Arrow Catchment

Hydrological Analysis:
to support EIA of proposed minimum flows

Contact Details

Name: Jack McConchie

Opus International Consultants Ltd
Wellington Office
The Majestic Centre, 100 Willis Street
PO Box 12 003, Wellington 6144
New Zealand

Telephone: +64 4 471 7095
Mobile: +64 27 211 5973

Document Details:

Date: December 2017
Reference: 3-53401.00
Status: Final

Prepared by:

Kirsty Duff | Graduate Water Resource Scientist
Lizzie Fox | Water Resource Scientist

Reviewed by:

Dr Jack McConchie | Technical Principal

Approved for release by:

Dr Jack McConchie | Technical Principal

Contents

1 Introduction

The Otago Regional Council (ORC) is preparing to change the provisions in the Regional Plan: Water for Otago (Water Plan) for particular rivers and streams. The Arrow catchment is one such river, where these changes seek to set a primary allocation limit, and a minimum flow. All water permits, both existing and new, will be subject to the minimum flow provision. Existing resource consents to take water will be reviewed, and a new minimum flow condition added to these consents.

At this stage, a range of minimum flows and allocation limits are being considered, and their potential economic impact assessed. The economic assessment requires a detailed hydrological analysis of the flow regime of the Arrow River, and the current abstraction of surface water (and hydraulically-connected groundwater) to support a range of land use practices. This hydrological analysis will help to inform the final decision-making process; and the setting of an 'optimum' allocation limit and minimum flow for the catchment. The final minimum flow and allocation limit will be determined through a community consultation process, and a holistic consideration of their potential environmental, socio-economic, and cultural impacts.

The Arrow River is located in Central Otago, and has a catchment area of 236km^2. The headwaters are in the Harris Mountains and flow in a south-east direction, joining the Kawarau River near Arrowtown. The catchment experiences a typical Central Otago climate; cold winters, followed by warm and dry summers. Steep tussock-covered mountains dominate the upper reaches of the Arrow catchment, with numerous bluffs and areas of exposed bedrock. Further down the catchment, the vegetation changes to exotic grasses and shrublands, reflecting the change in land use within the lower reaches. Here, agriculture dominates the landscape, with sheep and beef comprising the largest land use sector i.e. 54%.

Otago Regional Council have published two reports summarising the flow regime of the Arrow River (ORC, 2012 & 2017). Two different approaches have been adopted to characterise the flow regime. Since the approach in ORC (2012) was constrained by the lack of available data and information, the work was updated using additional data, and a revised methodology, in ORC (2017).

These approaches are discussed, together with the present hydrological analysis, in this report. Analysis of all the available information regarding flows, and the abstraction of water, in the Arrow catchment will allow the impacts of any proposed changes to the Regional Plan to be assessed, and where possible quantified.

2 Hydrology

2.1 Available flow series

There is currently one flow recorder on the Arrow River; Arrow River at Cornwall Street (Figure 2.1). This recorder was installed in December 2010, and therefore provides a flow series for only the past 7 years. This short flow record acts as a significant constraint on the robustness of any hydrological analysis, particularly when the flows, and therefore any analysis and results, might be affected by longer term trends or cyclic behaviour. A range of approaches have been considered with regard to extending this flow record; however, all are affected either by variable and modified flow regimes, or differences in rainfall-runoff relationships. Consequently, the short empirical data set from the Arrow River at Cornwall Street provides the best means of characterising the flow regime of the catchment. The constraint of using a short flow series, however, must be recognised when considering the implications of the various findings presented in this report.

There was a previous flow recorder in the catchment, operated by the Ministry of Works and Development, from April 1981 to January 1994. The use of these data, however, is considered problematic by ORC as there are no water use or abstraction information for the same period. It is therefore not possible to derive a naturalised flow series from these data. Consequently, ORC believe that it is not appropriate to use these data to derive representative flow statistics for the naturalised flow regime of the Arrow River.

ORC have synthesized a naturalised flow series for the Arrow River at Cornwall Street flow site, based on available consent data, from 2013 to the present. This naturalised flow series represents the best approximation available of the flow regime of the Arrow River if there were no water abstractions within the catchment. This naturalised record, however, is of only 4 years duration, and based on a range of assumptions detailed in ORC (2017).

There is also a flow recorder in the adjacent Cardrona catchment at Mt Barker. This recorder has been operating *"on and off"* since December 1976; providing a flow record spanning 41 years, although there is a gap in the record of 13 years. There are a number of differences between the rainfall-runoff relationships in the Arrow and Cardrona catchments, and the changes in land use and water abstraction over time. Consequently, ORC consider that the inherent uncertainty in any relationship between flows in the two catchments precludes the use of the flow record for the Cardrona River to model flows in the Arrow catchment. The longer term flow regime of the Cardrona, however, is considered useful for placing the 7-year flow record from the Arrow River in the wider context of climatic and flow variability.

The available flow series in the area are therefore summarised in Table 2.1, with the daily mean flow statistics displayed in Table 2.2. For each of the flow series, the distribution of mean daily flows were also derived (Table 2.3 & Table 2.4) to further characterise the flow regime.

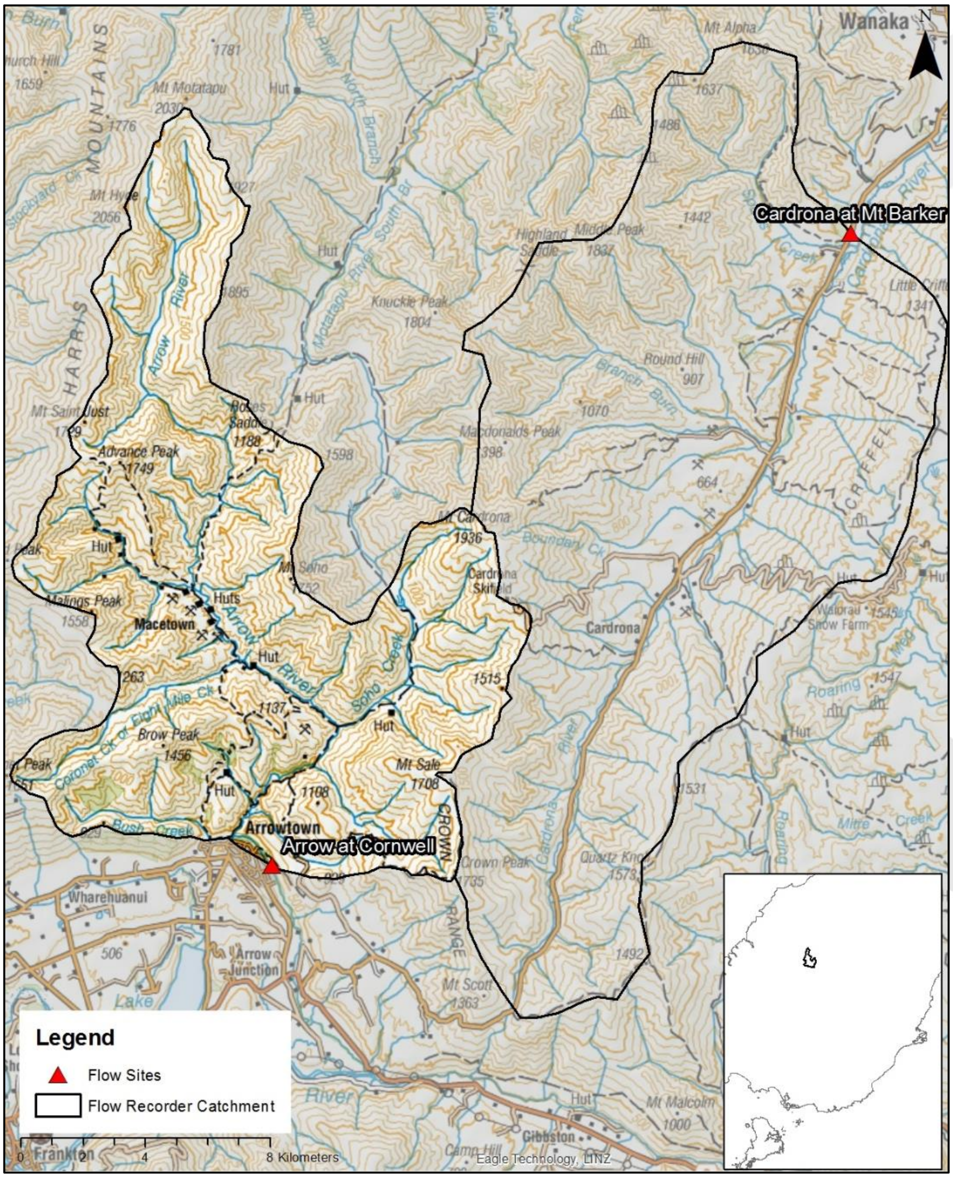

Figure 2.1: The Arrow and Cardrona catchments upstream of their respective flow monitoring sites. It should be noted that the Arrow catchment extends south to the Kawarau River and includes the hydraulically-connected aquifers.

Table 2.1: Summary of available flow records in the Arrow and Cardrona catchments.

Site	Start Date	End Date	Record length (yrs.)	Resolution	Missing record
Arrow River at Cornwall Street	Dec 2010	May 2017	7	15 minutes	4.7 months
Arrow River at Cornwall Street – 'Naturalised'	Oct 2013	May 2017	4	Daily	4.6 months
Cardrona River at Mt Barker	Dec 1976	Sep 2017	41	15 minutes	13.7 years

Table 2.2: Mean daily flow statistics (m^3/s) for the Arrow catchment.

Site	Minimum	Mean	Median	Maximum	Lower Quartile	Upper Quartile
Arrow River at Cornwall Street	0.6	3.5	2.8	63.1	1.8	4.3
Arrow River at Cornwall Street – 'Naturalised'	0.7	3.7	3.3	26.0	2.0	4.5

Table 2.3: Distribution of mean daily flows (m^3/s) in the Arrow River at Cornwall Street (2010-2017).

	0	1	2	3	4	5	6	7	8	9
0	63.1	14.1	10.6	9.2	8.4	7.7	7.1	6.8	6.5	6.3
10	6.1	5.9	5.8	5.6	5.5	5.3	5.2	5.1	5.0	4.9
20	4.8	4.7	4.6	4.5	4.4	4.3	4.3	4.2	4.2	4.1
30	4.1	4.0	3.9	3.9	3.8	3.7	3.7	3.6	3.5	3.4
40	3.4	3.3	3.3	3.2	3.2	3.1	3.1	3.0	2.9	2.9
50	2.8	2.8	2.7	2.7	2.6	2.5	2.5	2.5	2.4	2.4
60	2.4	2.3	2.3	2.3	2.2	2.2	2.1	2.1	2.1	2.0
70	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.6	1.6
80	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2
90	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.8
100	0.6									

Table 2.4: Distribution of 'naturalized' mean daily flows (m^3/s) in the Arrow River at Cornwall Street (2013-2017).

	0	1	2	3	4	5	6	7	8	9
0	26.0	12.1	9.9	9.0	8.1	7.3	6.9	6.7	6.5	6.2
10	6.1	6.0	5.8	5.7	5.5	5.4	5.3	5.2	5.1	5.0
20	4.9	4.8	4.7	4.6	4.6	4.5	4.5	4.4	4.3	4.3
30	4.2	4.2	4.1	4.1	4.0	4.0	4.0	3.9	3.9	3.8
40	3.8	3.7	3.7	3.6	3.6	3.5	3.5	3.4	3.4	3.4
50	3.3	3.3	3.2	3.2	3.1	3.1	3.1	3.0	2.9	2.9
60	2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.2
70	2.1	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.9
80	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7
90	1.7	1.6	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1
100	0.7									

ORC (2017), and the data upon which it is based, was peer reviewed by NIWA. The authors of this report have undertaken no further verification, independent audit, or quality assurance of these data. However, since the data have been collected, processed, and archived according to 'industry best practice', they have been assumed accurate. Where appropriate, any constraints inherent in the data have been discussed, together with their potential implications for the results and conclusions.

2.2 Arrow River flow record in context

As mentioned, the short flow record available for the Arrow River, and even shorter 'naturalised record', acts as a significant constraint on the robustness of any hydrological analysis. It is possible that the short record may coincide with atypical conditions; resulting in bias, and the skewing of any results.

This is particularly problematic as the flow record for the Arrow River includes 2016, which was an 'extremely dry' summer according to the New Zealand Drought Index (NIWA, 2017). Therefore, analysis of this record may result in conservatively low flow conditions i.e. lower than average. This would result in apparent restrictions on the abstraction of water which are greater than may occur over the longer term. This kind of bias, however, is preferable to that which would result in greater than average flows, and therefore less restrictions on abstraction.

To place the recent flow series for the Arrow River at Cornwall Street in a wider temporal context, a longer term synthetic flow series was derived using the flow record from the Cardrona River at Mt Barker. As mentioned, such an approach is problematic and contains considerable uncertainty, but it does allow the relatively short and recent flow series from the Arrow River to be placed in the context of wider variability of catchment-scale drivers of runoff. At a general level, the similarity of runoff in the two catchments is confirmed by the similarity of mean daily flows recorded in the two rivers (Figure 2.2).

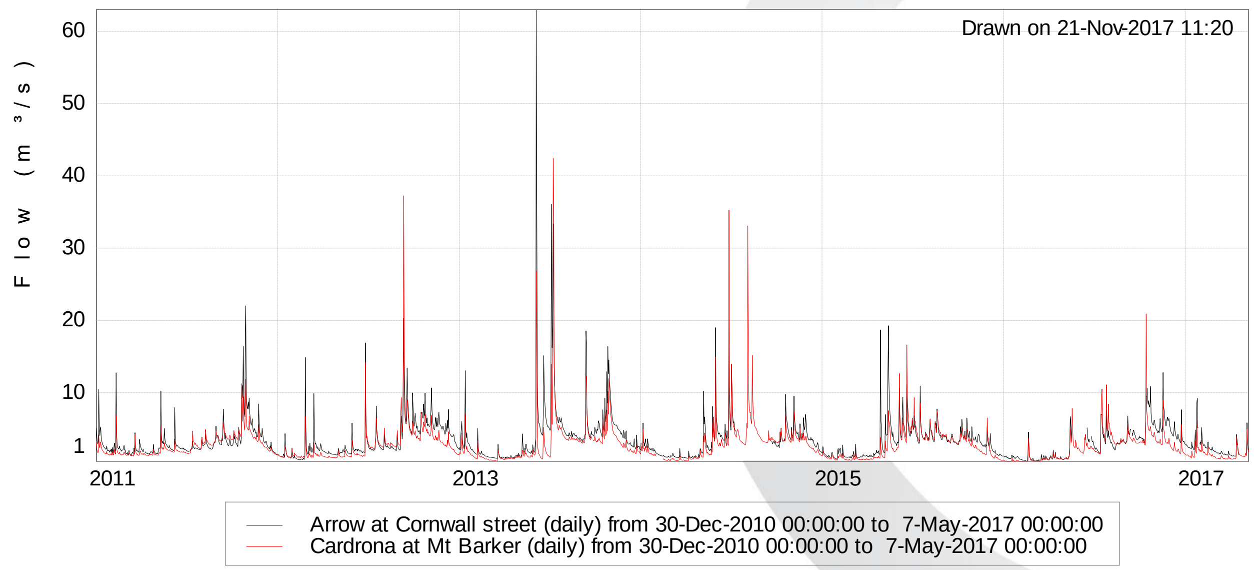

Figure 2.2: Daily mean flows in the Arrow River at Cornwall Street and the Cardrona River at Mt Barker.

