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Manuherikia Catchment Water Strategy Group
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MANUHERIKIA HYDROLOGY REVIEW

Dear Kate

1.0 SUMMARY

This letter[1] documents Golder Associates (NZ) Limited's (Golder) peer review of the Manuherikia catchment hydrological investigations and particularly Aqualinc (2013a). Hydrological investigations undertaken during the pre-feasibility investigations have allowed potential irrigation and storage development options to be identified. To identify, optimise and to cost the preferred option and to be ready for resource consent applications requires detailed hydrological information. Aqualinc Research Limited's (Aqualinc) existing hydrological models provide a suitable platform from which to derive the necessary hydrological information. However, Golder considers that a number of refinements to the models, the input data and the associated documentation are required. A list of recommended refinements and next steps are provided in Section 6.0 of this letter.

2.0 INTRODUCTION

The Manuherikia Catchment Water Strategy Group (MCWSG) is currently undertaking a feasibility level study of the Manuherikia River catchment to provide water storage and distribution for irrigation. In October 2013 a group led by Golder Associates (NZ) Limited (Golder) was commissioned to undertake the following four components of the feasibility study:

1) Geotechnical and engineering;
2) Environmental investigations;
3) Land tenure, water allocation, planning and resource management act (RMA) issues; and
4) Economic and commercial investigations, scheme ownership and management models

Aqualinc Research Limited (Aqualinc) who led the earlier pre-feasibility assessments was commissioned to undertake the hydrological component of the feasibility study. During the feasibility hydrological investigation Aqualinc have produced the following two hydrological reports which build on the earlier pre-feasibility hydrological investigations:

[1] This Letter Report is subject to the Report Limitations outlined in Attachment 1.

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1) Report titled: *Manuherikia Valley Hydrology: 2013 update* and numbered C14000/1 prepared by Aqualinc for the MCWSG and dated 17 September 2013. Electronic copy (file name Manuherikia_Hydrology_Update_FINAL.pdf) attached to an email from Kate Scott of BTWSouth to Ian Lloyd of Golder, dated 22 September 2013. This report is referred to as Aqualinc (2013a) in this letter.

2) Report titled: *Mt Ida Dam Hydrology* and numbered C14000/2 prepared by Aqualinc for the MCWSG, dated 17 September 2013. Electronic copy (file name IdaValleyHydrology_FINAL.pdf) attached to an email from Kate Scott of BTWSouth to Ian Lloyd of Golder, dated 22 September 2013. This report is referred to as Aqualinc (2013b) in this letter.

3.0 SCOPE

As part of the feasibility study MCWSG requested that Golder peer review the two hydrology reports outlined above. In order to complete the peer review it was also necessary for Golder to consider the pre-feasibility hydrological investigations. Golder has documented our peer review findings in three letters.

1) Golder (2014a) focuses on the hydrology information associated with the Mt Ida Dam, particularly Aqualinc (2013b).

2) As part of the feasibility study Golder were asked to undertake a high level engineering assessment of the proposed Hopes Creek Dam. Golder (2014b) summarises our findings following an initial preliminary desktop review and completion of a site visit on 29 January 2014. The high level engineering assessment of the proposed Hopes Creek Dam does not extend to a detailed assessment of the hydrological information; however Golder (2014b) does contain some initial consideration of the hydrology. Golder (2014b) was provided to MCWSG for comment on 3 February 2014.

3) The present letter documents Golder's peer review of the hydrological information associated with the wider Manuherikia catchment and particularly the findings of Aqualinc (2013a). Many of the findings included in Golder (2014a and 2014b) are relevant to the wider Manuherikia catchment and have been repeated in this letter.

4.0 METHODOLOGY AND INFORMATION SOURCES

In completing this review and providing our recommendations we undertook the following four steps:

1) Initial review of the relevant background hydrological material, particularly Aqualinc (2013a).

2) Two field visits to the Manuherikia catchment (18 to 22 November 2013 and 27 to 31 January 2014) which included various tours of the irrigation schemes and various discussions with Keith Campbell (the raceman for the Hawkdun Idaburn Irrigation Scheme), Roger Williams (the raceman for the Omakau Irrigation Scheme), John Anderson (Director of Aqua Irrigation Ltd who look after the Hawkdun Idaburn Irrigation Scheme, the Manuherikia Irrigation Scheme and operation of Falls Dam) and Ralph Hore (Chairman of the Blackstone Irrigation Company).

3) A meeting with Peter Brown of Aqualinc on 9 December 2013, to discuss the hydrological investigations.

4) Documentation of the review process and its key findings in this letter.

In completing this review Golder considered numerous documents, a list of which is provided in Attachment 2.

In completing this letter, we have not reviewed the hydrological models that were used by Aqualinc when preparing their reports. This review is principally based on the written documentation and discussions with various parties.

