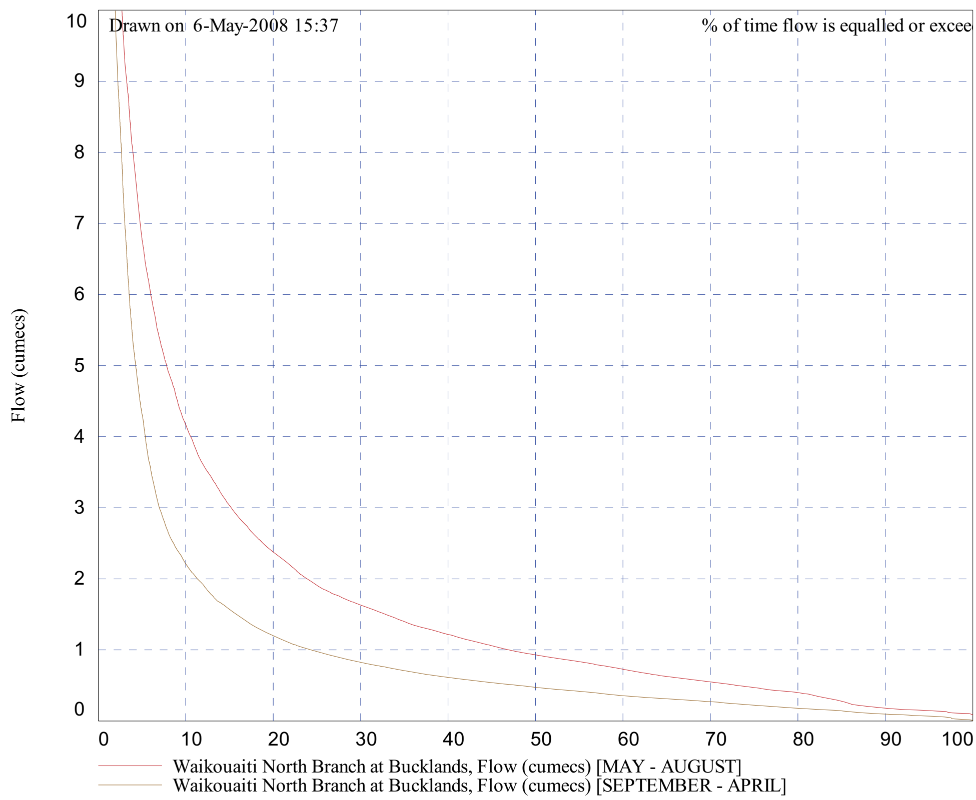

Figure 4.6 Flow duration curve for the Waikouaiti River (north branch) during the irrigation season (September - April) and winter season (May - August)

4.2 Flooding

Flooding in the Waikouaiti Catchment is relatively infrequent and there is a big difference between the largest floods that occur and those experienced on a regular basis. This pattern is typical of catchments on the east coast of the South Island as floods are caused by storms that have a different character to normal weather patterns (Pearson and Henderson, 2004). More than one large flood can occur in a year or none may occur for a few years. For example, of the floods over 50 m^3/s on record in the north branch, three occurred in 1992 but none in 1996, 1998 or 1999.

Flooding in the catchment usually results from strong easterly quarter winds that blow moist air off the Pacific Ocean onto the east coast of the South Island. These storms are usually 48 hours in duration and have relatively moderate rainfall intensities of around 3-4 mm hour at low altitudes and 7-8 mm per hour at higher altitudes. However, the duration of these storms results in the catchment becoming fully saturated after 12 hours after which significant run-off occurs.

The largest flood in recent history was that in June 1980, at the same time as the devastating flood on the Taieri Plains. Photos from the time show it blocking SH1 and inundating houses in Karitane (Figure 4.7 and Figure 4.8). Figure 4.9 shows the extent the floodwaters reached during the 1980 flood. Large floods also occurred in 1968, 1986, 1987, 1993, 1994, and 2006. They all resulted from easterly quarter rainstorms.