Regression analysis of the mean daily flows at the two sites was used to generate an extended flow series for the Arrow River at Cornwall Street. To obtain the most robust relationship, and therefore ensure that the derived synthetic flows are representative of the Cornwall site, the data for the overlapping period i.e. 2010 to 2017, were divided into two periods; November to end of March, and June to end of October.

The 6 years of overlapping data demonstrate the seasonal trend observed in the catchments. Snowfall and subsequent snow melt results in a different pattern of runoff during winter and spring compared to drier summer and autumn conditions when baseflow and rainfall-runoff dominate. Figure 2.3 and Figure 2.4 show the regression analyses between the two sites for the different seasonal periods is strong; the drier months have an r^2 of 0.89, and the wetter months an r^2 of 0.75.

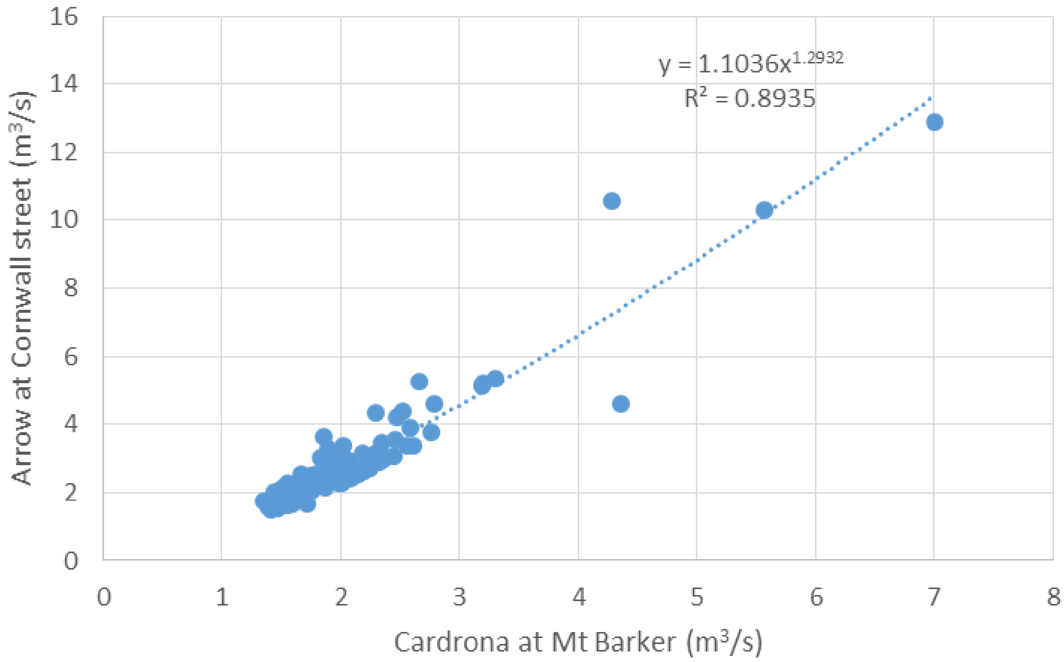

Figure 2.3: Regression analysis of Cardrona River at Mt Barker and Arrow River at Cornwall Street (2010-2017) for November through March.

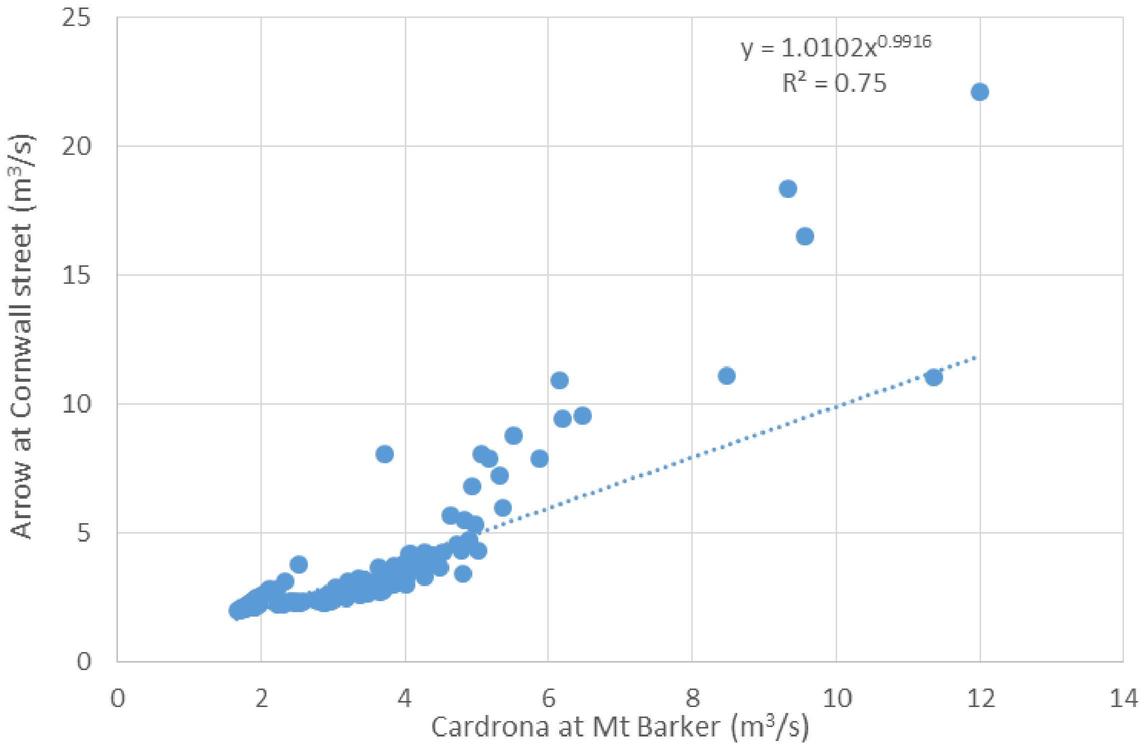

Figure 2.4: Regression analysis of Cardrona River at Mt Barker and Arrow River at Cornwall Street (2010-2017) for June through October.

The high r^2 value of 0.89 indicates that approximately 90% of the mean daily flows in the Arrow River during 'summer' can be explained by variation in the mean daily flow in the Cardrona River (Figure 2.3). The relationship between flows at the two sites appears stronger over the low flow range than at higher flows. The greater variability over the higher flows is likely the result of differences in the characteristics of precipitation and runoff within the two catchments.

This synthetic record derived for the Arrow River was compared to the actual measured flows in the Arrow River at Cornwall Street to verify the appropriateness of the synthesized data for placing runoff over the past few years in context (Figure 2.5). The synthetic flows closely follow the low flows in the Arrow at Cornwall Street; although some of the higher flows are over-estimated. As this study is focused on low flow conditions, the derived data are considered suitable, at a general level, for extending the Cornwall Street record from 2010 back to 1976 (Figure 2.6). It should be noted that this is only done so that the recent period of high resolution data can be placed in context of longer term variability. There is too much uncertainty in the relationship, even at low flows, to model flows in the Arrow catchment accurately. This uncertainty is compounded by varying rates of land use change and water abstraction within the two catchments over time. The summary statistics for this extended record are displayed in Table 2.5.

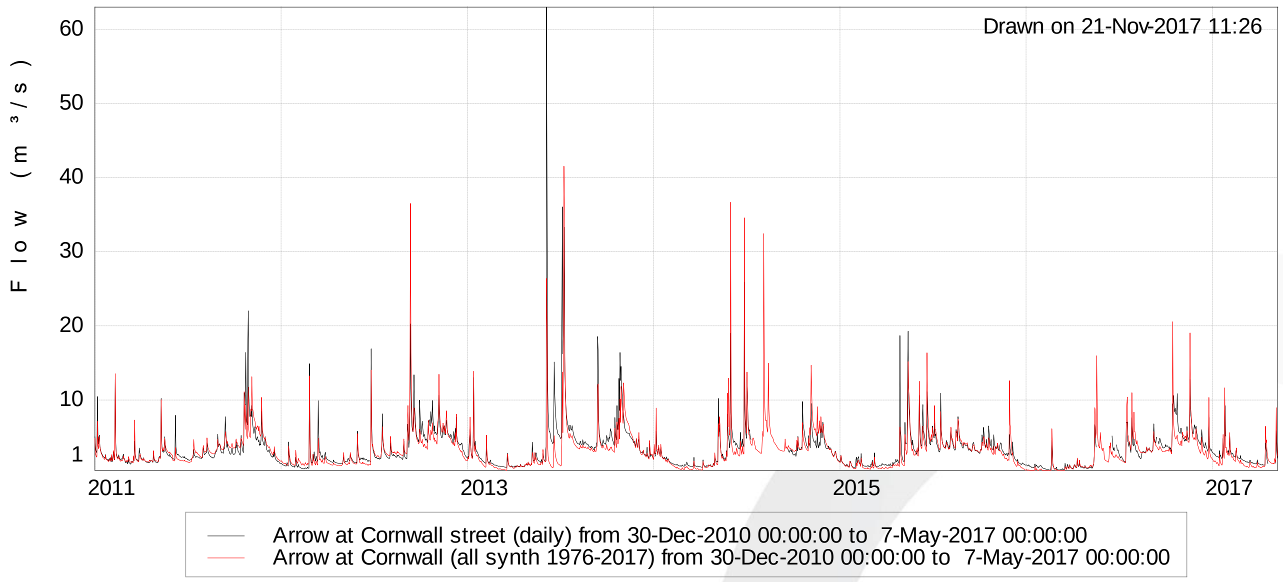

Figure 2.5: Comparison of the synthesised Arrow River at Cornwall Street to the measured data over the period of concurrent record (2010-2017).

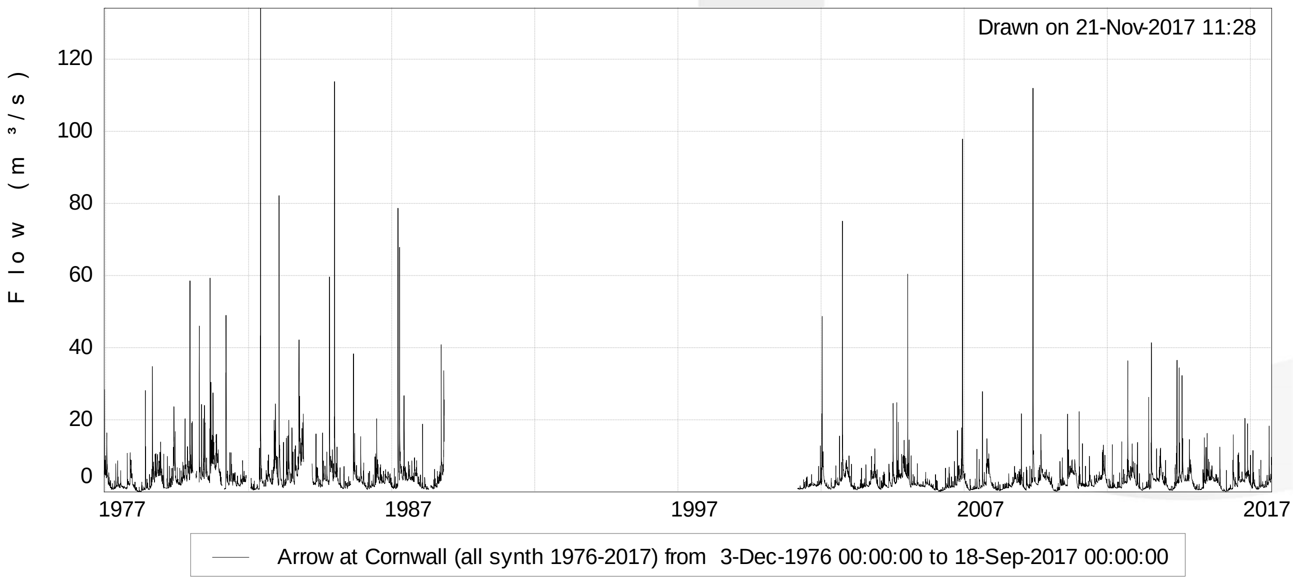

Figure 2.6: Extended Arrow River at Cornwall Street record. Measured data from 2010 to 2017; synthesized from 1976 to 2010.

Table 2.5: Summary statistics (m³/s) of Extended Arrow River at Cornwall Street flow series (1976-2017).

Site	Minimum	Mean	Median	Maximum	Lower Quartile	Upper Quartile
Extended Arrow River at Cornwall Street	0.243	3.85	2.77	134.4	1.75	4.63
Arrow River at Cornwall Street	0.63	3.48	3.48	63.09	1.75	4.34

Assuming that the extended mean daily flow series for the Arrow River provides a realistic approximation of the actual flow regime, for the purpose of placing the past 7 years into a wider context of climatic variability, the following conclusions are possible:

- The recorded flow series for the Arrow River at Cornwall Street since 2010 is consistent with the longer term flow regime, particularly with respect to the low flow regime;
- The last four years would appear to have been drier than average, with generally lower flows. This is consistent with other climate indices e.g. the drought index, which show that the past few years have been 'dry', particularly the period from October 2015 through to April 2016; and
- Any analysis based on the past few years is likely to be 'conservative', reflecting drier than average conditions.

Overall, it is likely that the past few years have been drier than 'average' within the Arrow catchment. This is likely to be reflected in lower than average flows, longer periods of low flows, and an increased demand for irrigation to offset any moisture deficit. Therefore, it is possible that these data reflect a 'bad case' scenario with respect to both water supply and water demand. This means that the use of these data in an analysis of the potential impact of a minimum flow regime is likely to be conservative, rather than optimistic i.e. the water supply is potentially slightly 'better' than indicated by this analysis.

2.3 Naturalised flow series

The current flow regime of the Arrow River is affected by spatially and temporally discontinuous abstractions. Therefore, fundamental to any assessment of the likely impact of establishing a minimum flow regime, and a primary abstraction limit, is the development of a robust 'naturalised' flow series for the Arrow River. A naturalised flow series represents what the flow of the river would have been without any abstractions.

Currently, there are 22 surface water takes, or groundwater takes hydraulically-connected to the surface water, in the Arrow River catchment. The total potential allocation of these water permits is 2.03m³/s. However, on average, it is estimated that only about 0.55m³/s of water is actually abstracted, with measured usage not exceeding 1m³/s (ORC, 2017). Three of these surface takes are upstream of the flow recorder at Cornwall Street.

Since a water take time series above Cornwall Street is available, the flow at this site can be naturalised by totalling the actual flow and all consumptive water takes upstream i.e. Naturalised flows in the Arrow at Cornwall Street = Actual flows measured in the Arrow at Cornwall Street + all the consumptive water takes above this flow site. However, measured water abstraction data for the three consents which are upstream only exist for two years (ORC, 2017). This is because the data for the third consent i.e. Consent No. 95696, only exists from 2015-2017. This period of the naturalised record is denoted ORC^1.

By examining the available water take data for Consent No. 95696, the maximum daily average rate of take is 23.8L/s. This is well below the consented allocation limit of 83.33L/s. To expand the length of the estimated naturalised flow series, the daily average rate of take for Consent No. 95696 between 2013-2015 can be assumed to vary from zero (the lower limit) to 20L/s (the upper limit). Based on this assumption, it was possible to synthesise an additional two years of data i.e. to extend the record from Consent No. 95696 so that it is consistent with that from WR1440AR; the next shortest abstraction record. This period of the naturalised record is denoted ORC^2.

