MANUHEREKIA CATCHMENT HYDROLOGY – JOINT EXPERT STATEMENT

TABLE OF CONTENTS

1.0 PURPOSE OF STATEMENT

Otago Regional Council (ORC) requires hydrological information to inform planning, consenting and water management processes currently being undertaken for the Manuherekia[(1)] Catchment. The Manuherekia Hydrology Group was formed in early 2020 to provide the required hydrological information.

The purpose of this joint expert statement is to document current understanding of the hydrology of the Manuherekia Catchment. It represents the agreed position of the Manuherekia Hydrology Group and its members with respect to their area of expertise. It has been prepared to provide the various stakeholders in the Manuherekia processes with an agreed summary of the catchment's hydrology. As the focus of the investigations has been on lower flows, this statement does not discuss either high flows or flood flows. The Manuherekia Hydrology Group is available collectively to explain and defend this joint statement as required.

Following these initial comments this statement contains the following five sections followed by a table of key references:

2.0 **Introduction and Background** – Provides brief background to the joint statement, including membership of the Manuherekia Hydrology Group and the process undertaken.

3.0 **Manuherekia Catchment** – Briefly describes the catchment – area, land use, main tributaries, general climatic setting, water use, and key water infrastructure. Includes a catchment map highlighting the key features.

4.0 **Available Hydrological Information** – Briefly summarises previous hydrological investigations and the available hydrological records. It briefly summarises the Manuherekia Catchment Hydrology Model, why it was developed, and what it has and can be used for.

5.0 **Current Hydrology and Management** – Briefly summarises current understanding of the hydrology of the Manuherekia Catchment. Including: flow statistics (measured, modelled actual and expected natural) at key locations, sub-catchment yield, flow permanence, and current flow management and flow regimes

6.0 **Future Flow Management** – Provides guidance on how the hydrological information should be used to inform future flow management and development of a flow regime. Includes comment on how climate change predictions should be included in the process and provides guidance on future hydrological monitoring.

[(1)] The spelling of Manuherekia has changed in recent years, but there are historic reports and several organisations that retain the previous spelling of Manuherikia.

2.0 INTRODUCTION AND BACKGROUND

The Manuherekia Hydrology Group[2] was formed in early 2020 and has collaboratively undertaken the work summarised in Table 1 below, as part of what has become known as the Manuherekia Hydrology Project. The extent and scope of the Manuherekia Hydrology Project was developed by the Manuherekia Hydrology Group following an assessment of expected information requirements, a thorough understanding of the available information and identification of the key knowledge gaps. It was developed with knowledge of the tight timeframes which prevented the collection of significant new monitoring data.

Table 1: Manuherekia Hydrology Project Key Tasks

Phase	Task	Agency Responsible	Status
1	Assessment of Flow Gauging Data.	Raineffects Ltd. (Raineffects)	Completed July 2020. (Raineffects 2020)
	Rainfall Sensitivity and Climate Change.	National Institute of Water and Atmospheric Research (NIWA)	Completed - Rainfall August 2020 (NIWA 2020a), Climate Change December 2020 (NIWA 2020b).
	Development of a hydrological model of the Manuherekia Catchment using the GoldSim modelling platform.	Davis Ogilvie & Partners Ltd. (Davis Ogilvie)	Initial model development completed January 2021. Subsequent updates. Final model, named Manuherekia Hydrology Model V4, September 2022.
	Pasture Production Modelling.	PZB Consulting Ltd. (PZB)	Completed February 2021. Results used in economic assessments.
	Use of the Manuherekia Catchment Hydrology Model to assess various scenarios.	Davis Ogilvie with scenarios developed by ORC	Numerous scenarios assessed between December 2020 and July 2021. Results have fed into economic and ecological assessments and ORC's Manuherekia Scenarios document.
2	Documentation of the Manuherekia Catchment Hydrology Model.	Davis Ogilvie	Final Report dated September 2022 (Davis Ogilvie 2022). Earlier draft prepared to assist Peer Review of the model dated February 2022.
	Independent Peer review of the Manuherekia Catchment Hydrology Model.	Led by Otago University with GoldSim support from NIWA	In press (Mager and Griffiths 2022) - key findings used to finalise the Manuherekia Hydrology Model V4 and in finalising the model report.
	Finalisation of model (post review) preparation of final Player version and training of model users.	Davis Ogilvie	Final model, named Manuherekia Hydrology Model V4 dated September 2022. Player version dated September 2022. Training yet to be scheduled.
	Final Scenario assessments using model.	Davis Ogilvie	Yet to be scheduled.
	Joint Expert Statement on Manuherekia Catchment Hydrology.	Led by Davis Ogilvie, with support from all members of the Manuherekia Hydrology Group	This Draft Statement completed in November 2022. Final statement to be reviewed and approved by all members of the Manuherekia Hydrology Group.

[2] The Manuherekia Hydrology Group currently consists of the following 12 members all of which are experienced technical experts who have experience in the Manuherekia Catchment: Pete Ravenscroft (ORC), Pete Stevenson (ORC), Xiaofeng Lu (ORC), Dave Stewart (Raineffects), Sarah Mager (University of Otago), the late Matt Hickey (Water Resource Management Ltd. (WRM)), Roger Williams (Omakau Area Irrigation Scheme (Omakau Irrigation)), Roddy Henderson (NIWA), Christian Zammit (NIWA), James Griffiths (NIWA), Peter Brown (PZB) and Ian Lloyd (DO).

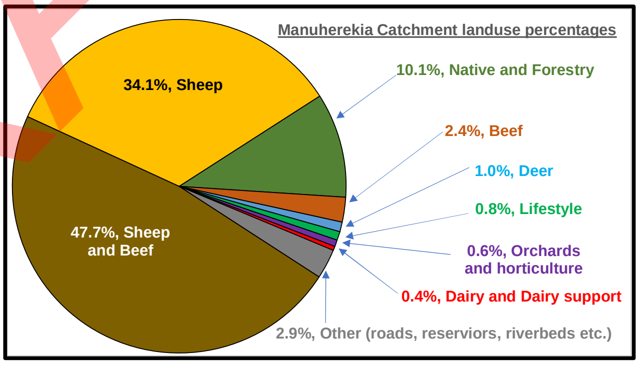
In parallel with the Manuherekia Hydrology Project, ORC have also commissioned various other workstreams including cultural, ecological, natural character, water quality, recreational and economic assessments for the Manuherekia Catchment.

3.0 MANUHEREKIA CATCHMENT

The Manuherekia River, in Central Otago, is a true left tributary of the Upper Clutha Mata-Au River. From its headwaters in the Hawkdun and Saint Bathans ranges, the Manuherekia River flows in a southwest direction to join the Clutha Mata-Au River at Alexandra. From the confluence of the Manuherekia River East and West branches to its confluence with the Clutha Mata-Au River, the main stem of the Manuherekia River is approximately 85 km long. The main stem has four main right bank tributaries (Dunstan Creek, Lauder Creek, Thomsons Creek and Chatto Creek), and two main left bank tributaries (the Ida Burn / Pool Burn system that drains the Ida Valley, and the Manor Burn).

The Manuherekia Catchment covers approximately 305,000 ha and is bounded by the Dunstan Mountains to the northwest, the Hawkdun Range to the northeast and the North Rough Ridge to the southeast. The catchment contains two main valley systems, the Ida Valley and the Manuherekia Valley, which are separated by Raggedy Ridge. The catchment ranges in elevation from approximately 140 m at Alexandra to Mount Saint Bathans at almost 2,100 m.

The catchment is predominantly farmland. The Agribase™ data (2013) indicates that sheep and beef farming is the dominant land use and covers approximately 48% of the catchment with a further 34% classified as sheep farming. Approximately 10% of the catchment is either native or forestry.



Most of the catchment is semi-arid, with a continental type of climate with larger seasonal temperature variations than is common elsewhere in New Zealand. Summers tend to be hot and dry while winters tend to be cold and relatively dry. Severe frosts are common in winter and can last for several days, while summer temperatures regularly exceed 30°C. Mean annual rainfall for the Manuherekia Catchment is about 630 mm / year ranging from approximately 350 mm / year at Alexandra to over 1,200 mm / year on the Hawkdun Range (Aqualinc 2012a). Mean annual evapotranspiration (as estimated by the Penman equations) across the catchment is estimated to range from 750-950 mm / year (Aqualinc 2012a). There is significant snow coverage of the Hawkdun, Saintt Bathans and Dunstan ranges during winter, which last through to early summer.

The catchment has a long history of active water management which stretches back to the early gold mining days in the 1800s, when numerous races were established to supply water to the various gold fields. In the early 1900s, many of these races were converted to supply water for irrigation and from the 1930s, various dams were constructed to store winter runoff and snow melt for summer irrigation use. The dams created three large reservoirs (Falls (1935), Manorburn / Greenland (1916), and Poolburn (1931)) and two smaller ones (Lower Manorburn (1934) and Idaburn (1931)). In addition to the above dams and reservoirs, there is a significant amount of other water infrastructure throughout the catchment including: numerous smaller dams and water storages, extensive water races covering much of the catchment including over 600 km of scheme races which include various tunnels, syphons, viaducts etc., a large number of intake structures and a lesser number of discharge structures. Water is imported to the Manuherekia Catchment from Totara Creek, a tributary of the upper Taieri River. Water is exported from the Manuherekia Catchment to both the Clutha Catchment via irrigation on, and discharges to, the Dunstan Flats; and to the Taieri Catchment via the Mount Ida Race. In addition to the above, there are numerous water transfers between sub-catchments and numerous watercourse reaches (including most of the main stem of the Manuherekia River below Falls Dam) are used to transport irrigation water including water discharged from upstream irrigation storages.

Approximately 25,000 ha is currently irrigated within the Manuherekia Catchment, of which approximately 15,000 ha is considered fully irrigated with the remainder only partially irrigated (Aqualinc 2012b). Six main irrigation companies (Omakau Irrigation Company, Blackstone Irrigation Company, Hawkdun / Idaburn Irrigation Company, Ida Valley Irrigation Company, Manuherikia[3] Irrigation Co-Operative Society and the Galloway Irrigation Society Incorporated) operate within the catchment as well as numerous private irrigators. The Omakau, Manuherikia, Galloway and Blackstone companies have shares in the Falls Dam Company Limited which manages Falls Dam, a key water storage for these irrigation companies. Falls Dam is also used for the generation of hydroelectricity (Pioneer Energy Limited). The Ida Valley Irrigation Company operates the Manorburn / Greenland and Poolburn reservoirs which supply irrigation water to the southern section of the Ida Valley. Prior to 1988 – 1990, the Government via the Ministry of Works and Development operated and managed the schemes, after which, ownership, operation and management of the schemes transferred to the irrigators.

Hydrologically, the Manuherekia Catchment is complex due to the catchment's physical characteristics, the large amount of water infrastructure and the extensive active water management.

A schematic of the Manuherekia Catchment which highlights its key components is shown in Figure 1 (**Attachment 1**).

[3] The spelling of Manuherekia has changed in recent years, but there are historic reports and several organisations that retain the previous spelling of Manuherikia.