Figure 4.7 Flood waters blocking SH1

Figure 4.8 Flood waters inundating houses in Karitane

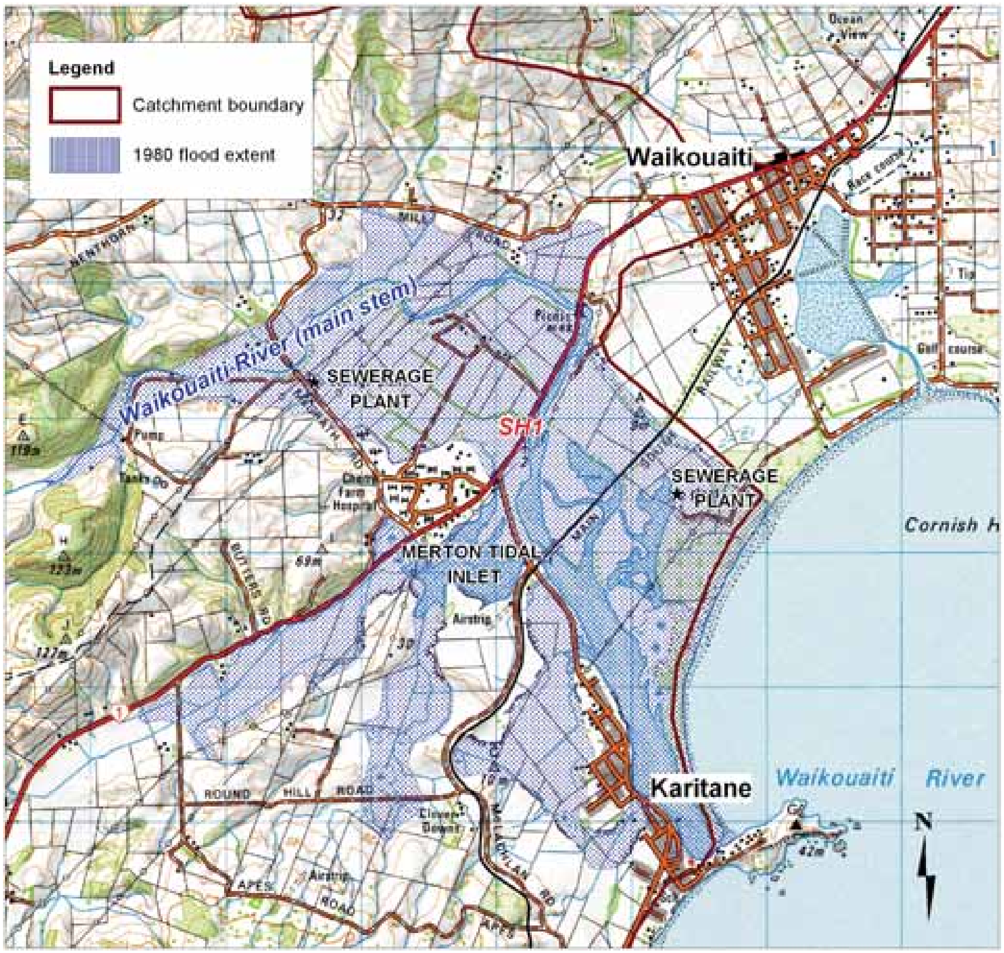

Figure 4.9 Waikouaiti flood plain

4.2.1 Flood flows – frequency estimates

The estimation of flood flows of different annual probabilities presents challenges in the Waikouaiti River due to the relatively short length of record. The only site with sufficient record to perform the more robust at-site analysis is the south branch at Lawsons. The continuous record from the north branch at Bucklands Crossing is too short for these methods and no continuous record exists for the main stem. Other techniques such as partial duration series may give better estimates of flood frequency, especially in short datasets and these methods are being investigated for the Waikouaiti Catchment.

To estimate flood frequency in the south branch, the annual maximum floods for the entire record (1991-2007) were used. These showed a good fit to both the Pearson type 3 and GEV distributions as shown by Figure 4.10. A combination of the two distributions gives a mean annual flood of 50 m^3/s and a 1% annual exceedance probability (AEP) event ('100 year' flood) of 210 m^3/s.

To estimate flood flows in the north branch, the specific discharges of surrounding catchments were pooled together and applied to the area above the Bucklands Crossing recorder (279 km^2), a method adapted from McKerchar and Pearson (1989). The specific discharges from the south branch at Lawsons, as well as the Nenthorn Stream at Mt Stoker and the Shag River at The Grange, were averaged with equal weighting given to each catchment. This method calculates a mean annual flood flow at Bucklands Crossing of 108 m^3/s. As shown in Table 4.4, a 1% AEP event is estimated at 630 m^3/s.