Therefore, using the available consent information, ORC derived a naturalised flow series for the Arrow River at Cornwall Street for the period from 2013 to 2017 (Figure 2.7).

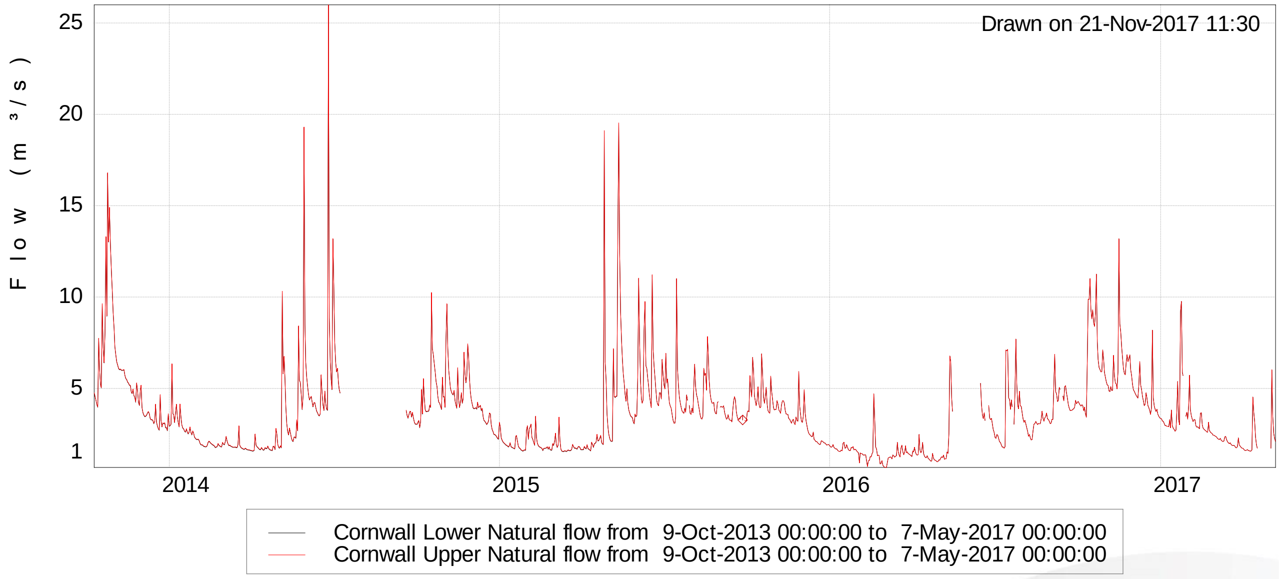

Figure 2.7: Naturalised flow series created by Otago Regional Council (ORC) (2013-2017).

Generally, a 4-year record would be considered too short for detailed analysis, and to provide robust results regarding the flow regime of a river. This issue is compounded in the current situation because approximately half of the 4-year record has been ‘estimated’ rather than measured; albeit by ±20L/s which is a relatively small amount of water. Since this is the total length of data available, some caution is required when applying the results to longer term management decisions.

However, as discussed above, some of this uncertainty is offset by the period of available record coinciding with lower than average flows, and potentially higher than average demand for, and therefore abstraction of, water.

In an attempt to provide more robust results, and to allow more confidence to be placed in the various statistics, the short naturalised flow record provided was extended back to 2010 i.e. an additional 3 years. The record could not be extended any further back because of the lack of abstraction data prior to 2010; i.e. abstraction before 2010 is unknown.

An extended naturalised Cornwall Street flow series was derived from the relationship between the measured flows and the calculated naturalised flow from 2013 to 2017. There is a very strong linear relationship, where over 99% of the variation in the naturalised flow can be explained by variation in the measured flow i.e. r^2 of 0.99 (Figure 2.8). This is not surprising given the relatively small volume of abstraction relative to the flow in the Arrow River. The extended naturalised flow record (2010-17) is shown in Figure 2.9. The period of the naturalised record from 2010-2013 is denoted Opus[1]. The summary statistics are compared with both the ORC[1] measured (2015-17) and ORC[2] derived naturalised (2013-17) flow statistics in Table 2.6.

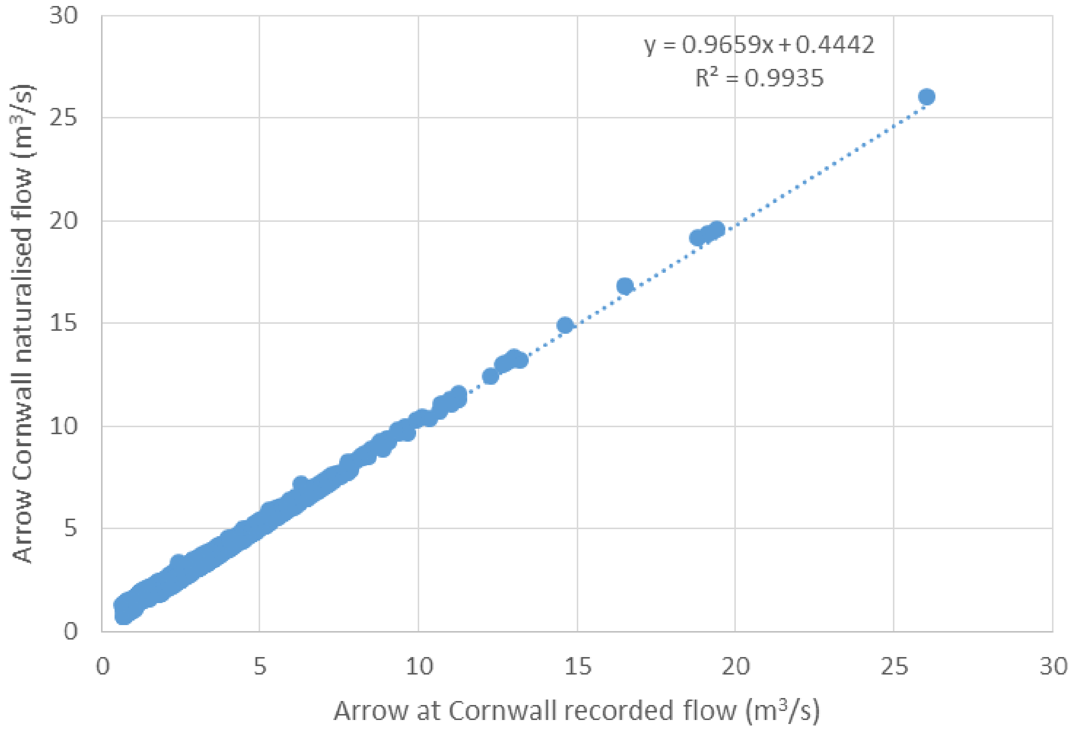

Figure 2.8: *Regression analysis of the naturalised and the measured Arrow River at Cornwall Street flow series (2013-2017).*

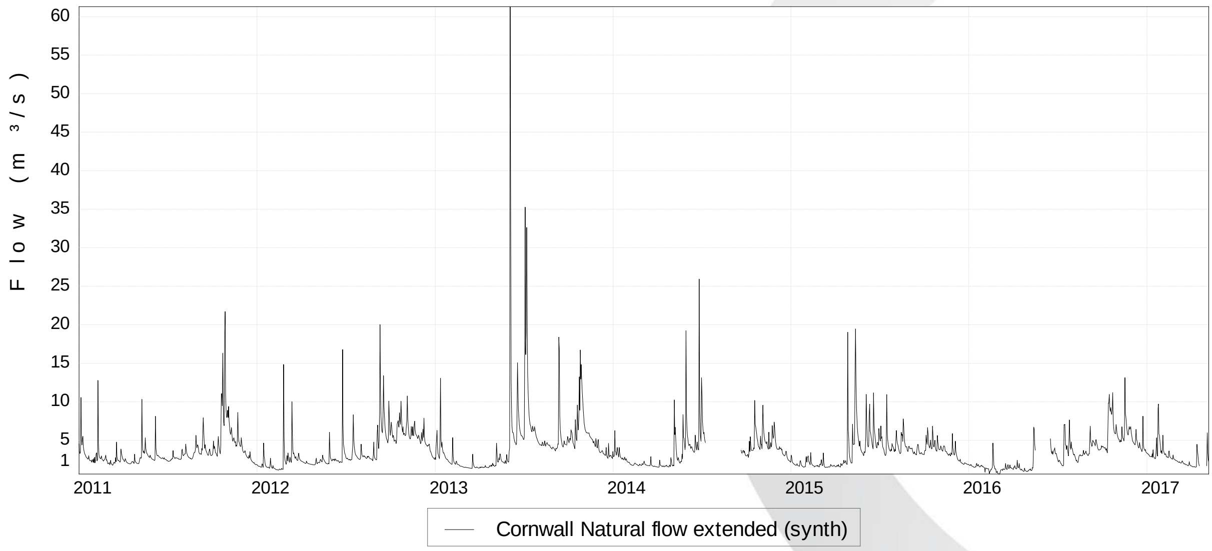

Figure 2.9: *Extended naturalised Arrow River at Cornwall Street flow record (2010-2017).*

Table 2.6: *Summary statistics of the daily naturalised Arrow River at Cornwall Street flow series and the extended naturalised Arrow River flow series (m³/s).*

Site	Minimum	Mean	Median	Maximum	Lower Quartile	Upper Quartile
ORC[1] actual 'measured' naturalised Arrow River (2015-17)	0.72	3.45	3.22	19.56	1.86	4.34
ORC[2] naturalised Arrow River (2013-17)	0.72	3.66	3.32	26.04	1.96	4.52
Opus[1] extended naturalised Arrow River (2010-17)	0.72	3.81	3.17	61.39	2.16	4.59

These naturalised flow series again highlight the fact that 2015-16 was an extremely dry irrigation season, and that the last 4 years have been, on average, drier than usual. This is reflected in the lower values of all indices determined for the period 2015-2016 compared to the other periods. Also, the mean and upper and lower quartiles over the past 4 years are lower when compared to those of the slightly extended record. The median flow, however, has been slightly higher over the past 4 years. The use of the 4-year record i.e. that provided by ORC is therefore likely to provide slightly conservative results, even when compared to the marginally longer record i.e. 2010-2017.

2.4 Number of days below minimum flow threshold

The Otago Regional Council (ORC) is preparing to change the provisions in the Regional Plan: Water for Otago (Water Plan) for the Arrow catchment. Three possible minimum flow thresholds have been proposed:

- A minimum flow of 800L/s recorded at Arrow River at Cornwall Street flow recorder, with a supplementary minimum flow of 1050L/s, and associated allocation block of 250L/s;
- A minimum flow of 900L/s recorded at Arrow River at Cornwall Street flow recorder, with a supplementary minimum flow of 1150L/s, and associated allocation block of 250L/s; or
- A minimum flow of 1000L/s as recorded at Arrow River at Cornwall Street flow recorder, with a supplementary minimum flow of 1250L/s, and associated allocation block of 250L/s.

Using the naturalised flow series for the Arrow River at Cornwall Street, it is possible to determine the number of days when the mean flow has been below each of the three proposed minimum flow thresholds. Table 2.7 compares the number of days, and the longest period of consecutive days, that the mean daily flow is less than a particular minimum flow.

Table 2.7: Summary of the number of days when flow drops below a particular minimum flow threshold.

Site	Minimum flow					
	800L/s		900L/s		1000L/s	
	No. of days	Longest 'run'	No. of days	Longest 'run'	No. of days	Longest 'run'
ORC[1&2] naturalised Arrow River (2013-17)	5	4	6	5	10	6
Opus[1] extended naturalised Arrow River (2010-17)	5	4	6	5	10	6

As expected, the higher the minimum flow, the greater the number of days, and the longer the period of consecutive days, that flow drops below a particular threshold. The mean daily naturalised flow has only dropped below 800L/s on four occasions over the past 7 years; with each of these days actually occurring over the past 4 years. These low flows also occurred consecutively, exacerbating any potential environmental effects.

A minimum flow of 900L/s increases the number of days below this threshold, although the longest consecutive period does not increase as significantly i.e. some of the additional days are 'isolated' occurrences. This is also true when the minimum flow is increased to 1000L/s. While the number of days with flows below the threshold doubles, from that with a minimum flow of 800L/s, the longest period of consecutive days only increases by 50% i.e. from 4 to 6 days.

3 Irrigation

3.1 Land use

Much of the irrigated land within the wider Arrow catchment is located around Arrowtown (Figure 3.1). The main land uses are sheep and beef farming, with the area above the Cornwall Street flow recorder being identified as un-irrigated sheep and beef farming (AgriBase, 2016).

Table 3.1: Land use within the wider Arrow catchment (AgriBase, 2016).

Land use type	Area (ha)	Percent of Arrow catchment
Sheep and beef	14122	55
Beef	6214	24
Sheep	1627	6
Deer	1232	5
NOF	1052	4
Life Style block	865	3
Grass	319	1
Other	89	0
Arable	75	0
TOTAL	256	98

3.2 Irrigation demand

Aqualinc (2017) provides the water requirements for all potentially irrigable areas in Otago. Irrigation demand is based on the amount of water needed to irrigate efficiently a range of crops under different climatic and soil conditions. The key inputs to the analysis were the location of the demand areas, climate from 1972 to 2014 (daily rainfall and evapotranspiration), soil type (plant available water), crop type (root depth and crop factors), the characteristics of the irrigation system, and the management regime. Daily time series of irrigation demand were developed for each soil class in the different zones. Irrigation demand can then be compared to the available water supply to determine periods and amounts of water excess or shortfall. This information was intended to be used for strategic water studies, and water allocation purposes.

Soils' information was obtained from the New Zealand Fundamental Soils Layer provided by Landcare Research (Newsome *et al.*, 2008). The Profile Available Water (i.e. PAW) was obtained for all soils with similar hydraulic properties (Table 3.2).

Table 3.2: Plant available water (PAW) of the irrigated areas in the Arrow catchment, along with their irrigation demand and rate calculated using Aqualinc (2017).

PAW	Consented irrigation blocks (ha)	Percent	Average annual demand (mm/yr.)	Max annual demand (mm/yr.)	Average irrigation rate (L/s)	Max irrigation rate (L/s)
45	1088	38%	579	821	405	574
60	2	0%	552	785	1	1
90	25	1%	508	771	8	12
155	1735	61%	427	679	476	758
				TOTAL	890	1345

The PAW of the various irrigated soils within the Arrow catchment was therefore mapped, and assigned to the classes developed in Aqualinc (2017). The relevant PAW classes are 45mm, 60mm, 90mm and 155mm. There are no soils with a PAW of 200mm in the Arrow catchment (Figure 3.2). The areas of soils in each PAW class, which affects both the irrigation depth and the inter-cycle period, within the irrigable area are summarised in Table 3.2.

