Arrow Catchment Hydrology

Low Flows at Cornwall Street and Kawarau confluence

Prepared for Otago Regional Council

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Prepared by:
Roddy Henderson
Dr Daniel Collins

For any information regarding this report please contact:
Roddy Henderson
Hydrologist
Hydrological Processes
+64-3-343 7873
roddy.henderson@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8011

Phone +64 3 348 8987

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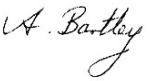	Formatting checked by:	Alison Bartley (Hamilton)
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Naturalised flows for the Arrow River at Cornwall Street are derived, using a mixed model that combines available water meter data with measured river flows over the last six years, and a regression with Cardrona at Mt Barker naturalised flows prior to that, to give a complete series from December 1976 to May 2019.

From this long naturalised time series of flows, a naturalised 7-day MALF for the Arrow at Cornwall Street is estimated to be 1730 L/s ± 12%, or 1500 to 1900 L/s.

Ratios of the estimate at Cornwall Street are used with national models of MALF to provide an estimate of naturalised 7-day MALF at the confluence with the Kawarau of 1900 L/s ± 15%, or 1600 to 2200 L/s.

1 Introduction

Knowledge of the Arrow catchment hydrology is used as a basis for water management and allocation. The recorded in-river data are affected by consented water abstractions, and the abstraction data are only available for a limited recent period. To get robust estimates of low flows for planning purposes it is necessary to combine data recorded in the catchment with data recorded elsewhere, so that longer-term climate variability is accounted for.

A natural 7-day mean annual low flow value is needed at the flow recorder at Cornwall Street, to be used as the basis of further decisions.

Reliability of water supply for out-of-stream users is an important aspect of the local and regional economy. Various scenarios of minimum flow setting and water allocation can be modelled to assess reliability, using the natural flow series developed below.

2 Data

Water data in the Arrow catchment are measured at flow recorders in the river and at water meters that are associated with the consented abstractions.

2.1 River flows

River flow data have been collected at sites in the Arrow catchment since 1974 (Table 2-1). Tobins Track and Beetham Creek sites were operated by MWD (Ministry of Works and Development) and NIWA. Unfortunately, there are no water meter data from the period in which they operated so they are of little use in the present study. The ORC operated Cornwall Street site dates from 30 December 2010, and over that time has 5% missing record, or 153 days.

Table 2-1: Flow recorders in the Arrow catchment. Where end dates are blank the recorder is open as of 2020.

Site Name	easting	northing	Catchment Area (km^2)	Start date	End date
Arrow at Tobins Track (75253)	1271894	5015202	199	7 Mar 1974	12 Mar 1982
Arrow at Beetham Creek (75272)	1272945	5012753	245	15 Apr 1981	24 Jan 1994
Arrow at Cornwall Street (1075291)	1272287	5014525	200	30 Dec 2010	open

2.2 Consents and water take data

Consents to use water have existed in the catchment since at least 1926, and have been renewed over time, some currently running until 2048. A full list of consents in the Arrow catchment upstream of the Clutha River/Mata-Au confluence, and meters where applicable is shown in Table 2-2.

Water take data are available from some water meters since December 2009. Some meters measure water that is removed from the river upstream of the flow recorder, and others measure water removed from downstream of the flow recorder or from nearby aquifers.

Of those that measure water taken upstream of the flow recorder, the meter that measures ~80% of the water used (WM0667) has data only since October 2013. This provides the earliest time from which direct synthesis of natural flows is feasible. Data available at the time the modelling was done are continuous from that date until 15 May 2019.

An unmetered take upstream of the flow recorder (RM17.214.01) has a MaxRate of 10 L/s, or 1%, and has been ignored. A larger consent upstream (2007.410) is not currently exercised so can also be ignored.

Table 2-2: Arrow catchment consents and water meters.

Consent Number	Consent Commencement	Consent Expiry Date	Water Meter Numbers	Rate l/s	Annual Volume m^3
Upstream of Cornwall Street					
2007.049	17/10/2007	1/10/2021	WM0458, WM0459	108	1,105,200
2007.410	19/10/2007	1/10/2021	Not exercised	61.8	1,950,260
95696	22/11/1995	1/10/2021	WM0733	83.33	2,629,800
RM17.214.01	15/08/2018	1/04/2048		10	300,000
RM17.214.02	21/05/2018	1/04/2048	Supplementary Take	40	300,000
WR1440AR	5/08/1926	1/10/2021	WM0667	1389	43,833,506
Downstream of Cornwall Street					
2000.263	18/07/2000	1/10/2021	WM0989	13.88	432,000
2000.361	25/09/2000	1/09/2021	WM1255	6.36	66,000
2001.913	13/11/2001	1/11/2026		2	6,552
2006.256	17/05/2007	1/10/2021	WM0449	12	224,985
96264	11/02/1997	1/10/2021	WM0449	13.9	432,000
96265	12/02/1997	1/10/2021	WM0963	27.77	876,600
96285	18/03/1998	1/10/2021	WM1202	13.9	432,000
97402	4/09/1997	1/10/2021	WM1285	83.33	2,629,800
98457	28/10/1998	1/10/2021	WM0989	13.88	438,300
3073B	27/11/1986	1/10/2021	WM0503, WM0503	111.11	576,000
97029.V1	4/08/1998	1/10/2021	WM0385	56	672,000
RM14.364.01	30/07/2015	1/10/2021	WM1202	55.6	952,200
RM15.027.01	2/03/2015	28/02/2030	WM0764, WM0764	6.04	103,117
RM18.034.01	27/06/2018	1/08/2043	WM0563	33	250,000