This puts the annual probability of the 1993 flood flow of 549 m^3/s between 1% and 2% (between a 50 and 100 year return period). A more detailed explanation of the methods is given in Appendix A.

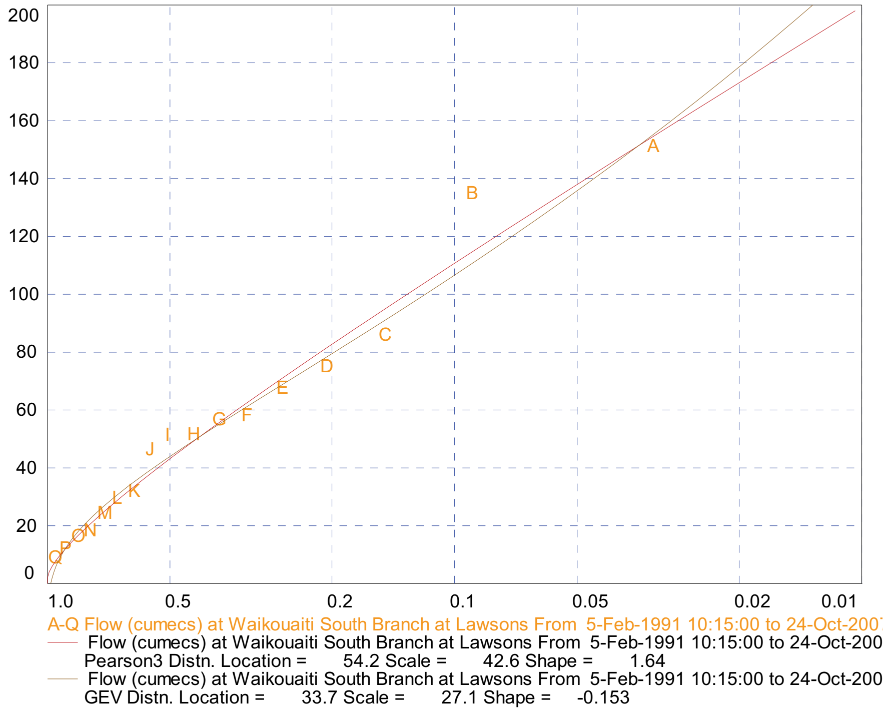

Figure 4.10 Annual maximum floods with GEV and P3 distributions fitted

To estimate flood flows in the main stem of the Waikouaiti River at Karitane, the specific discharges of each branch were averaged (weighted by their surface area) and this value applied to the total catchment area. As shown in Table 4.4, a mean annual flood was calculated to be 187 m^3/s and a 1% AEP event just less than 1000 m^3/s. This represents a substantial flow that must exit through the Karitane Estuary.

Table 4.4 Estimated flood flows for the Waikouaiti River

Annual Exceedance Probability [AEP]	Return period (years)	North branch at Bucklands Crossing Flow (m^3/s)	South branch at Lawsons Flow (m^3/s)	Main stem at Karitane Flow (m^3/s)
Mean annual flood	2.33	108	50	187
20%	5	200	80	331
10%	10	280	110	465
5%	20	375	140	608
2%	50	510	175	814
1%	100	630	210	990

NOTE: flood flows for frequencies over 40 years should be treated with caution as estimates over twice the length of record are subject to large uncertainty.

4.3 Low flow discharges

The Waikouaiti River is prone to extended periods of low flow due to the low relief and the unreliable rainfall within the catchment. The lowest 7-day mean flows in each branch were experienced in the early part of 1999 during the drought conditions experienced throughout Otago at this time. The south branch provided a majority of the flow during this time emphasised by the lowest 7-day low flows of 0.013 m^3/s (February 1999), 0.101 m^3/s (April 1999) in the north and south branches, respectively.

4.3.1 7-day MALF in the north and south branches

The 7-day MALF (hereafter referred to as MALF) for each branch were calculated from the records at Lawsons and Bucklands Crossing, using a year starting in July. As shown in Table 4.2 the MALF in the south branch is 0.182 m^3/s (using data February 1991-April 2008) and the MALF in the north branch is 0.172 m^3/s (using data from January 91 – July 99). Since 1999, there has been a steady reduction in MALF in other North Otago rivers and so the estimate of current MALF in the north branch has been adjusted down to 0.151 m^3/s.

