Interim Review of the Manuherekia Hydrological Flow Models v3

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Prepared by:
Sarah Mager, University of Otago
James Griffiths, NIWA

School of Geography, University of Otago
PO Box 56
Dunedin 9054

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

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Note this document is an interim report prepared for tabling at the Technical Advisory Group Meeting and contains expert opinion that may not reflect consensus of all authors, or the final opinions of the review panel.

The document uses the preferred Kai Tahu spelling of Manuherekia.

1 Introduction

The Manuherekia is a highly modified catchment, with flow being captured in multiple artificial storage reservoirs and routed through a myriad of water races and diversions to irrigation schemes. Water engineering has substantially transformed the hydrological network, and as such, it is difficult to identify any long-term records of 'naturalized flow'. The highly engineered system combined with low density of rain gauges and scant records of flow above irrigation schemes makes the determination of a naturalised flow and derivation of low flow statistics highly uncertain. Other models of the Manuherekia were reviewed in 2019, and on balance of evidence and associated uncertainties; it was recommended that the most appropriate model available to understand the effects of irrigation allocation on flow was that of GoldSim (Mager et al., 2019).

It should be noted that the GoldSim model is not designed to derive naturalised mean annual low flow for the specific purpose of regulatory limits; rather, it shows the effect on flow from a reconstructed flow input into the system and then what effects irrigation takes (or not) have on the flow observed downstream. This report makes no specific recommendations as to the appropriateness (or otherwise) of minimum flow thresholds at Ophir or Campground. Rather the model shows the effect of these thresholds on water allocation and reliability of supply for specific scenarios relative to specific low flow thresholds. In this way, the model is effects-based, so that the integrity of the entire catchment flow system can be evaluated for different flow setting criteria.

The objective of this report is to review version 3 of the Manuherekia Catchment Hydrology Model, which uses the GoldSim Player platform. Specifically, this review will consider:

1. Functionality of the model
2. Model Assumptions
3. Use and application of the model by the Otago Regional Council

The review has been undertaken in two stages: a review of model functionality and supporting documentation, and self-directed scenario testing using GoldSim Player.

2 Functionality of Model

2.1 Model overview

The Manuherekia Hydrological Model is platformed through GoldSim (v. 12) and has been newly built using routines from the previous iteration (Mager et al 2019). The model operates on principles of conservation of mass between different storage and routing units through the hydrological system. Version 3 of the Manuherekia Hydrological Model has added new storage components that previously existed but were not explicitly accounted for in the previous version of the model (i.e., storage from Ida Burn and Manor Burn).

Quantification of the volume of water within the Manuherekia river drainage system is based on inflow records (principally Falls Dam) that are used to approximate naturalized flow; water is then redistributed through the network via instantaneous transfers between different nodes. The model allows comparison of a set of scenarios that can be manipulated by the end-user to ascertain the effects of different allocation priorities on observed flow at Ophir and Campground. In this respect, the model is operationally directed to addressing the effects of water allocation, so that the effects of water allocation on other aspects of the hydrological system (e.g., ecosystem indicators or water quality) are not addressed. Updates in version 3 do, however, include an interface that projects the effect of allocation on habitat suitability for 11 species (but the appropriateness of these ecological indices has not been considered within this review).

2.2 Model design

The model has been set-up to allow future changes in model structure to be implemented relatively easily (albeit within the existing structure of the model). Changes to the model structure will require familiarity with GoldSim and its development platform, whereas changes to parameter values (e.g., irrigation type, or area irrigated in particular sub-catchments) can be easily changed using the GoldSimPlayer model interface.

Each sub-catchment within the model has its own set of 'local parameters' (for example: connectivity of channels within the catchment, water sharing arrangements and irrigations parameters). This structure allows changes to be made to each sub-catchment individually. These parameters are straightforward to manipulate and can be used to understand how changes in irrigation consent conditions may affect water availability to downstream locations and how flow varies in relation to minimum flow thresholds.

The GoldSim Player user-interface has been structured to allow comparison of outputs of more than one scenario at a time. This should make it easier for users to assess the main factors influencing water availability within the catchment and explore cumulative effects of changes in water allocation at multiple locations.

