DAVIS OGILVIE
ENGINEERS / SURVEYORS / PLANNERS

MANUHEREKIA CATCHMENT HYDROLOGY MODEL REPORT

40102 / MANUHEREKIA CATCHMENT HYDROLOGY / OTAGO REGIONAL COUNCIL

0800 999 333
hello@do.nz

Level 1, 42 Oxford Street, Richmond
www.do.nz

Davis Ogilvie & Partners Ltd

DAVIS OGILVIE
ENGINEERS / SURVEYORS / PLANNERS

QUALITY ASSURANCE

Title:	Manuherekia Catchment Hydrology Model Report	
Client:	Otago Regional Council	
File Location:	T:\projects\40s\40102 - Manuherekia Hydrology\Civil\hydrology model\Goldsim\Model\Report\220913.il.40102 Manuherekia model report - Final.docx	
Version:	Final	
Date:	September 2022	
Project No	40102	
Prepared By:	**Ian Lloyd** Senior Water Engineer MSc, BE (Civil), BSc (Geology)	**Signature:** I Lloyd
Reviewed By:	**Sophie South** Senior Civil Engineer ME, BE(Hons)NatRes, CPEng, CMEngNZ	**Signature:**

DISCLAIMER

This report has been prepared at the specific instruction of Otago Regional Council. It describes and documents the Manuherekia Catchment Hydrology Model (the Manuherekia Model) and has been prepared to facilitate peer review and subsequent use of the model.

The Manuherekia Model was developed through a collaborative process undertaken by the Manuherekia Catchment Hydrology Group (the Group). While Davis Ogilvie & Partners Ltd were responsible for development of the model, the model uses input data provided by various members of the Group and the overall model represents the combined understanding of the Group. The Manuherekia Model is based upon information from, and understanding of, the catchment and its hydrological system at the time the model was produced. It includes numerous assumptions and interpretations which were necessary in order to suitably represent what is a complicated, dynamic natural system by a relatively simple numeric model. The Manuherekia Model was developed to assist and inform decisions regarding future management of the Manuherekia Catchment's water resources. The model needs to be viewed in the context that it was produced and with the understanding that there will be discrepancies between the actual system and the model predictions. No warranty is included — either expressed or implied — that the actual hydrology of the Manuherekia Catchment will conform to the predictions provided by the Manuherekia Model.

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GLOSSARY AND ABBREVIATIONS

Dashboard	A model element that is a customary interface or control panel for a model.
Estimated Existing	The name of the Status Quo or Baseline scenario or model run. Is the model run that was used for model verification.
Final Model	Manuherekia Hydrology Model V4 and dated September 2022
GL	Gigalitres i.e., 109 L. Note 1 GL (gigalitre) = 1 M m3 (million cubic metres)
GoldSim	Modeling software which was used to create the Manuherekia Hydrology Model V4. GoldSim version 12.0 was used.
Player	A user version of the GoldSim Model which runs on free publicly available software.
Live Storage	Useable storage within a reservoir. Represents total storage less dead storage.
L/s	Litres per second
m^3/s	Cubic meters per second
M m^3	Million cubic metres i.e., 106 m^3. Note 1 M m^3 = 1 GL (gigalitre)
MALF	Mean Annual Low Flow
MRG	Manuherekia Reference Group
TAG	Technical Advisory Group
Scenario	Represents a model run i.e., a modelled scenario.

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1.0 INTRODUCTION

The Otago Regional Council (ORC) requires hydrological information (including a hydrological model) to inform planning, consenting and water management processes that are currently being undertaken for the Manuherekia catchment, Central Otago. The Manuherekia Hydrology Group[(1)] was formed in early 2020 to provide the required hydrological information. Since early 2020 the Manuherekia Hydrology Group has collaboratively undertaken the work summarised in Table 1 below, as part of what has become known as the Manuherekia Hydrology Project.

Table 1: Manuherekia Hydrology Project Key Tasks

Phase	Task	Agency Responsible	Status
1	Assessment of Flow Gauging Data	Raineffects Ltd. (Raineffects)	Completed July 2020
	Rainfall Sensitivity and Climate Change	National Institute of Water and Atmospheric Research (NIWA)	Completed - Rainfall August 2020, Climate Change December 2020
	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 an economic assessment.
	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	This report – earlier draft February 2022
	Independent Peer review of the Manuherekia Catchment Hydrology Model.	Led by Otago University with GoldSim support from NIWA	In press -key findings used to finalise the Manuherekia Hydrology Model V4 and in finalising this 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 of model users .scheduled for October 2022
	Final Scenario assessments using model	Davis Ogilvie	Scheduled for October 2022
	Joint Expert Statement on Manuherekia Catchment Hydrology.	Led by Davis Ogilvie, with support from others as required.	Draft statement scheduled for completion in September 2022. Final statement to be reviewed and approved by all members of the Manuherekia Hydrology Group

[1] 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.

The Manuherekia Catchment Hydrology Model (final model named Manuherekia Hydrology Model V4 and dated September 2022) is a key output from the Manuherekia Hydrology Project. It is based on current understanding of the catchment's hydrological system and provides a tool which can both suitably replicate current conditions and assess the implications of future water management decisions. The model was prepared to inform and support future water management decisions.

1.1 Purpose of this Report

This report documents the Manuherekia Catchment Hydrology Model, final model named Manuherekia Hydrology Model V4 and dated September 2022. An earlier draft of this report (dated February 2022) was prepared to facilitate peer review of the model. This final report updates the earlier draft to address the review findings and associated model updates. This final report is also designed to facilitate future use of the finalised (post peer review) model.

1.2 Report Structure

Following this introductory section this report contains the following eight sections followed by a list of references.

2.0 **Model Background** – Briefly explains the background to the model, why it was developed and a short summary of the model development process.

3.0 **Model Objective, Scope, and Logic Diagram** – Outlines the scope and objectives of the model and presents a model logic diagram which highlights the extent of the model, its key components, and key interactions.

4.0 **Key Model Details** – Briefly outlines the key assumptions that underpin the model, the model's functionality, and key outputs.

5.0 **Model Inputs** – Briefly describes the key model inputs (particularly the input times series) and how they were developed.

6.0 **Model Verification** – Briefly outlines the model verification process and provides the key results from the verification (called Estimated Existing in the model) model run.

7.0 **Model Limitations** – Outlines the limitations of the model and key considerations when using it.

8.0 **Model Use** – Briefly outlines how the model has been used to date including a summary of the scenarios that have been run. Also provides guidance on potential future use of the model, development of model scenarios and interpretation of model predictions.

9.0 **Conclusions and Recommendations** – Provides some brief concluding comments and recommendations for future work.

Development and initial use of the Manuherekia Catchment Hydrology Model did not include full documentation of the model. To help address the lack of documentation the following four memorandums were produced:

1. *Manuherekia Catchment GoldSim model – scoping document – revised draft*. A memorandum prepared by Davis Ogilvie for the ORC and the Manuherekia Hydrology Group dated 6 July 2020, referenced as Davis Ogilvie 2020.
2. *Manuherekia Hydrology model – Calibration Memorandum – Final Draft*. A memorandum prepared by Davis Ogilvie for the ORC and the Manuherekia Hydrology Group dated 21 May 2021, referenced as Davis Ogilvie 2021a. In developing this report it became apparent that "verification" is a better description of the process rather than "calibration". Within the model, the scenario named "Estimated Existing" represents the "Status Quo" or "Baseline" scenario which was used for model verification. The model verification process and the model predictions for the "Estimated Existing" scenario are explained in this memorandum.
3. *Manuherekia Hydrology model – Ecology Memorandum – Final Draft*. A memorandum prepared by Davis Ogilvie for the ORC and the Manuherekia Technical Advisory Group dated 21 May 2021, referenced as Davis Ogilvie 2021b. In June 2022 corrected ecology input was supplied by Richard Allibone of Water Ways Consulting Ltd. The corrected ecological input was included in the final model (named Manuherekia Hydrology Model V4 and dated September 2022). The corrected input meant that the model's ecological predictions outlined in the 21 May 2021 memorandum were incorrect.
4. *Manuherekia Hydrology model – Scenario Memorandum – Final Draft*. A memorandum prepared by Davis Ogilvie for the ORC dated 21 May 2021, referenced as Davis Ogilvie 2021c. This memorandum provided model results from 30 scenarios which included the "Estimated Existing" (also referred to as the "Status Quo" or "Baseline") scenario. Many of the scenarios were based on seven original scenarios developed by ORC named 900, 1200, 1500, 1700, 2000, 2500 and 3000 to reflect the minimum flow in the Manuherekia River at Campground in L/s that was used in each of the scenarios.

All four documents were living documents, and there were numerous earlier drafts of each, prior to the final versions mentioned above. This report draws extensively on all four documents. All four documents are relatively long and for that reason have not been attached to this report. All four documents are publicly available and can be supplied on request.

2.0 MODEL BACKGROUND

The Manuherekia River is a tributary of the Clutha / Mata-au River, which drains a catchment covering approximately 3,050 km^2 northeast of Alexandra in Central Otago. Hydrologically the Manuherekia catchment is known to be complicated. The catchment has a long history of active water management including water storage, water use and water transfers. Numerous hydrological investigations have been undertaken in the Manuherekia Catchment 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). Hydrological understanding of the catchment is predominantly held by a small number of people, the majority of which are part of the Manuherekia Hydrology Group and have been part of the Manuherekia Hydrology Project.

The Manuherekia Catchment Hydrology Model was developed to inform and support water management decisions. It aims to summarise and improve understanding of the catchment's hydrological system and provide a tool which can be used to assess the implications of future water management decisions. The Manuherekia Catchment Hydrology Model is a daily water balance model of the catchment from 1 June 1973 to 31 May 2020, which uses the GoldSim Modelling platform. The final model, named Manuherekia Hydrology Model V4 and dated September 2022 is documented in this report.

2.1 Previous Models

Earlier hydrological investigations in the Manuherekia Catchment included the development of various hydrological models. The current Manuherekia Catchment Hydrology Model builds on the earlier models particularly the TopNet / CHES model developed by NIWA for ORC and various Excel and GoldSim models prepared for MCWSG and MRL by Aqualinc Research Limited (Aqualinc), Golder Associates (NZ) Ltd (Golder) and Davis Ogilvie. Table 2 summaries the earlier models and how they have contributed to development of the current Manuherekia Hydrology Model V4.

Table 2: Previous Models

Model and key references	Brief Description	Used for	Contribution to current model
Manuherekia Valley Model Aqualinc 2012a and 2013a	Excel spreadsheet based daily water balance models covering the 40-year period June 1973 to May 2013.	Developed for MCWSG and used during pre-feasibility and feasibility studies to evaluate the Falls Dam reservoir, it's potential to irrigate land within the Manuherekia Valley and to predict flow in the Manuherekia River downstream of the dam.	Used extensively in development of the original GoldSim Manuherekia Catchment Hydrology Model in 2016 and its update in 2018.
Mt Ida Race and Dam model, Aqualinc 2013b		Developed for MCWSG and used during pre-feasibility and feasibility studies to evaluate the proposed Mt Ida Dam and reservoir including inflows from the Mt Ida Race and its potential to irrigate land within the command area of the Hawkdun Idaburn Irrigation Scheme.	
Hopes Creek Dam, Aqualinc 2012b	An Excel spreadsheet-based monthly water balance model covering the 14-year period January 1951 to May 1965.	Developed for MCWSG and used during pre-feasibility studies to evaluate the Hopes Creek reservoir and its potential interaction with the Ida Valley Irrigation Scheme.	
Falls Dam Storage, Golder 2014	A GoldSim daily water balance model replicating Aqualinc's Manuherekia Valley Model.	Developed for MCWSG and used during feasibility studies to evaluate and compare various water development options. Specifically used by the MCWSG in various flow regime workshops.	
Manuherekia Catchment Hydrology Model Golder 2016	A GoldSim daily water balance model covering the whole Manuherekia Catchment from June 1973 to May 2013.	Developed for MCWSG and used during an options validation and refinement process. Represents the first model of the total catchment. Relied heavily on the earlier models and directly used many of their input timeseries.	Some of the model logic, parts of the GoldSim code and some of the input timeseries were adapted for use in the current Manuherekia Hydrology Model V4.
Manuherekia Catchment Hydrology Model - updated DO 2018	Various updates to the earlier version including extending the period assessed to May 2017.	Developed for MRL and used for Project Viability and pre-Construction Commitment investigations. Included numerous water supply and water distribution options.	
CHES Implementation for the Manuherekia River NIWA 2019	CHES and TopNet models for the Manuherekia Catchment. Both models used a daily timestep from 1972 to 2019 with calibration focused on the period of significant water use records from 2014 to 2019.	Developed for ORC and the Manuherekia Technical Advisory Group (TAG).	A number of input time series and details from the Chatto Creek and Ida Burn sub-catchments were adapted and used in the current Manuherekia Hydrology Model V4.
Manor Burn Catchment Water Resource Study Raineffects 2020	An Excel spreadsheet-based daily water balance model of the Manor Burn catchment predominantly for the period 1982-1998.	Developed for the Galloway Irrigation Company to understand flows within the Manor Burn catchment.	A number of input time series and details from the Manor Burn sub-catchment were adapted and used in the current Manuherekia Hydrology Model V4.

2.2 Model Development Process

The Manuherekia Catchment Hydrology Model has been developed by Davis Ogilvie based on the scoping document dated 6 July 2020 (Davis Ogilvie 2020). The model was constructed using the GoldSim modelling platform version 12.0. Model development principally occurred in late 2020 and early 2021 with minor updates occurring through to August 2021. The model was peer reviewed in early to mid-2022 and was finalised post peer review in September 2022. This report covers the final version of the model namely:

- Manuherekia Hydrology Model V4 dated September 2022.

While the Manuherekia Hydrology Model V4 contains some of the logic from the earlier 2018 GoldSim model of the catchment, the current model was constructed from scratch rather than updating the earlier GoldSim model. Initial model build focused on the Lauder sub-catchment with the Lauder sub-catchment model checked by the GoldSim Technology Group[2] for overall logic. The Lauder sub-catchment model was then replicated and used to build the overall model. The model development process and use of the model to date is summarised in Figure 1 below**Error! Reference source not found.**.

In developing the Manuherekia Catchment Hydrology Model the following four minor changes were made from what was originally proposed in the model scoping document (Davis Ogilvie, 2020):

(a). Two additional small water storages were added – the Lower Manorburn Dam and the Ida Dam. Both dams were added to better model sub-catchment irrigation and downstream flow.

(b). At the request of the Manuherekia TAG[3], ecological parameters were added to the model to allow estimation of habitat area for 11 species at various locations and for various river reaches on the main stem of the Manuherekia River downstream of Falls Dam.

(c). Race losses of 5 % of the flow, were included from the Bonanza Race back into the Manor Burn. The race losses were included as they are known to occur and to better match flow in the lower Manor Burn and operation of both the Upper Manorburn Dam and the Bonanza Race.

(d). The Ida Valley Irrigation Scheme area was separated into two parts – Bonanza Race supplied by the Upper Manorburn Dam and the German Hill Race supplied by the Poolburn Dam and tributaries. In practice water from the Bonanza Race can also be used to supply the German Hill Race. This ability was excluded from the model, but the irrigated area supplied by each of the two races was adjusted to ensure a similar reliability for the two parts.

[2] The GoldSim Technology Group is based in the USA and owns and supports GoldSim software.
[3] Request made during a meeting of the Manuherekia TAG on 30 November and 1 December 2020.

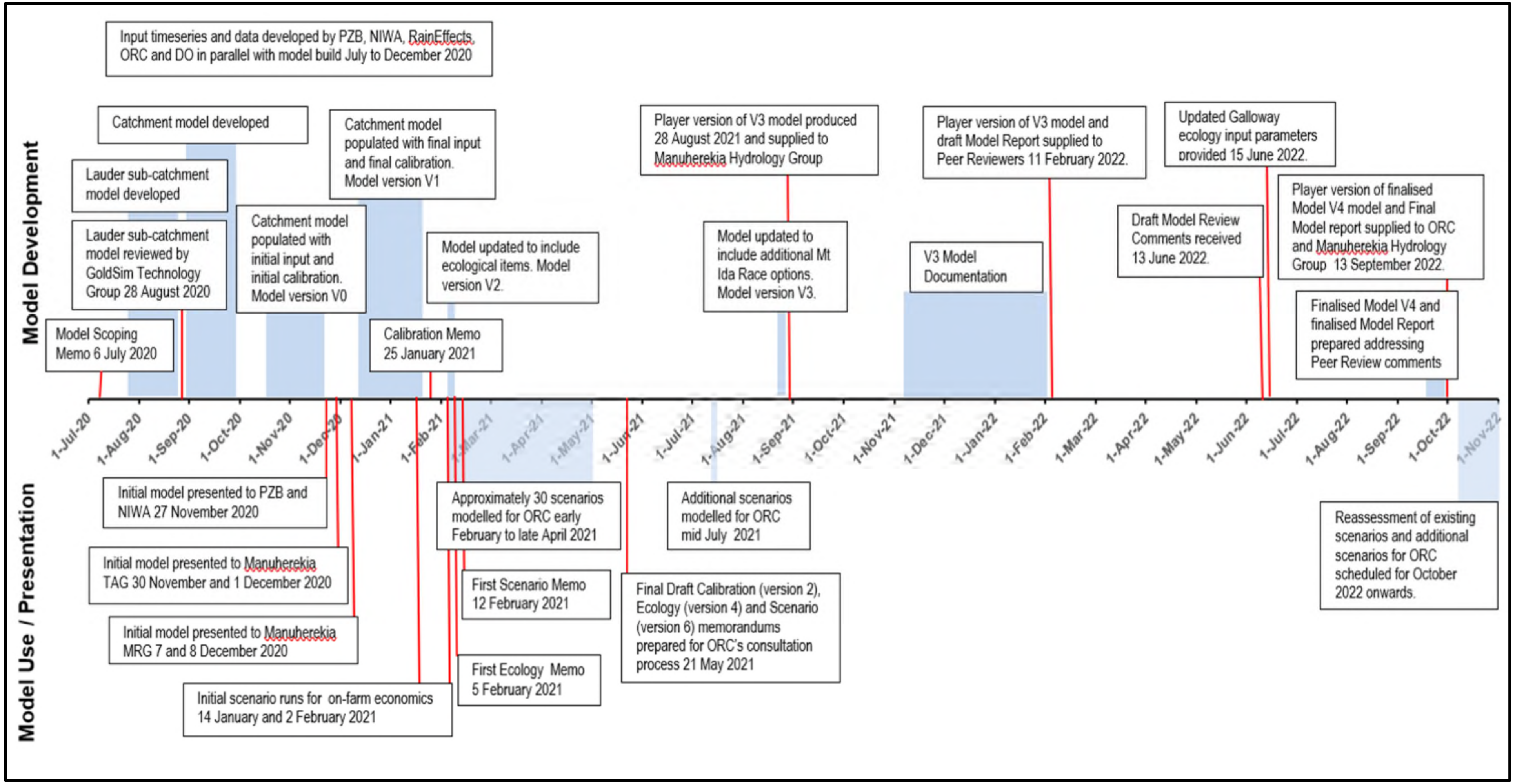

Figure 1: Manuherekia Catchment Hydrology Model – Model Development Process and Model Use.

2.2.1 Ecological Parameters

When including the ecological parameters, spreadsheets containing habitat area information for 11 species[4] at three locations (Blackstone, Ophir, and Galloway) under different flows were provided by Richard Allibone of Water Ways Consulting Ltd.[5] and were included into the Manuherekia Catchment Hydrology Model as various lookup tables. As the ecological assessments were focused on low flows, the habitat area spreadsheets contained habitat data for flows up to 6 m^3/s. The model requires data for all potential flows, so it was assumed that the habitat area values for all flows above the maximum specified in the spreadsheets were the same as the maximum value. As such the model ecological predictions for flows greater than 6 m^3/s should be ignored.

The Manuherekia Catchment Hydrology Model estimates daily average flow at numerous locations on the main stem of the Manuherekia River. The modelled flow was used to estimate how habitat area changes over time for the different species at each location on the main stem:

- The Blackstone habitat areas were applied to the main stem of the Manuherekia River from Falls Dam to above the Lauder Creek confluence.
- The Ophir habitat areas were applied from below the Lauder Creek confluence to Ophir.
- The Galloway habitat areas were applied from below the Chatto Creek confluence to Campground.