4.3.2 7-day MALF in the main stem

MALF in the main stem was calculated at the upstream Health Intake site, as this is the usual gauging site during low flow conditions (see Figure 3.3). To compute a MALF at this site the specific discharges under MALF conditions in each branch were pooled together with a weighting for the % of area each branch covered, respectively. This pooled specific discharge was then applied to the area upstream of the site (374 km^2). Finally, a water loss regression was then applied to correct for the water loss observed between the combined flows and the flow at the site (see NIWA 2005). This results in a 7-day MALF in the main steam of 0.334 m^3/s as shown in Table 4.5.

This is comparable with the estimate of 0.341 m^3/s made by NIWA (2005). The small decrease in MALF in the south branch from 0.188 to 0.182 m^3/s between 2005 and 2008 (3.3% decrease) helps explain the slightly lower number computed by the above method.

The NIWA (2005) estimates were part of a rigorous assessment of the low-flow characteristics of the main stem during the consent process for the Dunedin City Council water take in the main stem. This process resulted in a synthetic flow record being derived from the relationship between the flow records in both branches and the gauged flow in the main stem. The synthetic record gives the best estimates of flows of higher return periods and so they are presented in Table 4.5.

Table 4.5 7-day low flows in the Waikouaiti River at the upstream Health Intake site

Return period (years)	NIWA	ORC
MALF	0.341	0.334
2	0.364	-
5	0.161	-
10	0.120	-
20	0.094	-

4.4 Specific discharge from sub-catchments during summer conditions

During March 2007, gaugings were made in an effort to better understand the amount of water flowing from different sub-catchments within the Waikouaiti Catchment. The number of sub-catchments gauged was limited by the difficulty of access to the river and the need to have consecutive gaugings on the same day. Gauging runs were made on two days, both when the river flow had been stable for over a week. The first set of gaugings were in mid-summer and showed a larger amount of water coming out of the north branch than the south branch (Table 4.6) and a reasonable flow originating in the Dip Creek Catchment.

The second set of gaugings were made six weeks later when flow conditions had receded to under the 7-day MALF at the south branch recorder at Lawsons. Results from this day showed a lower amount of water coming from the north branch and a minimal amount from Dip Creek (Table 4.6). The area downstream of the Lawsons and Bucklands Crossing sites contributed a further 0.020 m^3/s.

As shown in Table 4.6, flow in the north branch dropped proportionally more than both the south branch and Dip Creek at Ramrock Road between the two gauging runs.

Table 4.6 Gauged flows and specific discharge in sub-catchments of the Waikouaiti River

		19/01/2007		1/03/2007	
Site	**Catchment area (km^2)**	**Flow (m^3/s)**	**Specific discharge ($m^3/s/km^2$)**	**Flow (m^3/s)**	**Specific discharge ($m^3/s/km^2$)**
Dip Creek at Ramrock Rd	31	0.0307	0.00099	0.0078	0.000252
Waikouaiti (north branch) at Bucklands Crossing	279	0.697	0.002498	0.084	0.000301
Waikouaiti (north branch) at Bucklands Crossing (minus Dip Creek)	248	0.666	0.002687	0.076	0.000307
Waikouaiti (south branch) at Lawsons*	79	0.322	0.004076	0.152	0.001924
Waikouaiti at Orbells Crossing (u/s intake)	376	1.130	0.003005	0.257	0.000684
Waikouaiti at Orbells Crossing (u/s intake) minus north and south branches	18	0.111	0.006167	0.021	0.001167

*mean daily flow

Figure 4.11 shows the specific discharge from this second run and emphasises the much higher flow originating in the south branch during low-flow conditions. The specific discharge in the north branch including Dip Creek was less than a quarter of that in the south branch. The specific discharge upstream of Orbells Crossing in the main stem is as would be expected between these two values.

