Methodology for calculating flow through the River Murray barrages

Department for Environment and Water
August, 2021

DEW Technical Report 2021/04

Government
of South Australia

Department for
Environment and Water

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Preferred way to cite this publication

Department for Environment and Water (2021). *Methodology for calculating flow through the River Murray barrages*, DEW Technical report 2021/04, Government of South Australia, Department for Environment and Water, Adelaide.

Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgements

This study has relied on multiple sources of existing data. In addition to a number of staff from within the Department for Environment and Water, the authors would like to thank those that provided this valuable information:

- Michael Shelton and Garry Fyfe at SA Water for providing details on the different barrage and fishway dimensions and configurations and for reports on gaugings undertaken at the barrages.
- Matt Hardy at the Murray-Darling Basin Authority for the Source model used to undertake the water balance, and his endless patience for answering questions.
- The SILO team for providing the code used to calculate Morton’s Lake evaporation and for a number of conversations on data sources and data quality.
- Ian Teakle from BMT and staff at the Murray-Darling Basin Authority for review and constructive comments on the report and methodology described.

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1 Introduction

Lake Alexandrina at the terminus of the River Murray is separated from the Coorong and Southern Ocean by a series of five barrages (Figure 1). The operation of the barrages is regularly and carefully managed to balance the different objectives for the Coorong, Lower Lakes and connectivity between the fresh and marine systems. With the increasing volumes of environmental water delivered for the ecological objectives of the site and river more broadly, calculation of flow through the barrages is necessary to support management and water accounting.

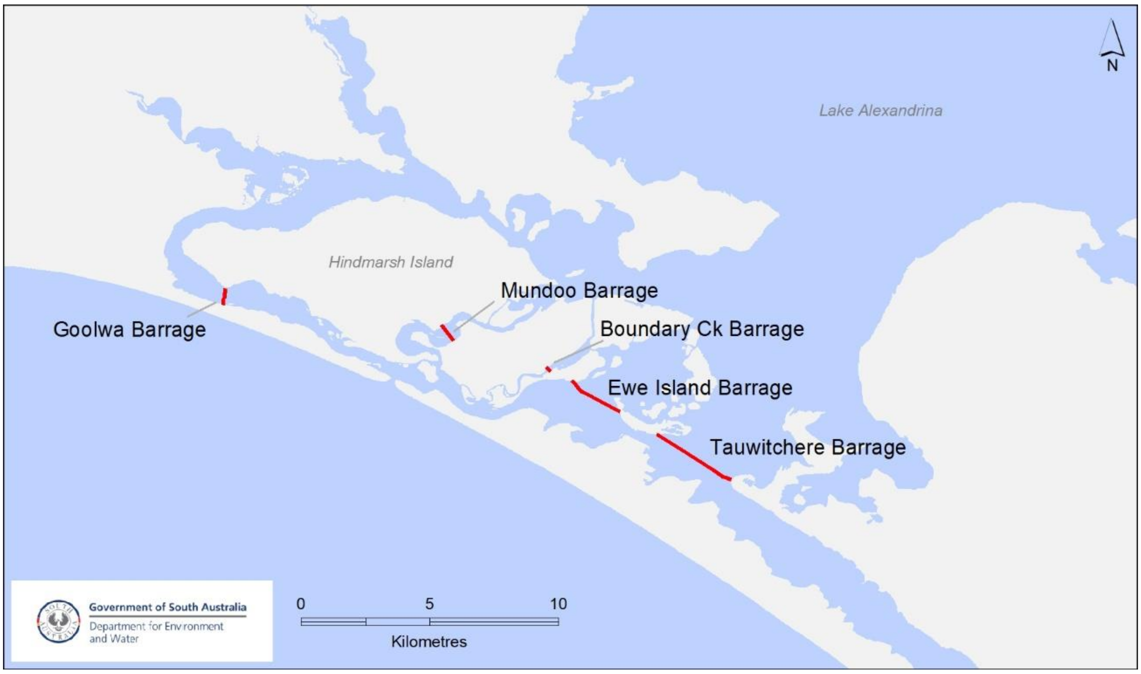


Figure 1 Lower lakes barrages

Weir equations were developed as part of the Coorong, Lower Lakes and Murray Mouth Recovery Project to calculate flow through each of the barrage bays based on their type, dimensions, location, open configurations, as well as the upstream and downstream water level at each barrage on an hourly basis (BMT WBM 2013). These hydraulic calculations were implemented in a macro enabled Excel spreadsheet, and is referred to as the "Barrage Calculator". The Barrage Calculator has been used in barrage operations since its development in 2013. More recently, the weir equations have been implemented in the DEW corporate Aquarius hydrographic database, to provide automated calculation of barrage flow within the database, and to be available on water.data.sa.gov.au.

This report documents the configuration of the barrages in the Barrage Calculator, subsequent calibration of the Calculator to an existing water balance model, and comparison to gauged flows.

2 Equations for calculating barrage flow

Three approaches to calculating barrage flow are utilised in the Barrage Calculator, depending on the gate configuration. These are: the theoretical broad crested weir equation; vertical sluice equations; and lookup tables. Each approach is outlined in detail below.

2.1 Broad crested weir

The broad crested weir equation is used for gates where flow occurs over a structure (i.e. for flow over stop logs, as shown in Figure 2). The theoretical equation relates discharge to head, with an adjustment factor used if the structure becomes submerged (i.e. downstream water level exceeds the sill level of the structure).