Habitat areas for each main stem river reach were estimated by averaging the values at the top and bottom of the reach and multiplying by the length of the reach. An overall main stem habitat area value for each species was determined by adding the river reaches together. The overall main stem habitat values were estimated in order to account for longitudinal flow changes down the river. In summing the main stem river reaches, gorge sections (namely Falls Dam to Loop Road and Ophir to the Chatto Creek confluence) were excluded as habitat was assumed to not change with flow in gorge sections. There was also uncertainty regarding the wide braided river reach between Loop Road and the Blackstone Intake, and whether the Blackstone habitat areas were applicable, as they were derived from measurements below the Blackstone Intake where the river, while braided, is more confined. An option was included in the model to both include and exclude the reach from Loop Road to the Blackstone Intake in the overall main stem habitat values.

[4] The 11 species were Diatoms, Aoteapsyche (net-spinning), Deleatidium (mayfly), Maoridiamesa (Diptera), Brown Trout < 100 mm, Brown Trout H&J, Longfin Eel < 300 mm, Longfin Eel > 300 mm, Adult Rainbow Trout (Wilding), Juvenile Rainbow Trout (Wilding) and Brown Trout Spawning (Shirvell and Dungey 1983).

[5] The spreadsheets of ecological input parameters were provided for 8 species on 28 November 2020, for 2 further species on 29 January 2021 and the final species on 14 March 2021. Subsequently corrected spreadsheets were provided on 15 June 2022. The corrected input resulted in the model's ecological predictions previously documented in Davis Ogilvie 2021b being incorrect and should be ignored.

As specific ecological expertise is required to fully interpret the model's ecological predictions, direct links to the model ecological predictions have been removed from the Results Dashboard in the final model, named Manuherekia Hydrology Model V4 and dated September 2022.

2.3 Model Verification

The model was verified in the following sequence:

(a) Dunstan sub-catchment with consideration of measured flow in Dunstan Creek at Beattie Road and at the downstream temporary flow recorder at Phil Smith's property.

(b) Lauder sub-catchment with consideration of measured flow in Lauder Creek at the Rail Trail.

(c) Thomsons sub-catchment with consideration of measured flow in Thomsons Creek at SH85.

(d) Chatto sub-catchment with consideration of measured flow in Chatto Creek above its confluence with the Manuherekia River.

(e) Manor Burn sub-catchment including the Upper Manorburn / Greenland Reservoir with consideration of the short, recent, measured flow record from Hopes Creek above the Manor Burn confluence and the time series of estimated inflow to the Lower Manorburn Dam developed by Raineffects.

(f) Pool Burn sub-catchment including the Poolburn Dam. There was no downstream flow record to calibrate to, although gaugings indicate that during periods of low flow the Pool Burn does not contribute very much flow i.e., < 20 L/s to the Ida Burn.

(g) Ida Burn sub-catchment, which includes the Pool Burn sub-catchment, with consideration of measured flow in the Ida Burn at Cob Cottage.

(h) Manuherekia Main Stem from Falls Dam to Ophir including Falls Dam and the various tributary inflows. Calibration considered measured flow in the Manuherekia River at Ophir and operation of Falls Dam (namely measured water level and known irrigation restrictions).

(i) Manuherekia Main Stem from Ophir to Campground with consideration of measured flow in the Manuherekia River at Campground.

Initial verification commenced prior to finalisation of all the input data with the input flow timeseries for Chatto Creek, Dovedale Creek and Ida Burn in draft form. Initial verification was based on visual curve matching with a focus on lower flows. The model and initial verification were shown to Roddy Henderson of NIWA and Peter Brown of PZB (27 November 2020), the Manuherekia TAG group (30 November and 1 December 2020) and the Manuherekia Reference Group (MRG) (7 and 8 December 2020). Initial verification indicated relatively good matching of downstream flows for the tributaries and the main stem. However, the initial model overestimated water level in the Falls Dam Reservoir and underestimated the associated Falls Dam management-imposed irrigation restrictions, particularly during drought conditions (i.e., Falls Reservoir was not working hard enough). Subsequently the following changes were made to the model:

(a) Chatto Creek, Dovedale Creek and Ida Burn inflow time series were finalised.

(b) Water Take Data was analysed and compared with modelled water supply in each sub-catchment resulting in slight adjustments to the irrigated area, in total, a further 2,200 ha of spray irrigated land was included in the model (original irrigation map 24,180 ha irrigated, initial model 25,010 ha irrigated, final model 27,210 ha irrigated).

(c) The management-imposed irrigation restrictions applied by the Falls Dam Company were reduced slightly, allowing harder use of storage at Falls Dam.

(d) Removal of dryland drainage return flow from all catchments – in order to reduce the excessively peaky nature of the modelled flow series.

(e) Review of the Falls Dam inflow time series particularly during periods of low flow – resulted in a slightly modified inflow series for Falls Dam.

The above changes significantly improved the model's ability to replicate water levels in Falls Dam, while maintaining a good match for downstream flows in the tributaries and the main stem. Subsequently flow duration curves, cumulative flow and 7 Day MALF were compared for the modelled and measured data at both Campground and at Ophir. The comparisons are based on periods when there is measured data at both sites (namely October 2008 to May 2020).

2.4 Model Peer Review

The model and a draft of this model report were peer reviewed by Sarah Mager (University of Otago) and James Griffiths (NIWA). The peer review process included the following three steps:

1. The model and a draft of this model report were supplied to the reviewers in mid-February 2022.
2. A series of meetings were held late February and early March 2022 where the model was demonstrated to the reviewers.
3. Subsequently the reviewers completed and documented their review of the model, with a draft model review report circulated in late July 2022 (Mager S and J Griffiths, 2022 in Press). The cover email circulated with the draft model review report included the following comment:

Our report affirms 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.

At the time of finalising both the model and this report, the model review document was yet to be finalised. However, meetings were held with both reviewers in early August 2022 to discuss the review and the key findings. The reviewers suggested a number of minor changes to improve both the model (namely suggested minor changes to the model dashboards) and this report, which were generally adopted, refer Table 3. The suggested changes to the model did not involve any changes to the structure or analytical aspects of the model and did not affect any of the model outputs.

Table 3: Manuherekia Hydrology Model Review – Suggested Improvements and responses

Review Suggestion	Response
On the model dashboards have constant locations for the dashboard buttons and highlight which one is active.	Completed – Active dashboard is highlighted, and its name is included in the final model (V4).
Single Dashboard of key results and graphs.	When graphs are included directly in dashboard the user cannot change the graph scale. Given the number of results and the desire to allow users to change graph scales (i.e. to focus on specific years of interest etc.) it was decided not to include graphs in the "Results" dashboard. However, the results Dashboard has been updated to make it as simple as possible and to focus on the key results only.
Add Glossary to Model Report.	Completed and a brief Glossary has been included at the start of this report.
In the Model Report provide a clearer description of the Falls Dam Irrigation Restrictions.	Completed – Section 5.1.1 Falls Dam Irrigation Restrictions added to this report.
Provide a clearer definition of the modelled scenarios in both the model report and the model itself.	Completed – Within the model the scenario names have been adjusted to provide further clarity. Similarly brief comments explaining use of the model and the scenario names has been included in the Introduction section of this Report.
In the Model Report provide a clearer explanation that the "Estimated Existing" scenario represents the baseline scenario.	Completed – Brief comments explaining the "Estimated Existing" scenario and that it represents the Status Quo or Baseline situation have been included the Introduction section of this Report.

3.0 MODEL OBJECTIVE, EXTENT AND LOGIC DIAGRAM

3.1 Model Objective

The objective of the Manuherekia Catchment Hydrology 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.

3.2 Model Extent

The Manuherekia Catchment Hydrology Model covers the surface water catchment of the Manuherekia River and its tributaries. The model includes water imported into the catchment from the upper Taieri River catchment and water exported out of the catchment via both the Mount Ida Race and irrigation supplies to Dunstan Flats.

3.3 Model Logic Diagram

The Manuherekia Catchment Hydrology Model is based on the model logic diagram shown in Figure 2. The model logic diagram has changed slightly from what was proposed in the model scoping document (Davis Ogilvie, 2020) due to more detail being included in the model. The model logic diagram highlights the water infrastructure that is included in the model and the key model nodes.

The Manuherekia catchment is known to be complicated, with a long history of active water management. There is a significant amount of water infrastructure including: numerous water storages, extensive water races covering much of the catchment, numerous water transfers between sub-catchments, and water is used extensively throughout the catchment. It is not possible to model all the intricacies of the catchment's hydrological system. The Manuherekia Catchment Hydrology Model is 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 Figure 2).

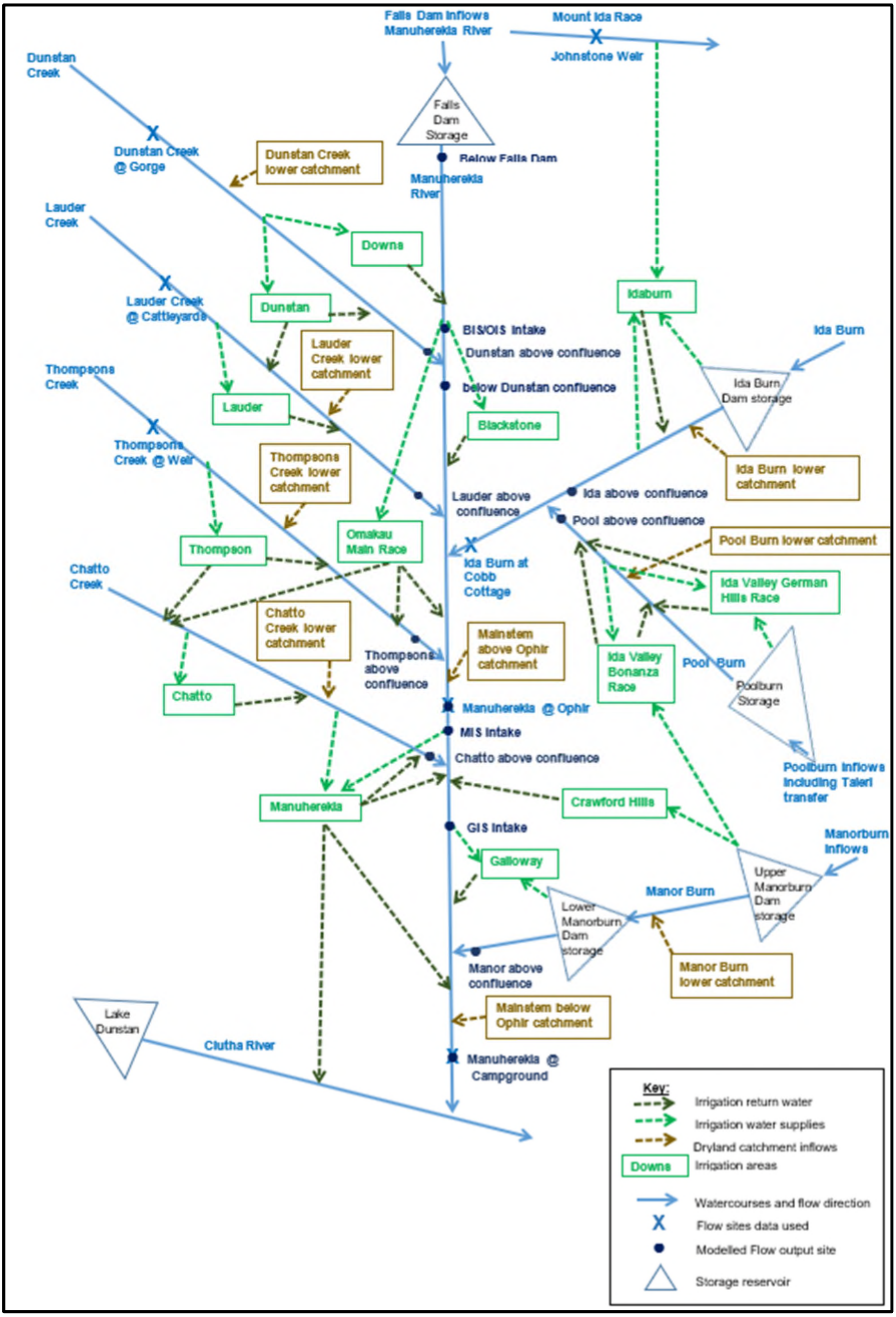

Figure 2: Manuherekia Catchment Hydrology Model – Model Logic Diagram.

4.0 KEY MODEL DETAILS

4.1 Key Model Assumptions

Due to catchment complexity, the Manuherekia Catchment Hydrology Model includes numerous assumptions, interpretations and simplifications which were necessary to suitably represent what is a complicated, dynamic, natural system by a relatively simple model. The key model assumptions and underlying principals are outlined below:

- The model is based on conservation of mass with inflow equalling outflow plus change in water storage.
- The model is flow based and does not directly consider the underlying climate components of rainfall and evaporation etc. However, the input timeseries used in the model (namely natural flow above the takes, irrigation demand and soil drainage / runoff) do consider the underlying climate and soil properties.
- The model is based on data from 1 June 1973 to 31 May 2020 and it does not attempt to predict future flows. When considering a potential future flow management regime, the model applies the potential flow management regime to the historic flow data and predicts downstream flows, water take reliability, and operation of the water storages. Comparing the model predictions for the potential flow management regime scenario against the model predictions for the "Estimated Existing" (Status Quo or Baseline) scenario allows the implications of the potential flow management regime to be assessed.
- The model uses a daily time step and is based on daily average flows. Fluctuations within the daily time step are not considered.
- Within each time step the model calculates flow in a downstream direction. It starts with various input timeseries of natural flow above the takes and storages then steps downstream taking or storing water as required and receiving tributary inflow etc. in order to predict downstream flow. The model ceases the time step after it has predicted flow in the Manuherekia River at Campground, then the model moves to the next time step.
- Water is assumed to pass through the system in each one-day time step and the model does not consider travel times. In practice, water takes longer than a day to flow from the top of the catchment to the bottom.
- The model does not consider groundwater. While groundwater is present within the catchment, it is not a big component of the overall water resources. The input flows series are almost exclusively based on measured flow data which will include gains and losses to the groundwater system. Similarly, the model has been verified against measured data which will include all the intricacies and components of the actual system.
- The model only considers the main water resources and areas of water use in the catchment. It is focused on the lower parts of the catchment; namely below the three main reservoirs of Falls Dam, Poolburn Dam, and the Upper Manorburn / Greenland Reservoir, and below where the main tributaries exit the foothills.

- The model only considers the main stem of the Manuherekia River from Falls Dam to the Campground flow recorder and the six main tributaries of Dunstan Creek, Lauder Creek, Thompsons Creek, Chatto Creek, Manor Burn, and the Ida Burn / Pool Burn system. The model does not consider any other tributaries or sub-tributaries.
- The model only considers the five main scheme storages within the catchment namely Falls Dam, Poolburn Dam, the Upper Manorburn / Greenland Reservoir, the Idaburn Dam, and the Lower Manorburn Dam. The model does not consider any other scheme or on-farm storages.
- Irrigated areas are consolidated into the main schemes and sub-catchments with all irrigation based on either a representative flood irrigation system or a representative spray irrigation system, irrigating pasture.
- The model only considers water taken for summer irrigation it does not consider water taken for other uses such as domestic supply, stockwater, frost fighting, etc.
- The model calculates the volume of water required for each irrigation take based on the following four variables:
    - The area irrigated.
    - The type of irrigation namely either a representative flood irrigation system or a representative spray irrigation system.
    - The location of the irrigation relative to three zones: Above Ophir, Below Ophir and Ida Valley.
    - Six daily irrigation demand timeseries which have been developed using a soil moisture and irrigation demand model that considers climate data, properties of the irrigated soils and representative irrigation regimes for both flood irrigation and spray irrigation in each of the three zones. The irrigation regimes do not include seasonal limits or allocations. It is noted that operation of the Ida Valley Irrigation Scheme is based on a seasonal allocation which is determined from the storage volume available at the start of the season.

The model then compares the water available at the take point against the irrigation water requirements to determine how much water is actually taken. The model's predicted take has been verified against measured take data for the years when water take data is available, which is predominantly from the 2008-2009 irrigation season onwards.

- The model applies current (i.e., the 2019-2020 season) conditions to the whole modelled period (1 June 1973 to 31 May 2020). Current irrigation practices, the area currently irrigated and current Falls Dam Management practices are assumed to be constant over the modelled period. Over the modelled period 1973-2020, there has been a change in irrigation practice with a move to increased spray irrigation, more land has been irrigated and Falls Dam Management practices have developed considerably. These actual changes are not included in the model although both the input flow timeseries and the measured timeseries used for verification do include the effect of these changes.

4.2 Model Operation and Functionality

A key advantage of the GoldSim modelling platform is that GoldSim based models generally have short run times which allows multiple scenarios to be quickly assessed. Through assessing multiple scenarios, an understanding of the relative sensitivities of the modelled variables is developed, which provides insight into the key factors that influence the actual physical system. The Manuherekia Catchment Hydrology Model has a very short run time, taking less than a minute per scenario to run through the 47 years of daily data. The short run time facilitates model use allowing a large number of model runs to be quickly assessed.

At the request of both ORC and the Manuherekia TAG, the Manuherekia Catchment Hydrology Model contains significant functionality and flexibility which allows a wide variety of future water management scenarios to be assessed. The required functionality and flexibility has been incorporated into the model by including four input dashboards, which allow the model variables listed below to be rapidly altered.

- Minimum / Residual flows at 23 locations and whether flow sharing is applied.
- Irrigation demand and the ability to factor up or down the irrigation demand timeseries.
- Irrigated area – separated into 37 spray irrigated and 37 flood irrigated areas depending on water source and catchment. All areas can be easily changed.
- Sub catchment areas.
- Various attributes associated with the five storages of: Falls Dam, Poolburn Dam, the Upper Manorburn / Greenland Reservoir, the Lower Manorburn Dam, and the Mount Ida Dam.
- Irrigation restrictions relative to storage in Falls Dam and the area the restrictions apply to.
- Various other options including: whether return water (drainage) is included from the non-irrigated areas, operation of Mount Ida Race, race losses from the Bonanza Race into the Manor Burn catchment, and simplistic climate change factors which allow input river flows and irrigation demand timeseries to be factored up or down.

The model has been set up to facilitate future changes and additions. The overall model is based on a series of sub-models which represent sub-catchments. The model separates global variables, which apply to the whole model; from sub-catchment variables, which apply to their sub-model only. The model structure and separation of variables allows global and / or sub-catchment changes to be easily made.

Table 4 below summarises the functionality included in the model. The four input dashboards with the “Estimated Existing” (Status Quo or Baseline) scenario inputs, are shown in Appendix A. The four input dashboards allow a large number of model variables to be quickly altered. This allows a large number of scenarios to be quickly developed. The ability to quickly generate multiple scenarios, coupled with the model’s short run time and its ability to compare multiple scenarios, provides a powerful tool which can be used to: improve understanding of the catchment’s hydrological system, provide insight into the key factors that influence the catchment’s hydrological system, and guide development of future water management regimes.

Table 4: Desired Model Functionality and Actual Model Functionality

<table>
<tr><th colspan="3">Functionality desired by ORC & Manuherekia TAG</th><th rowspan="2">Functionality included in the Manuherekia Model</th></tr>
<tr><th>Overview</th><th colspan="2">Details</th></tr>
<tr><td rowspan="13">Multiple minimum flow locations</td><td colspan="2">The following minimum flow sites desired</td><td rowspan="13">Included: all the requested minimum flow locations have been included in the model other than the Ida Burn at Auripo Road.