4.0 AVAILABLE HYDROLOGICAL INFORMATION

4.1 Previous Investigations

The Manuherekia Catchment has been studied extensively during the past 150 years. Numerous hydrological investigations have been undertaken, the most recent, and arguably the most comprehensive of which, have been investigations completed for ORC, the Manuherekia Catchment Water Strategy Group (MCWSG) and Manuherekia River Limited (MRL). A table of key references is included in Section 7.

4.2 Hydrological Records

4.2.1 Climate

When considering hydrological aspects, it is rainfall and evapotranspiration that are the dominant climate considerations. The key rainfall and evapotranspiration monitoring stations in and surrounding the Manuherekia Catchment are shown in Figure 1 (**Attachment 1**).

Rainfall has been measured at numerous locations within and surrounding the Manuherekia Catchment, and there are a number of long records. ORC currently operate three rainfall monitoring stations in the catchment (Merino Ridges, Ida Burn at Hills Creek, and Tunnel Hill). New Zealand's National Climate Database CliDB contains daily rainfall records from 35 sites within the catchment, 13 of which have greater than 35 years of data. Eight of the records are for stations which continue to operate. Particularly long, complete, and ongoing rainfall records are available from around Lauder, Ophir, Alexandra, Clyde and Ranfurly. Most of the rainfall records are from locations within the valley floors and there are limited records of rainfall at higher elevation.

NIWA's Atmospheric Research Station at Lauder has been operational for approximately 60 years and has a very good, complete, and ongoing record of evapotranspiration. CliDB contains daily evapotranspiration records from 8 sites within the Manuherekia Catchment, and a further 9 sites in neighbouring catchments. Records at Alexandra stretch back to the early 1970s, and to the early 1980s at Lauder. Particularly long, complete, and ongoing records of evapotranspiration are available from Lauder, Alexandra, Clyde and Ranfurly. The evapotranspiration records are from locations within the valley floors and there are no evapotranspiration records from higher elevations.

During the early 2000s, the growOTAGO project undertaken for the ORC by NIWA, AgResearch, Landcare, and the Universities of Otago and Auckland undertook detailed mapping of climate and soil throughout Otago including the Manuherekia Catchment. As part of the project, numerous temporary climate stations were established across the region to facilitate extrapolation of data from the permanent climate stations. The growOTAGO project significantly improved understanding of climate variation across the whole region, including how climate varies with elevation.

4.2.2 Flow Records

Continuous flow or water level records are available for 37 locations throughout the Manuherekia Catchment – although for many of the sites the records are short and / or have significant gaps and for the Chatto Creek, Ida Burn / Pool Burn and Manor Burn sub-catchments there is very limited data. Most of the sites were established by ORC to assist with water management, although a number were established by other organisations such as NIWA, irrigation companies, hydroelectric generation companies and Otago University. Currently ORC's website provides access to continuous flow records from 9[(4)] locations within the Manuherekia Catchment. Continuous records are also currently available for 7[(5)] other flow sites, outflow from the Falls Dam hydroelectric generation plant, and water level in the three main reservoirs (Falls, Poolburn and Manorburn / Greenland). Continuous flow or water level data is therefore currently available for 20 sites in the Manuherekia Catchment. Of the 20 sites only 4 (Manuherekia Downstream of Forks, Dunstan Creek at Gorge, Lauder Creek at Cattle Yards, and Thomsons at Weir) have no (or limited) water infrastructure or active water management upstream and are therefore considered to measure *'natural'* (or close to *'natural'*) flow conditions.

The oldest, longest, and most complete continuous flow record is from the Manuherekia at Ophir site which has data stretching back to February 1971 and remains operational. Four other operational sites (Manuherekia River at Forks, Dunstan Creek at Gorge, Dunstan Creek at Beaties Road and water level in Falls Dam) have in excess of 20 years of data and another two operational sites (Manuherekia River at Campground and Ida Burn / Pool Burn at Cob Cottage) have in excess of 10 years of data. The key flow monitoring sites are shown in Figure 1 (**Attachment 1**).

[(4)] On ORC's flow website the 9 locations are named Manuherekia Downstream of Forks, Manuherekia at Falls Dam 1000m downstream, Manuhereki River at Ophir, Manuherekia at Chattoe Creek Upstream, Manuherekia at Campground, Dunstan Creek at Beatie Road, Lauder Creek at Rail Train, Poolburn at Cob Cottage and Thomsons Creek at SH85.
[(5)] The 7 locations are Manuherekia Downstream of Dunstan Confluence, Dunstan Creek at Gorge, Lauder Creek at Cattle Yards, Thomsons at Weir, Chatto Creek above Manuherekia confluence, Neds Creek (in Chatto Creek catchment) and Hopes Creek above Manor Burn confluence.

In addition to the large number of instantaneous flow gaugings undertaken to support the continuous flow monitoring sites, instantaneous flow gaugings have been undertaken across the catchment, including a number of gauging runs on both the main stem and tributaries to assess longitudinal flow variations. A summary of the available flow gauging data undertaken in July 2020 identified 55 sites within the Manuherekia Catchment where at least 5 instantaneous flow gaugings had been undertaken, with over 600 gaugings having been undertaken at those sites (Raineffects 2020).

4.2.3 Water Use

The Resource Management (Measurement and Reporting of Water Takes) Regulations require that all consumptive takes of water greater than 5 L/s be measured and reported to the relevant Regional Council. There are a large number of takes within the Manuherekia Catchment and ORC receives a considerable amount of water use data. Water take data is available from the 2003 – 2004 irrigation season however it is not until the 2008 – 2009 season that most of the catchments water take is measured. The large amount of water use data coupled with the complexity of water use with numerous retakes, makes interpretation and quality assurance of the water use data extremely difficult. In early 2021, ORC provided data from all water meters in the Manuherekia Catchment which ORC had assessed as being takes (i.e., all retakes were excluded). That data contained records from 142 water meters and indicated the following.

Table 2: Manuherekia Catchment Water Take Data – Key Flow Statistics

Irrigation Season take (1 September – 30 April)				Non-Irrigation Season take (1 May – 31 August)			
99th Percentile	90th percentile	Mean	Median	99th Percentile	90th percentile	Mean	Median
13,900	12,000	8,100	8,700	3,900	2,000	1,100	1,000

Notes:
- All values are in L/s and are rounded to the nearest 100 L/s.
- All values are based on analysis of daily water take timeseries provided by ORC.
- Values are based on daily data from the 1 May 2008 to 30 April 2020.
- Extreme values >30,000 L/s have been removed from the time series as they are considered erroneous.
- Uncertainties associated with the values have not been estimated.

4.3 Hydrological Models

4.3.1 Available Models and Background

Earlier hydrological investigations and models in the Manuherekia Catchment were aimed at either further understanding the current hydrological system and / or assessing potential water developments (namely increased storage and irrigation). The earlier models have included:

- TopNet / CHES model developed by NIWA for ORC (NIWA 2019)

- Various Excel and GoldSim models prepared for MCWSG, MRL or individual irrigation companies by Aqualinc Research Limited (Aqualinc 2012c, 2012d, 2013a and 2013b), Golder Associates (NZ) Ltd. (Golder 2014 and 2016), Davis Ogilvie (2018) and Raineffects (2020a).

The Manuherekia Catchment Hydrology Model is a key output from the Manuherekia Hydrology Project. It builds on the earlier models and is based on current understanding of the catchment's hydrological system. A brief summary of the model is provided in the following section.

4.3.2 Manuherekia Catchment Hydrology Model

The Manuherekia Catchment Hydrology Model is a daily water balance model of the Manuherekia Catchment from 1 June 1973 to 31 May 2020, which uses the GoldSim Modelling platform. The model is documented in Davis Ogilvie 2022 and is available for all stakeholders to use. The objective of the model is to:

….provide ORC and the various stakeholders with a hydrological model, which can be used by all parties to improve understanding of the catchment's hydrological system and to assess the implications of future water management decisions. The model has been specifically developed to support the upcoming planning, consenting and water management processes throughout the Manuherekia catchment.
(From Davis Ogilvie 2022, Page 18)

The Manuherekia Catchment Hydrology Model was developed as a decision support tool and its real value lies in its ability to rapidly assess and compare multiple scenarios. Model use and interpretation of the model's predictions should focus on the relative change between scenarios rather than the specific values for any one scenario.

The hydrology of the Manuherekia Catchment is known to be complicated. The catchment contains a significant amount of water infrastructure and has a long history of active water management. It is not possible to model all the intricacies of the catchment's hydrological system. The Manuherekia Catchment Hydrology Model is therefore focused on the larger scheme storages, the main stem of the Manuherekia River below Falls Dam and the six main tributaries namely Dunstan Creek, Lauder Creek, Thompsons Creek, Chatto Creek, Manor Burn and the Ida Burn / Pool Burn system. Irrigated areas are consolidated into the main schemes and sub-catchments (refer the model logic diagram which is included in **Attachment 2**).

The model is based on the following 26 daily input timeseries:

- Six irrigation demand timeseries – one for each of flood and spray irrigation in each of the three zones of Above Ophir, Below Ophir and Ida Valley which were developed from soil moisture modelling.
- Nine return water timeseries – one each for flood irrigation, spray irrigation and dryland in each of the three zones. Return water represents the combined effect of soil drainage and runoff. These timeseries were again developed from soil moisture modelling.
- Three reservoir inflow timeseries – one each for Falls, Poolburn, and the Upper Manorburn / Greenland reservoirs.
- Seven flow timeseries – six of the timeseries represent natural flow above the takes in the sub-catchment tributaries (Dunstan Creek, Lauder Creek, Thompsons Creek, Chatto Creek, Ida Burn and Dovedale Creek). The other timeseries is flow in Mount Ida Race as it leaves the Falls Dam Catchment but prior to any offtakes (i.e., prior to the R race offtake).

The model predicts daily average flow at numerous locations, storage in the five modelled reservoirs (Falls, Poolburn, Manorburn / Greenland, Lower Manorburn and Idaburn), water reliability in 13 irrigation areas, and ecological habitat for 11 aquatic species at 3 locations.

The model and model report were peer reviewed (Mager and Griffiths 2022). They concluded that:

...the model is fit for the purpose of understanding the flow and its allocation across the catchment and we do not specify any changes be made to the model or flow series i.e., we support the flow time series produced by the model. (per coms Sarah Mager)

<u>Use to Date</u>

In addition to the verification run (called Estimated Existing (Status Quo or Baseline) in the model) the Manuherekia Catchment Hydrology Model has, to date, been used to run and assess 29 scenarios developed by ORC which focused on minimum flows in the Manuherekia River at Campground of 900, 1200, 1500, 1700, 2000, 2500 and 3000 L/s. All 29 scenarios were assessed prior to the model being peer reviewed and finalised. Details of the 29 scenarios and the model's predictions are summarised in Davis Ogilvie 2021. The model predictions were used to inform subsequent economic and ecological assessments and were used in ORC's Manuherekia Scenarios document entitled *"Manuherekia Scenarios - A discussion of freshwater management in the Manuherekia catchment"* dated May 2021.

Use of the model, and particularly the numerous runs that were completed during construction of the model and the subsequent verification process has provided an understanding of the relative sensitivities of the modelled variables, which provides insight into the key factors that influence the actual physical system. The key findings and improved understanding of the hydrology of the Manuherekia Catchment are summarised below.

