Manuherekia Hydrology: Report 1

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Executive summary

This report describes the derivation of climate, irrigation demand, soil drainage and naturalised flow timeseries that are used in the 2020 Manuherekia Catchment Hydrological Model.

There is a wealth of long-term rainfall records in the study area. These records were analysed and extended, to recreate continuous daily timeseries from 1924 to 2020. In total, 21 long-term daily rainfall records were generated. These high-quality rainfall records allow more recent flow records to be placed in the context of a much longer period.

Potential evapotranspiration (PET) depends on wind, radiation, humidity, and temperature. There is a limited number of full climate stations that include all these parameters, particularly radiation. There are nine long term full climate stations within or in the vicinity of the study area. Records from these stations were extended to create continuous daily PET timeseries for the period 1972 to 2020.

Soil moisture, drainage and irrigation dynamics were modelled for the period 1972 to 2020. We modelled two irrigation system types: a well managed 80% efficient spray system, and an inefficient flood system. Three sub-catchments were modelled: Lower Manuherekia Valley, Upper Manuherekia Valley, and Ida Valley. Outputs include a daily timeseries of gross and net irrigation demand, and soil drainage.

There are several flow recorder sites within the study area that measure flow from catchments that are not affected by irrigation abstraction (i.e. the flow is natural). For the Manuherekia Valley, the three most important natural flow records are Dunstan at Gorge, Manuherekia at Forks, and Falls Dam inflows. Falls Dam inflows is a derived series, calculated from dam outflows and changes in Falls reservoir storage. Collectively these three records were used to create a continuous Tier 1 timeseries from June 1973 to June 2020. This timeseries is used to extend the Dunstan range flow records that are natural: Dunstan Creek at Gorge, Lauder Creek at Cattle Yards, and Thomsons Creek U/S Diversion Weir.

1. Rainfall

There is a wealth of long-term rainfall records in the study area. Some of these records extend back as far as the 1880's and 1890's. These records were analysed and extended using PZB's WEATHERMAKER software, to recreate continuous daily timeseries from June 1924 to June 2020. A summary of these records is provided in Table 1 and Figure 1. Further details, including annual and seasonal summaries for each site, are included in Appendix A.

WEATHERMAKER calculates the relationship between different stations and uses this to extend records and fill in gaps. Correlation between stations is used to guide which sites are used for extension. The method adjusts for seasonal differences between stations. The extension algorithm is designed to retain long term trends and climate cycles. Because of the high spatial variability of rainfall, at least 10 years of timeseries overlap is required to determine the relationship between two stations.

Table 1: Long term rainfall recorder sites

Agent No.	Name	Record range		Mean Annual Rainfall (mm)	
		Start	End	1924-2020	1972-2020
12431	Clyde EWS	1996	2012	394	396
5576	Alexandra 1	1922	1983	347	354
5578	Alexandra	1985	2020	372	380
5587	Galloway 2	1922	1983	365	369
5544	Ophir 2	1924	2020	418	420
5530	Matakanui	1947	2020	517	524
5535	Lauder EWS	1985	2020	436	441
5537	Lauder Flat	1945	2020	509	516
26567	Lauder 2	2000	2020	477	484
5248	Cambrian	1950(1)	1973	761	773
5239	St Bathans 3	1989	2000	668	690
ORC	Manuherikia at Tunnel Hill	2008	2020	654	667
5252	Blackstone Hill	1940(2)	2007	605	625
5253	Oturehua	1917	1974	612	631
ORC	Ida Burn at Hills Creek	1988	2020	512	529
5255	Wedderburn	1957	1983	570	581
ORC	Poolburn at Merino Ridges	2009	2020	411	414
5545	Moa Creek	1913	1984	405	409
5608	Manorburn Dam	1913	1981	498	514
5621	Roxburgh	1897	2000	570	590
5630	Lake Onslow	1985	2013	566	586

(1) Data from 1944-1950 has potential quality issues so was not used in analysis
(2) Data from 1917-1940 has potential quality issues so was not used in analysis

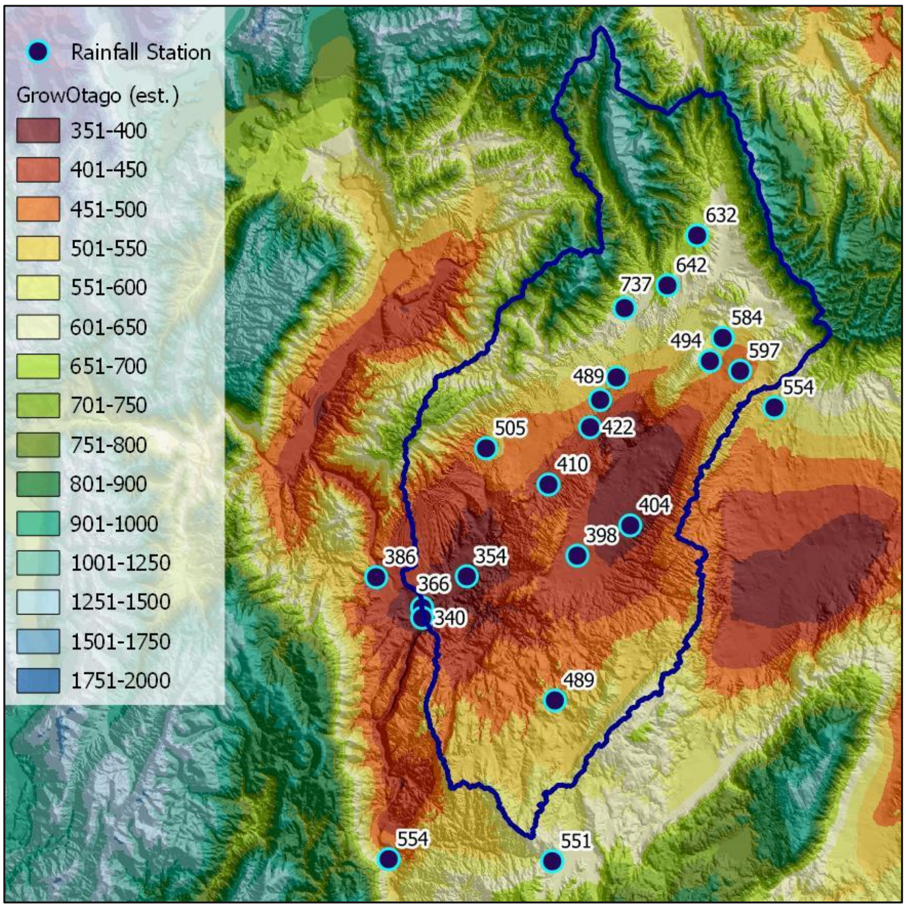

Figure 1: Median Annual Rainfall (1972 to 2020)

Rainfall records were extended back to 1924 (rather than 1973) for the following reasons:

(a) Many of the records extend back to at least 1924.
(b) Some long (and useful) records have limited overlap with the more recent 1973-2020 period.
(c) Places the flow simulation period (1973-2020) in the context of a longer record.
(d) Places individual seasons in the context of a longer record.

The period when flow records are available (1973 to 2020, 47 years) is reasonably representative of the longer rainfall record (1924 to 2020, 96 years). While average annual rainfall (for 1973-2020) is slightly higher (Table 1), the proportion of *dry* years during this period is also higher (Table 2).

Table 2: Dry year frequency comparison

Period	Total years	Dry years (1)		Proportion of dry year	
		Manuherekia Valley	Ida Valley	Manuherekia Valley	Ida Valley
1973-2020	96	20	19	21%	20%
1924-2020	46	13	12	28%	26%
(1) Lower 20%ile cumulative rainfall from 1 October to 31 March (1 in 5-year event).					

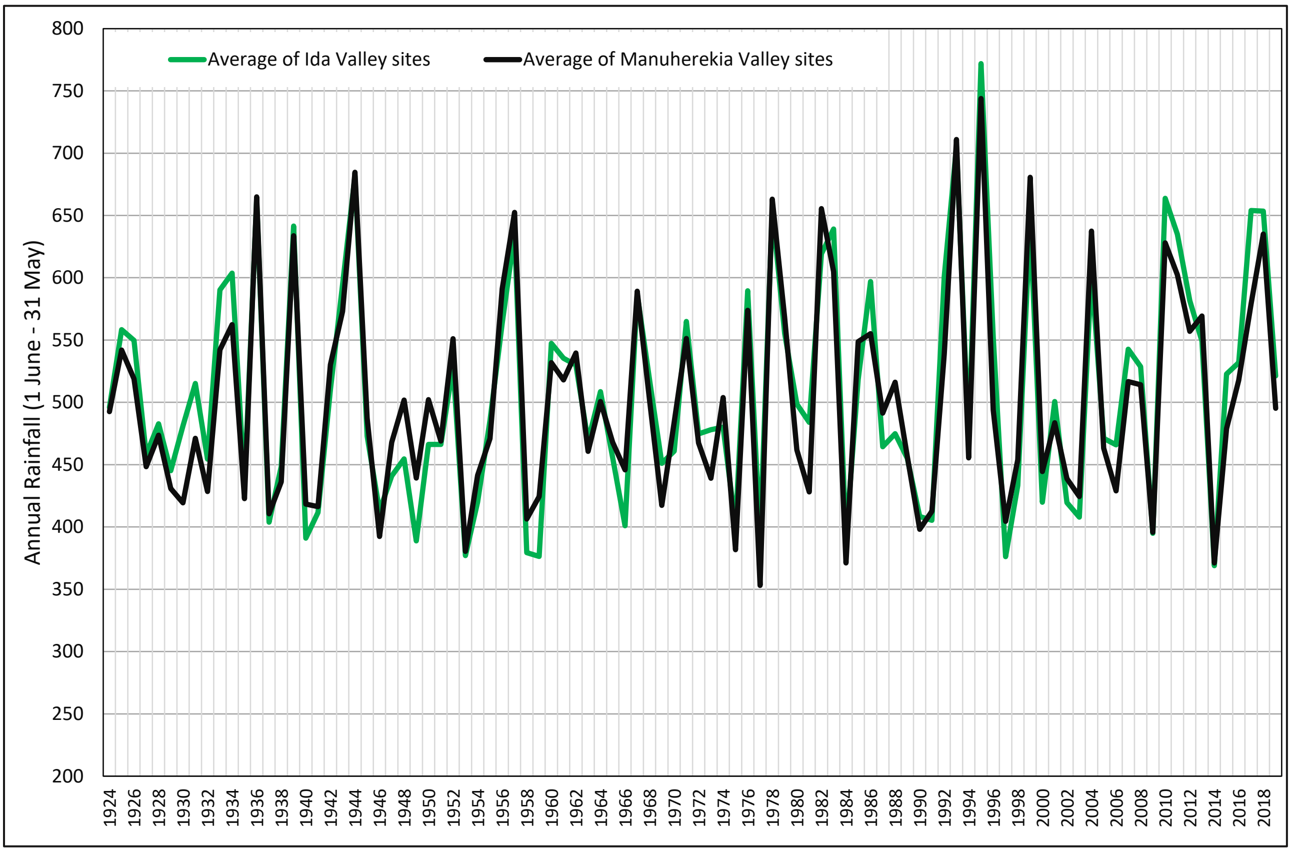

Figure 2: Annual rainfall, 1 June to 31 May

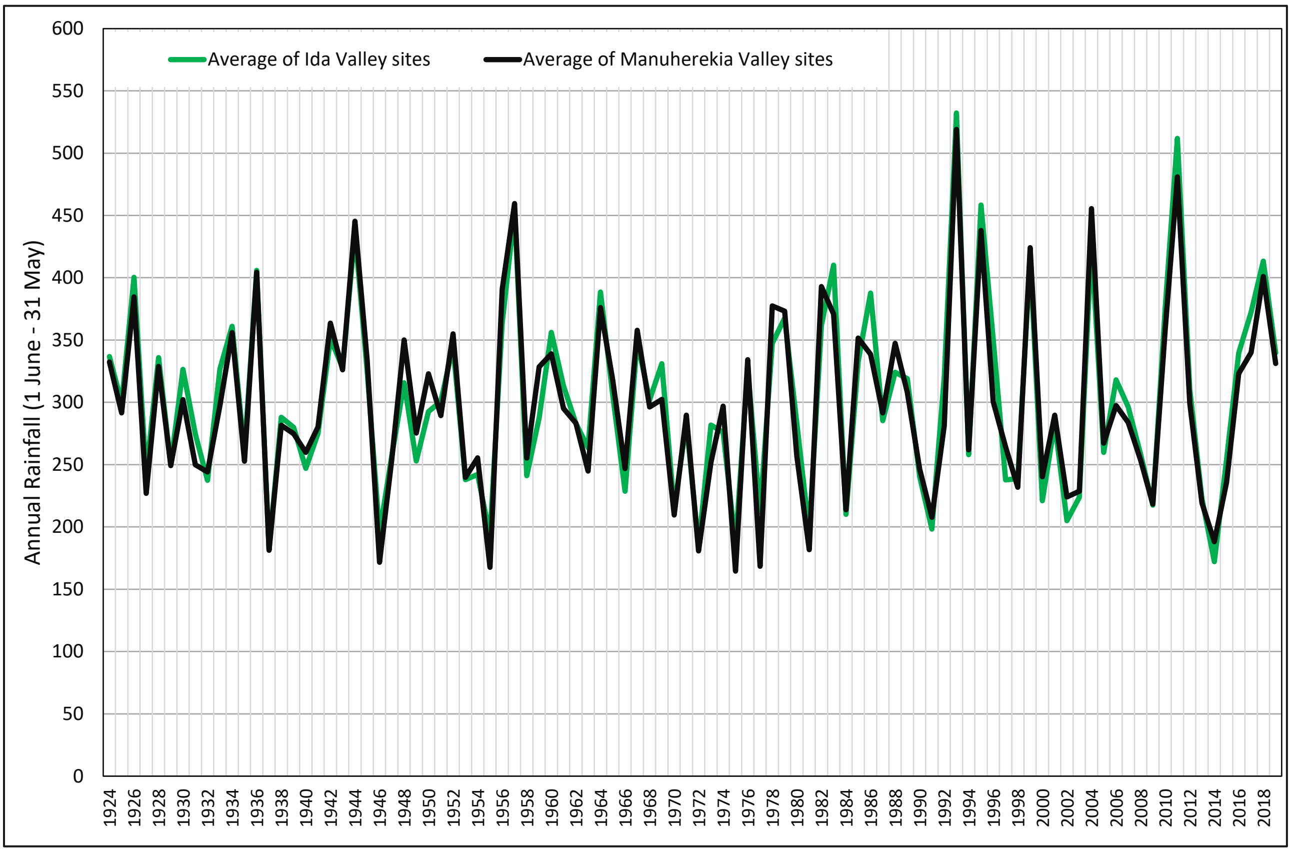

Figure 3: Seasonal rainfall (1 October to 31 March)

2. Evapotranspiration

Potential evapotranspiration depends on the wind, radiation, humidity, and temperature. There is a limited number of full climate stations that include all these parameters, particularly radiation. Long term full climate stations in the vicinity of the study area are summarised in Table 3 and Figure 4.

Potential Evapotranspiration (PET) estimates were from the National Climate database and use the Penman[1] method. We filled gaps and extended these records using WEATHERMAKER to produce a daily timeseries from June 1972 to June 2020. Annual totals for each station are included in Appendix A.

Table 3: Long term full climate stations

Agent No.	Name	Record range		Site elevation (m)	Anemometer height (m)	Annual PET	
		Start	End			Average	80%ile (1 yr in 5)
5535	Lauder EWS	1985	2020	375	10	963	1051
12431	Clyde EWS	1996	2020	171	10	809	875
39564	Clyde EWS 2	2011	2020	170	10	859	925
5577	Earnscleugh	1983	1996	171	6	898	976
5576	Alexandra 1	1972	1983	141	6	787	850
36592	Alexandra CWS	2008	2020	140	4	792	844
5212/5212	Tara Hills	1972	2020	488	10	960	1022
26381	Cromwell EWS	2006	2020	213	6.5	1008	1085
18593	Ranfurly EWS	2000	2020	450	10	874	933

Within the study area, measured mean annual PET ranged from 790 to 960 mm per year. Most of this variation is the result of differing exposure (i.e. wind speed).

[1] 1963 Penman (original)

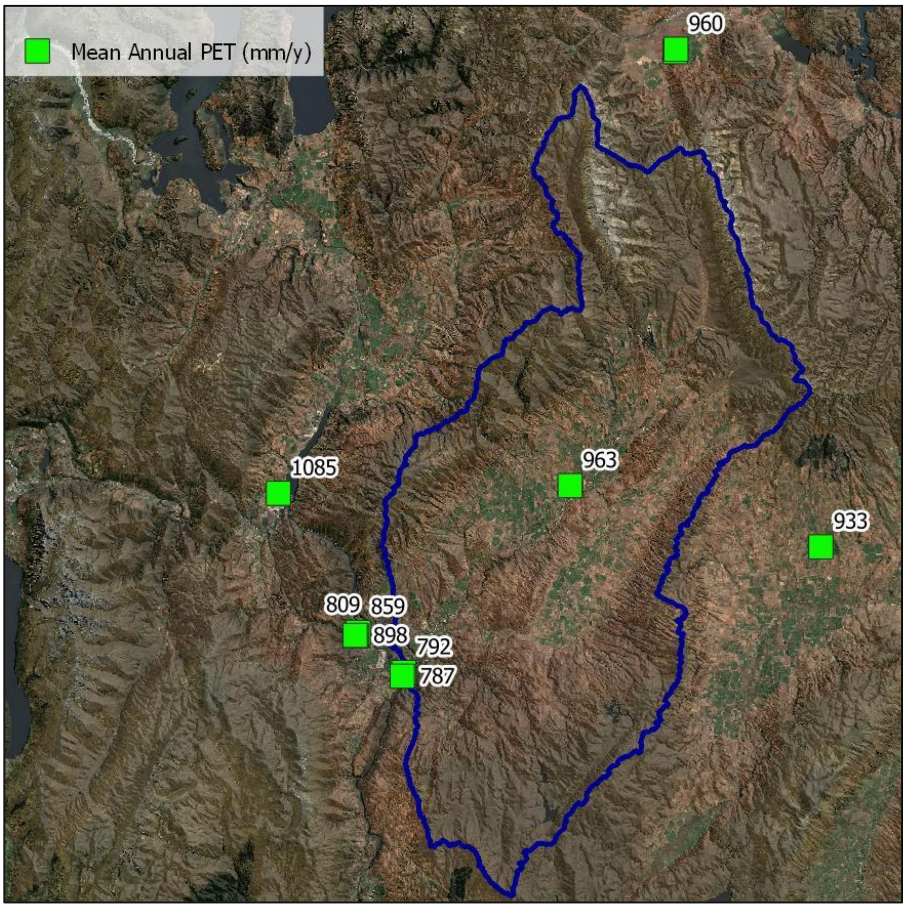

Figure 4: Mean Annual Potential Evapotranspiration

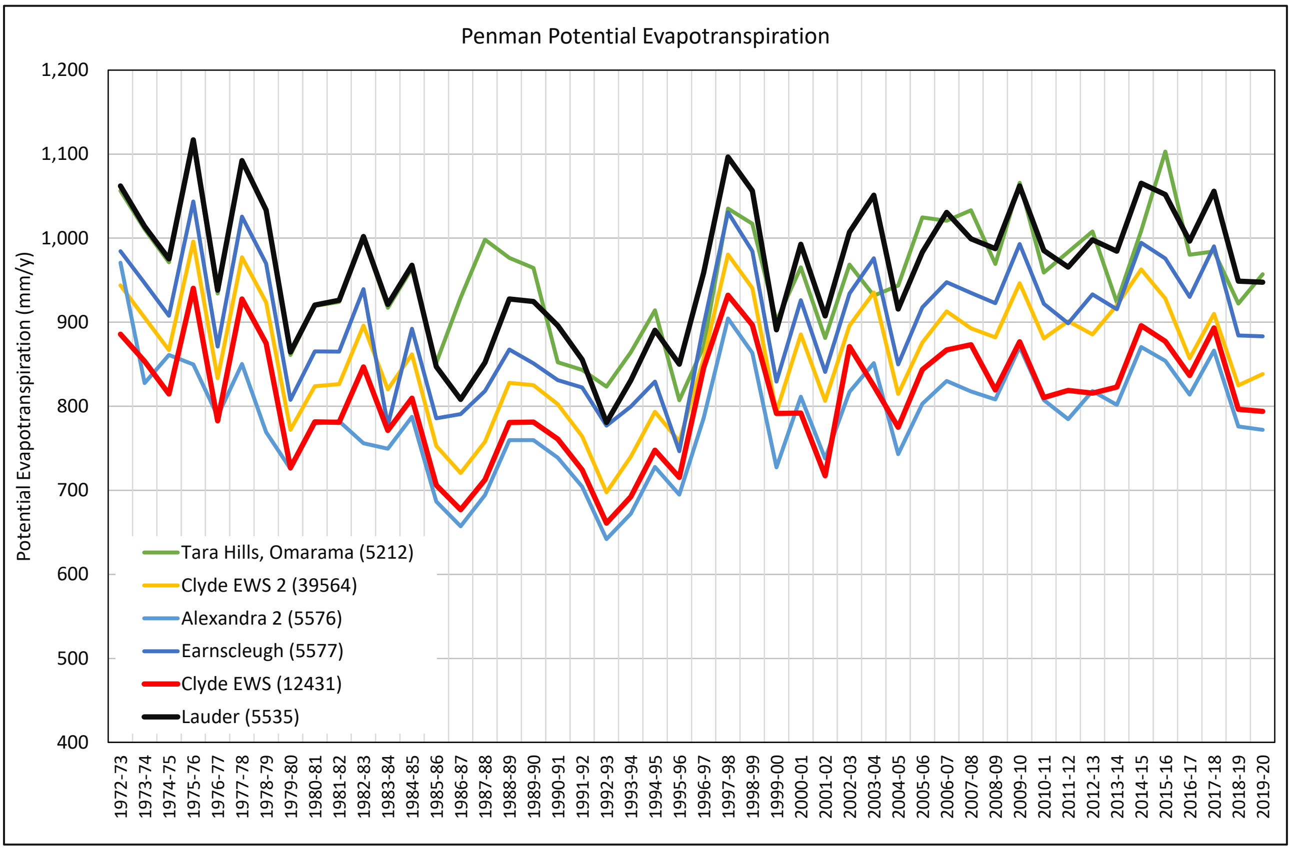

Figure 5: Potential Evapotranspiration: 1972 to 2020

3. Irrigation demand

Soil moisture, drainage and irrigation dynamics were modelled using PZB's irrigation scheduling software. This program uses a daily soil water balance model (refer Brown 2008, Allen et al 1998). The model has been validated against a large number of actual irrigation demand records.