As the main stem of the Manuherekia River is used to convey irrigation water the two upstream sites on the Manuherekia main stem namely below Falls Dam and at Ophir, only become important when Falls Dam is empty or during the non-irrigation season.</td></tr>
<tr><td>Location</td><td>Priority</td></tr>
<tr><td>Manuherekia Downstream of Falls Dam</td><td>A</td></tr>
<tr><td>Manuherekia @ Ophir</td><td>A</td></tr>
<tr><td>Manuherekia @ Campground</td><td>A</td></tr>
<tr><td>Dunstan Creek @ Confluence</td><td>A</td></tr>
<tr><td>Lauder Creek @ Rail Trail</td><td>A</td></tr>
<tr><td>Pool Burn @ Cob Cottage</td><td>B</td></tr>
<tr><td>Ida Burn @ Auripo Rd</td><td>B</td></tr>
<tr><td>Pool Burn @ Auripo Rd</td><td>B</td></tr>
<tr><td>Thomson's Creek @ SH85</td><td>A</td></tr>
<tr><td>Chatto upstream of Confluence</td><td>A</td></tr>
<tr><td>Manor Burn @ Confluence</td><td>B</td></tr>
<tr><td>Multiple minimum flow sites for each take</td><td colspan="2">The ability for takes to be linked to multiple minimum flow sites i.e., a tributary minimum and a minimum at Campground.</td><td>Not included: as would require multiple looping sub-models which is not possible.
Each of the takes is linked to one minimum flow site only. Tributary takes are linked to the tributary minimum while mainstem takes are linked to flow at Campground.</td></tr>
<tr><td>Seasonal minimum. flows</td><td colspan="2">The ability to stipulate different minimum flow conditions in the irrigation season than non-irrigation season.</td><td>Included: seasonal minimum flows can be stipulated for the Manuherekia River main stem sites and below each of the 5 reservoirs. As the model is focused on irrigation takes, there are no non-irrigation season takes in the tributaries without storages namely Dunstan, Lauder, Thomsons and Chatto creeks, and hence non-irrigation season minimum flows are not required in the model for these tributaries. For minimum flow purposes the model sets the irrigation season as 1 September to the following 30 April.</td></tr>
<tr><td>Flow sharing</td><td colspan="2">The ability to have flow sharing above the minimum flows.</td><td>Included: flow sharing is included for the four main tributaries of Dunstan, Lauder, Thomsons and Chatto creeks. Flow sharing is not included in either the Manuherekia River main stem or the other tributaries as these watercourses have on-river storages which capture all inflow and do not have the ability to share inflows.</td></tr>
<tr><td>Allocation Blocks</td><td colspan="2">The ability to have primary and secondary allocation blocks with different management regimes and potentially different uses i.e., take for irrigation rather than a take for storage.</td><td>Not included: allocation blocks are not currently applied in the Manuherekia Catchment and all takes are considered primary takes. The model treats all takes equally and does not apply allocation blocks.
Note earlier models (Golder 2016 and Davis Ogilvie 2018) included primary (existing takes) and secondary (new future takes) irrigation takes as those models were focused on irrigation developments (i.e., increased storage) where the current model is focused on management of the current system.</td></tr>
<tr><td>Storage Effect</td><td colspan="2">The ability to differentiate storage effects on flow and supply reliability from run-of river effects i.e., "run-of-river water" versus "stored water"</td><td>Included indirectly: through comparing differing scenarios (one with storage and one without) the influence of the storage can be determined.</td></tr>
<tr><td>Flushing Flows</td><td colspan="2">The ability to release flushing flows from Falls Dam.</td><td>Partially included: the limited capacity (max outlet discharge ~4 m^3/s) of the current Falls Dam outlet prevents the release of large flushing flows and hence flushing flows were not included in the model. While flushing flows from Falls Dam have not been directly included, the characteristics of the Falls Dam outlet are included and could be modified to potentially include flushing flows if required.</td></tr>
<tr><td>Climate Change</td><td colspan="2">The ability to assess the effects of climate change on flows, storage operation and supply reliability.</td><td>Included: simple climate change scaling factors which allow irrigation demand and natural inflows to be scaled up and down are included in the model. These factors allow a very preliminary assessment of the potential effects of climate change. A more robust assessment could be obtained by importing new input timeseries for irrigation demand and natural inflows which have been adjusted to include future climate change predictions.</td></tr>
</table>

4.3 Key Model Outputs

The Manuherekia Catchment Hydrology Model predicts daily timeseries which can be displayed in table or graph form within the model or can be exported from the model. The model also has the ability to calculate various statistics from the output timeseries and can compare output from multiple scenario runs. The key model outputs are summarised in Table 5 below.

Table 5: Manuherekia Catchment Hydrology Model – key output

Model component	Locations	Output (daily time series/plots of)	Comment
Reservoirs	Falls Dam, Poolburn Dam, Upper Manorburn / Greenland reservoir, Lower Manorburn Dam, and Ida Valley Dam.	Live storage volume, inflow, and outflows (both controlled and spills).	For Falls Dam daily water level and management imposed irrigation restrictions are also predicted to allow comparison with measured data during verification.
Irrigated area	Thirteen irrigation areas representing each of the main sub-catchment or irrigation scheme areas, refer Figure 2.	Water demand, water supply and the supply reliability percentage by volume (i.e. volume supplied/volume demanded)	Allows spatial and temporal variations in supply reliability to be assessed.
River flow node	The model predicts flow above and below all main take points, tributary confluences and infrastructure nodes shown on Figure 2. For output purposes ORC requested the following nine key locations. The Manuherekia River main stem at: • Below Falls Dam, • Below OIS intake, • Below Dunstan confluence, • At Ophir, and • At Campground. The following tributaries above their confluence with the Manuherekia River: • Dunstan Creek, • Lauder Creek, • Thompsons Creek, and • Chatto Creek	Daily average flow.	Allows spatial and temporal variations in flow to be assessed. To assist interpretation, the following standard hydrological statistics and plots were produced for each site, for each of the scenarios that were assessed: • Minimum flow. • 1 Day MALF. • 7 Day MALF. • Medium Flow. • Mean flow. • 1st, 5th, 10th, and 20th exceedance flows. • Annual days below a set minimum flow. • Annual maximum consecutive days below a set minimum flow. • A flow duration curve. • Hydrographs for the 2014-2015 hydrological year namely 30 June 2104 to 31 May 2015 (a recent dry year).
Ecological Habitat	The Manuherekia River main stem at: • Below BIS intake, • At Ophir, and • At Campground. Also for various main stem reaches and the main stem overall.	Daily habitat area for 11 aquatic species including algae, invertebrates and fish.	Allows spatial and temporal variations in habitat to be assessed.

To date, most of the model output has been assessed using graphs within the model or the tabulated data has been exported to spreadsheet for post processing. A "Results" dashboard has been included in the model which provides quick links to key model outputs and plots. The "Result" dashboard with the "Estimated Existing" (Status Quo or Baseline) scenario results, is shown in Appendix A.

5.0 MODEL INPUTS

The Manuherekia Catchment Hydrology Model relies on a significant amount of input data which consists of both discrete input variables and numerous input timeseries.

5.1 Input Variables

Input variables include: catchment areas, irrigated areas, storage variables (including maximum storage, initial storage, and outlet controls), irrigation variables, minimum flow, residual flow, and flow sharing requirements. Most of the input variables are individual numbers and are included in the input dashboards. However, a number of input relationships are also included in the model such as stage storage relationships, stage outflow relationship, storage management practices including the imposition of irrigation restrictions and ecological habitat area versus flow relationships. These relationships are entered into the model as lookup tables. All the relationships and discrete input data were derived either from previous Manuherekia models, technical reports or were supplied to Davis Ogilvie. Those input variables which are not included on the input dashboards can be readily viewed in the player and full versions of the model itself.

Irrigated area is a key variable in the model. It directly influences the volume of water taken for irrigation and therefore the flow that remains in the downstream system. The irrigated area is separated according to irrigation type (spray or flood), location relative to model sub-catchments and the source of the irrigation water. The irrigation information was developed and supplied by ORC. It is based on a combination of previous irrigation investigations, review of the most recent aerial imagery and some ground truthing through discussions with landowners and irrigators. During model verification, measured water take data supplied by ORC was compared with modelled water supply for each of the main irrigation schemes and on a sub-catchment and total catchment basis. Modelled water supply was initially found to be less than the measured take (note: retakes were accounted for). An additional 2,200 ha of irrigated area was added to the model to better match the measured take data. The additional irrigated area was added to the Blackstone, Dunstan Flats, and Ida Valley irrigation areas.

5.1.1 Falls Dam Restrictions

Fall Dam is operated by the Falls Dam Company Ltd. with water released from the dam to meet downstream flow requirements. Current management of the reservoir is based on an overall objective of maximising water supply reliability for the downstream irrigators while maintaining a voluntary minimum flow in the Manuherekia River at Campground of 900 L/s. During dry seasons, Falls Dam Company Ltd. apply voluntary irrigation restrictions in order to conserve storage and ensure water supply to irrigators is maintained as long as possible. Management is a juggling act between competing demands, it relies heavily on operator experience which considers numerous factors including future weather forecasts.

In deciding whether to impose restrictions and the level of any restrictions that are imposed the following variables are considered:

- The current level of live storage,
- The date, i.e., how far through the irrigation season,
- The weather forecast - both short and long term, and
- Past experience.

Accurately replicating such management in a model is extremely difficult. The Falls Dam Company have over 20 years of records of when they have imposed restrictions, namely from the 1998-1999 irrigation season to present. These records together with water level data from Falls Dam (used to calculate live storage) have been used to develop the following Falls Dam Restrictions relationship which has been included in the model as a Look Up table (Table 6).

Table 6 Falls Dam Restrictions
(1=100 % supply i.e., no restriction, 0.1 = 10 % supply i.e., 90 % restriction)

Falls Dam Live Storage GL)	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
0	0.1	0.1	0.1	0.1	1	1	1	1	0.1	0.1	0.1	0.1
0.5	0.25	0.25	0.5	0.75	1	1	1	1	0.5	0.25	0.25	0.1
1.5	0.5	0.5	0.75	1	1	1	1	1	1	0.5	0.5	0.3
3	0.75	0.75	1	1	1	1	1	1	1	1	1	0.5
6	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1

Note: The above lookup table is the final table that was included in the model. An earlier version was adjusted slightly as part of initial verification of the model.

5.2 Input Timeseries

The Manuherekia Catchment Hydrology Model uses the following 26 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.
- 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.
- Three reservoir inflow timeseries – one each for Falls Dam, Poolburn Dam, and the Upper Manorburn / Greenland Reservoir.

- 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).

Details of the input timeseries and their development is provided in Table 7 below:

Table 7: Manuherekia Model – Input Timeseries

Input	Detail	Comment
Reservoir inflows timeseries	Falls Dam inflow	Developed by PZB[6] which updated and extended earlier series developed by Raineffects[7]. Through the calibration process it was revealed that low flows during drought recessions were being slightly overestimated. The final series used was based on the time series developed by PZB Consulting supplemented during low flow periods (< 3 m^3/s) with the lower of either the PZB or Raineffects timeseries.
	Upper Manorburn Dam inflow	Predominantly developed by Raineffects with extension etc by PZB. In the model the same per hectare catchment yield is assumed from the Hopes Creek catchment, the catchment above Little Valley and the catchment between the Upper Manor Burn Dam and the Hopes Creek confluence.
	Poolburn Dam inflows	Developed by PZB assuming the same per hectare catchment yield as the Upper Manorburn Dam catchment.
Input flow timeseries	Dunstan at Gorge	Developed by PZB. In the model the same per hectare catchment yield is assumed for the catchment between the Gorge site and the main intake, namely OIS's Dunstan Race intake, downstream of the Donald Stuarts Creek confluence.
	Lauder at Cattle Yards	Developed by PZB. In the model the same per hectare catchment yield is assumed for the catchment between the Cattle Yards site and the main intake, namely OIS's Lauder Race intake near the exit from the foothills.
	Thomsons at Weir	Developed by PZB.
	Chatto Creek at confluence	Predominantly (June 1973 to December 2018) developed by NIWA[8]. Extended by Davis Ogilvie[9] for the period January 2019 to May 2020 using measured flows at the confluence, measured water take data, the irrigation area supplied by ORC[10] and modelled water take information.
	Ida Burn at Mt Ida Race	Developed by Davis Ogilvie using measured data extended using monthly correlations with Falls Dam inflow developed by PZB. In the model the same per hectare catchment yield is assumed for the remainder of the greater Ida Burn catchment above the Mt Ida Race.
	Dovedale at Willows	Developed by Davis Ogilvie using measured data extended using monthly correlation with initially the nearby Gimmer Burn flow record and then Upper Manorburn Dam inflow.
	Mt Ida Race flows	Developed by Davis Ogilvie using measured data from Johnsons Weir (accounting for R race) extended using monthly correlations with Falls Dam Inflow developed by PZB. In the model it is assumed one third of the flow in the Mt Ida Race is used within the Ida Burn catchment and the remainder is exported out of the Manuherekia catchment (i.e., to the Taieri).
Irrigation and return water timeseries	Irrigation Demand Series	Unit (per hectare) time series developed by PZB for both flood and spray irrigation in three locations (Above Ophir, Below Ophir and the Ida Valley) using a soil moisture model, local climate, soil and irrigation information.
	Drainage and return water time series	Unit (per hectare) time series developed by PZB for flood irrigation, spray irrigation and dryland in the three locations.

In addition to the above input timeseries, various timeseries of measured data were included in the model for verification purposes. All the input timeseries can be viewed in the model and / or exported from it.

[6] Peter Brown of PZB developed the various time series.
[7] Dave Stewart of RainEffects developed the various time series.
[8] Roddy Henderson and Christian Zammit using NIWA's Topnet model.
[9] Ian Lloyd of Davis Ogilvie.
[10] Water take data and irrigation maps supplied by Pete Ravenscroft of ORC.

6.0 MODEL VERIFICATION

The verification process for the Manuherekia Catchment Hydrology Model was documented in Davis Ogilvie 2021a. This section draws heavily on the earlier documentation but with plots and comments updated to provide more context and reflect the final version of the model.

6.1 Verification Results

The key results from the verification process are briefly presented in the following sections. In preparing this report the plots and calculations have been updated and there are minor changes to those shown in the Calibration Memorandum dated 21 May 2021 (Davis Ogilvie, 2021a).

6.1.1 Model Mass Balance

Confirmation that the model conserves mass has been completed by comparing total model inflows with total model outflow plus change in storage, both for the individual sub-catchment models and for the overall model. Figure 3 shows the mass balance for the total model over the full model period of 1 June 1973 to 31 May 2020. Note the two values overlay each other confirming conservation of mass.

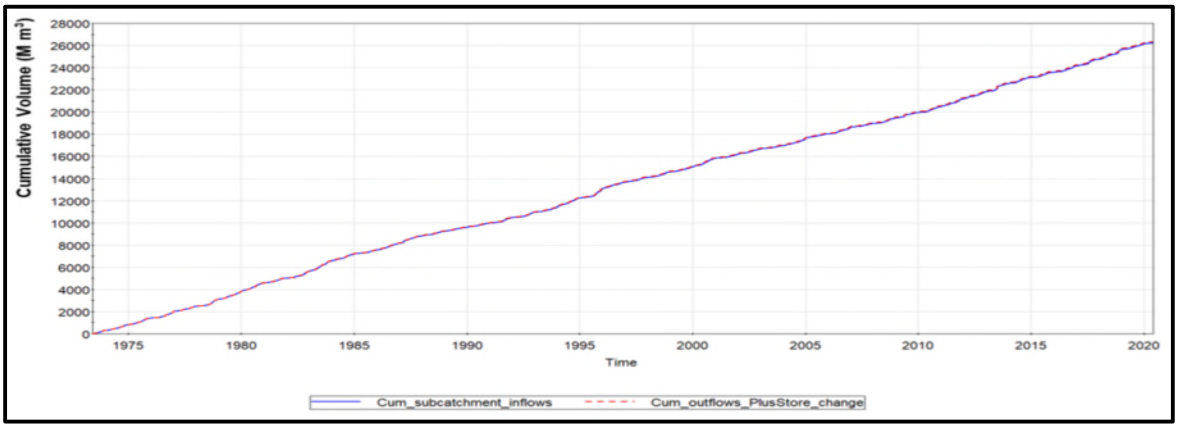

Figure 3: Total Model Mass Balance.

6.1.2 Manuherekia River at Campground

The modelled and measured daily average flow in the Manuherekia River at Campground are shown in Figure 4. Visually the data match very well with the modelled flow showing similar flow fluctuations and similar magnitude high and low flows. Flow duration curves (Figure 5) match well particularly for the lower 40 % and upper 20 % of the flow range. The model slightly underestimates mid-range flows (40 % to 80 %) and very low flows below 1,000 L/s (the lower 10 %). The model underestimates 7-day MALF by approximately 20 % (Table 8). The model's underestimation of low flow is considered conservative as it is expected to result in the development of more conservative future flow management regimes.

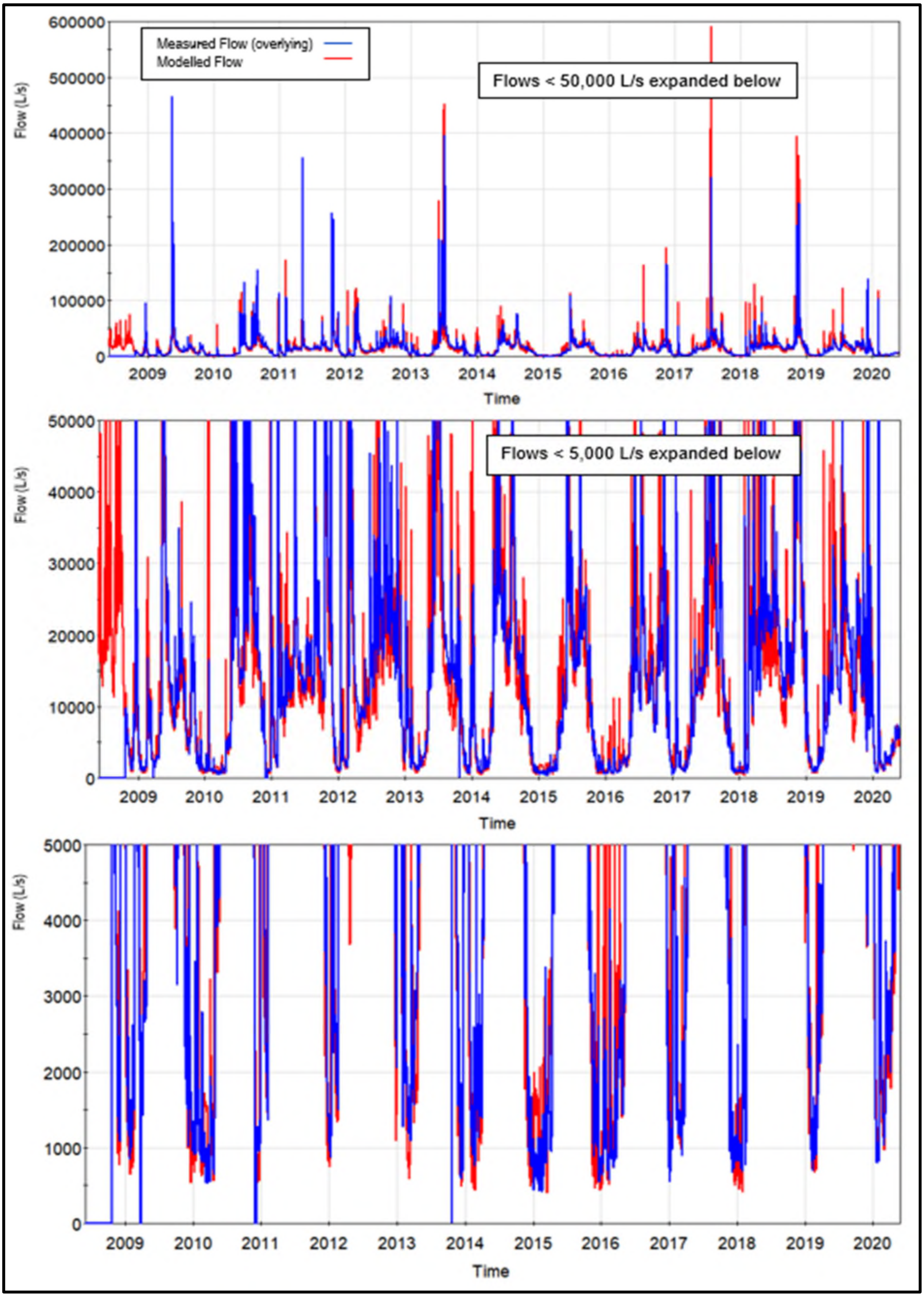

Figure 4: Manuherekia River at Campground – Daily average flow 1 June 2008 to 31 May 2020.