5.0 DISCUSSION POINTS AND KEY OBSERVATIONS

5.1 Scope of Studies

Water storage and irrigation scheme developments rely primarily on hydrological information in that the dam/spillway design, scheme/farm economics and the environmental effects are all strongly influenced by hydrological factors. Consistent hydrological information needs to feed into the other disciplines. Feasibility assessments of irrigation storage reservoirs and irrigation schemes require two key types of hydrological information.

1) A hydrological model is required which simulates operation of the scheme and allows various scheme layouts and management options to be assessed. Usually a water balance model is used which considers both water demand and water supply. These models should cover the reservoir and the irrigation scheme and extend downstream to allow potential downstream flow changes to be assessed. The model will be principally surface water based, but should consider groundwater changes associated with irrigation (i.e., increased recharge and potentially higher groundwater levels and spring flows). The model must allow climate fluctuations to be assessed, and usual practise is to develop a daily water balance model which considers water supply and demand, is based on historic climate and hydrological information that includes a variety of climatic conditions (i.e., wet year, dry years, etc.).

2) Detailed flood information is required for design of spillways and construction diversions. The flood information is also used when undertaking dam break assessments.

Aqualinc have developed a series of hydrological models (including Mt Ida Race and Dam (Aqualinc 2013b), Manuherikia Valley (Aqualinc 2012d and 2013a) and Hopes Creek Dam (Aqualinc 2012e)) and provide estimates of flood flows at the three dam sites (Falls Dam, Mt Ida Dam and Hopes Creek Dam). While Aqualinc (2012f) provides comment on the potential change to downstream flows at six locations along the main stem of the Manuherikia River, little information is provided regarding changes to tributary flows. The hydrological models do not consider groundwater in any detail although an allowance for irrigation return water is made.

This letter is focused on Aqualinc's Manuherikia Valley hydrological model and the flood flow estimates for Falls Dam (i.e. Aqualinc, 2013a). Where appropriate, brief comments are made relating to the Hopes Creek Dam hydrological model and flood flow estimates.

5.2 The Hydrological Model

5.2.1 Time-step and duration

Aqualinc's Mt Ida Race and Dam (Aqualinc 2013b) and Manuherikia Valley (Aqualinc 2012d and 2013a) hydrological models use a daily time-step and cover the 39-year period June 1973 to May 2013, whereas their Hopes Creek Dam (Aqualinc 2012e) hydrological model is based on a monthly time-step and covers the 14-year period January 1951 to May 1965. For reservoir sizing, assessing reservoir operation, and determining potential irrigation supply areas it is necessary to consider both wet and dry periods and it is preferable to use reservoir water balance models that are based on a daily time-step. Monthly models, such as the one used for the proposed Hopes Creek Dam, often do not identify the implications of critical periods of peak water demands.

A key assumption in all models is that future climatic conditions are likely to be similar to historic records. When considering future climate, both climate change and climate variability need to be addressed. The models do not consider climate change and they address climate variability by using long historic records (39 and 14 years). Aqualinc (2012g) discusses the potential implications of climate change and indicates that irrigation demand is likely to increase due to a combination of increased temperatures and lower summer rainfall, and that the occurrence of extreme floods would increase.

Golder recommends that Aqualinc's Manuherikia Valley hydrological model be the basis for the assessment of the storage reservoirs and irrigation schemes within the Manuherikia catchment. However consideration should be given to updating the model to include climate change factors which allow the effect of: increased temperatures, reduced summer rainfall, increased winter rainfall, crop demand, and other related factors to be assessed.

5.2.2 Model extent and downstream flows

Any change to Falls Dam and the associated irrigation schemes (i.e., raising the dam embankment to increase storage, changing the Falls Dam operating rules, and changing irrigation practices etc.) has the potential to alter flow in the Manuherikia River downstream of the dam. The construction and operation of the proposed Mt Ida Dam or any changes to the operation of the Mt Ida Race has the potential to alter flow in the Ida Burn, a number of its tributaries, and the Manuherikia River both upstream and downstream of Falls Dam. The construction and operation of the proposed Hopes Creek Dam has the potential to alter flow in Hopes Creek downstream of the dam, the Manor Burn and the Lower Manuherikia River. The Hopes Creek Dam also has the potential to alter operation of the Upper Manor Burn and Pool Burn reservoirs and would change irrigation practices in the Ida Valley which could potentially influence flows in the Pool Burn and some of its tributaries.

Given that options to increase the size of Falls Dam and construct the proposed Mt Ida and Hopes Creek Dams are currently being assessed, it is considered appropriate that the hydrological model used to assess these options covers the whole of the catchment. This would enable the cumulative impact of a joint scheme involving both the raising of Falls Dam and construction of the Mt Ida Dam and/or Hopes Creek Dam to be assessed.