We modelled two irrigation system types: a well managed 80% efficient spray system, and an inefficient flood system. We modelled two soils: Plant Available Water (PAW) at field capacity = 60 mm and PAW = 90 mm. We modelled pasture since this is the primary crop irrigated. The model assumes that the groundwater table is below the root zone. Climate records used in analysis are given in Table 4 and irrigation system parameters in Table 5 and

Table 6. In total we modelled 18 combinations. The model was run from 1 June 1960 to 31 May 2020, a total of 60 years. Model estimates from 1960 to 1971 will be less accurate, because it relies on PET records that were extended via Christchurch airport. There are however good local rainfall records for this period.

Table 4: Climate records used in irrigation demand modelling.

Representative area	Rainfall record	PET record
Lower Manuherekia Valley	Galloway 2	Clyde 2
Upper Manuherekia Valley	Lauder Flat	Average of Lauder EWS & Clyde 2
Ida Valley	Merino Ridges	

Table 5: Irrigation system parameters for Upper Manuherekia and Ida Valley

Parameter	Spray Irr.		Flood Irr.	
	PAW60	PAW90	PAW60	PAW90
Application depth (mm)	16	20	102	102
System capacity (mm/d)	4.0	4.0	3.0	3.0
Return period (days)	4	5	34	34
Soil moisture deficit trigger (mm)	24	30	24	30
Application efficiency	80%		40%	
Irrigation season	15 Sep - 30 April			

Table 6: Irrigation system parameters for Lower Manuherekia Valley

Parameter	Spray Irr.		Flood Irr.	
	PAW60	PAW90	PAW60	PAW90
Application depth (mm)	15	20	100	100
System capacity (mm/d)	5.0	5.0	5.0	5.0
Return period (days)	3	4	20	20
Soil moisture deficit trigger (mm)	24	30	24	30
Application efficiency	80%		40%	
Irrigation season	15 Sep - 30 April			

The irrigation demand timeseries estimate the farm demand. It does not include scheme distribution losses, which are additional.

The calculated timeseries is only the demand side of the equation (i.e. if the water supply were 100% reliability). Supply restrictions means that the actual use will be lower.

Under irrigation there is an increase in soil drainage and return flow. For flood irrigation, the return flow can be as high as 60 to 70% of the water applied. The net irrigation demand is the additional water that is removed from the catchment by evaporation. Net irrigation demand is equal to:

NET IRRIGATION = GROSS IRRIGATION – (IRRIGATED DRAINAGE – DRYLAND DRAINAGE)

Results are summarised in Table 7 and Table 9. Further details, including a breakdown by season, are provided in Appendix B.

Table 7: Annual water balance for Upper Manuherekia Valley scenarios

Parameter	Spray Irr.		Flood Irr.		Dry	
	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90
Potential Evapotranspiration	910	910	910	910	910	910
Evapotranspiration	810	822	630	670	443	469
Rainfall	514	514	514	514	514	514
Applied irrigation	555	539	689	674	0	0
Drainage & return flow	259	230	573	517	72	46
Additional drainage (1)	187	184	501	471	NA	NA
Net irrigation use	368	354	188	202	0	0
(1) Additional drainage and return flow associated with irrigation						

Table 8: Annual water balance for Lower Manuherekia Valley scenarios

Parameter	Spray Irr.		Flood Irr.		Dry	
	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90
Potential Evapotranspiration	858	858	858	858	858	858
Evapotranspiration	784	788	664	696	339	355
Rainfall	366	366	366	366	366	366
Applied irrigation	621	609	1073	1051	0	0
Drainage & return flow	203	187	775	721	27	12
Additional drainage (1)	175	175	748	710	NA	NA
Net irrigation use	445	434	325	341	0	0
(1) Additional drainage and return flow associated with irrigation						

Table 9: Annual water balance for Ida Valley scenarios

Parameter	Spray Irr.		Flood Irr.		Dry	
	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90
Potential Evapotranspiration	910	910	910	910	910	910
Evapotranspiration	805	819	596	629	381	399
Rainfall	413	413	413	413	413	413
Applied irrigation	596	593	691	691	0	0
Drainage & return flow	204	188	508	475	33	15
Additional drainage (1)	171	173	475	460	NA	NA
Net irrigation use	425	420	216	231	0	0
(1) Additional drainage and return flow associated with irrigation						

4. Falls Dam outflows

Falls Dam outflow records are summarised in Table 10. We preferentially used the records from the flow recorder site downstream of the dam when these were available. This site is/was regularly gauged and has a stable stage-flow relationship due to the rock gorge location.

Table 10: Falls Dam outflow records

Description	Start	End	Notes
D/S flow recorder (NIWA)	Feb-99	Jun-14	
D/S flow recorder (ORC)	Jul-19	Present	
Dam level recorder	Nov-03	Present	
Turbine flow	May-14	Present	
Bypass valve flow	Jul-16	Present	From valve position

For the period when this recorder site was not operating (June 2014 to July 2019) we used flow records from the dam operator. Turbine flow records were calibrated against the flow recorder site and scaled up by a factor of 1.163. Flow through the bypass valve is infrequent, and averaged about 17 l/s. Spill flows were calculated using the dam water level and the spillway equation given in Brown (2012c, Appendix G). There is about 20 l/s of leakage that is not measured by the Turbine or bypass valve (refer Stewart 2012). This leakage is incorporated into the turbine calibration factor. Estimated flows were compared with the downstream flow recorder records for the last 12 months, with the two data sources in good agreement (refer Figure 6).

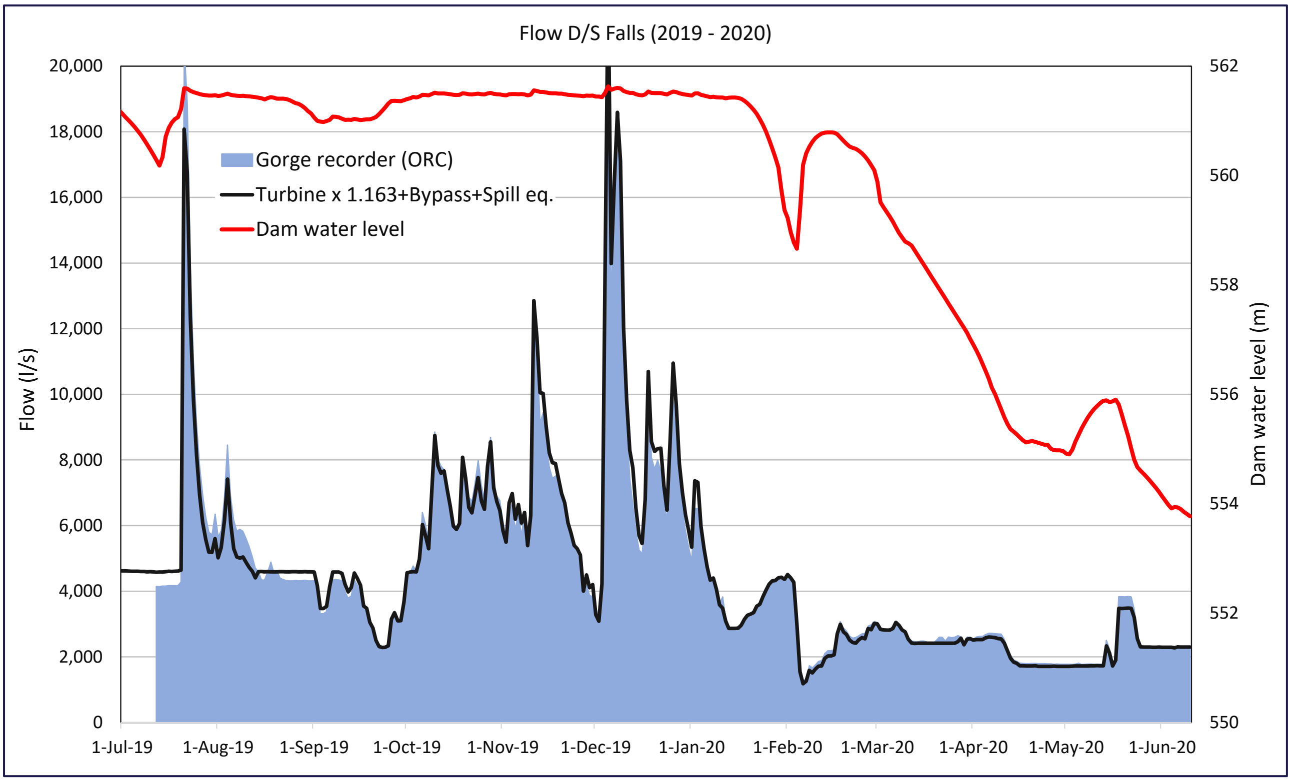

Figure 6: Falls Dam outflows. Dam operator records vs downstream flow recorder

There are some data discrepancies with the dam water level recorder that required some adjustments. This includes a datum discrepancy between the high and low range sensors. Particular periods where we have less confidence in the data include 9 Dec 2005 to 9 Feb 2006, 16 Feb to 18 Aug 2007, 4 Apr to 5 Nov 2009, and 19 Apr to 27 Jun 2012.

While we were able to derive a good match between downstream measured flows and dam release flows (by scaling the Turbine flow records), we can only assume that this relationship holds for the period between June 2014 and July 2019. High flow estimation is particularly sensitive to any drift in the pressure transducer, because of the morning glory spillway stage-flow relationship.

5. Falls Dam inflows

Falls Dam catchment is illustrated in Figure 7. There is no irrigation upstream of the dam. Flows into the dam are largely natural, except for the water taken via the Mt Ida race. This race is discussed in the next section.

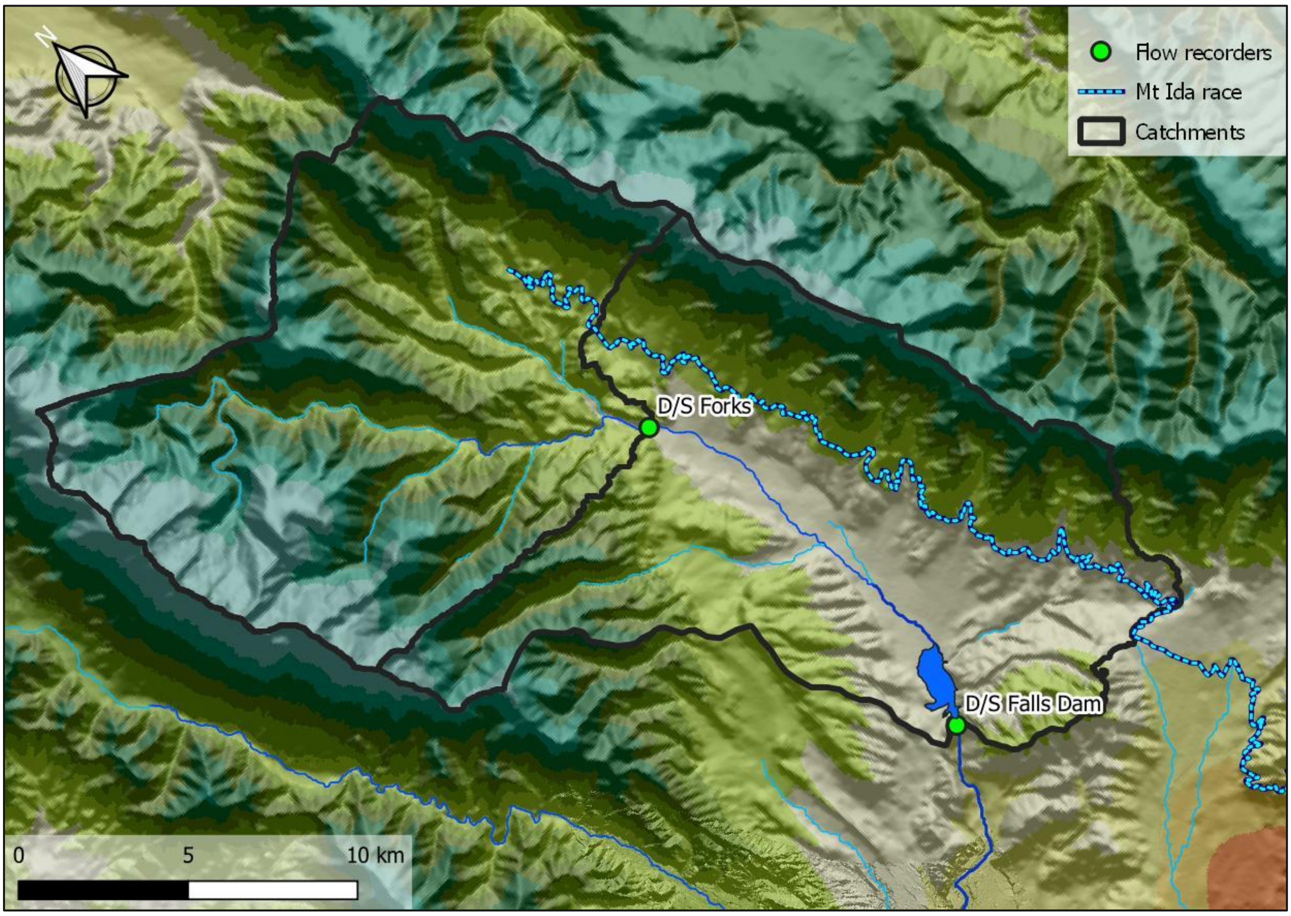

Figure 7: Falls Dam catchments

Inflows into Falls Dam were calculated as:

Inflow = Outflow - ΔStorage + Net evaporation

Net evaporation is the lake evaporation minus the evapotranspiration that would occur in the absence of the lake. This is a minor component of the water balance (annual average about 15 l/s) and was approximated as *0.4 x Lauder PET x Lake surface area*.

Calculation of the change in storage volume requires good water level recorder records. In general, the level records from 2004 to 2020 were reasonable, however some of the data in 2006 and 2007 needed to be excluded due to accuracy concerns.

Figure 8: Falls Dam water balance

Direct inflow records at the dam were calculated for the period from February 2004 to June 2020. While downstream flow data is available back to February 1999, and dam water level records from August 1999, these earlier dam level records have a number of discrepancies so were not used. Where water level records were not available, we could not calculate direct dam inflows.

A naturalised series was created by adding back in the Mt Ida race take.

6. Mt Ida Race

Mt Ida race intercepts a portion of the Falls Dam catchment yield from the Hawkdun range. This has been occurring for almost 150 years since the race was constructed in 1876. The majority of this water is conveyed to the Wedderburn catchment, and a smaller portion to the Ida Burn catchment. Mt Ida race catchment is illustrated in Figure 9. Not all the runoff from this sub-catchment is intercepted by the race. Some water is released as a residual flow, some returns to Falls Dam via race leakage, high flow water (above the race capacity) is not taken, and outside of the irrigation season only stock water is taken.

About 85% of the water taken from the Falls Dam catchment is measured at Johnson's Weir. The balance (15%) goes to the R-race offtake which is located before the weir. R-race supplies users in the Ida Burn catchment. The race has a capacity limit of about 900 l/s at Johnson's weir. The irrigation season generally runs from mid-September to the end of April.

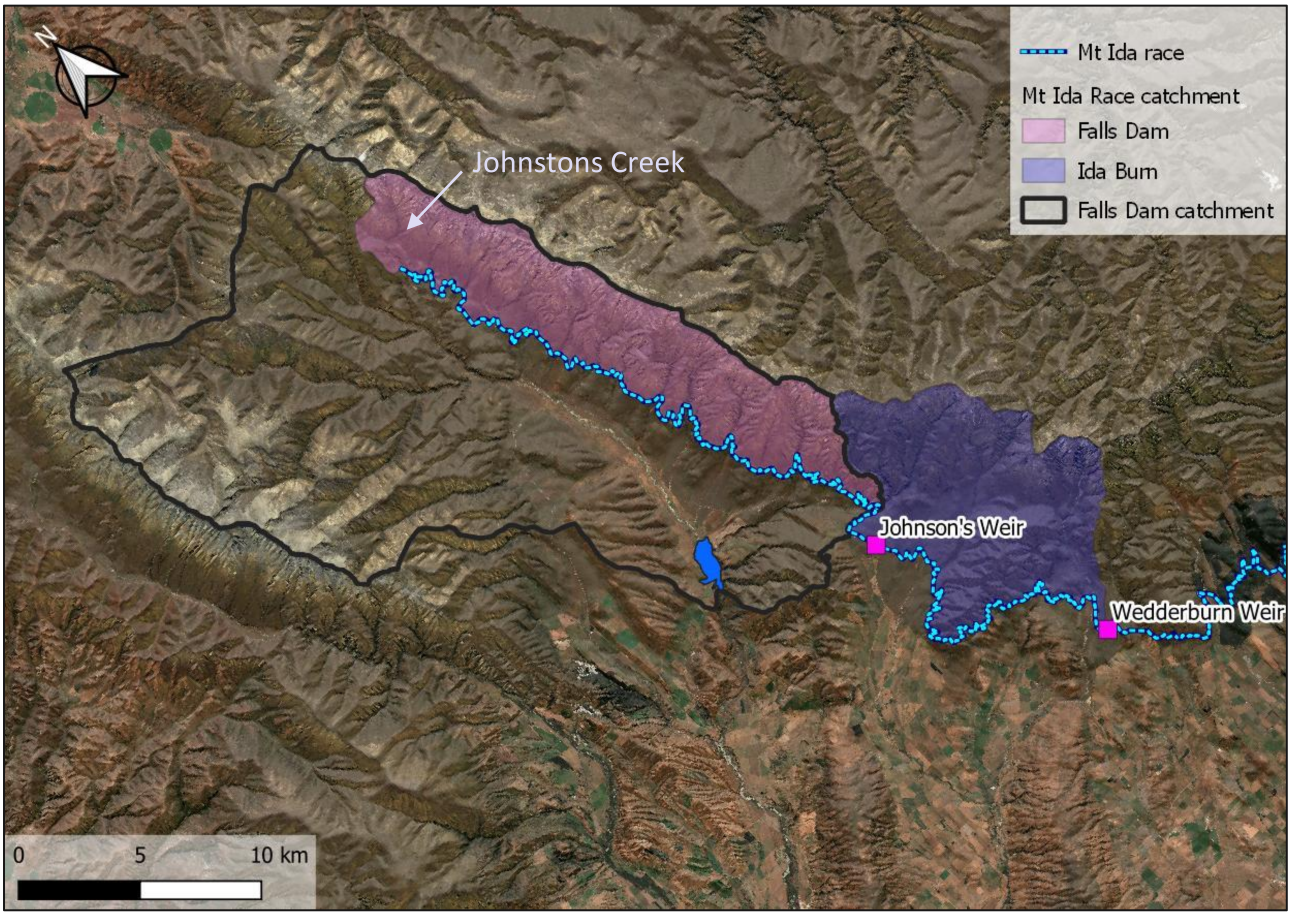

Figure 9: Mt Ida Race catchments

Figure 10: Mt Ida race and Johnstons Creek (elevation 850m)

Figure 11: Johnson's Weir (boundary of Falls catchment, elevation 725m)

Johnson's Weir records were analysed from May 2014 to June 2019. Flows were related to Falls Dam inflows (excl. Mt Ida race), and the following relationship was derived. This relationship could potentially be refined with more detailed analysis.

Figure 12: Estimated Mt Ida race take at Falls Catchment boundary

Month	Mt Ida race
Jan	0.164 x Falls Inflow
Feb	0.164 x Falls Inflow
Mar	0.164 x Falls Inflow
Apr	0.164 x Falls Inflow
15 Sep - 24 Apr	80 LPS
Sep	0.088 x Falls Inflow
Oct	0.088 x Falls Inflow
Nov	0.088 x Falls Inflow
Dec	0.105 x Falls Inflow

A comparison between the measured and modelled flow is provided in Figure 13. Data in this figure has a 14-day rolling average applied. Measured flows have been increased to account for the R-race take. Correlation between Falls Inflows and the Mt Ida race take is poor, which is surprising given the Hawkdun Range supplies about half of Falls Dam inflows. It may be that catchments on the Bathans and Hawkdun ranges are quite different in the weather systems they respond to. This discrepancy was also noted in the relationship between Forks and Falls flows (refer Section 7).

