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MEMORANDUM

To:	Sarah Mager (University of Otago), Roddy Henderson (NIWA) James Griffiths (NIWA)
From:	Ian Lloyd (DO Christchurch)
Date:	15 October 2019
Subject:	Manuherikia Catchment hydrology model comparison – Initial review of the Manuherikia Catchment GoldSim model

The following comments represent my rough initial thoughts on the Manuherikia Catchment GoldSim model in relation to each of the criteria and capabilities indicated by Otago Regional Council (ORC). They are just rough initial thoughts and are designed to provide some background and start discussion.

Criteria for a water reliability model	Current Manuherikia Catchment GoldSim model
i. Ability to output naturalised time series data for multiple sites in catchment.	Can output average daily flow at the following locations: • Falls Dam reservoir inflow (is a developed input time series for the model) • Manuherikia @ below Falls Dam (note can remove dam to estimate naturalised flow or can leave dam and remove irrigation). • Manuherikia @ below the Blackstone intake • Manuherikia @ below the Omakau Main Race intake. • Manuherikia @ Ophir • Manuherikia @ below MIS Main Race intake (assumes no inflow below Ophir). • Manuherikia @ below Galloway intake • Manuherikia @ Campground. • Dunstan Creek @ below the lumped takes • Lauder Creek @ below the lumped takes • Thompsons Creek @ below the lumped takes By removing Dams and irrigations takes the model provides an estimate of natural flow. The model also has inflow time series for yield into the Upper Manorburn/Greenland and Poolburn reservoirs plus flow along Mt Ida Race and flow in the Pool Burn at Cob Cottage. Additional locations (nodes) could be simply added to the model if needed, provided there is sufficient data to support their inclusion.
ii. Ability to alter take rates and volumes and take locations as well as tributary inflows simply and quickly.	Considers both primary (to data has been used to represent the current take) and secondary (increased future take) takes separately for each of the following irrigation areas: • Galloway • Manuherikia Irrigation Scheme (Main Race area) • Blackstone • Omakau Irrigation Scheme (Main Race) • Dunstan (lumps area between Dunstan and Lauder creeks i.e. true right of Dunstan Creek) • Lauder ((lumps area between Lauder and Thomsons creeks i.e. true right of Lauder Creek) • Thomsons (lumps area on true right of Thomsons Creek and includes Matakanui scheme). • Greenfields (new proposed area of irrigation from main stem above Becks) • Downs (lumps area between Dunstan Creek and Manuherikia main stem i.e. true left of Dunstan Creek). • Ida Burn (essentially Ida Burn part of Hawkdun Idaburn scheme) – considers split between flood and spray and supply via Mt Ida Race. • Ida Valley (namely Ida Valley Scheme) – considers split between flood and spray. The above takes are based on irrigation modelling of spray irrigation and three daily demand series (Above Ophir, Below Ophir and Ida Valley) were developed. Take amount is altered by changing irrigated area. Take location is fairly set within the architecture of the model although the current model includes two proposed water races (Manuherikia High Race and Ida Valley Race) which allow redistribution of water and differing supply for various takes which could be used to represent moving take locations. Note model does not include individual take data or locations but rather lumps takes into the areas outlined above. The model input time series (namely unit irrigation demand and tributary inflow) data can be easily changed within the model but requires knowledge of the model and the GoldSim programme. Scenario runs (i.e. changed irrigation take (area), minimum flows, storage size, climate change variables (namely decrease in flow and/or increase in irrigation demand), Falls Dam outlet configuration and active management of Falls Dam (imposition of restrictions)) can be simply changed within the Player version of the model and used to run scenarios.