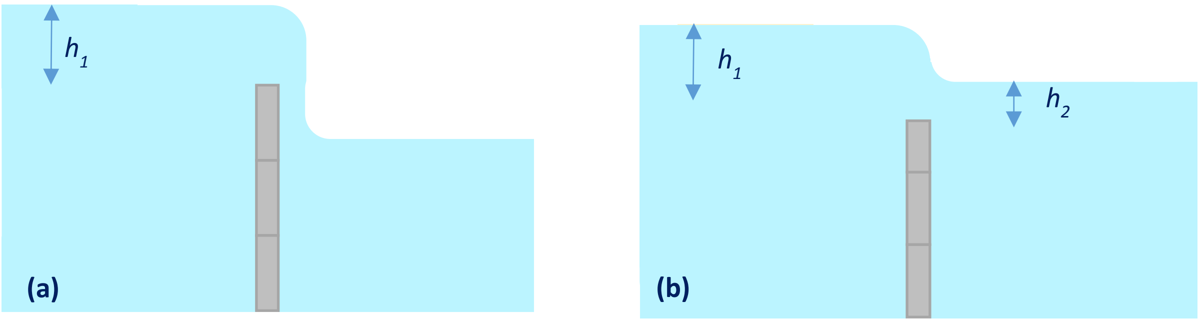


Figure 2 Flow over (a) unsubmerged, (b) submerged broad crested weir

If the flow is not submerged the implemented equation is:

Equation 1 $$Q_m = C_d \times 1.705 \times W \times h_1^{1.5}$$

Where:

$$C_d = discharge\ coefficient$$
$$W = gate\ width\ (m)$$
$$Q_m = discharge\ (cumecs)$$
$$h_1 = upstream\ depth\ over\ sill\ (m)$$

When the structure is submerged, the discharge calculation is reduced by a factor, and the equation becomes:

Equation 2 $$Q_s = Q_m \times \left[1 - \left[\frac{h_2}{h_1}\right]^{1.5}\right]^{0.385}$$

Where:

$$Q_s = submerged\ discharge\ (cumecs)$$
$$h_2 = downstream\ depth\ over\ sill\ (m)$$

The discharge coefficient (C_d) accounts for factors that occur outside the idealised theoretical assumptions, such as centripetal forces, zones of acceleration, viscosity, turbulence and non-uniform velocity distributions. There are some theoretical relationships for the discharge coefficient (Bos, 1989), dependent on the shape and type of structure. Alternatively, the discharge coefficient can be determined through calibration.

2.2 Vertical sluice

The vertical sluice flow function is implemented when flow goes through a structure (i.e. in the case of radial gates). This function has three potential scenarios: underflow, modular flow and non-modular flow, as per Table 1. When underflow conditions occur, the conditions become the same as for a broad crested weir, and the Calculator reverts back to Equation 1.

For modular flow, the following equation is used:

Equation 3 $$Q_m = C_d \times A \times [2 \times g \times (h_1 - 0.61 \times a)]^{0.5}$$

Where:

$$C_d = discharge\ coefficient$$
$$a = gate\ opening\ (m)$$
$$g = gravity = 9.81\ (m/s^2)$$
$$A = flow\ area\ under\ gate = W \times a\ (m^2)$$

Non-modular flow occurs when the downstream depth over sill is greater than the sequent depth (i.e. $h_2 > h_s$). The following equation is used to calculate the sequent depth:

Equation 4 $$h_s = sequent\ depth = \ 0.5\ \times\ h_c \times \left(\sqrt{(1 + 8 \times Fr_c^2)} - 1\right)$$

Where:

$$h_c = contracted\ depth = \ 0.61\ \times\ a$$
$$v = contracted\ velocity = \frac{Q_m}{h_1 W}$$
$$Fr_c = contracted\ Froude\ number = \frac{v}{\sqrt{g h_c}}$$

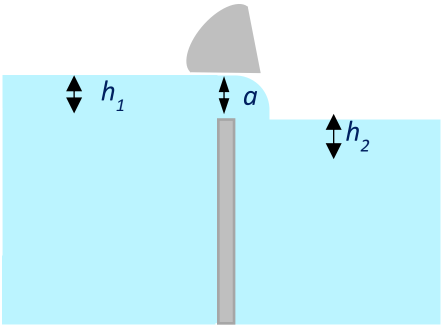
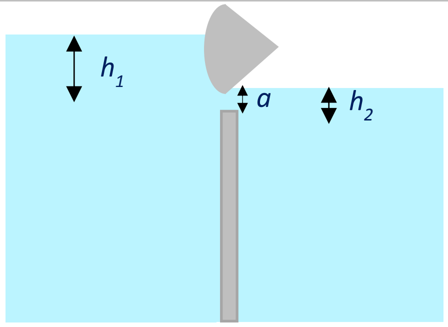
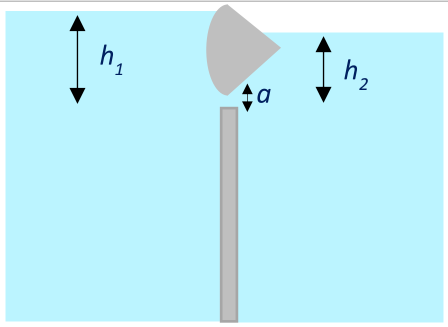
The non-modular flow rate is calculated by the following:

Equation 5 $$Q_s = C_{ds} \times A \times [2 \times g \times (h_1 - h_2)]^{0.5}$$

Where:

$$C_{ds} = submerged\ discharge\ coefficient = \frac{0.61}{\sqrt{\left(1 + \left(\frac{0.61\ x\ a}{h_1}\right)^2\right)}}$$

Table 1 Description and schematic diagrams of sluice flow types

Sluice flow type	Description (as per BMT WBM 2013)	Schematic
Underflow	The gate does not impede the flow of water and therefore flow can be calculated using the broad weir equation.	
Modular	The gate intersects the water surface and the downstream water level is not high enough to restrict the flow.	
Non-modular	The gate intersects the water surface and the downstream water level is high enough to restrict the flow	

2.3 Fishway lookup tables

Flow through the fishways is determined by lookup tables derived from hydraulic calculations based on the fishway geometry and upstream and downstream water levels, as detailed in Jacobs (2020). These calculations and derived lookup tables allow flow through each fishway on each barrage is looked up from the relevant table, based on the upstream and downstream water level. This approach provides flow estimates over a range of water levels (upstream water levels between -0.5 and 0.99 m AHD and downstream water levels between -0.47 and 1.0 m AHD).

