Otago
Regional
Council

MEMORANDUM

To: **ORC Policy Team**
From: **Dave Stewart (Raineffects Ltd)**
Date: **3rd October 2023**
Re: **Lakes Water Accounting**

Name	**Role**	**Date Completed**
Pete Stevenson	Reviewer 1	October 2023
Eve Bruhns	Reviewer 2	October 2023

Purpose

The purpose of this memo is to provide advice to the Policy Team regarding the practicality, benefits, challenges, and methodology for lake water accounting.

Inflows to In-Stream Reservoirs

Inflows to large or small reservoirs can be calculated by strategically measuring or estimating some or all the following parameters, including inflows, outflows, abstractions, rainfall, evaporation and groundwater gains and losses. Alternatively, the inflows can be calculated using hydrological models. Whichever way these are done, there will be margins of error involved which need to be considered and the more theoretical methods that rely on estimates of parameters will have higher errors than those using measured data. There are two parts to this, and they are based on the reservoir size.

Small Reservoirs

It is possible to measure the inflow for small reservoirs on small streams with no other significant inflows, and accuracy will be based on the measurement apparatus used. The only potential errors would be in the inflow and abstraction measurements. Providing these measurements are undertaken by trained technicians using good quality equipment this would give the most accurate inflow measurements possible. Where the reservoir has multiple inflows, then a simple inflow measurement is impossible and water level, lake area, outflow and abstraction measurements would be required. These calculations are likely to have at least 10-15% error which must be allowed for.

Large Reservoirs

Large reservoirs have multiple inflows, making total inflows impossible to measure accurately. It is possible to estimate major inflows into a lake based on a significant inflow that is measured and then correlating that with other larger inflow streams. However, it is not possible to estimate with any accuracy the extra inflow from the smaller streams or creeks and overland flow going directly into the reservoir. Potential errors of 10-20% at least are likely with this method.

For large reservoirs such as Lake Hawea, Lake Dunstan and Falls Dam, the standard method for measuring or estimating inflows is to accurately measure the water level ($^+/-$ 3mm) and the outflows ($^+/-$ 8%). Errors do compound.

Other measurements that can be included in this are precipitation (represents an inflow) and evaporation/evapotranspiration (outflow). However, these measurements are often ignored as they tend to balance each other out in many instances. It is also an added complication in calculations, especially in larger storages like Lake Hawea, where the rainfall inputs and evaporative outputs are difficult to estimate with any accuracy.

This method also requires the lake area at various levels, from the lowest water level to the highest. Lake area is a significant factor in calculating inflows.

Benefits and Challenges

If an inflow and an outflow recorder are installed, they could provide information on changes to the natural waterway regime, an estimate of the actual amount of water impounded or passed downstream compared to that used consumptively, and general information for freshwater accounting. Uncertainty must be acknowledged; however, water use data is important and currently lacking at ORC.

Getting accurate measurements/estimates of the various parameters involved in these calculations is a challenge. Flow measurement has a nationally recognised error of $^+/-$8%, and water level measurement usually has recognised errors of $^+/-$3%. Rainfall is a point estimate only with potential errors due to wind and shelter, to name a few, and evaporation/evapotranspiration is difficult to measure and estimate; the accuracy of the data being evaluated will always have some questions. A simple inflow measurement into a small dam will provide the best and most accurate information, providing there are no other significant inflows.

Rainfall and evaporation are point measurements, but modelling is required to use them to estimate related measurements across areas or times and fill gaps in data. Based on the report prepared for the Ministry for the Environment (Bright J, Daughney C, Jackson B, McDowell R, Smith R, van Uitregt, B, 2022. Future Focused Freshwater Accounting: Report Appendices. Ministry for the Environment, ARL Report RD21011/1. Aqualinc Research Limited) (page 9):

“Interpolation of the measured climate data at the national scale, over a regular (~5 km) grid, is provided by the Virtual Climate Station Network (VCSN) operated by NIWA. The VCSN provides estimates of daily rainfall and other climate variables such as air and vapour pressure, maximum and minimum air temperature, soil temperature, relative humidity, solar radiation, wind speed at each grid point, and data derived from them, such as potential evapotranspiration and soil moisture.” (Page 9). Note the important word “estimates”. Recent experience with this virtual climate Station Network in the Taieri catchment suggested it can be wildly inaccurate in some parts. There are rainfall estimates of 800mm per year from the VCSN in the headwaters of the Taieri when, in fact, they are around 1600mm per year.