iii. Identify and recognise data uncertainties and confidence intervals associated with hydrological data ecological data, reliability of supply, economic and dam filling analysis.	Current model does not include extensive calculations of uncertainties – rather it produces time series output which accurately replicates Aqualincs earlier hydrology work. Note Aqualinc indicated that they expected "*individual tributary flow estimates to be accurate to within ±15%"*. Aqualincs work focused on producing time series output, which are compared with measured data to assess the overall predictive accuracy of the model. Hydrographs and flow exceedance curves of average daily flow were visually compared for specific periods together with the following average daily flow statistics: mean, median, 7D MALF, FRE3 and average monthly flow. Comparison of modelled versus measured flow were undertaken at both Ophir and Campground. As the GoldSim model only considers the main stem and the three main tributaries its biggest limitation and source of uncertainty is in relation to the assumptions made in relation to the other tributaries particularly Chatto Creek, Manor Burn and the details of both the Ida Burn and Pool Burn systems. GoldSim has the ability to undertake statistics on the output if required; similarly there is ability to run Monte Carlo simulations if required. Confidence intervals could be assessed though scenario runs if required. Documentation of both the GoldSim and earlier Aqualinc hydrological models includes discussion on the input data, its accuracy and overall limitations of the model and its predictions. The overall concept of the model is to use historic data to assess the implications of future changes. Through using a long times series (1 June 1973 to 1 June 2017) the model attempts to reduce uncertainty.
iv. Consider the effects of minimum flow and allocation scenarios on main stem and tributaries spatially and temporally.	The model contains the following minimum flow sites: • Manuherikia immediately below Falls Dam • Dunstan Creek below the lumped irrigation take for the Dunstan area • Lauder Creek below the lumped irrigation take for the Lauder area • Thomsons Creek below the lumped irrigation take for the Thomsons area. • Manuherikia @ Ophir • Manuherikia @ Campground. The three minimum flow sites on the Manuherikia have the ability to set separate minimum flows for during the irrigation season and during the off season. Allocation is assessed via the irrigation takes. The Model contains allocators which set priority between minimum flows and abstraction and multiple levels of propriety can be applied. The current allocator which assigns flow and storage from Falls Reservoir has 8 levels of priority. The Model can be run for whatever time period is required between 1 June 1973 to 1 June 2017 although to date the Model has generally been run for the whole period and then specific years considered in detail when interpreting results (i.e. in a 1 in 10 year drought year etc.). The model can output the flow effects of any flow regime at the locations outlined in point i) above and the supply reliability effects for each of the irrigated area outlined in point ii) above. The Model is run for the whole catchment and it is not designed to run for individual sub-catchments. Although model predictions can be assess at each item / node and for each irrigation area as required. GoldSim has the ability to run various scenarios simultaneously and to compare predictions. The most recent Manuherikia Catchment GoldSim model is set up to run 10 scenarios simultaneously and to create overlying comparison plots and statistics.
v. Ability to consider the effect of climate change.	The model includes the following two simple scaling variables which can be used to assess climate change either together or separately: • % change in flows (applies to all input flow series), • % change in irrigation demand (applied to all irrigation takes).
vi. Model scenarios as quickly as possible.	The model runs very quickly on a standard PC. The most recent model is set up to run 10 scenarios simultaneously and to create overlying plots and statistics for the whole time series (i.e. daily from 1 June 1973 to 1 June 2017). Run times for the 10 scenarios are less than 1 minute. Individual model runs take less than 10 seconds.
vii. Scale and effects on connectivity and	The model architecture is based on nodes at specific points. It does not link into ArcGIS or a mapping tool and does not include a spatial gridded component. The current model does not consider what happens between each node point and does not try to mimic actual water movement rather it assumes water moves through the model within each daily time