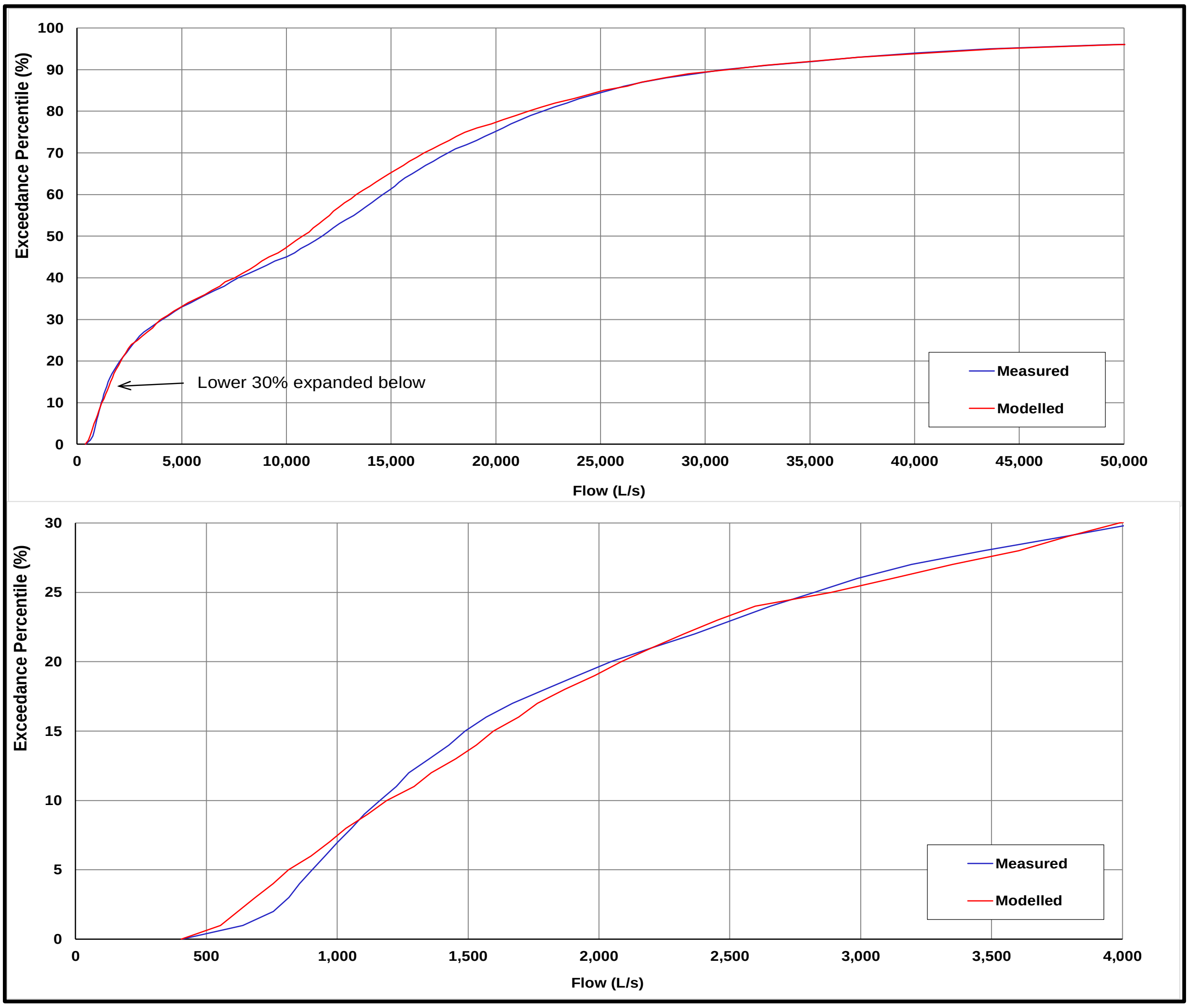

Figure 5: Manuherekia River at Campground – Flow Duration Curve 1 June 2008 to 31 May 2020.

Table 8: Manuherekia River at Campground – 7 Day MALF	
	7 Day MALF 23 October 2008 – 31 May 2020 (L/s)
Measured	906
Modelled	719

Notes:

- 7 Day MALF is based on hydrological years 1 June to the following 31 May.
- In order to maximise the available data in calculating 7 Day MALF four gaps in the measured record from the Manuherekia River at Campground have been ignored as outlined below:
  2008-2009 – Data starts 23 October 2008 so gap from 1 June 2008 to 22 October 2008. This winter spring period typically has higher flow and 7 Day ALF unlikely to occur in this period, so gap ignored.
  2008-2009 – 2-day gap 25-26 March 2009, flow before and after the gap was moderate i.e., 2,500 L/s and well above 7 Day ALF so gap ignored.
  2010-2011 – 8-day gap 1-8 December 2010, flow before and after the gap was moderate and well above 7 Day ALF i.e., 3,400 – 1,300 L/s and continued to drop after the gap, so gap ignored.
  2013-2014 – 2-day gap 24-25 October 2013, flow before and after the gap was high i.e., 20,000 L/s and well above 7 Day ALF so gap ignored.

Cumulative volume (Figure 6) matches well, with the model tending to slightly underestimate the cumulative volume passing Campground. In part the underestimation of cumulative volume is likely to be due to the underestimation of mid-range flows, but cumulative volume is also highly affected by high flow events which are difficult to accurately model.

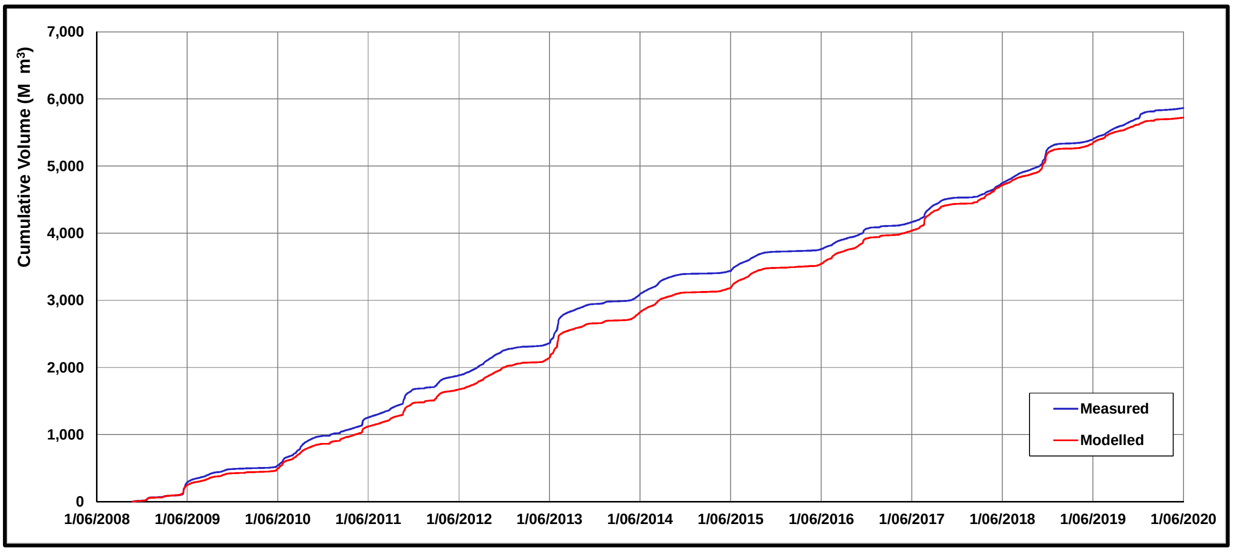

Figure 6: Manuherekia River at Campground – Cumulative Volume Passing 1 June 2008 to 31 May 2020.

6.1.3 Manuherekia River at Ophir

The modelled and measured daily average flow in the Manuherekia River at Ophir are shown in Figure 7. Visually the data match very well with the modelled flow showing similar flow fluctuations and similar magnitude high and low flows.

Flow duration curves (Figure 8) match well particularly for the lower 10 % and upper 20 % of the flow range. The model tends to underestimate mid-range flows (10 % to 80 %). The model underestimates 7-day MALF by approximately 15 % (Table 9). The underestimation of low flows is considered conservative as it is expected to result in the development of more conservative future flow management regimes.

Table 9: Manuherekia River at Ophir – 7 Day MALF

	7 Day MALF 23 October 2008 – 31 May 2020 (L/s)
Measured	2,120
Modelled	1,794

Notes:
- 7 Day MALF is based on hydrological years 1 June to the following 31 May.
- While there are no gaps in the measured flow record from the Manuherekia River at Ophir to be consistent with the analysis undertaken for the Manuherekia River at Campground (namely consistent with Table 8) only data from 23 October 2008 has been used so for the 2008-2009 hydrological year there is a gap from 1 June 2008 to 22 October 2008. This winter spring period typically has higher flow, and 7-Day ALF is unlikely to occur in this period so gap ignored.

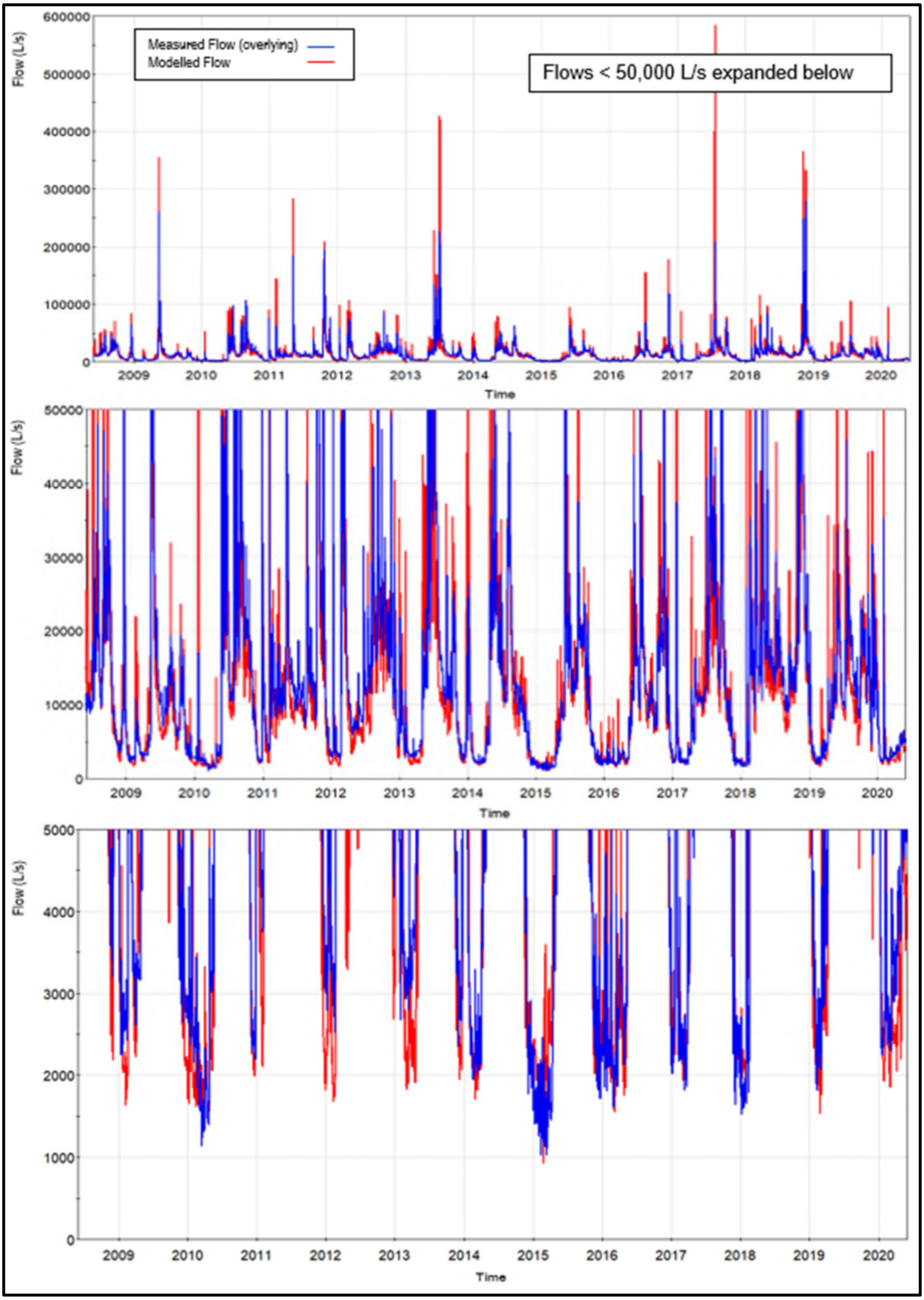

Figure 7: Manuherekia River at Ophir – Daily average flow 1 June 2008 to 31 May 2020.

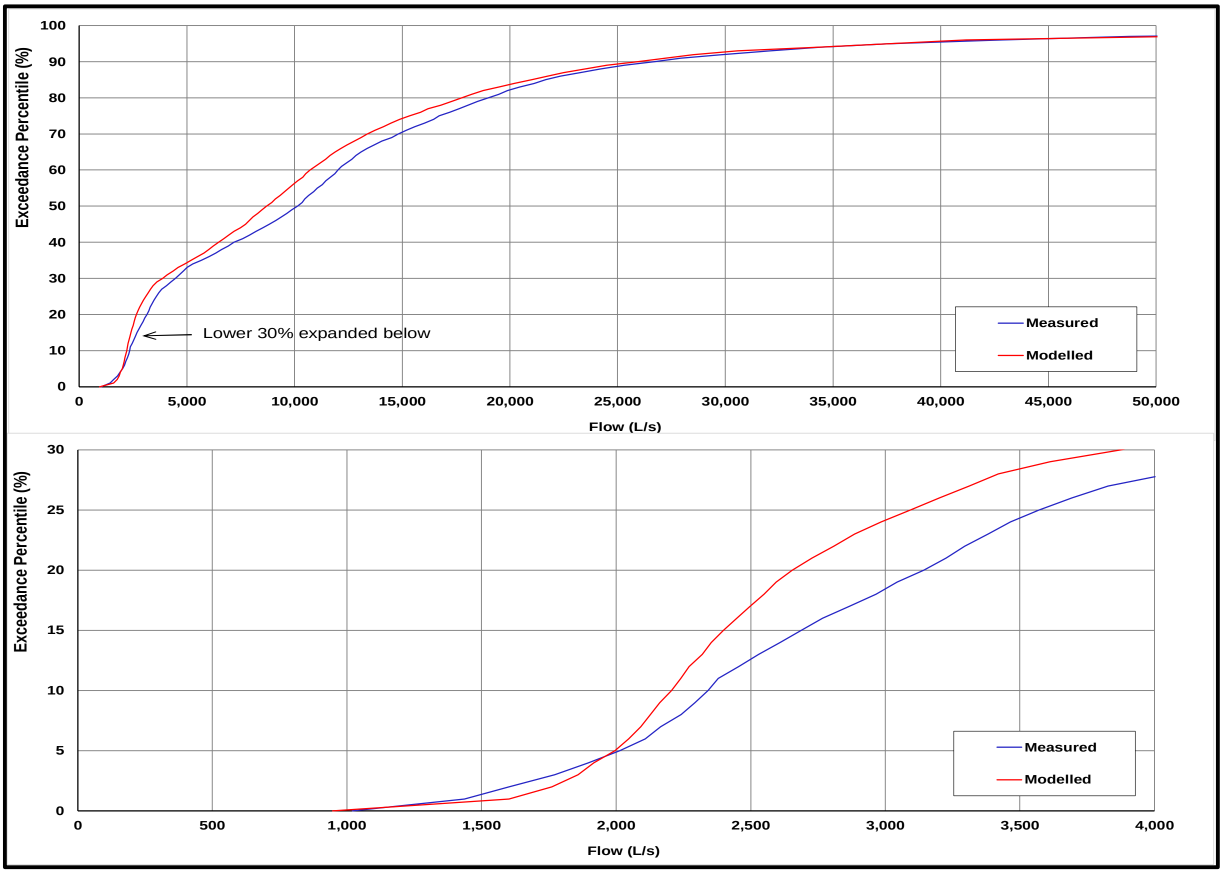

Figure 8: Manuherekia River at Ophir – Flow Duration Curve 1 June 2008 to 31 May 2020.

Cumulative flow (Figure 9) matches well, with the model tending to slightly underestimate cumulative flow at Ophir. In part the underestimation of cumulative flow is likely to be due to the underestimation of mid-range flows, but cumulative flow is also highly affected by high flow events which are difficult to accurately model.

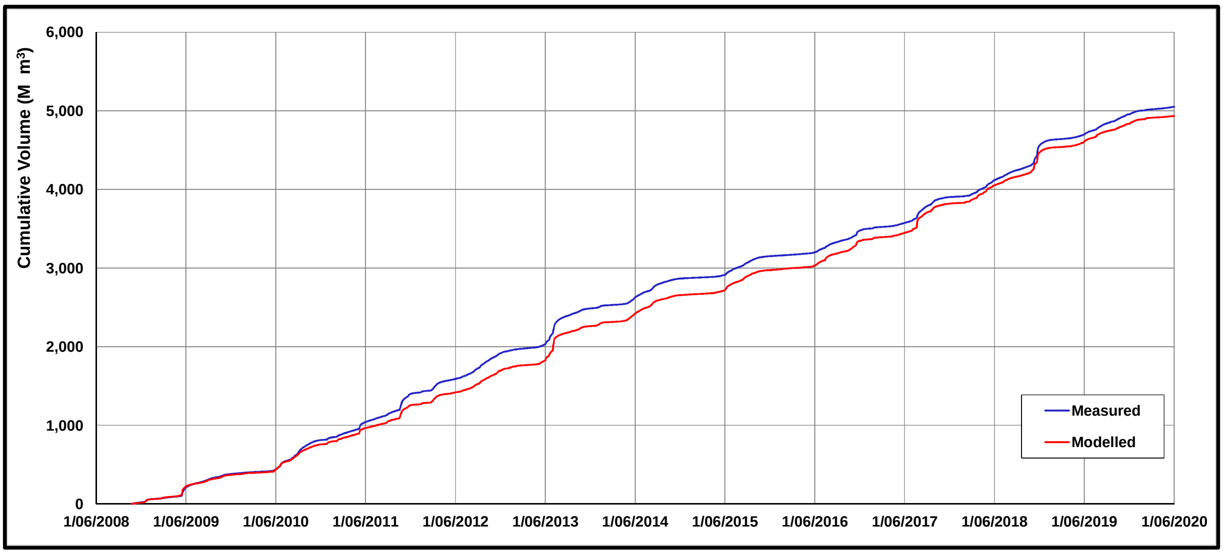

Figure 9: Manuherekia River at Ophir – Cumulative Volume Passing 1 June 2008 to 31 May 2020.

6.1.4 Falls Dam Operation

Falls Dam and its associated reservoir are a critical feature on the main stem of the Manuherekia River and operation of the reservoir has a significant effect on downstream flow. It is critical that the Manuherekia Catchment Hydrology Model suitably replicates operation of Falls Dam.

Comparison plots from the model are shown below for Water Level in Falls Dam (Figure 10) and Management Imposed Irrigation Restrictions (Figure 11). In both cases the modelled data is considered a good visual match to the measured data particularly given the complexities associated with dam management and the imposition of irrigation restrictions (refer Section 5.1.1).

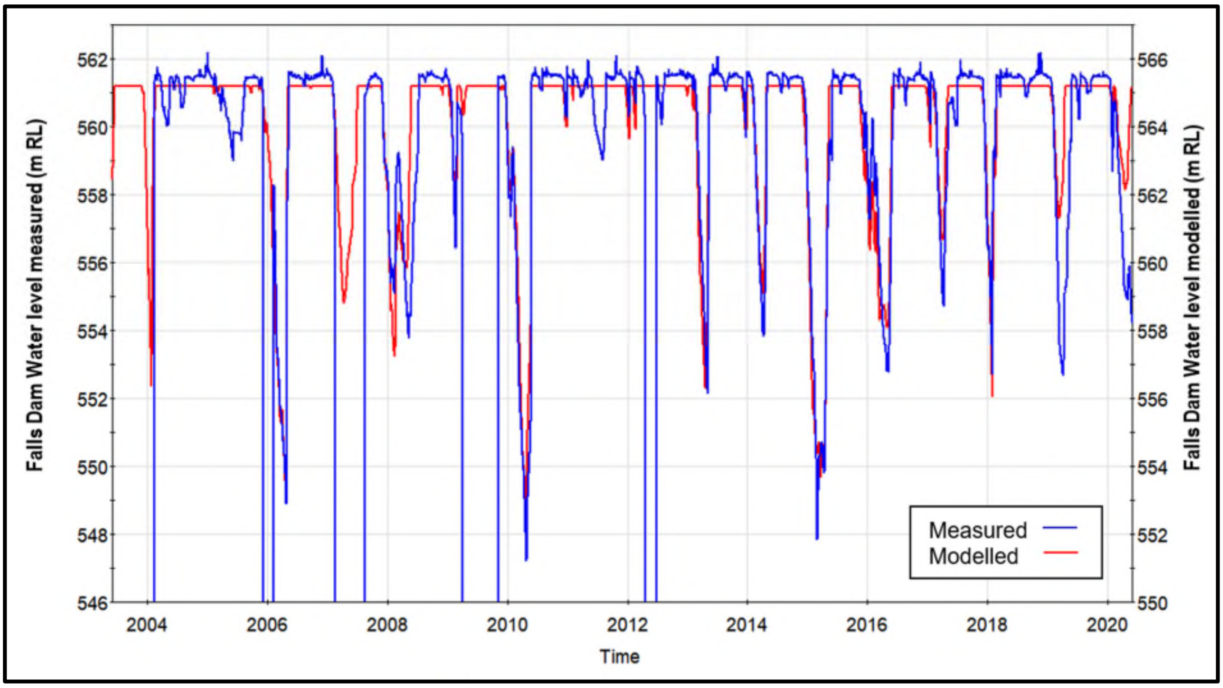

Figure 10: Falls Dam Reservoir Water Level - 1 June 2003 to 31 May 2020.