Actual evapotranspiration (AET) is also required to estimate losses and to quote from the same report (page 10):

"Wide-scale estimation of AET over bare and vegetated land generally requires measured or modelled soil moisture estimates along with potential evapotranspiration, and a function reducing the fraction of PET that is actually evaporated as soil moisture levels drop below critical points (such approaches are referred to as soil moisture accounting). Most catchment scale flow models take PET along with precipitation as input driving data, and internally calculate and report back estimates of actual evapotranspiration and soil moisture through some form of soil moisture accounting."

Models of some or all these parameters to produce flows have a variety of potential errors, and results are likely to be $^+$/-20% at least and usually higher.

Measuring this data could be a crucial issue given the high cost of installing and maintaining rainfall and water level recorders and the lack of trained technicians, which is already an issue.

A review of the climate stations in Otago (18) showed that while almost all recorded rainfall, none recorded evaporation.

Lake Water Level Recorders

Specialists must install water level recorders in lakes, especially large ones. Accuracy in measuring lake levels is essential as there are challenges in lake level measurement that do not occur in rivers and streams. The essential installation in a lake is a recorder tower that has deeper intakes to avoid as much as possible any surface water effects, such as wind-generated waves affecting the recording.

Unlike rivers and streams, lake surfaces are subject to wind effects that can profoundly impact what is being measured. Wind can create waves that could show rapid rises and falls in the lake level, which are not real.

The other effect is wind setup or seich. A Google quote on what is a 'wind seich effect' is as follows:

"S*eiches are typically caused when strong winds and rapid changes in atmospheric pressure push water from one end of a body of water to the other. When the wind stops, the water rebounds to the other side of the enclosed area. The water then continues to oscillate back and forth for hours or even days".*

The major lakes in Otago (Lakes Wanaka, Wakatipu and Hawea) all have their levels measured by NIWA. Through its various identity changes, NIWA has been undertaking this work over the last 50 years. The key is to use a skilled organisation/operator to at least install the measuring devices, given their experience over many years.

Wave action is the main issue for smaller dams and lakes, but wind seiche may occur under strong winds. The data are often useless if the measuring equipment is not installed correctly. For example, data collected for the Logan Burn storage facility from the 1990's was unusable for calculating an inflow series to the dam because the wave effects showed significant changes daily, up and down. The lack of dampening the wave effects rendered the data useless for calculating storage daily.

There are only two suggestions for potential installers of lake-level recorders – LandPro and Boraman Consultants. NIWA are moving away from water level and flow measurement as much as possible except for servicing the major companies like Contact Energy, Meridian Energy and Genesis Energy, so they are no longer available for such work.

Minimum Requirements for Collecting Discharge Data from Dams

The minimum requirements for collecting discharge data from dams to provide useful data for an inflow series calculation include:

- A water level recorder installed appropriately in the most suitable location, including an appropriate, expertly installed stilling well for the situation, a sensor or other equipment capable of measuring water level to $^{+}$/-3mm, an internal staff gauge in the stilling well, and a datalogger with telemetry to store and transmit the data. These water level recorders serve two purposes. Firstly, they provide ongoing information regarding the accurate level in the lake, but they also give the stage reading for outflow measurements in lakes with uncontrolled outflows. Lakes Wanaka and Wakatipu are good examples of this. Costs for such an installation and ongoing maintenance are currently $12,000 to $16,000, with outflow measurement gaugings an extra cost.
- Highly trained technicians to accurately measure flow immediately downstream of the outlet at a carefully selected, stable gauging site.
- Highly trained technicians to develop and maintain rating curves using the measured flow gaugings and relating them to water level.

