REPORT

MINISTRY FOR THE ENVIRONMENT

Waitaki Catchment
Hydrological Information

February 2005

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for consideration by the Waitaki Catchment Water Allocation Board

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Executive Summary

This report is a collation of hydrological information for the Waitaki Catchment. It uses existing hydrological information to illustrate the magnitude and variability of flows within the catchment, including the influence of existing infrastructure on natural flows. Flow data tables, flow statistics, catchment maps, and graphs of historical water levels and flows are provided for lakes, canals, and rivers/streams.

The report describes a spreadsheet model developed for assessing reliability of supply to run-of-river users within the mainstream Waitaki River and its tributaries.

The information in this report provides a means to broadly assess river flows and resource availability under various potential environmental flow and allocation regimes. The report does not make any recommendations on appropriate environment flows/levels or allocation regimes.

Flow information for this report was provided by Environment Canterbury, Meridian Energy Limited and NIWA.

Appendices to the report provided detailed hydrological information for sites within the catchment that have recorded flows.

1 Introduction

1.1 Background

The Resource Management (Waitaki Catchment) Amendment Act provides for the establishment of the Waitaki Catchment Water Allocation Board who will develop a regional plan to address water allocation in the Waitaki Catchment. The regional plan will be prepared, submissions received and heard, and approved within 12 months of the board being established.

The board will be serviced by the Ministry for the Environment, who are initiating projects to provide the board with relevant information for policy development. The resulting reports will become public documents.

In October 2004, Tonkin & Taylor was commissioned by the Ministry for the Environment to provide an independent overview of the hydrology of the Waitaki Catchment.

1.2 Project brief

The deliverables under the project brief were:

- a graphical presentation of the flow regimes in the Waitaki Catchment, supported with tabular data, which illustrates the relative size of the various flows at critical times and seasons, and the effect of infrastructure operation
- a method, likely to be spreadsheet-based, that can be used to assess the reliability of supply to run-of-river users within the tributaries based on daily time-series flows
- a method, also likely to be spreadsheet-based, that can be used to assess river flows and resource availability to all users within the main stem of the river under various allocation options.

The project brief is focused on existing hydrological information on the Waitaki Catchment, specifically historical flow data. Data is to be presented to provide a clear understanding of the magnitude and variability of flows within the catchment, including the influence of existing infrastructure on natural flows. In addition, this project provides a means to broadly assess river flows and resource availability under various potential allocation options.

This report is a collation of the hydrological information and spreadsheet models furnished to the board via the Ministry for the Environment in fulfilment of the project brief.

1.3 Scope

The following aspects are excluded from this project brief:

- effects on flows in rivers potentially receiving Waitaki water
- the recommendation of allocation options for tributaries and the Waitaki main stem
- an assessment of the water requirements of individual resource consent applications
- system modelling to replicate Meridian Energy's operation of its power infrastructure
- modelling of historical and projected irrigation and other water demands within the Waitaki Catchment
- checking and auditing of the historical hydrological records which this report relies on.

1.4 Acknowledgements

Hydrological databases and other relevant data for this project were kindly provided by the following agencies:

- Meridian Energy Ltd:
  - TIDEDA flow and water level records from their Power Archive for the Waitaki
  - lake level and flood operation guidelines, and storage tables for the hydro lakes
- Environment Canterbury:
  - TIDEDA flow databases, including ratings, gaugings and comments, for their recording stations in the Waitaki
  - naturalised flow records for the Hakataramea and Omarama Rivers
  - mean annual low flow (MALF) and five-year seven-day low flow estimates for gauged tributaries in the Waitaki, including mean flow estimates for some sites
  - irrigation flow records for the irrigation schemes in the lower Waitaki
- NIWA:
  - TIDEDA flow databases, including ratings, gaugings and comments for their recording stations in the Waitaki, including stations operated on behalf of other agencies
  - index of water level and flow recording sites in New Zealand
- Ministry for the Environment:
  - GIS coverage of the location of existing and proposed resource consents
  - various reference documents.

2 Available Flow Data

2.1 Inventory of water level and flow recording sites

Tables 2.1 and 2.2 list all the water level and flow recording sites in the Waitaki Catchment that are included in NIWA's index to water-level recording sites in New Zealand as at 2004. Sites in bold font are part of the National Hydrometric Reference Network, and generally have records of higher data quality and are operated by NIWA or regional councils.

Table 2.2 shows the sites from the Power Archive. Note that this list is not the complete list of sites available in the Power Archive.

Sites for which data have been acquired for this project are shaded grey. These sites generally have more established (longer) records and/or provide coverage of certain parts of the Waitaki Catchment which lack long-term flow recorders.

Sites are listed in numerical order based on the site number in both tables.

2.2 Previous studies and references

Below is a list of the previous investigation reports and references used for this project:

- Project Aqua – Waitaki River Hydrology Study, Appendix AG to Project Aqua AEE, by JR Waugh et al, Opus International Consultants Ltd, April 2003
- Canterbury Strategic Water Study, by M Morgan et al, Lincoln Environmental, August 2002
- Lower Waitaki Catchment – Hydrology Report, by Ian Jowett, Hydrology Section, Power Directorate, MWD, November 1984
- Inventory of the Hydrology of the Waitaki River, by John Young, Waitaki Catchment Commission, September 1987
- Index to Hydrological Recording Sites in New Zealand, by Kathy Walter, NIWA, 2000.

2.3 Low flow data

As part of Environment Canterbury's recent investigation of the Waitaki Catchment hydrology, Environment Canterbury has prepared mean flow and low flow estimates for approximately 130 sites, both permanent and temporary, throughout the catchment. Data for the temporary sites typically comprise a series of spot gaugings, which are correlated with contemporaneous data from established permanent flow recording sites.

Flow parameters such as the mean annual low flow (MALF) and the five-year and 10-year seven-day low flows, have been estimated by Environment Canterbury for tributaries with long-term flow records. These low flow estimates are shown with the flow statistics in the Flow Data Tables in Section 4 of this report.