<table>
<tr><td>longitudinal flow variability.</td><td>step. GoldSim has the ability to include delays and travel times for both information and/or variables (in this case water) if required.</td></tr>
<tr><td>viii. Include actual data over synthetic data as much as possible – extrapolation to longer time series.</td><td>The model is based on the following main input times series:
<table>
<tr><th>Time-series</th><th>Comment</th></tr>
<tr><td>Falls Dam inflow</td><td>Developed by Dave Stewart of Rain Effects for the period 1973-2012 subsequently extended by Davis Ogilvie through to 2017 using the same methodology. Based on a combination of reservoir data and measured flow records. Reservoir in-flows are not directly measured and the time series is derived from calculation including regression analysis for gap filling and consideration of the effects of the Mt Ida Race. Derivation of the time series is documented in a report available from the MCWS group website.
https://www.mcwater.co.nz/ManuherikiaCatchment/files/d8/d8acb8e9-8771-4a42-86b8-d54c31267559.pdf</td></tr>
<tr><td>Ida Valley storages</td><td>Peter Brown of Aqualinc developed daily inflow (yield) time-series for the Poolburn and Upper Manorburn / Greenland reservoirs. It is based on tabulated monthly inflow data records for these two dams and correlation with a daily time series record from a neighbouring flow record. Note due to the time since the model was developed we cannot recall of hand which neighbouring flow record was used and are undertaking further investigations to determine.</td></tr>
<tr><td>Tributary inflows from:
Dunstan @ Gorge
Lauder @ Cattle Yards
Thomsons @ Diversion Weir
Poolburn @ Cob Cottage</td><td>Daily average flow time-series were developed for each of these sites by Peter Brown of Aqualinc, with gap filling using regression relationships and monthly correlations to account for seasonal variations in flow. The first three tributary sites were considered natural (above any takes) whereas the final site (Poolburn @ Cob Cottage) is downstream of extensive irrigation and no attempt was made to assess naturalised flows at Cob Cottage. Initial derivation of the time series is document in a number of reports available from the MCWS group website but mostly in:https://www.mcwater.co.nz/ManuherikiaCatchment/files/6f/6f49e02a-c86b-419c-89c3-fbe7328069c9.pdf .</td></tr>
<tr><td>Irrigation demand and deep drainage/return water.</td><td>Developed through daily irrigation modelling completed by Aqualinc using local climate, soil and irrigation information. Three main unit (i.e. per hectare) demand series are used; Above Ophir, Below Ophir and Ida Valley. Modelled demand was based on spray irrigation and was compared against actual take data. Initial derivation of the time series is document in the Stage 1 (Land) and Stage 2 (hydrology) reports available from the MCWS group website. Use of modelled irrigation demand allows future irrigation changes to be assessed (i.e. wild flood to spray etc.) and particularly return water and the concept of net water use. Note when the initial model was developed back in 2011 and 2012 limited water take data was available.</td></tr>
</table>
Initially the time series were developed for the period 1 June 1973 to 1 June 2013 but were extend to 1 June 2017 in mid to late 2017. The model can be run for all or part of the time series. The overall concept behind the Model is to use historic data to assess the implications of future changes. Note the model could be set up to randomly select hydrological years from the existing data set so as to assess the effects of different year combinations (i.e. two extreme dry years in a row etc.).</td></tr>
<tr><td>ix. How effect on reliability and supply is considered.</td><td>The model outputs daily time series of both irrigation demand and the volume of water that is supplied to each of the 11 irrigation areas outlined in point ii) above. The time series are used to assess how water supply reliability changes with time (both season to season and within a season). The model currently produces both daily plots and season cumulative plots of water demand, water supply and supply reliability for the main irrigated areas and for quick reference a total supply reliability percentage for the period simulated (i.e. volume supplied / volume demanded). Note – with the complicated nature of water supply and the varying water sources and the impacts of minimum flow –supply reliability varies spatially across the catchment and the supply reliability, of areas irrigated from the main stem of the Manuherikia River, is affected by minimum flows applied to both the tributaries and the main stem.</td></tr>
</table>

x. Usefulness for considering changes in lake levels and storage volumes in reservoirs such as Falls Dam, Deemed Permits, and water take renewal process.	The model currently includes 3 storages (Falls, Poolburn and Upper Manorburn / Greenland) and predicts how storage fluctuates with time. Storage parameters; including the size of the live storage, the initial live storage volume and whether or not carry over storage is allowed, can be simply changed and assessed within the player version of the model. For Falls Dam the model includes the stage / storage and stage / reservoir surface area curves, details of the current and proposed outlet configurations, consideration of dead storage and includes typical dam management rules namely the imposition of irrigation restrictions. For Falls Dam the current Model can output time series of stage (depth), live storage, total storage and surface area. The model was developed to principally consider overall catchment water management and particularly storage and Falls Dam, and supply of irrigation water within the main Manuherikia Valley. While it can consider implications at various nodes it was not designed to assess each of the deemed permits individually, rather takes were lumped into areas within the model.
xi. Ability to model effects of various storage scenarios including levels and volumes at different locations (including, but not limited to Falls Dam).	While the current GoldSim model has only three reservoirs (Falls, Poolburn and Upper Manorburn / Greenland) and is principally focused on Falls Dam, the underlying models developed by Aqualinc considered new reservoirs at both Mt Ida and Hopes Creek, both of which could be included relatively simply. Similarly earlier stages of the MCWS group process considered numerous dam sites and storage options, all of which are documented in reports available from the MCWS group website. Note adding new nodes such as a new Reservoir element to the model is simple and is just a matter of defining a storage volume and linking a water source/s, water demand outflow/s (including spills) and priorities. The current GoldSim model includes two proposed water races (Manuherikia High Race and Ida Valley Race) which allow redistribution of water and differing supply for various takes which could be used to supply water to new storages. The current GoldSim model also includes the option for supplying the lower parts of the Manuherikia Valley with water from the Clutha system (i.e. an expansion or similar of the Dairy Creek scheme).