3 Barrage structure configuration

Barrage structure details, including type of structure, sill heights for different settings and widths of bays, are required to apply the equations outlined in the previous section. This information is presented in this section and has been compiled from various sources, including:

- Structure drawings and previous reports
- Personal communication with SA Water staff
- Observations from site visits

3.1 Tauwitchere

There are 320 bays across the Tauwitchere barrage, along with four fishways. The configuration of these in the Barrage Calculator is provided in Table 2. The modular height of the radial gates has been set to 0.447 m AHD (500 mm above the sill height) (pers. Comm. Michael Shelton). In operation, these gates are understood to be only fully open or closed, as there can be vibration issues when partially opened.

A single sill height has been adopted for the rock ramp fishway, allowing for the adoption of the Broad Crested Weir equation, despite the triangular shape of this structure as indicated in Figure 3. This approximation has been considered acceptable given the small flow through the fishway.

Table 2 Tauwitchere barrage settings

Opening name	No. Openings	Sill level (m AHD)	Width (m)	Modular height (m AHD)	Calculation Method
Western	130	-0.053	3.886	n/a	Broad crested weir
Eastern	190	-0.053	3.886	0.447	Vertical sluice
Rock ramp fishway	1	0.45	3.886	n/a	Broad crested weir
Small vertical slot fishway	1 (option to select 4 different gate openings)	n/a	n/a	n/a	Lookup table
Large vertical slot fishway	1	n/a	n/a	n/a	Lookup table
Trapezoidal fishway	1	n/a	n/a	n/a	Lookup table

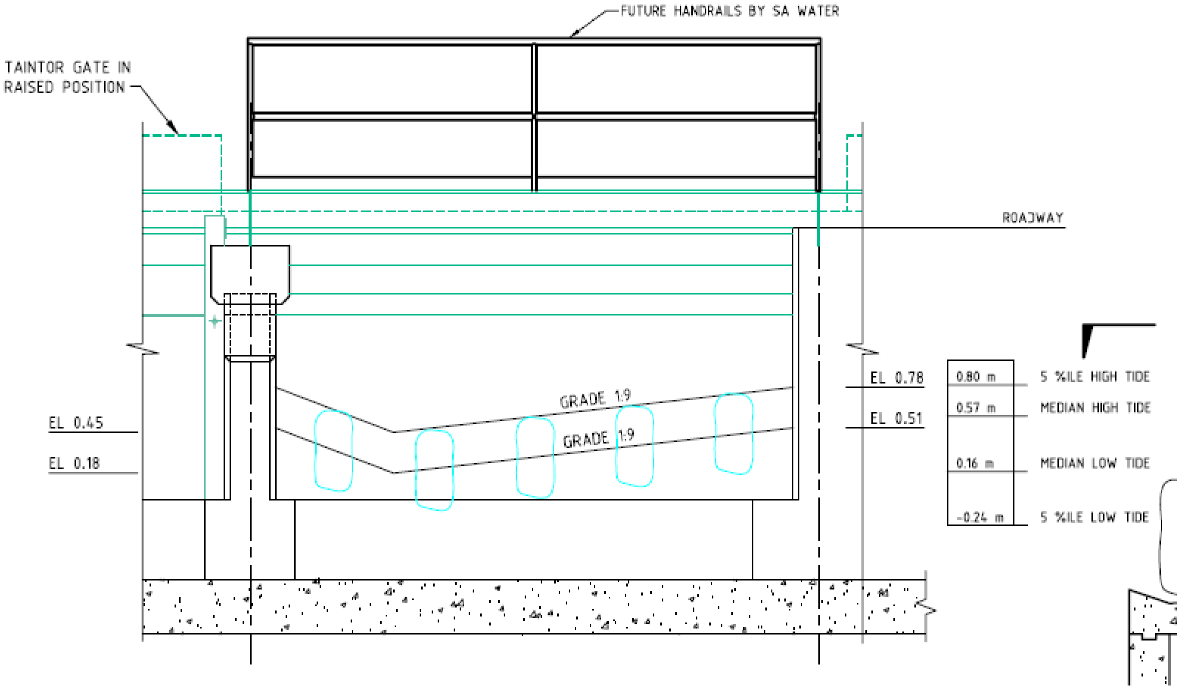


Figure 3 Cross-section of a rock ramp fishway

3.2 Ewe Island

Ewe Island has a total of 110 bays and one dual vertical slot fishway. The configuration of these structures in the Barrage Calculator is provided in Table 3. As with the radial gates at Tauwitchere, the modular height has been set to 0.447 m AHD (500 mm above the sill height) and assumed to operate only fully open or closed.

Table 3 Ewe Island barrage settings

Opening name	No. Openings	Sill level (m AHD)	Width (m)	Modular height (m AHD)	Calculation Method
Western (radial)	1	-0.053	3.886	0.447	Vertical sluice
Western (stop logs)	51	-0.053	3.886	n/a	Broad crested weir
Eastern (radial)	58	-0.053	3.886	0.447	Vertical sluice
Dual vertical slot fishway	1	n/a	n/a	n/a	Lookup table

3.3 Boundary Creek

Boundary Creek has a total of 5 bays, and a single small vertical slot fishway (with three gates). The configuration of these structures in the Barrage Calculator is provided in Table 4.

The sill level of the attractant flow gate is variable, and calculated from the percentage of gate open. The calculation is as follows:

Sill level = open sill level + (1-percentage open * operating range)

Note that the open sill level has been set to 0.452 m AHD, and the operating range to 0.633, based on a closed sill level of 1.085 m AHD, (pers. comm. Michael Shelton, 16 April 2020). By this calculation, the sill level at 50% open (common operation) is 0.7685 m AHD.