- Other than water which goes into storage, water tends to flow through the system rapidly and there are no big delays or excessive travel times. This confirms that groundwater is limited and does not significantly influence the overall hydrology of the catchment. Water storage within the soil profile and the "sponge effect" particularly associated with flood irrigation influences local conditions but does not significantly influence overall catchment hydrology.
- Flow in the main stem of the Manuherekia River and operation of Falls Dam is very sensitive to what happens in the tributaries and how much water is available for main stem water users from the tributaries.
- Flow in the Manuherekia River at Campground is dominated by outflows from Falls Dam and contributions from the six main tributaries of Dunstan Creek, Lauder Creek, Thompsons Creek, Chatto Creek, Manor Burn and the Ida Burn / Pool Burn system. Contributions from the numerous other small tributaries and from the valley floor areas are not significant.
- While area wise, the Ida Burn, Pool Burn and Manor Burn sub-catchments represent a significant proportion of the overall Manuherekia Catchment, their contribution to flow in the Manuherekia River at Campground is predominantly limited to fresh and flood flows. During periods of low flow, they do not contribute very much as most of the flow is either stored or used for irrigation.
- The Poolburn and Manorburn / Greenland reservoirs have very large storage volumes relative to their inflows. They typically take multiple years to fill and are managed on a multi-year basis.
- Falls reservoir has a relatively small storage volume relative to the inflow it receives, and it refills quickly. During dry periods when inflow is low and demand for water is high, storage in Falls reservoir can be quickly depleted (i.e., within two months) which is consistent with actual observations (per coms Roger Williams).
- Irrigation within the Poolburn Catchment is predominantly supplied from stored water whereas run of river takes dominate irrigation water supply for the remainder of the catchment, including irrigation supplies downstream of Falls Dam.

- The current Falls Dam management practices of:
    - o Imposing voluntary irrigation restrictions on irrigators in the Manuherekia Valley in order to retain storage in Falls Dam, and
    - o Using storage in Falls Dam to augment minimum flows in the Manuherekia River at Campground,

  have a significant effect on the overall system. The management practices affect all parts of the system including flow in four of the modelled tributaries (namely Dunstan, Lauder, Thomsons, and Chatto creeks), flow in the main stem of the Manuherekia River below Falls Dam, storage in Falls reservoir and irrigation reliability throughout the Manuherekia Valley.
- Management of Falls Dam and flow in the main stem of the Manuherekia River downstream of Falls Dam is complicated and involves a fine balancing act between competing demands. The characteristics of the outlet from Falls Dam, travel times through the system, the complexities of the main stem water takes (i.e., their large number, the variety of intake infrastructure, and their varying ability to predict actual water demand) and the complex nature of the flow interactions; makes managing the system in real time to achieve a downstream goal i.e., a minimum flow in the Manuherekia River at Campground, extremely difficult. Management relies on access to accurate real time flow and water take data. Given the complexities of the system, unintended short-term variations from stated management goals are likely to be unavoidable.
- Key flow statistics from both the model input timeseries and the results from the verification run (called Estimated Existing (Status Quo or Baseline) in the model) are summarised in the following table.

Table 3: Manuherekia Catchment Hydrology Model V4 – Key Flow Statistics for Status Quo Scenario						
Sub-Catchment	**Site**	**1 percentile flow**	**5 percentile flow**	**7-day MALF**	**Median**	**Average**
Manuherekia River Main Stem	Inflow to Falls Dam*	820	1,246	1,267	3,906	5,254
	Ophir	1,394	1,824	1,834	8,080	12,226
	Campground	482	685	818	10,151	14,602
Dunstan Creek	Gorge*	531	665	671	1,767	2,398
	Manuherekia confluence	61	280	267	2,501	3,505
Ida Burn / Pool Burn	Inflow to Poolburn reservoir*	3	5	8	61	109
	Ida Burn above Mount Ida Race*	28	37	36	105	210
	Cob Cottage	4	7	16	442	983
Lauder Creek	Cattle Yards*	246	303	306	816	1,111
	Manuherekia confluence	53	113	103	756	1,134
Thomsons Creek	Weir*	140	181	185	570	777
	Manuherekia confluence	18	27	41	499	731
Chatto Creek	Above takes*	103	190	215	850	1,365
	Manuherekia confluence	60	30	88	790	1,314
Manor Burn	Inflow to Manorburn / Greenland reservoir*	8	15	30	425	695
	Manuherekia confluence	0(1)	0(1)	36	994	1,736

Notes:
- All values are in L/s.
- All values are based on analysis on average daily (midnight to midnight) flow series.
- Modelled results are from the Manuherekia Catchment Hydrology Model V4 - Status Quo (Estimated Existing) scenario for the period 1 June 1973 to 31 May 2020.
- 7 Day MALF is based on hydraulic years 1 June to following 31 May.
- Uncertainties associated with the values have not been estimated.

* Represent model input timeseries. All other sites represent model results.

(1) Modelled extreme low flows in the Manor Burn at confluence are heavily influenced by the Lower Manorburn Dam immediately upstream and assumptions regarding live storage and supply of water to part of the Galloway Irrigation Scheme.

Recommendations for Future Use

The Manuherekia Catchment Hydrology Model provides a powerful tool which can be used to guide development of future water management regimes for the Manuherekia Catchment. The model contains significant functionality and flexibility, allowing a wide variety of future water management scenarios to be rapidly assessed.

A player version of the finalised model (named Manuherekia Hydrology Model V4, September 2022) which runs on freely available software is publicly available for all stakeholders to use. This allows stakeholders to develop and assess their own potential future water management regimes for the catchment. The model was developed to be easy to use, and with a relatively small amount of training, it is expected that all stakeholders will be able to use it.

As highlighted in the limitations section of the model report (Section 7.0 of Davis Ogilvie 2022) care is required when developing scenarios and interpreting model predictions. When using the model to develop and assess potential future water management regimes the following steps are recommended:

1. Determine the desired outcomes i.e., what changes to the current system are desired.

2. For each of the key model outputs of flow, aquatic habitat, storage operation, and irrigation reliability determine performance criteria associated with the desired outcome.
3. Use the model to determine what model parameters have the most influence on each of the performance criteria.
4. Starting from the "Estimated Existing" (Status Quo or Baseline) model scenario, use the model to build up a potential water management regime (a scenario) by altering the most relevant model parameters first. Given the large number of interactions in the model it is recommended that the model parameters are adjusted one at a time so that their influence can be assessed. If multiple parameters are adjusted at the same time, it becomes very difficult to determine how and to what extent each of the adjustments has affected each of the model outputs. In assessing the model output, initial focus should be on a few key outputs.
5. Once the scenario has been sufficiently developed it should then progress to a more detailed evaluation of the model outputs to determine if the scenario achieves the desired outcomes.
6. Through setting a number of desired outcomes, multiple scenarios are developed which can be compared to identify preferred scenarios and preferred future water management regimes.

It is recommended that the above steps are completed in a workshop environment ideally with multiple stakeholders present. Doing so will build confidence in the model, improve understanding of the system, will allow the relative positions of the stakeholders to be presented, and will facilitate the development of scenarios and future water management regimes which are more widely accepted. If such workshops are undertaken, we recommend that someone who is familiar with both the Manuherekia Catchment Hydrology Model and the actual hydrology of the Manuherekia Catchment is included to ensure the model is used appropriately and the model outputs correctly interpreted.

4.4 Climate Change Assessments

Two main climate change assessments have been undertaken for the Manuherekia Catchment Aqualinc 2012f and NIWA 2020.

Aqualinc 2012 summarised knowledge of climate change with a focus on the potential impacts on irrigation and water infrastructure, and included the following comments:

> *The key potential climate change projections for the Manuherikia area are:*
>
> - *The mean annual temperature would increase by 0.9 and 2°C relative to 1990 (i.e., the average of 1980-1999) by 2040 and 2090, respectively.*

- *The mean annual precipitation would increase by up to 5% and 10% relative to 1990 by 2040 and 2090, respectively.*
- *However, most of the precipitation increase would occur in winter and the average summer rainfall would reduce.*
- *Low summer rainfall will increase the crop-water deficit, increasing irrigation requirements.*
- *It is likely that current 1-in-20 year droughts would occur approximately three times more frequently by 2090.*
- *Occurrence of extreme climate events such as floods, severe droughts, and warmer days would increase.*

NIWA 2020, assessed the potential impacts climate change may have on natural river flows in the Manuherekia catchment and included the following comments:

The aim was to assess if and when climate change is likely to affect flow regimes and associated environmental flow estimation at each proposed water allocation control point within the Manuherekia catchment. This was carried out to ascertain whether the impacts of climate change on flow regime are expected to impact currently designed environmental flows across the Manuherekia catchment.

Key results are as follows:

- *High flows are expected to increase by over 5% by 2050;*
- *Median and mean flows are expected to slightly increase up to 5% by 2050;*
- *Low flows and Mean Annual Low Flow calculated over a running 7 day period (7-day MALF) are expected to slightly increase up to 5% by 2020 before decreasing back to their historical level by 2050, except in the Manuherekia headwaters where low flows are expected to decrease by up to 5%;*
- *Seasonally, mean and median discharge over Winter-Spring and Autumn are expected to increase with warming across the Manuherekia catchment, while mean and median discharge during Summer are expected to decrease from the 2020s onward;*
- *Low flows during the irrigation season (taken from September to March) are expected to increase in Spring, while decreasing in Summer. This behaviour is spatially variable as Summer low flows are expected to increase by the 2020s and decrease to their historical simulated levels by the 2050s for Ida Burn, while Spring flows at Falls Dam are projected to increase up to the 2020s before reducing to their historical simulated level by 2050s;*
- *Median number of consecutive days below hindcast 7-day MALF is not expected to change with warming, while the maximum number of events of five consecutive days is expected to increase by up to 10 occurrences. If 7-day MALF is used as a water consent threshold, this would point towards a shift in the distribution of periods where water consent will be restricted with restriction being less often but potentially lasting longer;*

- *Analysis of the Wilcoxon Signed Rank test[(6)] indicates that across the Manuherekia catchment changes in discharge are extremely likely to be associated with climate change effects (95% confidence level) for a majority of the overlapping time periods analysed over the period 2006 to 2060.*

It is clear from both studies that future changes in climate will influence soil moisture levels, natural flows in watercourses and demand for water. How these changes will affect the performance of the existing water infrastructure and influence water management decisions is less well understood.

5.0 CURRENT HYDROLOGY OF THE MANUHEREKIA CATCHMENT

New Zealand climate and hydrology is strongly influenced by a number of large drivers, including the Interdecadal Pacific Oscillation (IPO) that typically lasts 20 – 30 years, the El Niño-Southern Oscillation (ENSO) which occurs every 2 – 7 years and typically lasts around a year, and the Southern Annular Mode (SAM) which can last for several weeks, but changes phases quickly and unpredictably (stats.govt.nz website). These large influences make comparing hydrology and flow statistics difficult, and it is preferable to use long records which are over the same time period (*'normalised'*) where possible. Shifts in the IPO occurred in the mid-1940s, mid-1970s, late 1990s and mid-2010s[(7)]. The oldest continuous flow record available in the Manuherekia Catchment is from the Manuherekia at Ophir site which has data stretching back to February 1971. This record therefore covers 4 phases of the IPO (negative in the early 1970s, and from the late 1990s to mid-2010s; and positive from mid-1970s to late 1990s and since mid-2010s). In developing the Manuherekia Catchment Hydrology Model average daily flow series were developed from 1 June 1973 to 31 May 2020 for various locations, which were predominantly upstream of any water infrastructure. Together these developed flow series provide an indication of *'natural'* flow conditions over a consistent (*'normalised'*) time period.