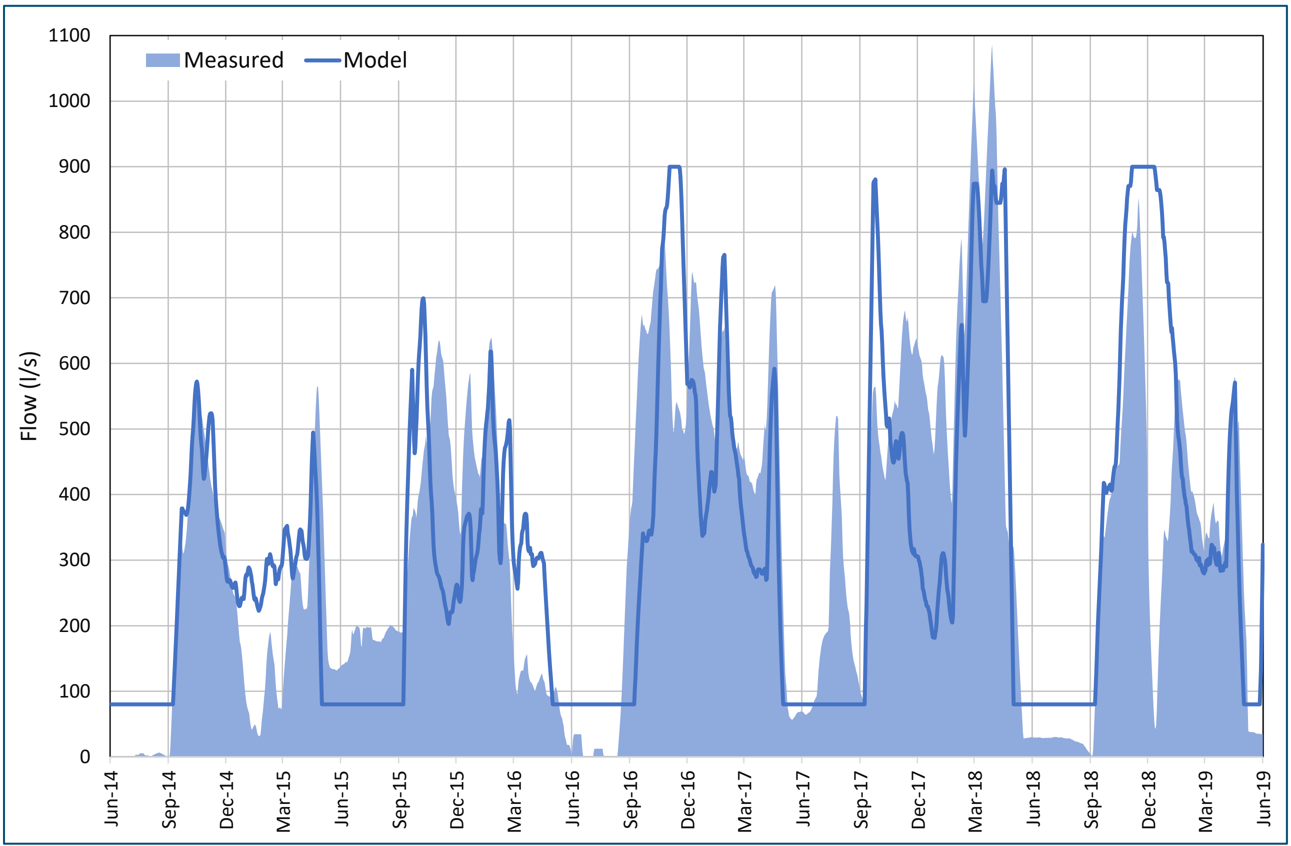

Figure 13: Mt Ida race take from Falls catchment. Measured vs modelled

7. Natural flow timeseries extension

There are a number of flow recorder sites within the Manuherekia, (or adjacent catchments) that measures flow from catchments that are not affected by irrigation abstraction (i.e. the flow is natural). An overview of the catchments is provided in Table 11 with further details in Appendix C. Record lengths range from 3.5 to 43 years.

Table 11: Natural flow catchments

Name	Catchment	Area (ha)	Mean Yield (l/s/km^2)	Low flow yield(1) (l/s/km^2)
Dunstan Ck at Gorge	Manuherekia Valley	158.5	15.1	4.2
Falls Dam inflow	Manuherekia Valley	353.3	16.0	4.7
Lauder Ck at Cattle Yards	Manuherekia Valley	73.8	15.1	4.1
Manuherekia D/S Forks	Manuherekia Valley	173.2	18.3	5.3
Thomsons Ck at Diversion Weir	Manuherekia Valley	64.8	12.0	2.9
Woolshed Ck at Lauder Station	Manuherekia Valley	13.4	15.1	4.2
Lindis R. at Lindis Peak	Lindis	548.6	11.0	2.7
Dovedale Ck at Willows	Ida Valley	39.1		
Gimmerburn at Doughertys Gorge	Ida Valley	23.9		
Ida Burn North Branch at Race	Ida Valley	19.8		
Ida Burn U/S Race	Ida Valley	15.0		
Moa Ck at Rock Bivvy	Ida Valley	49.1		
Pool Burn Reservoir	Ida Valley	57.4		
Upper Manor Burn Reservoir	Manor Burn	97.1		
Taireri at Canadian Flat	Taireri	159.6		
(1) 7MALF				

Flow timeseries extension involves finding relationships with comparable catchments and using these relationships to fill in gaps and extend the original timeseries. This report focuses on the Manuherekia Valley catchments. The Ida Valley catchments could be analysed using a similar process.

Extended flow series are only an approximation, and do not have the same confidence as real data. Rainfall (and by implications flow) has a high spatial variability. This means there is year to year variability in the relationship between catchments, and the period of timeseries overlap that is analysed can therefore affect the relationship that is derived.

For the Manuherekia Valley, the three most important natural flow records are Dunstan at Gorge, Manuherekia at Forks, and Falls Dam inflows. Falls Dam inflows is a derived series (refer Section 5). Unfortunately, none of these three flow records extend for the full record, so all three sites need to be combined to create one single long record. In addition, each of these three sites have their own challenges with data confidence. Collectively these create a Tier 1 timeseries that is used to relate and extend all the other natural tributary flows.

The primary validation site for the Catchment is Manuherekia at Ophir. What the original 2012 study illustrated, was despite some of the data challenges, the final catchment model provided a surprisingly good fit with the measured flows at Ophir. The reason for this probably relates to the dominant role that irrigation and Falls Dam have on the hydrological dynamics at Ophir. The high-quality climate records mean irrigation demand dynamics can be calculated with a high degree of confidence.

The extended daily timeseries are intended for water resource management purposes. They are not suitable for extreme flood analysis. Flood frequency analysis generally requires 15-minute data and uses a different set of analysis tools.

Falls Dam inflows (naturalised)

A derived inflow series for Falls Dam is available from 13 Feb 2004 to 31 May 2020 (refer Section 5). The naturalised flow includes the addition of the Mt Ida race water. Stewart (2012) provides an extensive discussion on the challenges of extending this time series.

The relationship between Forks and Falls Inflows requires particular mention, because of how it affects the extended flow timeseries for not only Falls Dam, but all the Dunstan Range tributaries. The relationship between Falls and Forks is quite variable (refer Figure 14). The ratio of Falls Inflow to Forks ranges from 1.76 to 2.04, depending on the period analysed. Table 12 shows that this parameter makes a 3-4% difference in the mean and low flow estimates of the final extended timeseries.

Table 12: Impact of Falls/Forks ratio on extended timeseries (1973-2020)

Recorder site	Falls/Forks = 1.76		Falls/Forks = 2.04	
	Mean	5%ile	Mean	5%ile
Falls Inflow (naturalised)	5,675	1,657	6,264	1,836
Dunstan at Gorge	2,401	667	2,297	644
Lauder at Cattle Yards	1,114	303	1,066	294
Thomsons U/S Diversion Weir	780	181	745	174
Total	**9,970**	**2,808**	**10,372**	**2,949**

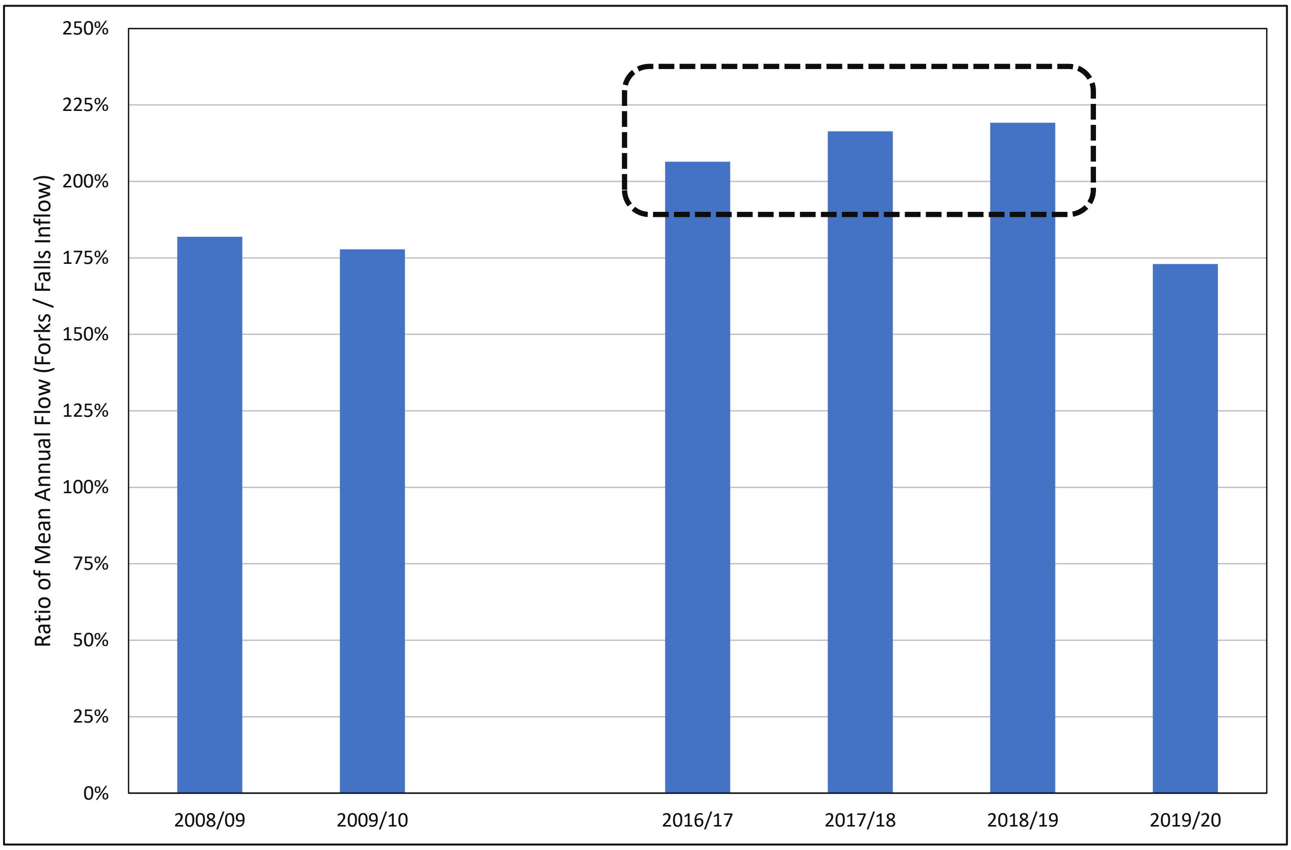

Figure 14: Ratio of mean annual flow (Forks / Naturalised Falls Inflow)

The ratio variability occurs when comparing both mean and median flows, so is not isolated to high flows. The degree of variability (between Forks and Falls) is somewhat surprising and could be due to three possibilities

1. The variability is real and is due to the poor correlation between inflows from Bathans and Hawkdun ranges.
2. Due to data accuracy challenges associated with the unstable bed at the Forks flow recorder site. Refer Stewart (2012). or
3. Due to data accuracy challenges with the flows at Falls Dam.

There is some evidence for Option 1 in the Mt Ida race record (refer Section 6). Option 3 is considered unlikely, because the ratio variability occurs when comparing both Pioneer dam outflow records[2] and the downstream recorder records. Option 2 is difficult to reconcile given monthly gaugings should provide a reasonable estimate of the median flow. For simplicity, and to provide closer agreement with earlier work, we have opted to use a ratio of 1.76, to match Stewart (2012).

Falls naturalised inflows were extended using the following relationships (in order of priority):

(A) Direct estimates, where available (2004-2020)
(B) Falls Inflow = 1.76 x (1.31 x Dunstan at Gorge + 74)
(C) Falls Inflow = 1.76 x Forks
(D) Relationship with Lindis at Lindis Peaks, via Dunstan at Gorge (refer Appendix D)
(E) Relationship with Ophir (minor gaps only)

Relationships (B) and (C) are the same as used by Stewart (2012). Relationship (D) adjusts for the seasonal differences between Dunstan at Gorge and Lindis at Lindis Peaks. Relationship (E) is only used for minor gap filling prior to the start of the Lindis recorder opening in 1976. Flows at Ophir are heavily influenced by irrigation abstraction and Falls Dam dynamics, so are far from a natural timeseries. The resulting timeseries is summarized in Figure 15 and Appendix E.

[2] Turbine, bypass valve and spillway flow records

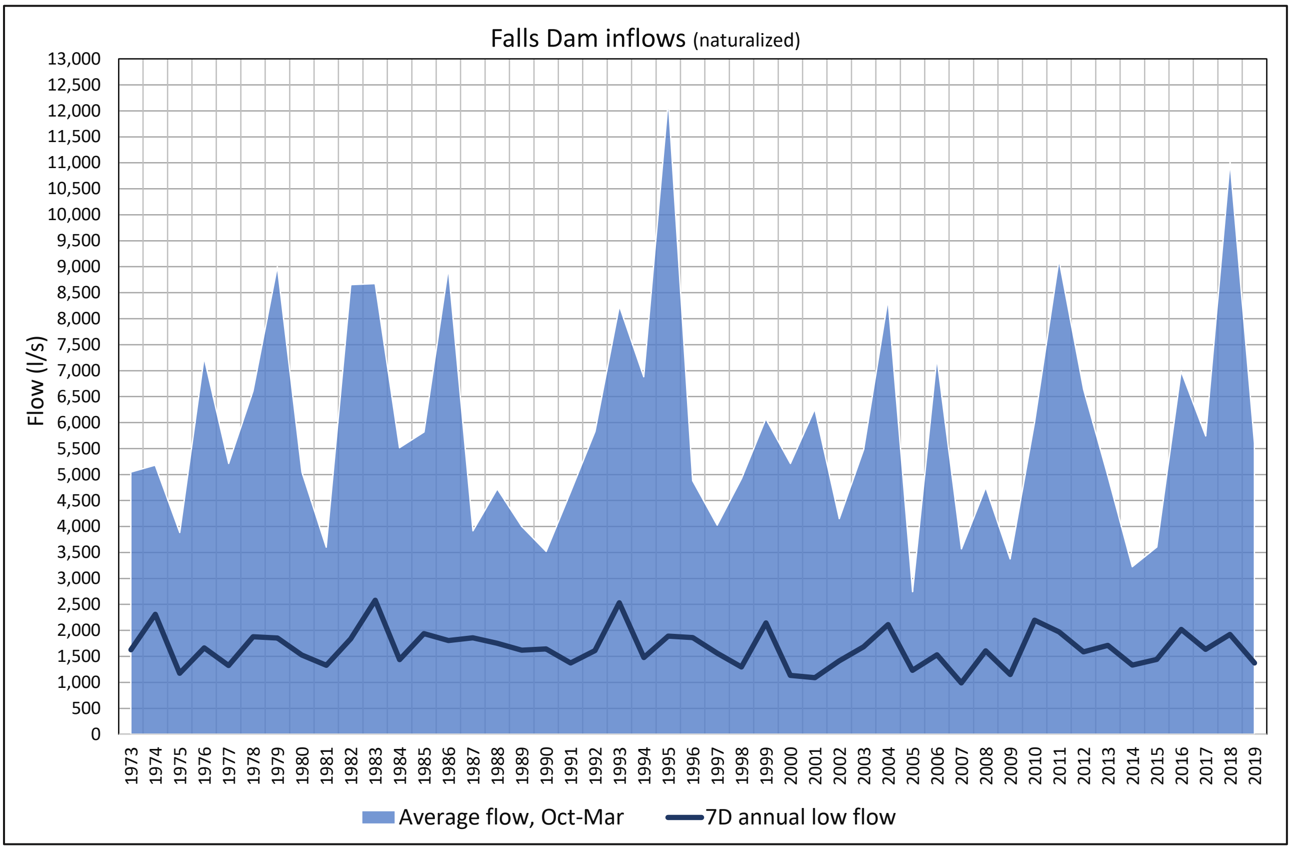

Figure 15: Falls Dam naturalised inflow extended timeseries.

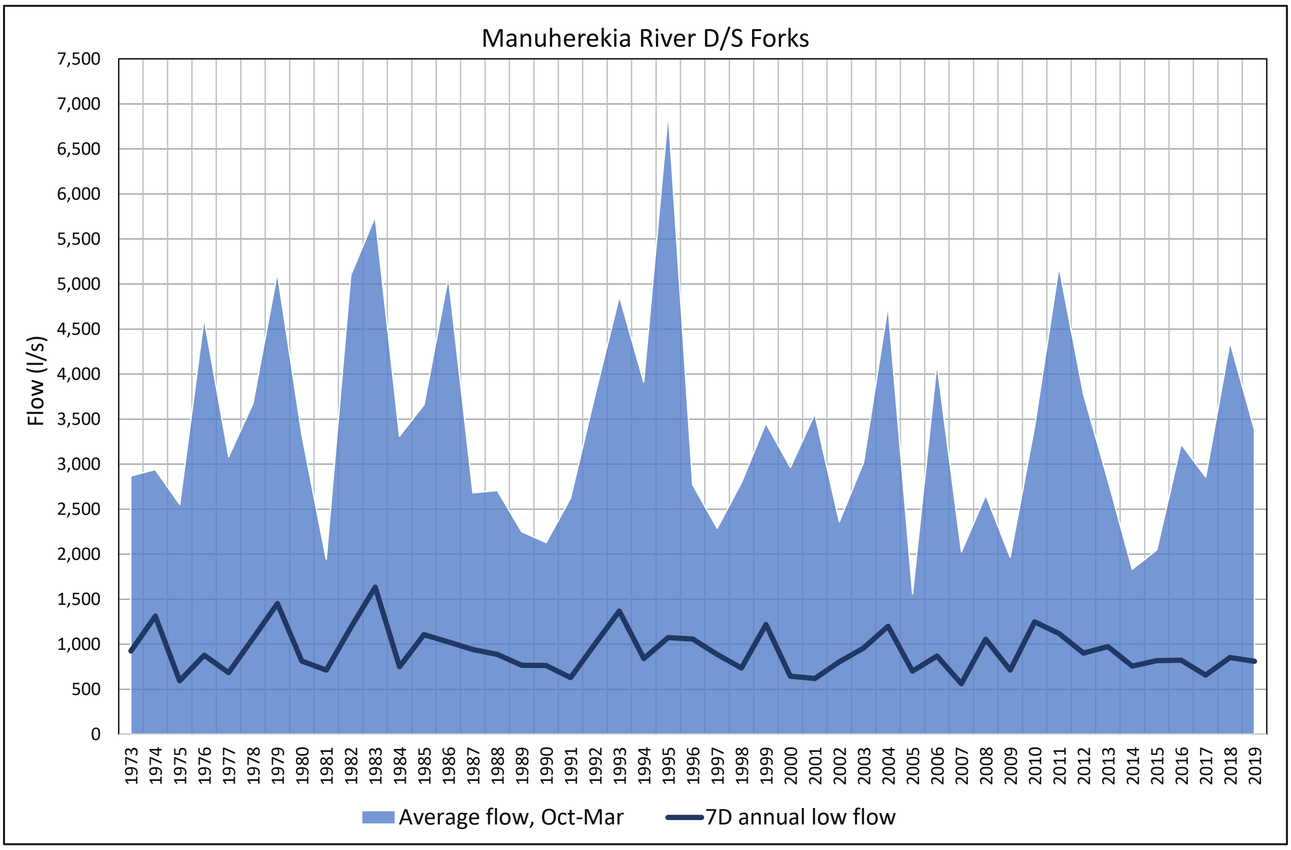

Figure 16: Manuherekia River D/S Forks extended timeseries.

Dunstan at Gorge

Dunstan at Gorge flow was extended using the following relationships (in order of priority):

(A) Direct records, where available (1976 to 1994, 2007 to 2010)

(B) Dunstan = 0.433 x Falls Inflow (naturalised) – 56 l/s

(C) Dunstan = 0.763 x Forks – 56 l/s

(D) Relationship with Lindis at Lindis Peaks (refer Appendix D)

(E) Relationship with Ophir (minor gap filling only)

Relationships (B) and (C) are the inverse of (B) and (C) from the previous section. The resulting timeseries is summarized in Figure 17 and Appendix E.

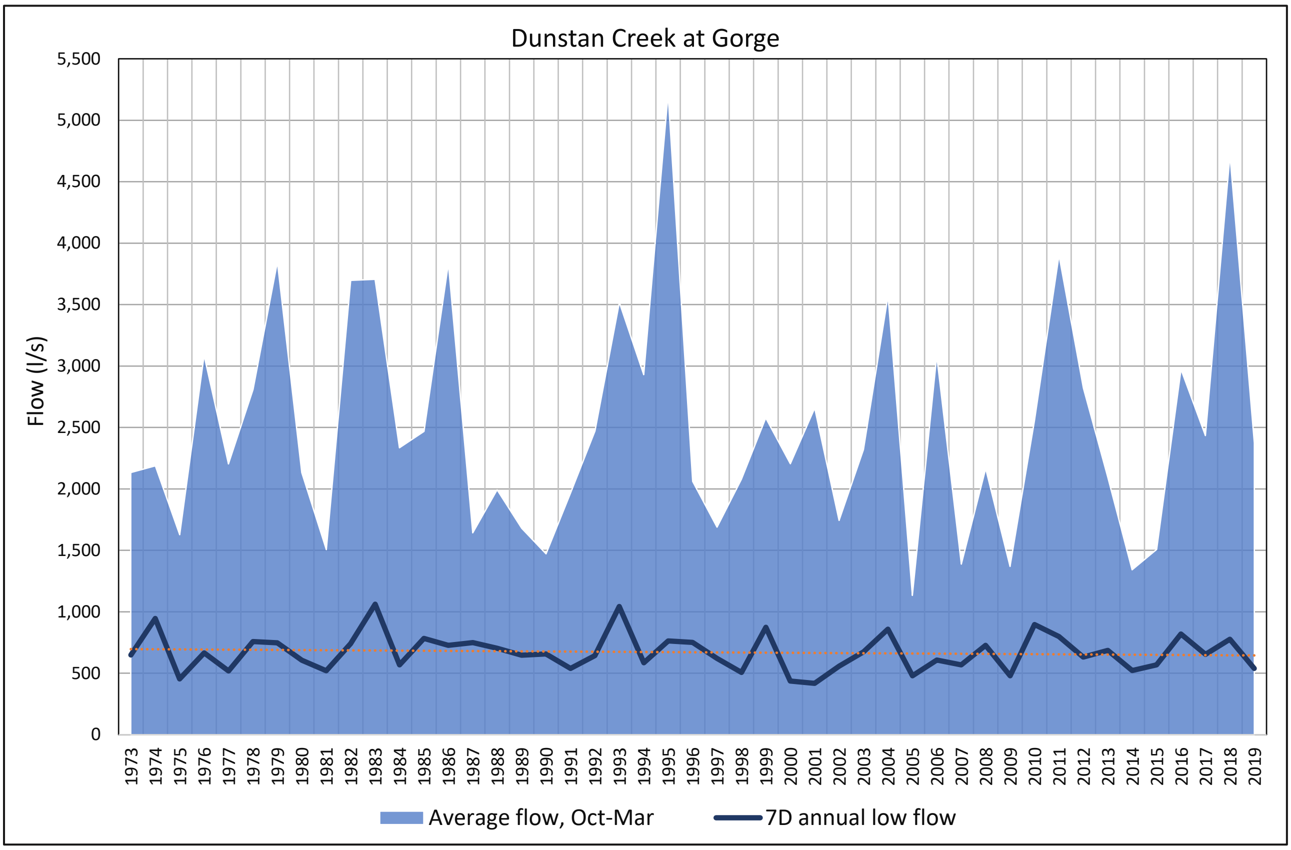

Figure 17: Dunstan Creek at Gorge extended timeseries.