Table 4 Boundary Creek barrage settings

Opening name	No. Openings	Sill level (m AHD)	Width (m)	Modular height (m AHD)	Calculation Method
1 log	4	0.5894	3.581	n/a	Broad crested weir
2 logs		-0.325	3.581	n/a	Broad crested weir
Attractant flow	1	variable	3.581	n/a	Broad crested weir
Small vertical slot fishway	1 (option to select 3 different gate openings)	n/a	n/a	n/a	Lookup table

3.4 Mundoo

There are a total of 25 openings across the Mundoo Barrage, in addition to a dual vertical slot fishway and the Hunters Creek small vertical slot fishway. The configuration of these structures in the Barrage Calculator is provided in Table 5.

The western, central and eastern stop log gates are able to have more than one log removed, however this functionality has not been included in the current calculator as this operation is unlikely to be used in practice in other than extremely high flow with every other bay across all barrages open. Hence the current Barrage Calculator has implemented one sill level.

Table 5 Mundoo barrage settings

Opening name	No. Openings	Sill level (m AHD)	Width (m)	Modular height (m AHD)	Calculation Method
Western	2	-0.81	3.581	n/a	Broad crested weir
Central	9	-1.12	3.581	n/a	Broad crested weir
Spindle gates	6	-1.12	3.500	n/a	Broad crested weir
Eastern	8	-0.81	3.581	n/a	Broad crested weir
Dual vertical slot fishway	1	n/a	n/a	n/a	Lookup table
Hunters creek SVS	1	n/a	n/a	n/a	Lookup table

3.5 Goolwa

The Goolwa barrage has a total of 120 gates, three fishways, an automatic gate and five navigable pass bays. The navigable pass bays are excluded from the Barrage Calculator. The configuration of all other bays is provided in Table 6.

Table 6 Goolwa barrage settings

Opening name	No. Openings	Sill level (m AHD)	Width (m)	Modular height (m AHD)	Calculation Method
½ log	119	0.418	3.581	n/a	Broad crested weir
1 log		0.118			
2 logs		-0.492			
3 logs		-1.402			
Automatic gate	1	n/a	n/a	n/a	Equation fitted to CDF modelling
Large slot fishway #1	1	n/a	n/a	n/a	Lookup table
Large slot fishway #2	1	n/a	n/a	n/a	Lookup table
Small slot fishway	1	n/a	n/a	n/a	Lookup table

4 Calibration of calculated flow to a water balance

A monthly water balance is often used to estimate barrage flow. The method is outlined in MDBA (2019):

> *The Source Murray Model (SMM) is used to undertake a hydrological water balance between Lock 1 and the barrages. Each day, the modelled flow at Lock 1 is set to the gauged daily flow record. At the downstream end of the system, the barrage gates regulate the discharge from the Lower Lakes to the Murray mouth. If all gates are closed, then there is no discharge. When the gates are open, the model sets the water level in Lake Alexandrina to the observed value. In the intervening reaches between Lock 1 and the Lower Lakes, a storage-routing procedure calculates the reach inflow, extractions, losses and outflow on a daily basis.*

This water balance approach has been used to estimate the monthly barrage flow to calibrate the total barrage calculated from the weir equations outlined in Section 2 and structure dimensions outlined in Section 3.

4.1 Calculation of the water balance

This work has adopted the same methodology as MDBDA (2019) to provide an estimate of barrage flow to compare to the calculator equations. One change has been implemented, the five site seven day rolling average Lake Alexandrina water level has been used, as calculated by DEW River Operations, and this water level time series has been used as the maximum operating constraint for Lake Alexandrina with barrage flow the spill occurring over this water level, as opposed to applying a gauged water level and calculating barrage flow as the unaccounted volume difference to this water level.

During low flows and the summer months, evaporative loss can be a large component of the Lower Lakes water balance, and as such has a substantial influence on the remainder of the water balance calculated, i.e. the barrage flow. McMahon et al. (2013) recommends Morton's Lake evaporation (Mlake) as the preferred method for lakes (Morton, 1986). The effect of the assumptions in the estimation of the evaporative loss from the lakes on the calculated barrage flow has been further investigated and is presented in Appendix A.

4.1.1 Evaluation of the water balance for periods of barrage closure

Times when the barrages are closed provide useful periods to evaluate the accuracy of the water balance approach. The updated Mlake evaporation rates based on observed solar radiation data have been used to calculate the water balance below Lock 1, to derive an estimate of monthly barrage flow (see Appendix A). This monthly time step used for the water balance will be influenced by short term fluctuations in water level, but are expected to average out at longer time steps. The methodology is based on that outlined in MDBA (2019). The water balance was simulated from 1/7/2015 to 31/3/2020, as this period has reliable observed solar radiation data, and all the necessary information for the barrage gate settings available (i.e. all gates shut, with the exception of fishways).

There are two periods of particular interest over the modelled results, when the barrage gates were shut. The most recent was for 65 days from 17/12/19 to 19/2/20, with only the fishways open. The lookup tables for flow through the fishways that were open were used to derive the barrage flow volume that was occurring over this period as 11.7 GL.

The components of the water balance over this period can be seen in Figure 4, with the only difference being the two different estimates for the evaporative loss. Lock 1 inflow is based on station A4260903, plus the five tributary gauges representing the Eastern Mount Lofty Ranges (EMLR) inflows, which contribute very little flow over summer. Diversions are a combination of SA Water records and estimates from crop demand models (MDBA, 2019). The storage change is based on a change in water level from 0.704 m AHD to 0.591 m AHD over the period, derived from depth – area – volume relationships based on the Digital Elevation model for the Lower Lakes. The resulting barrage flow of 15 GL over the period with closed barrages in close agreement to that derived from the fishway flow lookup tables, of 11.7 GL. While this difference of 3.3 GL is a 28% difference and may seem large, the difference is less than 1% of the total evaporative loss from the system over this period, and well within the accuracy the estimate of this term (see Appendix A).