3 Data analysis

Water take data have been plotted and scrutinised. No obvious issues were identified. The water take data are complete for the period 9 October 2013 to 15 May 2019. Thus, the naturalisation of flows simply involves adding the measured water takes to the measured river flows (Figure 3-1).

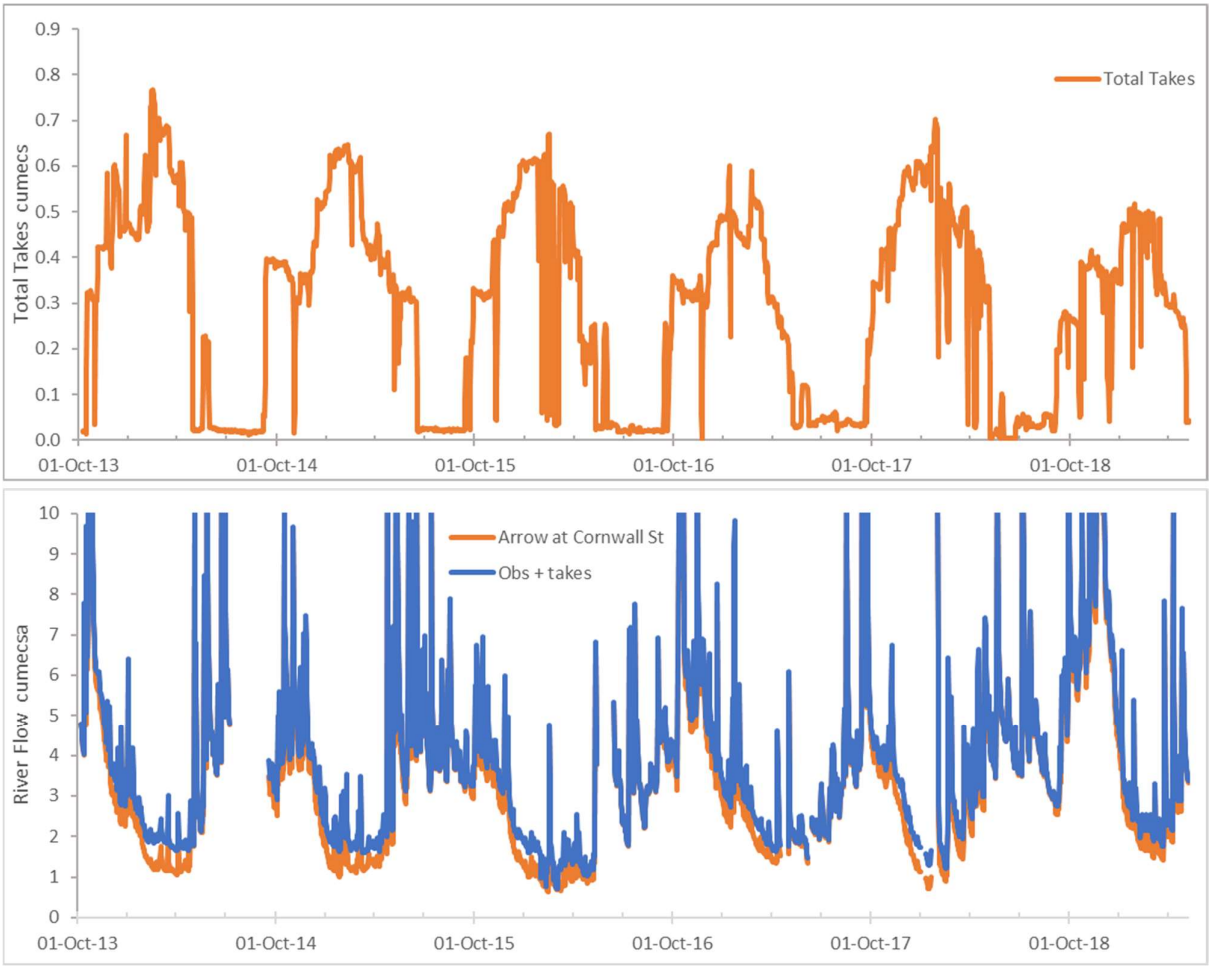

Figure 3-1: Total water takes, measured and naturalised flow at Cornwall St. The top plot shows the summed water takes from four meters. The bottom plot shows the recorded flows (orange) and the naturalised flows (blue).