2.3 Model Inputs

The model is run using an historic inflow record (June 1973 to May 2020) that is the basis for all manipulations of water use downstream. The system is dominated by inflows into the Falls Dam sub-catchment; with significantly lower inflows from the other storage reservoirs in the catchment. The model is designed to calculate flow in the main stem of the Manuherekia River from Falls Dam to Campground. Six of the main tributaries are also modeled as inputs into the main stem: Chatto, Dunstan, Lauder, Manorburn, Poolburn-Idaburn, and Thompsons.

Catchment/sub-catchment characteristics specified in the model include: catchment size, irrigation area, storage specifications, and flow sharing criteria; all of which can be modified through the GoldSim Player interface. Catchment characteristics are based on assumptions about irrigation efficiency made from prior studies and reports completed for the Manuherekia Water Users Group, the latter is available as supplementary information. A review of the catchment characteristics suggests that they appear fit for purpose for model integrity. There are no 'calibration factors' within the model, rather the model is based on system characteristics and knowledge of likely flow sharing and usage processes.

2.4 Calibration

For calibration, the model is first checked for conservation of mass, both at sub-catchment and at whole catchment scale across whole time period (1973–2020). The model was initially calibrated (in Dec 2020) through visual matching of flow duration curves at the locations of data observation; however, there is no in-built functionality for assessing the statistical fit of flow matching from 'observed' versus 'modelled' outputs. In this regard any assessment of the statistical fit of the model would need to occur outside of the GoldSim environment (i.e., there is no in-built functionality to assess the root mean square, Nash Sutcliffe Efficiency, per cent bias, or other statistical indicators of model fit).

The model was validated against measured downstream flows, operation of Falls Dam, and measured irrigations takes. The model run is 47 years. Investigation into the flow matching suggests that there was some over-estimation of water levels in Falls Dam (see Section 2.3 (Lloyd, 2022)) and some under-estimation of irrigation restrictions. Arguably, variation of some parameters within the model can be used to improve model performance against measured data, but this is predominantly parameters for which there is a high degree of uncertainty (e.g., take magnitude and frequency) rather than physical processes or catchment characteristics. In this regard, the model is functionally suited to variations in existing water allocation, rather than improvements in understanding of physical processes.

Input and calibration data include the following timeseries:

- 6 irrigation timeseries;
- 9 return water timeseries;
- 3 reservoir inflow timeseries and
- 7 flow timeseries.

3 Model Assumptions

3.1 Irrigation calculation

Irrigated areas are a key variable of the model and the supporting information to define the parameters is based on previous investigative work, and information provided by ORC. The calculation of irrigation demand is based on area of irrigation, type of irrigation; location within the catchment (zone); and irrigation demand time series.

The modelled irrigation time series are built on knowledge about the general soil moisture capacity and irrigation demand for spray and flood irrigation. At present the model structure assumes no irrigation during the winter period. Irrigation takes and their effect on water allocation are based on a relatively short time series of data from the period 2008–2009. These data match how much water was available at the take point, to the irrigation demand, as a way of determining how much water was actually taken for irrigation (as opposed to how much was allocated). These data are only from one season, and may not necessarily scale to irrigation and take demand under high water stress conditions and when evaporative stresses may be greater. In this regard, it may be useful to observe the difference between water availability and irrigation demand at key take points during future summer seasons, especially in periods of high water stress to see whether these assumed rates between demand and availability are appropriately scaled.

4 Use and Application

4.1 Model Outputs

The model produces flow time series at pre-defined locations in the catchment. However, the model does not produce statistical summaries of modelled time series compared to measured time series (apart from reliability and flow duration curves). This is partly because the model does not accurately represent flow travel time in the catchment, so that all flows propagate down the catchment at the same rate within each time step. This is in contrast to reality, where larger flows tend to flow more quickly down the catchment. As a result, the use of time increment sensitive statistics would not be a reliable measure of predictive capability of the model for catchment water budget. Similarly, the simplified representation of processes between the main stem and tributaries means that direct comparison of modelled and measured time series within the catchment may not yield good results.