[(6)] Wilcoxon signed-rank test is a nonparametric test that can be used to determine whether samples were selected from populations having the same distribution. In our case it is used to assess if historical and climate change driven simulations belong to the same population.
[(7)] https://www.stats.govt.nz/indicators/interdecadal-pacific-oscillation.

The hydrology of the Manuherekia Catchment is known to be complicated due principally to the large amount of water infrastructure and the extensive active water management practices. Flow in almost all of the main stem and all the main tributaries particularly downstream of the foothills is highly modified. Water harvesting to fill irrigation storages and hydro generation at Falls Dam effects downstream flows outside the irrigation season whereas irrigation itself, the associated movement of water (including releases from storage), in-season refilling of irrigation storages, and current water management practices significantly influence flows over the irrigation season. While the flow modifications tend to have a greater influence on the lower parts of the flow regimes, refilling of the larger storages influences fresh and to a lesser extent flood flows, particularly during the latter part of the irrigation season and post season. These effects on the flow regime have been occurring since at least the early 1930s and there is little if any actual data on what the *'natural'* flow regime would have been in the mid to lower reaches of the river. Continuous flow or water level data is currently available for 20 sites in the Manuherekia Catchment. Only 4 of these sites (Manuherekia Downstream of Forks, Dunstan Creek at Gorge, Lauder Creek at Cattle Yards, and Thomsons at Weir) have no (or limited) water infrastructure or active water management upstream and are therefore considered to measure *'natural'* (or close to *'natural'*) flow conditions.

The following section describe the general hydrology of the main stem of the Manuherekia River followed by sections on each of its main tributaries in a downstream order.

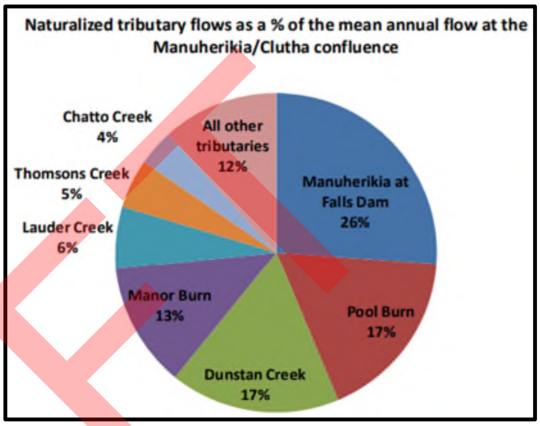
5.1 Manuherekia River Main Stem

The main stem of the Manuherekia River starts at the confluence of the Manuherekia River East and West branches. Other than remnants of historic water races, the Manuherekia River West Branch contains no water infrastructure, whereas the Manuherekia River East Branch is influenced by the top part of the Mount Ida Race which draws water from four creeks within the East Branch Catchment. For approximately its first 1 km the main stem of the Manuherekia River flows through a valley section where it is relatively confined. This reach contains the uppermost flow monitoring site, Manuherekia River at Forks. Downstream the main stem expands into a braided river section stretching approximately 15 km down to Falls reservoir. The Mount Ida Race traverses the western flanks of the Hawkdun Range extracting water from numerous small creeks and capturing overland flow, which would otherwise flow into Falls reservoir. The ORC's Tunnel Hill rainfall station is located northwest (upstream) of Falls Dam on the catchment boundary with Station Creek. Numerous old water races which historically supplied water to the numerous gold diggings around Saint Bathans are located in the lower western part of the catchment above Falls Dam.

Falls Dam is a key water storage for downstream irrigators, it is approximately 33 m high, and the reservoir is estimated to store approximately 10.3 Mm^3 of which approximately 10 Mm^3 is considered useable (Golder 2015). The storage is relatively small when compared to both inflow and outflow. The storage is rapidly drawn down (can be drained in approximately 2 months) during periods of high downstream demand and rapidly refills during fresh and flood events. When full, the reservoir stretches back approximately 2.3 km from the dam wall and has a surface area of approximately 145 ha. The reservoir has an approximately 20 m operating range and during droughts the reservoir is drawn down very low exposing large mud flats. Water level in the reservoir is measured along with outflow from the Falls Dam hydroelectric generation. Controlled outflow (excludes spillway discharges) from the dam is limited to a maximum of 4 m^3/s when the reservoir is full but reduces to approximately 1.5 m^3/s when the reservoir is low. Resource Consents associated with the operation of Falls Dam currently require a minimum flow below the dam of 0.5 m^3/s, although during the irrigation season this is generally significantly exceeded as stored water is released for downstream irrigation.

From Falls Dam to approximately Loop Road the Manuherekia River flows through the approximately 7 km long Fiddlers Gorge within which ORC operate a flow monitoring site. Below Loop Road, the river become more braided again for approximately 6 km before reaching the first of the four major irrigation off-takes, Blackstone Irrigation Scheme (BIS), with the Omakau Irrigation Scheme (OIS) main race intake located approximately 5.5 km further downstream. The BIS scheme irrigates land on the left bank, whereas the OIS main race supplies irrigation water to the right bank with the irrigated area extending into the catchments of Dunstan Creek, Lauder Creek, Thomsons Creek and Chatto Creek. Dunstan Creek the largest of the tributaries (flow wise) joins from the right approximately 3.5 km downstream of the OIS main race intake. The Ida Burn / Pool Burn joins from the left approximately 8 km downstream from the Dunstan Creek confluence, and Lauder Creek joins from the right approximately 2.5 km further downstream. Below the Lauder Creek confluence, the Manuherekia River flows through the approximately 2 km long Lauder Gorge before expanding out for a further approximately 6 km down to the Manuherekia River at Ophir flow monitoring site. Thomsons Creek joins from the right immediately upstream of the Manuherekia River at Ophir flow monitoring site. Downstream of the Manuherekia at Ophir flow monitoring site, the Manuherekia River flows through the approximately 12 km long Tiger Hill Gorge within which the Manuherekia Irrigation Scheme's (MIS) main race intake is located. Chatto Creek joins from the right just downstream of the end of the Gorge. The last of the 4 main irrigation scheme intakes (Galloway Irrigation Scheme (GIS)) is located approximately 3 km downstream of the Chatto Creek confluence. Approximately 8.5 km downstream of the GIS intake the last main tributary, the Manor Burn joins from the left. ORC's Manuherekia River at Campground flow monitoring site is located approximately 1.5 km downstream of the Manor Burn confluence. Below the Manuherekia River at Campground flow monitoring site the Manuherekia River flows for approximately 2 km before entering the Clutha Mata-Au River.

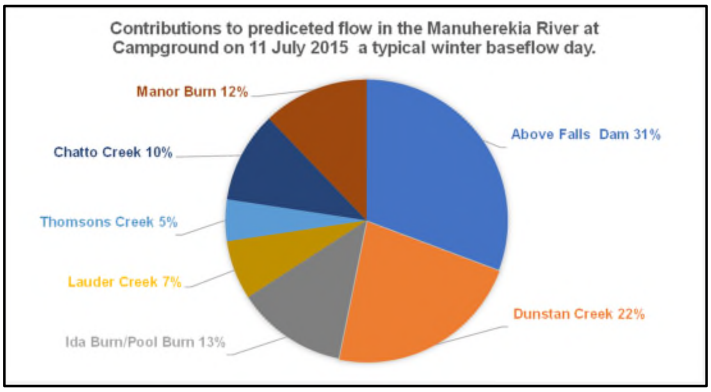
Travel times down watercourses generally increase with flow, with velocities within any reach predominantly dependant on slope, roughness, and restrictions. Analysis of flood peaks measured at the flow monitoring sites down the main stem of the Manuherekia River indicated velocities ranging from 0.9 to 3.5 m/s with flood flows travelling from Falls Dam to the Campground flow monitoring site in 8 – 14 hours. During low flow conditions average velocities decrease to below 1 m/s, with travel times estimated to be 13 – 15 hours from Falls Dam to Ophir and 26 – 28 hours from Falls Dam to the Campground flow monitoring site (Raineffects 2021a).



Flow down the main stem of the Manuherekia River varies significantly due to tributary inflows, irrigation and its associated activities and active water management practices. Aqualinc (2012b) assessed naturalised tributary flows as a percentage of the mean annual flow from the overall Manuherekia Catchment and summarised the results in the plot opposite. Raineffects (2021a) undertook a similar exercise using winter flow data from the main stem when Falls Dam was full and spilling and found that flow in the Manuherekia River at Campground was made up as follows:

- 28 % from the catchment above Falls Dam – with a roughly even split between the catchment above and below the Manuherekia Downstream of Forks flow recorder.
- 53 % from the catchment between Falls Dam and the Ophir flow recorder – namely the main tributaries of Dunstan Creek, Ida Burn / Pool Burn, Lauder Creek and Thomsons Creek.
- The remaining 19 % came from the catchment below Ophir – namely the main tributaries of Chatto Creek and Manor Burn.

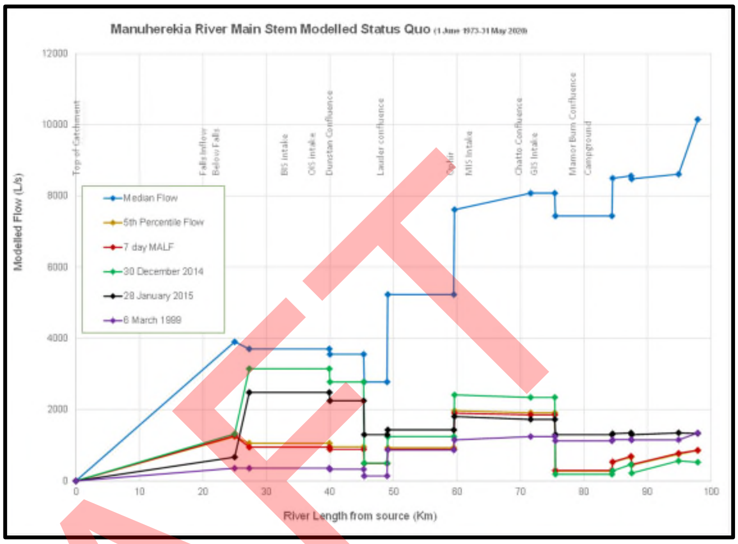
For the 11 July 2015 which was a day when flow in the Manuherekia at Campground was predicted to be close to its median value, Falls Dam was full and spilling and the Ida Valley storages were close to full but were not spilling (i.e., typical winter baseflow type conditions) the model predicted that flow in the Manuherekia River at Campground would be made up as shown in the figure opposite. In terms of water yield per area the catchment above Falls Dam and Dunstan Creek Catchments are the highest yielding, with Pool Burn particularly low yielding.