Lauder Creek at Cattle Yards

Lauder Creek at Cattle Yards flow was extended using the following relationships (in order of priority):

(A) Direct records, where available (2008 – 2010, 2016 – 2020)

(B) Relationship with extended Dunstan Creek record (refer Appendix D)

The resulting timeseries is summarized in Figure 18 and Appendix E.

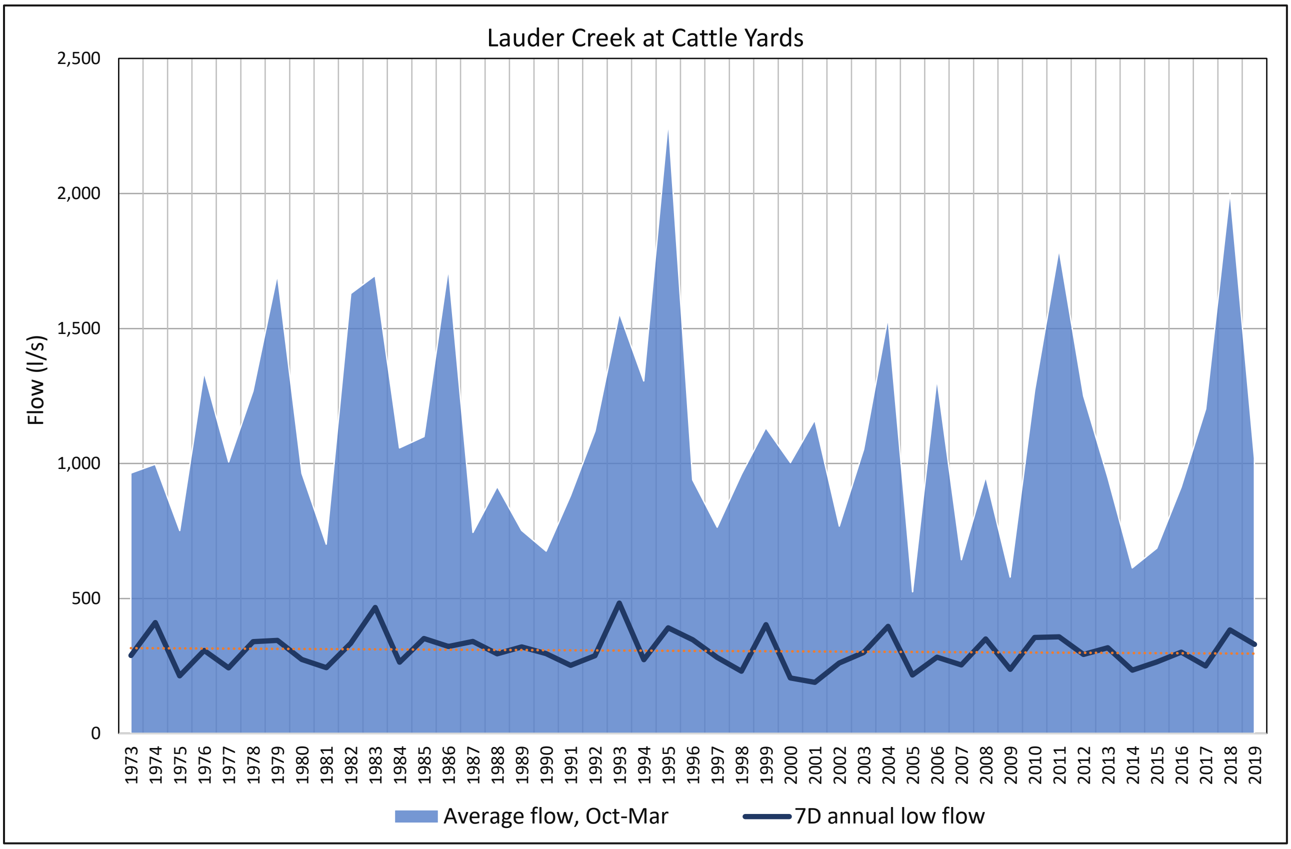

Figure 18: Lauder Creek at Cattle Yards extended timeseries

Thompsons Creek U/S Diversion Weir

Thompsons Creek U/S Diversion Weir flow was extended using the following relationships (in order of priority):

(A) Direct records, where available (2008 – 2010, 2019 – 2020)

(B) Relationship with extended Dunstan Creek record (refer Appendix D)

The resulting timeseries is summarized in Figure 19 and Appendix E.

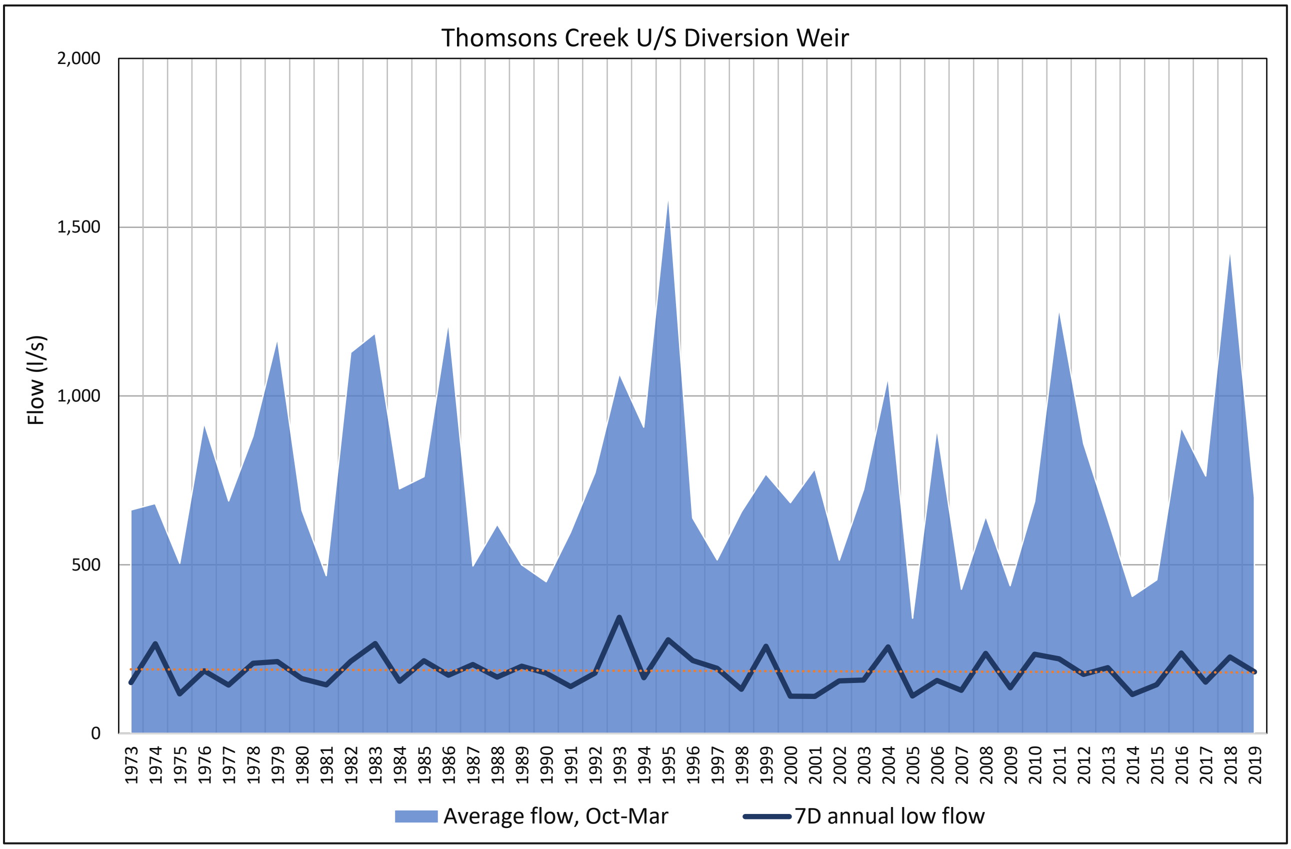

Figure 19: Thomsons Creek U/S Diversion Weir

This flow series could be refined for the period 2016 to 2019 by consideration of the relationship between Thompsons Creek and Lauder Creek since Thompsons is more correlated with Lauder than with Falls Dam inflows.

9. References

Reports

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Data Support

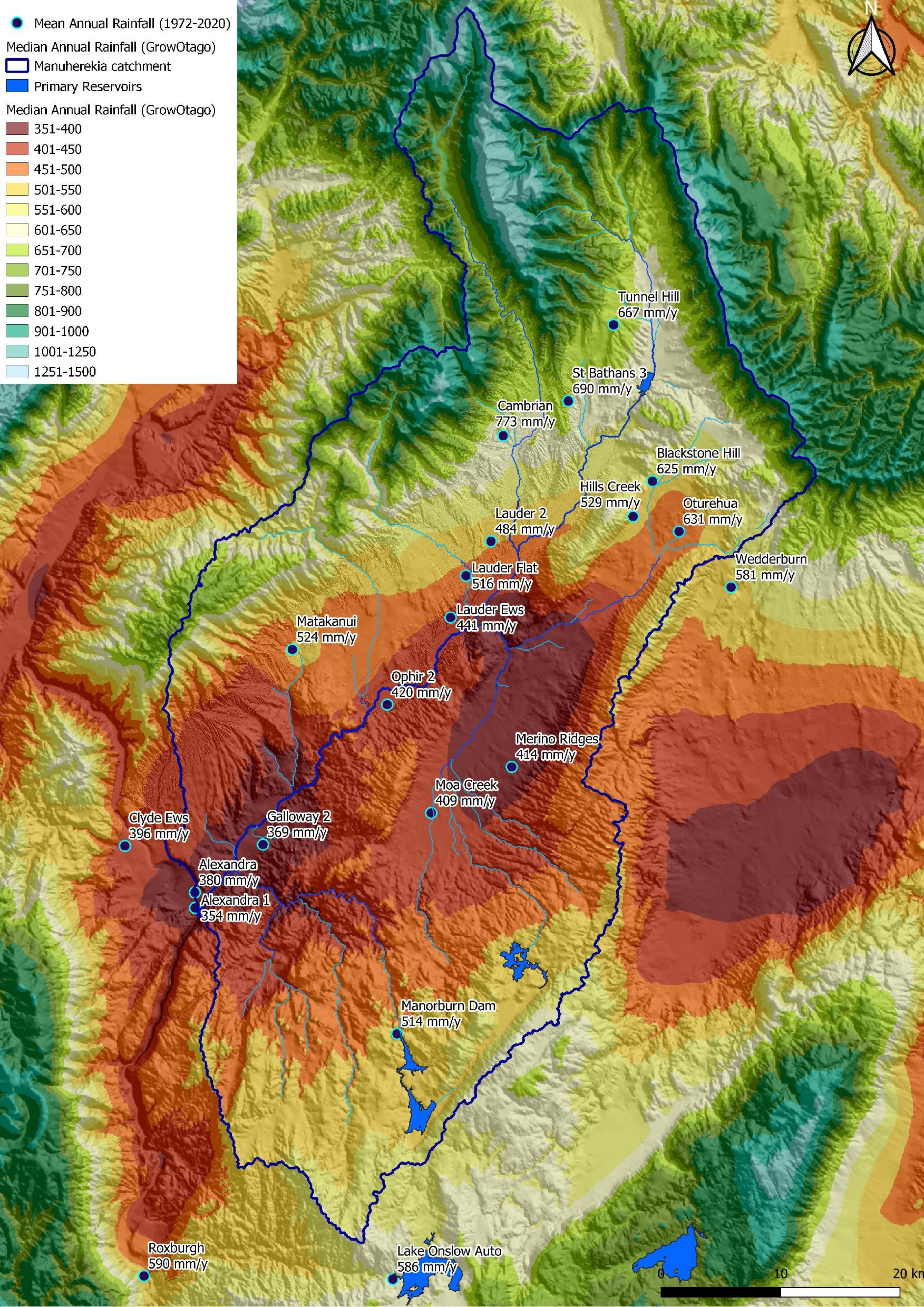
This study would not be possible without the data support of the following:

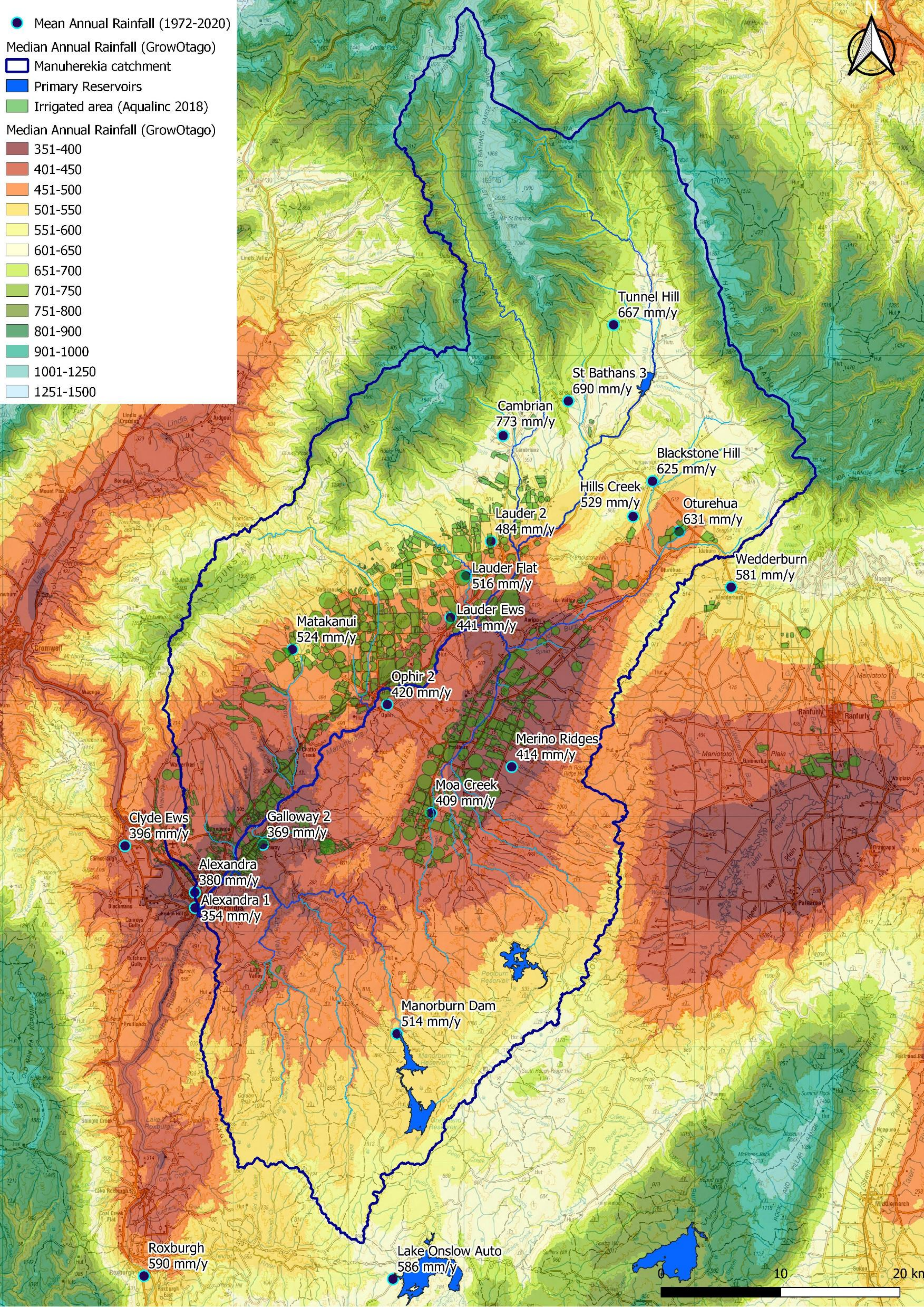
Flow recorder and ORC rainfall data was provided by Lauren Hunter of Otago Regional Council.
GIS support was provided by Andrew MacKay of Otago Regional Council.
Flow recorder data for Manuherekia at Ophir was provided by Kathy Walter of NIWA.
Falls Dam outflow and level records were provided by Tony Jack of Pioneer Energy.
Water meter data was provided from Otago Regional Council (passed on from NIWA).
Mt Ida race photos (cover photo, Figure 9 and Figure 10) were provided by Tim Anderson.

Appendix A: Climate

Map 1. Annual Rainfall, 1 June to 30 May
Map 2. Annual Rainfall including approximate irrigated area
Table 1. Annual rainfall for each season (1 June to 30 May).
Table 2. Total rainfall from 1 October to 31 March, for each season.
Table 3. Annual Potential Evapotranspiration for each season (1 June to 30 May).

For tables, blue shading indicates years when the recorder site was operating. For other years, data is derived from the relationship with other comparable sites. Red cells are 20%ile years (i.e. 1 year in 5 dry events).


Mean Annual Rainfall (1972-2020)
Median Annual Rainfall (GrowOtago)
Manuherekia catchment
Primary Reservoirs
Median Annual Rainfall (GrowOtago)
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
751-800
801-900
901-1000
1001-1250
1251-1500
N
Tunnel Hill 667 mm/y
St Bathans 3 690 mm/y
Cambrian 773 mm/y
Blackstone Hill 625 mm/y
Hills Creek 529 mm/y
Oturehua 631 mm/y
Lauder 2 484 mm/y
Lauder Flat 516 mm/y
Wedderburn 581 mm/y
Lauder Ews 441 mm/y
Matakanui 524 mm/y
Ophir 2 420 mm/y
Merino Ridges 414 mm/y
Moa Creek 409 mm/y
Clyde Ews 396 mm/y
Galloway 2 369 mm/y
Alexandra 380 mm/y
Alexandra 1 354 mm/y
Manorburn Dam 514 mm/y
Roxburgh 590 mm/y
Lake Onslow Auto 586 mm/y
0
10
20 km



Mean Annual Rainfall (1972-2020)
Median Annual Rainfall (GrowOtago)
Manuherekia catchment
Primary Reservoirs
Irrigated area (Aqualinc 2018)
Median Annual Rainfall (GrowOtago)
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
751-800
801-900
901-1000
1001-1250
1251-1500
N
Tunnel Hill 667 mm/y
St Bathans 3 690 mm/y
Cambrian 773 mm/y
Blackstone Hill 625 mm/y
Hills Creek 529 mm/y
Oturehua 631 mm/y
Lauder 2 484 mm/y
Wedderburn 581 mm/y
Lauder Flat 516 mm/y
Lauder Ews 441 mm/y
Matakanui 524 mm/y
Ophir 2 420 mm/y
Merino Ridges 414 mm/y
Moa Creek 409 mm/y
Clyde Ews 396 mm/y
Galloway 2 369 mm/y
Alexandra 380 mm/y
Alexandra 1 354 mm/y
Manorburn Dam 514 mm/y
Roxburgh 590 mm/y
Lake Onslow Auto 586 mm/y
0
10
20 km

ANNUAL RAINFALL, 1 JUNE - 31 MAY. (mm)