Water take patterns show the expected low in winter of less than 100 L/s. Season to season average take is variable, with some years (2013/14 and 2014/15) using more water than others.

4 Naturalised flows for MALF estimation

The measured water meter data can be used with the measured flow data to provide several estimates of natural behaviour, or at least to provide some bounds for this, so that a naturalised MALF may be derived. Time series of daily flow data are prepared and the 7-day minimum extracted on an annual basis. The average of these provides the MALF, subject to issues related to the continuity of the various series that may be derived.

4.1 Models for naturalised flow estimation

The Arrow catchment complete water meter data only date from October 2013, limiting the direct calculation of natural flows to the six most recent years. Because of variations in climate and hence flow over longer periods than this, extension of the natural flows to a longer period is desirable. The nearest and most similar catchment record to the Arrow is that from the Cardrona at Mt Barker. This record has recently been naturalised (Henderson and Collins 2019) and thus is the best available for simulating natural behaviour in the Arrow River.

Four different models of Cardrona natural flows were tested for use in regression relations with naturalised Arrow flows from October 2013. Table 4-1 shows the r^2 and standard error of the MALF estimate (SE) values for these comparisons, and the supporting plots are shown in Appendix A.

Table 4-1: Statistics of regressions between naturalised Cardrona and Arrow flows. Data are daily average flows between October 2013 and June 2019.

Cardrona Model	Model description	R^2	Estimated Arrow at Cornwall Street MALF (m^3/s)	SE of estimated Arrow MALF (1.1)
Model 4	Observed flow + average water use model	0.848	1.742	21.0%
Model 5	Observed flow + estimated water use data	0.833	1.702	21.9%
Model 6	Mt Barker GMR regression with Lindis	0.708	1.717	29.3%
Model 8	Hybrid Cardrona model using best available estimates	0.847	1.731	21.1%

There is little difference in the goodness of fit amongst these different Cardrona models when used to predict Arrow flows. Each was applied to produce a long Arrow flow series (December 1976 to May 2019). Like the Cardrona, a hybrid model was also developed for the Arrow using the sum of measured Arrow flows and meter data when available, and the Cardrona hybrid model regression (model 8 in Table 4-1) otherwise.

4.2 MALF estimates

The four models described above plus the hybrid Arrow model were analysed to produce 7-day MALF estimates. As for the Cardrona analysis (Henderson and Collins 2019), estimates vary depending on the time period used, most evidently related to the Interdecadal Pacific Oscillation (IPO) signal. This

similarity with Cardrona patterns is to be expected since the Cardrona regressions form the bulk of the modelled flow series (36 years out of 43). However, the proximity of these two catchments, the general strength of the correlations between them, and the independent evidence from the Lindis (Henderson, 2018) mean that there is confidence in the overall results.

Table 4-2 shows the MALF estimates and standard errors for the five models, and for different time periods. IPO positive (IPO+ive) estimates for models 4 & 5 cannot be calculated because of significant missing data in the Cardrona record within that period.

Table 4-2: Estimates of MALF and standard error, L/s. Four regression models and a hybrid model are shown, plus standard errors. Time periods are IPO+ive (1977-1999), IPO-ive (2001-2019), all data, and the period of water meter data (2014-2019).

Time period	Cardrona Model 4	Cardrona Model 5	Cardrona Model 6	Cardrona Model 8	Arrow Hybrid
MALF Estimates (L/s)					
IPO+ive (77-99)			2000	1906	1906
All data (77-19)			1789	1732	1729
IPO-ive 01-19	1541	1503	1541	1550	1542
Water meter data (14-19)	1425	1389	1356	1476	1452
Standard errors (L/s)					
IPO+ive (77-99)			130	119	119
All data (77-19)			84	78	77
IPO-ive 01-19	85	84	90	86	85
Water meter data (14-19)	148	146	131	169	173

Figure 4-1 shows the time series behaviour of the Arrow hybrid model 7-day low flows. MALF estimates are shown from the two IPO periods and the full record. Standard errors indicate that there is a case for considering these periods to be different but at a low level of confidence. For example, the error bars overlap between the IPO+ive and the long series.