Capability of hydrological model	**Manuherikia Catchment GoldSim model**
i. Presentation – Ability to generate outputs in a manner that is easy to interpret for lay persons	Output from the current model is presented in a series of plots (typically standard time series and cumulative frequency plots) and statistics which have previously been used in numerous reports and public presentations. GoldSim has the ability to present output in a variety of formats (i.e. a wide variety of plot types, tables, statistics, visual sliders etc.) and it is relatively easy to prepare output in whatever format is needed. Similarly model output can be easily exported to Excel or other similar programs.
ii. User-friendliness - Ability to be used by individuals with little or no prior understanding of the "architecture" that underpins then model	GoldSim is relatively easy to use with publically available software. There are two formats of the software: the full proprietary GoldSim model software within which models are constructed and edited; and GoldSim Player which is freely available software which allows models to be inspected, run and outputs manipulated (i.e. output graphs or tables produced or edited) . A player version of the current Manuherikia Catchment GoldSim model is available and can be run by anyone who has the free GoldSim Player Software. Dashboards within the model allow the player version to run numerous scenarios including changing over 50 parameters covering: irrigated areas, minimum flows, storage size and rules, various water supply options and simple climate change variables. The model was built so that others could easily use it to run scenarios with the freely available software; however changes or edits to the model require the full GoldSim software and a more detailed understanding and familiarity of the model and the software.
iii. Durability – Likeliness that the model will continue to be developed or supported by the developer. Likeliness that the model will continue to be operational given future technological advances and upgrades to operating system	GoldSim is publically available software which is readily available and is widely used throughout the world. It was first produced over 25 years ago and has been continually developed ever since. While the model software is periodically upgraded (current version is 12.1) all older models can be opened and run in new versions of the software. There is a global GoldSim helpdesk available to assist with any questions and training. Further details can be found at the GoldSim website https://www.goldsim.com/Web/Home/ . To date the Manuherikia Catchment GoldSim model has

and hardware.	predominantly been developed and edited by myself. While the model is quite large and complicated it would be relatively simple for someone new to pick it up. Minimal training or experience with GoldSim is required to run the Player version of the current Manuherikia Catchment GoldSim Model. Similarly with some explanation and training someone familiar with GoldSim would be able to understand and edit the full model.
iv. Surface – groundwater interaction - Ability to incorporate hydrological connection and interaction between surface water and groundwater (i.e. surface flow loss and groundwater recharges)	During upgrades to the Manuherikia Catchment GoldSim undertaken in late 2017 there was a desire to incorporate groundwater/soil storage to allow better assessment of the sponge effect of flood irrigation and stream base flows. The necessary architecture was included in the updated model. However, to fully implement a groundwater/soil store, recalibration of the model against measured flow data is required. Refer model update report prepared by Davis Ogilvie dated updated September 2018.
v. Residual flow conditions - Ability to simulate the effect of residual flow restrictions on individual takes (requirement to maintain a minimum or "residual" flow immediately below individual points of take.	The current model is focused on maintaining minimum flows at certain locations and typically uses releases from Falls Dam to maintain minimum flows within the main stem of the Manuherikia River. For the three key tributaries (Dunstan, Lauder and Thomsons creeks) takes are lumped together and located above tributary minimum flow points as such the tributary minimum flows act like residual flow restrictions.
vi. Flexibility around the location of take - Ability to simulate the hydrological impacts across the entire main stem of changes to the location of takes.	The GoldSim model architecture is based on nodes at specific points. For each node the model outputs time series data. Currently take points have been lumped together. Additional take point (nodes) could be simply added if needed, provided there is sufficient data to support their inclusion. Note if a new tributary is added, typically new inflow and demand time series (from 1 June 1973 to 1 June 2017) would be required. If only a shorter time series is available then it could still be added to the current Model but the resulting model could only be successfully run for the shorter time period.
vii. Applying multiple minimum flow levels - Ability to simulate the impact of takes which are operating simultaneously but are subject to different minimum flow levels (i.e. takes subject to a primary minimum flow (lowest minimum flow level) and takes subject to supplementary minimum flow (highest minimum flow level)	The current model includes 6 sites where minimum flows can be set. Flow allocators at each point allow water to be prioritised between various uses (i.e. meeting minimum flow, meeting irrigation demand etc.). Currently takes from the three tributaries (Dunstan, Lauder and Thomsons creeks) are only linked to meeting minimum flows within their respective tributaries and are not linked to main stem minimum flows. Along the main stem of the Manuherikia River, water from Falls Dams is released to meet any shortfall in flow at the three main stem minimum flow sites with the following priority: 1 Meet minimum flow below Falls Dam, 2 Meet minimum flow at Ophir, 3 Meet minimum flow at Campground, then meet irrigation demand. It is easy to change the priorities or to link the tributaries to the main stem if required.
viii. Storage – Ability to identify suitable locations for water storage based on (water yield, available inflows).	The current Model is not designed to do this. Initial stages of the MCWS group process considered numerous dam sites and storage options all of which are documented in reports available from the MCWS group website. All the known potential on river dam sites within the catchment have been investigated previously.