(Note: the modelled water level uses a datum which is 4 m higher than the measured water level datum. The scales on the above plot have been adjusted so the data overlays.)

The model assesses irrigation restrictions on a daily basis whereas the Falls Dam Company Ltd. make actual restrictions decisions on an approximately fortnightly basis. Hence the stepped nature of the actual restrictions in Figure 11 below. The irrigation restrictions imposed by the Falls Dam Company Ltd. only directly affect irrigators who are supplied water from Falls Dam. However the restrictions are voluntarily adopted by many of the irrigators who take water from tributaries and who are not directly supplied with water from Falls Dam. The model assumes that the irrigation restrictions are imposed equally on all irrigators in the Manuherekia Valley which is not always the case. The above in part explains the difference between the irrigation restrictions predicted by the model and the actual restrictions imposed. Overall, the model is considered to be replicating operation of Falls Dam very well particularly given how complex actual management is.

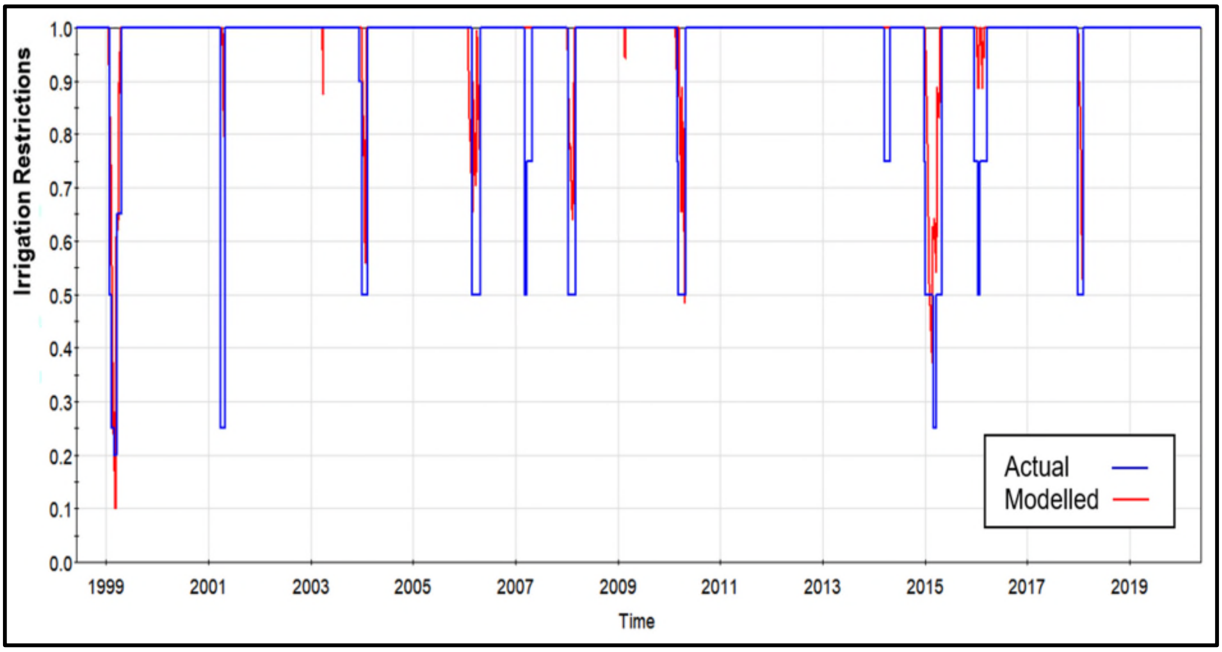

Figure 11: Falls Dam Irrigation Restrictions - 1 June 1998 to 31 May 2020.

6.1.5 Ida Valley Storage Operation

Modelled live storage in the Poolburn Dam and the Upper Manorburn / Greenland Reservoir is shown in Figure 12 below. There is very limited measured data available for either storage which prevents verification of the model predictions. However the modelled live storage fluctuates as expected.

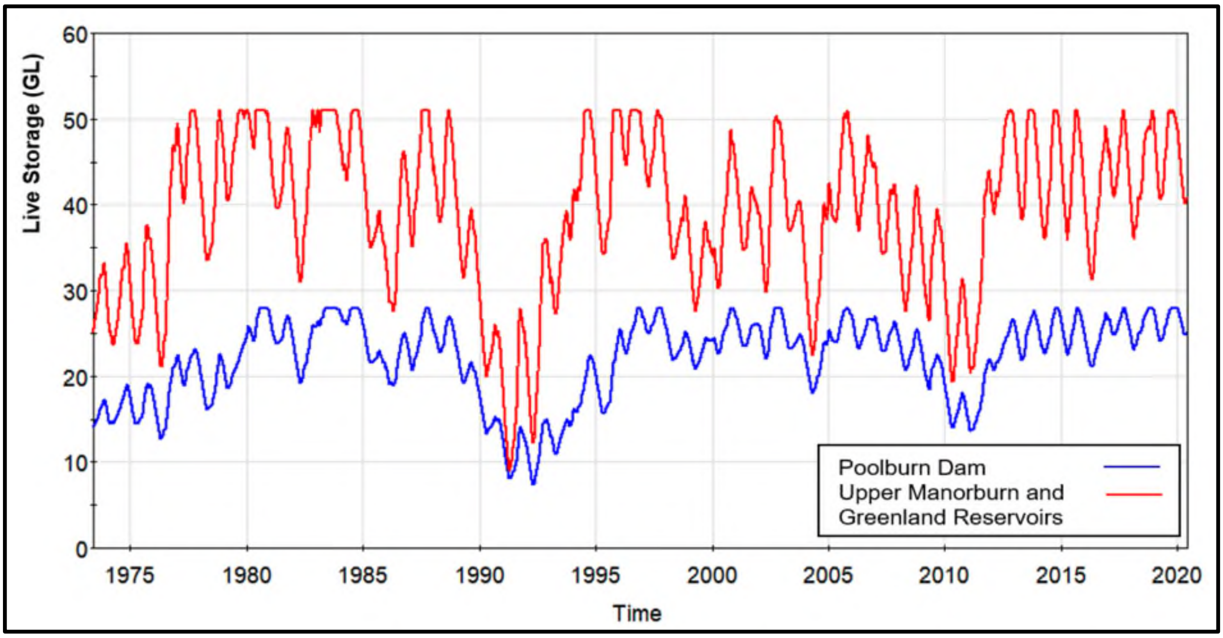

Figure 12: Ida Valley Reservoirs – Live storage – 1 June 1973 to 31 May 2020.

6.1.6 Total Catchment Water Supply

A large volume of water is taken across the Manuherekia Catchment which directly affects flow in the various watercourses and operation of the various storages. Controlling the take through the imposition of minimum flow, residual flows, flow sharing regimes and irrigation restrictions is a key tool for water managers. It is critical that the Manuherekia Catchment Hydrology Model suitably replicates the water taken and the demand for water. The volume of water taken for irrigation across the whole catchment predicted by the model is compared against measured water take data supplied by ORC in Figure 13 below. In both cases retakes have been excluded. The extreme peaks in the measured data are expected to be erroneous. 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.

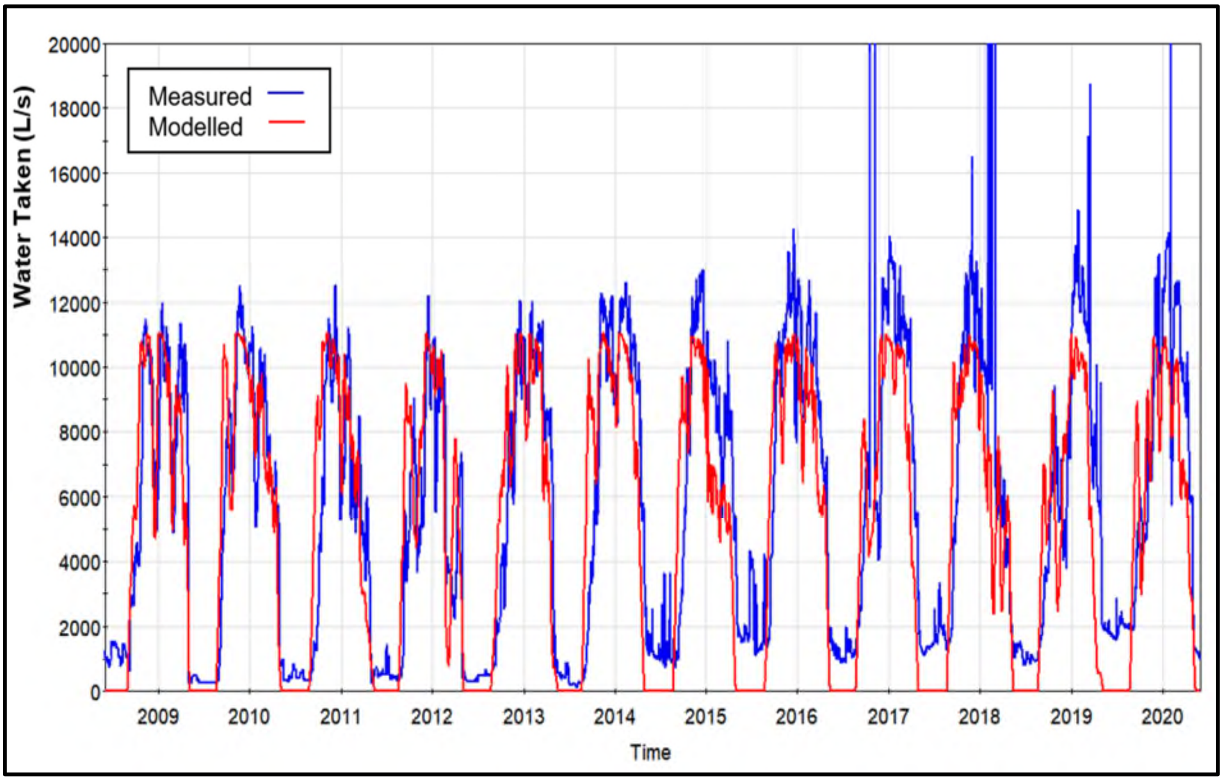

Figure 13: Manuherekia Catchment total irrigation take – 1 June 2008 to 31 May 2020.

The modelled take generally matches the measured take reasonably well, although the modelled take does not include winter takes and underestimates the peak measured take particularly since 2014. The lower modelled take is expected to be due to the model using a relatively simplistic approach to estimating irrigation demand and supply which will not fully replicate the many intricacies associated with actual irrigation. Given the model is predicting flow exiting the system (namely flow in the Manuherekia River at Campground) well it is expected that the model's underestimation of the measured take is off-set by the model predicting higher use of the water that is taken, i.e., more efficient irrigation.

The following two situations are expected:

1. Actual – more water is actually taken, but it is used less efficiently so more water returns.
2. Model – less water is predicted to be taken, but it is used very efficiently so less water returns.

While both situations result in a similar flow exiting the system (namely flow in the Manuherekia River at Campground) and a similar demand for water from Falls Dam, care is required when interpreting the model's predictions for intervening locations.

6.1.7 Tributary Flows

Comparison plots of measured flow and modelled flow for Dunstan Creek at Beattie Road (Figure 14), Lauder at Rail Trail (Figure 15), Thompsons at SH85 (Figure 16), Chatto at Confluence (Figure 17), Manor Burn inflow to the Lower Manorburn Dam (Figure 18) and Ida Burn at Cob Cottage (Figure 19) are shown below.

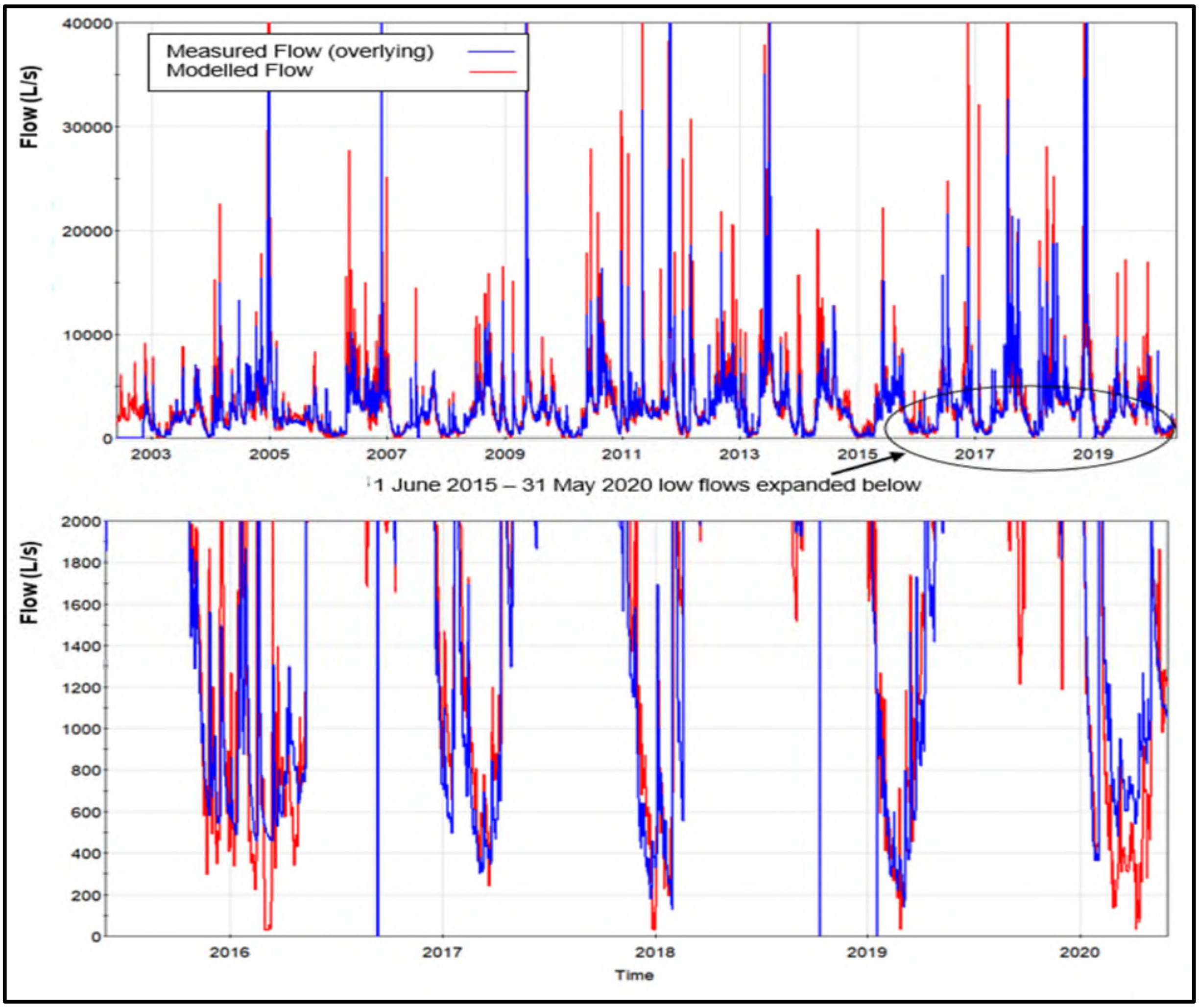

Figure 14: Dunstan Creek at Beattie Road – 1 June 2002 to 31 May 2020.

Modelled flow in Dunstan Creek at Beaties Road is considered a good visual match to the measured data and shows similar flow fluctuations. The modelled flow slightly underestimates extreme low flows which is considered conservative. The underestimation of low flows over the 2015-2016 irrigation season is expected to be related to irrigation restrictions which were applied by the Falls Dam Company Ltd but were not predicted as being necessary by the model (refer Figure 11). Beaties Road is located part way down the Dunstan Creek catchment, which is difficult to replicate in the model as the model is focused on estimating flow in the tributaries at their confluence with the Manuherekia River. Unfortunately, there is very limited measured flow data from the bottom of Dunstan Creek above its confluence with the Manuherekia River.

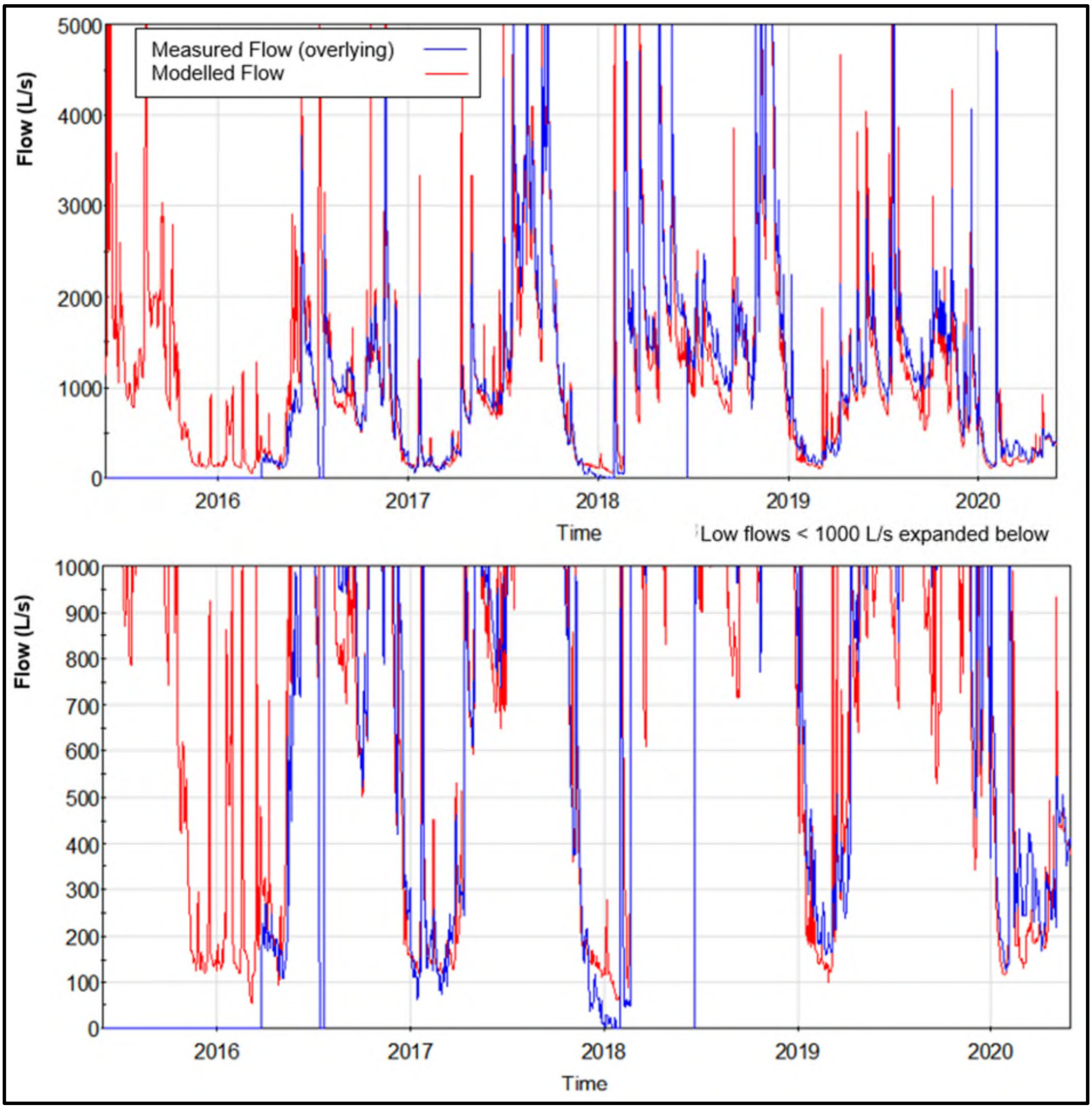

Figure 15: Lauder Creek at Rail Trail - 1 June 2015 to 31 May 2020.

Modelled flow in Lauder Creek at the Rail Trail is considered a good visual match to the measured data. The modelled flows are of a similar magnitude and show similar fluctuations as the measured flows. In December 2007 and January 2018 the model slightly overestimated extreme low flow in Lauder Creek. This was a period of very extreme low flow and the measured data indicates that Lauder Creek at Rail Trail dried. This period also coincides with a period when irrigation restrictions were both imposed by the Falls Dam Company Ltd and predicted as being necessary by the model (Figure 11). Assuming that the measured flow data is real, and Lauder Creek dried the overestimation of flow by the model could be explained by the model assuming all irrigators taken water from Lauder Creek went on restriction where in practice some may not have.