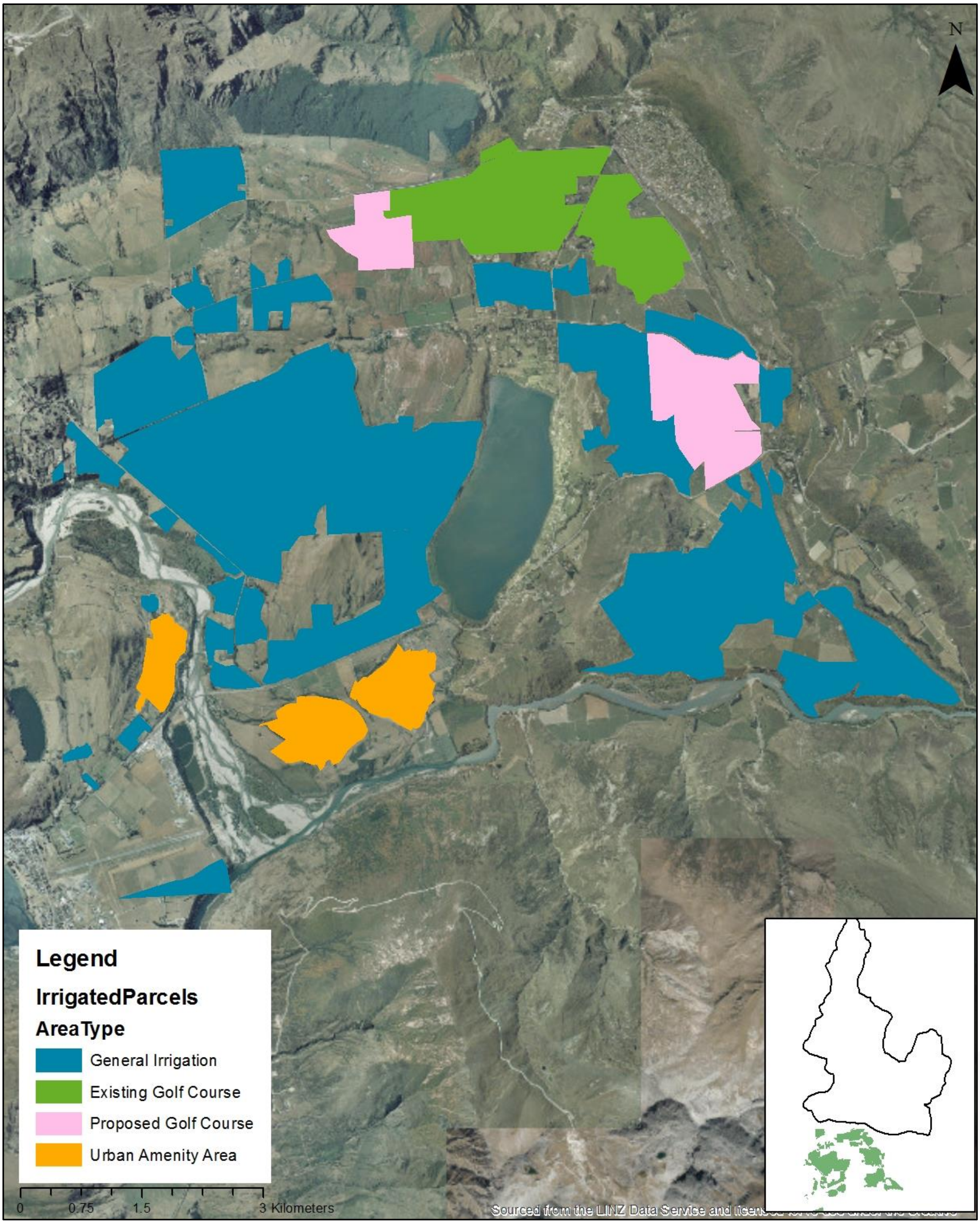

Figure 3.1: Irrigation within the wider Arrow catchment (Data supplied by ORC, 2017).

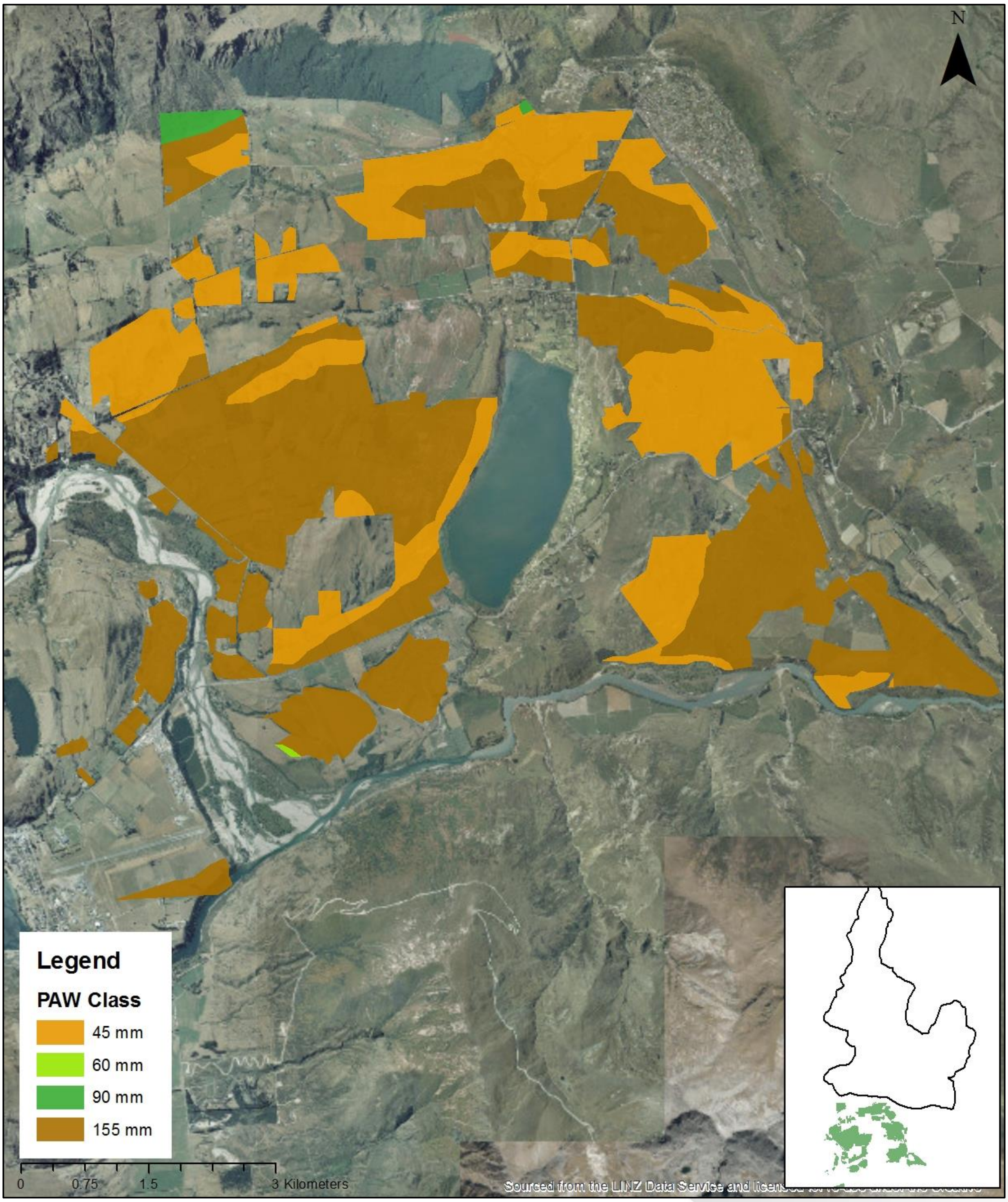

Figure 3.2: Soil PAW throughout the irrigable area (Newsome et al., 2008 – Fundamental Soil Data).

To irrigate the total irrigable area efficiently, as defined by Aqualinc (2017), over the irrigation season (i.e. October-April), would require a maximum rate of abstraction of approximately 1,350L/s (Table 3.2). This is less than the current allocation of the three consents above the Cornwall Street flow recorder; with a combined allocation of 1,580L/s. It should be noted, however, that not all of the current allocation is actually used. It is also likely that not all the land which is potentially irrigable is actually irrigated; at least not at present.

Using a water balance approach, Aqualinc (2017) modelled daily irrigation requirements (mm/day) for each soil PAW within the Arrow catchment. Modelled results are only available from the June 1972 to April 2014. The maximum daily irrigation demand for soils of various PAW classes in the Arrow catchment is presented in Table 3.3.

Table 3.3: Irrigation demand for Otago modelled by Aqualinc (2017).

	Grapes	Pasture
Soil PAW	Maximum irrigation demand (mm/day)	Maximum irrigation demand (mm/day)
PAW 40	2.44	5.2
PAW 60	2.44	4.4
PAW 90	2.44	4.0
PAW 120	4.89	-

3.3 Water permits

There are 13 water permits for irrigation of the lower areas of the Arrow catchment, with a total allocation of 2030L/s (Table 3.4). Although these consents specify the maximum allocation, the actual abstraction is significantly less than this amount. Using data from the various water meters, the actual abstraction varies temporally, monthly, seasonally and annually. The maximum average monthly metered abstraction has been just over 700L/s; while the maximum instantaneous abstraction is reported to have never exceeded about 1m³/s. The difference between the maximum and minimum average monthly abstraction can be up to 250L/s e.g. March (Figure 3.3). It would appear that the maximum average monthly abstraction has not exceeded about 35% of the average monthly allocation (Figure 3.4). This is consistent with findings of other studies which have investigated the difference between allocation and abstraction in other areas of New Zealand. For comparison, the average average monthly abstraction, which is up to 164L/s less than the maximum average monthly abstraction, has also been used in the subsequent analysis of the potential impact of minimum flow thresholds on periods when abstraction may be restricted in some manner.

Table 3.4: Summary of surface and groundwater consented abstraction within the Arrow catchment.

Consent number	Consented take (L/s)	Length (year)	Gap (days)	Completion (%)
2007.049	108	7.160	90	97
WR1440AR	1389	3.617	0	100
RM15.027.01	6.04	7.190	0	100
RM14.364.01 & 96285	69.5	1.372	0	100
97029	55.6	3.606	0	100
3073B	111.1	3.617	0	100
98457 & 2000.263	27.76	1.043	0	100
98120	30.55	2.746	0	100
96265	27.77	3.491	0	100
97402	83.33	3.296	0	100
96264 & 2006.256	25.9	3.406	0	100
95696	83.33	2.196	0	100
2000.361	6.36	1.002	0	100
Extra	5.96			
Total	2030.2 (L/s)			

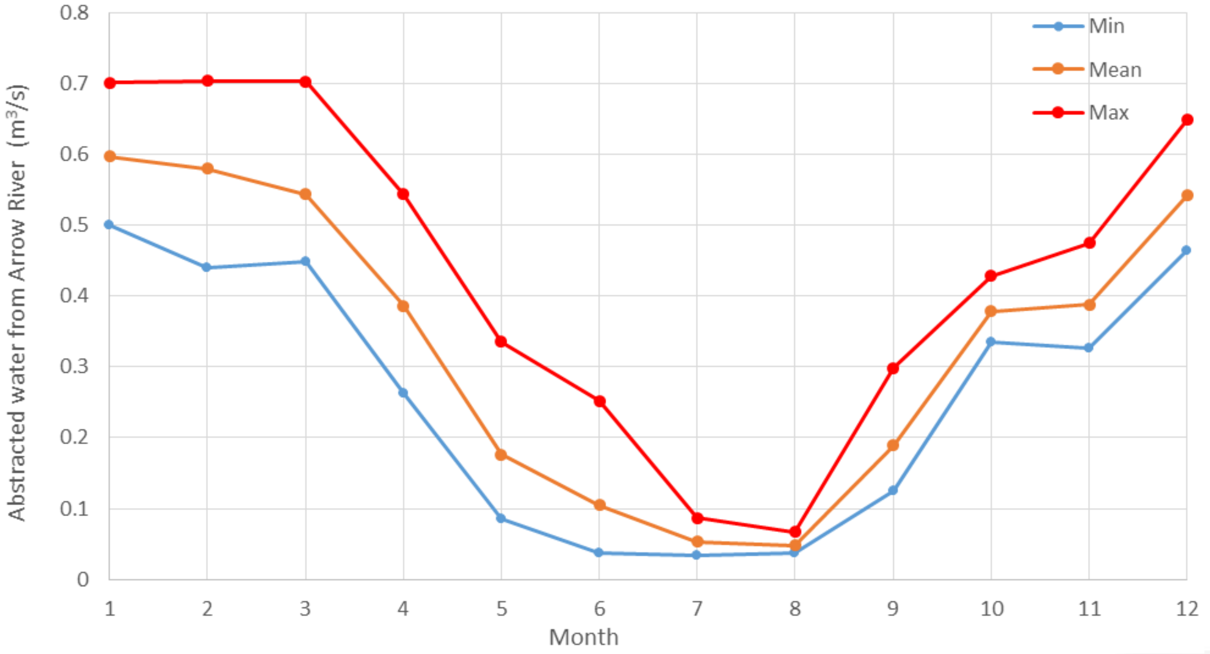

Figure 3.3: *Monthly abstraction from the Arrow catchment.*

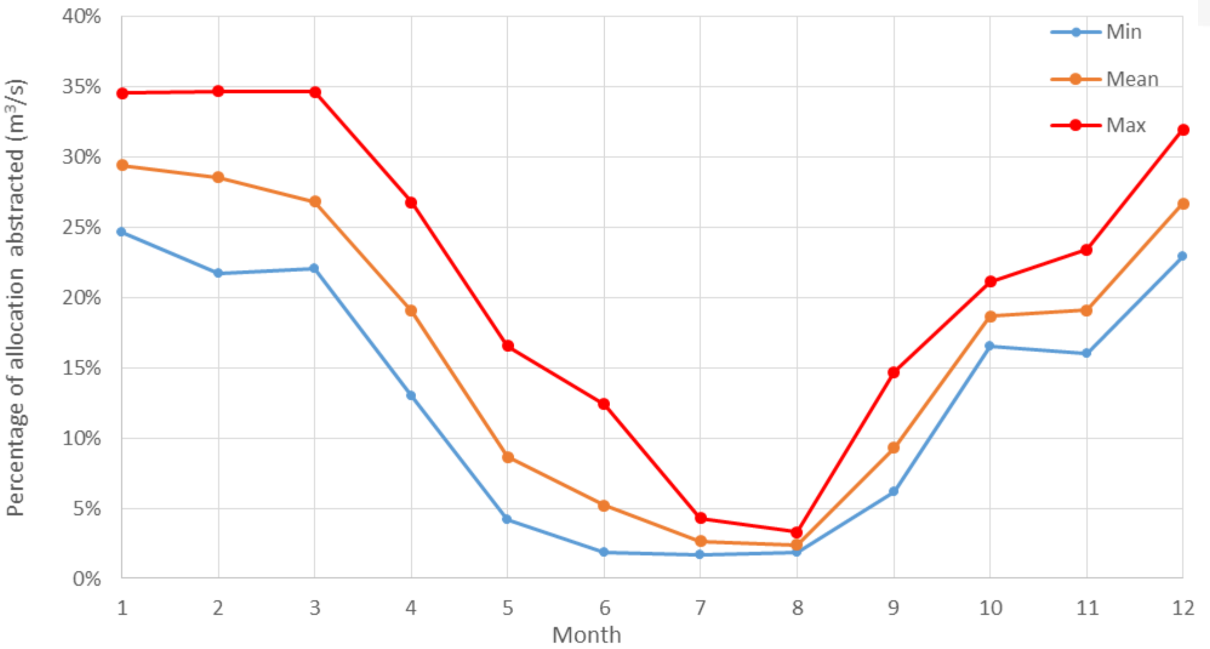

Figure 3.4: *Monthly abstraction as a percentage of the total allocation.*

The modelled daily irrigation demand for the Arrow catchment derived from Aqualinc (2017) can be compared to the actual metered water abstraction. Since the modelled time series ends in April 2014, and full metering of the three abstractions upstream of the Cornwall Street flow site only began in 2015, it is difficult to make a direct comparison. However, the two of the principal water abstractions were metered prior to 2015 so it is possible to compare these two data sets for the summer of 2014 (Figure 3.5).