	Clyde EWS	Alexandra	Alexandra 1	Galloway 2	Ophir 2	Matakanui	Lauder EWS	Lauder Flat	Lauder 2	Cambrian	St Bathans 3	Tunnel Hill	Blackstone Hill	Oturehua	Hills Creek	Wedderburn	Merino Ridges	Moa Creek	Manorburn Dam	Roxburgh	Lake Onslow
Season	12431	5578	5576	5587	5544	5530	5535	5537	22567	5248	5239	1001	5252	5253	1002	5255	1003	5545	5608	5621	5630
1924	359	398	369	335	405	501	423	495	465	737	647	643	585	648	499	546	381	376	486	433	429
1925	489	492	459	459	425	530	441	519	488	787	686	677	622	641	525	648	501	492	569	628	627
1926	397	399	371	350	436	535	457	529	496	774	684	676	623	608	531	610	472	467	597	630	622
1927	323	285	267	316	380	473	395	464	435	704	614	601	554	542	468	528	370	364	451	434	436
1928	376	317	292	324	403	498	422	492	462	727	640	635	580	586	495	577	399	393	443	550	538
1929	355	354	329	353	345	430	359	423	397	640	558	553	504	628	428	507	349	341	422	478	480
1930	358	305	284	361	348	428	364	421	396	620	547	539	500	568	424	557	409	407	577	602	594
1931	435	394	367	426	373	465	388	456	428	692	603	591	546	586	461	498	498	489	511	571	567
1932	338	267	252	333	364	449	380	443	414	662	583	565	524	489	444	437	416	412	441	544	549
1933	442	381	356	413	452	560	470	551	516	830	726	709	656	661	555	585	573	563	534	554	548
1934	385	368	343	392	482	594	503	584	547	866	763	744	695	666	587	584	581	575	519	635	632
1935	303	261	247	302	363	447	379	442	412	656	579	561	521	588	442	498	329	326	394	489	490
1936	462	430	402	467	568	701	593	690	647	1028	904	884	821	760	695	609	532	526	643	755	750
1937	310	312	294	328	334	416	346	409	382	625	544	528	488	498	411	477	324	318	385	375	380
1938	335	295	277	300	368	455	384	451	422	672	590	584	528	569	453	500	368	362	411	538	531
1939	445	447	416	431	526	657	544	641	602	983	894	831	807	793	676	728	525	515	534	710	713
1940	378	335	313	335	345	427	359	419	394	627	509	540	463	465	392	441	317	313	396	437	433
1941	322	327	305	323	350	429	365	423	396	624	499	538	452	459	384	451	357	354	465	511	505
1942	390	391	363	387	449	555	469	548	515	814	632	711	571	608	487	534	465	459	469	531	523
1943	418	417	391	377	467	575	488	568	530	846	925	719	832	700	702	675	419	418	494	613	606
1944	515	512	480	496	561	690	604	701	656	1038	899	893	817	812	692	765	544	540	687	851	853
1945	384	388	357	363	422	524	410	478	450	708	643	617	584	551	498	546	376	371	459	488	480
1946	319	277	255	295	318	396	330	390	367	600	578	508	524	514	441	496	294	286	418	390	392
1947	388	337	318	370	392	488	409	480	449	728	561	615	507	540	429	501	361	359	450	491	490
1948	423	412	386	351	430	572	421	487	455	716	677	613	613	584	521	540	312	310	388	529	516
1949	337	287	267	295	413	489	418	486	456	634	541	546	492	511	418	533	283	279	351	507	502
1950	400	363	340	348	428	535	469	544	509	735	625	629	569	632	483	585	374	368	372	513	508
1951	281	398	368	392	387	515	365	429	403	704	595	602	537	545	460	513	410	401	445	567	557
1952	454	448	417	490	525	528	498	580	543	731	680	621	616	601	524	629	480	473	482	552	547
1953	491	262	245	262	320	351	356	415	390	582	504	497	458	471	388	426	307	303	336	453	453
1954	219	326	305	345	404	489	406	475	446	612	529	520	479	518	404	527	366	364	390	596	590
1955	425	318	301	324	401	409	402	477	445	768	702	634	626	657	527	584	367	362	375	438	445
1956	495	502	469	466	544	643	527	614	575	781	718	662	647	646	549	647	495	492	551	656	655
1957	569	483	452	444	555	710	597	692	646	946	839	812	759	779	648	754	513	512	602	739	737
1958	333	295	277	285	346	371	355	414	387	649	541	551	483	507	412	503	286	284	304	505	503
1959	353	352	329	281	334	467	368	425	397	664	481	571	437	474	372	485	295	295	385	458	444
1960	378	342	319	369	450	540	490	568	532	810	743	688	673	684	570	663	434	432	492	561	555
1961	384	349	327	354	428	522	458	532	497	820	721	691	658	668	554	644	407	404	522	565	556
1962	428	377	349	386	407	530	477	562	529	876	702	743	635	657	537	608	408	400	543	521	517
1963	378	279	260	315	412	454	404	476	447	766	605	650	548	569	464	517	383	375	476	538	541
1964	368	362	340	346	424	481	464	535	500	768	629	660	574	535	487	523	409	412	636	649	634
1965	360	333	312	335	376	566	364	421	394	782	594	670	539	517	458	537	350	349	521	516	506
1966	373	331	313	277	334	486	408	478	446	687	564	579	507	471	430	464	324	320	354	445	448
1967	480	432	405	409	541	631	485	566	529	927	772	785	695	676	588	619	492	490	580	509	501
1968	392	385	360	354	368	436	464	542	509	793	625	677	568	569	481	589	438	432	619	621	619
1969	367	328	303	322	388	477	328	381	359	646	498	560	456	469	388	471	399	392	603	579	574
1970	425	373	343	342	421	541	412	486	459	744	578	625	528	539	442	464	400	389	467	510	505
1971	473	454	427	414	460	555	435	511	478	867	728	734	655	674	554	652	457	451	598	610	616
1972	370	384	356	358	412	464	382	455	427	692	630	581	564	544	475	516	383	372	511	589	606
1973	281	309	285	299	394	458	366	429	403	647	691	549	627	541	529	495	365	360	446	507	506
1974	432	399	372	403	405	555	439	512	479	763	565	651	512	520	431	484	447	441	530	591	584
1975	293	278	258	301	310	392	324	384	361	590	533	469	481	492	406	444	310	301	416	483	486
1976	401	424	393	385	490	623	492	578	543	871	761	751	683	693	583	572	489	477	612	641	644
1977	256	224	210	215	307	409	302	358	335	549	512	463	460	469	389	443	317	315	395	382	379
1978	477	502	466	503	553	736	570	668	629	1007	869	790	790	804	667	724	520	509	640	657	655
1979	465	496	462	460	450	625	465	543	510	809	737	691	672	679	570	603	439	432	539	654	640
1980	436	414	382	349	423	506	351	413	390	629	640	582	580	588	492	568	410	402	520	540	545
1981	398	358	336	355	322	472	334	394	368	600	647	523	583	598	490	470	382	374	477	530	530
1982	488	502	470	445	511	704	575	672	629	1005	840	859	756	765	643	668	480	474	598	865	852
1983	474	473	438	460	508	666	499	583	548	870	859	752	782	790	662	725	498	492	612	722	722
1984	291	278	253	267	324	429	304	359	340	547	508	472	463	472	391	432	319	311	388	442	442
1985	389	374	343	360	478	624	503	583	547	865	615	744	559	566	473	529	469	465	579	528	616
1986	418	385	372	390	458	574	523	554	518	819	817	696	746	752	629	713	448	447	559	597	729
1987	420	384	374	393	371	582	517	461	433	694	612	582	556	561	495	524	364	359	450	710	737
1988	420	365	372	392	394	516	476	549	513	804	607	691	552	555	493	528	386	385	479	572	541
1989	344	305	303	317	367	526	463	446	416	653	663	564	532	534	498	505	360	359	448	435	416
1990	310	320	272	287	323	386	371	395	370	589	558	506	503	511	413	471	317	314	393	462	449
1991	376	336	326	341	308	412	387	381	358	581	612	498	508	518	430	470	304	297	375	630	560
1992	383	374	334	349	438	523	530	546	513	829	783	706	766	778	675	715	431	423	533	644	496
1993	617	590	550	581	553	750	679	692	649	1013	916	848	864	868	760	824	541	538	661	807	554
1994	382	349	334	350	366	484	448	446	418	667	580	567	586	597	479	550	359	356	445	495	481
1995	570	551	496	522	686	743	666	748	704	1133	959	975	896	907	659	839	677	662	830	830	794
1996	398	412	354	372	460	572	417	481	448	713	596	609	668	674	510	634	452	449	564	635	685
1997	304	292	268	284	324	432	368	410	385	612	546	530	421	427	388	394	318	313	390	482	515
1998	372	364	327	343	368	494	360	455	427	691	580	584	524	532	373	493	362	357	452	554	611
1999	495	514	436	459	626	826	621	684	654	1018	779	870	633	639	613	601	613	610	760	773	571
2000	371	323	325	341	370	427	419	465	398	704	517	601	470	480	403	437	364	357	447	511	554
2001	373	366	331	349	407	519	375	492	442	738	671	631	607	616	487	569	401	395	497	577	665
2002	355	302	310	325	352	436	345	470	423	713	545	605	491	500	405	458	347	342	433	479	479
2003	443	367	391	410	310	464	305	397	352	600	562	509	510	517	434	482	305	301	380	515	480
2004	524	517	462	487	515	632	520	673	593	989	760	863	688	693	619	649	506	502	623	745	620
2005	240	245	211	222	340	404	408	559	475	838	678	715	606	615	523	569	335	330	418	610	724
2006	284	278	249	262	309	370	324	468	422	694	736	608	664	670	487	619	304	299	372	496	558
2007	386	341	339	355	444	483	429	546	523	822	709	694	640	649	557	602	436	430	543	590	480
2008	369	372	322	337	416	510	406	532	516	814	696	736	629	641	571	585	422	402	507	554	685
2009	316	278	277	289	307	402	310	428	354	636	560	512	505	512	376	480	300	299	378	401	503
2010	442	433	392	412	517	593	539	677	661	1013	886	786	802	814	710	759	518	505	634	685	752
2011	396	389	356	377	502	539	556	674	611	976	876	770	800	800	647	766	472	491	601	678	507
2012	389	361	343	360	451	524	445	602	536	910	790	806	716	728	639	671	420	437	551	632	607
2013	478	441	417	433	427	585	447	548	539	840	765	819	680	696	564	636	406	416	534	578	660
2014	317	299	280	294	268	320	293	344	360	521	512	592	462	472	397	431	296	259	328	523	517
2015	308	288	272	285	386	412	425	498	519	751	746	685	670	682	567	630	366	376	478	554	557
2016	454	428	396	417	444	462	415	487	490	728	700	730	633	639	503	596	450	430	537	572	562
2017	435	415	391	412	533	496	470	546	587	814	846	861	773	786	715	730	480	520	649	654	653
2018	517	487	454	478	537	568	558	654	611	973	849	816	766	774	662	720	546	520	653	665	662
2019	371	352	327	346	419	504	442	517	489	769	685	598	623	630	526	586	440	405	504	548	539
20%ile	333	303	282	308	345	430	364	423	396	638	559	552	504	512	420	481	326	323	394	488	483
1972-2019	396	380	354	369	420	524	441	516	484	773	690	667	625	631	529	581	414	409	514	590	586

6 MONTHLY RAINFALL, 1 OCTOBER TO 31 MARCH. (mm)

	Clyde EWS	Alexandra	Alexandra 1	Galloway 2	Ophir 2	Matakanui	Lauder EWS	Lauder Flat	Lauder 2	Cambrian	St Bathans 3	Tunnel Hill	Blackstone Hill	Oturehua	Hills Creek	Wedderburn	Merino Ridges	Moa Creek	Manorburn Dam	Roxburgh	Lake Onslow
Season	12431	5578	5576	5587	5544	5530	5535	5537	22567	5248	5239	1001	5252	5253	1002	5255	1003	5545	5608	5621	5630
1924	236	278	258	227	278	336	294	337	316	477	427	429	388	421	337	363	266	266	343	260	246
1925	252	286	266	239	234	282	247	282	264	397	357	354	325	328	281	365	265	266	331	323	305
1926	292	284	264	238	334	402	353	402	376	565	508	504	464	454	401	473	328	331	424	391	369
1927	148	141	132	150	201	242	212	242	226	340	306	304	279	293	241	297	193	194	253	204	193
1928	259	215	199	209	288	349	305	349	327	492	442	442	402	429	349	413	268	268	301	374	353
1929	208	232	216	232	198	240	209	240	225	340	304	306	276	324	240	282	208	206	246	236	224
1930	267	230	215	276	254	305	269	305	284	426	384	377	352	339	303	344	289	292	385	383	362
1931	256	230	214	251	199	240	211	240	224	337	303	300	277	270	239	248	281	283	298	330	312
1932	199	147	137	197	214	258	226	258	241	361	325	321	297	269	256	262	210	211	181	256	242
1933	248	218	204	240	253	305	268	305	285	428	385	381	352	372	304	343	312	313	308	349	330
1934	237	214	201	242	319	382	337	381	356	532	481	470	442	369	379	366	350	355	272	339	318
1935	153	144	134	184	225	271	238	271	253	380	342	338	313	361	270	339	196	197	221	250	236
1936	258	240	224	268	362	435	383	435	406	608	549	540	502	450	432	417	330	332	389	433	409
1937	158	154	144	160	148	179	157	179	168	252	227	226	207	237	179	287	140	140	188	157	149
1938	206	190	176	193	242	294	256	295	277	420	374	381	339	315	296	293	249	246	283	356	339
1939	221	218	204	221	234	280	248	280	261	390	344	344	316	317	271	312	266	268	242	319	300
1940	254	214	200	224	217	261	230	261	244	366	314	326	287	307	248	275	196	198	247	260	245
1941	230	213	199	231	243	291	257	291	272	407	319	360	292	273	251	282	252	254	327	326	308
1942	261	276	257	278	312	378	330	379	355	536	416	482	378	406	328	371	340	339	315	338	320
1943	248	261	244	227	275	330	291	330	308	461	452	408	414	375	357	360	272	276	273	370	349
1944	342	334	313	334	373	448	405	459	429	642	593	570	544	494	467	497	365	368	381	426	402
1945	241	249	232	239	287	346	302	345	323	486	433	435	394	375	342	369	252	253	334	312	296
1946	109	118	110	119	130	157	156	178	167	251	275	224	252	236	217	224	123	124	220	180	171
1947	230	203	189	232	236	273	213	243	227	341	327	304	300	311	258	288	210	212	250	275	261
1948	309	314	295	254	309	417	293	332	310	463	455	409	417	385	359	362	223	226	285	380	359
1949	195	159	149	172	251	309	279	317	296	391	355	350	325	334	280	344	177	179	222	280	264
1950	182	191	178	188	279	324	336	381	356	475	425	420	390	392	335	394	217	217	204	313	296
1951	160	245	227	243	245	292	232	266	249	415	400	369	364	354	316	346	250	249	273	382	363
1952	222	292	271	337	342	333	326	371	346	442	455	390	416	390	359	435	297	297	312	332	313
1953	199	162	151	162	201	213	239	272	254	348	328	308	300	285	259	279	190	191	203	233	219
1954	130	173	162	205	232	267	243	276	258	369	300	325	275	281	236	307	223	226	211	369	349
1955	185	122	114	129	157	149	146	166	156	244	246	215	225	243	194	231	164	164	168	173	163
1956	282	372	346	336	387	451	353	402	376	450	426	398	389	379	336	388	346	347	385	375	354
1957	397	346	322	319	399	506	419	476	444	648	603	574	551	550	475	531	360	363	421	423	400
1958	216	203	189	189	216	226	229	262	245	386	319	343	291	312	252	313	197	197	198	296	280
1959	282	294	275	219	266	362	291	331	309	478	365	423	335	354	288	355	226	228	295	352	332
1960	228	225	211	270	294	341	333	377	352	463	455	408	418	413	358	412	306	310	333	341	322
1961	220	214	200	221	252	274	282	317	295	406	429	357	396	386	338	362	235	239	287	355	335
1962	226	189	177	197	214	290	259	295	276	452	368	399	337	348	291	343	216	217	291	295	278
1963	183	124	116	168	239	238	220	251	235	404	342	358	312	333	270	299	209	211	246	251	237
1964	288	289	272	274	336	369	340	384	358	554	473	488	435	407	372	391	324	329	464	463	435
1965	234	218	204	229	259	402	255	289	269	518	399	458	365	343	314	376	237	239	339	352	332
1966	207	188	175	164	198	253	234	268	251	358	312	316	285	238	246	262	211	210	182	216	205
1967	333	282	263	286	374	417	300	341	318	498	419	440	384	356	330	349	339	341	344	333	315
1968	201	208	194	189	199	251	306	349	326	458	374	406	342	356	295	359	237	239	343	336	318
1969	254	205	191	229	287	335	253	289	271	469	382	415	349	362	301	371	294	294	387	335	316
1970	182	161	151	154	195	203	200	226	211	285	266	252	244	246	210	220	186	189	212	296	279
1971	239	223	209	213	236	319	222	253	236	474	382	419	350	342	301	361	209	211	291	269	253
1972	114	115	106	126	154	188	162	186	175	288	234	256	213	221	185	204	143	142	203	152	144
1973	167	188	174	185	246	273	215	245	229	343	367	305	335	300	289	281	239	240	288	269	255
1974	245	243	226	256	232	328	272	309	288	432	297	384	272	269	234	269	276	278	328	374	355
1975	114	109	101	116	135	155	158	180	169	254	237	196	216	213	187	210	146	145	209	228	216
1976	244	227	210	227	292	353	305	351	329	498	435	450	394	389	344	319	261	259	314	327	311
1977	138	121	112	116	169	218	139	160	149	225	243	202	221	218	192	236	199	200	242	227	216
1978	279	284	262	300	309	425	353	402	376	565	445	429	405	401	351	399	289	289	350	375	357
1979	297	337	314	315	297	414	308	351	328	493	487	458	445	440	384	414	292	292	354	453	428
1980	221	227	212	195	251	298	201	230	215	324	365	304	333	329	288	331	227	229	292	231	219
1981	192	167	156	161	129	186	157	180	169	254	249	191	228	225	197	193	162	163	197	270	254
1982	314	324	302	282	290	426	353	403	377	567	492	507	448	442	388	435	277	278	337	559	529
1983	281	272	254	272	304	363	332	378	353	531	544	476	498	492	429	517	323	326	393	371	351
1984	177	167	158	170	181	263	183	209	196	295	265	264	242	239	209	234	177	178	215	215	204
1985	226	229	204	219	322	396	341	388	362	544	376	485	345	341	297	336	315	317	383	311	354
1986	236	234	217	232	287	298	320	354	330	493	543	416	500	494	427	491	279	284	342	372	469
1987	258	237	236	252	215	370	294	266	249	373	392	322	358	354	323	346	210	212	256	421	423
1988	269	249	245	262	262	315	324	383	357	532	426	468	391	386	342	382	255	259	312	345	298
1989	191	175	171	184	263	348	321	317	297	446	467	399	371	366	352	358	257	257	311	228	249
1990	193	201	173	186	205	257	230	248	232	349	318	312	275	272	251	266	200	201	243	321	293
1991	175	155	157	169	164	210	208	200	188	284	292	257	236	233	206	225	161	159	194	358	274
1992	185	213	166	178	243	267	292	289	271	407	402	364	404	400	354	390	238	238	288	350	275
1993	418	458	381	409	431	520	510	516	482	721	645	639	639	632	567	623	420	424	512	602	372
1994	192	174	174	187	222	297	292	265	247	370	327	326	297	293	260	291	216	219	264	244	253
1995	334	335	298	319	425	465	414	434	407	615	551	555	531	525	360	510	417	414	503	513	386
1996	233	232	212	227	294	342	262	296	277	416	376	372	434	429	316	420	287	288	349	391	390
1997	213	203	192	206	215	259	259	270	252	381	328	342	253	250	248	244	210	210	255	319	267
1998	195	207	178	190	196	259	190	229	214	321	280	286	295	292	231	285	191	192	232	301	375
1999	307	272	276	296	419	538	386	427	411	598	510	532	398	393	388	388	408	413	498	559	383
2000	197	163	177	190	216	242	241	259	224	363	243	324	222	219	206	215	211	212	256	315	327
2001	245	224	221	237	249	336	247	284	273	401	357	360	326	322	272	316	244	243	295	308	341
2002	180	162	162	174	181	263	177	242	208	341	251	305	229	226	207	221	177	177	214	249	248
2003	237	207	217	232	163	243	167	215	186	300	320	266	294	290	246	286	158	160	194	284	246
2004	339	355	305	327	374	445	393	500	444	706	527	633	479	474	439	461	365	367	444	505	367
2005	159	162	142	152	193	243	243	321	261	453	362	407	329	325	299	316	189	188	228	320	457
2006	181	200	161	173	232	257	237	333	308	475	463	432	419	414	348	399	228	225	274	335	345
2007	199	179	180	193	241	261	242	308	300	433	389	395	356	352	311	345	236	237	286	299	267
2008	190	199	171	184	221	265	223	265	258	375	330	301	301	297	259	289	216	216	261	260	338
2009	145	143	132	142	170	226	189	251	203	350	317	281	291	288	197	285	161	167	201	186	272
2010	261	245	239	256	301	337	301	387	379	540	489	469	449	443	403	438	303	297	358	416	420
2011	305	294	279	299	414	434	453	548	498	767	703	600	644	636	515	626	377	408	492	473	322
2012	208	205	191	204	243	269	250	329	293	462	416	429	380	376	347	369	233	238	288	340	339
2013	163	158	147	158	183	219	180	206	212	290	286	370	261	258	251	252	169	179	217	289	307
2014	174	170	159	170	128	165	152	173	174	242	222	315	203	201	200	197	151	126	152	310	292
2015	159	154	144	154	191	186	216	245	260	342	361	340	331	327	272	322	182	187	226	268	253
2016	263	254	236	253	288	292	268	307	316	433	439	467	400	396	326	387	293	282	341	393	372
2017	283	277	261	279	345	305	286	322	334	446	448	437	414	409	372	408	289	340	410	336	317
2018	321	310	288	309	330	326	373	428	405	604	539	501	490	484	451	469	344	322	390	389	370
2019	258	249	232	249	284	340	307	350	322	493	436	381	398	393	339	384	295	278	336	357	338

20%ile	**182**	**162**	**158**	**171**	**198**	**242**	**211**	**242**	**225**	**341**	**305**	**305**	**277**	**271**	**241**	**271**	**192**	**193**	**218**	**257**	**248**
1972-2019	**226**	**222**	**206**	**220**	**252**	**306**	**269**	**307**	**287**	**432**	**392**	**386**	**358**	**353**	**309**	**345**	**248**	**249**	**303**	**340**	**322**

Penman Potential Evapotranspiration, 1 Jun to 31 May (mm/y)

	Lauder EWS	Clyde EWS	Clyde EWS 2	Earns cleugh	Alexandra 1	Alexandra CWS	Tara Hills	Cromwell EWS	Ranfurly EWS
Season	5535	12431	39564	5577	5576	36592	5212/5212	26381	18593
1972-73	1,062	886	944	984	971	871	1,056	1,109	962
1973-74	1,014	854	905	947	828	835	1,011	1,062	921
1974-75	975	815	867	908	861	797	971	1,018	885
1975-76	1,117	940	996	1,044	850	919	1,113	1,169	1,015
1976-77	938	783	833	871	788	768	934	980	850
1977-78	1,092	928	977	1,026	850	905	1,093	1,149	994
1978-79	1,034	875	924	970	769	851	1,033	1,084	940
1979-80	865	727	772	808	725	710	861	904	785
1980-81	920	781	824	865	779	761	919	967	838
1981-82	926	781	826	865	782	763	924	971	841
1982-83	1,002	847	896	939	756	827	1,000	1,051	911
1983-84	921	771	820	778	750	755	917	962	836
1984-85	968	810	862	892	787	794	964	1,012	877
1985-86	847	706	753	786	687	692	852	883	767
1986-87	808	677	721	791	657	663	929	845	733
1987-88	852	713	758	818	694	699	998	890	772
1988-89	928	781	828	868	760	763	977	971	843
1989-90	925	781	825	851	760	762	964	970	840
1990-91	896	761	802	831	739	742	852	942	815
1991-92	856	724	764	822	704	708	843	899	778
1992-93	781	661	698	777	642	644	823	819	710
1993-94	831	692	740	800	672	681	864	867	753
1994-95	890	748	793	829	728	731	914	932	809
1995-96	850	715	758	747	695	699	807	890	772
1996-97	959	846	856	897	786	791	871	1,005	871
1997-98	1,097	932	980	1,031	904	906	1,035	1,152	998
1998-99	1,056	897	941	984	864	868	1,017	1,105	958
1999-00	891	792	794	829	727	732	901	932	808
2000-01	993	792	885	926	811	817	965	1,040	932
2001-02	908	717	806	841	738	744	881	947	849
2002-03	1,007	871	896	934	817	825	969	1,052	915
2003-04	1,051	824	935	976	851	860	932	1,098	922
2004-05	916	775	815	850	743	750	944	956	848
2005-06	983	844	876	918	803	806	1,025	1,030	895
2006-07	1,031	867	913	948	830	838	1,021	1,083	894
2007-08	999	873	893	935	818	824	1,033	1,090	918
2008-09	988	819	882	923	808	784	969	1,060	908
2009-10	1,062	877	946	993	871	817	1,066	1,125	975
2010-11	985	810	881	922	807	797	959	1,041	881
2011-12	966	819	901	899	785	840	983	1,028	913
2012-13	998	816	885	933	818	841	1,008	1,058	924
2013-14	984	823	920	915	802	819	924	1,029	906
2014-15	1,065	896	963	995	870	842	1,009	1,039	975
2015-16	1,052	877	928	976	854	862	1,103	1,113	997
2016-17	997	837	857	930	814	814	980	1,027	859
2017-18	1,056	893	910	990	866	886	984	1,072	882
2018-19	949	796	825	884	776	802	922	968	819
2019-20	947	794	838	883	772	790	957	989	877
80%ile	1,051	875	925	976	850	844	1,022	1,085	933
Average	963	809	859	898	787	792	960	1,008	874

Appendix B: Irrigation demand

Table 1. Upper Manuherekia

Table 2. Lower Manuherekia

Table 3 Ida Valley

Orange cells are 80%ile years (i.e. 1 year in 5 dry events). The three driest years are red. Because of the way irrigation scheduling is modelled, annual water use by season is always a multiple of the application depth.