To assess the effect of any proposed scheme it is necessary to understand any potential changes to downstream flows. In relation to Falls Dam, Aqualinc (2012f) provides comment on potential changes to downstream flow at six locations (downstream of Falls Dam, the Omakau irrigation scheme intake, SH85 Bridge (Downstream of Dunstan Creek Confluence), at the flow recorder site at Ophir, downstream of the Manuherikia Irrigation Scheme intake and at the flow recorder site at the Alexandra Campground) along the main stem of the Manuherikia River. However, little information is provided regarding changes to tributary flows. Understanding potential flow changes is particularly important when considering potential effects on aquatic ecology. The limited flow change information available from the current hydrological models (namely six sites on the main stem of the Manuherikia River) will mean that assessment of potential effects on aquatic ecology will be limited to the main stem of the Manuherikia River and particularly the six sites.

Downstream of Ophir, the Manuherikia Valley hydrological model considers all tributary inflow as one item (Lower Manuherikia tributaries). To allow a more refined assessment of potential changes in flows in the Manuherikia River downstream of Ophir we suggest that the model should be updated to separate inflows from Chatto Creek and from the Manor Burn, from the general Lower Manuherikia tributaries. This would allow potential changes in flow in the Manuherikia River downstream of the Chatto Creek confluence to be assessed.

To allow potential downstream flow changes associated with the proposed Mt Ida Dam to be assessed we suggest that the model should be updated to allow changes in flow to be predicted at the following locations:

i) Ida Burn downstream of proposed Mt Ida Dam,

ii) Ida Burn downstream of Hills Creek Confluence,

iii) Ida Burn upstream of confluence with Pool Burn, and

iv) Ida Burn upstream of confluence with Manuherikia River.

Should the proposed Hopes Creek Dam be progressed to a pre-feasibility assessment the following locations should also be included:

v) Hopes Creek downstream of proposed Hopes Creek Dam,

vi) Manor Burn downstream of Hopes Creek confluence,

vii) Manor Burn upstream of confluence with Manuherikia River, and

viii) Pool Burn upstream of confluence Ida Burn.

5.2.3 Model calibration

Aqualinc (2012d and 2013a) describe the model calibration and validation process that was undertaken for the Manuherikia Valley hydrological model. The model calibration and validation process is based on comparing model projections of flow against measured flow data. Aqualinc (2012d and 2013a) provide flow hydrographs, a flow duration curve and flow statistics comparing measured and modelled flow in the Manuherikia River at both Ophir and Campground. It is unclear from the reports how the parameterisation, calibration and validation process was undertaken and whether it involved a formal automated process or a less formal manual process involving matching curves and 'eye-balling' results. The Manuherikia Valley hydrological model contains a significant number of parameters (including tributary inflows, irrigation takes, irrigation return flows, storage volumes for the reservoirs, and residual flow requirements) and it is expected that the calibrated parameters will not be unique solution and a variety of parameter values could provide similar projected downstream flows. For example, a larger take from the main intake of the Omakau Irrigation Scheme and increased irrigation return water above Ophir, could result in similar projected flows at Ophir as a lower irrigation take and less return water. However the two scenarios would result in a different projected flow in the Manuherikia River between the take point and Ophir, which could have a different potential effect on that stretch of river.

Given the large number of parameters in the model, model calibration and verification should utilise all the available data. The water level in Falls Dam has been measured and recorded since August 1999 (Raineffects 2012) with measurements ongoing. Golder understands that at least four[2] of the irrigation schemes in the catchment (Hawkdun Ida Burn, Omakau, Blackstone and Manuherikia) have installed flow meters and continuous data on actual scheme flows and water use is available. Golder recommends that calibration of the hydrological model be extended to include the water level data that is available for Falls Dam and the water take information that is available from the various irrigation schemes.

5.2.4 Operation of the existing irrigation schemes and modelling of the current situation

In developing additional storage and new irrigation area within the Manuherikia catchment it is anticipated that current operation of the existing scheme will have priority. The water supply reliability that current irrigators experience will need to be maintained or improved prior to consideration of new irrigation. Current operation of the existing schemes needs to be well understood and included in the model. Aqualinc (2013a) states that:

'The model considered the irrigation water use above Ophir in a lumped manner. It did not consider individual irrigation takes or sub-catchment demands. ……

Upper Manuherikia Valley irrigation demand assumed Lauder Flats rainfall and Lauder evapotranspiration. We assumed 50 % of the irrigated area was on light soils, and 50 % was on medium soils. We modelled the equivalent area of full irrigation (Golder understands this is based on 80 % efficient spray irrigation)*, which is the water required to fully irrigate and achieve close to 100 % of the potential production.*

Below Ophir, we assumed a fixed seasonal demand profile for Manuherikia Irrigation Scheme.'

As highlighted in Aqualinc (2012a) the majority (70-80 % by area) of the existing irrigation is via surface flooding (i.e., either borderdykes or contour) and irrigators tend to spread their water thinly over a large area. Aqualinc (2012a) estimates that approximately 25,000 ha are irrigated within the Manuherikia Catchment of which only about 15,000 ha is considered well irrigated.