There is a high degree of consistency between the irrigation demand modelled by Aqualinc (2017) and the actual rate of abstraction. It would appear that the modelled data are actually slightly more conservative (i.e. higher) than the actual abstraction. This could be the result of either:

- A smaller area under irrigated land uses than indicated in the various databases;
- Differences in actual water demand, as a function of soil type and PAW; or
- Slightly conservative water demand modelling.

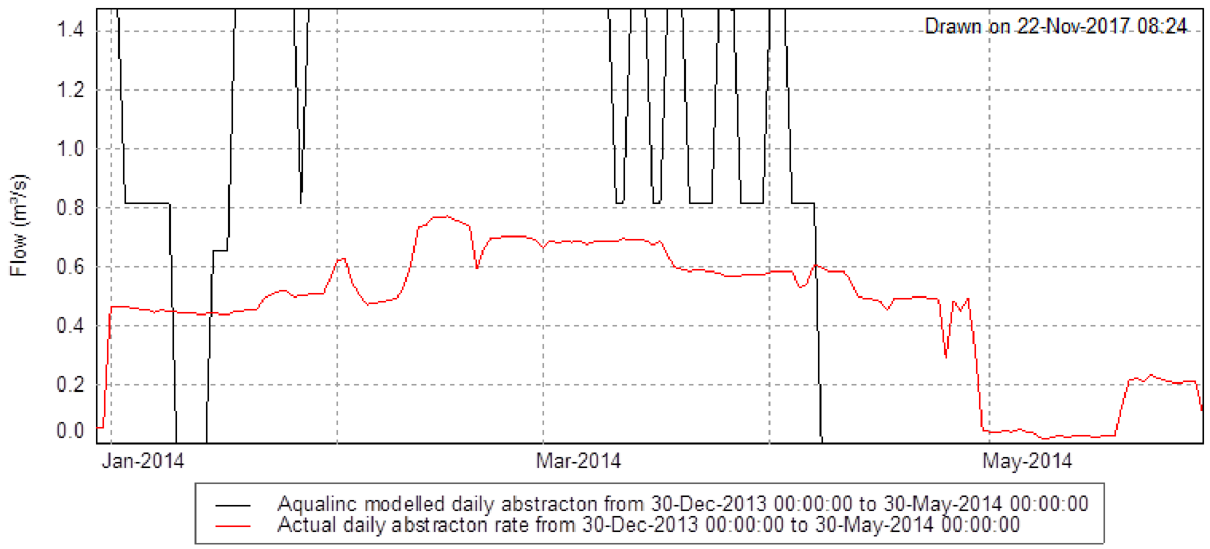

Figure 3.5: Comparison of modelled irrigation demand and actual water abstraction.

4 Minimum Flow Scenarios

Using the Naturalised Arrow River flow series the potential number of days when flow would have been below the various minimum thresholds can be quantified. This analysis can be used as a baseline to characterise the natural flow conditions before any abstraction is considered in the Arrow River.

Since abstraction is predominantly for irrigation, and the irrigation season extends across two calendar years, the analysis has considered 'Irrigation years' i.e. from 1 October through to 30 April the following year. The use of calendar years would have 'split' the irrigation season, potentially under-representing periods of restricted water availability and their severity.

Table 4.1 shows that over the 7-year duration of the extended naturalised flow series, only during the 2015/2016 Irrigation year would flow have dropped below all three potential minimum flow thresholds. Even with no abstraction, the mean daily flow of the Arrow River would have dropped below 0.8m³/s, 0.9m³/s and 1.0m³/s for 5, 6 and 10 days respectively. The longest period of consecutive days below the threshold would have been 6 days; with a minimum flow threshold of 1m³/s.

In effect, the days in Table 4.1, are those when no water would be available for abstraction under the different minimum flows that have been proposed i.e. the worst case scenario.

Table 4.1: Number of days, and the longest period, when flow is below the minimum flow threshold without any abstraction. The origin of the naturalised series is indicated.

	Total days			Longest consecutive days		
Year	Min. flow of 0.8m³/s	Min. flow of 0.9m³/s	Min. flow of 1.0m³/s	Min. flow of 0.8m³/s	Min. flow of 0.9m³/s	Min. flow of 1.0m³/s
2011/2012 (Opus[1])	0	0	0	0	0	0
2012/2013 (Opus[1])	0	0	0	0	0	0
2013/2014 (ORC[2])	0	0	0	0	0	0
2014/2015 (ORC[2])	0	0	0	0	0	0
2015/2016 (ORC[1])	5	6	10	4	5	6
2016/2017 (ORC[1])	0	0	0	0	0	0

4.1 Irrigation demand scenarios

There are a range of estimates of the potential irrigation demand within the Arrow catchment, depending on which data are used. These are summarised as four scenarios for each Irrigation year:

- Scenario 1: The mean monthly abstraction measured for each month as recorded by ORC (Table 4.2);
- Scenario 2: The maximum average monthly abstraction as recorded by ORC (Table 4.3);
- Scenario 3: The maximum modelled rate of irrigation demand (Aqualinc, 2017) i.e. 1.4712m³/s; and
- Scenario 4: The estimated daily abstraction rates needed for efficient irrigation based on Aqualinc (2017).

Table 4.2: Average monthly recorded abstraction (m³/s).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.597	0.579	0.544	0.386	0.176	0.105	0.053	0.049	0.189	0.378	0.388	0.542

Table 4.3: Maximum average monthly recorded abstraction (m³/s).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.701	0.703	0.702	0.543	0.335	0.252	0.087	0.067	0.298	0.428	0.475	0.649

Using these four scenarios, and the naturalised flow series described in Section 2.3, it is possible to determine the impact of setting each of the three potential minimum flows for the Arrow River i.e. 0.8m³/s, 0.9m³/s and 1.0m³/s. The total number of days when some restriction of abstraction, and the longest period of consecutive days with some restricted abstraction, were determined (Table 4.4 through Table 4.6). Days were defined from midnight to midnight and not some other time that spans two days.

Obviously, there are numerous ways in which any flow available for abstraction could be allocated among those who hold a water permit. There are also likely to be different demands, from different potential users, at different times, of the Irrigation year. Furthermore, the available water may be more critical to some users than to others. It is impossible to model all these different 'demand scenarios' with the information which is available currently. Consequently, only those days, and those periods, when there would be some restriction on abstraction have been identified.

Since the available data series relating to daily irrigation demand ends in 2014, the potential effect of the proposed minimum flow thresholds on Scenario 4 can only be determined for the 2011/2012 through 2013/2014 Irrigation years. The data used to derive the summary statistics for each month are in Appendix A.

4.2 Minimum flow of 0.8m³/s

Table 4.4: Total number of days, and longest period of consecutive days, with restricted abstraction under a minimum flow threshold of 0.8m³/s.

Year	Scenario							
	Total days				Longest period			
	1	2	3	4	1	2	3	4
2011/2012	15	22	89	57	9	20	26	22
2012/2013	0	8	87	50	0	6	47	29
2013/2014	0	0	86	50	0	0	33	33
2014/2015	0	0	99		0	0	41	
2015/2016	37	59	136		15	22	66	
2016/2017	0	0	35		0	0	15	

4.3 Minimum flow of $0.9 m^3/s$

Table 4.5: Total number of days, and longest period of consecutive days, with restricted abstraction under a minimum flow threshold of $0.9 m^3/s$.

Year	Scenario							
	Total days				Longest period			
	1	2	3	4	1	2	3	4
2011/2012	21	28	94	62	19	21	26	25
2012/2013	0	23	90	55	0	13	48	29
2013/2014	0	0	87	57	0	0	34	34
2014/2015	0	3	104		0	2	41	
2015/2016	55	72	136		22	22	66	
2016/2017	0	0	39		0	0	29	

4.4 Minimum flow of $1.0 m^3/s$

Table 4.6: Total number of days, and longest period of consecutive days, with restricted abstraction under a minimum flow threshold of $1.0 m^3/s$.

Year	Scenario							
	Total days				Longest period			
	1	2	3	4	1	2	3	4
2011/2012	28	38	102	63	21	21	31	25
2012/2013	14	34	93	63	9	21	48	29
2013/2014	0	6	89	63	0	5	49	42
2014/2015	0	22	108		0	11	41	
2015/2016	65	87	138		22	22	66	
2016/2017	0	0	45		0	0	42	

As expected, the highest minimum flow threshold i.e. $1.0 m^3/s$, for the Arrow River results in the greatest number of days when abstraction would be restricted, as well as the longest period of consecutive days with restricted abstraction. The effect of the a minimum flow threshold of $1.0 m^3/s$, assuming the existing average measured monthly abstraction rate, is shown in Figure 4.1. Obviously, the higher the 'allocation or usage' the greater the number of days, and the longer the period of consecutive days, when abstraction would be restricted. Graphs of each scenario, under the different minimum flow thresholds, are contained in Appendix B.

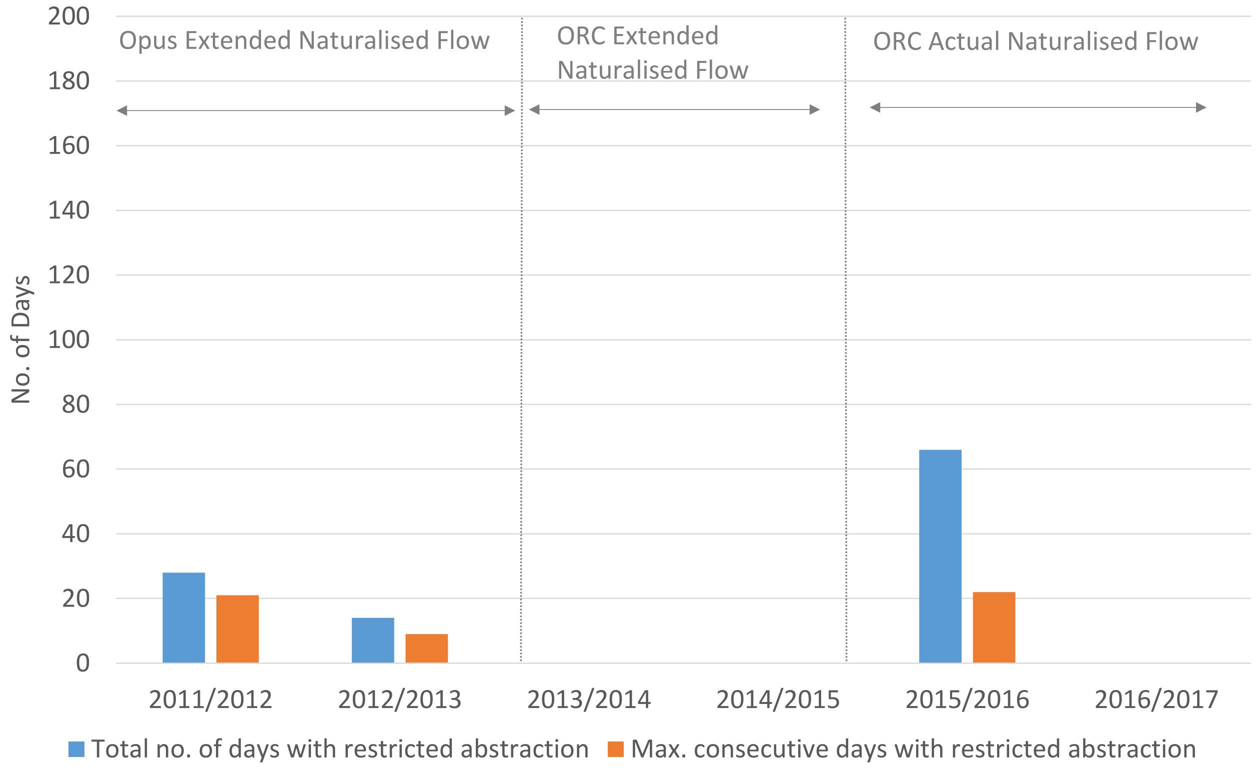

Figure 4.1: *The number of days with restricted abstraction, and the longest period of consecutive days with restricted abstraction, over each Irrigation year if the minimum flow threshold in the Arrow River was 1m³/s, and assuming the current average monthly water usage. The manner in which different periods of the naturalised flow record were derived is described in the text.*

5 Balancing supply and demand

The above analysis, irrespective of the particular irrigation demand scenario adopted, has simply considered meeting this demand from the immediate flow in the Arrow River i.e. no consideration has been given to water storage.

Storage is generally used to buffer the difference between the supply and demand for water. In the case of the Arrow catchment, the buffer could be provided by:

- On-farm, or community storage; or
- Utilising the 'effective storage' within the Kawarau River.

The difficulties with on-farm or community storage are the high cost, the need to match storage volume against risk, and the finite nature of the storage, and therefore the size of the buffer provided.

Utilising the effective storage within the Kawarau River would certainly be an option worth considering. There are a number of advantages of using water from the Kawarau River to either replace or augment abstraction from the Arrow catchment. These include:

- Since the source of the Kawarau River is Lake Wakatipu, the flow regime is relatively stable, particularly within the low flow range;
- The Arrow River flows into the Kawarau, and so essentially a component of the same water source would be utilised;
- The maximum abstraction rate required to support irrigation in the Arrow catchment represents a small percentage of the flow in the Kawarau River. Under the majority of flows, the effect of abstraction would not be able to be measured within the Kawarau;
- The supply of water to support irrigation in the Arrow catchment could therefore be almost guaranteed i.e. 100% irrigation security;

- The cost of associated infrastructure to pump and distribute water from the Kawarau would be relatively low, and offset by the greater level of irrigation water supply security;
- Using the Kawarau River as a potential water source would allow scope for further irrigation within the Arrow catchment; and
- The shifting of a major component of irrigation demand from the Arrow River to the Kawarau River could potentially result in improved environmental services within the Arrow catchment.

The use of water from the Kawarau River for irrigation, however, might meet resistance from existing users; particularly Contact Energy Ltd. However, the total irrigation demand from the Arrow catchment is a very small percentage of the potential 'fuel resource' of the Kawarau River.

6 Summary

The Otago Regional Council (ORC) is preparing to change the provisions in the Regional Plan. One option is that the Arrow catchment would be subject to a primary allocation limit and a minimum flow. All water permits, both existing and new, would be subject to the minimum flow provision.

There is a 7-year record of flows in the Arrow River; Arrow River at Cornwall Street. The short length of this flow record acts as a significant constraint on the robustness of any hydrological analysis, particularly when flows might be affected by longer term trends and cyclic behaviour. This constraint must be recognised when considering the implications of the various results presented in this report.

ORC have synthesized a naturalised flow series for the Arrow River at Cornwall Street flow site, based on available consent data; from 2013 to the present. This naturalised flow series represents the best approximation available of the flow regime of the Arrow River if there were no water abstractions within the catchment. This naturalised record, however, is of only 4 years duration, and is based on a range of assumptions.