Methodology for an Inflow Series Calculation

In a small instream dam with only one inflow source, direct measurement of that inflow is all that is required. Providing that a trained technician installs and maintains a good quality recording system for measuring water level in the inflow immediately upstream of the dam and this same technician derives and maintains a good flow rating for the inflow measurement, no further calculation would be needed.

In a large dam/lake, the inflow series is usually calculated using measured outflows and lake-level changes over a specified period. This is because there are typically many inflow sources (tributaries), and measurement of the main inflow is unlikely to apply to all the other sources. There is also the inflow from overland flow that is not in a stream or river. There is a formula that is commonly used, and that is:

Inflow = outflow + change in storage/time step ($I = O + {}^{\text{change in storage}}/_{\text{selected time step}}$)

Using outflow and change in storage includes all the inflows too numerous to measure.

The measured outflow is self-explanatory, but the change in storage is not. If the outflows are measured, and the lake is rising, inflows are more than outflows, and lake storage increases and vice versa.

There is a water level recorder at the outlet for measured lake levels and outflows in Lakes Wanaka and Wakatipu. The outflow reach is gauged as often as necessary to set up a rating curve with which levels from the water level recorder can be compared, and flows calculated.

The flow through the turbines is usually used for lakes like Dunstan and Roxburgh. The spillways are rated so that the total discharge downstream is available if a spill occurs. However, I note a flow recorder immediately downstream of Roxburgh Hydro operated by NIWA, presumably for Contact Energy.

The lake storage is calculated by measuring the lake area at various levels between low and high, and from that, a level/storage (lake area versus elevation change) rating is calculated.

Water level, outflow and change in storage are the fundamental variables that need to be measured and calculated to simplify the calculation. Rainfall and evaporation are usually not calculated because they are assumed to cancel each other out. Part of the reason for this is the difficulty in providing an accurate average rainfall and average evaporation for the lake area, especially on a short-term basis (e.g., daily). If the calculations are seasonal or annual, estimates can be made of the seasonal or annual rainfalls and actual evaporation. For these large lakes, it is a fact that rainfall usually varies considerably from, say, Glenorchy to Queenstown or from the Makarora River/Lake Wanaka confluence to Wanaka township, as will evaporation/evapotranspiration rates. However, I note that a water accounting system states they are an essential part of the calculations. Including these in the calculations will be challenging, especially if short-term accounts are required.

Daily inflows are probably routinely calculated by NIWA or the consent holder (e.g., Contact Energy) for Lakes Wanaka, Wakatipu and Hawea. Inflows to Lakes Dunstan and Roxburgh will also routinely be calculated by Contact Energy, and inflows into irrigation/electricity storage dams like Falls Dam, Logan Burn Reservoir, Lake Onslow, Upper and Lower Manor Burn Dams, Lake Mahinerangi, Poolburn Dam, and Fraser Dam and other smaller dams operated by an irrigation company will be calculated by the scheme operators at least daily, especially during the irrigation season. It would be better for the ORC to negotiate access to these data rather than try to duplicate the calculations in-house, whether daily, seasonal, or annual values are required. These external organisations should be the organisations that prepare the water accounts for their storage annually or more frequently if required. I suspect they are unlikely to measure evaporation but likely have rain gauges. But there will probably be a NIWA virtual climate network layer for this.

Commentary on the Difficulty of Daily Calculations

In the Aqualinc report titled “Water Management Report. Future Focussed Freshwater Accounting” prepared for the Ministry for the Environment 30/05/2022 Section 4.3 pages 21 and 22 states:

“Section 4.3 Time interval and temporal resolution for freshwater accounting

At minimum, freshwater accounts should be produced annually and cover the period of one hydrological year. This time interval corresponds with the frequency at which regional authorities must report (Clause 3.30 (1) in NPS-FM (2020)) and corresponds with normal freshwater accounting practices overseas such as the AWAS.