A similar scenario occurred over the period from 26/11/2015 to 9/2/2016. The same approach was applied and results are presented in Figure 5 for the observed solar radiation data. In this case, the barrage flow resulting from the water balance was 28 GL, higher than that calculated by the fishway lookup tables in the barrage calculator of 13.5 GL. As above, this is expected to be within the accuracy of the input terms, and the barrage calculator fishway look up tables themselves.

The comparison between the water balance and fishway only estimates of barrage flow for periods when it is known the gates were shut provides an indication of the accuracy of the water balance approach. The resulting monthly water balance over the five year period can be seen in Appendix B and has been used to calibrate discharge coefficients for the barrage calculator.

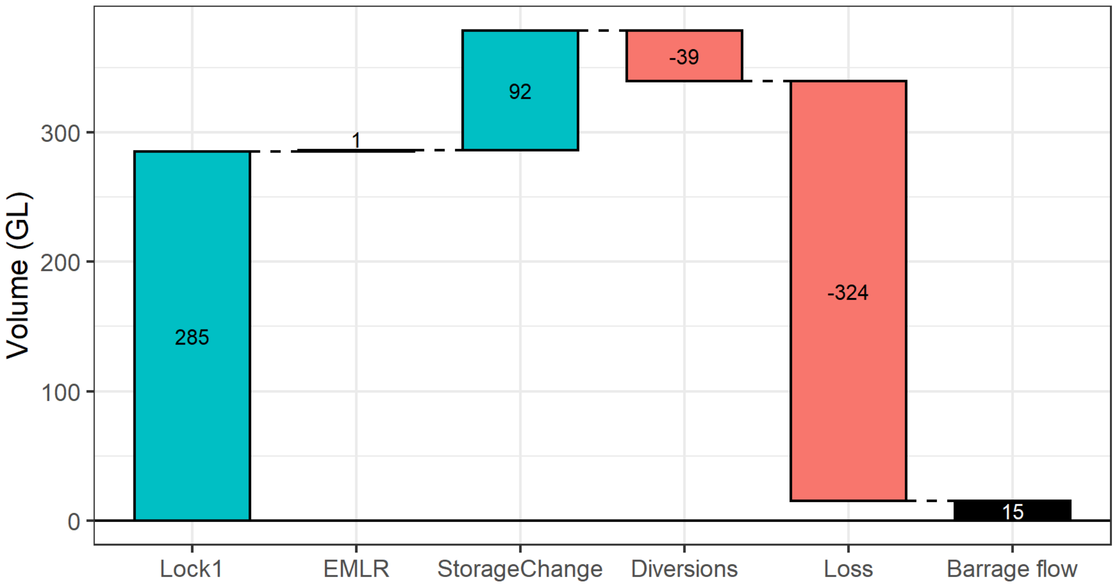


Figure 4 Water balance components for the period with barrages shut (17/12/19-19/02/2020), with the loss derived using observed solar radiation data as input to the Morton's Lake evaporation estimate

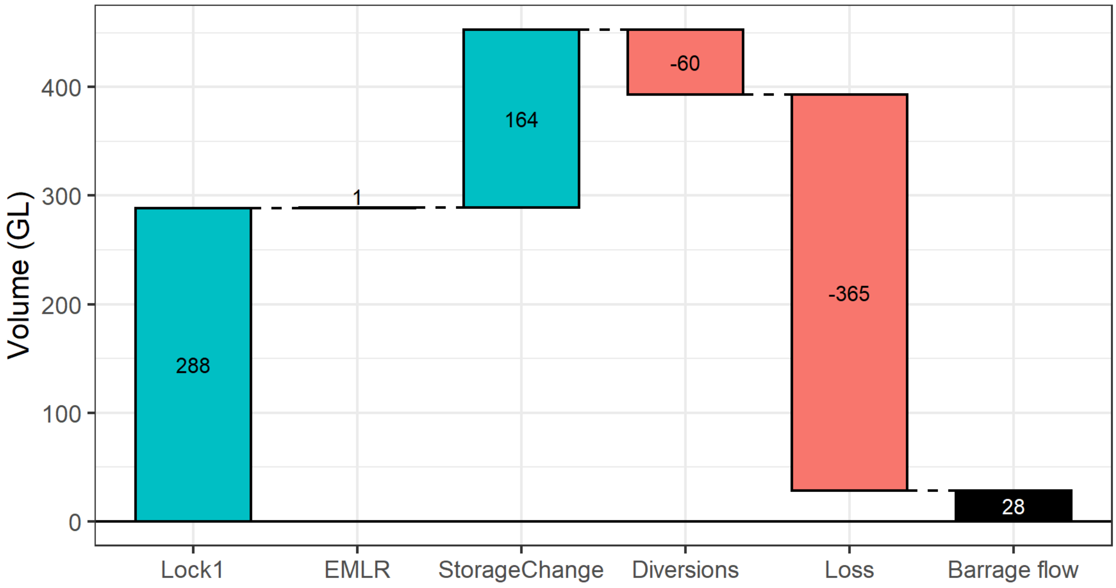


Figure 5 Water balance components for the period with barrages shut (26/11/2015-9/02/2016), with the loss derived using observed solar radiation data as input to the Morton's Lake evaporation estimate

4.2 Methodology to calibrate the barrage calculator

The water balance outlined in the previous section provides a monthly time series of calculated barrage flow to calibrate the barrage calculator to. Four calibration parameters have been introduced:

- $C_{d,weir}$ a discharge coefficient for the broad crested weir structures
- $C_{d,sluice}$ a discharge coefficient for the sluice structures (radial gates)
- *a* and *b*, as parameters to a head dependent seepage term, to account for the flow as seepage through the barrages, even when gates are not open

The hourly seepage flow rate was calculated using a power relationship typically used for rating curves, in the form:

$$Q_s = \sum_{i}^{n=5} \max(0, a(h_{i,1} - h_{i,2})^b)$$

Where *i* is an index representing each of the five barrages, $h_{i,1}$ and $h_{i,2}$ are the upstream and downstream hourly averaged water level at barrage *i*, respectively, and a and b are calibration parameters. If the downstream water level is above the upstream level at a given barrage, no seepage is calculated.