No independent audit or quality assurance has been undertaken of the various data provided by ORC for use in this study. However, since they data have been collected, processed, and archived according to 'industry best practice', the data have been assumed accurate. Where appropriate, any constraints inherent in the data have been discussed, together with their potential implications for the results and conclusions.

Overall, it is likely that the past few years have been drier than 'average' within the Arrow catchment. This is likely to be reflected in lower than average flows, longer periods of low flows, and an increased demand for irrigation to offset any moisture deficit. Therefore, it is possible that these data reflect a 'bad case' scenario with respect to both water supply and water demand. The use of these data in an analysis of the potential impact of a minimum flow regime is therefore likely to be conservative, rather than optimistic i.e. the water supply situation is potentially slightly 'better' than indicated by this analysis.

Generally, a 4-year record would be considered too short for detailed analysis, and to provide robust results regarding the naturalised flow regime of a river. This issue is compounded in the current situation where approximately half of the 4-year naturalised record has been 'estimated' rather than measured. Since this is the total length of data available, some caution is required when applying the results to longer term management decisions.

There are a range of estimates of the potential irrigation demand within the Arrow catchment, depending on which data are used. These are described under 4 scenarios for each Irrigation year as follows:

- Scenario 1: The mean monthly abstraction measured for each month as recorded by ORC (Table 4.2);
- Scenario 2: The maximum average monthly abstraction as recorded by ORC (Table 4.3);
- Scenario 3: The maximum modelled rate of irrigation demand (Aqualinc, 2017) i.e. 1.4712m³/s; and
- Scenario 4: The estimated daily abstraction rates needed for efficient irrigation based on Aqualinc (2017).

Using these four scenarios, and the naturalised flow series for the Arrow River, it is possible to determine the potential impact of setting one of three possible minimum flows i.e. 0.8m³/s, 0.9m³/s and 1.0m³/s.

The implementation of a minimum flow will increase the number of days when abstraction of water for irrigation would be restricted. As expected, the greatest minimum flow threshold i.e. 1.0m³/s, results in the greatest number of days when abstraction would be restricted, as well as the longest period of consecutive days when abstraction would be restricted.

The above analysis, irrespective of the particular irrigation demand scenario, has only considered meeting this demand from the immediate flow in the Arrow River i.e. no consideration has been given to storage.

Storage can buffer the difference between the supply and demand for water. In the case of the Arrow catchment, the buffer could be provided by:

- On-farm or community storage; or
- Utilising the effective storage within the Kawarau River.

The difficulties with on-farm or community storage are the high cost, the need to match storage against risk, and the finite nature of the storage and therefore the size of the buffer provided.

Utilising the effective storage within the Kawarau River should be considered. There are a number of potential advantages of using water from the Kawarau River to either replace, or augment, abstraction from the Arrow catchment.

7 References

Aqualinc 2017: Guidelines for reasonable irrigation water requirements in the Otago Region. Report prepared for Otago Regional Council by Aqualinc Research Ltd. Project No. C15000. 24 July 2017.

Newsome, P.F.J.; Wilde, R.H. & Willoughby, E.J. 2008: Land resource information system spatial data layers. Landcare Research, Palmerston North, New Zealand 75p.

ORC, 2012: Management flows for aquatic ecosystems in the Arrow River. Report prepared by Justin Kitto, September 2012.

ORC, 2017: Update of scientific information on the Arrow catchment. Report prepared by Dean Olsen, Xiaofeng Lu and Peter Ravenscroft, July 2017.

https://www.niwa.co.nz/climate/information-and-resources/drought-monitor

Appendix A

Statistical summary of the impact of various minimum flow thresholds on four different irrigation demand scenarios for each Irrigation year i.e. 1 October through 30 April.

Scenario 1

Average monthly abstraction as recorded by ORC (2017)

Table A - 1: Minimum flow of 0.8m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	0	15	0	0			15
2012/2013				0	0	0	0	0	0	0			0
2013/2014				0	0	0	0	0	0	0			0
2014/2015				0	0	0	0	0	0	0			0
2015/2016				0	0	0	0	14	13	10			37
2016/2017				0	0	0	0	0	0	0			0

Table A - 2: Minimum flow of 0.9m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	2	19	0	0			21
2012/2013				0	0	0	0	0	0	0			0
2013/2014				0	0	0	0	0	0	0			0
2014/2015				0	0	0	0	0	0	0			0
2015/2016				0	0	0	0	21	20	14			55
2016/2017				0	0	0	0	0	0	0			0

Table A - 3: Minimum flow of 1.0m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	7	21	0	0			28
2012/2013				0	0	0	0	0	14	0			14
2013/2014				0	0	0	0	0	0	0			0
2014/2015				0	0	0	0	0	0	0			0
2015/2016				0	0	0	1	25	23	16			65
2016/2017				0	0	0	0	0	0	0			0

Scenario 2

Maximum monthly abstraction as recorded by ORC (2017)

Table A - 4: Minimum flow of 0.8m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	2	20	0	0			22
2012/2013				0	0	0	0	0	8	0			8
2013/2014				0	0	0	0	0	0	0			0
2014/2015				0	0	0	0	0	0	0			0
2015/2016				0	0	0	0	22	22	15			59
2016/2017				0	0	0	0	0	0	0			0

Table A - 5: Minimum flow of 0.9m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	7	21	0	0			28
2012/2013				0	0	0	0	2	21	0			23
2013/2014				0	0	0	0	0	0	0			0
2014/2015				0	0	0	0	0	3	0			3
2015/2016				0	0	0	1	25	27	19			72
2016/2017				0	0	0	0	0	0	0			0

Table A - 6: Minimum flow of 1.0m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	0	17	21	0	0			38
2012/2013				0	0	0	0	6	27	1			34
2013/2014				0	0	0	0	0	6	0			6
2014/2015				0	0	0	6	4	12	0			22
2015/2016				0	0	0	13	25	27	22			87
2016/2017				0	0	0	0	0	0	0			0

Scenario 3

The maximum modelled rate of irrigation demand (Aqualinc, 2017) i.e. 1.4712m³/s

Table A - 7: Minimum flow of 0.8m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	11	27	24	2	25			89
2012/2013				0	0	0	5	23	29	30			87
2013/2014				0	0	0	2	28	29	27			86
2014/2015				0	0	1	25	22	29	22			99
2015/2016				0	0	18	31	27	31	29			136
2016/2017				0	0	0	0	0	22	13			35

Table A - 8: Minimum flow of 0.9m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	12	27	24	4	27			94
2012/2013				0	0	0	6	24	30	30			90
2013/2014				0	0	0	3	28	29	27			87
2014/2015				0	0	2	26	24	29	23			104
2015/2016				0	0	18	31	27	31	29			136
2016/2017				0	0	0	0	0	26	13			39

Table A - 9: Minimum flow of 1.0m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	13	27	25	8	29			102
2012/2013				0	0	0	7	26	30	30			93
2013/2014				0	0	0	4	28	30	27			89
2014/2015				0	0	3	28	24	29	24			108
2015/2016				0	0	20	31	27	31	29			138
2016/2017				0	0	0	0	0	31	14			45

Scenario 4

Daily abstraction needed for efficient irrigation based on Aqualinc (2017)

Table A - 10: Minimum flow of 0.8m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	11	23	20	0	3			57
2012/2013				0	0	0	5	18	22	5			50
2013/2014				0	0	0	3	28	17	2			50
2014/2015													
2015/2016													
2016/2017													

Table A - 11: Minimum flow of 0.9m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	12	26	21	0	3			62
2012/2013				0	0	0	6	18	26	5			55
2013/2014				0	0	0	4	28	22	3			57
2014/2015													
2015/2016													
2016/2017													

Table A - 12: Minimum flow of 1.0m³/s – No. of days with restricted abstraction

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total days
2011/2012				0	0	13	26	21	0	3			63
2012/2013				0	0	0	7	19	26	11			63
2013/2014				0	0	0	5	28	27	3			63
2014/2015													
2015/2016													
2016/2017													

Appendix B

Graphs of the impact of various minimum flow thresholds on four different irrigation demand scenarios for each Irrigation year i.e. 1 October through 30 April.

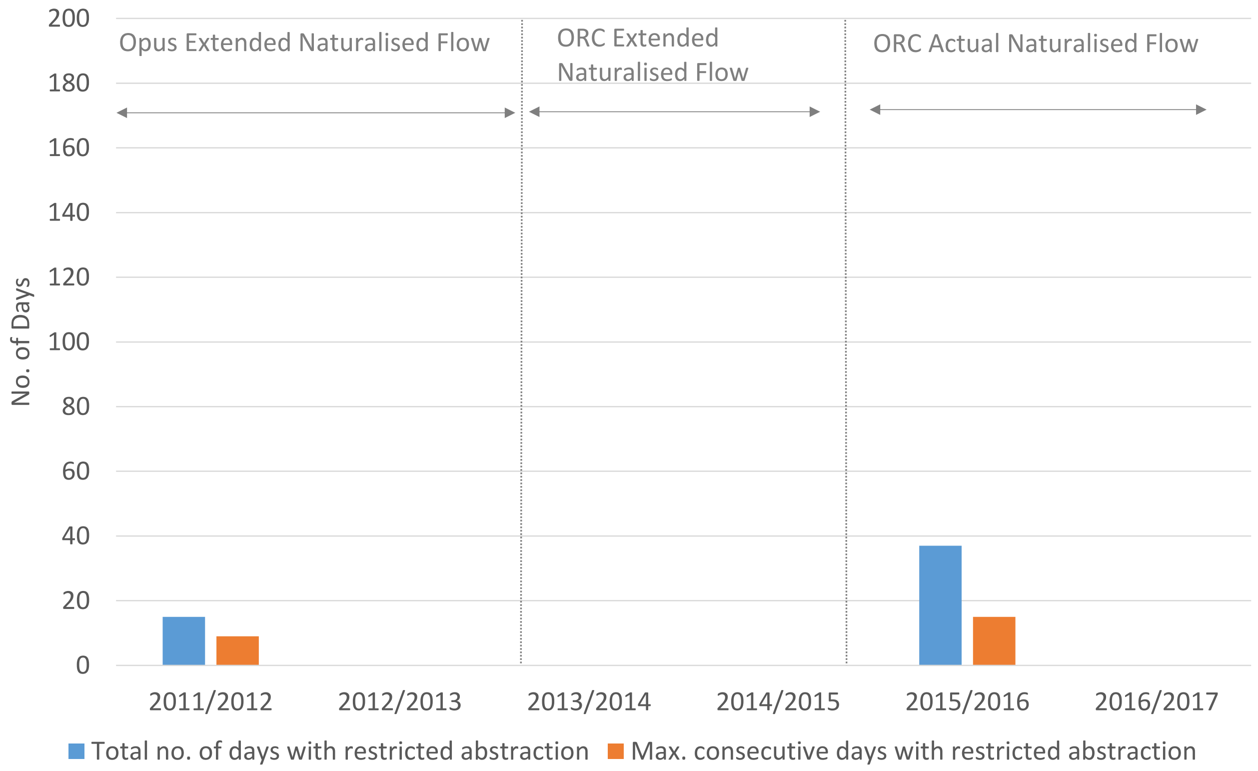

Figure B1: Scenario 1 while maintaining a minimum flow of 0.8m³/s.

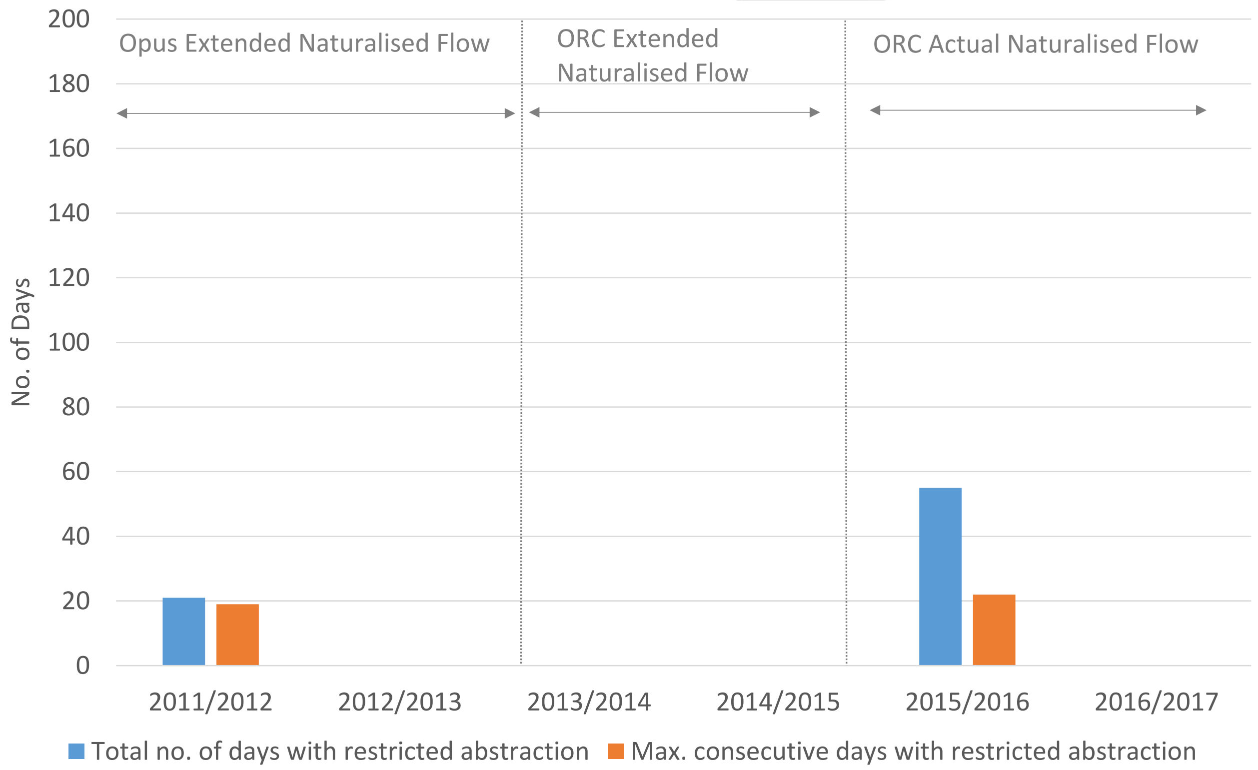

Figure B2: Scenario 1 while maintaining a minimum flow of 0.9m³/s.