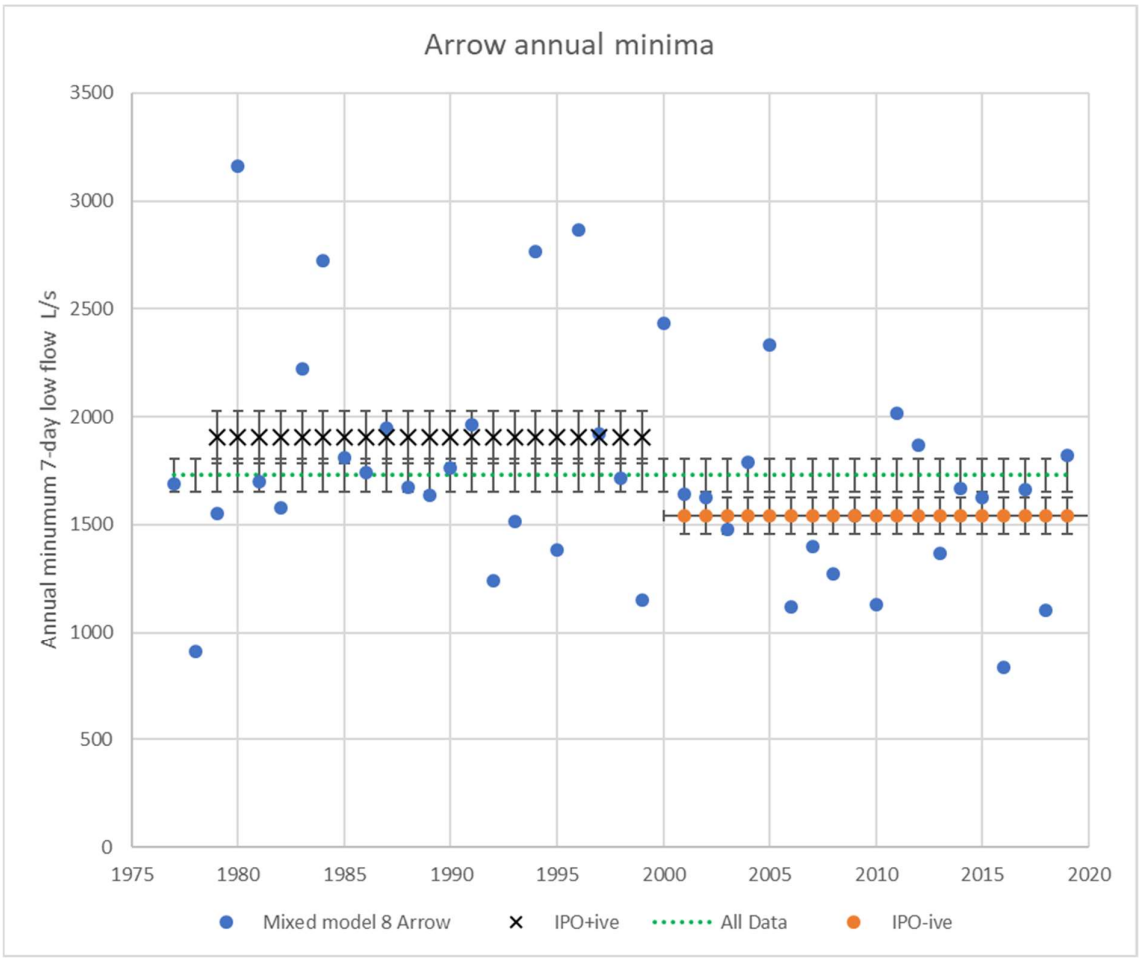

Figure 4-1: 7-day low flows for the Arrow at Cornwall Street. Blue dots show the annual 7-day low flow; black crosses are the IPO+ive average; orange circles the IPO-ive average; green dots the long-term average. Standard errors for each average MALF estimate are also shown.

An estimate of 7-day MALF has two uses: firstly, to provide a baseline flow against which environmental assessments are carried out; secondly, to provide a basis for the adoption of rules about water allocation under the water plan and to provide guidance for consenting into the future.

The future is uncertain, and specific predictions of future hydrology are even more so, based on work done using global climate models downscaled to NZ and run through rainfall-runoff models (Collins et al. 2018, Collins and Zammit 2016). Additionally, there are no useable predictions of future IPO states, and if there were, the uncertainty of their effect on river flows could not be assessed rigorously.

For all these reasons, the recommended MALF estimate is that from the "all-data 1977-2019" period, of the Arrow mixed model. This estimate is 1730 L/s ± 4-20%. 4% is the standard error of the estimated MALFs for the full record, without including the uncertainty on the individual annual low flow estimates. The standard error of the regression estimation of flows in the Arrow from flows in the Cardona is ~21% at the daily time step. Averaging to obtain 7-day means, and further averaging to obtain a MALF should result in a reduction of this uncertainty. An overall standard error of 12% seems reasonable, giving a MALF range of 1500 to 1900 L/s.