We note that it may be necessary to publish (i.e., produce) freshwater accounts at greater than annual frequency for some IOUs, for example if a particular catchment experiences seasonal or sub-seasonal risks of over-allocation. Generating frequent or even near-real-time updates for freshwater accounting is not presently possible with sufficient resolution and accuracy for all parts of New Zealand. However, significant advances are being made for telemetered data collection, automated quality control checking, and rapid assimilation into models, all of which can support the more frequent generation of freshwater accounting information in the future. We note that even where near-real-time updating of freshwater accounting information is possible, it is likely that the reporting period would continue to cover one hydrological year. The temporal resolution of the accounting is different from the reporting interval or period covered by the accounts. For example, accounts covering one hydrological year might be produced annually, but the information contained within the accounts might have a seasonal, monthly, or even weekly temporal resolution.

Freshwater accounting as recommended in this report will likely require a finer temporal resolution than employed in other countries. Overseas, it is common for freshwater accounts to have a yearly temporal resolution, corresponding the same interval at which the accounts are updated. However, New Zealand has smaller and steeper catchments with less storage, and higher average precipitation and contaminant leaching rates than many overseas countries that have implemented standardised freshwater accounting systems. Thus, on average, the fluxes of water and nitrogen (an exemplar contaminant) are higher and catchment residence times are shorter in New Zealand compared to overseas, indicating a need for relatively high temporal resolution (McDowell et al. 2021).

Thus, we recommend that the temporal resolution of the accounts, at least initially, should coincide with common data collection intervals in New Zealand, which are typically at least monthly for water flows and at least quarterly for water quality. As noted above, with automated data collection, telemetry and modelling becoming more common, in the future it will likely be possible to have finer temporal resolution in the accounting statements in the future, corresponding with a suitable frequency for their updates as may be possible with near real-time measurements and modelling."

Where there is significant calculation and models involved, the results can be quite coarse. An example in the Aqualinc report previously detailed on pages 17, 18, and 21, shows that all units are in millions of cubic metres. In the illustrative AWAS report titled "Illustrative Water Accounting Reports for Australian Water Accounting Standard 1", which accompanied the report titled "Illustrative Water Accounting Reports for Australian Water Accounting Standard 1: Preparation and Presentation of General Purpose Water Accounting Reports" 2012, the numbers are in megalitres (millions of litres).

Given the potential errors involved in these water accounts, it is unlikely to be something that can be used for compliance on a day-to-day basis for the larger water users. However, they could be used where the operation is a small single inflow dam with minimal measurement errors, and the only measurements required are the inflow and the abstraction.

For this smaller operator with more than one inflow source, if the simple formula of inflow = outflow plus the change in storage was acceptable, some computer routine could be set up and data provided daily. It would also need to include the abstraction on the day. But even with the smaller operator, this is more complicated than simply measuring inflows and abstractions, so that the results will be less accurate than the simple inflow-abstraction measurement situation. It is unlikely to be feasible if it became more complicated than that and rainfall and actual evaporation were required.

Some of the issues likely with this for the larger dams include:

- Accuracy of the results. As already noted, there are errors associated with this type of calculation. Errors are likely to be greater the shorter the time period used. In a longer period like a year, many errors can cancel each other out, but on a daily basis, errors cancelling each other out is unlikely and the uncertainty must be considered.
- There could be a significant increase in data coming into the ORC, which must be addressed.
- The ORC already has a large database of abstraction data, much of which has a huge question mark over it due to the lack of accuracy and is unusable. If more data is introduced these issues will need to be addressed to make collection useful and the costs justifiable.

- The lack of accuracy will need to be considered to use these data for compliance purposes, and the calculations will be contestable.

Some of the issues likely with this for the smaller dams include:

- The cost increases for the irrigator since either an inflow or lake level/outflow recorder will need to be installed but they would also still need to measure their abstraction to ensure compliance with their consent.
- The requirement for qualified technicians to install and maintain the current abstraction measurement equipment is already a significant issue given the lack of such trained people. If the demand is there, consultancies may begin to fill that gap.
- It may be a complicated calculation since most instream storages in perennial rivers must release a minimum flow when filling. Once filled, they pass all flows downstream, which must be considered.