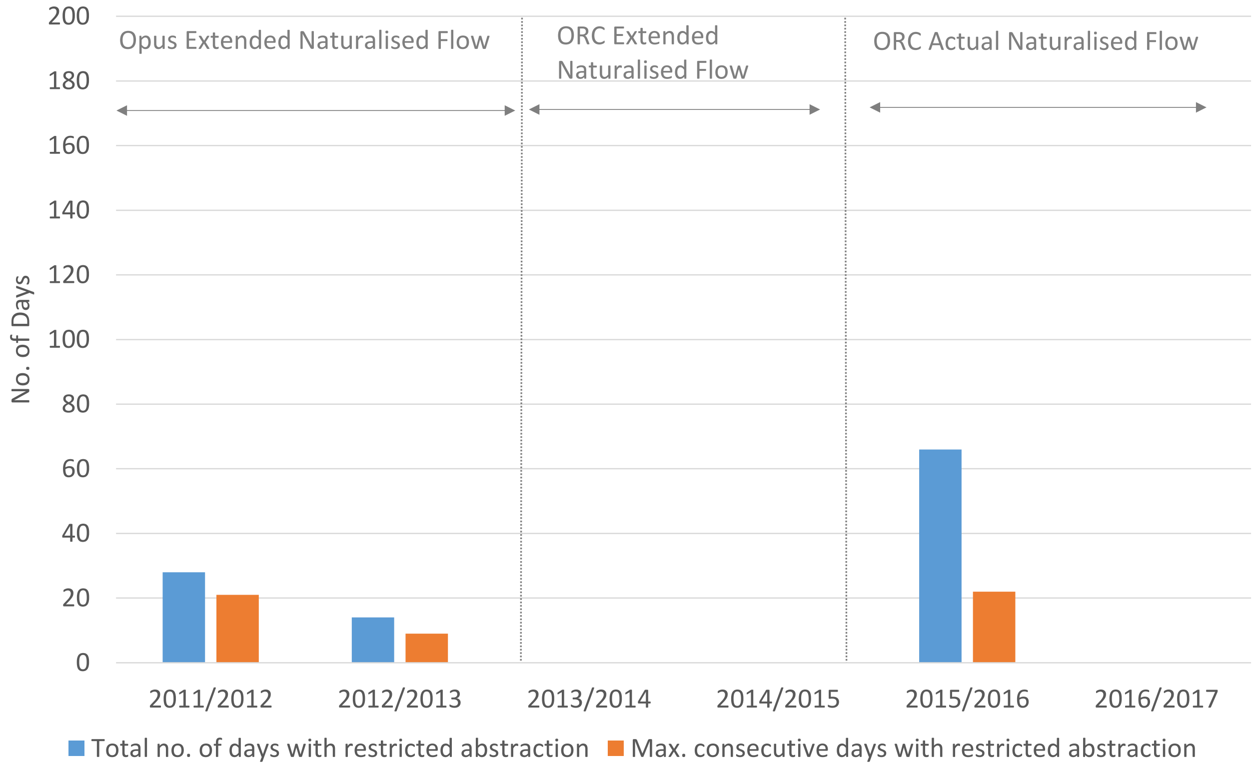

Figure B3: Scenario 1 while maintaining a minimum flow of 1.0m³/s.

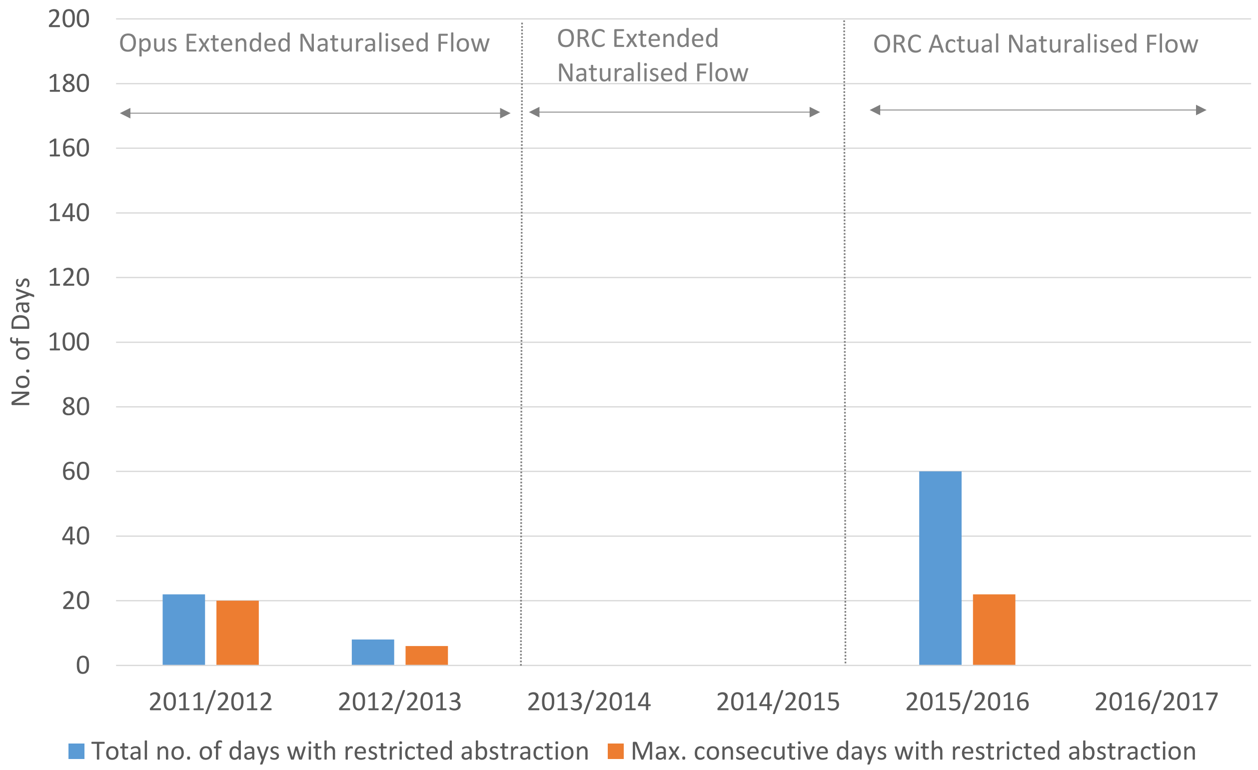

Figure B4: Scenario 2 while maintaining a minimum flow of 0.8m³/s.

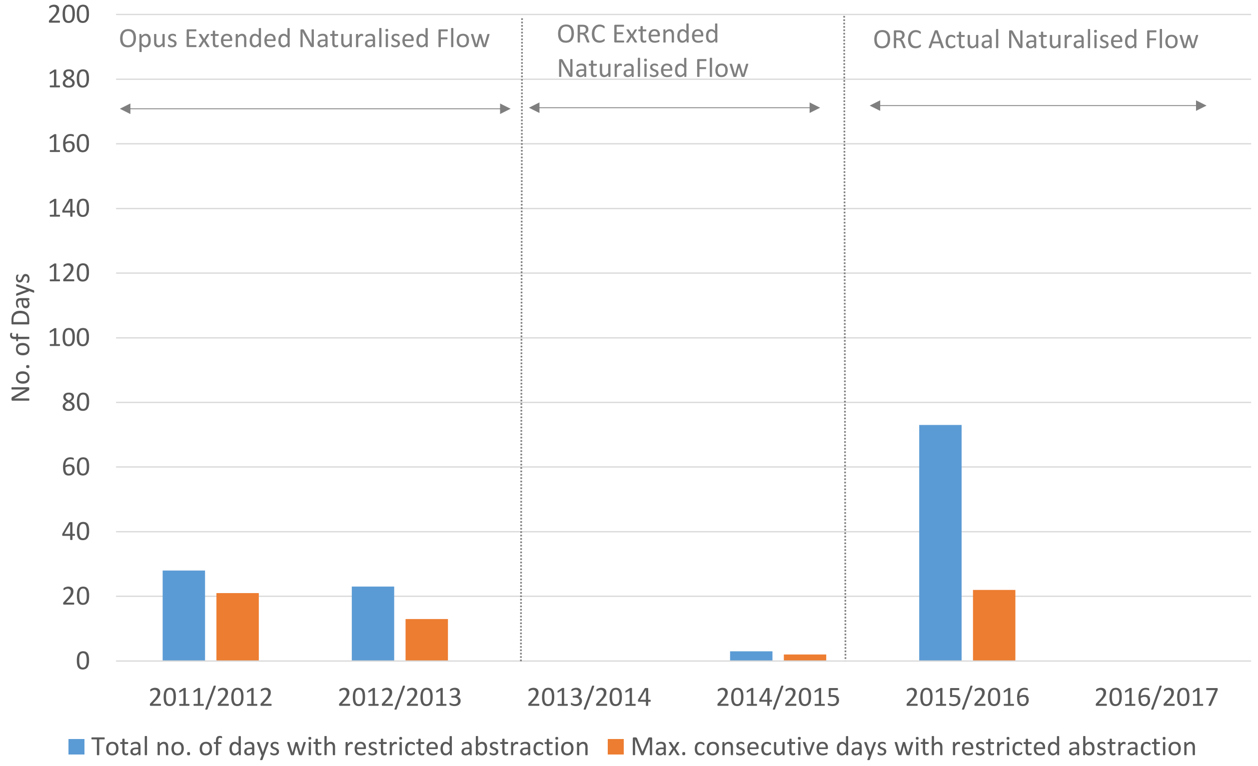

Figure B5: Scenario 2 while maintaining a minimum flow of 0.9m³/s.

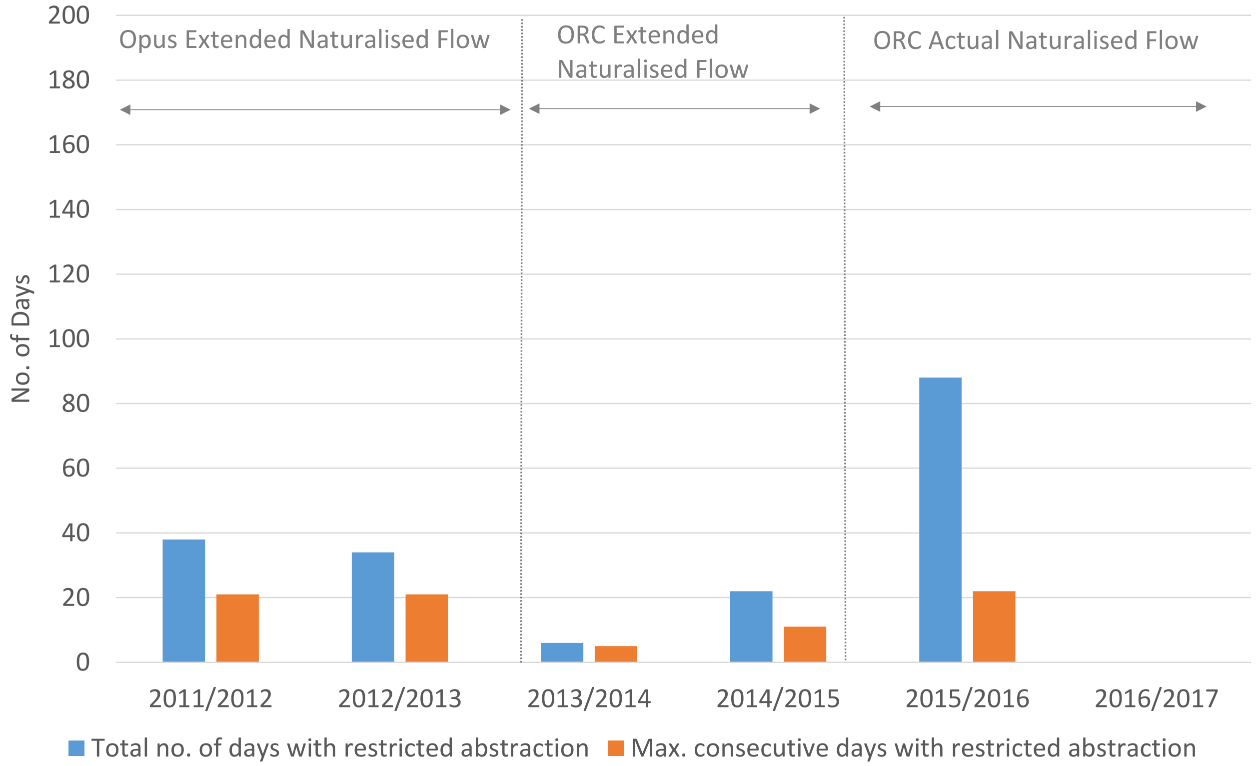

Figure B6: Scenario 2 while maintaining a minimum flow of 1.0m³/s.

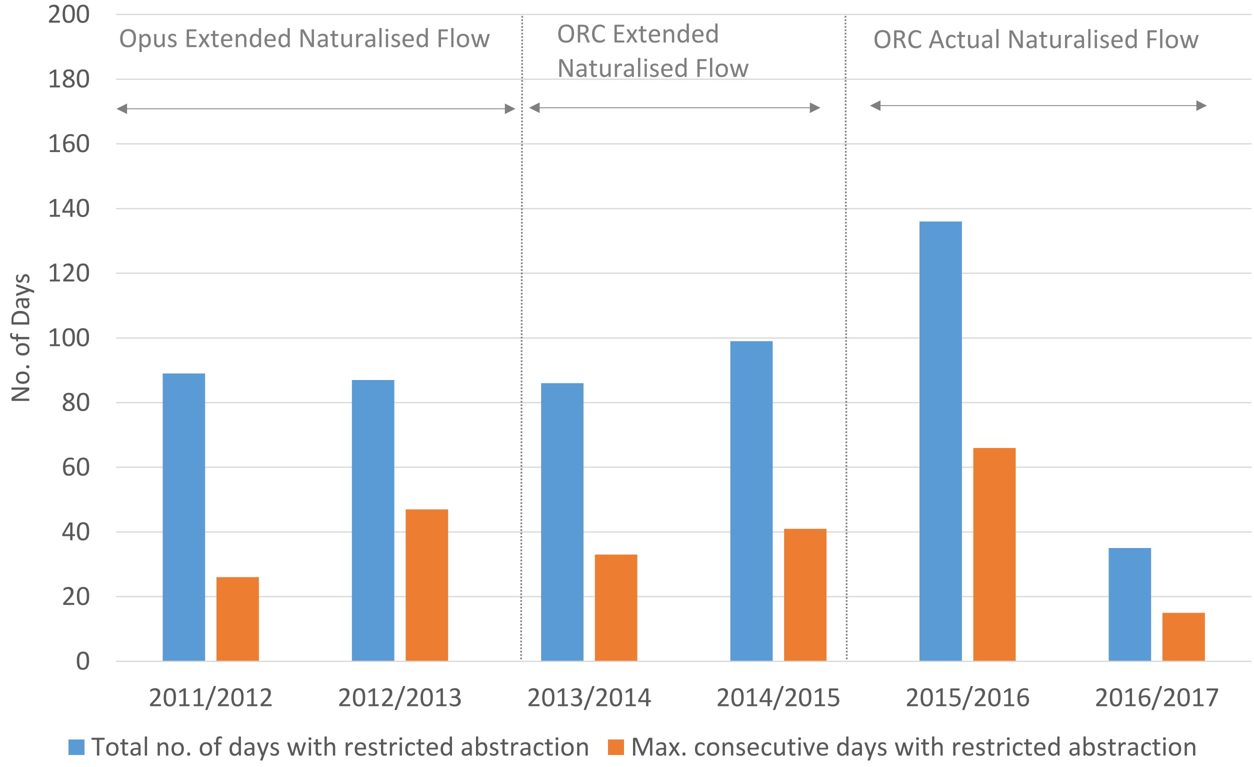

Figure B7: Scenario 3 while maintaining a minimum flow of 0.8m³/s.