A draft report by Opus (2017) estimates MALF for two recent periods (2013-2017 and 2010-2017) of 1430 and 1510 L/s respectively. They do not provide standard errors. The present study, using water meter data to estimate MALF between 2014 and 2019 (bottom row of Table 4-2), gives a recent MALF estimate of 1450 L/s ±12%, which is consistent with the Opus estimates over a similar time period.

4.3 Extension to Arrow-Kawarau confluence

An estimate of MALF at Cornwall Street can be extended to an estimate at the confluence of the Arrow with the Kawarau. There are three ways in which this could be done:

1. establish a flow recorder at the confluence, and either collect sufficient data to estimate MALF independently (say five years) or use the data to derive a regression between the two sites
2. use simultaneous gauging data at and below the flow recorder to establish a regression relationship with the flow record that can be used to estimate flows at other locations, or
3. use ratios of MALF estimates from national models at the two locations.

In lieu of simultaneous gauging data and recognising the need for estimates in a timely manner the third approach is used.

Table 4-3 shows estimates of MALF at the confluence from two different national models – the physically-based Hydrology of Ungauged Catchments, and the empirically based Random Forest model. These are described in detail in Booker and Woods (2013).

Table 4-3: MALF estimate at the confluence. Hydrology of Ungauged Catchments (HUC - a physically-based method) and Random Forest (RF - a statistically-based method) are used.

	Cornwall Street L/s	Ratio of model to data)	Confluence MALF L/s	MALF Ratio (confluence/recorder)
Arrow hybrid model estimate	1730		**1894**	109%
HUC	370	21%	386	104%
RF	999	58%	1113	111%

The HUC model tends to significantly underestimate MALF in the central Otago region, whereas the Random Forest model provides estimates closer to the data although still on the low side (column 2 of Table 4-3). The ratios of confluence MALF to Cornwall Street MALF are similar (column 5). An adjustment term derived as the ratio of the model to the data (column 3) provides a weighting that is applied to the respective increased MALF estimates (column 5) to produce the estimate of MALF at the confluence of 1900 L/s (row 2, column 4 in bold).

Uncertainty of this estimate can be assumed greater than that for the Cornwall Street estimate, perhaps 15%. Thus, MALF at the confluence is estimated to be between 1600 and 2200L/s.

5 Summary

Naturalised flows for the Arrow River at Cornwall Street are derived, using a mixed model that combines available water meter data with measured river flows over the last six years, and a regression with Cardrona at Mt Barker naturalised flows prior to that, to give a complete series from December 1976 to May 2019.

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6 Acknowledgements

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7 References

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Appendix A Scatter plots of Cardrona vs. Arrow flows

These plots represent the relationship between daily average naturalised flows at Cardona (Mt Barker) and Arrow (Cornwall Street). They show all available data from October 2013 to July 2019. Cardrona flows are as according to four different naturalisation methods as described in Henderson and Collins (2019). Model 8 is the recommended model for adoption.