Table 2.1: NIWA index of water level recording sites in the Waitaki Catchment (2004)

Site No.	River	Site Name	Map ref. (metric)	Catchment Area (km^2)	Recording Authority*	Records begin	Records end	Comment
71101	Waitaki	SHBr	J41:600850		NIWA-Tekapo			
71102	Otekaieke	Stockbridge	I41:141880	78.7	NIWA-Tekapo	17-Dec-1970	18-Feb-1977	Replaced by 71167
71103	**Hakataramea**	**Above MHBr**	**I40:112062**	**899**	**NIWA-Tekapo**	**26-Nov-1963**		
71104	**Waitaki**	**Kurow**	**I40:080088**	**9760**	**ECan**	**29-May-1963**		**Gap in record**
71105	Awakino	SH83	I40:071088	67	ECan,NIWA-Tek	8-Jun-1986	8-Aug-1989	Gap in record
71106	**Maerewhenua**	**Kellys Gully**	**I41:197820**	**187**	**NIWA-Tekapo**	**4-Mar-1970**		
71107	Awahokomo	Bellamore	I40:011069	16.3	ECan	10-Jan-1986	15-Jan-1988	Gap in record
71108	Waitaki	Parson's Rock	I40:904178	9174	NIWA-Tekapo	29-May-1963	21-Jul-1968	
71109	Otematata	Pumphouse	H40:878171	668	NIWA-Tekapo	10-Jan-1964	10-Jan-1970	
71110	Waitaki	Below Dam	I40:064097	9760	NIWA-Tekapo	10-Oct-1992		
71112	Ahuriri	Benmore	H39:865246		NIWA-Tekapo			
71113	Omarara Stn Race	Ahuriri Intake	H39:614301		ECS	19-Aug-2004		
71114	Fraser	Ben Ohau	H38:750606	81.6	ECan	1-Sep-1987	3-Aug-1988	
71116	**Ahuriri**	**Sth Diadem**	**G39:497320**	**557**	**NIWA-Tekapo**	**18-Sep-1963**		
71117	Twizel	Lk Poaka	H38:784628	121	ECan	3-Jul-1986	1-Jul-1995	
71118	Quail Burn	QuailBurn Rd	H39:631385	74.3	ECan	15-Oct-1986	1-Jun-1988	
71119	Ohau	SHBr	H38:777538	1250	NIWA-Tekapo	5-Jul-1963	30-Jul-1980	
71120	Lk Ohau	Lk Middleton	H38:588539	1190	NIWA-Tekapo	1-Jan-1963	5-Dec-1977	Replaced by 71168
71121	Twizel	SHBr	H38:794573	250	NIWA-Tekapo	25-Jul-1962	3-Apr-1973	
71122	**Mary Burn**	**Mt MacDonald**	**I38:923783**	**52.2**	**NIWA-Tekapo**	**22-Oct-1969**		
71123	Lk Pukaki	Canal Inlet Gate	H38:811656	1360	NIWA-Tekapo	20-Sep-1963		
71124	Devils Elbow	Recorder	H37:769075	2.7	NIWA-Tekapo	1-Jan-1962	10-Sep-1967	
71125	Hooker	Ball Hut Rd Br	H36:783146	103	NIWA-Tekapo	2-Sep-1963	28-Aug-1979	Gap in record
71126	Tara Hills Race	Ahuriri Intake	H39:614300		ECS	19-Aug-2004		
71127	Mary Burn	Maryhill	I38:942715	82.1	ECan	20-Dec-1963	13-Aug-1985	Gap in record
71128	Irishman	Windy Ridge	I38:978766	142	NIWA-Tekapo	8-Jan-1964	18-Jan-1972	
71129	**Forks**	**Balmoral**	**I37:014892**	**98**	**NIWA-Tekapo**	**30-Jul-1962**		
71130	Mary Burn	SH8	I38:960668		Ecan	12-Jun-2003		
71131	Tekapo	Spillway	I37:079860	1420	ECan	20-Dec-1963		Gap in record. Previously NIWA
71132	Lk Tekapo	Power Station Intake	I37:074865	1420	NIWA-Tekapo	28-Jun-1963		
71133	Elephant Hill	Elephant Hill Rd	J40:393973	48.3	ECan	4-Dec-1986	20-Jul-1988	
71134	Pukaki	Wardells	H38:828641	1360	NIWA-Tekapo	17-Sep-1964	26-Oct-1982	
71135	**Jollie**	**Mt Cook Stn**	**H37:835019**	**139**	**NIWA-Tekapo**	**7-Dec-1964**		
71136	Omarama	Wardells Br	H39:677305	281	ECan	3-Aug-1988	7-Jul-1995	
71137	Elephant Hill		J40:359982		ECS	10-Jun-2003		
71138	Peter Stm	Cloverbank	I39:270341	18	ECan	28-Aug-1985	12-Apr-1988	
71139	Cattle Ck	Invercroy	I39:184313	12	ECan	28-Aug-1985	12-Apr-1988	
71140	Tara Hills Race	Below Pump	H39:631262		ECS	20-Aug-2004		
71141	Tara Hills Race	Omarama Intake	H39:626261		ECS	20-Aug-2004		
71142	Station Peak Race	Intake	I40:149016		ECS	Aug-04		
71143	Hakataramea	Mt Florence	I39:246253	437	ECan	11-Dec-1995		Stage only
71148	Aviemore Spawning Race	Below Dam	I40:002134	na	ECan	11-Jun-1991	6-Jan-1996	
71154	Homestead Ck	Haughs Gorge	I40:220138	41.5	ECan	1-Oct-1985	7-Apr-1988	
71167	Otekaieke	Gorge	I41:141880	78.7	NIWA-Tekapo	6-Sep-1976	3-Sep-1984	Replaced by 71178
71168	Lk Ohau	Moose Lodge	H38:648552	1190	NIWA-Tekapo	20-Sep-1977		Replaces 71120
71169	Tekapo	Tekapo A	I37:065850	1425	NIWA-Tekapo	2-Mar-1978		Weir
71170	Awamoko	Georgetown	J41:389868	115	NIWA-Tekapo	9-Mar-1979	30-Jun-1995	
71171	Lk Ohau	Wetheralls	H38:562659	1190	NIWA-Tekapo	9-Dec-1991	1-Jul-1996	
71173	Morven Glenavy I.S.	Crowes	J40:623994	n/a	ECS	2-Sep-1980		Gap in record. Previously ECan
71174	Morven Glenavy I.S.	Horsnells	J40:613992	n/a	ECS	6-Nov-1980		Gap in record. Previously ECan
71175	Outlet Ck	Lk Alexandrina	I37:062936	54	ECan	22-May-1981	22-Jul-1992	
71177	Waitaki	Mouth	J41:639846		NIWA-Tekapo	28-Mar-1985	30-Aug-1994	
71178	**Otekaieke**	**Weir**	**I41:143880**	**78.7**	**NIWA-Tekapo**	**9-Jul-1984**	**30-Jun-1995**	**Replaces 71167**
71179	Omarama	Tara Hills	H39:625261	177	ECan	30-Jun-1984	13-Jul-1988	
71180	Awamoko	Smiths Rd Culvert	I41:212781	30	ECan	22-Mar-1984	12-Feb-1985	
71181	Wardells Race Bywash	above Omarama Stm	H39:656279	na	ECan	19-Sep-1984	21-May-1986	
71182	Omarama Swamp	Outlet	H39:607248	64	ECan	4-Sep-1984	10-Nov-1986	
71183	Sth Maerewhenua	Danseys Pass Rd	I41:177813	70.9	ECan	4-May-1984	9-Jan-1986	
71184	Waikoura Channel	Irvine Rd	J41:456837	34.5	ECan	6-Nov-1984	11-Feb-1988	
71185	Knowles Knob Stm	Lk Alexandrina	I37:049936	10.3	ECan	23-Mar-1984	18-Jun-1985	
71186	Scotts Ck	Deer Paddocks	I37:052974	8.5	ECan	23-Mar-1984	14-May-1985	
71187	Redcliffs	Intake	J40:364907	n/a	ECS	20-Sep-1990		Previously ECan
71188	Hakataramea	McRaes Gorge	I39:216476	81	ECan	17-Oct-1985		Gap in record
71189	Omarama	Above Tara Hills	H39:625260	171	ECan	9-Feb-1988		
71190	Morven Glenavy I.S.	Ross Rd	J41:503880	na	ECS	2-Nov-1990		Gap in record. Previously ECan
71191	Waikakahi Stream	Old Ferry Rd	J41:547890		ECan	23-Jan-1987	20-May-1988	
71192	Bogroy Irrigation	Intake			ECS	1-Mar-2002		
71193	Lower Waitaki I. S.	Bortons	J41:363894	na	ECS	23-Jul-1991		Previously ECan
71194	Ohau	below Syphon	H38:672537	1250	ECan	9-Sep-1992		
71195	Waikakahi	Te Maiharoa	J41:595861	154.9	NIWA-Tekapo	23-May-2001		
71196	MCIS Water Race	Control Gates	I41:230861		Tony Davoren	13-Dec-2000		
71197	Station Stm	Stockwater main race	I39:155219		ECS	2002		
71198	Glen Bouie Stm	Above Intake main race	H39:792082		ECS	2002		
71199	Otamatapaio Irrigation	Intake			ECS	2002		