The discrepancies between the contribution estimates highlight the difficulty in estimating *'natural'* flows in such a highly modified system.

The Manuherekia Catchment Hydrology Model verification run (called Estimated Existing or Status Quo) predicted flow down the main stem would vary as outlined in the figure below. Predicted flows are shown for the following for situations:

- Median flow.
- 5th percentile low flow.
- 7-day MALF.
- On 30 December 2014 a typical low Falls Dam inflow, high irrigation demand, high storage in Falls Dam (approximately 65% full) and no management-imposed irrigation restrictions, situation.



- On 28 January 2015 a typical very low Falls inflow, high irrigation demand, low storage in Falls Dam (approximately 20% full) and high management-imposed irrigation restrictions, situation.
- On 6 March 1999 a typical low Falls inflow, high irrigation demand, Falls Dam empty and very high management-imposed irrigation restrictions (namely stockwater only) situation.

Key flow statistics from the main stem of the Manuherekia River are summarised in the following table:

Table 4: Manuherekia River Main Stem – Key Flow Statistics

Site	Data	Minimum	1 percentile flow	5 percentile flow	7-day MALF	Median	Average
Manuherekia at Ophir	Measured 1/6/73 – 31/5/20	457	1,220	2,083	2,175	9,322	13,943
Manuherekia at Campground	Measured 23/10/08 – 31/5/20	406	639	905	895	11,706	16,062

Notes:
- All values are in L/s.
- All values are based on analysis on average daily (midnight to midnight) flow series.
- 7 Day MALF is based on hydraulic years 1 June to following 31 May. Gaps in the measured records were assessed and were ignored if they occurred over winter or were short and were preceded and followed by elevated flows.
- Measured results are for the period indicated. Care is required when comparing values over differing time periods.
- Uncertainties associated with the values have not been estimated.

A number of studies have estimated *'natural'* 7-day MALF in the Manuherekia River at both the Ophir and Campground flow monitoring sites. At Ophir estimates for *'natural'* 7-day MALF include 3.27 m^3/s (is 5th percentile low flow, Aqualinc 2012e), 3.54 m^3/s (Aqualinc 2014), 3.2 m^3/s ± 20% (NIWA 2016) and 3.3 m^3/s, 4.07 m^3/s and 4.50 m^3/s (NIWA 2019). At Campground estimates for *'natural'* 7-day MALF include 3.51 m^3/s (is 5th percentile low flow, Aqualinc 2012e), 3.77 m^3/s (Aqualinc 2014), 3.9 m^3/s ± 20% (NIWA 2016) and 4.4 m^3/s, 5.08 m^3/s and 5.50 m^3/s (NIWA 2019). As highlighted by the varying estimates it is very difficult to estimate *'natural'* flows in such a highly modified system.

The Manuherekia Catchment Hydrology Model was not developed to estimate *'natural'* flows. However, for a scenario which considered no irrigation and full storages the model predicted 7-day MALF in the Manuherekia River based on average daily flow for the period 1 June 1973 to 31 May 2020 and hydrological years from 1 June to the following 31 May, to be 3.4 m^3/s at Ophir and 4.0 m^3/s at Campground. Note the scenario included continued use of both the Mount Ida Race and the importing of water into the Pool Burn Catchment from the Taieri Catchment. Uncertainties were not estimated for these predictions but are expected to be at least ± 20% given that the model was not developed to estimate *'natural'* flows.

5.2 Dunstan Creek

Dunstan Creek is the largest (flow wise) tributary of the Manuherekia River. It drains a steep sided valley system between the Dunstan Range and Chain Hills to the west and the Wether and Saint Bathans ranges to the east. From its headwaters near Old Man Peak, Dunstan Creek flows predominantly towards the south for approximately 60 km before joining the Manuherekia River at the State Highway 85 Bridge. Through its upper and middle reaches, the creek's channel is relatively confined as it flows in the base of steep sided valleys and through gorge sections. ORC's Dunstan Creek at Gorge flow monitoring site is located mid catchment approximately 8 km upstream of the Loop Road Bridge. While there are a significant number of historic gold mining related water races in the catchment no active water races are understood to extend upstream of the Gorge flow monitoring site. While there are significant data gaps the flow record from the Dunstan Creek at Gorge flow monitoring site extends back to March 1973 and represents the longest record of *'natural'* flow in the catchment.

Upon exiting the foothills near Saint Bathans, Dunstan Creek widens out and the creek bed becomes heavily vegetated with predominantly willows and gorse. Blue Lake at Saint Bathans and the surrounding goldfields are within the Dunstan Creek Catchment and there are numerous old water races in the area, which historically supplied water to the gold diggings.

In addition to private water takes, there are two main irrigation scheme takes from Dunstan Creek. The most upstream of which is located approximately 6 km downstream of the Loop Road Bridge and takes water for irrigation on the right bank. The second intake is located approximately 3 km further downstream near Cambrians. This intake feeds OIS's Dunstan Race which supplies irrigation water to approximately 850 ha (Golder 2105) on the left bank with the irrigated area extending into the neighbouring Lauder Creek catchment. Approximately 3 km downstream of OIS's intake, Dunstan Creek crosses Beatties Road where ORC's main flow monitoring site (Dunstan Creek at Beatties Road) is located. Dunstan Creek joins the Manuherekia River approximately 6 km downstream of Beatties Road.

An assessment of flow differences in Dunstan Creek between Beatties Road and the Manuherekia Confluence (Raineffects 2021b), found that mean flows increased by approximately 300 L/s. Approximately 40% of the increase was attributed to the increased catchment area, with the remaining 60% attributed to shallow groundwater which was previously flowing in the gravels beneath and alongside the creek (underflow), but had being forced to the surface due to an outcrop of relatively impermeable mudstone near the Manuherekia Confluence (Raineffects 2021b). This highlights the need to consider underflow and hydraulic linked shallow groundwater as part of surface water management.

In addition to the flow records from the Gorge and Beatties Road sites, flow records are also available for Woolshed Creek[8] at Lauder Station (1972-1989 although data quality is poor (Raineffects 2021b)) and ORC operated a temporary flow site just above the Manuherekia Confluence from November 2020 to April 2021.

Key measured flow statistics for Dunstan Creek are summarised in the following table:

Table 5: Dunstan Creek – Key Flow Statistics

Site	Data	Minimum	1 percentile flow	5 percentile flow	7-day MALF	Median	Average
Dunstan Creek at Beatties Road	Measured 14/11/02 – 31/05/20	38	169	308		2,329	3,051

Notes:
- All values are in L/s.
- All values are based on analysis on average daily (midnight to midnight) flow series.
- 7 Day MALF is based on hydraulic years 1 June to following 31 May. Gaps in the measured records were assessed and were ignored if they occurred over winter or were short and were preceded and followed by elevated flows.
- Measured results are for the period indicated. Care is required when comparing values over differing time periods.
- Uncertainties associated with the values have not been estimated.

[8] Woolshed Creek is a lower right bank tributary of Dunstan Creek.

A number of studies have estimated *'natural'* 7-day MALF in the Dunstan Creek. Aqualinc 2014 estimated 7-day MALF for Dunstan Creek at the Gorge to be 620 L/s. For Dunstan Creek at Beatties Road estimates of *'natural'* 7-day MALF include 934 L/s (ORC 2016) and 887 L/s (NIWA 2019). Given the irrigation takes upstream of Beatties Road it is very difficult to estimate *natural* flows during the irrigation season at this location.

5.3 Ida Burn / Pool Burn

The Ida Burn and its main tributary the Pool Burn drain the Ida Valley, which lies between Raggedy Ridge to the west and Rough Ridge to the east. The Ida Burn flows south and drains the northern part of the Ida Valley while the Pool Burn flows north and drains the southern part of the valley. After merging with the Pool Burn the Ida Burn flows west through the Poolburn Gorge to join the Manuherekia River approximately opposite Lauder township.

From its headwaters near Mount Ida (1,690 m) at the southern end of the Hawkdun Range, Ida Burn flows in a roughly south to south-westerly direction for approximately 8 km before crossing the Mount Ida Race. The Mount Ida Race was constructed in the 1870s to provide water to goldfields surrounding Naseby. By the 1920s, mining had decreased, and the race was converted to supplying irrigation water. The race crosses the Ida Burn Catchment and in additional to formal takes from the main Ida Burn tributaries, it intercepts runoff from the catchment above the race. Approximately 7,570 ha of the Ida Burn Catchment (represents approximately 9 % of the total Ida Burn / Pool Burn Catchment) is located above the race and particularly during low flows is essentially cut-off from the remaining catchment by the Mount Ida Race. The Mount Ida Race has 2 off-takes in the Ida Burn Catchment R Race and A Race, which supply irrigation water to the upper parts of the Ida Burn Catchment with the irrigated area extending into Williamsons Creek, a tributary of the main stem of the Manuherekia River.

Below the Mount Ida Race, the Ida Burn flows for approximately 6 km before crossing under SH85 then for approximately 10 km past Oturehua before entering the Idaburn reservoir. The reservoir was formed when the approximately 10 m high Idaburn Dam was completed in 1932. The reservoir has limited live storage and when full covers over 9.5 ha. The Idaburn reservoir supplies irrigation water to part of the Hawkdun Idaburn Irrigation Scheme.

Below the Idaburn Dam, the Ida Burn meanders down the Ida Valley for approximately 14 km before joining with the Pool Burn after which it flows through the approximately 5 km long Poolburn Gorge. The ORC's Poolburn at Cobb Cottage flow monitoring site is located at the downstream end of the gorge and is the only permanent flow monitoring site currently operating in the Ida Burn / Pool Burn catchments[9]. Below the flow monitoring site, the Ida Burn flows for approximately 2 km before joining the Manuherekia River.

The upper Pool Burn Catchment is dominated by the Poolburn reservoir. The reservoir was formed when the approximately 25 m high Poolburn Dam was completed in 1931. The reservoir has a live storage of approximately 28 Mm^3 and when full covers over 450 ha. The Poolburn reservoir together with the Manorburn / Greenland reservoir supply water to the Ida Valley Irrigation Scheme (IVIS) which covers the southern part of the Ida Valley. The catchment above the Poolburn Dam is approximately 4,400 ha which is approximately 5% of the total Ida Burn / Pool Burn Catchment. Water is also imported into the Poolburn Dam Catchment via a water race which draws water from the catchment of Totara Creek, a tributary of the Taieri River. A low dam / weir intake is located approximate 15 km downstream of the main Poolburn Dam and directs water into the IVIS's German Hill Race. When required water is released from the reservoir into the Pool Burn and then directed into the German Hill Race by the downstream intake.

Below the German Hill Race, the Pool Burn flows down the Ida Valley in a northerly to north easterly direction for approximately 23 km before its confluence with the Ida Burn. Through this section much of the creek has been straightened and flows are often low due to abstractions and upstream storage.

There is limited information on flows within the Ida Burn / Pool Burn Catchment and while it is included within the Manuherekia Catchment Hydrology Model hydrological understanding of the system is relatively limited.