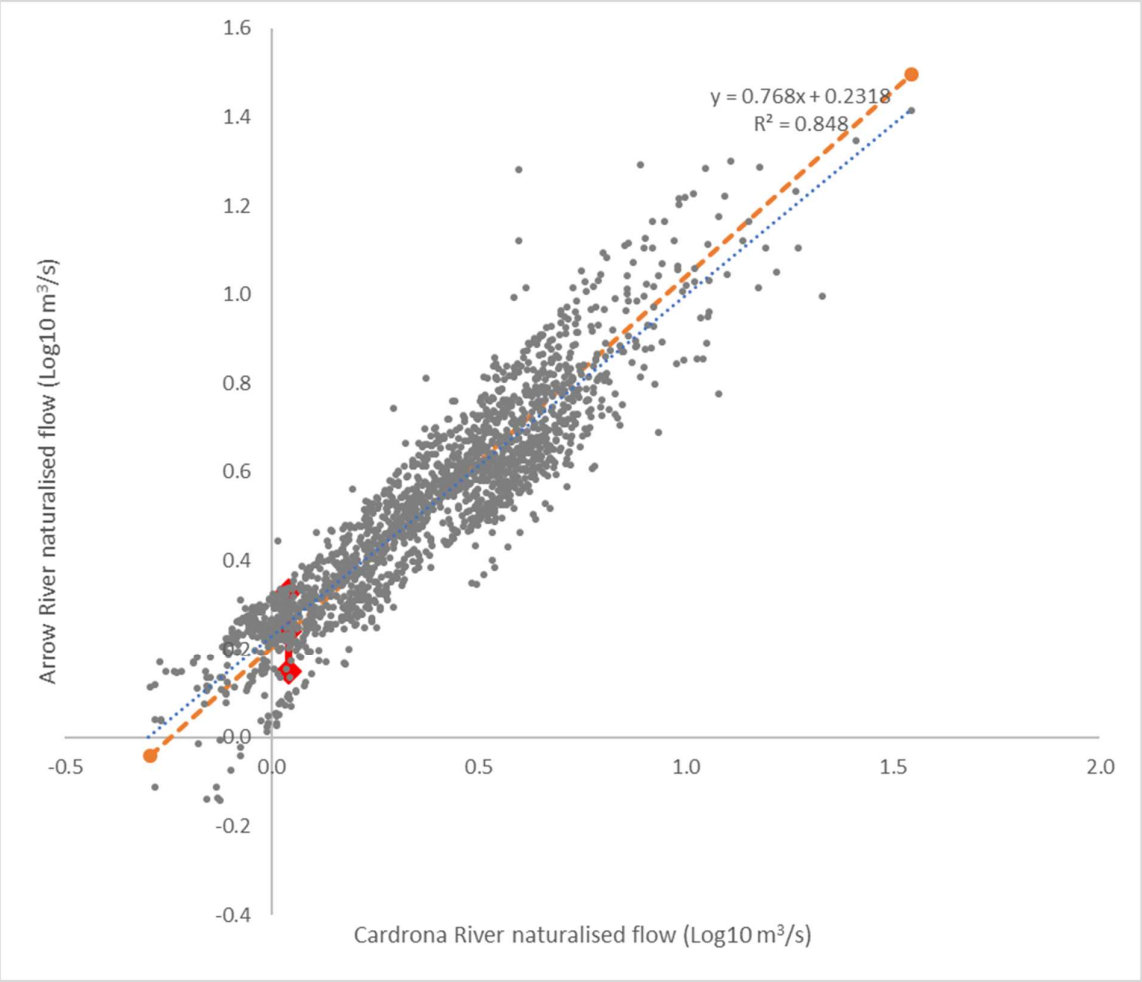

Figure A-1: Model 4 (Observed flow plus the average water use model). Arrow vs Cardrona daily mean naturalised flows 2013 - 2019. Blue dotted line and equation show least squares regression, orange dotted line shows GMR regression. Red points show ±1 se at a Cardrona flow of 1.1 m^3/s.