4.2 Evaluation of Flow Performance

Assessment of model performance can be made by viewing how the modelled performed during calibration and validation (as described in Lloyd, 2022). Key points to note from that process at different locations in the catchment include:

- **Manuherikia (@Campground)** – generally a good fit of modelled to observed flows but model underestimates low flows (e.g. 7DMALF under-estimated by c.20%). Slight underestimation of total flow volume was due mainly to underestimation of high peak flows.
- **Manuherikia (@Ophir)** – under-estimation of 7DMALF by c. 15%, and under-estimation of mid-range flows. Slight under-estimate of cumulative volume of flow due to under-estimation of mid-range flows and impact of high flow events.
- **Falls Dam Operation** – water level and releases are generally well represented by the model (compared to observed data) despite the fact that measured data are the result of multiple complex management decisions and is recorded only fortnightly compared to daily model output.
- **Ida Valley Operation** – Pool Burn and Upper Manor Burn storages appear well represented within the model (though limited validation data was available).
- **Total catchment water supply** – modelled takes generally match measured takes where observed data are available. However, there is an underestimate of total measured takes (and winter takes are not modelled). This suggests that modelled water-use is over-estimated to offset the under-estimated takes and preserve the water balance of the model.
- **Tributary flows** – in Dunstan Creek, the model under-estimates extremely low flows (perhaps because irrigation restrictions not well represented by the model). Lauder Creek and Thompson Creek are generally well represented in the model except in extreme low flow conditions when actual restrictions may differ from modelled restrictions. Chatto Creek is less well modelled due to limited measured flow and thus higher uncertainty.

4.3 Modelling effect of Climate Change forcing on Flow Regimes

Climate change effects are calculated using a simple scaling factor tool within the modelling platform; which allows irrigation demand and natural inflows to be either increased or decreased respectively. The model will generate adjusted outputs of flow duration curves and water reliability statistics (in response to the applied changes), but does not account for any seasonal-specific changes that are normally associated with future climate change.

4.4 Initial Outcomes

Model scenarios (as reported by Lloyd, 2022) indicate that:

- Groundwater plays a limited role in influencing flows within the catchment.
- Flow in the main stem (and hence Falls Dam) is sensitive to flows from the tributaries.
- Flow at Campground is dominated by flows from Falls Dam and the six main tributaries.
- Ida Burn, Pool Burn and Manor Burn cover a large area of the catchment, but their flows only become significant during high flow or during flood events.
- Pool Burn and Manor Burn are large and will take multiple years to fill.
- Falls Dam is relatively small and fills quickly but also drains quickly.
- Pool Burn catchment is mainly supplied from stored water whereas downstream run-of-river takes dominate the supply to irrigation.

4.5 Limitations

The Manuherekia Hydrological Model (v.3) has been developed from available measured data and assumes this data to be a true and accurate representation. As a result, the model may be less accurate in areas of the catchment where there is less measured data available.

In the Manuherekia catchment (3075 km^2) there are six rain gauges (Ida Burn; Poolburn; Manuherekia; Alexandra; Lauder; Ophir). This is well below the usual density of rain gauges needed to quantify hyetographic patterns. Generally these rain gauges are not representative of hyposmetric variations across the block mountain-valley systems found in the headwaters of the Manuherikia. Consequently, precipitation is poorly constrained over the area and not used as an independent input into the model. Thus, inputs into the model are *flow-based*, and are not derived from specific rainfall or evaporation measurements (Lloyd, 2022, p. 17). Rather the model assumes that naturalized flow records above takes are representative of the combined effects of rainfall and evaporation. This means that modelled flows in the Manuherekia catchment are based only on historic inflow records. Thus, the model cannot be run in 'real time'. As a result, it should be noted that any allocation decisions based on model output, are based on historic, rather than current conditions.

It follows that 'future' scenarios run using the model (attenuated to represent changed climate conditions) are also based on the historic inflows data set. Changes to seasonality or spatial patterns of precipitation and flows that may emerge from the reorganization of the hydrological cycle with climate change are therefore not represented in such scenarios.

References

Lloyd, I. 2022. Manuherekia Catchment Hydrology Model Report (Draft) for Otago Regional Council,

Mager, S., Henderson, R. Griffiths, J. and Lloyd, I. 2019. Interim Manuherekia Hydrological Flow Models – Review Assessment Prepared for the Otago Regional Council