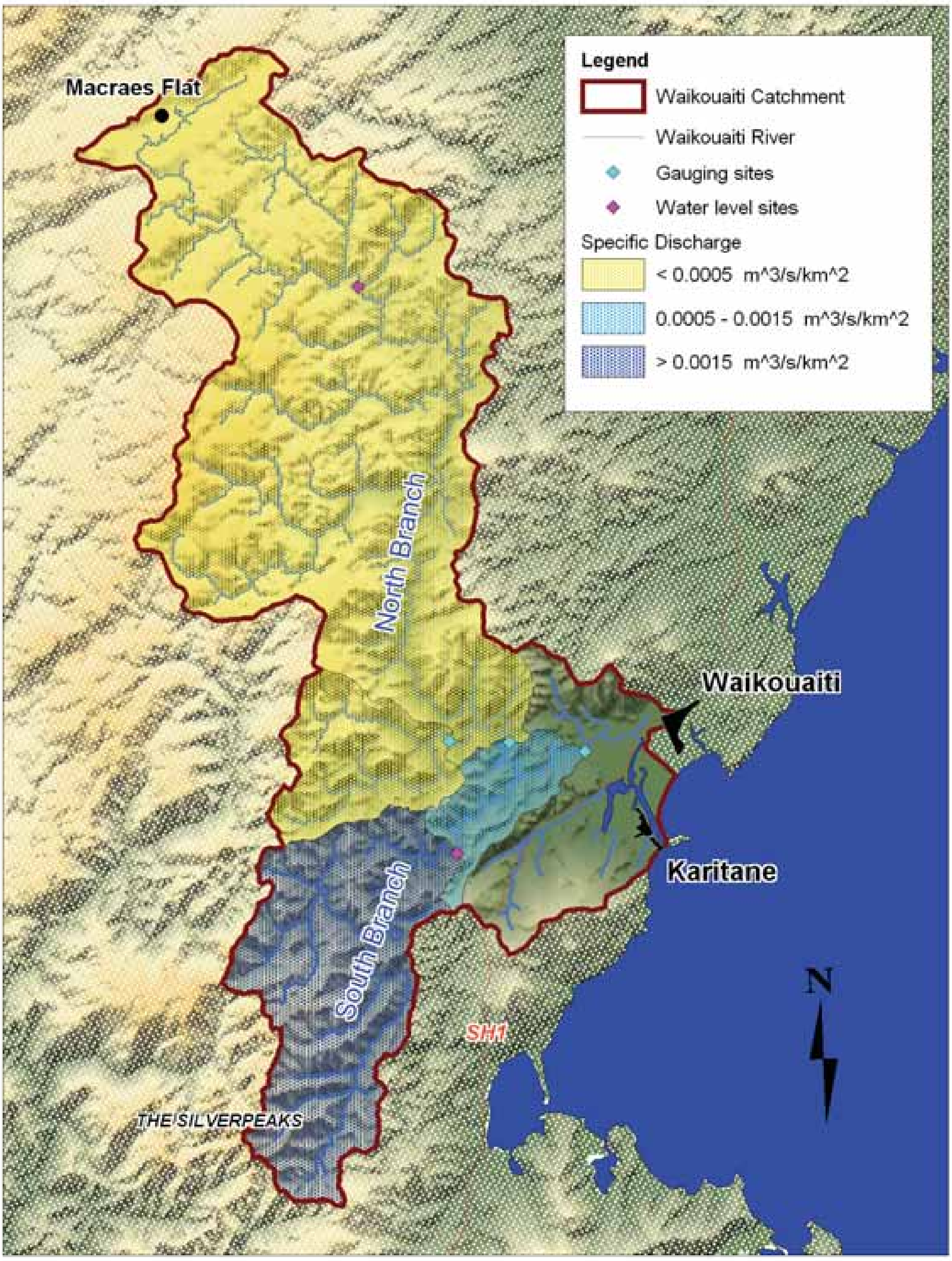

Figure 4.11 Specific discharge under low flow conditions 1/3/07

5. Conclusion

The Waikouaiti River Catchment, while large and of moderate elevation, yields little water under normal conditions because of the low and sporadic rainfall received across the catchment. During the summer months, the river often reaches minimal flows with the north branch contributing proportionally less as conditions become drier. These modest summer flows experienced in the lower reaches do support some abstraction for community water supply and irrigation and at present three-quarters of the primary allocation of flow is consented. The river also supports a variety of aquatic life, with significant habitat for native and introduced species.