The four parameters ($C_{d,weir}$, $C_{d,sluice}$, a and b) were implemented in the barrage calculator and calibrated to the water balance derived monthly barrage flow volumes using the Solver GRG Non-linear algorithm in Excel, with multiple restarts to reduce the likelihood of identifying local minima, to minimise the objective function:

$$f = \sum_{i} \left(\sqrt{Q_{wb}} - \sqrt{Q_{bc}}\right)^2 + abs\left(\sum_{i} Q_{wb} - \sum_{i} Q_{bc}\right)$$

Where Q_{wb} and Q_{bc} are the monthly barrage flow volume from the water balance and barrage calculator, respectively. The first term in the objective function is the sum of squared errors based on the square root transform of the monthly volumes, and the second term the overall volume bias. The square root transform was adopted to avoid the optimisation biasing the parameter values toward the largest errors, typically occurring for the highest flow months.

The calibration period was February 2017 to March 2019, as during this period there is greater confidence in the hourly barrage flow data, and excludes the 2016 high flow event, which is expected to include flow paths over the islands between barrages, that are not included in the calculator. The period from July 2015 to January 2017 is used as a validation period, to test the parameter values on data not used for calibration.

4.3 Input data review

Barrage gate opening and hourly averaged upstream and downstream water level data for each barrage were reviewed prior to the calibration period. Some inconsistencies in the barrage gate data in 2016 were rectified from original records. Some modifications to the water level data was required on the downstream side of the barrages, including:

- interpolating short term (less than 1 day) gaps with data from the nearest barrage
- infilling missing and low (below 0.06 m AHD) water level readings at Ewe Island with data from Tauwitchere

- replacing poor quality data (as indicated by quality codes) at Boundary Creek in October and November 2018 at with data from Ewe Island
- replacing a period over December 2019 to January 2020 at Goolwa with data from the nearest site at Beacon 17
- replacing data in November 2017 at Tauwitchere and Ewe Island with data from Beacon 1
- replacing data in June 2018 for Ewe Island with data from Tauwitchere.

Less modifications were undertaken upstream of the barrages, however comparison of data across sites identified spurious data at these locations and times:

- Goolwa data was replaced with Hindmarsh Island Bridge data for a period from November 2017 to January 2018
- Tauwitchere replaced with data from Ewe Island in October 2018

DEW extended this review to identify and correct any gaps or erroneous data for the period January 2011 to January 2021. This work was undertaken as part of implementation of the barrage calculator in Aquarius, the South Australian Government's surface water database. Data from adjacent monitoring stations were assessed as suitable for providing proxy values given their relatively close geographic proximity and being subject to similar meteorological conditions. When required, data from these sites were used to patch data gaps or to correct erroneous data to produce continuous, quality lake level and tide height time series (*hourly patched* time series). The primary and secondary datasets that underpin the barrage calculator implemented in Aquarius are presented in Table 7.

Table 7 List of primary lake level and tide height monitoring stations and corresponding reference sites used for data verification

Lake Level	Primary site	Reference site
Goolwa	A4261034 – Lake Alexandrina at Goolwa Barrage	A4261123 – Goolwa Channel at Signal Point
Mundoo	A4261042 – Lake Alexandrina at Mundoo Barrage	A4261045 – Lake Alexandrina at Boundary Creek Barrage
Boundary Creek	A4261045 – Lake Alexandrina at Boundary Creek Barrage	A4261042 – Lake Alexandrina at Mundoo Barrage
Ewe Island	A4261047 – Lake Alexandrina at Ewe Island	A4260527 – Lake Alexandrina at Tauwitchere Barrage
Tauwitchere	A4260527 – Lake Alexandrina at Tauwitchere Barrage	A4261047 – Lake Alexandrina at Ewe Island
Tide / Estuary	**Primary site**	**Reference site**
Goolwa	A4260525 – Goolwa Channel at Goolwa Barrage	A4261036 – Beacon 17 adjacent Reedy Island
Mundoo	A4261041 – Mundoo Channel at Mundoo Barrage	A4261044 – Boundary Creek downstream Boundary Creek channel
Boundary Creek	A4261044 – Boundary Creek downstream Boundary Creek channel	A4261041 – Mundoo Channel at Mundoo Barrage
Ewe Island	A4261046 – Coorong at Ewe Island Barrage	A4261048 – Tauwitchere Channel at Tauwitchere Barrage
Tauwitchere	A4261048 – Tauwitchere Channel at Tauwitchere Barrage	A4261046 – Coorong at Ewe Island Barrage

4.4 Results of water balance calibration

The calibrated parameter values were: $C_{d,weir}$ = 1.33, $C_{d,sluice}$ = 1.76, a = 0.5 and b = 0.116. Given the objective function used with the second bias term, these values resulted in the same volume over the calibration period from the water balance and the barrage calculator. Typically C_d values are less than

1, to represent additional losses compared to the theoretical weir equation. However, C_d values greater than 1 can be appropriate in some instances, for example when a velocity correction coefficient is used to account for the weir equations neglecting the velocity head on approach to the barrage gate. With b<1, the seepage flow rating curve will asymptote at higher head differences as expected, and a=0.5 results in an average daily seepage loss across the calibration period of 50 ML/d, which is a plausible rate. R^2 values for the calibration, validation and high flow periods were 0.88, 0.94 and 0.78, respectively, indicating an acceptable fit between the Barrage Calculator and water balance derived barrage flow (Figure 6).