Golder accepts the data limitations and the reasons why Aqualinc chose to represent the current irrigation as a simplified fully irrigated spray system. However, the simplifications outlined above are a significant departure from what actually occurs. In practice significantly more water is likely to be both extracted from the river and returned (due to by-wash and the inefficiencies of flood irrigation) downstream and a significantly larger area is actually irrigated albeit in some cases marginally irrigated.

For the assessment of the current and proposed irrigation schemes, consistent hydrological information is required. For the economic and environmental investigations, change is the critical element (i.e., how will

[2] Golder has not as yet visited the Ida Valley and Galloway Irrigation schemes, however we expect both will also have water take monitoring.

the area irrigated change, what production increase is expected, what flow changes are anticipated). By simplifying the current situation Golder is concerned that the current hydrological model may not identify the degree of change associated with the development options.

Aqualinc (2012a) provides a description of the various irrigation schemes and estimates actual water use. As outlined above Golder understands that at least four of the irrigation schemes in the catchment have installed flow meters and continuous data on actual scheme flows and water-use is available. This data should be used to create a realistic time series for existing scheme water-use and to check the model projections.

5.2.5 Irrigation demand

Aqualinc (2013a) developed daily irrigation demand time series for the current and future areas that are/will be supplied with irrigation water from Falls Dam and run of river takes from within the Manuherikia catchment. The method used to develop the time series was documented in Aqualinc (2012a) which indicates that irrigation demand was calculated using the AusFarm model coupled with a custom irrigation component developed by Aqualinc. It is unclear from the documentation how the irrigation component developed by Aqualinc works, although Golder understands that it schedules irrigation based on a soil moisture model which considers climatic, crop, soil type, and irrigator characteristics. Golder supports the use of a soil moisture model to estimate irrigation demand; however we have the following concerns regarding the input values that were used.

Climatic data

Aqualinc (2013a) used evapotranspiration data from Lauder EWS (Site 5535) and rainfall data from Lauder Flat (Site 5537) to represent climatic conditions in the potential irrigation supply area above Ophir. For the irrigation areas below Ophir a fixed seasonal irrigation demand profile was used that did not consider annual variations.

The current and future irrigation supply areas above Ophir cover a large area from Omakau at an elevation of approximately 300 m above mean sea level (amsl) up to Cambrians at an elevation of over 500 m amsl. Aqualinc (2012a) indicates that mean annual rainfall for the period 1972-2010 is 510 mm at Lauder Flat and 750 mm at Cambrians. Raineffects (2012) indicates that mean annual temperature and evaporation tend to decrease with elevation. The Otago Regional Council's (ORC) growOTAGO programme produced very detailed estimates of climate throughout Otago. A preliminary inspection of the growOTAGO maps available on the ORC website (http://growotago.orc.govt.nz/) suggests considerable climatic variation over the current and future irrigation supply areas above Ophir.

Aqualinc's use of evapotranspiration data from Lauder EWS (Site 5535) and rainfall data from Lauder Flat (Site 5537) to represent climatic conditions over all the irrigation supply areas above Ophir is likely to underestimate irrigation demand near Omakau and overestimate demand in the higher elevation and rainfall areas such as near Cambrians and Matakanui.

Irrigation use will vary considerably from year to year due to climatic conditions i.e., wet year versus dry year. By using a fixed seasonal irrigation demand profile for irrigation below Ophir, Aqualinc's (2013a) Manuherikia Valley hydrological model is likely to overestimate demand during a wet year and underestimate demand during a dry year.

We recommend that Aqualinc's model be updated to use actual climate data for the estimation of irrigation demand below Ophir and that the climate data used in the model be updated to reflect the local climatic conditions within the potential irrigation supply area as identified by the growOTAGO programme.

Aqualinc (2012a) developed irrigation demand time series for the period 1 June 1972 through 31 May 2011, which were subsequently extended to 31 May 2013 in Aqualinc (2013a and 2013b). Golder notes that evapotranspiration measurements began at Lauder EWS in 1985. Aqualinc (2012a) indicates that the missing records were filled using Aqualinc's climate extension software. This software is not explained and it is unclear how representative the filled climatic records are.

Crop type

Aqualinc (2012a) indicates that 100 % pasture was modelled. From discussions with Peter Brown of Aqualinc it is understood that a crop coefficient of 0.95 % was used and that irrigation was scheduled to maximise grass production. Golder agrees that it is appropriate to model a pasture based system but it is important that water demand estimates are based on expected crop rotations. The crop rotations used by local irrigators are likely to involve regular re-grassing, use of green feed crops, and potentially use of lucerne. Lucerne, due to its deep roots, can access water from lower in the soil profile therefore potentially requires less irrigation water. Such crop rotations are likely to have a lower irrigation demand than a rotation that is based on 100 % pasture. Similarly, it is unclear if the current irrigation demand estimates consider pasture management and the effects of grazing and different levels of canopy cover.