Upper Manuherekia Valley

Season	Gross irrigation demand (mm/y) Spray Irr.		Gross irrigation demand (mm/y) Flood Irr.		Net irrigation (mm/y) Spray Irr.		Net irrigation (mm/y) Flood Irr.	
	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90
1960	416	400	612	612	229	218	130	130
1961	560	580	612	612	392	378	149	156
1962	560	540	714	714	403	409	219	249
1963	576	580	714	714	396	399	183	195
1964	512	500	612	612	344	338	181	203
1965	592	560	714	714	399	408	200	263
1966	592	560	714	714	370	373	164	204
1967	544	540	714	612	343	322	134	161
1968	592	580	714	714	394	402	221	262
1969	544	540	714	714	398	396	237	276
1970	544	540	510	612	376	350	174	173
1971	640	620	714	714	445	439	204	220
1972	688	700	714	714	500	478	238	228
1973	624	620	714	714	444	466	254	286
1974	544	540	714	612	328	304	169	160
1975	752	760	714	714	543	541	249	250
1976	464	440	714	714	307	282	166	188
1977	688	700	714	714	515	509	217	220
1978	496	480	612	510	309	291	133	123
1979	448	380	714	714	252	243	148	179
1980	624	600	714	714	446	446	222	257
1981	640	620	714	714	436	426	196	199
1982	544	500	612	612	310	284	144	174
1983	448	420	714	612	288	279	171	185
1984	656	640	714	714	487	470	244	251
1985	400	340	714	714	182	175	120	172
1986	416	420	612	510	281	258	138	149
1987	512	500	714	714	326	328	209	234
1988	608	560	714	714	346	285	194	176
1989	560	540	714	714	380	365	225	236
1990	560	560	714	714	379	364	183	202
1991	560	540	714	714	409	392	228	246
1992	400	380	612	612	231	191	127	112
1993	352	280	714	510	151	115	101	80
1994	560	540	714	714	376	378	227	262
1995	384	340	612	510	171	129	95	88
1996	576	560	714	714	397	382	222	239
1997	672	680	714	714	508	519	226	256
1998	624	600	714	714	418	407	159	191
1999	464	420	612	612	249	157	144	117
2000	624	600	714	714	458	466	237	271
2001	496	480	714	714	320	301	192	237
2002	624	600	714	714	453	430	248	248
2003	608	620	714	714	464	478	241	271
2004	400	340	612	612	179	141	107	124
2005	592	560	714	714	380	366	198	215
2006	608	620	714	714	412	423	216	239
2007	576	600	714	714	358	341	185	218
2008	576	560	714	612	373	369	206	193
2009	672	680	714	714	476	457	235	253
2010	512	480	612	612	304	291	138	144
2011	496	480	612	612	288	238	130	142
2012	528	500	714	612	314	295	175	168
2013	656	660	714	714	472	476	219	238
2014	688	680	714	714	530	543	255	276
2015	640	660	714	714	459	451	228	227
2016	528	540	714	714	367	364	194	198
2017	592	580	714	714	394	354	180	154
2018	448	400	612	612	262	228	130	129
2019	528	500	714	714	358	345	220	238

Average	**555**	**539**	**689**	**673**	**368**	**354**	**188**	**202**
1 yr in 5	**624**	**620**	**714**	**714**	**452**	**450**	**228**	**251**
1 yr in 10	**670**	**678**	**714**	**714**	**486**	**477**	**241**	**263**

Lower Manuherekia Valley

Season	Gross irrigation demand (mm/y) Spray Irr.		Flood Irr.		Net irrigation (mm/y) Spray Irr.		Flood Irr.	
	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90	PAW60	PAW90
1960	525	500	1000	900	362	340	285	307
1961	675	660	1000	1000	483	486	312	327
1962	630	620	1100	1000	480	461	358	345
1963	675	660	1000	900	498	490	306	319
1964	600	600	1000	1000	436	454	326	353
1965	630	620	1100	1100	434	411	352	372
1966	690	680	1100	1100	502	519	371	411
1967	600	600	1000	1000	412	388	302	318
1968	675	660	1100	1100	517	515	394	414
1969	570	540	1100	1100	415	407	360	400
1970	585	580	900	900	441	436	296	301
1971	615	620	1100	1100	461	443	343	355
1972	735	720	1100	1100	530	498	348	337
1973	675	660	1100	1100	523	524	363	402
1974	660	620	1100	1000	428	397	267	242
1975	855	860	1200	1200	642	655	409	442
1976	570	540	1100	1100	421	394	320	342
1977	840	860	1100	1100	659	677	404	428
1978	615	600	900	900	416	395	245	251
1979	420	400	1100	1000	269	251	236	248
1980	660	660	1100	1100	495	459	346	336
1981	645	640	1100	1100	458	438	343	352
1982	675	640	1100	1000	422	380	280	304
1983	465	440	1000	900	330	322	267	301
1984	660	660	1100	1200	508	503	391	434
1985	510	500	1100	1000	370	374	313	327
1986	495	480	1000	1000	337	294	265	242
1987	510	500	1000	900	343	333	289	300
1988	570	560	1100	1100	385	370	299	330
1989	660	640	1100	1100	456	444	332	363
1990	600	600	1100	1100	464	435	356	360
1991	555	540	1100	1100	419	393	350	346
1992	495	480	1000	1000	332	313	277	281
1993	360	320	1000	700	178	121	147	117
1994	570	560	1100	1100	435	437	357	393
1995	390	380	1000	900	222	181	204	178
1996	615	600	1100	1100	441	422	347	360
1997	765	760	1200	1100	605	597	416	416
1998	735	720	1100	1000	522	523	315	353
1999	555	540	1100	1000	336	307	286	292
2000	660	660	1100	1100	498	491	391	390
2001	540	520	1100	1100	392	384	329	371
2002	675	660	1100	1200	498	485	382	425
2003	615	600	1100	1100	445	461	305	314
2004	450	440	900	900	280	258	225	249
2005	735	720	1200	1200	579	576	434	464
2006	705	720	1200	1200	535	564	423	468
2007	675	680	1100	1100	489	494	319	349
2008	660	640	1100	1100	476	473	331	358
2009	765	760	1200	1200	572	581	396	414
2010	630	620	1000	1000	410	382	273	295
2011	630	620	1100	1100	445	451	303	353
2012	660	640	1100	1100	473	469	331	364
2013	720	720	1100	1100	528	502	350	344
2014	720	740	1000	1100	566	570	373	400
2015	765	740	1200	1200	576	581	407	423
2016	570	540	1000	1000	404	384	287	297
2017	675	660	1000	1000	437	428	281	297
2018	450	440	1000	1000	292	283	227	254
2019	615	600	1100	1000	431	396	326	337

Average	**621**	**609**	**1073**	**1050**	**445**	**433**	**325**	**341**
1 yr in 5	**687**	**680**	**1100**	**1100**	**521**	**512**	**372**	**402**
1 yr in 10	**735**	**738**	**1190**	**1200**	**572**	**575**	**404**	**425**

Ida Valley

Season	Gross irrigation demand (mm/y) Spray Irr. PAW60	Gross Spray Irr. PAW90	Gross Flood Irr. PAW60	Gross Flood Irr. PAW90	Net irrigation (mm/y) Spray Irr. PAW60	Net Spray Irr. PAW90	Net Flood Irr. PAW60	Net Flood Irr. PAW90
1960	480	460	714	612	314	312	186	200
1961	592	620	612	612	420	444	171	214
1962	624	620	714	714	467	461	246	242
1963	624	600	612	714	457	443	202	231
1964	576	600	612	612	412	438	201	237
1965	576	580	714	714	447	431	254	249
1966	640	640	714	714	479	510	265	286
1967	592	560	714	714	372	359	163	210
1968	640	640	714	714	499	505	277	284
1969	544	520	714	714	387	382	220	274
1970	576	580	612	612	415	414	185	207
1971	640	640	714	714	470	458	231	231
1972	704	720	714	714	520	508	229	224
1973	608	600	714	714	458	462	266	274
1974	560	560	714	714	384	381	201	216
1975	800	820	714	714	589	603	258	262
1976	544	540	714	714	405	387	227	236
1977	720	740	714	714	560	582	259	281
1978	560	560	510	612	368	352	138	133
1979	480	440	714	714	327	317	215	241
1980	592	600	612	714	434	399	207	213
1981	656	660	714	714	473	467	223	209
1982	608	620	714	714	430	403	175	186
1983	496	480	714	714	343	343	190	224
1984	704	700	714	714	538	522	266	253
1985	448	400	714	714	290	303	194	250
1986	464	440	612	510	315	287	153	142
1987	560	540	714	714	400	406	243	263
1988	640	620	714	714	451	426	256	255
1989	608	600	714	714	435	443	251	273
1990	608	600	714	714	425	442	199	248
1991	592	600	714	714	448	436	226	240
1992	432	440	612	612	285	258	160	164
1993	384	360	714	714	187	164	130	127
1994	576	580	714	714	432	425	248	255
1995	384	360	612	510	194	156	112	123
1996	576	560	714	714	411	399	241	248
1997	704	720	714	714	555	557	253	257
1998	688	680	714	714	463	475	189	237
1999	480	480	612	612	269	212	145	151
2000	672	660	714	714	519	508	240	254
2001	560	540	714	714	382	383	233	271
2002	688	700	714	714	526	524	262	267
2003	672	680	714	714	515	531	256	286
2004	496	440	612	714	275	273	167	234
2005	688	720	714	714	509	518	257	267
2006	688	700	714	714	525	525	265	277
2007	624	640	714	714	444	468	236	267
2008	624	620	714	714	423	429	237	241
2009	752	780	714	714	533	564	258	286
2010	592	560	714	612	387	360	157	168
2011	528	540	612	612	378	379	195	225
2012	624	620	714	714	451	462	249	264
2013	688	720	714	714	505	507	226	235
2014	688	700	714	714	548	543	262	259
2015	688	700	714	714	513	514	238	245
2016	528	540	714	612	391	380	200	185
2017	624	620	714	714	408	387	174	173
2018	496	480	612	714	314	296	157	146
2019	544	520	714	714	397	364	228	241

Average	**596**	**593**	**690**	**690**	**425**	**420**	**216**	**231**
1 yr in 5	**688**	**696**	**714**	**714**	**513**	**509**	**256**	**267**
1 yr in 10	**702**	**720**	**714**	**714**	**533**	**531**	**262**	**277**

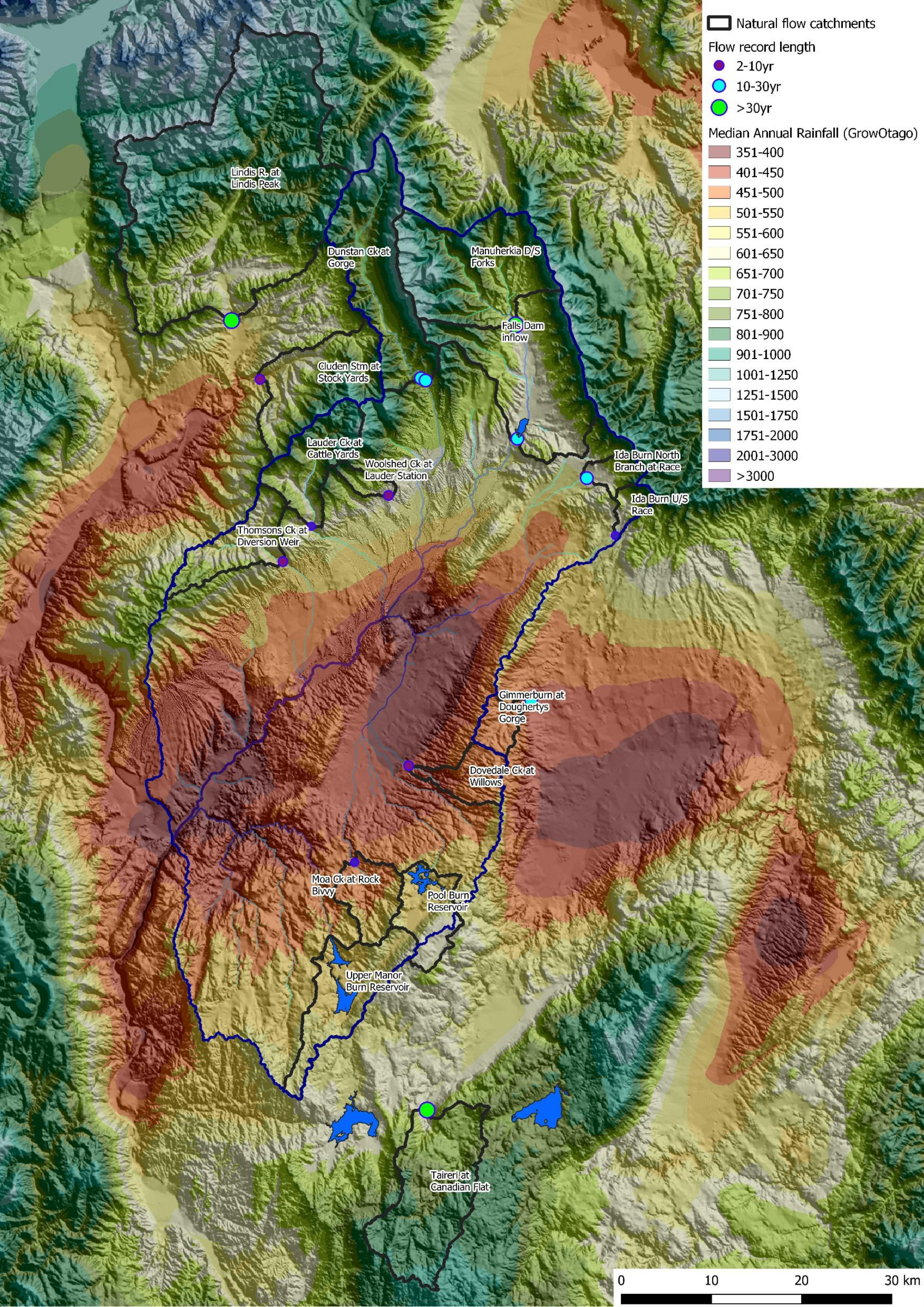
Appendix C: Flow records

The flow sites summarized below do not include all the sites in the Manuherekia. Rather they are limited to the sites that were reviewed when considering how best to create long term naturalised flow timeseries.

Table 1: Summary of flow recorder sites

Figure 1: Catchment map

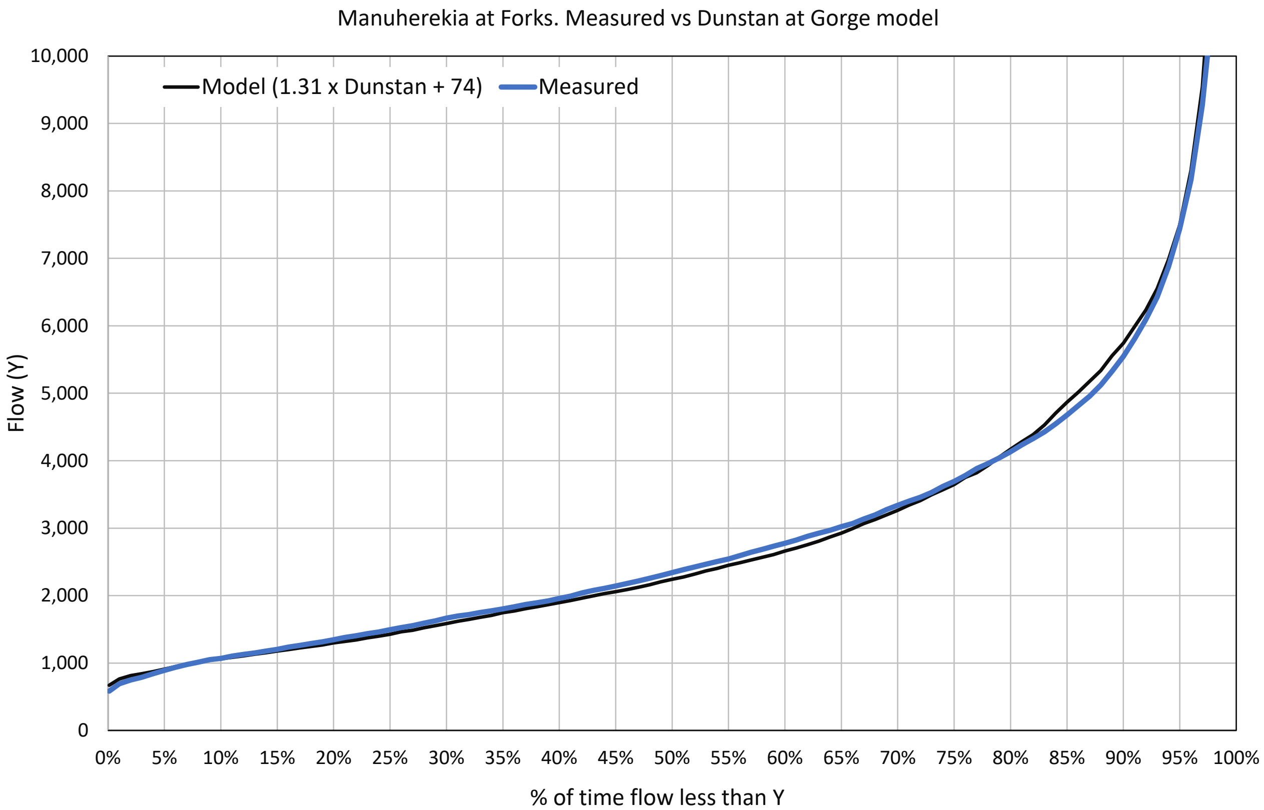
Site	Start	End	Gaugings	Gaps	Upstream influences	Notes
Chatto Creek at Matakanui Station	2008-09-24	2010-09-29	Regular low flow gauging.	None	Matakanui Station, County Race	
Manuherekia DS Forks	1975-05-29	2020-06-10	Regular low and mid flow gaugings.	**13-04-2004 to 24-09-2008, 14-09-2010 to 04-06-2016**	None	
Manuherekia DS Falls	1999-02-12	2020-06-11	Regular low and mid flow gaugings. Gorge site. High flows validated against Falls spill records.	**2-06-2014 to 11-07-2019**	Mt Ida race (but flows measured)	Requires lake ΔStorage and lake exporation adjustment
Falls Dam water level recorder	2004-02-13	2020-06-01		10-11-2009 to 4-12-2009		
Dunstan Creek at Gorge	1973-03-08	2010-09-28	Regular low flow gauging. Gorge site.	22-07-1976 to 11-11-1976, 29-05-1977 to 13-07-1977, 22-07-1983 t0 14-10-1983, 26-11-1986 to 19-02-1987, 03-09-1991 to 29-10-1991, 25-11-1991 to 21-02-1992, **28-04-1994 to 21-03-2007**, 23-06-2008 to 14-08-2008, 16-05-2009 to 16-10-2009, 03-06-2010 to 21-07-2010	None	
Lauder Creek at Cattle Yards	2008-09-24	2020-06-09	Regular low flow gauging.	**10-11-2010 to 11-08-2016**,	None	
Woolshed Ck at Lauder Station	1979-12-03	1986-08-15	Regular low and mid flow gaugings.	9-12-1980 to 21-02-1981	None	
Cluden Stm at Stock Yard	2012-11-21	2020-06-05	Unknown.	None of significance	None	
Thomsons Creek U/S Division Weir	2008-09-23	2020-05-07	Regular gauging, low to high flow	**01-06-2011 to 01-08-2019**	None	
Lindis at Lindis Peak	1976-09-24	2020-06-01	Regular low to high flow gaugings	None of significance	Small amount of irrigation	
Gimmerburn at Doughertys Gorge (Rough Ridge)	2009-09-18	2011-10-06	Regular low and mid flow gaugings.	7-05-2011 to 6-07-2011	None	Same site. Provides long flow record for Ida Valley climate
Gimmerburn at Doughertys Gorge (Rough Ridge)	1971-08-18	1994-01-12	Gauging record not available. But data looks good, and gorge	None of significance	None	
Dovedale Creek at Willows	1979-05-03	1987-09-30	Regular low flow gauging.	10-04-1982 to 01-07-1982	None	
Moa Creek at Rock Bivvy	2008-10-09	2010-11-08	Regular low and mid flow gaugings.	None of significance	None	
Taieri at Canadian Flat	1982-11-17	2020-05-07	NIWA site	All < 1 month	None	
Ida Burn at Auripo Rd	2008-10-08	2020-06-09	Regular low flow gauging. Station closed from 2012 to 2016		Yes	These two sites are closely correlated.
Poolburn at Cob Cottage	1989-03-15	2020-06-09	Regular low and mid flow gaugings.	Sept 1994 - Oct 2008, Apr 2011 to Mar 2016	Yes	