* Note: ECS = Environmental Consultancy Services.

Table 2.2: NIWA index of power archive sites in the Waitaki Catchment (2004)

Site No.	River	Site Name	Map ref. (metric)	Catchment Area (km^2)	Recording Authority	Records begin	end
8712	Waitaki	Waitaki Spillway	I40:060099	9735	Meridian	10-Oct-1936	
8713	Waitaki	Waitaki Machine	I40:060099	9735	Meridian	30-Jul-1965	
8714	Waitaki	Waitaki Total	I40:060099	9735	Meridian	30-Jun-1927	
8722	Waitaki	Aviemore Spillway	I40:003134	9665	Meridian	31-Aug-1968	
8723	Waitaki	Aviemore Machine	I40:003134	9665	Meridian	31-Aug-1968	
8724	Waitaki	Aviemore Total	I40:003134	9665	Meridian	31-Aug-1968	
8732	Waitaki	Benmore Spillway	H39:870233	8500	Meridian	30-Jul-1965	
8733	Waitaki	Benmore Machine	H39:870233	8500	Meridian	30-Jul-1965	
8734	Waitaki	Benmore Total	H39:870233	8500	Meridian	31-Jul-1965	
8743	Ohau B	Machine	H38:797525	4075	Meridian	26-Mar-1984	
8748	Ohau C	Machine	H39:856478	4075	Meridian	22-Sep-1985	
8752	Ohau A	Bypass Valve	H38:732559	3995	Meridian	10-Jun-1979	
8753	Ohau A	Machine	H38:732559	3995	Meridian	10-Jun-1979	
8754	Ohau A	Total	H38:732559	3995	Meridian	10-Jun-1979	
8760	Lk Ohau	Inflow	H38:658536	1190	Meridian	7-Oct-1926	
8762	Lk Ohau	Spillway	H38:658536	1190	Meridian	6-Jun-1979	
8763	Lk Ohau	Canal	H38:658536	1190	Meridian	16-Jul-1979	
8764	Lk Ohau	Total	H38:658536	1190	Meridian	19-Feb-1926	
8770	Lk Pukaki	Inflow	H38:819651	1360	Meridian	26-Jul-1925	
8772	Lk Pukaki	Spillway	H38:819651	1360	Meridian	31-Jan-1952	
8773	Lk Pukaki	Sluice/Canal	H38:819651	1360	Meridian	28-Feb-1947	
8774	Lk Pukaki	Total	H38:819651	1360	Meridian	26-Jul-1925	
8783	Tekapo B	Machine	H38:864721	na	Meridian	21-Aug-1977	
8790	Lk Tekapo	Inflow	I37:064850	1420	Meridian	3-Mar-1925	
8792	Lk Tekapo	Spillway	I37:064850	1420	Meridian	5-Feb-1952	
8793	Lk Tekapo	Machine	I37:064850	1420	Meridian	24-Jun-1951	
8794	Lk Tekapo	Total	I37:064850	1420	Meridian	3-Mar-1925	
88765	Lk Ohau	Unadjusted level	H38:648552	1190	Meridian	19-Feb-1926	
88775	Lk Pukaki	Unadjusted level	H38:811656	1360	Meridian	26-Jul-1925	
88795	Lk Tekapo	Unadjusted level	I37:074865	1420	Meridian	3-Mar-1925	

3 Mean and Median Flow Maps

3.1 General

A series of maps (Appendix B) has been produced to show the geographical distribution of flows in the Waitaki Catchment:

- ***Figure 1 – Mean flow by zone*** shows the mean flows, including the seasonal distribution of flows, on an area-by-area (or zone) basis on a 1:600,00 scale (at A3 size) map of the Waitaki Catchment. Details of the derivation of the mean flows for each zone are provided in Section 3.2.
- ***Figure 2 – Mean flow at flow recording sites*** shows the mean flow at key locations and long-term flow recording sites in the catchment. A tabulated summary for these sites is given in Section 3.3.
- ***Figure 3 – Median flow at flow recording sites*** shows the median flow at long-term flow recording sites. A tabulated summary for these sites is given in Section 3.3.