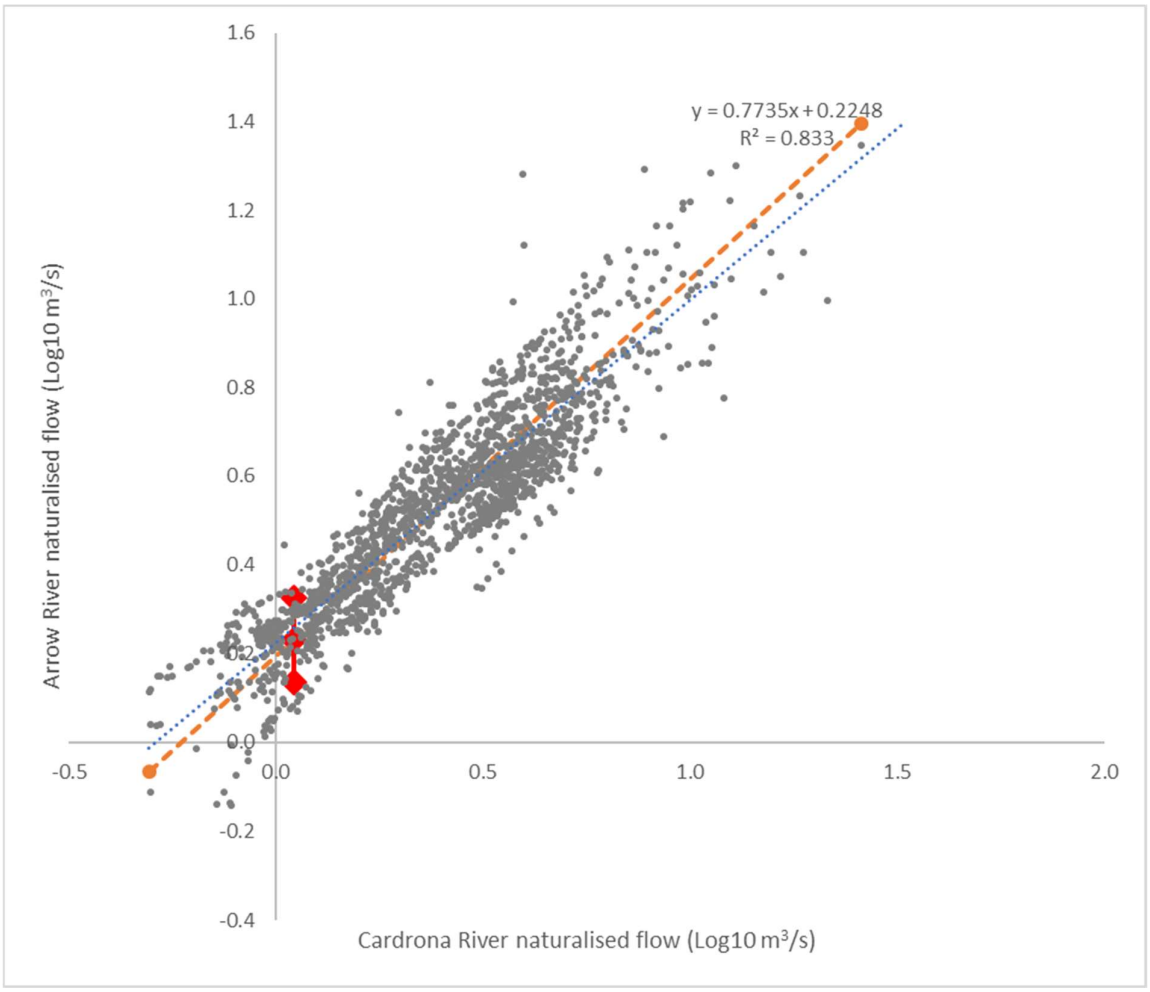

Figure A-2: Model 5 (observed flow plus estimated water use data). Arrow vs Cardrona daily mean naturalised flows 2013 - 2019. Blue dotted line and equation show least squares regression, orange dotted line shows GMR regression. Red points show ±1 se at a Cardrona flow of 1.1 m^3/s.

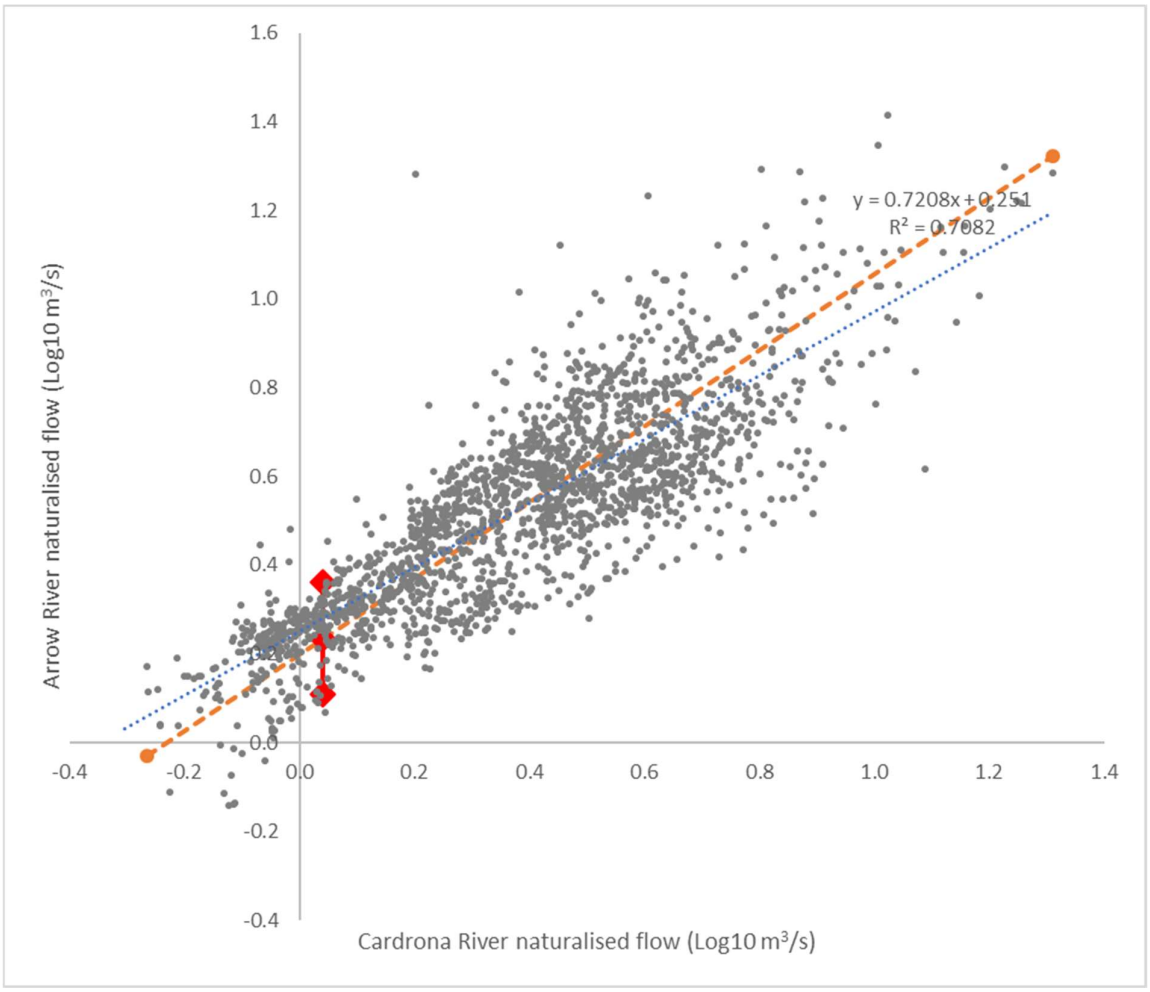

Figure A-3: Model 6 (Mt Barker GMR regression with Lindis. Arrow vs Cardrona daily mean naturalised flows 2013 - 2019. Blue dotted line and equation show least squares regression, orange dotted line shows GMR regression. Red points show ±1 se at a Cardrona flow of 1.1 m^3/s.