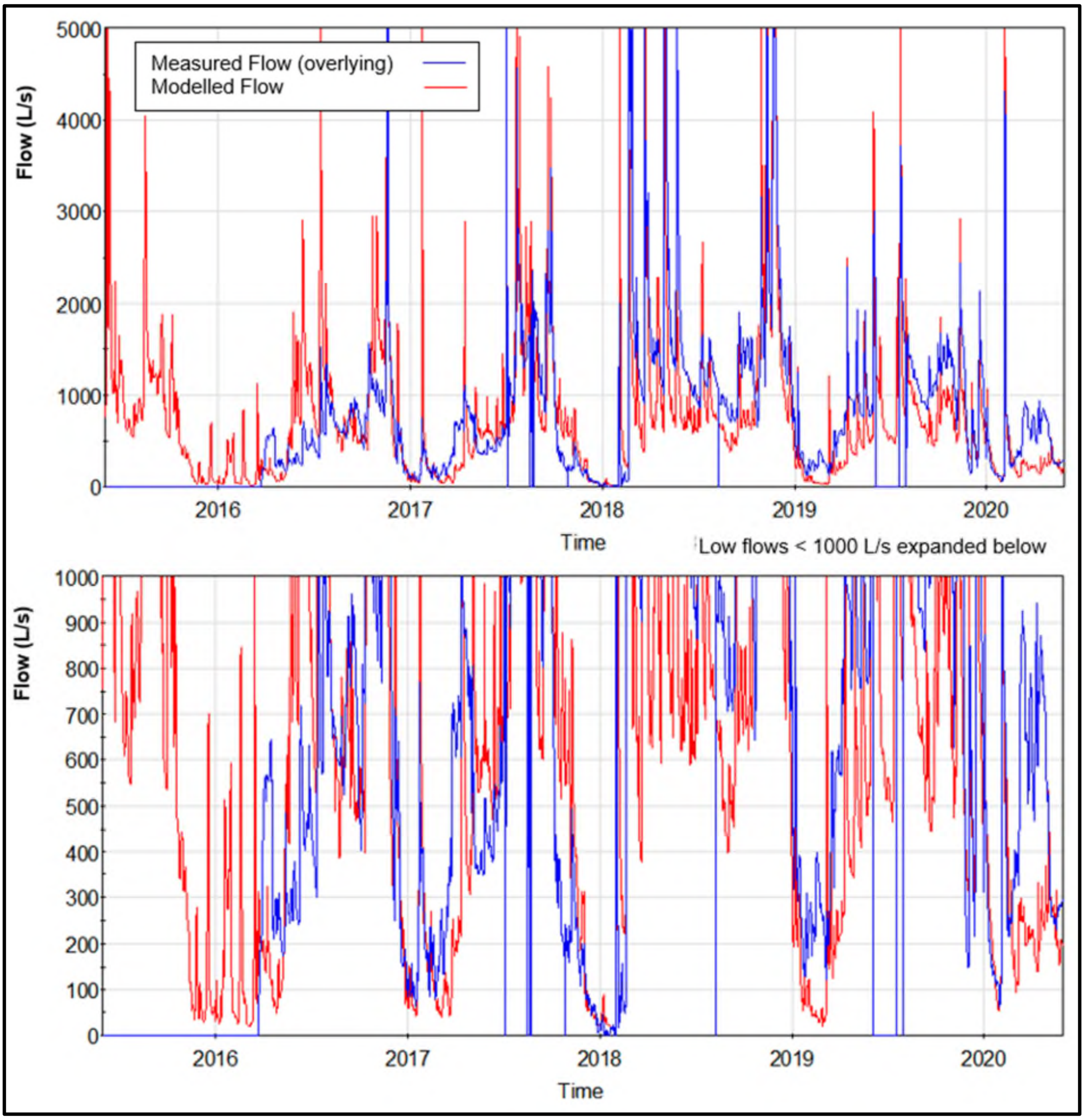

Figure 16: Thomsons Creek at SH85 – 1 June 2015 to 31 May 2020.

Modelled flow in Thomsons Creek at SH85 is considered a good visual match to the measured data. The modelled flows are of a similar magnitude and show similar fluctuations as the measured flows. The model predicts extreme low flows in December 2017 and January 2018 which is consistent with the measured data which indicated that Thomsons Creek went dry at SH85 during this time.

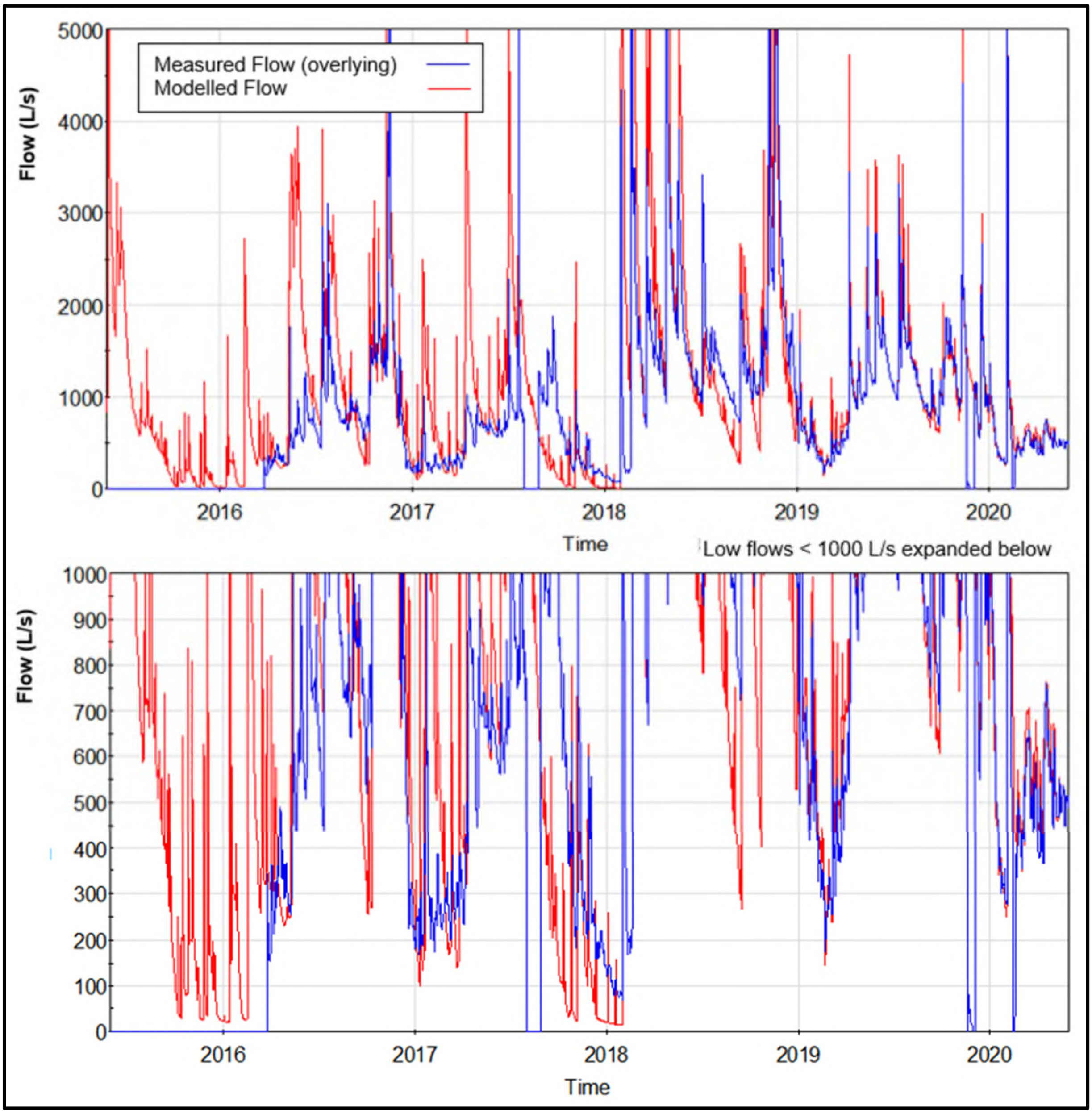

Figure 17: Chatto Creek at Confluence – 1 June 2015 to 31 May 2020.

Modelled flow in Chatto Creek at its confluence with the Manuherekia River is considered a reasonable visual match to the measured data, although modelled flow fluctuates more than measured flow and low flows tend to be underestimated particularly during the 2017-2018 irrigation season. The model prediction of low flows which are lower than measured is considered conservative as it will lead to more conservative water management and water allocation decisions. Overall the match (modelled versus measured) for flow in Chatto Creek is not as good as for Dunstan Creek, Lauder Creek or Thomsons Creek. The poorer match is expected to be predominantly due to uncertainties in the input flow series used for Chatto Creek (i.e., flow above the irrigation takes) which is due to there being very limited measured flow data from the Chatto Creek catchment.

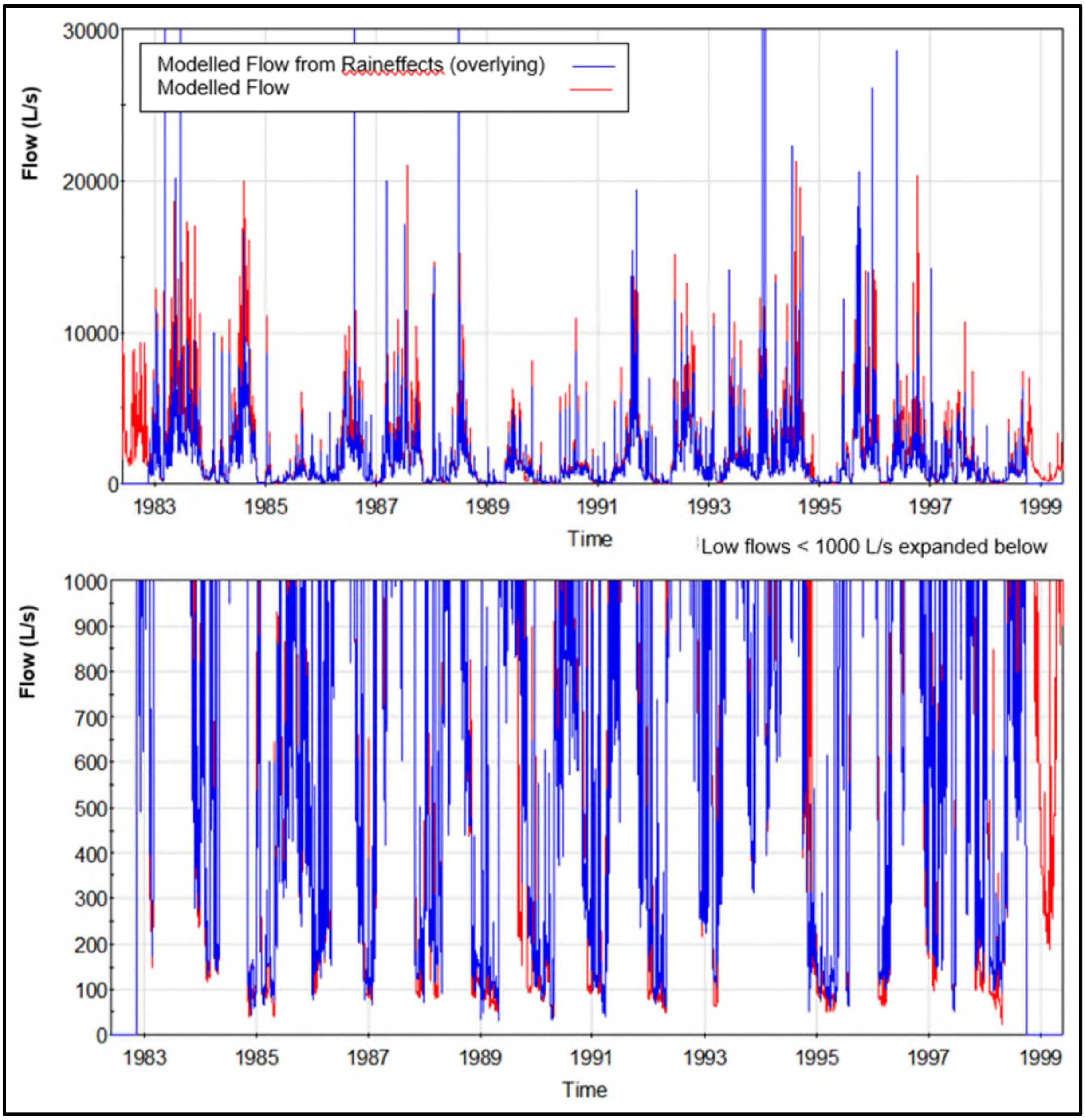

Figure 18: Inflow to the Lower Manorburn Dam – 1 June 1982 to 31 May 1999.

There is very limited measured data available for the Manor Burn catchment and as such it was not possible to verify this part of the Manuherekia Model. However, modelled inflow to the Lower Manorburn Dam is considered a reasonable visual match to the modelled flow series produced by Raineffects which was produced by a separate process (Raineffects 2020).

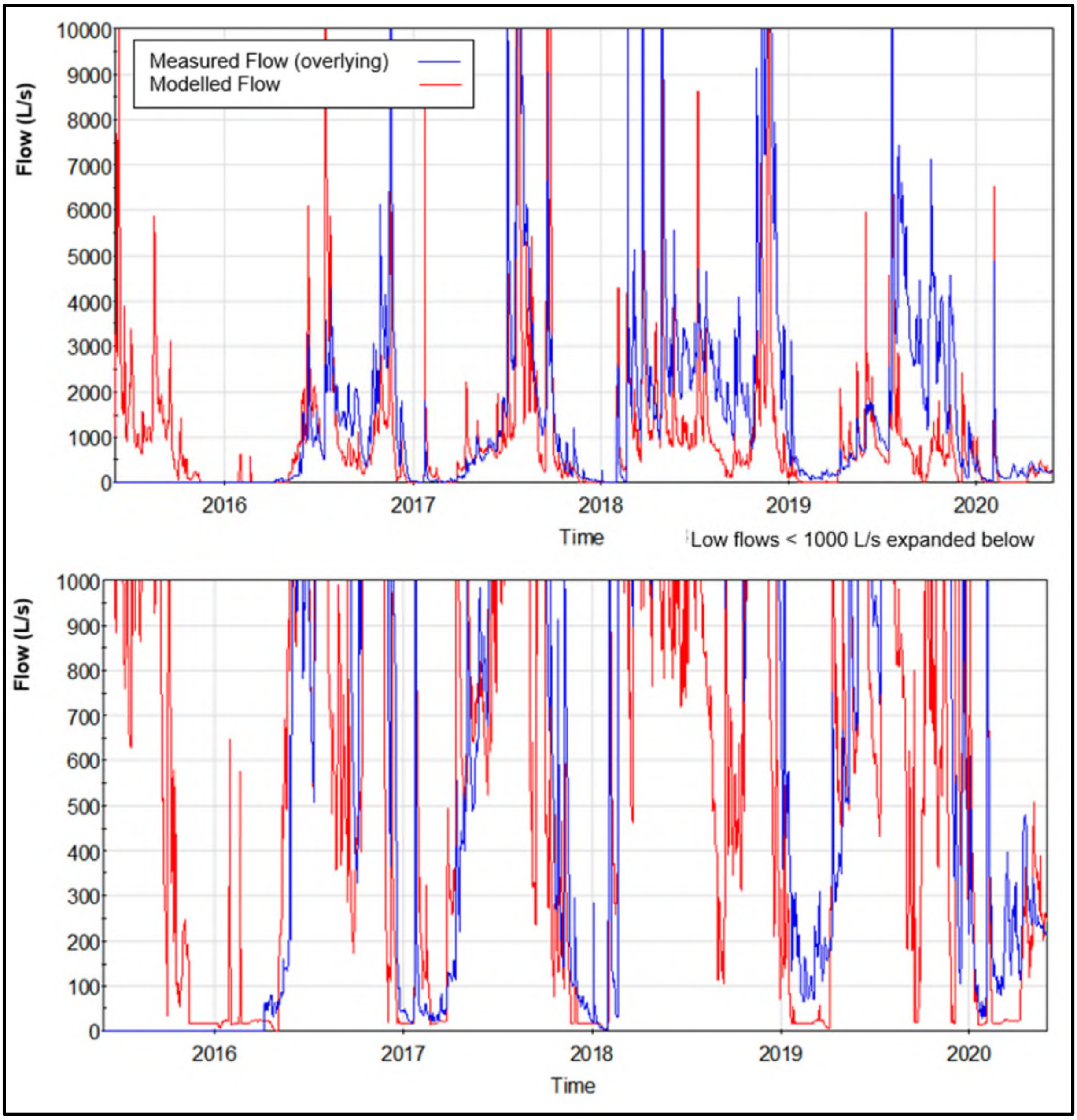

Figure 19: Ida Burn at Cob Cottage – 1 June 2015 to 31 May 2020.

Modelled flow in the Ida Burn at Cob Cottage is considered a reasonable visual match to the measured data although modelled flow fluctuates more than measured flow, and low flows tend to be underestimated. Overall the match for modelled versus measured flow in the Ida Burn at Cob Cottage is not as good as for either Dunstan Creek, Lauder Creek or Thomsons Creek. The poorer match is expected to be predominantly due to uncertainties in the input flow series used for the Ida Burn and its main tributary the Pool Burn (i.e., flow above the irrigation takes) which is due to there being very limited measured flow data from either sub-catchment.

6.2 Verification Conclusions

The Manuherekia Catchment Hydrology Model does not include any parameters which were specifically adjusted or altered during verification. Rather, the model itself was constructed based on a thorough understanding of the physical system, various simplifying assumptions (refer Section 4.1), and input timeseries which were developed from measured data. When the initial model (prior to final development and verification) was run it provided predictions (of downstream flow, storage operation and irrigation supply) which were consistent with measured data. In finalising the model only very minor changes to the model and the input data were made. This confirms the general suitability of the model build process, the underlying assumptions and the completed model.

The model has been verified against measured data including downstream flow, operation of Falls Dam and measured irrigation takes. The wide scope and extended duration of the measured verification data increases the robustness of the verification process and the model itself. Verification has focused on visual comparisons of hydrographs and time series plots. Detailed statistical comparisons between the measured verification data and the model predictions were not undertaken for the following two reasons:

1. The model time step and the model not considering travel times. Measured flow in the Manuherekia River at Campground is a key verification data set as it represents flow exiting the model. It takes more than a day for water to flow from Falls Dam to Campground. The model is based on a daily time step and does not consider travel times. As such, while modelled and measured flows line up at the top of the catchment; at Campground, flow predicted by the model often slightly predate measured flow.
2. The complexity of the system and the wide scope and extent of the verification data. Hydrologically the Manuherekia catchment is known to be complicated. While the Manuherekia Catchment Hydrology Model includes numerous simplifying assumptions, the model is still complex with numerous interacting variables. This complexity coupled with the wide scope and extended duration of the measured verification data would make direct statistical comparisons with all the verification data difficult.

The overall representativeness of the model predictions indicates that the model is suitably replicating the hydrology of the Manuherekia Catchment.

7.0 MODEL LIMITATIONS

The limitations of the Manuherekia Catchment Hydrology Model are principally related to the assumptions that underpin the model (refer Section 4.1), which were required to suitably represent what is a complicated, dynamic natural system by a relatively simple model. The key limitations and future model use considerations associated with the Manuherekia Catchment Hydrology Model are listed below.

- The Manuherekia Catchment Hydrology Model needs to be used and its predictions interpreted in accordance with the objectives of the model and why it was produced (Section 3.1). The model is predominantly a decision support tool rather than a traditional hydrological or hydraulic model. The model provides a simplistic representation of the hydrology of the Manuherekia Catchment, it is not designed to replicate all the intricate details of the catchment's actual hydrology. The model was not developed to assess individual small tributaries nor individual water takes nor individual irrigated properties rather it is focused on the catchment as a whole and the key features that dominate the catchment's hydrology.
- 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 verification run (called Estimated Existing (Status Quo or Baseline) in the model), which is considered to suitably replicate the known hydrology of the Manuherekia Catchment, should be used as the base scenario against which future scenarios are assessed.
- The model is based on data from 1 June 1973 to 31 May 2020 and it does not attempt to predict future flows. When considering a potential future flow management regime, the model applies the potential flow management regime to the historic flow data and predicts downstream flows, water take reliability, and operation of the water storages. Actual future flows will be the combined result of future climate and future water management decisions and will be different to historic flows.
- The model will be most accurate at assessing relatively small changes to current conditions and current water management practices. As the degree of change increases, the model's ability to suitably estimate the implications of the change will reduce.
- The model will have higher uncertainties in sub-catchments with limited measured data namely the Chatto Creek, Ida Burn, Pool Burn and Manor Burn sub-catchments and care is required when interpreting model predictions from these sub-catchments.
- There is significant water movement between sub-catchments and flow in the main stem of the Manuherekia River and operation of Falls Dam is very sensitive to what happens in the modelled tributaries.