To allow a meaningful comparison of flow statistics from different sites, it is desirable to generate statistics from each record for a common data period. The period 1980 to 2003 (complete calendar years) has been selected as the reference data period for the following reasons:

- Apart from the Power Archive sites, many of the recording sites did not have records that extended significantly earlier than 1980. That is, and importantly, the majority of sites have data from 1980 to 2003.
- The Pukaki High Dam was built and commissioned about 1980, which resulted in a paradigm shift in the operation of the power infrastructure from 1980 onwards.
- Any trends in the flow data as a result of climate change would be better captured in the more recent data compared with earlier data. That is, earlier data would be less representative of expected flow regimes in the immediate future.
- Data was truncated at the end of 2003 because the records for the 2004 year were incomplete at the time of study.

There is a suggestion that the selected data period 1980 to 2003 encompassed a particularly wet period (compared with long-term average) because of its coincidence with the positive or wet cycle of the Pacific Decadal Oscillation (PDO) from 1978 to 1999. The PDO index has recently (1999/2000) shifted to a negative cycle, which some climatologists believe heralds a return to generally drier conditions that existed before 1977.

A brief assessment of the available long-term records indicates that inflows to the upper Waitaki lakes between 1980 and 2003 averaged about 2.4% greater than from 1925 to 2004 (varies from 0% to 5.3% depending on the lake concerned). Long term flow records in the upper Mackenzie area show a mean flow about 4% greater for the period 1980 to 2003 compared with the full record from the mid-1960s to 2004.

On the main stem of the Waitaki, there is a 3.6% greater mean flow for the period 1980 to 2003 compared with the period mid-960s to 2004. However, about 1.6% (or about 6 m^3/s) of this increase is attributed to the flow lost to dead storage when the hydro lakes were raised (Lake Pukaki) or created (Benmore and Aviemore) by dam construction. Thus, the net increase in mean flow from natural variability is about 2%. It is worth noting that flow records for the Waitaki Dam have been excluded from this analysis because of a suspected over-prediction of flows in the latter half of that record (see, for example, Table 3.1).

While the increased mean flow in the reference period has been linked with the cyclical pattern in the PDO, the effects of long-term climate change from global warming cannot be ruled out as a contributing factor. The extent of current investigations in New Zealand to unravel the component effects of climate change and the PDO is unclear. However, the results from any such analysis would be tenuous given the significant year-to-year variability of the parameters involved.

3.2 Mean flows by zone

The Waitaki Catchment has been divided into nine broad areas or zones, each between about 900 km^2 and 2000 km^2, to show the relative magnitudes of the annual and seasonal mean flows generated in the various parts of the Waitaki Catchment.

Computation of the flow statistics for the three upper Waitaki lakes was relatively straightforward. However, derivation of the mean flow parameters for the other six zones required varying degrees of analysis and inference, which were based on:

- all available flow records within that zone, including Environment Canterbury's mean flow estimates for several temporary sites
- reference to mean annual rainfall contours (e.g. Figure A.1 in the Project Aqua – Waitaki River Hydrology Study)
- reference to previous hydrological study reports, especially the 1984 report by Jowett and the 1987 report by Young
- a broad overall catchment water balance analysis.

In particular, there was a distinct lack of flow recording sites in two of the zones, namely, Benmore and Aviemore. Thus, mean flow estimates in these zones have greater uncertainty.

The flow data plotted in Figure 3.1 is summarised in tabular format in Table 3.1 overleaf.

3.3 Summary flow statistics

Mean and median flows at recording sites are plotted on Figures 2 and 3 respectively. These estimates were obtained directly from the relevant TIDEDA database supplied to Tonkin & Taylor Ltd as part of this project. Where data is available, the flow for the reference period 1980 to 2003 has been shown, otherwise the flow for the full record period is given.

Four of the sites in Figure 2, that is, Grays River at Bridge, Stony River at Slip Panel Corner, Otamatapaio River at Top Bridge and Waitaki at River Mouth, are not flow recording sites. However, estimates have been given for the expected mean flow at these locations. The flow data plotted in Figures 2 and 3 is summarised in Table 3.2.

Table 3.1: Waitaki Catchment – mean flows by zone

Annual Mean Flows

Zone	Catchment Area (km^2)	Mean Flow (m^3/s)	Specific Discharge ($l/s/km^2$)
1 Lake Tekapo	1448	**85.9**	59.3
2 Lake Pukaki	1372	**128.4**	93.6
3 Lake Ohau	1105	**83.0**	75.1
4 Ahuriri (above SH8)	1300	**32.2**	24.8
5 Upper McKenzie	2097	**16.5**	7.9
6 Benmore	1109	**7.4**	6.7
7 Aviemore	1220	**11.9**	9.8
8 Hakataramea	899	**5.78**	6.4
9 Lower Waitaki	1359	**7.9**	5.8
Total	**11908**	**379.0**	

Check Totals	Site	Catchment Area Check (km^2)	NIWA Site Index Catchment Area (km^2)	Mean Flow Check (m^3/s)	Recorded Mean Flow (m^3/s)
a **1+2+3+4+5+6**	**Benmore Total**	8430	8500	353.4	354
b **1+2+3+4+5+6+7**	**Waitaki Dam Total**	9651	9735	365.3	385

Seasonal Mean Flows

Zone	Catchment Area (km^2)	Summer (m^3/s)	Summer (%)	Autumn (m^3/s)	Autumn (%)	Winter (m^3/s)	Winter (%)	Spring (m^3/s)	Spring (%)
1 Lake Tekapo	1448	**122.3**	35.1%	**78.2**	22.9%	**55.1**	16.1%	**89.3**	25.9%
2 Lake Pukaki	1372	**216**	41.6%	**124**	24.3%	**64**	12.6%	**111**	21.5%
3 Lake Ohau	1105	**113.7**	33.9%	**76.4**	23.2%	**53**	16.1%	**89.4**	26.8%
4 Ahuriri (above SH8)	1300	**35.4**	27.1%	**26.3**	20.5%	**27.3**	21.3%	**40.2**	31.0%
5 Upper McKenzie	2097	**16.3**	24.4%	**12.1**	18.5%	**15.7**	24.0%	**21.9**	33.1%
6 Benmore	1109	**5.81**	19.3%	**5.78**	19.6%	**8.62**	29.2%	**9.54**	31.9%
7 Aviemore	1220	**9.5**	19.8%	**13.8**	29.3%	**7.1**	15.1%	**17.1**	35.9%
8 Hakataramea	899	**4.47**	19.0%	**5.06**	22.0%	**6.83**	29.7%	**6.83**	29.3%
9 Lower Waitaki	1359	**6.82**	21.3%	**5.89**	18.7%	**10.56**	33.6%	**8.37**	26.4%
Total	**11908**	**530.3**		**347.5**		**248.2**		**393.6**	

Note: Data period 1980–2003.