Irrigation demand used in the hydrological model

Aqualinc (2012a) states that *'48 different climate, soil and irrigation system combinations'* were modelled to determine irrigation demand. However, Aqualinc (2013a) indicates that only 2 combinations (Lauder climate, 80 % efficient spray irrigation, on two soil types: 50 % light soil and 50 % medium soil) were used to develop the irrigation demand time series used in the Manuherikia Valley hydrological model. Golder acknowledges that future irrigation demand is dependent on which engineering option is advanced and Aqualinc require information from Golder to model future irrigation demand. However, we are concerned that Aqualinc's modelling of the current situation does not consider local climate, soil and irrigation system information to assess localised irrigation demand requirements.

5.2.6 Potential irrigation supply area and supply reliability

Aqualinc's hydrological models are designed to estimate the potential irrigation supply area and to assess supply reliability. The Manuherikia Valley, Mt Ida Race and Dam and Hopes Creek Dam hydrological models use a fixed reservoir size (operational live storage of 10 Mm^3 in the existing Falls Dam, 14.6 Mm^3 in the proposed Mt Ida Dam and 15 Mm^3 in the proposed Hopes Creek Dam). Aqualinc (2012d) assesses the supply reliability associated with Fall Dams by considering the periods when operational live storage is depleted. While high water supply reliability is preferred, it is usually not economic to design irrigation schemes to achieve 100 % supply reliability and irrigators generally accept some supply restrictions. In order to determine the acceptable level of supply restrictions, potential irrigators require information on the severity of supply restrictions which is a function of:

- Size – The amount of restriction (e.g., no water available versus a 20 % cutback)
- Frequency – How many times a year are restrictions to be expected or in how many years?
- Duration – How long do the restrictions last?
- Timing – When in the season do the restrictions occur?
- Warning – How much notice of upcoming restrictions is given? How predictable are the restrictions?
- The irrigation infrastructure and physical environment (crop type, soil type, etc.)

Aqualinc (2013d) does not discuss potential supply restrictions in any detail. Future hydrological modelling should provide information on the severity of supply restrictions associated with a variety of potential irrigation supply areas.

5.2.7 Falls Dam reservoir losses

The Aqualinc (2013a) Manuherikia Valley hydrological model does not specifically consider leakage from Falls Dam and evaporation from the reservoir surface. To some extent reservoir losses are incorporated in the Falls Dam inflow series developed by Raineffects (2012). Raineffects (2012) provides a thorough description of how the Falls Dam inflow series was developed, the input data used and the accuracy of the derived inflow series. Raineffects (2012) states:

In the current inflow series analysis, the data used (lake levels, downstream flows) already include the losses of seepage and evaporation. The lake level and downstream flow measurements are the results after these evaporation and seepage losses and after the input of rainfall throughout the year. Given the likely errors *involved in all these calculations and estimates, the losses from increased evaporation due to lake area increasing are likely to be small so no adjustment to the series is necessary and any increase to the lake area and therefore evaporation is likely to be offset by rainfall.*

Golder notes that the lake levels and downstream flow data was used to estimate inflow into Falls Dam for the period since August 1999. Prior to this, inflow into Falls Dam was predominantly derived from the flow record for the Manuherikia River at D/S Forks which is upstream of Falls Dam and therefore does not consider reservoir losses.

5.2.8 Development of model input flow data

The Aqualinc (2013a) Manuherikia Valley hydrological model relies on a considerable amount of input flow records most of which are synthetic rather than measured. Synthetic flow records for various sites were developed using a combination of measured data, correlation with neighbouring records, and catchment scaling with consideration of mean catchment rainfall. Golder generally supports the methodologies used; however there is a general lack of description of the quality of the base data, the accuracy of the correlations and the resulting uncertainties in the derived synthetic flow records.

Golder considers it important that when undertaking correlations and developing synthetic flow records, care is required to minimise correlation errors. Correlation against already synthetic records is not good practice and can lead to compounding errors. Standard practice when assessing hydrological data is to undertake the following steps.

1) Collect all available flow information; both continuous records and instantaneous flow gaugings. Note it is unclear if instantaneous flow gauging data has been considered.

2) Review the data, assess its accuracy, and determine the reliable data which can subsequently be used. Usually this involves reviewing the site establishment records, any site visit records, consideration of the accuracy of the water level measurement equipment, reviewing the rating curves particularly any rating changes, and assessing the overall data processing and data management.

3) Sites are then separated into “primary” sites, which have long reliable records, and “secondary” sites which have shorter records often with gaps.

4) Records at a “secondary” site are then extended through correlation with a “primary” site. Relationships with a coefficient of determination (R^2) of at least as high as 0.8 are preferable.