Manuherikia Catchment GoldSim Model - advantages and disadvantages.

The list of advantages and disadvantages represent my rough initial thoughts. They are in no particular order and are designed to provide background and start discussion.

Advantages:

1. The Current Manuherikia Catchment GoldSim Model was developed through an extensive period that built up though a thorough review of understanding of the catchment including land, water use, water demand and water availability to eventually get to management options with the model developed to specifically help assess management options.
2. The Current Model has been used extensively through the MCWS group and MRL processes and has been presented at numerous public meetings and considerable parts of the community are familiar with it.
3. The Current Model was designed specifically as a decision support tool allowing various scenarios to be quickly run and assessed and allowed various workshop sessions to be held where potential options could be rapidly compared. The usability of the model is probably best demonstrated.
4. The Current Model is calibrated to the current situation using predominantly measured flow data and is used to assess change relative to the current situation. This method allows calibration to be improved through further measurement of the current flow conditions, plus ongoing verification of the model with the collection of ongoing flow data.
5. The Current Model uses modelled irrigation demand which allows changes in irrigation efficiency (particularly future changes) to be assessed separately.

Disadvantages:

1. Significant data has been collected since the Current Model was developed and the model would benefit from including this recent data. Note the Current Model was developed some time ago and while it can be run using data from 1 June 1973 to 1 June 2017 it was principally calibrated and verified using data up to 2012, and as such it does not include recent data. Similarly the model was last updated in mid 2017 and there has been no development effort spent on the model since then.
2. The Current Model was developed to assess a wide range of water management options (particularly storage and distribution) and while it can be used to assess the current situation and potential future flow regimes it was not designed to specifically do that. Similarly the Current Model contains a number of items and options which are not particularly relevant to the current minimum flow discussions (i.e. a very large new dam at Falls, the proposed Manuherikia High Race and the Ida Valley Race for distributing water from Falls Dam, importing water supply from the Clutha River system etc.). These items make the current Model more complicated than it needs to be.
3. The irrigation demand modelling is based on spray irrigation. While spray is becoming more dominant and will continue to do so, there remains considerable flood irrigation within the catchment and the Current Model would benefit from also including flood irrigation. While the model upgrades undertaken in late 2017 included the basis for consideration of flood irrigation and the associated “sponge” effect, recalibration of the model is required to allow these parts of the model to be fully operational.
4. The Current Model is based on the main stem of the Manuherikia River and the main tributaries of Dunstan, Lauder and Thomsons creeks. Within the Main Manuherikia Valley the Current Model would benefit from inclusion of some of the key other tributaries particularly Chatto Creek and Manor Burn.
5. While the Current Model covers the whole Manuherikia catchment it is focused on the Manuherikia Valley. The Current Model would benefit from further and more detailed consideration of the Ida Valley.
6. The Current Model uses a number of input time series that were developed outside of the current Model. Many of these time series (particularly the irrigation demand and drainage) could be easily recreated within GoldSim from actual measured data, thereby making the model more stand alone.
7. The Current Model is predominantly based on calibrations and verifications undertaken for the underlying models prepared by Aqualinc. I understand that most of those calibrations and verifications were done by fairly informal comparison of hydrographs, flow duration curves and key flow statics. If the model is updated its calibrations should be checked ideally using a more formal and controlled process.