Table 3.2: Waitaki Catchment – flow statistics at flow recording sites

DATA PERIOD Full Record

	Site Name	Data Available	Site No.	Min	Max	Mean	Std.Dev	Median	Lower Q.	Upper Q.	95%
1	Lake Tekapo Inflow	1925-2004	8790	2.000	2924	**81.53**	77.25	63.85	38.66	99.43	203.0
2	Tekapo Canal	1977-2004	8793	0.000	134.1	**64.84**	41.410	67.13	30.61	104.2	116.0
3	Lake Pukaki Natural Inflow	1925-2004	68770	2.000	2688	**128.2**	121.0	99.1	54.9	161.7	322.3
4	Pukaki Canal	1979-2004	8773	-0.001	676.3	**182.8**	120.9	124.3	36.1	231.2	367.6
5	Lake Ohau Inflow	1926-2004	8760	2.000	2380	**81.37**	73.53	63.44	40.13	97.73	196.9
6	Lake Ohau Canal	1979-2004	8763	0.000	220.5	**72.89**	56.78	52.68	30.98	108.8	185.3
7	Ahuriri at South Diadem	1963-2004	71116	6.611	570.0	**23.70**	20.32	18.23	12.97	27.36	54.92
8	Omarama at Above Tara Hills	1988-2004	71189	0.293	24.65	**1.534**	1.303	1.147	0.732	1.823	4.122
9	Omarama at Wardells Br	1988-1995	71136	0.416	35.04	**2.419**	1.970	1.927	1.304	2.844	5.392
10	Twizel at Lake Poaka	1986-1995	71117	0.005	98.99	**2.573**	3.583	1.646	0.863	3.134	7.421
11	Twizel at SHBr	1962-1973	71121	0.256	139.5	**4.638**	5.560	3.013	1.856	5.27	13.45
12	Mary Burn at Mt MacDonald	1969-2004	71122	0.098	17.10	**0.566**	0.471	0.414	0.306	0.648	1.346
13	Mary Burn at Mary Hill	1964-1985	71127	0.275	36.42	**0.689**	0.848	0.495	0.419	0.703	1.548
14	Irishman at Windy Ridge	1962-1971	71128	0.017	75.29	**1.348**	2.076	0.832	0.477	1.543	3.678
15	Forks at Balmoral	1962-2004	71129	0.741	61.52	**3.202**	2.378	2.524	1.784	3.863	7.174
16	Grays River at Bridge										
17	Otamatapaio at Top Bridge										
18	Stony at Slip Panel Corner										
19	Waitaki at Benmore Dam	1965-2004	8734	0.000	2581	**341.4**	178.3	335.3	227.8	441.1	613.7
20	Otematata at Pumphouse	1962-1969	71109	0.165	190.5	**7.753**	8.078	5.302	3.212	8.947	21.82
21	Waitaki at Aviemore Dam	1968-2004	8724	0.000	2674	**356.5**	185.0	367.7	232.9	473.3	624.0
22	Waitaki at Waitaki Dam	1927-2004	8714	2.460	2914	**358.5**	178.2	336.5	244.5	429.6	656.2
23	Waitaki at Kurow	1964-2004	71104	19.768	2669	**368.1**	151.5	356.0	275.9	435.4	593.6
24	Hakataramea at above MHbr	1964-2004	71103	0.446	1352	**5.792**	13.28	3.417	1.789	6.065	16.38
25	Otekaieke at Weir	1971-1995	71102/67/78	0.022	144.5	**1.154**	2.73	0.695	0.389	1.175	3.12
26	Maerewhenua at Kellys Gully	1970-2004	71106	0.201	319.2	**2.823**	6.47	1.629	0.987	2.844	7.507
27	Awamoko at Georgetown	1979-1995	71170	0.000	147.5	**0.245**	2.57	0.046	0.007	0.13	0.525
28	Waitaki at River Mouth										
29	Redcliffs at Intake	1990-2004	71187	-0.033	6.740	**2.281**	1.77	1.951	0.563	3.435	5.622
30	Morvern Glenavy I.S. at Ross Rd	1990-2004	71190	-0.323	16.52	**6.589**	4.68	7.509	1.679	10.84	13.01
31	Lower Waitaki I.S. at Bortons	1991-2004	71193	0.596	17.98	**10.22**	4.99	11.60	4.644	14.98	16.30

DATA PERIOD 1980 - 2003

	Site Name	Data Available	Site No.	Min	Max	Mean	Std.Dev	Median	Lower Q.	Upper Q.	95%
1	Lake Tekapo Inflow	1925-2004	8790	2.000	2345	**85.86**	79.33	67.14	43.53	101.9	207.8
2	Tekapo Canal	1977-2004	8793	0.000	129.8	**75.73**	38.27	93.09	52.64	107.2	118.7
3	Lake Pukaki Natural Inflow	1925-2004	68770	2.000	2688	**128.2**	124.5	99.77	58.08	157.7	316.0
4	Pukaki Canal	1979-2004	8773	-0.001	676.3	**185.2**	131.2	191.9	63.89	288.0	399.2
5	Lake Ohau Inflow	1926-2004	8760	2.000	2380	**82.99**	83.57	62.08	39.51	98.31	206.9
6	Lake Ohau Canal	1979-2004	8763	0.000	220.5	**72.90**	57.05	52.50	30.97	108.9	186.3
7	Ahuriri at South Diadem	1963-2004	71116	6.661	570.0	**24.52**	20.71	19.02	13.72	28.33	56.02
8	Omarama at Above Tara Hills	1988-2004	71189	0.293	24.65	**1.522**	1.313	1.118	0.720	1.802	4.133
9	Omarama at Wardells Br	1988-1995	71136								
10	Twizel at Lake Poaka	1986-1995	71117								
11	Twizel at SHBr	1962-1973	71121								
12	Mary Burn at Mt MacDonald	1969-2004	71122	0.193	7.290	**0.596**	0.457	0.443	0.329	0.685	1.405
13	Mary Burn at Mary Hill	1964-1985	71127								
14	Irishman at Windy Ridge	1962-1971	71128								
15	Forks at Balmoral	1962-2004	71129	0.815	61.52	**3.31**	2.40	2.61	1.87	3.99	7.31
16	Grays River at Bridge										
17	Otamatapaio at Top Bridge										
18	Stony at Slip Panel Corner										
19	Waitaki at Benmore Dam	1965-2004	8734	0.000	2581	**353.6**	168.6	343.5	250.7	447.2	600.2
20	Otematata at Pumphouse	1962-1969	71109								
21	Waitaki at Aviemore Dam	1968-2004	8724	0.000	2674	**369.2**	180.4	382.3	252.5	479.3	624.4
22	Waitaki at Waitaki Dam	1927-2004	8714	61.721	2914	**384.6**	144.5	369.4	307.3	439.6	568.2
23	Waitaki at Kurow	1964-2004	71104	45.16	2669	**374.6**	130.5	362.0	300.5	433.0	559.5
24	Hakataramea at above MHbr	1964-2004	71103	0.446	1352	**5.714**	15.24	3.237	1.745	5.822	15.59
25	Otekaieke at Weir	1971-1995	71102/67/78								
26	Maerewhenua at Kellys Gully	1970-2004	71106	0.235	319.2	**2.791**	6.987	1.573	0.972	2.708	7.288
27	Awamoko at Georgetown	1979-1995	71170								
28	Waitaki at River Mouth										
29	Redcliffs at Intake	1990-2004	71187								
30	Morvern Glenavy I.S. at Ross Rd	1990-2004	71190								
31	Lower Waitaki I.S. at Bortons	1991-2004	71193								