5) Uncertainties associated with both the original data and the correlation process are then assessed to provide an estimate for the overall accuracy of the extended record.

The uncertainties associated with the synthetic flow records used in Aqualinc’s hydrological models are not well documented in the respective reports. That lack of assessment of uncertainties means that it is not possible for Golder to determine the overall accuracy of the model projections.

5.2.9 Model logic and irrigation takes

The model logic for the Manuherikia Valley hydrological model is described in Appendix A of Aqualinc (2013a). The model logic indicates that releases from Falls Dam are triggered due to consideration of the following three items:

1) Minimum flow requirements below Falls Dam,

2) Flow requirement at Ophir which includes consideration of minimum flow and downstream demand requirements, and

3) Shortfalls in demand, where demand is first satisfied by takes from Dunstan Creek, Lauder Creek, Thomsons Creek and other tributaries from Falls Dam to Ophir. While minimum flows are considered for the Dunstan Creek take, it is unclear if other minimum flows are considered. Also there does not seem to be a maximum limit on the size of the takes. In practice the maximum flow that can be taken from these tributaries will be limited by the take infrastructure.

Golder’s interpretation is that the above logic will favour takes from the tributaries over takes from the main stem of the Manuherikia River and potentially flow that is spilt from Falls Dam. Golder agrees that run of river takes should be prioritised over takes from storage, but during periods when Falls Dam is full Golder is concerned that the model logic does not match what actually occurs. By not imposing a maximum rate on the tributaries, the above logic is likely to project that significantly more water is abstracted from these tributaries than actually occurs. Golder accepts that the logic used may be more reflective of the proposed situation under a new high race system but the model must also appropriately reflect the current situation.

5.2.10 Model availability and documentation

The final hydrological report associated with any storage or irrigation development in the Manuherikia catchment will be a key technical document that will support any future consent application through the hearing processes. Both the report and the underlying models are likely to be reviewed for their technical robustness during the consenting process. To facilitate a defensible review the model needs to be in a form which is readily available and model documentation needs to be complete. It is unclear what software the Aqualinc model used and the ease at which the model can be reviewed. The spreadsheet of model scenario outputs provided by Aqualinc simply shows the projections and provides limited guidance on how the values were derived.

Final model documentation should include:

- A full description of the model including how it conceptualises and represents the physical system.
- A description of the input data used, its source and any associated uncertainties.
- All modelling assumptions.
- A discussion of the model limitations and uncertainties.
- A description of calibration and validation methodology and the results achieved.
- A description of the scenarios modelled and various model projections.

5.3 Flood Flow Estimation

Flood flows into Falls Dam (Aqualinc 2012d and 2013a), in the Ida Burn at the proposed Mt Ida Dam site (Aqualinc 2013b) and in Hopes Creek at the proposed Hopes Creek Dam site (Aqualinc 2012e) have been estimated. Flood flows directly influence spillway and construction diversion requirements.

Aqualinc (2012d and 2013a) utilise flood flow information for the Manuherikia River at Ophir and provide indicative estimates for flood flows into Falls Dam during the probable maximum flood (PMF), a 1 in 500 year event and a 1 in 5,000 year event. Golder generally agrees with the methodology used however we note that the indicative nature of the extreme flood flow estimates will result in considerable uncertainty in the spillway design and associated cost estimates. To improve the estimation of flood flows into Falls Dam the installation of automatic rainfall recorders upstream of Falls Dam should be considered.

To estimate flood flows for the proposed Mt Ida and Hopes Creek Dams Aqualinc (2013b and 2012e) used an interpretation of the methodology outlined in McKerchar and Pearson (1989). Aqualinc estimates flood flows at the dam sites using flood flows previously estimated for neighbouring sites (Falls Dam for the Mt Ida Dam and the Manuherikia at Ophir for the Hopes Creek Dam) with an adjustment for the differing catchment areas. The area adjustment used by Aqualinc relies on the variable $Q/A^{0.8}$ (flood flow/catchment area$^{0.8}$) being constant for the dam site and respective neighbouring site. While the dam sites are located relatively near their respective neighbouring sites their catchments have different characteristics (i.e. elevation, topography, aspect, vegetative cover, soil type and rock type etc.) and Golder considers it unlikely that the variable $Q/A^{0.8}$ will be the same for the paired catchments.

McKerchar and Pearson (1989) included three flow sites within the Manuherikia catchment (Site I75251 Manuherikia D/S Forks, Site I75253 Manuherikia at Ophir, and Site I75257 Dunstan Creek at Gorge) in the 343 reference sites they used to develop their methodology. McKerchar and Pearson's original 1989 calculations indicated significant difference between the Manuherikia D/S Forks, Manuherikia at Ophir, and Dunstan Creek at Gorge site, with the variable $Q/A^{0.8}$ for mean annual flood being 0.93, 0.41, and 0.62 respectively at the three sites.