Due to the lack of data from the Ida Burn / Pool Burn Catchment and the extent of upstream water infrastructure it is very difficult to estimate either actual or *'natural'* flows within the system.

[9] Note there is also a permanent flow recorder on the Mount Ida Race at Johnsons weir which is within the Ida Burn catchment.

5.4 Lauder Creek

Lauder Creek drains the eastern flanks of a part of the Dunstan Mountains and lies between the catchments of Dunstan Creek to the north and Thomsons Creek to the south. From its headwaters near the Lauder Basin Hut, Lauder Creek flows roughly south through an upper catchment dominated by short steep sided valleys for approximately 13 km before exiting the foothills and emerging onto the floor of the Manuherekia Valley. ORC's Lauder Creek at Cattle Flats flow monitoring site is located approximately 1.5 km upstream from where Lauder Creek exits the foothills. Numerous historic water races extend upstream of the Lauder Creek at Cattle Flats flow monitoring site and historically provided water to the nearby Drybread Diggings goldfields. One of the races remains operational and is now used to supply irrigation water to a private scheme.

Upon exiting the foothills near the Drybread Diggings, Lauder Creek widens, and the creek meanders its way initially to the southeast and then south across the floor of the Manuherekia Valley for approximately 9 km before joining the Manuherekia River near Lauder Township. The lower approximately 4 km of Lauder Creek are heavily vegetated with large willows. The ORC's Lauder Creek at Rail Trail flow monitoring site is located approximately 0.5 km upstream of the Manuherekia confluence.

In addition to numerous private water takes, the OIS takes irrigation water from an intake weir near where Lauder Creek exits the foothills. The intake feeds OIS's Lauder Race which supplies irrigation water to the left bank with the irrigated area extending into the neighbouring Thomsons Creek Catchment. Significant areas in the lower Lauder Catchment are irrigated using water from the main stem of the Manuherekia River via the OIS main race.

Surface flow in Lauder Creek currently dries every summer over an approximate 2 km reach between where Lauder Creek exits the foothills and Glassford Road. In 2021 Raineffects undertook an assessment of the hydrology of Lauder Creek using data held by ORC (Raineffects 2021c) to assess if the drying reach is natural or induced by irrigation takes. That assessment identified flow losses to shallow groundwater in the order of 320 L/s between OIS's Lauder Race intake weir and the point of highest loss approximately 3 km upstream of Glassford Road. The assessment concluded that Lauder Creek is likely to dry naturally in the above reach approximately once every 2 years (Raineffects 2021c). Water abstractions will increase the frequency and duration of drying events and increase the length over which drying occurs.

A number of studies have estimated *'natural'* 7-day MALF in Lauder Creek at Cattle Yards. Estimates include 230 L/s (Aqualinc 2014), 316 L/s (NIWA 2019), 320 and 329 L/s (Raineffects 2021c).

5.5 Thomsons Creek

Thomsons Creek drains the eastern flanks of a part of the Dunstan Mountains and lies between the catchments of Lauder Creek to the north and Chatto Creek to the south. Cloudy Peak on the catchment boundary with the Lindis River is the highest point in the Thomsons Creek Catchment at 1,526 m. From its headwaters near Mount Makariri, Thomsons Creek flows initially northeast before turning to the southeast, through an upper catchment dominated by short steep sided valleys, for approximately 20 km, before exiting the foothills and emerging onto the floor of the Manuherekia Valley near Tinkers Diggings. ORC's Thomsons Creek at Weir flow monitoring site is located approximately 1.2 km upstream from where Thomsons Creek exits the foothills. The Weir flow monitoring site is located approximately 50 metres upstream from the irrigation intake weir for OIS's Matakanui Race. Numerous historic water races extend upstream of the Thomsons Creek at Weir flow monitoring site and historically provided water to the nearby Tinkers Diggings goldfields.

Upon exiting the foothills, Thomsons Creek widens and meanders its way south across the floor of the Manuherekia Valley for approximately 16 km before joining the Manuherekia River immediately upstream of the Manuherekia at Ophir flow monitoring site. The ORC's Thomsons Creek at SH85 flow monitoring site is located approximately 0.5 km upstream of the Manuherekia confluence.

The OIS's Matakanui Race supplies water to irrigation on the left bank of Thomsons Creek, with the irrigated area extending south to near the Chatto Creek Catchment. In addition to the Tinkers Diggings goldfield in the Thomsons Creek Catchment, the Devonshire Diggings goldfields are located just across the catchment boundary in the adjoining Chatto Creek Catchment. There are numerous historic water races in the general area which historically supplied water to both goldfields. A number of these races are now used for local irrigation and move water between sub-catchments. Significant areas in the lower Thomsons Catchment are irrigated using water from the main stem of the Manuherekia River via the OIS main race.

Surface flow in Thomsons Creek currently dries every summer in several places between where it exits the foothills and Mawhinney Road. In 2021 Raineffects undertook an assessment of the hydrology of Thomsons Creek using data held by ORC (Raineffects 2021d) to assess if the drying is natural or induced by irrigation takes. That assessment identified significant natural flow losses to shallow groundwater between OIS's Matakanui Race intake weir and Wedding Ford (approximately 2 km downstream of Glassford Road). The assessment concluded that Thomsons Creek is very unlikely to dry naturally between OIS's Matakanui Race intake weir and Glassford Road but is likely to dry naturally between Glassford Road and Wedding Ford (Raineffects 2021d). Water abstractions will increase the frequency and duration of drying events and increase the length over which drying occurs. The assessment also found that the shallow groundwater store under and surrounding the creek has a significant influence on surface flows. In dry times, the shallow groundwater store delays the onset of drying but once depleted it requires significant replenishment which can delay the reestablishment of surface flow.

A number of studies have estimated *'natural'* 7-day MALF in Thomsons Creek. Aqualinc 2014 estimated 7-day MALF for Thomsons Creek at Diversion Weir to be 170 L/s, NIWA 2019 estimated it to be 183 L/s and Raineffects 2021d 214 L/s.

5.6 Chatto Creek

Chatto Creek drains the eastern flanks of the south-eastern end of the Dunstan Mountains and lies between the catchments of Thomsons Creek to the north and Waikerikeri Creek (a tributary of the Clutha Mata-Au River) to the south. Mount Dunstan on the catchment boundary with the Clutha Mata-Au River is the highest point in the Chatto Creek catchment at 1,667 m. Chatto Creek is fed by numerous headwater creeks which flow in a generally south easterly direction. Chatto Creek itself starts at the confluence of Devonshire Creek and Scotts Creek and flows to the south for approximately 18 km before joining the Manuherekia River immediately downstream of the Otago Central Rail Trail bridge over the Manuherekia River.

In addition to numerous private water takes which are mostly from tributaries of Chatto Creek there are two scheme takes. OIS's County Race takes water from a number of northern tributaries to irrigate land near the Thomson Creek Catchment boundary. The MIS Borough race draws water from the middle reaches of Chatto Creek with the intake located approximately 8 km upstream of the Manuherekia Confluence. The Borough Race was constructed as a mining race in the 1860s, but since the early 1920s has been used to supply irrigation water to land that extends down to Alexandra including the Dunstan Flats, which are in the Clutha Mata-Au River Catchment. Significant areas in the lower Chatto Catchment are irrigated using water from the main stem of the Manuherekia River via the OIS main race.

There is limited information on flows within the Chatto Creek Catchment. ORC have established a permanent flow monitoring site upstream of the Manuherekia Confluence, but the flow record is relatively short.

NIWA 2019 estimated *'natural'* 7-day MALF in Chatto Creek at confluence to be 576 L/s. Due to the lack of data from the Chatto Creek Catchment, the extent of upstream water infrastructure, the numerous water takes and water transfers, it is very difficult to estimate either actual or *'natural'* flows within the system.

5.7 Manor Burn

The Manor Burn drains the northern flanks of the Knobby Range and the western flanks of the southern end of Rough Ridge. The catchment lies between the Teviot River Catchment to the south, the Taieri River Catchment to the east and the Pool Burn Catchment to the north. South Rough Ridge Hill is the highest point in the Manor Burn Catchment at a modest 1,166 m, although the catchment contains significant areas which are above 700 m. The upper catchment is dominated by the Manorburn / Greenland reservoir. The reservoir was formed when the Upper Manorburn Dam was completed in 1916. The dam is approximately 27 m high, and the reservoir has a live storage of approximately 51 Mm^3. When full, the reservoir covers over 800 ha. The Manorburn / Greenland reservoir together with the Poolburn reservoir supply water to the IVIS which covers the southern part of the Ida Valley. The Manorburn / Greenland reservoir also supplies irrigation water to the Crawford Hills irrigation area in the lower Manuherekia Valley. The catchment above the Upper Manorburn Dam is approximately 9,700 ha which is approximately 20 % of the total Manor Burn catchment. Inflow to the reservoir is small compared to storage, and if drained the reservoir generally takes multiple years to refill.

Storage in the Manorburn / Greenland reservoir is managed on a multiyear basis with the annual irrigation quota set at the start of each irrigation season depending on the level of storage. The reservoir has an approximately 15 m operating range and when drawn down large areas of lake bed are exposed. Water level in the reservoir is measured although it is only in the last few years that an automatic water level recorder has been installed. A low dam / weir intake is located approximately 5 km downstream of the Upper Manorburn Dam and directs water into the IVIS's Bonanza Race. When required, water is released from the reservoir into the Manor Burn and then directed into the Bonanza Race by the downstream intake. A number of sections of the upper Bonanza Race are known to leak and return water back to the Manor Burn system.

There is limited irrigation within the Manor Burn catchment. Almost all of which is located within the Little Valley Creek Catchment, which is a significant left tributary of the lower Manor Burn. Much of this irrigation is associated with large private irrigation storages located on Speargrass Creek and Campbells Creek.

The lower catchment is dominated by the Lower Manorburn Reservoir which is located approximately 1.5 km upstream of the Manor Burn's confluence with the Manuherekia River. The reservoir was formed when the approximately 16 m high Lower Manorburn Dam was completed in 1934. The reservoir has limited live storage and when full covers approximately 20 ha. The Lower Manorburn Reservoir supplies irrigation water to approximately half of the Galloway Irrigation Scheme (GIS) which is located within the catchment of the Lower Manuherekia River.

There is limited information on flows within the Manor Burn Catchment and while it is included within the Manuherekia Catchment Hydrology Model, hydrological understanding of the system is relatively limited.

Raineffects 2020 estimated both actual and *'natural'* inflows to the Lower Manorburn reservoir for the period 1982 to 1998 (Raineffects 2020b) to be:

- Actual mean inflow 1,530 L/s, with an actual 7-day MALF of 90 L/s.
- *'Natural'* mean inflow 2,460 L/s, with a *'natural'* 7-day MALF of 95 L/s.

Due to the lack of data from the Manor Burn and the extent of upstream water infrastructure it is very difficult to estimate either actual or *'natural'* flows within the system.