6. References

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Appendix A Details of flood flow estimation methods

To calculate flood frequency in the south branch at Lawsons, the annual maximum flood flows from the entire data set from February 1991 – October 2007 were used. The specific flows used are listed below:

```
Source is U:\Certified Data.hts
Flow (m3/s) at Waikouaiti South Branch at Lawsons
From  5-February-1991 10:15:00 to 24-October-2007 12:00:00

  12 mth           Recorded         Maximum
 partition          value          measured
  starts             at
01-Jan-2002 12-Jan-2002 06:15:00    151.261 A
01-Jan-2007 30-Jul-2007 20:30:00    134.884 B
01-Jan-1994 27-Jul-1994 13:45:00     86.059 C
01-Jan-1992 14-Aug-1992 19:23:46     75.115 D
01-Jan-2006 26-Apr-2006 11:30:00     67.597 E
01-Jan-1993 22-Dec-1993 11:30:00     58.041 F
01-Jan-2000 31-Aug-2000 14:45:00     56.716 G
01-Jan-2001 20-Jul-2001 10:45:00     51.547 H
01-Jan-1991 18-Feb-1991 13:37:19     51.487 I
01-Jan-1997 11-Feb-1997 11:00:00     46.398 J
01-Jan-2004 06-Aug-2004 23:45:00     32.075 K
01-Jan-2005 12-Feb-2005 04:45:00     29.595 L
01-Jan-1995 13-Jun-1995 04:45:00     24.455 M
01-Jan-1999 27-Jul-1999 13:15:00     18.448 N
01-Jan-1996 12-Nov-1996 01:15:00     16.461 O
01-Jan-2003 31-Oct-2003 23:15:00     12.137 P
01-Jan-1998 12-Oct-1998 23:15:00      9.094 Q
                           Mean =    54.198
```

McKerchar and Pearson (1989) recommend that where a dataset from a flow recorder is less than 10 years, then at-site analysis alone should not be used to estimate flood flows in the catchment. The Bucklands Crossing site in the north branch only has nine years of data and the annual maxima series does not show a good fit with any distribution, so regional methods were chosen as the optimal method to estimate flood flows of different probabilities.

To make the estimates, the specific discharge for a mean annual flood in rivers in similar neighbouring catchments was applied to the Waikouaiti Catchment. This should give more accurate estimates than using the contour line plots given in McKerchar and Pearson as much longer datasets exist on the north coast of Otago nowadays. Three catchments were chosen - the Shag River at the Grange (21 years of data), the Nenthorn Stream at Mt Stoker (25 years of data) and the Waikouaiti River south branch (17 years of data). To estimate the flood flows, the three specific discharges were averaged with equal weighting given to each of the three catchments and this pooled specific discharge applied to the area upstream of the Bucklands Crossing recorder.

Table A.1 Specific discharge of streams neighbouring the Waikouaiti River (north branch) during flooding

Annual Exceedance Probability [AEP]	Return period (years)	Specific discharge ($m^3/s/km^2$)		
		Shag at The Grange	Nenthorn at Mt Stoker	South branch
Mean annual flood	2.33	0.251	0.272	0.634
20%	5	0.532	0.563	1.03
10%	10	0.815	0.845	1.38
5%	20	1.134	1.17	1.73
2%	50	1.58	1.67	2.23
1%	100	2.01	2.11	2.62

As there are no flow records for the main stem of the Waikouaiti River, the same method as above was used to estimate flood flows at Karitane. In this case, the specific discharges of each branch were averaged (weighted by their surface area) and this value applied to the total catchment area. The calculation for a mean annual flood is given below as an example.

Specific discharge of the entire catchment = specific discharge south branch* % area + specific discharge north branch* % area
= 0.634*22% + 0.386*78%
= 0.441 $m^3/s/km^2$

Flow at Karitane (@ mean annual flood) = Specific discharge*catchment area
= 0.441*425
= 187 m^3/s

The computed specific discharges are shown in Table A.2.

Table A.2 Specific discharge and flow under flood conditions in each branch and the main stem of the Waikouaiti River

Annual Exceedance Probability [AEP]	Return period (years)	North branch at Bucklands Crossing		South branch at Lawsons		Main Stem at Karitane	
		Specific discharge	Flow (m^3/s)	Specific discharge	Flow (m^3/s)	Specific discharge	Flow (m^3/s)
Mean annual flood	2.33	0.386	108	0.634	50	0.440	187
20%	5	0.708	200	1.03	80	0.779	331
10%	10	1.01	280	1.38	110	1.09	465
5%	20	1.34	375	1.73	140	1.43	608
2%	50	1.83	510	2.23	175	1.92	814
1%	100	2.25	630	2.62	210	2.33	990

Appendix B Details of the low flow analysis methods

Table B.1 shows the annual 7-day low-flows used to calculate MALF in the Waikouaiti River (south branch) and Table B.2 shows the same for the Waikouaiti River (north branch).