Irrespective of the storage size, the flow regime downstream of the dam will be changed even when the storage is full, and inflows are passing straight through. A large lake example of this is the two uncontrolled lakes Wanaka and Wakatipu, where very high inflows are often recorded or calculated in the major rivers feeding the lakes, but the subsequent outflow is usually very muted. In a much smaller storage, there is still a flattening of the inflow hydrograph because when the inflow to the storage emerges from the narrow river/stream/creek channel, it spreads out over the area of the dam, and this causes a delay in the water exiting the storage.

To summarise, for smaller single inflow dams, accurate inflow and abstraction measurements will be simple enough to measure and provide daily if required. For larger dams with multiple inflows, accurate level and discharge data are best measured at the dam/reservoir/lake outlet, which comes with inherent inaccuracy (the national standard for flow measurement is still $^{+}$/-8%). Errors will be compounded by the potential inaccuracy of the water level/storage area rating curve.

Consideration of Scale of Reservoir and Onstream Reservoirs

There is no simple answer to whether this approach would be unreasonable or impractical and if this could be applied to all onstream reservoirs. It depends on whether there is more than one significant inflow into the dam, irrespective of the size/capacity of the dam. With a single inflow, it is possible to measure this inflow, and along with a measure of abstraction, day-to-day monitoring by the ORC is possible for compliance purposes, irrespective of the dam's size. When there are multiple inflows, the inflows must be calculated using the formula of Inflow = outflow + change in storage per time step and other parameters if required. As soon as the formula is involved, the potential errors increase, and the use of this system for compliance purposes is compromised.

Day-to-day monitoring of instream dams needs to be dealt with in two scenarios. Firstly, there are the larger dams, most of which are associated with irrigation, hydro generation schemes or water supplies. The organisation that owns and operates these dams will closely monitor them. These storages usually have multiple inflows, so outflows and lake levels will be measured, and the inflows will be calculated using a formula with several different parameters already discussed.

Secondly, where the individual irrigator has dammed a watercourse that may be ephemeral, intermittent, or perennial, but there is only one significant inflow to it. These dams will vary in size, so the reservoir size is less important than the number of significant inflows to it. Where there is only one significant inflow that can be measured, those are the storages that could be monitored daily.

In our telephone discussion on Monday 18 September, I suggested that currently, the accuracy of calculations and measurements is not good enough for day-to-day monitoring to be helpful for the larger on-stream dams. The accuracy is likely to be measured in terms of plus or minus at least $1000m^3$. The results could be easily challenged and if the data are not accurate enough, it could give the ORC the wrong information for day-to-day compliance. The ORC could request this information from the many dams and reservoirs associated with irrigation, hydro generation, and water supply schemes since these storages will likely be closely monitored already, and the data should be available. These scheme operators will be fully aware of their consents and conditions and are less likely to breach them. Maybe a weekly or fortnightly update (water account?) would be useful to the ORC to monitor storage, especially in dry seasons, so that when flows are getting close to the minimum, and the storage is running low, the ORC could be a lot more vigilant. But probably not so useful in seasons when there is plenty of rain, and low flows are not significant.

I would class the larger onstream dams as those with a capacity larger than the permitted activities volume of $20,000m^3$. However, to some extent, it may depend on the reservoir area and catchment area upstream of the reservoir. The bigger the reservoir and catchment area, the more likely there will be more than one significant inflow. I note that the previously referred to Aqualinc report on page 42, discusses how many dams there are with capacities greater than 18,000 m^3. Still, the previous paragraph, noted that "…the influence on water stocks and flows of small on-farm dams will be sufficiently small to ignore." Unfortunately, it doesn't define "small on-farm dams".