- Use of the Manuherekia Catchment Hydrology Model and the development of model scenarios should utilise the model's ability to quickly generate multiple scenarios, its short run time and its ability to compare multiple scenarios. It is recommended that model scenarios should be developed through use of the model rather than separate from it. The model was specifically designed to allow it to be used in scenario development type workshops where potential future water management regimes (i.e., model scenarios) are developed through assessing the various components of the regime. An iterative process was envisaged where the model would be run multiple times, with interpretation focused on a few key model outputs, in order to develop potential future water management regimes that would then progress to detailed assessment involving more detailed interpretation of model outputs. The iterative process is recommended due to the complexities and numerous interactions in the model and the physical system. Relatively small changes in one location can affect significant parts of the system and can result in unintended consequences. For example, imposing a minimum flow at the bottom of Lauder Creek will cause the following.
    - Supply reliability for irrigators who use Lauder Creek water will reduce. As Lauder Creek water is used to irrigate land in the Thomsons Creek catchment their reliability will also be reduced. Similarly, not all the irrigators in the Lauder Creek catchment will have their supply reliability reduced as some receive their water from Dunstan Creek and others from the Omakau Main Race which draws water from the main stem of the Manuherekia River.
    - During periods when the Lauder Creek minimum flow is in force, Lauder Creek will contribute more water to the main stem of the Manuherekia River. This will increase the water available for downstream uses (both for minimum flows and irrigation) and reduce demand for water from Falls Dam allowing storage to be retained for longer which will influence conditions later in the season. Potentially this could lead to an increase in supply reliability for the Lauder Creek irrigators who receive their water from the Omakau Main Race.

8.0 MODEL USE

8.1 Model Use to Date

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. Details of the scenarios are provided in Table 10 below. The 29 scenarios were developed by ORC independently from the model. The results of the 29 scenarios were documented in Davis Ogilvie 2021c. The ecological results from the verification run (called Estimated Existing (Status Quo or Baseline) in the model) and eight of the scenarios were documented in Davis Ogilvie 2021b. This section summaries the key findings from the model runs but does not reproduce all the scenario results. The reader is referred to Davis Ogilvie 2021c for all the model's hydrological results and Davis Ogilvie 2021b for the ecological results.

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 has provided 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. The points below have been discussed with key operators of the system and are consistent with their experience of the actual system.

- 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 main stem irrigators can access 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 which are included in the model. Contributions from the numerous other small tributaries which are not included in the model 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.
- The Poolburn Dam and the Upper Manorburn / Greenland Reservoir 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 Dam 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 Dam can be quickly depleted (i.e., within two months).
- 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 imposing voluntary irrigation restrictions on irrigators in the Manuherekia Valley in order to retain storage in Falls Dam, and using storage in Falls Dam to augment minimum flows 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 Dam 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.

Table 10: Manuherekia Hydrology Model Scenarios – Requested by ORC

Model Run / Scenario		Total irrigated area	Falls Dam outlet restrictions	Falls Dam irrigation restrictions	Falls Dam storage used to supplement minimum flows at Campground	Below Falls Minimum flow	Ophir Minimum flow	Campground Minimum flow	Main stem residuals below takes	Dunstan Confluence Minimum Flow	Dunstan Residual below take	Lauder Confluence Minimum flow	Lauder Residual below take	Thomsons Confluence Minimum flow	Thomsons Residual below take	Chatto Confluence Minimum flow	Chatto Residual below take	Flow Sharing	Comment
		ha				L/s	L/s	L/s	L/s	L/s	L/s	L/s	L/s	L/s	L/s	L/s	L/s	%	
Verification – Estimated Existing (Status Quo or Baseline)		27,210	Current	Yes	Yes	500	820	0	100	0	30	0	10	0	10	0	10	nil	Verification was based on measured flow data particularly in the Manuherekia River at Campground. As there is currently no minimum flow at Campground none was applied to ensure the model replicated measured flow data.
900	Scenario name is based on the minimum flow in the Manuherekia River at Campground in L/s.	27,210	Current	Yes - apply to whole Manuherekia Valley	Yes	500	820	900	100	0	30	0	10	0	10	0	10	nil	Scenario designed to represent current water management objectives.
1200								1200		410		130		70		70			Future scenarios developed by ORC.
1500								1500		510		160		80		90			
1700								1700		580		180		90		100			
2000								2000		680		210		110		120			
2500								2500		850		260		140		150			
3000								3000		1020		320		170		180			
Full Dams and No Irrigation		0	N/A	N/A	N/A	0	0	0	0	0	0	0	0	0	0	0	0		Scenario designed to assist ecological interpretations, not designed to represent "natural" hydrological conditions. The scenario uses current inflow to Falls Dam which includes operation of the Mt Ida Race. Caution required when interpreting the model output for this scenario as model not developed to assess such a major change from current conditions.
No Falls Irrigation Restrictions	Status Quo or Baseline	27,210	None	None	Yes	500	820		100		30		10		10		10		Designed to assess implications of the Management Imposed Restrictions. Outlet restrictions removed to allow clearer comparison.
	900							900											
	1200							1200		410		130		70		70			
	1500							1500		510		160		80		90			
	3000							3000		1020		320		170		180			
No Falls Irrigation Restrictions and no Augmentation.	Status Quo or Baseline				No			0		0		0		0		0			Designed to assess implications of using storage in Falls Dam to augment minimum flows at Campground. Outlet restrictions removed to allow clearer comparison.
	900							900											
	1200							1200		410		130		70		70			
	1500							1500		510		160		80		90			
	3000							3000		1020		320		170		180			
No Falls Irrigation Restrictions no Augmentation higher residual below Falls	1200					620		1200		410		130		70		70			As above but with higher residual flows below Falls Dam. The higher residual flows have been estimated using the relative contribution of the Falls Dam Catchment to flow at Campground as derived from modelled 5th percentile flows under the "Full Dams and No Irrigation" scenario and assuming only Falls Dam and the four main tributaries contribute to flow at Campground, plus 100 L/s to be consistent with current 500 L/s residual. Outlet restrictions removed to allow clearer comparison.
	1500					760		1500		510		160		80		90			
	3000					1410		3000		1020		320		170		180			
Flow regime components Lauder Creek 1500 base	Base				Yes	500		1500		510		0	0	80		90			Designed to show the effects that each of the various components, that make up a potential flow and allocation regime, have on flow. The Lauder Catchment is used to highlight the effects.
	Min Flow											160							
	Residual (50)											0	50						
	Flow sharing												0					50	
	Allocation 80	80%																nil	
	Allocation 50	50%																	
Allocation Manuherekia Valley 1500 base	Allocation 80	80%		Yes								160	10						Designed to show the effects that differing levels of allocation across the Manuherekia Valley has on flow at Campground.
	Allocation 50	50%																	

Notes: The ORC initially requested that the Verification scenario (blue shaded) and the five yellow shaded future scenarios be included in the production modelling and subsequent economic assessment. ORC subsequently requested that the orange shaded scenario (1200) be included as well.
The scenario data used in the model are shown in Appendix B.

8.2 Future Use of the Model

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. To date the model has been used to assess 29 scenarios which were developed by ORC. Collectively the 29 modelled scenarios have used most, but not all, of the model's functionality.

A Player version of the finalised model (named Manuherekia Hydrology Model V4, September 2022) which can run on software which is freely available is to be made publicly available for all stakeholders to use. This allows stakeholders to develop and assess their own potential future water management regimes for the catchment. ORC also plan to use the finalised model to assess additional scenarios.

As highlighted in the limitations section (Section 7.0) 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. For example, improved trout fishing in the main stem of the Manuherekia River between the Chatto Creek confluence and Campground.
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. For the above example the key criteria might be: flows at Campground ranging from X to Y L/s and averaging Z L/s over the critical fishing season, improved habitat areas for both adult trout and their key food sources below the Chatto Creek confluence – say a 20 % increase (from current) in average habitat area, plus improved habitat area for juvenile trout in the key spawning and rearing areas while maximising water supply reliability for water users.
3. Use the model to determine what model parameters have the most influence on each of the performance criteria. For the above example low flow at Campground is likely to be most strongly influenced by the minimum flow at Campground and Falls Dam Management practices.
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.

The Manuherekia Catchment Hydrology Model has been developed to be easy to use. Four “Input” dashboards have been included which allow both model inputs to be rapidly changed to create new scenarios for assessment. Similarly, a “Results” dashboard provides quick access to the key model outputs. The five dashboards with the “Estimated Existing” (Status Quo or Baseline) scenario inputs and outputs, are shown in Appendix A. With a relatively small amount of training, it is expected that all stakeholders will be able to easily use the Player version of the finalised Manuherekia Model. Despite its ease of use, given the complexity of the hydrology of Manuherekia catchment it is recommended that interpretation of outputs from the Manuherekia Catchment Hydrology Model is undertaken by people who are familiar with the hydrology of the catchment.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This report describes and documents the Manuherekia Catchment Hydrology Model (final model, named Manuherekia Hydrology Model V4, dated September 2022) and has been prepared to facilitate peer review and subsequent use of the model. The Manuherekia Catchment Hydrology Model provides a tool which can be used to improve understanding of the catchment’s hydrological system and to assess the implications of future water management decisions. The Manuherekia Catchment Hydrology Model was developed through a collaborative process undertaken by the Manuherekia Catchment Hydrology Group. While Davis Ogilvie were responsible for development of the actual model, the model uses input data provided by various members of the Group and the overall model represents the combined understanding of the Group.

The Manuherekia Catchment Hydrology Model has been verified against measured data including downstream flow, operation of Falls Dam and measured irrigation takes. The wide scope and extended duration of the measured verification data increases the robustness of the verification process. Verification has focused on visual comparisons of hydrographs and time series plots.

The overall representativeness of the model predictions indicates that the model is suitably replicating the hydrology of the Manuherekia Catchment.

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. It has already been used to assess a number of potential future water management scenarios developed by ORC. Future use of the model is expected to include assessment of additional scenarios for both ORC and other stakeholders. Guidance on how to use the model to develop and assess future water management scenarios is provided in Section 8.2.

9.2 Recommendations

Recommendations on future use of the Manuherekia Catchment Hydrology Model V4 are provided in Section 8.2 above and are not repeated here. Recommendations for improving the Manuherekia Catchment Hydrology Model V4 are provided below:

1. The Manuherekia Catchment Hydrology Model V4 relies on input timeseries which have been derived from the available measured data. The Manuherekia Catchment has numerous measured records and since 2016 ORC have invested heavily in establishing additional flow recorder sites. Despite this there are a number of sub-catchments where there is limited data available which limits the detail and accuracy of the model in those sub-catchments. The model would benefit from increased monitoring of the following:
    a. Chatto Creek catchment – particularly flow above the main water takes and in the lower reaches of Chatto Creek above its confluence with the Manuherekia River.
    b. Manor Burn Catchment – particularly water level in, and outflow from, the Upper Manorburn Dam, and either flow in the lower reaches of the Manor Burn or water level in and outflow from the Lower Manorburn Dam.
    c. Pool Burn Catchment – particularly water level in and outflow from the Poolburn Dam, flow in the lower reaches of the Pool Burn and flow in Dovedale Creek above the water takes.
    d. Ida Burn – particularly flow above the main water takes.

    The above monitoring could be used to improve the 1 June 1973 – 31 May 2020 timeseries used in the model or ideally the model timeframe would be expended to include any new monitoring data.

2. A significant amount of water is taken and used in the Manuherekia Catchment and the takes have a significant effect on the catchment's hydrology and are a significant component of the Manuherekia Catchment Hydrology Model. ORC have considerable water use data (particularly since the 2008-2009 irrigation season) for the Manuherekia Catchment which has been used to assist in verification of the model. However, there are concerns regarding the accuracy of the water take data and what it represents (i.e., initial takes versus retakes). Verification of the model to the water use data would be improved if the water use data was fully quality assured.

3. The Manuherekia Catchment Hydrology Model uses irrigation demand and return water timeseries to determine both the amount of water taken for irrigation, and of that, how much returns to downgradient waterways. The timeseries have been derived from a soil moisture and irrigation demand model that considers climate data, properties of the irrigated soils and representative irrigation regimes. They represent our best estimate of what actually occurs. The robustness of the model would be enhanced through detailed monitoring of some representative irrigation takes to confirm the suitability of the irrigation demand and return water timeseries.

10.0 REFERENCES

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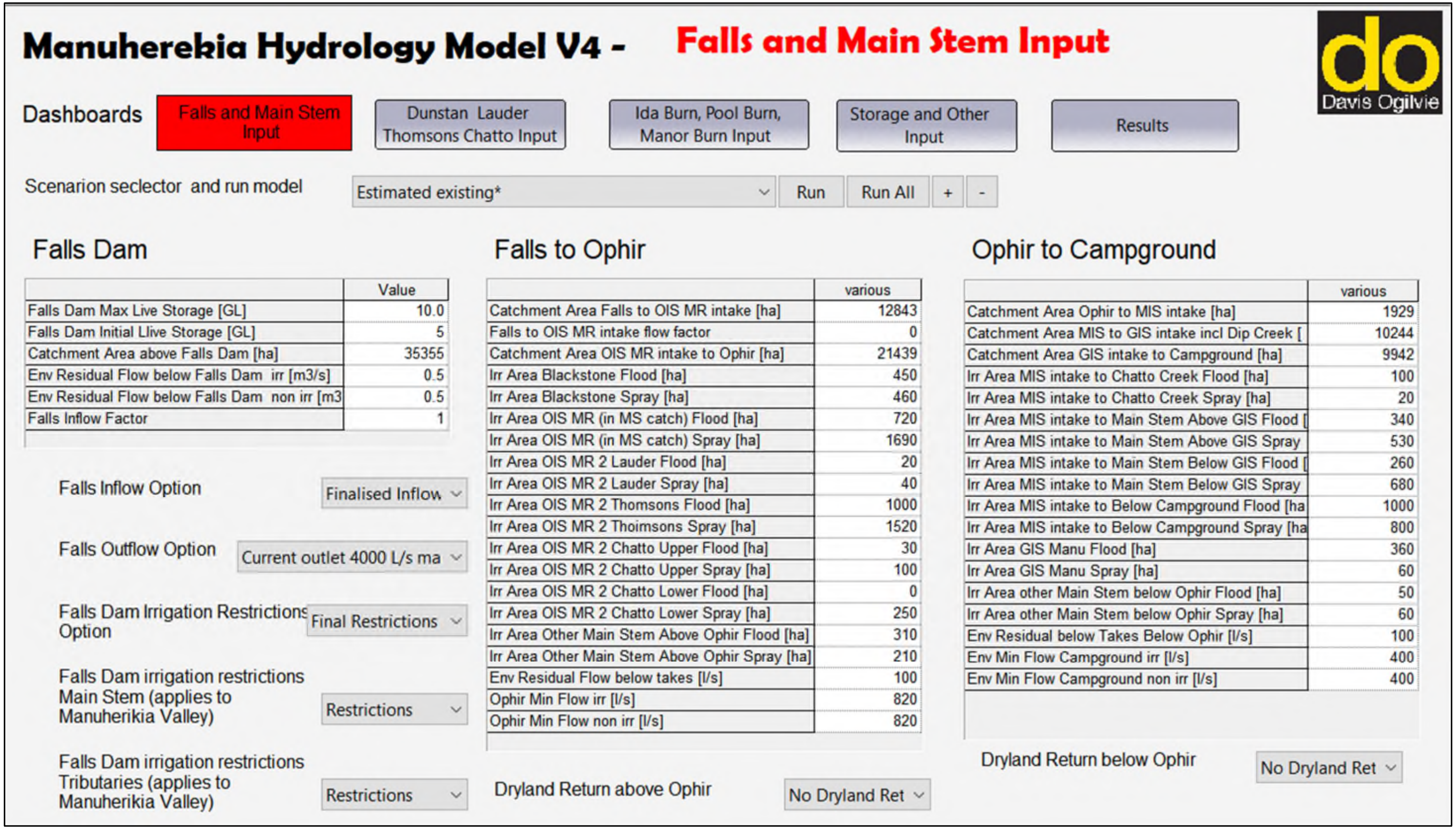


Manuherekia Hydrology Model V4 - Falls and Main Stem Input

Dashboards: Falls and Main Stem Input | Dunstan Lauder Thomsons Chatto Input | Ida Burn, Pool Burn, Manor Burn Input | Storage and Other Input | Results

Scenarion seclector and run model: Estimated existing* | Run | Run All | + | -

Falls Dam

	Value
Falls Dam Max Live Storage [GL]	10.0
Falls Dam Initial Llive Storage [GL]	5
Catchment Area above Falls Dam [ha]	35355
Env Residual Flow below Falls Dam irr [m3/s]	0.5
Env Residual Flow below Falls Dam non irr [m3	0.5
Falls Inflow Factor	1

Falls Inflow Option: Finalised Inflow

Falls Outflow Option: Current outlet 4000 L/s ma

Falls Dam Irrigation Restrictions Option: Final Restrictions

Falls Dam irrigation restrictions Main Stem (applies to Manuherikia Valley): Restrictions

Falls Dam irrigation restrictions Tributaries (applies to Manuherikia Valley): Restrictions

Falls to Ophir

	various
Catchment Area Falls to OIS MR intake [ha]	12843
Falls to OIS MR intake flow factor	0
Catchment Area OIS MR intake to Ophir [ha]	21439
Irr Area Blackstone Flood [ha]	450
Irr Area Blackstone Spray [ha]	460
Irr Area OIS MR (in MS catch) Flood [ha]	720
Irr Area OIS MR (in MS catch) Spray [ha]	1690
Irr Area OIS MR 2 Lauder Flood [ha]	20
Irr Area OIS MR 2 Lauder Spray [ha]	40
Irr Area OIS MR 2 Thomsons Flood [ha]	1000
Irr Area OIS MR 2 Thoimsons Spray [ha]	1520
Irr Area OIS MR 2 Chatto Upper Flood [ha]	30
Irr Area OIS MR 2 Chatto Upper Spray [ha]	100
Irr Area OIS MR 2 Chatto Lower Flood [ha]	0
Irr Area OIS MR 2 Chatto Lower Spray [ha]	250
Irr Area Other Main Stem Above Ophir Flood [ha]	310
Irr Area Other Main Stem Above Ophir Spray [ha]	210
Env Residual Flow below takes [l/s]	100
Ophir Min Flow irr [l/s]	820
Ophir Min Flow non irr [l/s]	820

Dryland Return above Ophir: No Dryland Ret

Ophir to Campground

	various
Catchment Area Ophir to MIS intake [ha]	1929
Catchment Area MIS to GIS intake incl Dip Creek [	10244
Catchment Area GIS intake to Campground [ha]	9942
Irr Area MIS intake to Chatto Creek Flood [ha]	100
Irr Area MIS intake to Chatto Creek Spray [ha]	20
Irr Area MIS intake to Main Stem Above GIS Flood [	340
Irr Area MIS intake to Main Stem Above GIS Spray	530
Irr Area MIS intake to Main Stem Below GIS Flood [	260
Irr Area MIS intake to Main Stem Below GIS Spray	680
Irr Area MIS intake to Below Campground Flood [ha	1000
Irr Area MIS intake to Below Campground Spray [ha	800
Irr Area GIS Manu Flood [ha]	360
Irr Area GIS Manu Spray [ha]	60
Irr Area other Main Stem below Ophir Flood [ha]	50
Irr Area other Main Stem below Ophir Spray [ha]	60
Env Residual below Takes Below Ophir [l/s]	100
Env Min Flow Campground irr [l/s]	400
Env Min Flow Campground non irr [l/s]	400

Dryland Return below Ophir: No Dryland Ret

Davis Ogilvie

Manuherekia Hydrology Model V4 - Dunstan Lauder Thomsons Chatto Input

Davis Ogilvie

Dashboards: Falls and Main Stem Input | Dunstan Lauder Thomsons Chatto Input | Ida Burn, Pool Burn, Manor Burn Input | Storage and Other Input | Results

Scenarion seclector and run model: Estimated existing* | Run | Run All | + | -

Dunstan Sub-catchment

	Value
Catchment Area above Gorge Flow site [ha]	15870
Catchment Area above Main Take [ha]	26290
Catchment Area above Lower Flow Site [ha]	30080
Irr Area Main Take Flood [ha]	310
Irr Area Main Take Spray [ha]	550
Irr Area Re-take Flood [ha]	0
Irr Area Re-take Spray [ha]	200
Irr Area in Lauder Cat from Dunstan Flood [ha]	450
Irr Area in Lauder Catt from Dunstan Spray [ha]	310
Irr_Area_in Manu MS from Dunstan Flood [ha]	700
Irr_Area_in Manu MS from Dunstan Spray [ha]	570
Env Residual Flow below takes [l/s]	30
Env Min Flow at lower site [l/s]	0
Env Flow Sharing for main take [%]	0