5.8 Current Flow Management and Flow Regime

There is currently no formal flow regime for the Manuherekia River system, and ORC are in the process of developing one. ORC's current Regional Plan: Water for Otago indicates a minimum flow in the Manuherekia River at Ophir of 820 L/s and a primary allocation limit of 3,200 L/s for the Manuherekia River catchment upstream of Ophir. The minimum flow at Ophir was set through the Environment Court (NZEnvC 229 (25 June 2002)). Resource consents for the operation of Falls Dam also require a residual flow below Falls Dam of 500 L/s. Flow records from Ophir indicated that between 1 June 1973 and 31 May 2020 average daily (midnight to midnight) flow in the Manuherekia River at Ophir dropped below 820 L/s on 53 occasions[10], which were spread over 4 years representing approximately 0.7% of the time. All 53 occasions occurred prior to the minimum flow at Ophir being set. Through the irrigation season flows in the Manuherekia River at Ophir are enhanced by water released from Falls Dam for irrigation by the MIS and the GIS.

[10] The 53 occasions were 4 days late January to early February 1974, 11 days in late March and early April 1976, 25 days in February and predominantly March 1982 and 13 days in February and early March 1999

Currently the flow regime of the Manuherekia River and its main tributaries is predominantly managed by the existing water users (namely the 6 main irrigation schemes, the Falls Dam Company, and to a lesser extent Pioneer Energy Ltd.). Their management practices have been developed over many years and are based on carefully balancing storage, river flow, water demand and imposing voluntary water restrictions. Two main management practices are imposed:

1. For the main stem of the Manuherekia River, Falls Dam Company impose voluntary water restrictions on irrigators in the Manuherekia Valley in order to retain storage in the Falls Dam reservoir and then use that storage to, when necessary, augment flow in the Manuherekia River to achieve a voluntary minimum flow of 900 L/s at Campground. The voluntary water restrictions imposed by the Falls Dam Company are generally accepted by the vast majority of water users in the Manuherekia Valley even those who do not directly benefit from water released from Falls Dam. The voluntarily imposed water restrictions achieve two things:
    a) They restrict water takes throughout the Manuherekia Valley, thereby reducing run of river demand and allowing more water to be retained in the tributaries and main stem, thereby improving downstream flows. This has a particularly strong influence in the tributaries.
    b) By restricting water takes from the main stem of the Manuherekia River the voluntarily imposed water restrictions reduce demand on storage in Falls Dam. Storage is retained for longer, prolonging the ability of Falls Dam to provide both water to main stem users and for augmentation of downstream flows. Retaining storage and prolonging water supplies, benefits the majority of the main stem as it is used to convey irrigation water, particularly Falls Dam to the MIS intake and to a lesser extent down to the GIS intake. It also prolongs return irrigation water - while most of the water supplied to irrigators is used, a proportion is returned to the system through irrigation not being 100% efficient in terms of water use.
2. The IVIS manages storage in their Poolburn and Manorburn / Greenland reservoirs on a multiyear basis with the annual irrigation quota set at the start of each irrigation season depending on the available storage.

Both management practices have a significant effect not only on flow downstream of the reservoirs but also (via the numerous water races and sub-catchment water transfers) irrigation season flows in the lower reaches of many other tributaries.

The majority of water use in the Manuherekia Catchment was previously authorised under *'mining privileges'* or *'deemed permits'*, which expired on 1 October 2021. The *'deemed permits'* included a priority system which typically was based on the age of the permit. While the priorities were not often enforced their existence encouraged water users to work together and are a key reason why the voluntary water restrictions imposed are generally widely accepted.

The Manuherekia Catchment Hydrology Model clearly indicates that when storage in the catchment's main storage reservoirs is depleted, downstream flows often fall to low levels.

6.0 FUTURE FLOW MANAGEMENT

While the hydrology of the Manuherekia Catchment is complex and is highly modified, it has been extensively studied over many years. The large amount of water infrastructure and the high degree of active water management, makes developing water management solutions which achieve multiple desired outcomes very difficult. Currently the flow regime of the Manuherekia River and its main tributaries is predominantly managed by the existing irrigators (namely the 6 main irrigation schemes and the Falls Dam Company). Their management practices have been developed over many years and are based on carefully balancing storage, river flow, irrigation demand and imposing voluntary irrigation restrictions. Given the complexity of the system it is considered critical that the experience of the existing managers who understand the existing water infrastructure is fully utilised in the development of any future flow regimes.

The development of flow regimes for many New Zealand catchments has often used a good understanding of *'natural'* conditions. In the case of the Manuherekia Catchment, the extent and longevity of both the water infrastructure and active water management practices are such that despite extensive study the *'natural'* hydrology of the catchment is not well understood. Given this, it is recommended that the development of future flow regimes places less weight on estimated *'natural'* flows. We recommend a process which looks at desired changes (improvements) to the current regime and then utilises the considerable experience of the existing water managers to determine how best to achieve the desired improvements. The Manuherekia Catchment Hydrology Model provides a tool which can assist in this process. The model can assist both the development of potential future water management regimes and then assess the implications of those regimes.

When developing future flow regimes, the potential effects of climate change need to be fully considered. Climate change is expected to result in changing rainfall patterns across the catchments with a move to more extreme events i.e., larger, more intense rainfall events and longer and more frequent droughts. This will lead to both changing water demand and changing water availability. How these changes will affect the operation of the existing water infrastructure and how best to manage for such events needs to be carefully assessed. We recommend that modified input timeseries are developed for the Manuherekia Catchment Hydrology Model, which take into account potentially higher irrigation demand through higher temperatures and more frequent drought conditions and changed runoff in the foothills, which will alter inflows to the storages and water availability. The model could then be used to assess the implications of future climate change on the existing water infrastructure the help develop future water management regimes which suitably consider climate change.

6.1 Future Hydrological Monitoring

On-going hydrological monitoring is critical to future management of the Manuherekia River system particularly as the hydrological system will change due to the effects of both climate changes and management changes. In terms of future hydrological monitoring, we recommend the following:

- Continued flow monitoring particularly at the sites with existing long records and at sites upstream of water infrastructure namely:
    - Predominantly natural sites: Manuherekia at Forks, Dunstan at Gorge, Lauder at Cattle Yards, and Thomsons at Weir.
    - Water level in, and outflow from, the main reservoirs namely Falls, Poolburn, and Manorburn / Greenland. Such measurements allow reservoir inflow to be estimated.
    - Downstream sites: Manuherekia at Ophir (to continue the longest and most complete record in the catchment) and Manuherekia at Campground.
    - If tributaries are to be managed as individual systems, then measurement of flow at the downstream end of the tributaries will be beneficial.
- Continuation of the long-term climate records particularly: both rainfall and evapotranspiration at Lauder, Alexandra, Clyde and Ranfurly, and rainfall only at Ophir.
- Improved understanding of water use with continued monitoring of all the main water takes with improved quality assurance and analysis of the collected data. Currently, concerns over the available water use data, limits its use in estimating '*natural*' flow conditions.

7.0 REFERENCES

The following table provides a brief summary of the key hydrological references for the Manuherekia Catchment.

Table 6: Key Hydrological References for the Manuherekia Catchment	
Reference	**Comments on Hydrology Topics Covered**
Aqualinc 2012a, Manuherikia Catchment Study: Stage 1 (Land). Report numbered C12040/1 prepared for the MCWSG, dated 6 November 2012.	Includes comments on climate (rainfall and evaporation), soils, irrigable area, irrigation practices and the results of irrigation demand modelling. Mainly focused on the Manuherekia Valley. Provides filled climate records for numerous sites.
Aqualinc 2012b, Manuherikia Catchment Study: Stage 2 (Hydrology). Report numbered C12040/2 prepared for the MCWSG, dated 22 September 2012.	Includes general comments on the hydrology of the Manuherekia Catchment including river flows, water availability, existing storages, existing irrigation and potential future water demand. Includes correlations between various flow sites.
Aqualinc 2012c, Manuherikia Valley: Detailed Hydrology. Report numbered C12040/3 prepared for the MCWSG, dated 22 September 2012.	Follows in from the above report and includes a more details assessment of the hydrology of Falls Dam and the main stem of the Manuherekia River. Includes a description of the Manuherekia Valley model the first hydrology model developed in the catchment. Includes the development of a timeseries of average daily inflow to Falls Dam.
Aqualinc, 2012d. Manor Burn Catchment Detailed Hydrology. Report numbered C12119/4 prepared for the MCWSG, dated 22 September 2012.	Assess the hydrology of the Manor Burn including a proposed new storage in Hopes Creek to supply water to the southern part of the Ida Valley.
Aqualinc, 2012e. Manuherikia Flow Regime and Water Quality impacts, Report numbered C12119/7 prepared for the MCWSG, dated 6 December 2012.	Includes estimates for 5th percentile low flows (often similar to 7-day MALF) at various locations down the main stem of the Manuiherekia River under a no-irrigation scenario.
Aqualinc, 2012f. Impact of Climate Change on the Manuherikia Irrigation Scheme, Report numbered C12119/10 prepared for the MCWSG, dated 6 December 2012.	Summaries current knowledge of climate change and its potential impact on irrigation with a focus on the Manuherekia Valley.
Aqualinc, 2013a. Manuherekia Valley Hydrology: 2013 update. Report numbered C14000/1 prepared for the MCWSG, dated 17 September 2013.	Updates Aqualinc 2012c including updates to the Manuherekia Valley model
Aqualinc, 2013b. Mt Ida Dam Hydrology. Report numbered C14000/2 prepared for the MCWSG, dated 17 September 2013.	Assess the hydrology of the Ida Burn including the Mount Ida Race and specifically a proposed new storage in the Ida Burn to supply water to part of the Hawkdun Idaburn Irrigation Scheme.
Aqualinc, 2014. Various spreadsheets containing hydrological model output sent by Aqualinc to Golder dated 21 November 2014.	Represents the most resent predictions for the Manuherekia Valley model which were subsequently used in feasibility investigations undertaken by the MCWSG.