Natural flow catchments
Flow record length
2-10yr
10-30yr
>30yr
Median Annual Rainfall (GrowOtago)
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
751-800
801-900
901-1000
1001-1250
1251-1500
1501-1750
1751-2000
2001-3000
>3000
Lindis R. at Lindis Peak
Dunstan Ck at Gorge
Manuherkia D/S Forks
Falls Dam inflow
Cluden Stm at Stock Yards
Lauder Ck at Cattle Yards
Woolshed Ck at Lauder Station
Ida Burn North Branch at Race
Ida Burn U/S Race
Thomsons Ck at Diversion Weir
Gimmerburn at Doughertys Gorge
Dovedale Ck at Willows
Moa Ck at Rock Bivvy
Pool Burn Reservoir
Upper Manor Burn Reservoir
Taireri at Canadian Flat
0
10
20
30 km

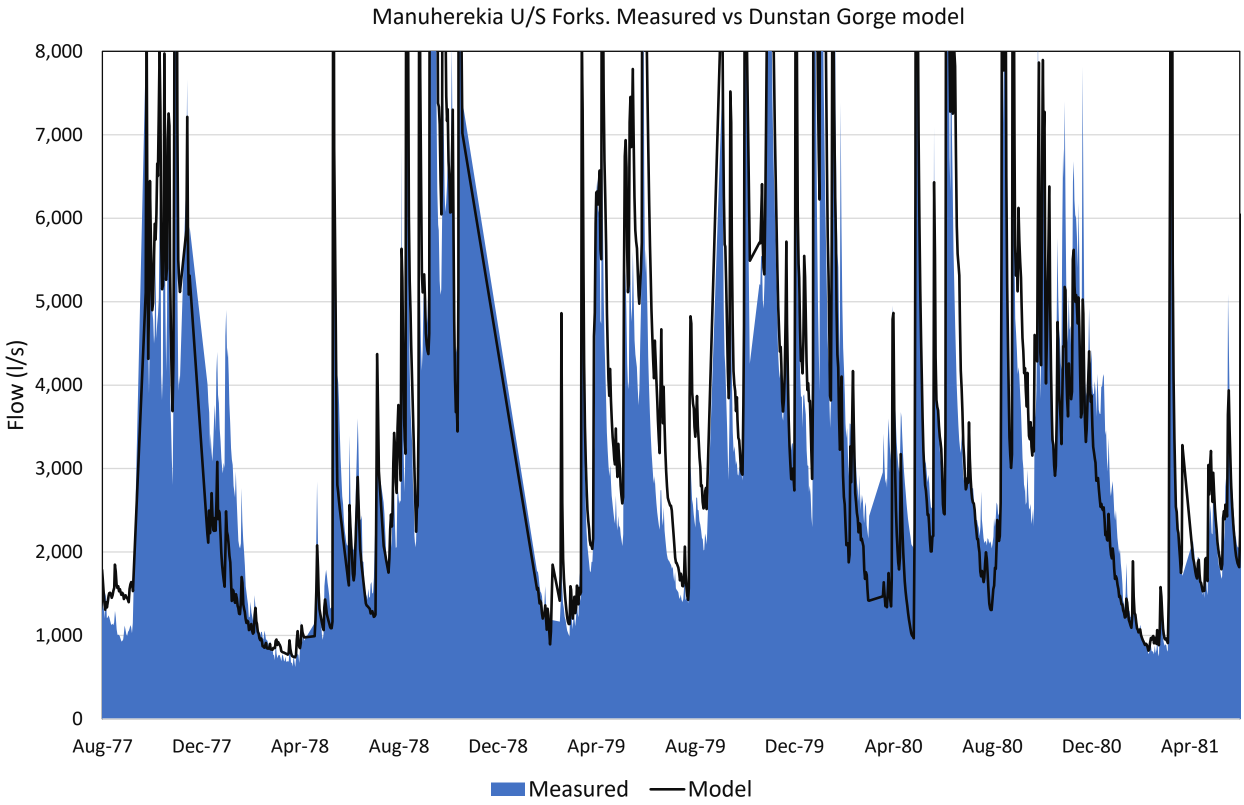
Appendix D: Flow relationships

Manuherekia D/S Forks vs Dunstan at Gorge



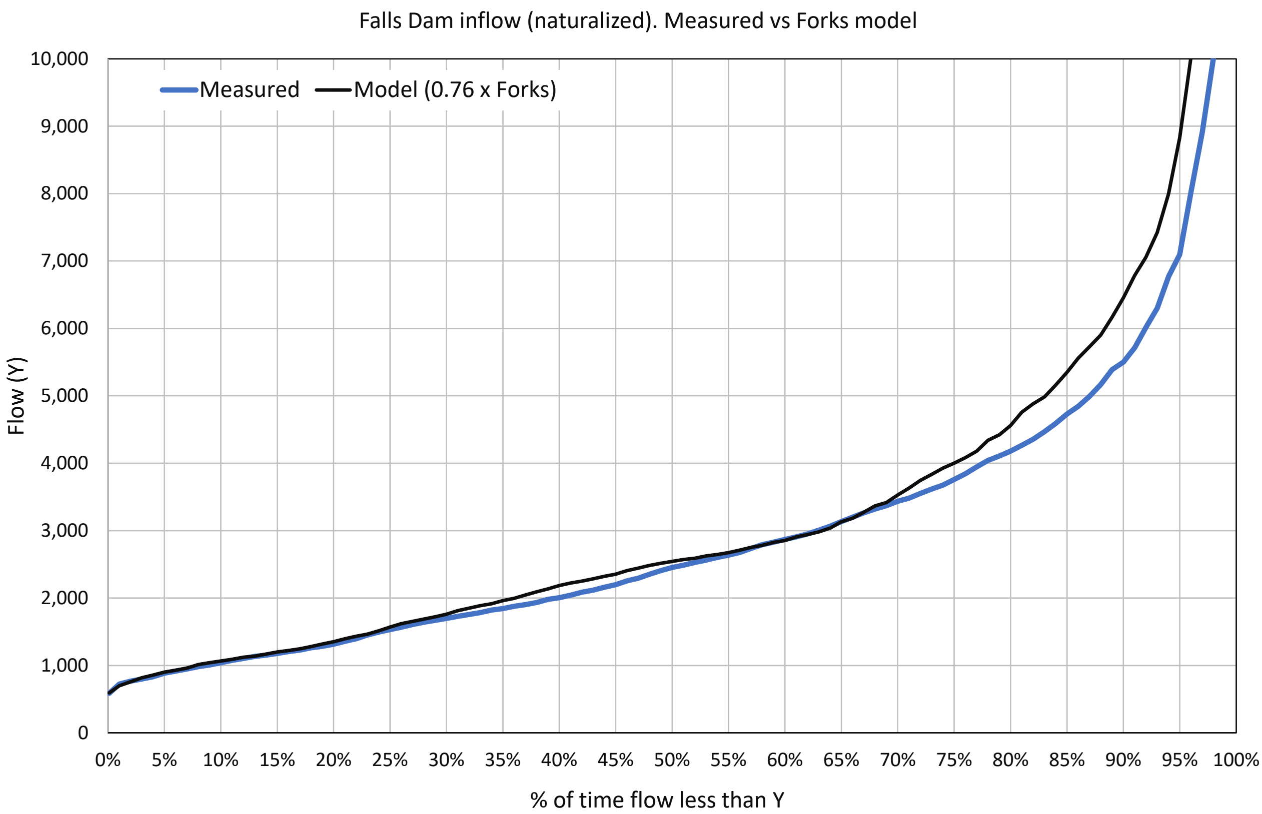
Parameter	Measured	Model	Difference
Mean	3,058	3,079	1%
Median	2,342	2,241	-4%
5%ile	893	912	2%
1%ile	693	764	10%
Correlation	N/A	92%	
Days of overlap	6316		

Season	Average flow		Difference
	Measured	Model	
Summer	2,897	2,469	-15%
Autumn	2,430	2,447	1%
Winter	2,707	3,011	11%
Spring	4,310	4,492	4%



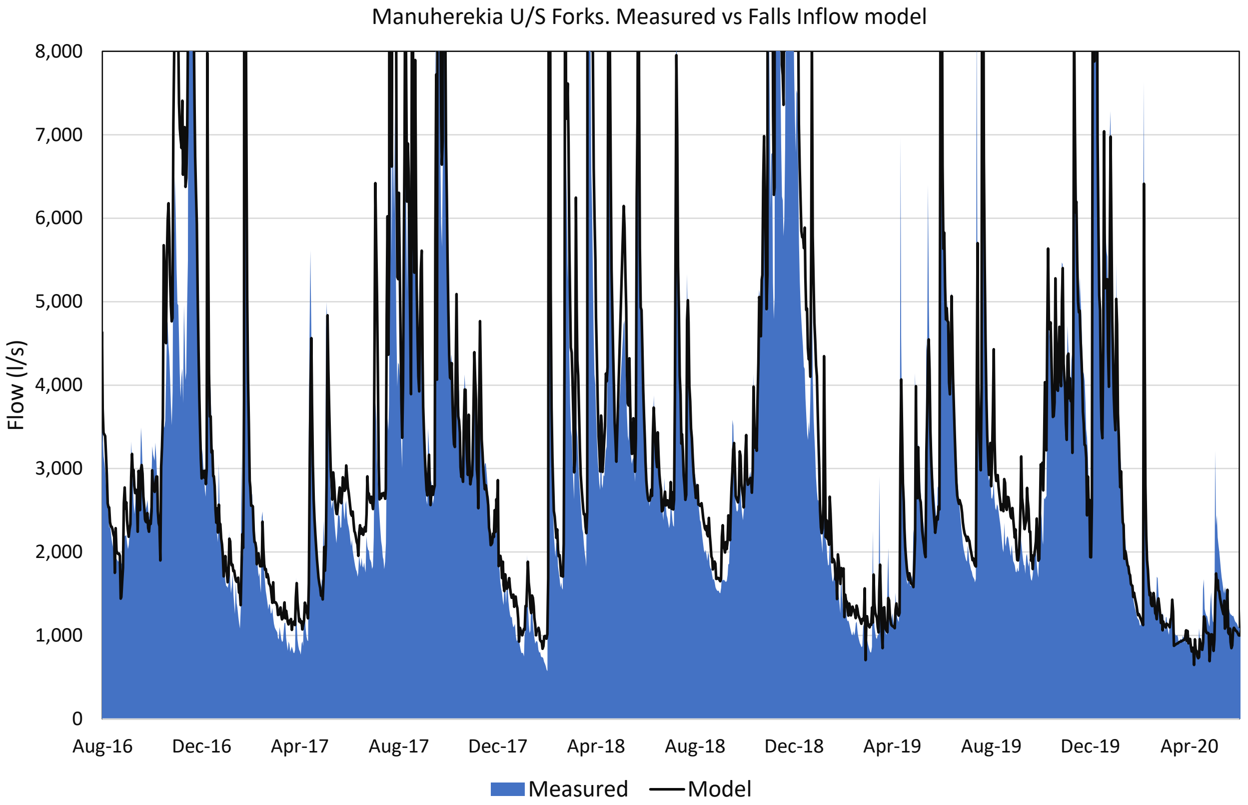
Manuherekia U/S Forks. Measured vs Dunstan Gorge model
Flow (l/s)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Aug-77
Dec-77
Apr-78
Aug-78
Dec-78
Apr-79
Aug-79
Dec-79
Apr-80
Aug-80
Dec-80
Apr-81
Measured
Model

Falls Dam inflow (naturalised) vs Manuherekia at Forks



Parameter	Measured	Model	Difference
Mean	3,077	3,570	16%
Median	2,454	2,544	4%
5%ile	885	902	2%
1%ile	724	700	-3%
Correlation	N/A	88%	
Days of overlap	1953		

Season	Average flow		Difference
	Measured	Model	
Summer	2,567	2,672	4%
Autumn	2,294	2,439	6%
Winter	3,318	4,169	26%
Spring	4,404	5,440	24%

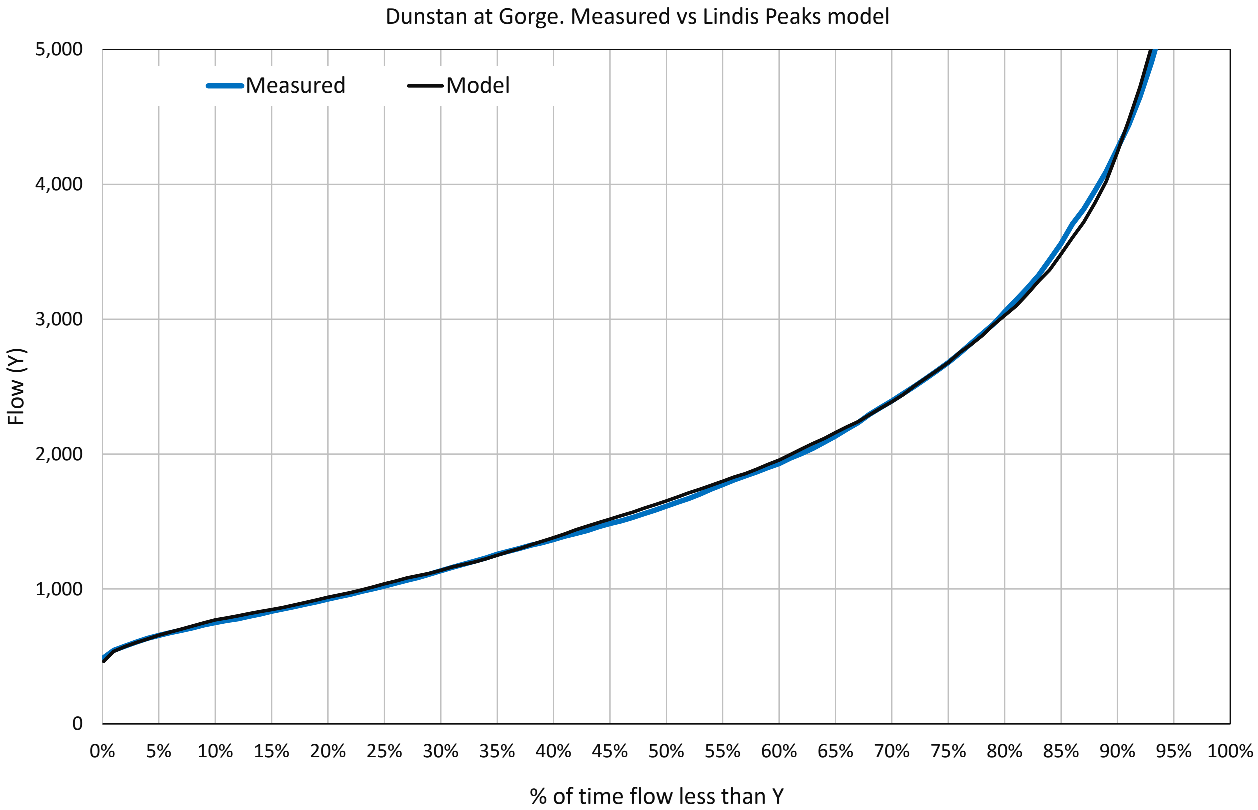

Manuherekia U/S Forks. Measured vs Falls Inflow model
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (l/s)
Aug-16
Dec-16
Apr-17
Aug-17
Dec-17
Apr-18
Aug-18
Dec-18
Apr-19
Aug-19
Dec-19
Apr-20
Measured
Model

Dunstan at Gorge vs Lindis at Lindis Peaks

Model:

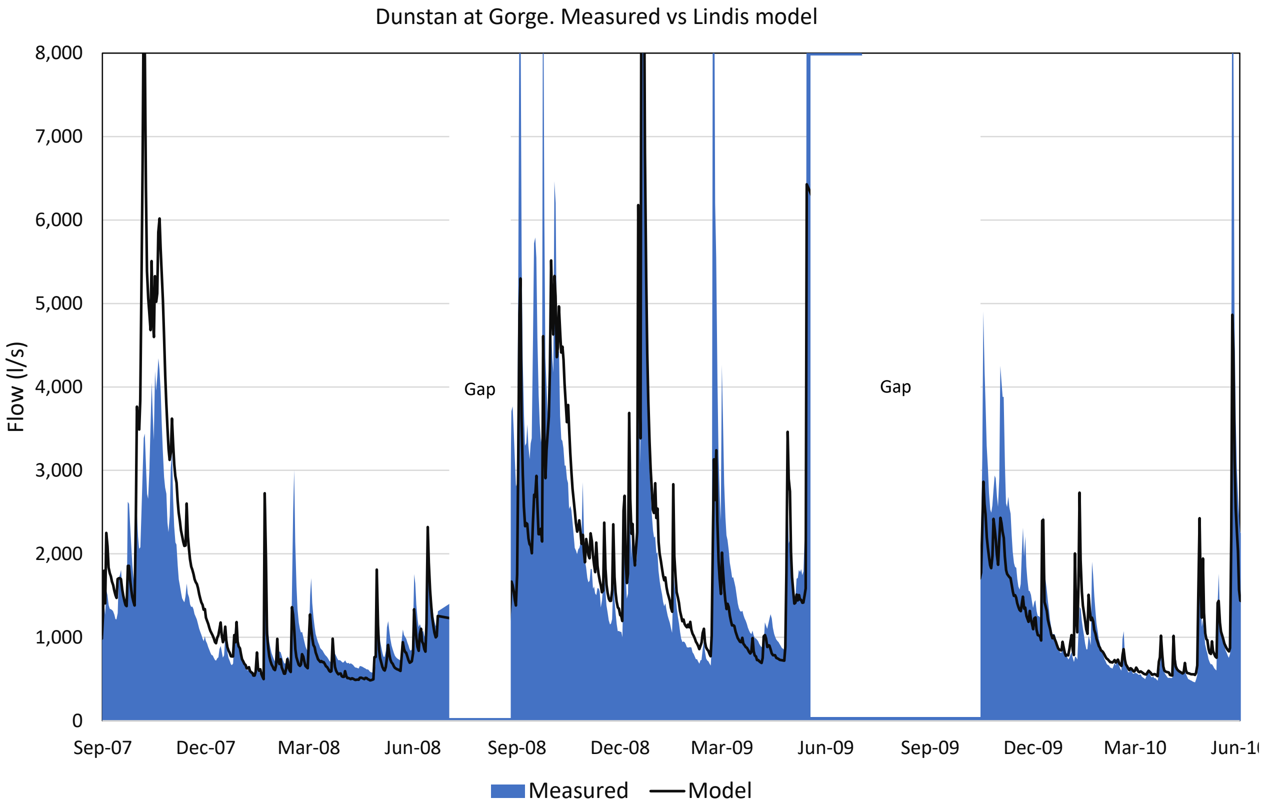
Dunstan at Gorge = Lindis x Monthly ratio + 130 l/s

Month	Ratio
Jan	0.43
Feb	0.43
Mar	0.43
Apr	0.40
May	0.35
Jun	0.30
Jul	0.26
Aug	0.23
Sep	0.29
Oct	0.39
Nov	0.46
Dec	0.43



Parameter	Measured	Model	Difference
Mean	2,252	2,242	0%
Median	1,614	1,645	2%
5%ile	655	645	-2%
1%ile	545	524	-4%
Correlation	N/A	79%	
Days of overlap	6746		

Season	Average flow		Difference
	Measured	Model	
Summer	1,919	1,947	1%
Autumn	1,768	1,756	-1%
Winter	2,146	2,122	-1%
Spring	3,254	3,220	-1%

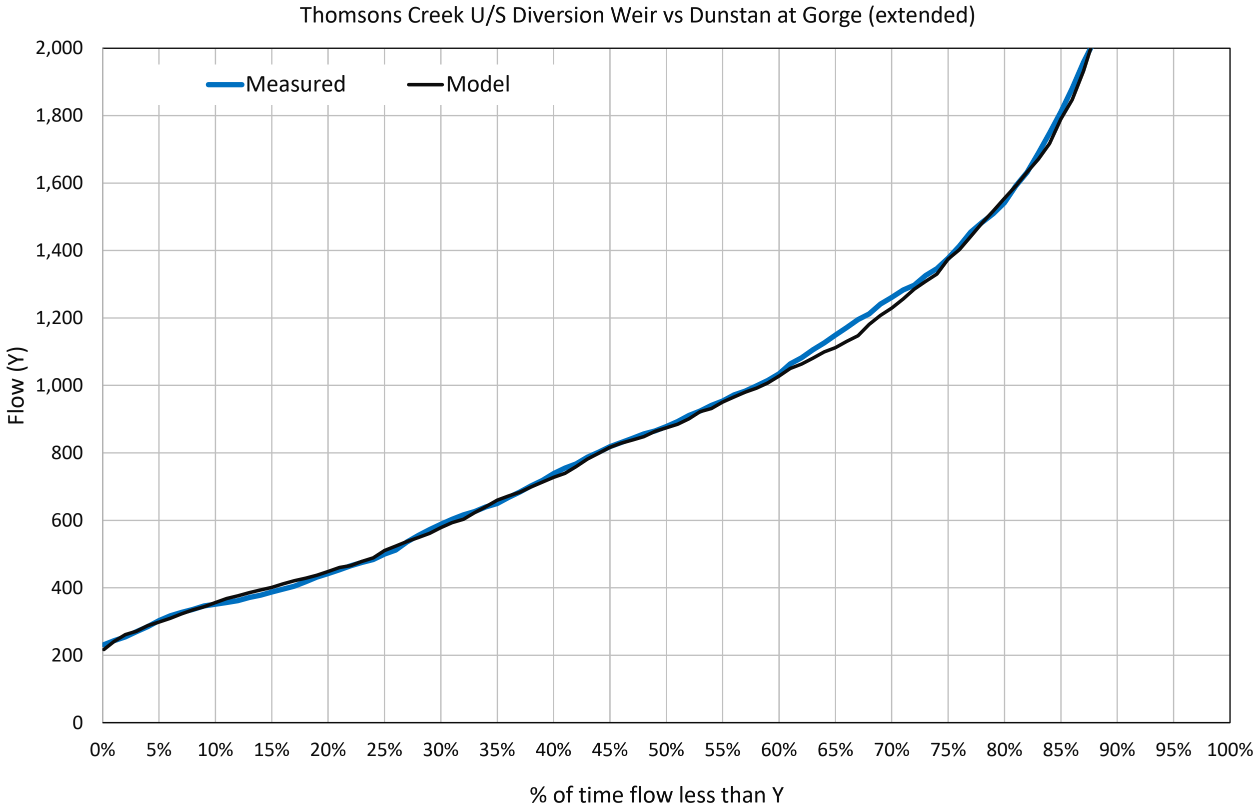


Lauder Creek at Cattle Yards vs Dunstan at Gorge (extended)