4.4.1 Monthly water balance results

The monthly water balance and barrage calculator results are compared as a scatter plot and hydrograph in Figure 6 and Figure 7, respectively. In general good agreement is achieved between the two methods, with the line of best fit between the scatter points for the different periods of data close to the 1:1 line. 90% of the differences between the two methods are less than 46 GL/month, which could be expected to be the accuracy of the water balance, in particular the estimate of evaporation rates (see Appendix A), and this volume difference is the equivalent an accuracy of approximately 0.05 m in the estimate of the average water level across Lakes Alexandrina and Albert to determine the change in storage volume.

Annual volumes of barrage flow from the barrage calculator and water balance from the two sources of solar radiation data (SILO and observed) are presented in Table 8. Again, good agreement between the barrage calculator and the water balance is achieved at the annual time scale, with the difference between the two methods similar to the difference in the water balance result depending on the source of data for the evaporative loss term.

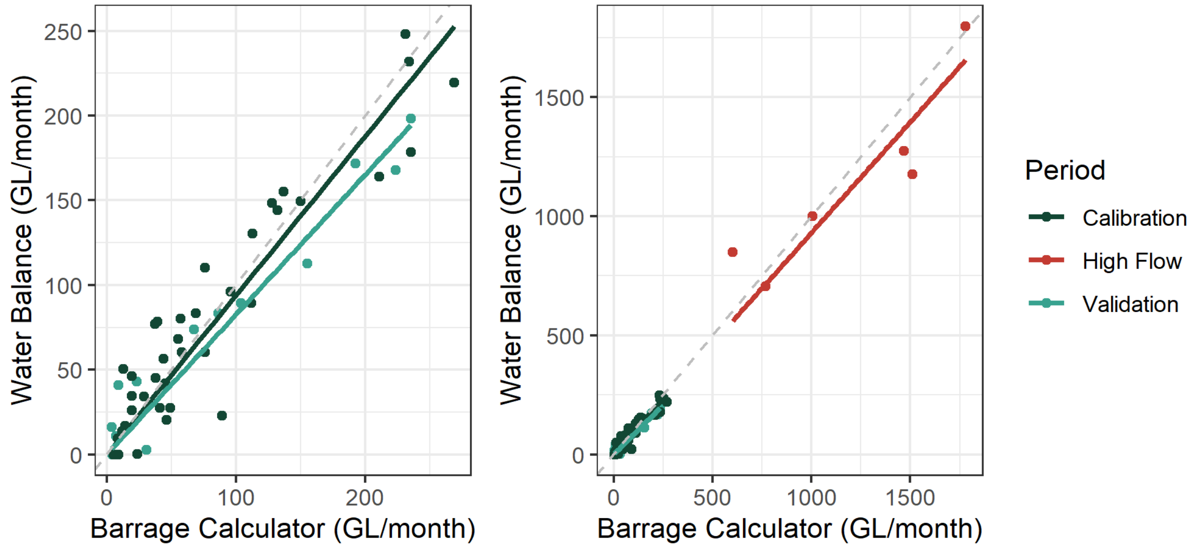


Figure 6 Scatter plot of monthly barrage flow volume from the barrage calculator compared to the water balance, for the calibration period (February 2017 – March 2020), validation period (July 2015 to August 2016) and high flow period (September 2016 – January 2017)

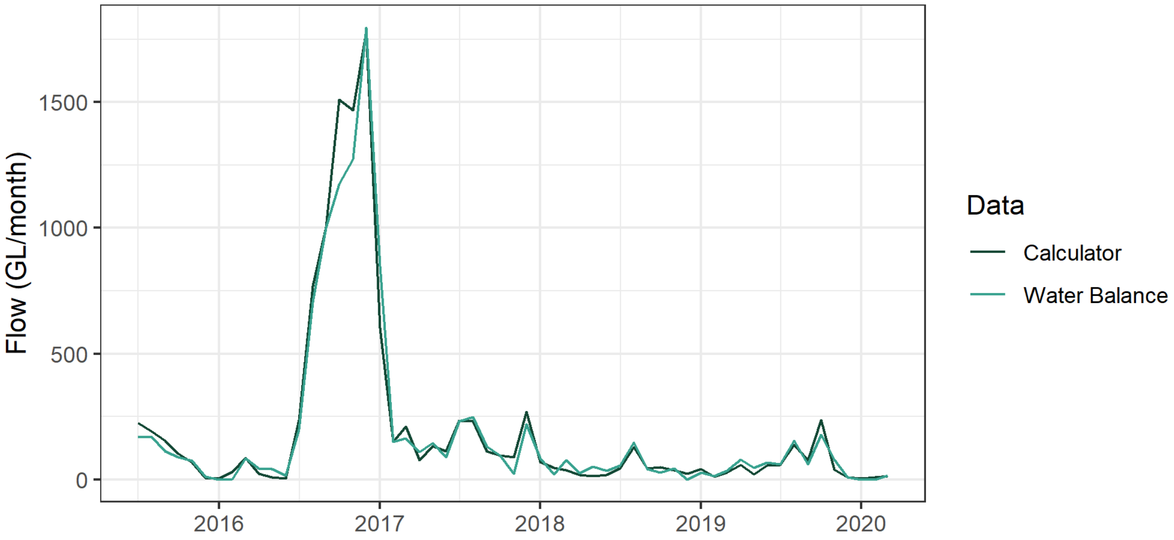


Figure 7 Time series of barrage flow, from the barrage calculator and the water balance

Table 8 Modelled annual barrage flow (GL/yr) based on SILO and observed solar radiation data as input to the calculation of Morton's Lake evaporation and calculated barrage flow

Water Year	Barrage Calculator	Water Balance Model	
		Observed Radiation	SILO
2015/16	909	812	833
2016/17	8,048	7,655	7,697
2017/18	1,238	1,240	1,294
2018/19	542	590	678
2019/20*	584	558	652

5 Comparison of calculated flow to gaugings

Various gaugings have been recorded for the barrages in recent years, as well as hydraulic modelling of the Mundoo barrage. The available records, and comparison to the Calculator, have been summarised in Table 9, including fishway gaugings at the Tauwitchere rock ramp fishway, which also uses the broad crested weir equation. The gate configurations and upstream/downstream water levels were replicated in the calculator for comparison, the results of which are discussed below. In some instances, details of the gate configurations were not sufficient, or in contrast to the current understanding of barrage operations (as outlined in Section 3), to be confidently replicated.