This volume ($18,000m^3$) is similar to the permitted activities capacity, so the $20,000m^3$ is probably a good starting point. Note that the capacity of the Idaburn Dam is given as $210,000m^3$ (dam area 8.82ha), the Lower Manor Burn Dam is $230,000m^3$ (dam area 18.24ha), Conroys Dam is $930,000m^3$ (dam area 12.58ha), and the West Eweburn Dam is $1,650,000m^3$ (dam area 25.10ha) in the report titled "Central Otago Irrigation Dams. Contingent Liabilities arising from Return to Crown Ownership" Report No. 562 R2 prepared by MAF Policy April 2000. They are the smallest in terms of capacity in the group of 9 dams considered in this report and all have multiple inflow sources some of which are quite small but would compromise accuracy of any inflow calculations.

The section of the Aqualinc report referred to is quoted here.

"Constructed storage

New Zealand has many thousands of dams, most of which are small water supply dams on farms.

In most catchments the influence on water stocks and flows of small on-farm dams will be sufficiently small to ignore. However, in some catchments the cumulative effect of many small dams will be sufficiently large to warrant the inclusion of stored volume in a stock account, and inflow/outflow fluxes in a flows account.

There are more than 400 dams in New Zealand that have storage capacities greater than 18 million litres. They range in height from two metres to 118 metres (the latter height being New Zealand's largest dam, the Benmore Dam on the Waitaki River). Some of these large dams were built to store water for irrigation, others for power generation, and others for domestic and industrial supply or flood water control, and some serve multiple purposes. They must be included in Freshwater Accounts."

Advice, Benefits and Challenges for Determining Inflows for Small On-stream Reservoirs

If the storage is small and has no other significant inflow sources, then measuring the inflows upstream of the dam inlet is a viable option and probably quite accurate as only one measurement is required.

If there is more than one significant inflow, then the outflow and lake level must be measured, so the formula of Inflow = outflow + change in storage/time step (see page 3 of this memo) must be applied. This formula is associated with significant potential errors, and the coarseness of the result may well render it unusable for day-to-day compliance. Larger dams like those used by irrigation companies will likely have outflows and water level recorded to account for all of the inflows.

There are potential problems in applying the concept of the inflow being the actual consented abstraction from the watercourse. The abstractor will need to comply with that rather than the current system where the abstraction is the amount of water taken out of the watercourse for whatever purpose.

In an ephemeral watercourse, the storage is unlikely to have a minimum/residual flow applied, so all flow reaching the storage is captured unless the storage is full. However, by definition, an ephemeral watercourse flows only after significant rain. If, for example, inflow occurs into storage, say early May, when irrigation has ceased for the season, and there is no further inflow for several weeks, some or all stored water could be lost in the interim through dam leakage, loss to groundwater and evaporation. Come springtime, there is no storage available for irrigation purposes, and potentially, the irrigator has used a significant proportion of their water allowance for no return.

In a watercourse with continuous flow (for example, the Manuherikia upstream of Falls Dam), at the end of the irrigation season, the outflow from the reservoir is reduced to the likely minimum/residual flow already imposed in the consent. This residual is likely to continue until the reservoir is full, and then any water entering it passes through it and becomes the outflow. Once the reservoir is full, the inflow rate compared with the outflow rate will likely differ, especially if the inflow changes significantly daily. While the water is being stored in the reservoir, there will be losses through evaporation, dam leakage, and gains from and loss to groundwater. In addition, there may be significant rainfall adding to the reservoir. The question is how will these losses and gains be measured and counted against the consent's annual allocation?

This same question will likely apply to a much smaller instream storage. Losses will occur similarly, but they are virtually impossible to quantify.

I am unaware of how many small storage dams exist in Otago. If they are all to have inflow recorders installed and maintained, there will be significant initial and ongoing costs for the irrigator.

There is the problem of the lack of suitably qualified technicians/organisations to install and maintain these recorders. Currently, those available technicians are extremely busy and there is a continual backlog of work to maintain the current abstraction data measurement. It could be hoped that consultancies may begin to fill that gap.