Table 6: Key Hydrological References for the Manuherekia Catchment – continued	
Reference	**Comments on Hydrology Topics Covered**
Davis Ogilvie, 2018. Manuherekia Catchment Hydrological Model – Update Report. Prepared for Manuherekia River Limited, reference number 180904.37308, dated 13 September 2018.	Summaries updates made to the initial Manuherekia Catchment Hydrology Model which is documented in Golder 2016. This report is designed to be read in conjunction with Golder 2016.
Davis Ogilvie 2022, Manuherekia Catchment Hydrology Model Report, Report prepared for ORC, dated September 2022.	Documents the latest hydrology model namely Manuherekia Catchment Hydrology Model V4 September 2022.
Golder 2014. Manuherikia Catchment Feasibility Study Flow Regimes. Letter from Golder to the Manuherikia Catchment Water Strategy Group, reference 1378110270-2999_L_Rev1-222, dated 1 December 2014.	Briefly documents a potential flow regime for the main stem of the Manuherekia River which was developed via a workshop which used the first Manuherekia GoldSim model which was focused on Falls Dam and the main stem of the Manuherekia Rive.
Golder 2015. Irrigation Distribution Report. Report numbered 1378110270-2000-R-Rev1-223 prepared for the Manuherikia Catchment Water Strategy Group, dated June 2015.	Summaries existing irrigation infrastructure for the main irrigation schemes (all except the Ida Valley Scheme). Outlines existing irrigated area and expected future irrigation areas throughout the catchment. Outlines storage in Falls Dam which is based on the most recent stage storage cure.
Golder 2016. MCWSG Optimisation Process – Optimisation Modelling. Draft Report numbered 1545649_7410-002-R-Rev0 prepared for the MCWSG, dated February 2016.	Documents the Manuherekia Catchment Hydrology model that was the first hydrology model developed for the full catchment using the GoldSim modelling platform.
Mager S and J Griffiths, 2022 in Press. Review of the Manuherekia Hydrology Model. A report prepared by Sarah Mager (University of Otago) and James Griffiths (NIWA) for ORC.	Documents peer review of the Manuherekia Catchment Hydrology Model V3 February 2022. Following the peer review the model and the associated model report were updated to address the peer review finings. The final (post peer review) model is Manuherekia Catchment Hydrology Model V September 2022.
NIWA, 2016. Estimation of Natural 7-Day Mean Annual Low Flow at two sites on the Manuherikia River. Letter from NIWA to ORC, dated 19 August 2016.	Provides estimates of 7-day natural MALF in the Manuherekia River at Ophir and Campground.
NIWA, 2019. CHES Implementation for the Manuherekia River, Otago Report for Manuherekia TAG. Draft report prepared for ORC (by Henderson, Zammit, Griffiths) dated November 2019.	Documents a CHES-TopNet model develop by NIWA for the Manuherekia catchment and includes estimates of natural 7-day MALF at a number of locations throughout the catchment.
NIWA, 2020a, Manuherekia Rainfall Sensitivity. Report prepared for ORC by C Zammit of NIWA, dated August 2020.	Describes how sensitive the TopNet estimates of flows in the Manuherekia catchment are to potential errors in rainfall measurement.
NIWA, 2020b, Potential climate change impacts on streamflow in the Manuherekia catchment. Report prepared for ORC by C Zammit of NIWA, dated 7 December 2020.	Uses the TopNet model developed by NIWA (NIWA 2019) to assess the potential impacts climate change may have of natural river flows in the Manuherekia catchment.

Table 6: Key Hydrological References for the Manuherekia Catchment – continued	
Reference	**Comments on Hydrology Topics Covered**
ORC, 2016. Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek. ORC report prepared by D Olsen, X Lu and P Ravenscroft of ORC, dated September 2016	Includes estimates of natural 7-day MALF at a number of locations throughout the catchment.
PZB Consulting, 2020. Manuherekia Hydrology: Report 1. A report prepared for ORC by P Brown of PZB Consulting, dated August 2020.	Describes the derivation of climate, irrigation demand, soil drainage and naturalised flow timeseries that are used in the Manuherekia Catchment Hydrological Model.
Raineffects, 2020a. Discharge Gauging Data for the Manuherekia Catchment. A report prepared for ORC by D Stewart of Raineffects and S Mager of University of Otago, dated July 2020.	Summarises the available instantaneous flow gauging data that is available from the Manuherekia Catchment and comments on its potential usefulness.
Raineffects, 2020b. Manor Burn Catchment Water Resources Study. A report prepared for WSP Global, dated April 2020.	Summarises the hydrology of the Manor Burn catchment including the development of initial flow series that were subsequently used in the development of input flow series for the Manuherekia Catchment Hydrology Model V4 September 2022.
Raineffects, 2021a, Natural Flow Relativities and Travel Times Between Water Level Recorder Sites on the Manuherikia River. A report prepared for ORC by D Stewart of Raineffects, dated 1 November 2021.	Provides estimates of travel times down the main stem of the Manuherekia River and sub-catchment flow contributions.
Raineffects, 2021b, Comparison of Dunstan Creek at Beattie Road 100m Downstream and Dunstan Creek at Manuherikia Confluence 400m Upstream Flow Records. A report prepared for ORC by D Stewart of Raineffects, dated July 2021.	Provides estimates of flow changes in lower Dunstan Creek below Beatties Road.
Raineffects, 2021c, Lauder Creek Hydrology. A report prepared for ORC by D Stewart of Raineffects, dated February 2021.	Summaries the hydrology of Lauder Creek including changes in flow and the permanence of surface flows between the flow monitoring site at Cattle Yards and Glassford Road.
Raineffects, 2021d, Thomsons Creek Hydrology. A report prepared for ORC by D Stewart of Raineffects, dated Auguat 2022.	Summaries the hydrology of Thomsons Creek including changes in flow and the permanence of surface flows between the flow monitoring site at Diversion Weir and Mawhinney Road.

In preparing this Joint Hydrology Expert Statement and in undertaking the Manuherekia Hydrology Project the Manuherekia Hydrology Group acknowledge the significant contribution the late Matt Hickey of Water Resource Management Ltd made to understanding of the hydrology of the Manuherekia Catchment.

Signatures:

Pete Ravenscroft (ORC) Date:

Pete Stevenson (ORC) Date:

Xiaofeng Lu (ORC) Date:

Dave Stewart (Raineffects) Date:

Sarah Mager (University of Otago) Date:

Roger Williams (Omakau Irrigation) Date:

Roddy Henderson (NIWA) Date:

Christian Zammit (NIWA) Date:

James Griffiths (NIWA) Date:

Peter Brown (PZB) Date:

I. Lloyd

Ian Lloyd (Davis Ogilvie) Date: 28 February 2023

ATTACHMENT 1

Figure 1: Schematic of the Manuherekia Catchment

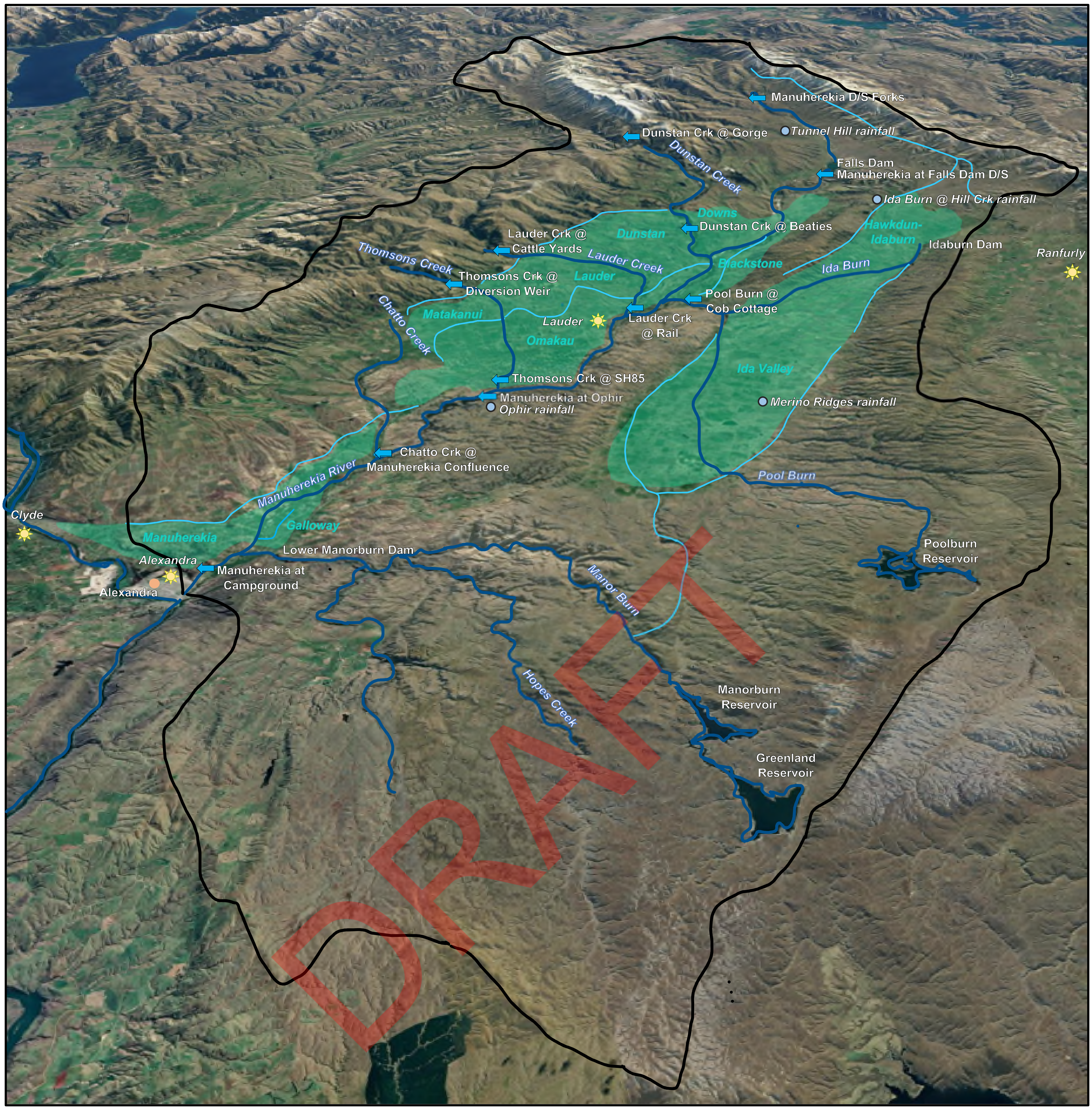
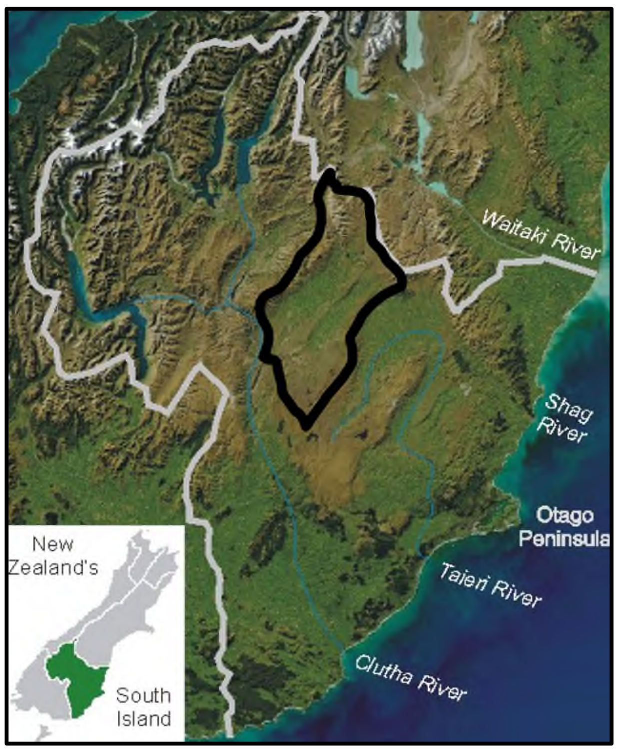


Figure 1: Schematic of the Manuherekia Catchment[1]



Key

- Current permanent flow site
- Key rainfall and evapotranspiration station
- Key rainfall station
- Catchment boundary
- Natural waterway
- Main water races
- Irrigable area and Main scheme names

[1] Aerial image: sourced from Google Earth
Oblique basemap – not to scale
Schematic only, not to be interpreted as an engineering design or construction drawing

ATTACHMENT 2

Manuherekia Catchment Hydrology Model V4, September 2022 – Model Logic Diagram