To further aid understanding the model logic diagram for the Current Manuherikia Catchment GoldSim Model is included below.

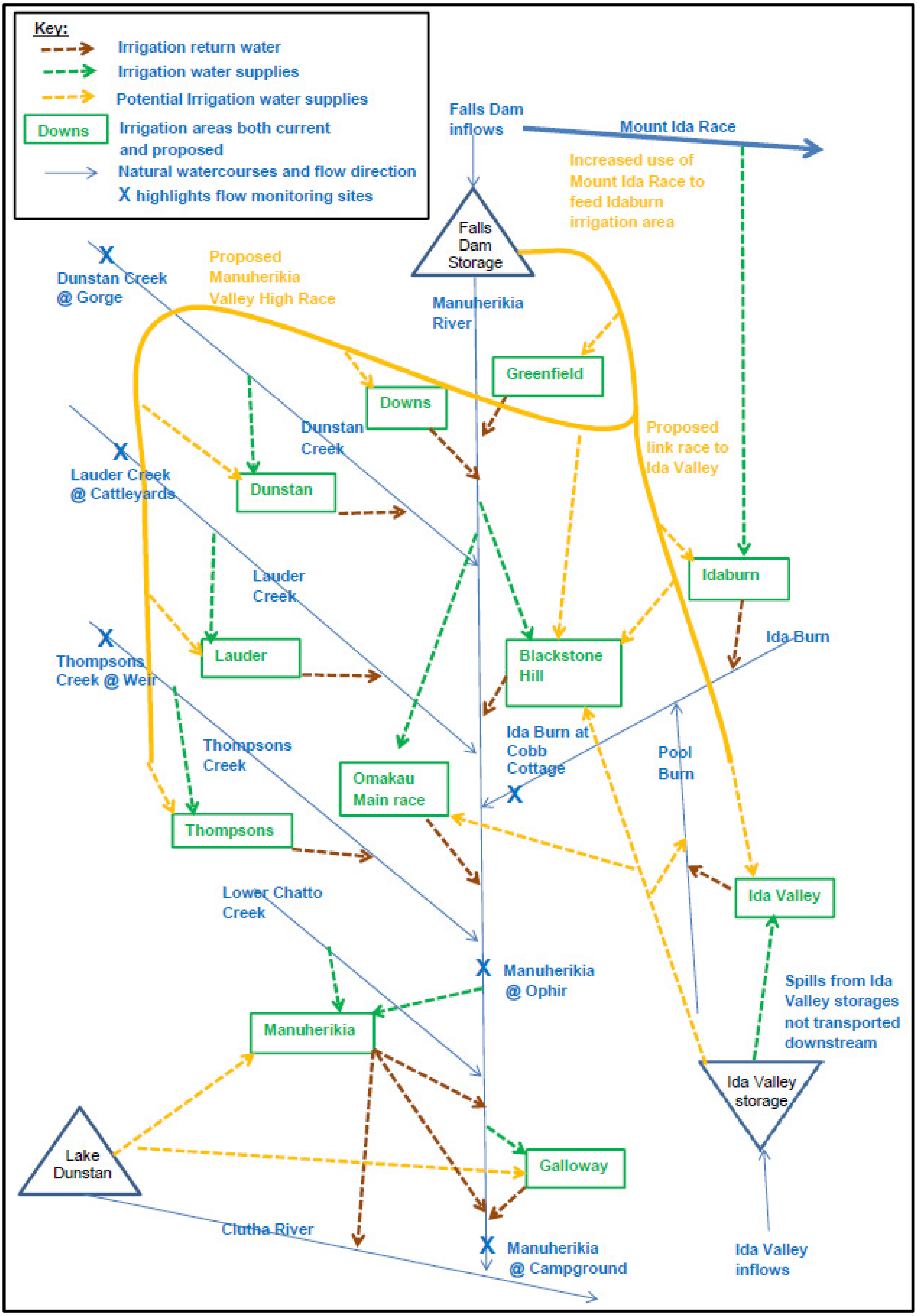

Figure 1: Manuherikia Catchment Hydrology Model (Updated version) - Model logic diagram

(Adapted from Figure 1 in Golder 2016)