Table B.1 Annual 7-day low flows in the Waikouaiti River (south branch)

Source is U:\Certified Data.hts
Flow (m^3/s) at Waikouaiti south branch at Lawsons
From 5 February 1991 10:15:00 to 10 March 2008 10:15:00
Data selected from months 7 to 6 inclusive

12 mth partition starts	7 day mean starts	Measured minimum
Jul-98	31/03/1999 10:00	0.101
Jul-91	14/04/1992 12:20	0.112
Jul-03	18/01/2004 20:15	0.116
Jul-94	3/03/1995 2:00	0.118
Jul-06	16/05/2007 4:00	0.125
Jul-00	11/04/2001 3:15	0.134
Jul-02	22/03/2003 14:30	0.134
Jul-97	11/04/1998 0:00	0.148
Jul-05	18/04/2006 5:30	0.159
Jul-07	4/02/2008 9:15	0.165
Jul-99	7/12/1999 3:00	0.198
Jul-01	2/07/2001 23:45	0.202
Jul-93	9/11/1993 7:30	0.208
Jul-95	2/04/1996 0:00	0.209
Jul-04	25/07/2004 11:45	0.226
Jul-92	1/07/1992 10:04	0.359
Jul-96	1/07/1997 0:00	0.372
		Mean = 0.182

Table B.2 Annual 7-day low flows in the Waikouaiti River (north branch)

Source is U:\Certified Data.hts
Flow (m^3/s) at Waikouaiti north branch at Bucklands
From 30 January 1991 13:00:00 to 30 June1999 24:00:00
Data selected from months 7 to 6 inclusive

12 mth partition starts	7 day mean starts	Measured minimum
1-Jul-98	9/02/1999 8:45	0.013
1-Jul-97	16/02/1998 12:00	0.056
1-Jul-91	23/03/1992 15:17	0.065
1-Jul-94	13/02/1995 5:00	0.085
1-Jul-93	8/11/1993 8:15	0.188
1-Jul-95	31/01/1996 22:15	0.263
1-Jul-92	11/03/1993 4:06	0.284
1-Jul-96	25/09/1996 19:15	0.420
		Mean = 0.172

NOTE: The values for the earlier part of 1991 are included here as representative of the lowest flows in the period July 1990 to July 1991 as records from the neighbouring Shag Catchment show the lowest flows occurring in the early part of 1991. Values after 30 June 1999 have been omitted, as they are not representative of the low flows in the period July 1999 to June 2000.

Deviation of MALF from 1999 to 2008

A comparison was made between MALF calculated for the entire record at Lawsons (to April 2008) and one just using the period of record captured by the north branch. This shows a much higher MALF of 0.203 m^3/s for the earlier period as there have been lower summer flows in recent times. Over the same time periods, MALF in the Shag River at the Grange dropped from 0.208 to 0.174 m^3/s, and MALF in the Nenthorn Stream decreased from 0.041 to 0.033 m^3/s, decreases of 16 and 19.5 %, respectively. To be able to combine the earlier estimate of north branch MALF with the recent estimate in the south branch, the north branch estimate was adjusted downward by a fraction estimated by the pooled fraction decrease in the three neighbouring catchments as shown below:

Fraction decrease = (0.182/0.203 + 0.174/0.208 + 0.033/0.041)/3
= 0.879

MALF (north branch adjusted to 2008) = MALF (1990-1999) * fraction decrease
= 0.0172 * 0.879
= 0.0151 m^3/s

MALF in the main stem at Upstream Health Intake site

To compute a MALF for the main stem at the Upstream Health Intake (the usual low flow gauging site), the specific discharges under MALF conditions were pooled together with a weighting for the % of area each branch covered, respectively. This pooled specific discharge was then applied to the area upstream of the upstream Health Intake (374 km^2) as shown below.

MALF (main stem) = specific discharge at MALF * area

Specific discharge at MALF = specific discharge north branch at MALF * % total area
+ specific discharge south branch at MALF * % total area
= (0.000541*283/369 + 0.002304*83/358)

MALF = 0.000952*374
= 0.351 m^3/s

A water loss regression was then applied to this estimate to correct for the water loss observed between the combined flows and the flow at the upstream Health Intake (see NIWA 2005).

MALF (corrected) = 1.0783*combined flow – 49.577
= 0.334 m^3/s at the upstream Health Intake site.