Model:

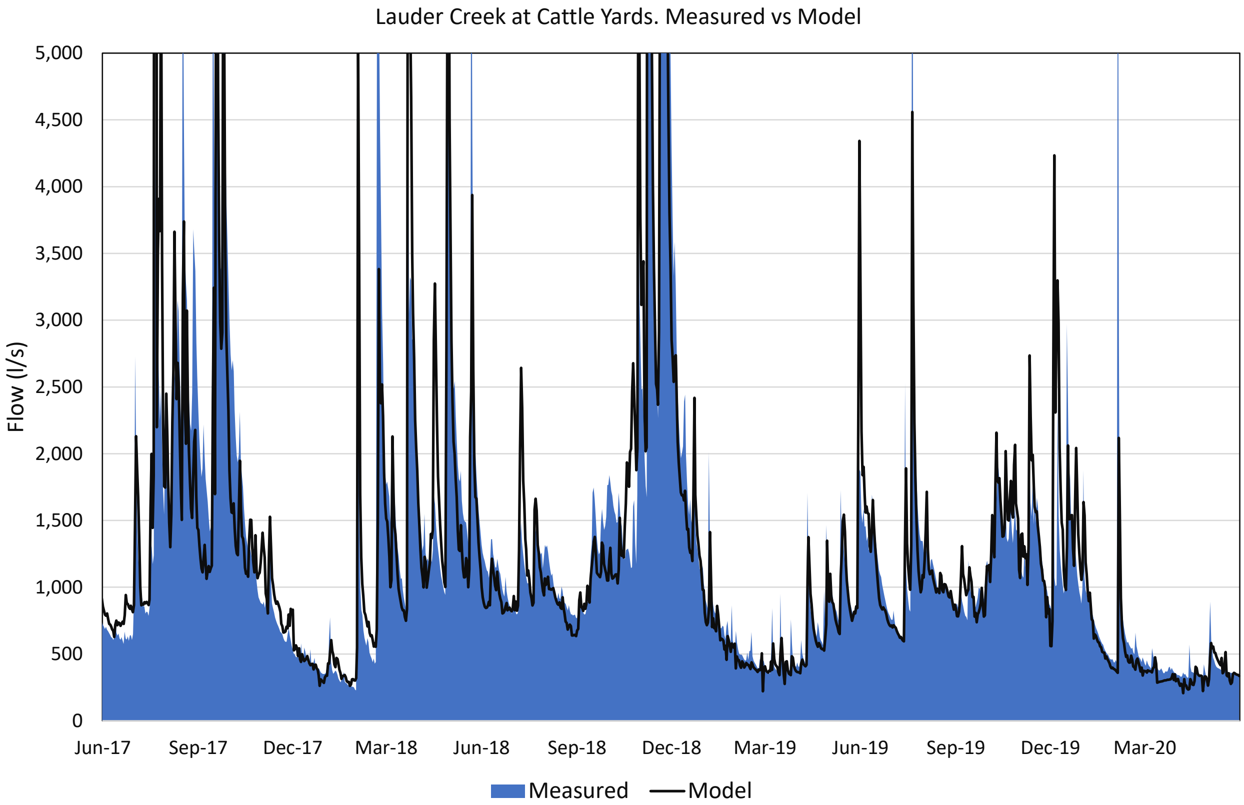
Lauder = Dunstan x Monthly ratio + 10 l/s

Month	Ratio
Jan	0.43
Feb	0.44
Mar	0.45
Apr	0.45
May	0.45
Jun	0.43
Jul	0.44
Aug	0.51
Sep	0.55
Oct	0.51
Nov	0.42
Dec	0.39



Parameter	Measured	Model	Difference
Mean	1,184	1,195	1%
Median	878	875	0%
5%ile	303	298	-1%
1%ile	243	241	-1%
Correlation	N/A	82%	
Days of overlap	2124		

Season	Average flow		Difference
	Measured	Model	
Summer	837	816	-3%
Autumn	791	790	0%
Winter	1,252	1,312	5%
Spring	1,796	1,808	1%

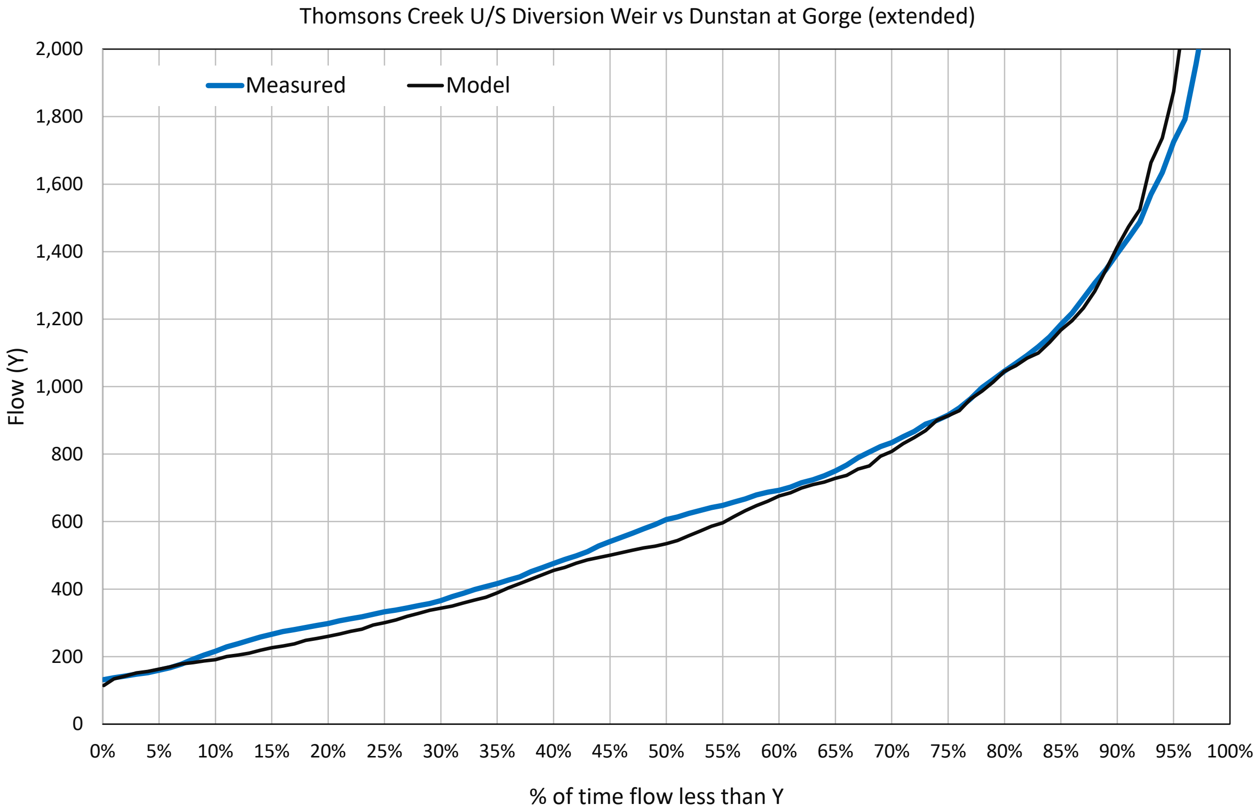


Thomsons U/S Diversion Weir vs Dunstan at Gorge (extended)

Model:

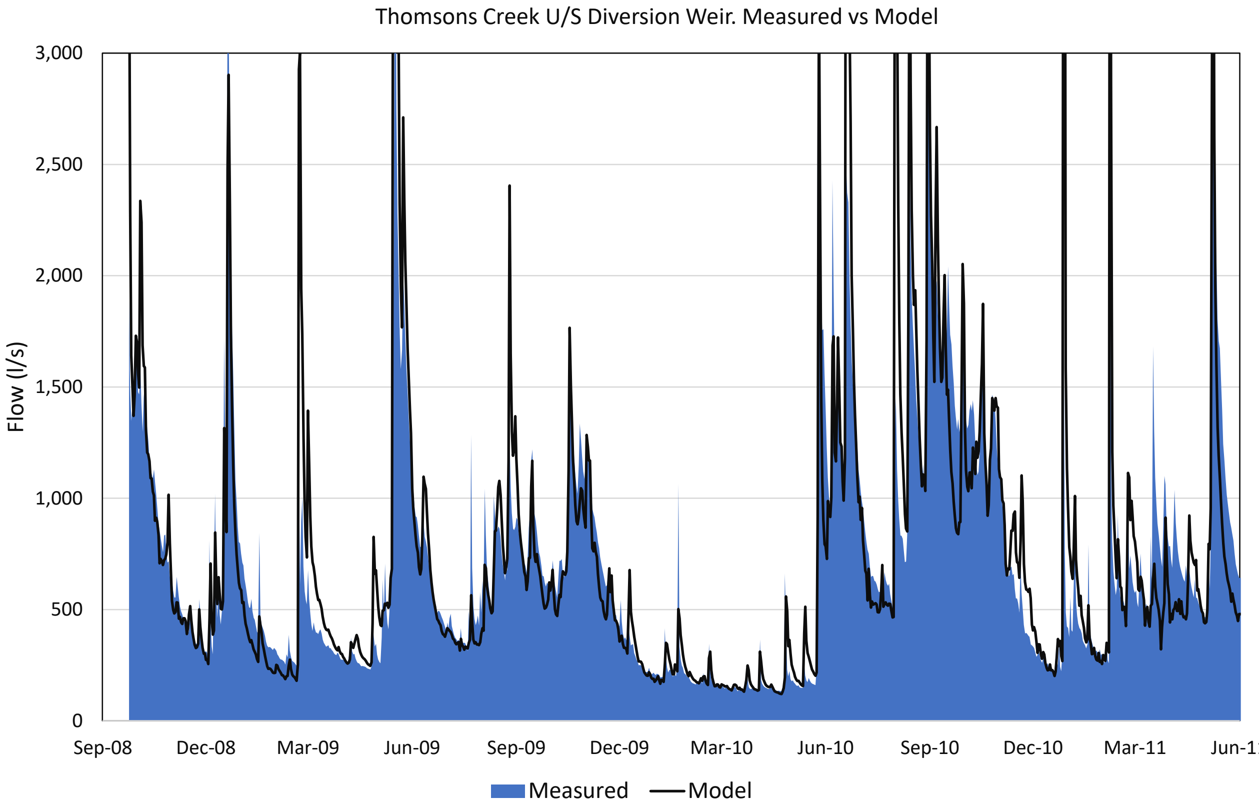
Thomsons = Dunstan x Monthly ratio - 30 l/s

Month	Ratio
Jan	0.28
Feb	0.32
Mar	0.33
Apr	0.33
May	0.31
Jun	0.34
Jul	0.37
Aug	0.40
Sep	0.38
Oct	0.37
Nov	0.31
Dec	0.29



Parameter	Measured	Model	Difference
Mean	714	753	5%
Median	606	535	-12%
5%ile	160	163	2%
1%ile	137	134	-2%
Correlation	N/A	72%	
Days of overlap	1259		

Season	Average flow		Difference
	Measured	Model	
Summer	507	560	10%
Autumn	564	610	8%
Winter	927	1,005	8%
Spring	949	941	-1%



Appendix E: Natural flows

Table 1. Average annual flow by season (1 June to 31 May)
Table 2. Average from 1 October to 31 March by season
Table 3. 7-day annual low flow by season (1 June to 31 May)

Blue shading indicates years when the recorder site was operating. For other years, data is derived from the relationship with other comparable sites. Red cells are 20%ile years (i.e. 1 in 5-year events). The three lowest values (i.e. three driest years) are underlined.

Mean Annual Flow (1 June to 31 May)

Season	Manuherekia DS Forks	Dunstan Creek at Gorge	Falls Dam inflows (naturalized)	Lauder Ck at Cattle Yards	Thomsons Ck US Diversion Weir	Lindis at Lindis Peak
1973	2,639	1,958	4,644	914	632	4,901
1974	3,128	2,325	5,491	1,088	756	5,547
1975	2,918	2,146	5,078	1,034	730	6,088
1976	3,711	2,592	6,108	1,168	813	5,958
1977	2,657	1,887	4,481	882	607	3,237
1978	3,953	3,293	7,722	1,564	1,100	7,169
1979	4,145	3,248	7,619	1,486	1,039	8,736
1980	3,458	2,481	5,850	1,164	825	10,013
1981	2,397	1,903	4,518	898	624	5,322
1982	4,089	3,129	7,344	1,427	991	6,976
1983	4,713	3,397	7,962	1,585	1,131	10,732
1984	2,632	1,988	4,714	929	648	7,266
1985	2,997	2,113	5,003	984	685	6,078
1986	4,196	3,284	7,702	1,508	1,075	7,910
1987	2,439	1,674	3,991	788	543	5,198
1988	2,495	1,867	4,434	885	606	5,446
1989	2,269	1,722	4,101	787	541	3,882
1990	2,098	1,589	3,794	744	514	4,379
1991	2,707	1,991	4,721	955	666	5,394
1992	2,988	2,014	4,774	946	653	4,601
1993	3,677	2,719	6,398	1,243	858	7,552
1994	3,725	2,787	6,556	1,293	923	7,451
1995	5,824	4,389	10,250	2,026	1,424	10,672
1996	2,523	1,870	4,441	870	599	4,870
1997	2,494	1,847	4,389	880	612	5,265
1998	3,063	2,282	5,391	1,078	763	6,313
1999	2,978	2,216	5,242	1,012	699	7,182
2000	3,595	2,687	6,327	1,264	905	10,296
2001	2,665	1,977	4,690	896	612	3,312
2002	2,180	1,607	3,836	747	510	5,450
2003	2,572	1,943	4,611	901	622	5,004
2004	3,663	2,739	6,446	1,230	856	6,547
2005	2,094	1,542	3,686	719	484	3,165
2006	3,425	2,557	6,028	1,145	808	5,408
2007	1,908	1,315	3,358	624	423	3,946
2008	3,700	2,832	6,681	1,310	815	6,408
2009	2,112	1,517	3,757	714	522	4,330
2010	3,698	3,120	7,315	1,499	964	6,801
2011	3,768	2,819	6,632	1,320	930	4,679
2012	3,556	2,657	6,259	1,241	864	5,231
2013	4,230	3,172	7,445	1,444	1,044	7,523
2014	2,633	1,953	4,634	919	650	4,875
2015	2,794	2,076	4,918	979	690	4,005
2016	3,143	2,722	6,407	1,026	875	3,970
2017	3,636	3,318	7,783	1,638	1,119	5,636
2018	3,617	3,381	7,929	1,518	1,067	6,669
2019	2,867	2,094	4,959	963	695	5,532

Average	**3,165**	**2,399**	**5,669**	**1,111**	**777**	**6,020**
20%ile	**2,495**	**1,868**	**4,438**	**881**	**607**	**4,512**

Average flow, 1 Oct to 31 Mar

Season	Manuherekia DS Forks	Dunstan Creek at Gorge	Falls Dam inflows (naturalized)	Lauder Ck at Cattle Yards	Thomsons Ck US Diversion Weir	Lindis at Lindis Peak
1973	2,868	2,133	5,048	964	662	4,816
1974	2,940	2,188	5,175	997	682	4,913
1975	2,552	**1,627**	**3,882**	**752**	504	3,788
1976	4,614	3,087	7,249	1,337	921	5,493
1977	3,082	2,204	5,211	1,005	689	**2,782**
1978	3,674	2,808	6,605	1,268	881	5,328
1979	5,122	3,848	9,001	1,699	1,172	9,079
1980	3,322	2,132	5,046	963	662	5,014
1981	**1,941**	**1,506**	**3,602**	**701**	**468**	3,621
1982	5,098	3,697	8,653	1,629	1,129	6,564
1983	5,749	3,705	8,674	1,697	1,186	8,798
1984	3,310	2,335	5,514	1,057	725	8,510
1985	3,660	2,468	5,820	1,099	761	4,989
1986	5,077	3,833	8,969	1,722	1,220	6,496
1987	2,681	**1,642**	**3,916**	**744**	**496**	4,172
1988	2,706	1,993	4,726	915	620	5,642
1989	**2,250**	1,681	4,005	752	**500**	**2,970**
1990	**2,128**	**1,471**	**3,521**	**675**	**450**	3,721
1991	2,619	1,964	4,658	881	596	**3,231**
1992	3,767	2,472	5,829	1,120	773	4,643
1993	4,862	3,518	8,241	1,556	1,067	8,434
1994	3,911	2,929	6,883	1,306	908	6,505
1995	6,902	5,212	12,149	2,268	1,601	9,967
1996	2,773	2,060	4,881	940	639	4,603
1997	**2,287**	1,689	4,024	764	514	3,684
1998	2,796	2,078	4,921	961	657	4,651
1999	3,451	2,577	6,074	1,132	769	8,809
2000	2,962	2,204	5,214	1,003	684	4,820
2001	3,556	2,658	6,259	1,161	784	3,904
2002	2,359	1,744	4,151	768	514	3,870
2003	3,024	2,319	5,479	1,052	723	5,224
2004	4,754	3,571	8,367	1,539	1,057	5,953
2005	**1,559**	**1,134**	**2,744**	**525**	**341**	~~**2,232**~~
2006	4,113	3,082	7,240	1,314	905	5,742
2007	**2,027**	**1,388**	**3,567**	**643**	**427**	3,854
2008	2,656	2,166	4,751	951	644	4,934
2009	**1,966**	**1,368**	**3,376**	**579**	**438**	**2,573**
2010	3,420	2,553	6,018	1,271	687	5,042
2011	5,188	3,902	9,131	1,794	1,261	5,168
2012	3,772	2,822	6,639	1,251	859	4,602
2013	2,822	2,097	4,967	947	634	3,775
2014	**1,832**	**1,342**	**3,224**	**613**	**406**	~~**2,512**~~
2015	**2,048**	**1,506**	**3,604**	**686**	**455**	~~**2,135**~~
2016	3,221	2,973	6,987	912	907	**3,429**
2017	2,855	2,434	5,743	1,202	763	**3,077**
2018	4,352	4,716	11,008	2,006	1,441	6,777
2019	3,383	2,374	5,605	1,019	699	6,444

Average	**3,362**	**2,494**	**5,880**	**1,109**	**763**	**5,049**
20%ile	**2,330**	**1,665**	**3,970**	**752**	**503**	**3,544**

7-day annual low flow (1 June to 31 May)

Season	Manuherekia DS Forks	Dunstan Creek at Gorge	Falls Dam inflows (naturalized)	Lauder Ck at Cattle Yards	Thomsons Ck US Diversion Weir	Lindis at Lindis Peak
1973	924	649	1,626	289	151	1,332
1974	1,312	945	2,310	411	266	1,855
1975	594	453	1,176	213	117	958
1976	878	664	1,662	308	186	1,629
1977	685	519	1,326	243	143	876
1978	1,067	758	1,878	340	208	1,487
1979	1,452	747	1,854	345	213	3,388
1980	814	606	1,528	274	163	1,366
1981	714	520	1,330	244	144	1,311
1982	1,183	740	1,837	334	213	1,636
1983	1,633	1,062	2,579	467	266	3,150
1984	751	568	1,439	264	155	1,447
1985	1,106	783	1,937	352	216	2,411
1986	1,025	726	1,804	322	173	1,502
1987	941	749	1,857	341	204	1,609
1988	887	704	1,753	295	167	1,264
1989	767	646	1,619	321	200	1,370
1990	764	656	1,643	296	179	1,536
1991	629	539	1,372	252	139	945
1992	1,001	643	1,613	288	179	1,168
1993	1,367	1,043	2,534	483	344	2,614
1994	841	585	1,480	273	165	1,059
1995	1,074	763	1,890	392	278	2,766
1996	1,058	751	1,862	347	216	1,499
1997	888	621	1,562	282	193	1,330
1998	737	506	1,296	231	131	874
1999	1,219	874	2,146	403	259	2,137
2000	645	436	1,136	206	111	1,088
2001	620	417	1,091	190	110	1,329
2002	803	557	1,414	261	156	1,281
2003	958	675	1,685	300	158	1,375
2004	1,199	859	2,110	396	257	2,004
2005	701	478	1,233	217	111	724
2006	869	607	1,529	282	157	1,105
2007	561	567	988	254	128	911
2008	1,055	727	1,606	350	237	1,469
2009	712	478	1,149	237	135	984
2010	1,248	896	2,197	356	235	1,520
2011	1,119	798	1,970	358	221	1,455
2012	901	631	1,585	293	175	1,433
2013	973	686	1,713	318	195	1,097
2014	757	521	1,332	234	115	1,001
2015	818	568	1,440	265	145	742
2016	822	819	2,019	302	239	1,194
2017	657	653	1,635	250	152	780
2018	853	777	1,922	384	226	1,443
2019	811	539	1,373	330	183	1,649

Average	**923**	**671**	**1,660**	**306**	**185**	**1,470**
20%ile	**713**	**532**	**1,331**	**248**	**141**	**994**