Raineffects (2006) also provided an estimate of flood flows at the proposed Mt Ida Dam site using the methodology outlined in McKerchar and Pearson (1989). Raineffects (2006) used updated flow data from the Manuherikia D/S Forks site to update McKerchar and Pearson's estimate of the variable $Q/A^{0.8}$ (mean flood flow/catchment area$^{0.8}$). Raineffects (2006) then adjusted the variable slightly to account for the expected lower flows in the Ida Burn at the Mt Ida Dam site and followed the McKerchar and Pearson (1989) methodology to estimate flood flows with a return period (1/AEP) of up to 200 years. Raineffects (2006) then extended the methodology to estimate larger return interval floods. Golder discussed the derivation of the flood flow estimates with David Stewart of Raineffects and we support the methodology that was used. Golder recommends that a similar methodology be used for the Hopes Creek Dam. In both cases the calculations should be updated to take into account all relevant flow data and to provide a description of the uncertainties associated with the flood estimates.

6.0 RECOMMENDATIONS

The recommendations outlined are aimed at providing guidance to MCWSG regarding hydrological investigations of potential water storage and irrigation schemes in the Manuherikia catchment. The recommendations are provided in what Golder considers to be a logical progression toward finalising the hydrological investigations. The recommendations, which are not listed in any order of relative importance, are as follows:

1) It is recommended to use the Aqualinc (2012c and 2013a) Manuherikia Valley hydrological model as the basis for the investigations, but update it to ensure that it is based on the best available input data and assumptions. Specifically the following items need to be addressed:

   a) ***Critical for completion of project*** The Mt Ida Race and Dam hydrological model (and potentially the Hopes Creek Dam hydrological model) should be integrated into the Manuherikia Valley hydrological model to allow the cumulative effect of the proposed Mt Ida Dam and the various options to raise Fall Dam (and potentially the proposed Hopes Creek Dam, on downstream flows to be assessed. When integrating the Mt Ida Race and Dam hydrological model the recommendations made in that report (Golder 2014) should also be considered.

   b) The model should be updated to separate inflows from Chatto Creek and the Manor Burn from the 'Lower Manuherikia Tributary' inflows.

   c) ***Critical*** The model should be updated to allow potential downstream flow changes to be assessed at various other locations including the following locations:

      i) Manuherikia River downstream of Chatto Creek Confluence,

      ii) Ida Burn downstream of proposed Mt Ida Dam,

      iii) Ida Burn downstream of Hills Creek Confluence,

      iv) Ida Burn upstream of confluence with Pool Burn, and

      v) Ida Burn upstream of confluence with Manuherikia River.

      Should the proposed Hopes Creek Dam be progressed to a pre-feasibility assessment the following locations should also be included:

      vi) Hopes Creek downstream of proposed Hopes Creek Dam,

      vii) Manor Burn downstream of Hopes Creek confluence,

      viii) Manor Burn upstream of confluence with Manuherikia River, and

      ix) Pool Burn upstream of confluence with Ida Burn.

   d) ***Critical*** Modelled irrigation demand should be based on local climatic conditions and expected crop rotations. The climatic estimates developed through the growOTAGO programme should be used as the basis for determining local climatic conditions. Crop rotations and management practises used by local irrigators should form the basis for estimating potential irrigation demand.

e) The model should be updated to allow various potential irrigation supply areas and the severity of supply restrictions to be assessed.

f) The model should be updated to allow the implications of various residual, minimum and environmental flow regimes to be assessed.

g) In updating the model, consideration should be given to including climate change factors which allows the effect of climate change (increased temperature, reduced summer rainfall, increased winter rainfall, etc.) to be assessed.

h) ***Critical*** Uncertainties in the input data (particularly the synthetic flow records developed to assess reservoir and tributary inflows), modelling process, and the model projections need to be well understood and documented.

i) ***Critical*** Model calibration should be extended to include the water level data that is available for Falls Dam and the water take information that is available from the various irrigation schemes.

2) For flood flow estimates for the Mt Ida and Hopes Creek Dam sites, Golder supports the methodology used in Raineffects (2006) for the Mt Ida Dam. We recommend that a similar methodology be used for Hopes Creek. In both cases the calculations should be updated to take into account all relevant flow data and to provide a description of the uncertainties associated with the flood estimates.

3) ***Critical*** MCWSG should co-ordinate a meeting of the key stakeholders and technical advisors (Aqualinc and Golder) to confirm items 1) and 2) above.

4) Following updating, the Manuherikia hydrological model should be re-run with the projections discussed by the technical advisors (Aqualinc and Golder) prior to being briefly documented. Following this brief documentation of model projections, MCWSG should co-ordinate a second meeting of the key stakeholders and technical advisors to discuss the implications of the model projections and to confirm next steps.