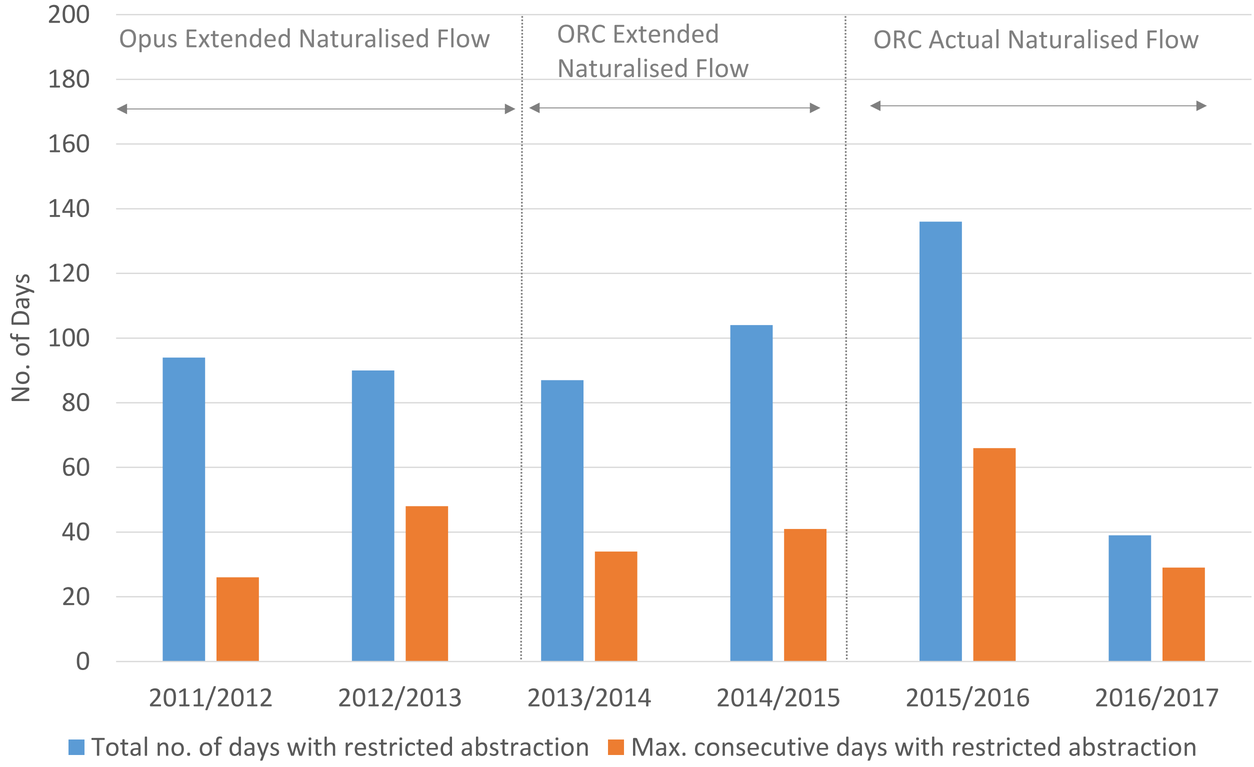

Figure B8: Scenario 3 while maintaining a minimum flow of 0.9m³/s.

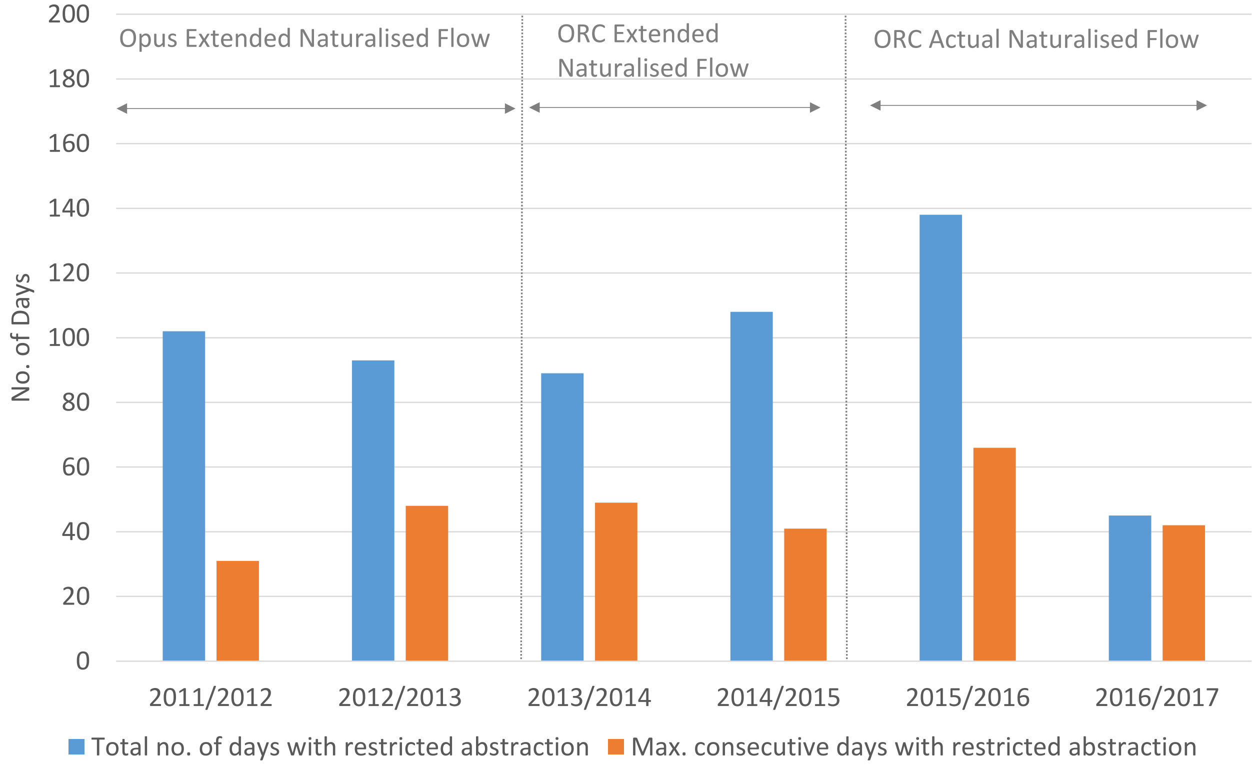

Figure B9: Scenario 3 while maintaining a minimum flow of 1.0m³/s.

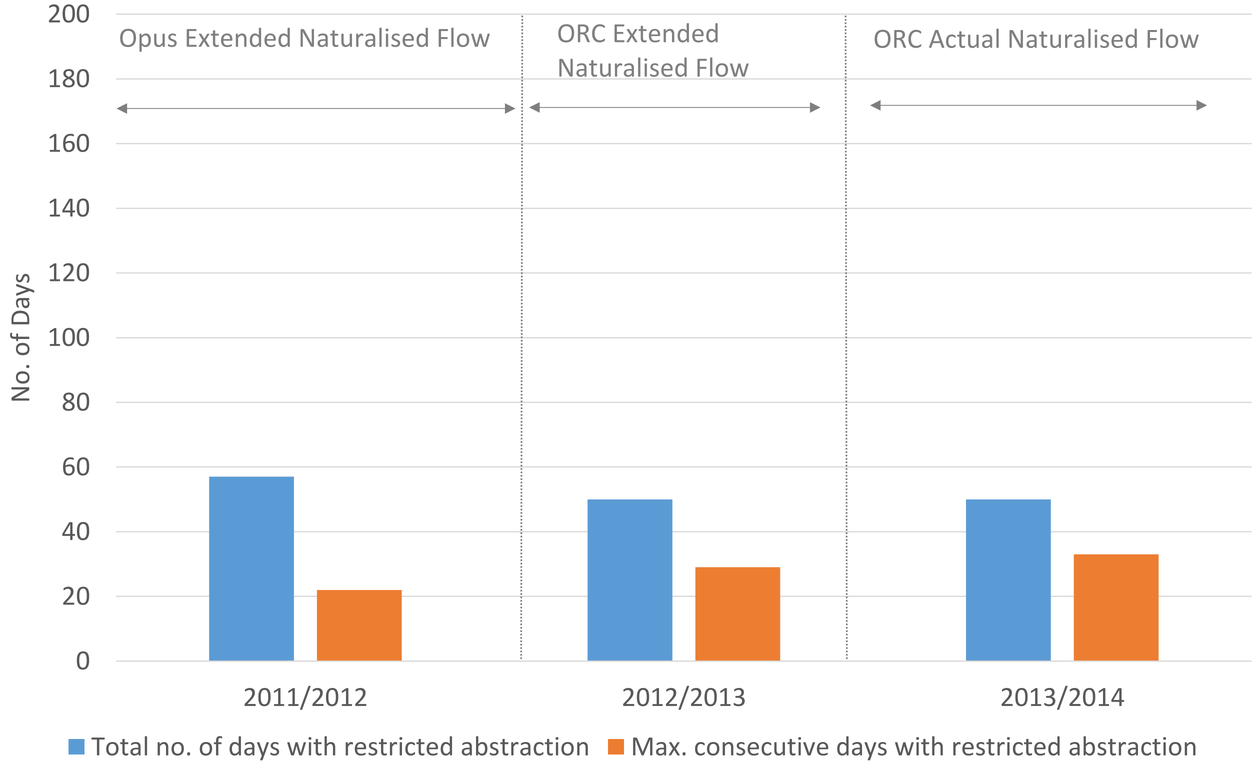

Figure B10: Scenario 4 while maintaining a minimum flow of 0.8m³/s.

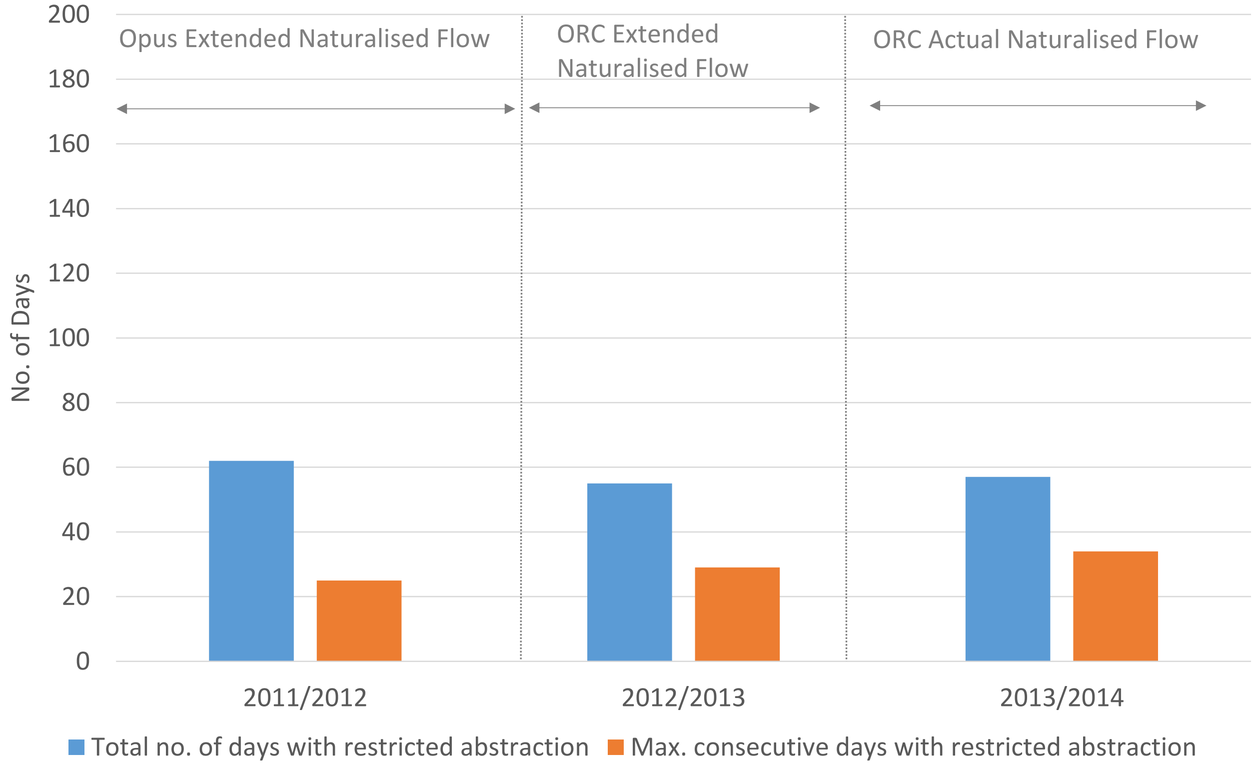

Figure B11: Scenario 4 while maintaining a minimum flow of 0.9m³/s.

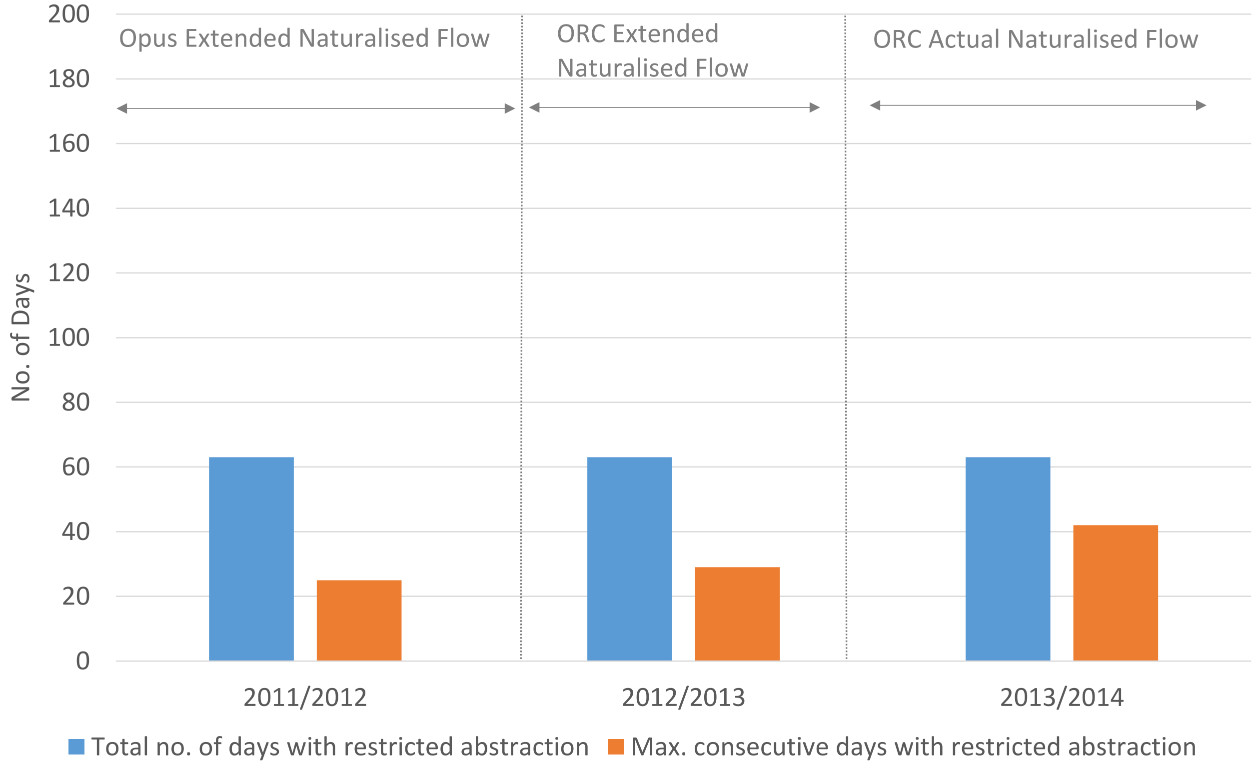

Figure B12: Scenario 4 while maintaining a minimum flow of 1.0m³/s.

OPUS

www.opus.co.nz