Note: All flows in cubic metres per second.

4 Flow Data Tables

4.1 Introduction

Flow data tables for established flow recording sites are included in Appendix A of this report. Below is a list of the flow data tables, which are ordered in alphabetical order.

Site name	Data period
Ahuriri River at South Diadem	1963–2004
Awamoko Stream at Georgetown	1979–1995
Forks River at Balmoral	1962–2004
Hakataramea River at above MHBr	1964–2004
Irishman Creek at Windy Ridge	1964–1971
Lake Ohau Canal	1979–2004
Lake Ohau Inflow	1926–2004
Lake Pukaki Canal	1979–2004
Lake Pukaki Inflow	1925–2004
Lake Tekapo Canal	1977–2004
Lake Tekapo Inflow	1925–2004
Lower Waitaki I.S. at Bortons	1991–2004
Maerewhenua River at Kellys Gully	1970–2004
Mary Burn at Mt MacDonald	1969–2004
Morven Glenavy I.S. at Ross Rd	1990–2004
Omarama Stream at above Tara Hills	1988–2004
Omarama Stream at Wardells Br	1988–1995
Otekaieke River at Stockbridge / Gorge / Weir	1971–1995
Otematata River at Pumphouse	1962–1969
Redcliffs at Intake	1990–2004
Twizel River at Lake Poaka	1986–1995
Waitaki at Aviemore Dam	1968–2004
Waitaki at Benmore Dam	1965–2004
Waitaki at Waitaki Dam	1927–2004
Waitaki River at Kurow	1964–2004

With regard to the upper and mid-Waitaki Catchment, 1976 and 1977 were clearly the driest years on record. Other notable dry years were 1930, 1932, 1939 and 1992. In the lower Waitaki Catchment, 1988 appeared to have been the driest year for a number of sites. Other dry years in the lower catchment were 1998 and 2003.

5 Spreadsheet Models for Assessing Run-of-River Reliability

5.1 Introduction

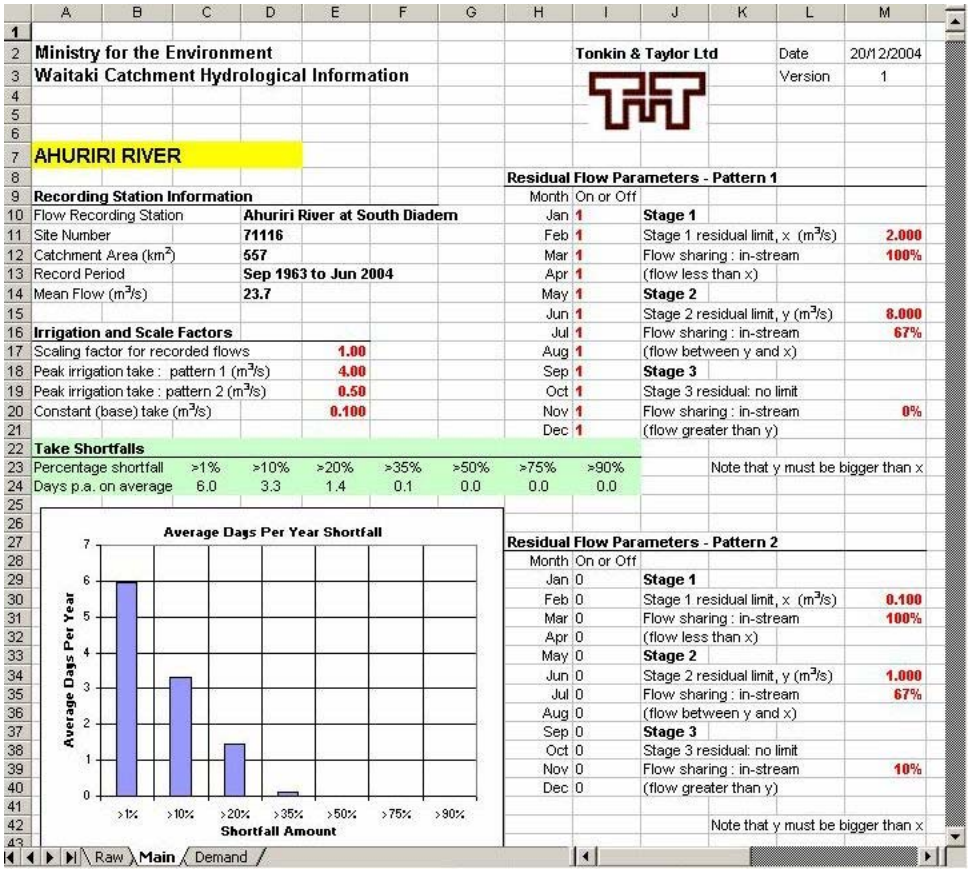
Spreadsheet models for assessing the reliability of supply from tributaries to run-of-river users have been developed for a number of gauged tributaries. These models, which are based on the full record of historical daily flows, may be used to evaluate various environmental flow-sharing regimes and allocation quantities and patterns. There is a model for each of the following sites (in alphabetical order):

- Ahuriri River at South Diadem
- Awamoko Stream at Georgetown
- Forks River at Balmoral
- Hakataramea River at Above Main Highway Bridge (Environment Canterbury's naturalised flow record used)
- Irishman Creek at Windy Ridge
- Mary Burn at Mt MacDonald
- Maerewhenua River at Kellys Gully
- Omarama Stream at Above Tara Hills (Environment Canterbury's naturalised flow record used)
- Otekaieke River at Stockbridge/Gorge/Weir
- Otematata River at Pumphouse
- Twizel River at Lake Poaka.