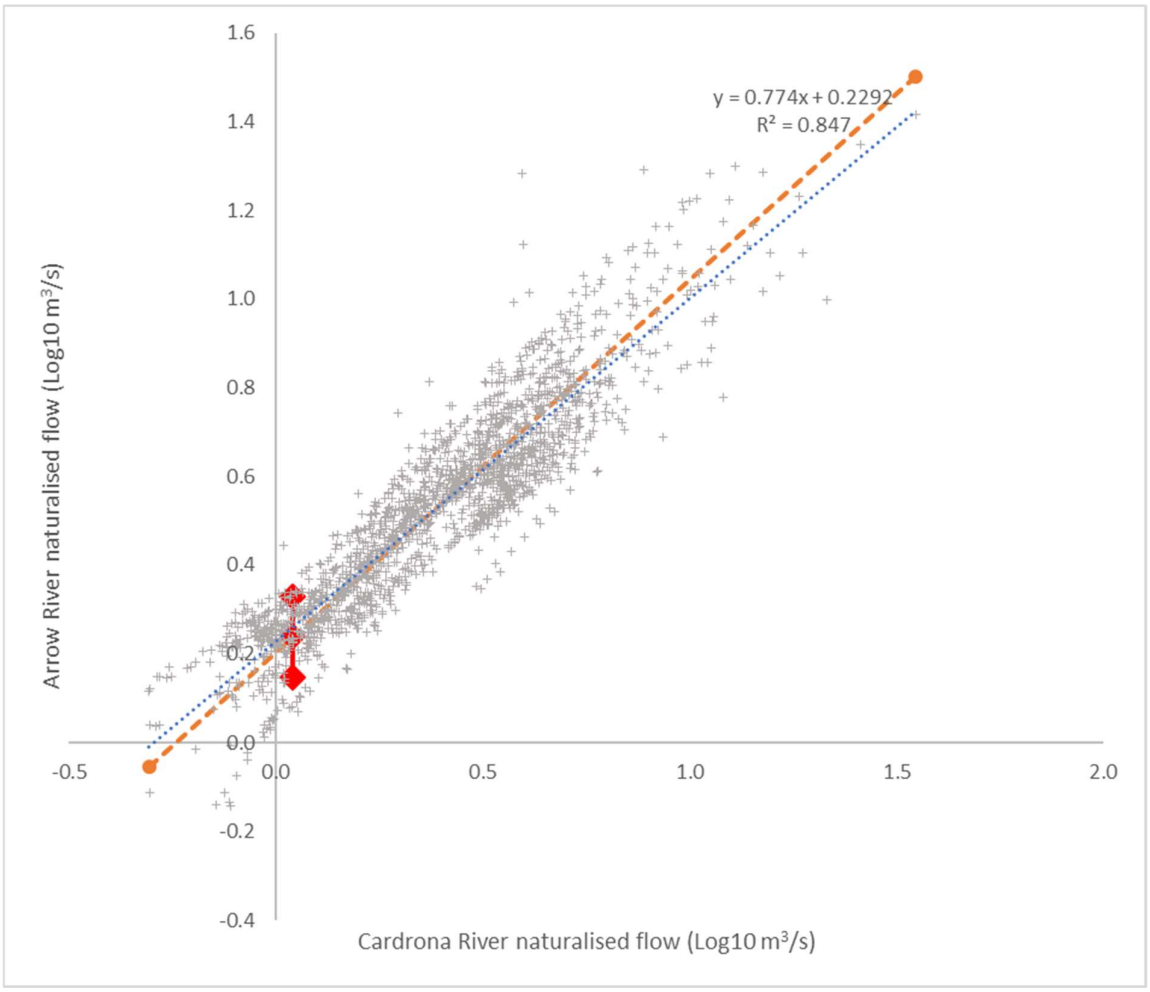

Figure A-4: Model 8 (Hybrid Cardrona model using best available estimates). Arrow vs Cardrona daily mean naturalised flows 2013 - 2019. Blue dotted line and equation show least squares regression, orange dotted line shows GMR regression. Red points show ±1 se at a Cardrona flow of 1.1 m^3/s.