5) ***Critical*** Final model documentation should be to a level that allows external technical peer review of the model and its projections. This documentation should also include:

a) A full description of the model including how it conceptualises and represents the physical system.

b) A description of the input data used and its source.

c) All model assumptions.

d) A discussion of the model limitations and uncertainties.

e) A description of the scenarios modelled and the various model projections.

7.0 CLOSING REMARKS

We trust this letter provides peer review of the Manuherikia catchment hydrological investigations (particularly Aqualinc 2013a) and provides direction in regard to the hydrological assessment for the Manuherikia catchment. If you have any queries or wish to discuss the above please contact Ian Lloyd (illoyd@golder.co.nz or telephone 03 377 5696).

Yours sincerely

GOLDER ASSOCIATES (NZ) LIMITED

Ian Lloyd
Senior Water Resource Engineer

Attachments:
1. Report Limitations
2. References, Documents Considered and Source

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Attachment 2: References, Documents Considered and Source

Aqualinc, 2013a. *Manuherikia Valley Hydrology: 2013 update.* Report numbered C14000/1 prepared for the MCWSG, dated 17 September 2013. Electronic copy (file name Manuherikia_Hydrology_Update_FINAL.pdf) attached to an email from Kate Scott of BTWSouth to Ian Lloyd of Golder, dated 22 September 2013.

Aqualinc, 2013b. *Mt Ida Dam Hydrology.* Report numbered C14000/2 prepared for the MCWSG, dated 17 September 2013. Electronic copy (file name IdaValleyHydrology_FINAL.pdf) attached to an email from Kate Scott of BTWSouth to Ian Lloyd of Golder, dated 22 September 2013.

Aqualinc, 2013c. A spreadsheet titled *Manuherikia Valley model outputs for Golder* which was sent by Kate Scott of BTWSouth to Ian Lloyd via Golder's secure file transfer system on 20 December 2013.

Aqualinc, 2012a. *Manuherikia Catchment Study: Stage 1 (Land).* Report numbered C12040/1 prepared for the MCWSG, dated 12 November 2012. Electronic copy (file name Manuherikia_Stage 1_Land_FINAL.pdf) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012b. *Manuherikia Catchment Study: Stage 2 (Hydrology)*. Report numbered C12040/2 prepared for the MCWSG, dated 22 September 2012. Electronic copy (file name Manuherikia_Stage 2_Hydrology_FINAL.pdf) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012c. *Manuherikia Catchment Study: Stage 3a (High Level Options)*. Report numbered C12040/3 prepared for the MCWSG, dated 25 October 2012. Electronic copy (file name Manuherikia_Stage_3_High_Level_Options.pdf) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012d. *Manuherikia Valley: Detailed Hydrology.* Report numbered C12040/3 prepared for the MCWSG, dated 22 September 2012. Electronic copy (file name Manuherikia_Valley_Hydrology_FINAL.pdf) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012e. *Manor Burn Catchment Detailed Hydrology*. Report numbered C12119/4 prepared for the MCWSG, dated 22 September 2012. Electronic copy (file name ManorBurn_Hydrology_FINAL.pdf) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012f. *Manuherikia Flow Regime and Water Quality impacts.* Report numbered C12119/7 prepared for the MCWSG, dated 6 December 2012. Electronic copy (file name WaterQntQty_Final) available from the MCWSG website, www.mcwater.co.nz.

Aqualinc, 2012g. *Climate change Impact of Climate change on the Manuherikia Irrigation Scheme*, Report numbered C12119/10 prepared for the MCWSG, dated 6 December 2012. Electronic copy (file name Climate_Change_FINAL.pdf) available from the MCWSG website, www.mcwater.co.nz.

Golder, 2014a. *Mt Ida Dam Hydrology Review.* Letter from Golder to the MCWSG, reference number 1378110270-204-L-Rev0 dated 18 March 2014.

Golder, 2014b. *Hopes Creek – Initial Engineering Assessment.* Letter from Golder to the MCWSG, reference number 1378110270-304-LR-RevA-3040-DRAFT, dated 3 March 2014

McKerchar A.I.and Pearson C.P., 1989. *Flood Frequency in New Zealand.* DSIR Publication No. 20 of the Hydrology Centre, Christchurch.

Raineffects, 2006. *Upper Ida Burn Irrigation Dam Feasibility Study Hydrology Report*. Report prepared by David Stewart of Raineffects Limited for David Hamilton and Associates Ltd , dated June 2006. Electronic copy (file name Idaburn.pdf and Title page–Ida Burn Hydrology.pdf) included on a CD supplied by David Hamilton on 21 November 2013.

Raineffects, 2012. *Falls Dam Inflows 1975-2012.* Report prepared by David Stewart of Raineffects Limited for Aqualinc dated July 2012. Attached as Appendix A of Aqualinc (2012d). Electronic copy (file name Manuherikia_Valley_Hydrology_AppdxA.pdf) available from the MCWSG website, www.mcwater.co.nz.