In addition, a similar spreadsheet model for the lower Waitaki River based on the historical daily flows recorded at Kurow (Site No. 71104) from mid-1979 has also been developed to assess river flows and resource availability to potential users within the main stem of the river under various environmental flow-sharing regimes.

Sample screen views of a typical spreadsheet model are shown on Figure 5.1 overleaf.

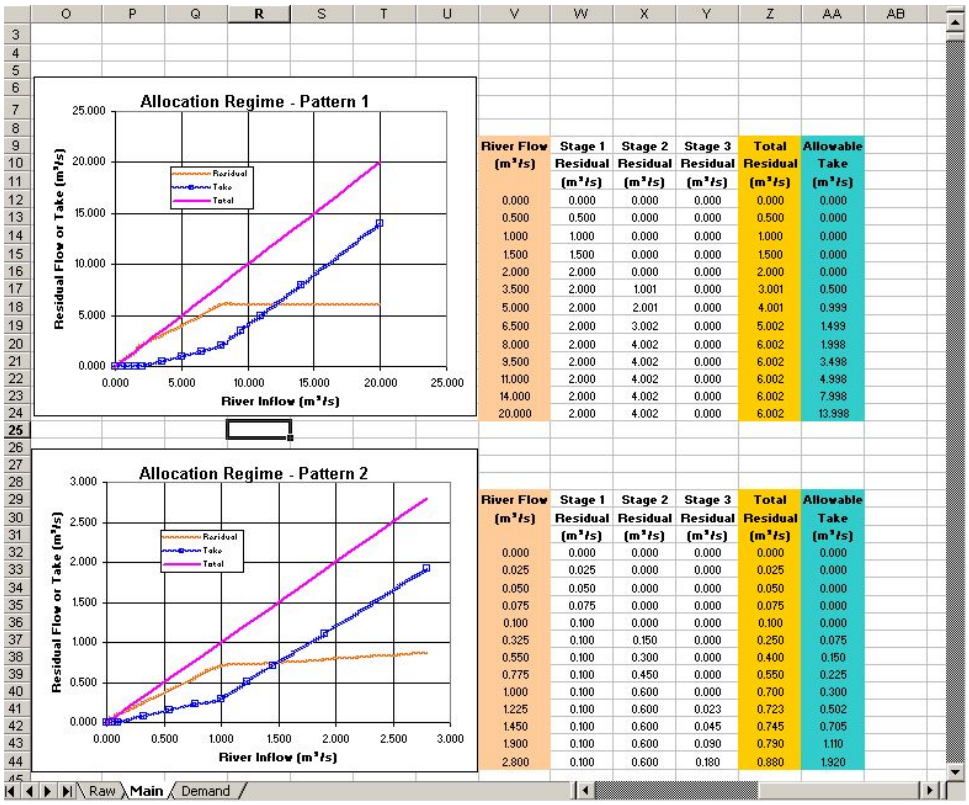
Figure 5.1: Sample screen views of spreadsheet model



2	Ministry for the Environment								Tonkin & Taylor Ltd			Date	20/12/2004
3	Waitaki Catchment Hydrological Information											Version	1
7	AHURIRI RIVER												
9	Recording Station Information								Residual Flow Parameters - Pattern 1				
10	Flow Recording Station		Ahuriri River at South Diadem						Month	On or Off			
11	Site Number		71116						Jan	1	Stage 1		
12	Catchment Area (km²)		557						Feb	1	Stage 1 residual limit, x (m³/s)		2.000
13	Record Period		Sep 1963 to Jun 2004						Mar	1	Flow sharing : in-stream		100%
14	Mean Flow (m³/s)		23.7						Apr	1	(flow less than x)		
15									May	1	Stage 2		
16	Irrigation and Scale Factors								Jun	1	Stage 2 residual limit, y (m³/s)		8.000
17	Scaling factor for recorded flows			1.00					Jul	1	Flow sharing : in-stream		67%
18	Peak irrigation take : pattern 1 (m³/s)			4.00					Aug	1	(flow between y and x)		
19	Peak irrigation take : pattern 2 (m³/s)			0.50					Sep	1	Stage 3		
20	Constant (base) take (m³/s)			0.100					Oct	1	Stage 3 residual: no limit		
21									Nov	1	Flow sharing : in-stream		0%
22	Take Shortfalls								Dec	1	(flow greater than y)		
23	Percentage shortfall	>1%	>10%	>20%	>35%	>50%	>75%	>90%			Note that y must be bigger than x		
24	Days p.a. on average	6.0	3.3	1.4	0.1	0.0	0.0	0.0					

29									Residual Flow Parameters - Pattern 2				
30									Month	On or Off			
31									Jan	0	Stage 1		
32									Feb	0	Stage 1 residual limit, x (m³/s)		0.100
33									Mar	0	Flow sharing : in-stream		100%
34									Apr	0	(flow less than x)		
35									May	0	Stage 2		
36									Jun	0	Stage 2 residual limit, y (m³/s)		1.000
37									Jul	0	Flow sharing : in-stream		67%
38									Aug	0	(flow between y and x)		
39									Sep	0	Stage 3		
40									Oct	0	Stage 3 residual: no limit		
41									Nov	0	Flow sharing : in-stream		10%
42									Dec	0	(flow greater than y)		
43											Note that y must be bigger than x		

Raw | Main | Demand



River Flow (m³/s)	Stage 1 Residual (m³/s)	Stage 2 Residual (m³/s)	Stage 3 Residual (m³/s)	Total Residual (m³/s)	Allowable Take (m³/s)
0.000	0.000	0.000	0.000	0.000	0.000
0.500	0.500	0.000	0.000	0.500	0.000
1.000	1.000	0.000	0.000	1.000	0.000
1.500	1.500	0.000	0.000	1.500	0.000
2.000	2.000	0.000	0.000	2.000	0.000
3.500	2.000	1.001	0.000	3.001	0.500
5.000	2.000	2.001	0.000	4.001	0.999
6.500	2.000	3.002	0.000	5.002	1.499
8.000	2.000	4.002	0.000	6.002	1.998
9.500	2.000	4.002	0.000	6.002	3.498
11.000	2.000	4.002	0.000	6.002	4.998
14.000	2.000	4.002	0.000	6.002	7.998
20.000	2.000	4.002	0.000	6.002	13.998