Dryland Return Dunstan: No Dryland Ret

Lauder Sub-catchment

	various
Catchment Area above Cattle Yards Flow site [ha]	7390
Catchment Area above Main Take [ha]	8350
Catchment Area above Lower Flow Site [ha]	15940
Irr Area Main Take Flood [ha]	550
Irr Area Main Take Spray [ha]	450
Irr Area Re-take Flood [ha]	0
Irr Area Re-take Spray [ha]	250
Irr Area in Thom Cat from Lauder Flood [ha]	30
Irr Area in Thom Cat from Lauder Spray [ha]	230
Env Residual Flow below takes [l/s]	10
Env Min Flow at lower site [l/s]	0
Env Flow Sharing for main take [%]	0
Irr_percent_Lau [%]	100

Dryland Return Lauder: No Dryland Ret

Thomsons Sub-catchment

	various
Catchment Area above Weir Flow site [ha]	6480
Catchment Area above Main Take [ha]	6480
Catchment Area above Lower Flow Site [ha]	16240
Irr Area Main Take Flood [ha]	310
Irr Area Main Take Spray [ha]	460
Irr Area Re-take Flood [ha]	0
Irr Area Re-take Spray [ha]	190
Env Residual Flow below takes [l/s]	10
Env Min Flow at lower site [l/s]	0
Env Flow Sharing for main take [%]	0

Dryland Return Thomsons: No Dryland Ret

Chatto Sub-catchment

	Value
Catchment Area above Input Flow site [ha]	11270
Catchment Area above Main Take [ha]	11270
Catchment Area above confluence [ha]	16600
Irr Area Main Take Flood [ha]	400
Irr Area Main Take Spray [ha]	200
Irr Area Re-take Flood [ha]	0
Irr Area Re-take Spray [ha]	200
Irr Area in Manu MS Cat from Chatto Flood [ha]	0
Irr Area in Manu MS Cat from Chatto Spray [ha]	0
Env Residual Flow below takes [l/s]	10
Env Min Flow at lower site [l/s]	0
Env Flow Sharing for main take [%]	0

Dryland Return Chatto: No Dryland Ret

Manuherekia Hydrology Model V4 - Ida Burn, Pool Burn, Manor Burn Input

Dashboards: Falls And Main Stem Input | Dunstan Lauder Thomsons Chatto Input | Ida Burn, Pool Burn, Manor Burn Input | Storage and Other Input | Results

Davis Ogilvie

Scenarion seclector and run model: Estimated existing* | Run | Run All | + | -

Manor Burn Sub-catchment

	various
Catchment Area above UMD [ha]	9720
Catchment Area Hopes Creek [ha]	12460
Catchment Area above Little Valley takes [ha]	16390
Catchment Area UMD to intake weir [ha]	2100
Catchment Area Intake Weir to Hopes Creek [ha]	4960
Catchment Area Hopes Creek to LMD [ha]	4290
Irr Area Little Valley Flood [ha]	130
Irr Area Little Valley Spray [ha]	0
Irr Area Galloway from LMD Flood [ha]	180
Irr Area Galloway from LMD Spray [ha]	10
Irr Area Crawford Hills Flood [ha]	340
Irr Area Crawford Hills Spray [ha]	170
Irr Area Bonanza Race Ida V Flood [ha]	1690
irr Area Bonanza Race Ida V Spray [ha]	1170
Bonanza Race loss rate	0.05
Env Residual Flow below takes [l/s]	0
Env Residual Flow below UMD irr [L/s]	0
Env Residual Flow below UMD noirr [L/s]	0
Env Min Flow at confluence [l/s]	0

Dryland Return Manor: No Dryland Ret

Pool Burn Sub-catchment

	various
Catchment Area above PBD Poolburn [ha]	4400
Catchment Area above PBD Taieri [ha]	1340
Catchment Area Dovedale Willows [ha]	3910
Catchment Area above GH Race [ha]	21240
Catchment Area above Main BZ Take [ha]	13110
Catchment Area above Lower Flow Site [ha]	52860
Irr Area GH Race Main Take Flood [ha]	1420
Irr Area GH Race Main Take Spray [ha]	220
Irr Area GH Race Re-take Flood [ha]	0
Irr Area GH Race Re-take Spray [ha]	290
Irr Area Bonanza Race Re-take Flood [ha]	0
Irr Area Bonanza Race Re-take Spray [ha]	600
Irr Area Poolburn Creek main take Flood [ha]	0
Irr Area Poolburn Creek main take Spray [ha]	950
Irr Area Poolburn Creek Re-take Flood [ha]	0
Irr Area Poolburn Creek Re-take Spray [ha]	200
Env Residual Flow below PDam irr [L/s]	0
Env Residual Flow below PDam non irr [L/s]	0
Env Residual Flow below Poo takes [l/s]	0
Env Min Flow at Poo confluence [l/s]	0

Dryland Return Pool Burn: No Dryland Ret

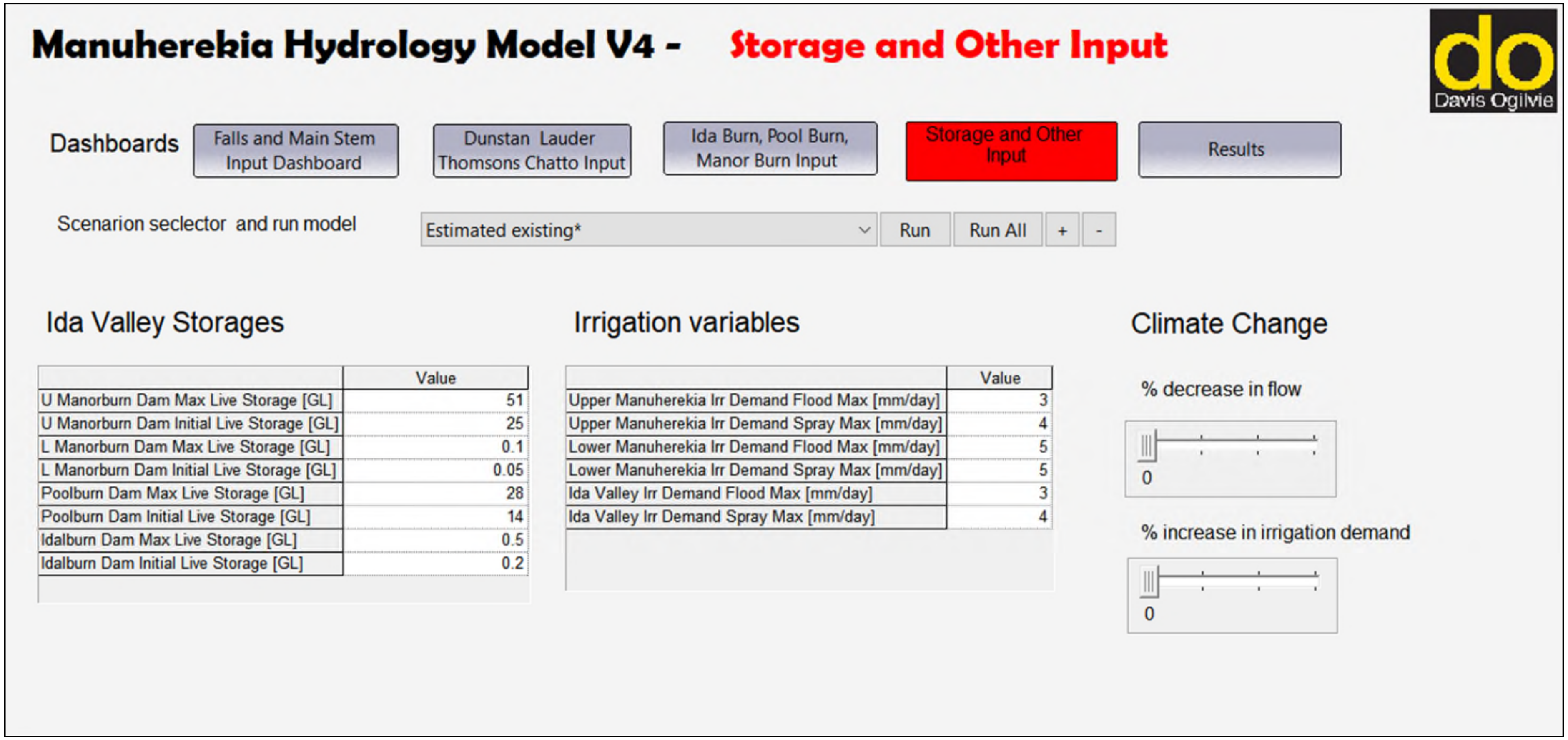
Ida Burn Sub-catchment

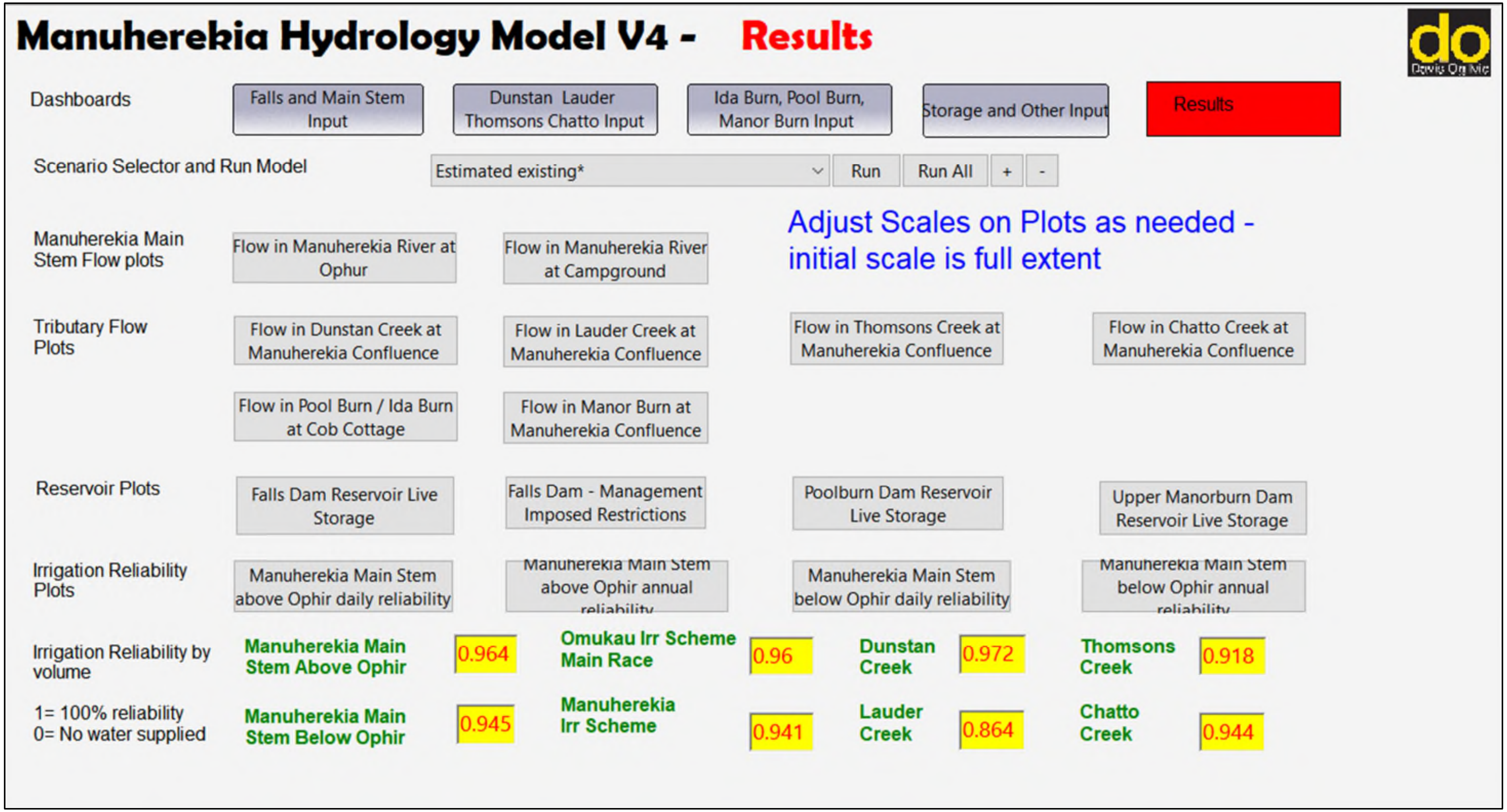
	various
Catchment Area Ida Burn above Race [ha]	1510
Catchment Area above Mt Ida Race [ha]	7570
Catchment Area Mt Ida Race to Ida Dam [ha]	10210
Catchment Area Ida Dam to Cob Cot [ha]	11640
Mt Ida Race used in Ida Burn	0.3
Irr Area Ida Upper Take Flood [ha]	390
Irr Area Ida Upper Take Spray [ha]	600
Irr Area Ida Lower MT Flood [ha]	130
Irr Area Ida Lower MT Spray [ha]	500
Irr Area Ida Lower RT Flood [ha]	0
Irr Area Ida Lower RT Spray [ha]	150
Env Residual Flow below Ida Dam irr [L/s]	0
Env Residual Flow below Ida Dam non irr [L/s]	0
Env Residual Flow below Ida takes [l/s]	0
Env Min Flow at Cob Cottage [l/s]	0

Mt Ida Race restricted 1 = current situation 0 = no take: 1

Dryland Return Ida Burn above Dam: No Dryland Ret

Dryland Return Ida Burn below Dam: No Dryland Ret


Manuherekia Hydrology Model V4 - Storage and Other Input
Davis Ogilvie
Dashboards
Falls and Main Stem Input Dashboard
Dunstan Lauder Thomsons Chatto Input
Ida Burn, Pool Burn, Manor Burn Input
Storage and Other Input
Results
Scenarion seclector and run model
Estimated existing*
Run
Run All
+
-
Ida Valley Storages
Value
U Manorburn Dam Max Live Storage [GL] 51
U Manorburn Dam Initial Live Storage [GL] 25
L Manorburn Dam Max Live Storage [GL] 0.1
L Manorburn Dam Initial Live Storage [GL] 0.05
Poolburn Dam Max Live Storage [GL] 28
Poolburn Dam Initial Live Storage [GL] 14
Idalburn Dam Max Live Storage [GL] 0.5
Idalburn Dam Initial Live Storage [GL] 0.2
Irrigation variables
Value
Upper Manuherekia Irr Demand Flood Max [mm/day] 3
Upper Manuherekia Irr Demand Spray Max [mm/day] 4
Lower Manuherekia Irr Demand Flood Max [mm/day] 5
Lower Manuherekia Irr Demand Spray Max [mm/day] 5
Ida Valley Irr Demand Flood Max [mm/day] 3
Ida Valley Irr Demand Spray Max [mm/day] 4
Climate Change
% decrease in flow
0
% increase in irrigation demand
0


Manuherekia Hydrology Model V4 - Results
Dashboards
Falls and Main Stem Input
Dunstan Lauder Thomsons Chatto Input
Ida Burn, Pool Burn, Manor Burn Input
Storage and Other Input
Results
Scenario Selector and Run Model
Estimated existing*
Run
Run All
+
-
Adjust Scales on Plots as needed - initial scale is full extent
Manuherekia Main Stem Flow plots
Flow in Manuherekia River at Ophur
Flow in Manuherekia River at Campground
Tributary Flow Plots
Flow in Dunstan Creek at Manuherekia Confluence
Flow in Lauder Creek at Manuherekia Confluence
Flow in Thomsons Creek at Manuherekia Confluence
Flow in Chatto Creek at Manuherekia Confluence
Flow in Pool Burn / Ida Burn at Cob Cottage
Flow in Manor Burn at Manuherekia Confluence
Reservoir Plots
Falls Dam Reservoir Live Storage
Falls Dam - Management Imposed Restrictions
Poolburn Dam Reservoir Live Storage
Upper Manorburn Dam Reservoir Live Storage
Irrigation Reliability Plots
Manuherekia Main Stem above Ophir daily reliability
Manuherekia Main Stem above Ophir annual reliability
Manuherekia Main Stem below Ophir daily reliability
Manuherekia Main Stem below Ophir annual reliability
Irrigation Reliability by volume
1= 100% reliability
0= No water supplied
Manuherekia Main Stem Above Ophir
0.964
Omukau Irr Scheme Main Race
0.96
Dunstan Creek
0.972
Thomsons Creek
0.918
Manuherekia Main Stem Below Ophir
0.945
Manuherekia Irr Scheme
0.941
Lauder Creek
0.864
Chatto Creek
0.944

Assigned Data Values for each Scenario:

Element ID	Full Dam No Irrigation	Estimated existing	900 L/s Campground Min	1100 L/s Campground Min	1200 L/s Campground Min	1500 L/s Campground Min	1700 L/s Campground Min	2000 L/s Campground Min	2500 L/s Campground Min	3000 L/s Campground Mi
Action:	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results	Delete Results
Campground_min_flow_irr	0 l/s	400 l/s	900 l/s	1100 l/s	1200 l/s	1500 l/s	1700 l/s	2000 l/s	2500 l/s	3000 l/s
Campground_min_flow_non_irr	0 l/s	400 l/s	900 l/s	1100 l/s	1200 l/s	1500 l/s	1700 l/s	2000 l/s	2500 l/s	3000 l/s
Falls_inflow_option	1	1	1	1	1	1	1	1	1	1
Falls_Dam_outflow_options	0	1	1	1	1	1	1	1	1	1
Above_Falls_Flow_Factor	1	1	1	1	1	1	1	1	1	1
Irr_Restrictions_options	1	1	1	1	1	1	1	1	1	1
Irr_Restrictions_Mainstem_YN	0	1	1	1	1	1	1	1	1	1
Irr_Restrictions_Tribs_YN	0	1	1	1	1	1	1	1	1	1
Dun_Residual_below_maintake	0 l/s	30 l/s	30 l/s	30 l/s	30 l/s	30 l/s	30 l/s	30 l/s	30 l/s	30 l/s
Dun_Confluence_min_flow	0 l/s	0 l/s	0 l/s	370 l/s	410 l/s	510 l/s	580 l/s	680 l/s	850 l/s	1020 l/s
Lau_Residual_below_maintake	0 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s
Lau_Confluence_min_flow	0 l/s	0 l/s	0 l/s	120 l/s	130 l/s	160 l/s	190 l/s	210 l/s	260 l/s	320 l/s
Tho_Residual_below_maintake	0 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s
Tho_Confluence_min_flow	0 l/s	0 l/s	0 l/s	60 l/s	70 l/s	80 l/s	90 l/s	110 l/s	140 l/s	170 l/s
Cha_Residual_below_maintake	0 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s	10 l/s
Cha_Confluence_min_flow	0 l/s	0 l/s	0 l/s	60 l/s	70 l/s	90 l/s	100 l/s	120 l/s	150 l/s	180 l/s
IdB_Residual_below_Takes	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
IdB_Cob_Cot_min_flow	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
Poo_Residual_below_maintake	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
Poo_Confluence_min_flow	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
MaB_Residual_below_Takes	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
MaB_confluence_min_flow	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s	0 l/s
Minimum_flow_below_Falls_irr	0 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s
Minimum_flow_below_Falls_noirr	0 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s	0.5 m3/s
Ophir_min_flow_irr	0 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s
Ophir_min_flow_nonirr	0 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s	820 l/s
Residual_below_Takes_AOphir	0 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s
Residual_below_Takes_BOphir	0 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s	100 l/s
Initial_live_storage_Falls_dam	10 GL	5 GL	5 GL	5 GL	5 GL	5 GL	5 GL	5 GL	5 GL	5 GL
Initial_live_store_UpperMan	51 GL	25 GL	25 GL	25 GL	25 GL	25 GL	25 GL	25 GL	25 GL	25 GL
Initial_live_store_Poolburn	28 GL	14 GL	14 GL	14 GL	14 GL	14 GL	14 GL	14 GL	14 GL	14 GL
Initial_live_store_LowerMan	0.1 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL	0.05 GL
Initial_live_store_IdaBurn	0.5 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL	0.2 GL
UpperManu_unit_demand_floodMax	0 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day
UpperManu_unit_demand_sprayMax	0 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day
LowerManu_unit_demand_floodMax	0 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day
LowerManu_unit_demand_sprayMax	0 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day	5 mm/day
IdaValley_unit_demand_floodMax	0 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day	3 mm/day
IdaValley_unit_demand_sprayMax	0 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day	4 mm/day
Lau_flow_sharing_ratio	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Irr_percent_Lau	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Mt_Ida_Race_percent_open	1	1	1	1	1	1	1	1	1	1