River Flow (m³/s)	Stage 1 Residual (m³/s)	Stage 2 Residual (m³/s)	Stage 3 Residual (m³/s)	Total Residual (m³/s)	Allowable Take (m³/s)
0.000	0.000	0.000	0.000	0.000	0.000
0.025	0.025	0.000	0.000	0.025	0.000
0.050	0.050	0.000	0.000	0.050	0.000
0.075	0.075	0.000	0.000	0.075	0.000
0.100	0.100	0.000	0.000	0.100	0.000
0.325	0.100	0.150	0.000	0.250	0.075
0.550	0.100	0.300	0.000	0.400	0.150
0.775	0.100	0.450	0.000	0.550	0.225
1.000	0.100	0.600	0.000	0.700	0.300
1.225	0.100	0.600	0.023	0.723	0.502
1.450	0.100	0.600	0.045	0.745	0.705
1.900	0.100	0.600	0.090	0.790	1.110
2.800	0.100	0.600	0.180	0.880	1.920

Raw | Main | Demand

5.2 Spreadsheet user's guide

Below is a brief user's guide to the spreadsheet models:

The variables to be defined by the user are:

- *Residual Flow Regime – there are two three-stage flow-sharing regimes (Pattern 1 or Pattern 2 residual) allowed for in the spreadsheet, and either one can apply each month of the year*
- *Scaling factor for recorded flows – a simple scaling factor has been included for modifying tributary inflows. It is possible to programme in a full correlation relationship for a virtual site, either upstream or downstream of the actual recorder location.*
- *Demand or Take – three types of take are permissible, i.e. a constant take and two user-defined monthly take patterns.*

How to use the spreadsheet:

1. General

Only values in bold red font are meant to be modified by the user. These user-modifiable cells are in the "Main" and "Demand" worksheets. Other cells should be left unmodified.

The "Raw" worksheet contains the raw data extracted from the TIDEDA database, and cells must not be modified.

The "Main" worksheet contains the computation of the residual flow, the available take and the shortfall amount on a daily basis. The main variables to be modified by the user are also on this worksheet, including the residual flow parameters, the peak irrigation and other takes, and the flow scaling factor.

The "Demand" worksheet contains the pattern of take by month-of-year, expressed as a percentage of the peak take rate. Two such take patterns have been allowed for.

2. Residual flow regime

The three-stage flow regime works as follows:

(i) for inflows less than x, residual = lesser of the actual inflow or x multiplied by the flow sharing ratio r1, i.e. residual = r1.inflow

(ii) for inflows between x and y, a proportion r2 of the inflow between x and y is added to the bypass, i.e. residual = r1x + r2(inflow – x)

(iii) for inflows greater than y, a proportion r3 of the inflow above y is added to the bypass, i.e. residual = r1x + r2(y – x) + r3(inflow – y).

Two sets of residual flow parameters have been allowed for, and each month of the year can either have one pattern or the other. The user will have to set the parameters x, y and r1, r2 and r3. If only one regime is to be used, then it is not necessary to define the Pattern 2 parameters. In this case, ensure that under Pattern 1, and under "On or Off" all values in column I from rows 10 to 21 are set to 1. If some months are to have Pattern 2 residual, then for these months the corresponding values under Pattern 1 (between I10 and I21) should be set to 0. There is no need to change the values under "On or Off" in Pattern 2 as these change automatically.

The graphs to the right of the residual flow parameters illustrate the flow-sharing regime specified by the parameters. The data for plotting these graphs are tabulated to the right of these graphs.

3. Demand pattern

Three separate take patterns are provided for in the spreadsheet model, comprising a constant take and two by-month take patterns. The two take patterns are specified in the "Demand" worksheet, and are expressed as a percentage of the peak take. The peak take rates are specified in the "Main" worksheet in cells E18 and E19. The base constant take rate is specified in cell E20 in the "Main" worksheet. The total take applied is the sum of the three takes.

However, we note that, if an allocation is granted, the consent owner can theoretically take the full allocated amount (but within the applicable residual flow rules) at any time of the year. Thus, there is a case for setting all the percentage values at 100%, unless the consent conditions specify a lower limit outside the irrigation season.

4. Shortfall computation

Conceptually, the total take is assumed to be lumped at the flow site, and the shortfall = total take less the scaled inflow. The scaling factor (cell E17), which is applied to the recorded mean daily inflows, allows for the situation where some of the take occurs below the flow recording station, and compliance with the environmental flow regime is monitored at some virtual downstream flow site. The actual situation can be significantly more complicated because some rivers have less surface flow at downstream locations because of flow loss to the river bed and aquifers.

The number of shortfall days on a year-by-year basis is summarised in the table below the flow-sharing graphs. The shortfall criteria can be changed by the user by changing the values in cells Q47 to W47. For example, ">10%" will return the number of days with shortfall greater than 10% of the total demand, and so on.

Seven classes of shortfall criteria (Q47 to W47) have been allowed for to enable plotting of the average shortfall days per year versus shortfall severity. This graph appears on the left below "Take Shortfalls" on the "Main" worksheet. The "Rank" (column X to the right of the table of year-by-year shortfall days) gives an indication of the dry years in the record, with rank 1 being the driest (based on the criteria in R47).

6 Other Hydrological Information

6.1 Introduction

As this project progressed, the Waitaki Catchment Water Allocation Board through the MfE requested various other hydrological information, which was duly provided. Information provided included the following:

- lake level exceedance curves for:
  - Lake Aviemore, from mid-1979
  - Lake Benmore, from mid-1979
  - Lake Ohau, from mid-1979
  - Lake Pukaki, from mid-1979
  - Lake Tekapo, from mid-1979
  - Lake Waitaki, from mid-1979
- lake level time-series plots curves for:
  - Lake Aviemore, from mid-1979
  - Lake Benmore, from mid-1979
  - Lake Ohau, from mid-1979
  - Lake Pukaki, from mid-1979
  - Lake Tekapo, from mid-1979
  - Lake Waitaki, from mid-1979
- flow duration curves for:
  - Waitaki River at Kurow, from mid-1979, full flow range
  - Waitaki River at Kurow, from mid-1979, low flow range
- flow time-series plots for:
  - Waitaki River at Kurow, sample comparison of instantaneous and mean daily flows
- graphs showing the effects of storage management in the upper Waitaki lakes on the flows in the Waitaki main stem below Benmore Dam.

These plots and graphs are included in Appendix B.

7 Applicability

This report has been prepared for the benefit of the Ministry for the Environment with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

TONKIN & TAYLOR LTD

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor by:
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Appendix A Flow Data Tables

Appendix B Maps, Plots and Graphs