5.1 Tauwitchere barrage

Gaugings from two periods are available at Tauwitchere, in 2003 and 2019. The barrage calculator with calibrated discharge coefficient for the sluice equation was found to overestimate the gaugings undertaken in 2019 through an individual gate by an average of 57%. This may highlight the difficulty in gauging an individual gate, particularly with the measurements taken a number of meters out into Lake Alexandrina from the barrage structure. Also the gate where the gaugings were recorded may not behave as a 'typical' gate because the slight protection afforded by its eastern location. However it's worth noting that this gate is frequently used to provide a fish attractant flow to the Rock Ramp fishway.

For the 2003 gaugings, the calculator consistently underestimated the gaugings. There is less confidence in the older gaugings, as these were derived using a current meter to derive velocity, and multiplied by the water depth and sill width to determine discharge. However, for the modular flow conditions at Tauwitchere (see above) that would have been occurring for the upstream water levels recorded during the gaugings, this calculation of cross sectional area is likely to overestimate the true cross sectional area, and hence overestimate the discharge.

5.2 Tauwitchere rock ramp fishway

Six gaugings were available for the Tauwitchere rock ramp. Initial results indicated that the calculated discharge was approximately 12 times greater than the gauged flow, warranting changes to the adopted discharge coefficient. This is not surprising, given the rock ramp fishway has a long sill with protruding rocks to enable fish movement, and as such substantial energy losses, and hence reduced flow, is expected. Subsequently, the discharge coefficient was calibrated to 0.07, to minimize deviations. The results are summarized in Table 9.

It should be noted that the rock ramp is actually a v-shaped weir and as such does not behave as a broad crested weir as assumed in the calculator. The rock ramp has a minimum width at a sill level of 0.45 m AHD, increase to full width at a height of 0.78 m AHD. The gaugings were all taken at water levels around 0.57 m AHD. While adopting broad crested weir equation will not represent this geometry, this simplification has been considered adequate because the contribution of the rock ramp to total flow is small (roughly 2% of flow through a single gate). Additional gaugings at higher water levels (i.e. > 0.78 m AHD) would assist in understanding if a more accurate representation, or different C_d, is warranted.

5.3 Boundary Creek

Four gaugings were available for the Boundary Creek barrage: two at 1 log open and two at 2 logs. The calculated and gauged results generally matched well, as seen in Table 9. The calculated discharge through single gate openings was higher than the gaugings, while much closer for the two log openings. This two log comparison is the best fit between the gaugings and barrage calculator across all barrages.

5.4 Mundoo barrage

Hydraulic modelling of the Mundoo barrage was undertaken by WBM (2004) to assess the capacity of the Mundoo Channel under different water level conditions. There are a number of issues in using these modelled results to validate the calculator, including: details of the gates at Mundoo used in the modelling are different to the understanding of the barrages as outlined in Section 3.4, the modelling was not calibrated to data, and finally it was noted in the modelling report that channel capacity limited the discharge through the Mundoo Channel when the gates were modelled as fully open, rather than the barrage structure. For this last limitation, it means the modelling does not provide a suitable estimate of the flow through a barrage bay when the barrage is controlling the flow. The calculated discharge is significantly larger than the modelled estimate (approximately 2 times), however low confidence is placed in the comparison between the modelled and calculated datasets in Table 9.

5.5 Goolwa barrage

Based on the documentation available in WDS (2004), the calculator overestimates the gaugings undertaken for one and two logs open in the order of 50 – 60%. There are some uncertainties in the gate operations at the time of the gaugings to configure the barrage calculator to the same scenario, which may contribute to some of the differences.

5.6 Summary

In most cases, when comparing the barrage calculator to the gauged discharge through one barrage gate, the calculator tends to overestimate the gauged discharge. There are many variables that are difficult to quantify to ensure a direct comparison, including:

- Water levels recorded at one end of a barrage, but gaugings undertaken at the other, particularly for long barrages such as Tauwitchere (over 1 km).
- Difficulty in safely deploying an instrument into the high velocity structure of a barrage gate, and instead gaugings are taken a distance upstream or downstream of the structure.
- Variability within the barrage bays themselves, where different sills have been observed across a barrage (e.g. at Goolwa).
- Uncertainty in the conditions when the original gaugings were undertaken, preventing an accurate ‘apples with apples’ comparison.

The main purpose of the barrage calculator is to calculate the total flow occurring across the barrages, and the long term comparison to the water balance is expected to provide the best indication of this, as outlined in Section 4. Further consideration is required to identify a suitable approach to further validate the barrage calculator, if the agreement between the water balance, gaugings and the calculator can be improved. Potentially additional modelling tools can provide another line of evidence, such as Computational Fluid Dynamics modelling, that is undertaken at a very high resolution and accounts for the compressibility of water.

Table 9 Available gaugings and the calculated barrage flow for the same barrage gate, upstream and downstream water level. All flows for one open bay with the exception of the modelled results for Mundoo barrage.

Barrage - gauging	Date	U/S WL (m AHD)	D/S WL (m AHD)	ΔH (m)	Width (m)	Sill (m)	Flow Calc. (m^3/s)	Flow Gauged (m^3/s)	Diff. (%)	Comment
Goolwa - 01[1]	16/09/2003	0.62	0.58	0.04	3.581	0.118	1.21	0.757	60%	21 gates open; 1 stop log removed
Goolwa – 02[1]	16/09/2003	0.645	0.58	0.065	3.581	0.118	1.53	0.834	83%	21 gates open; 1 stop log removed
Goolwa - 03[1]	16/09/2003	0.63	0.51	0.12	3.581	0.118	1.85	0.887	109%	21 gates open; 1 stop log removed
Goolwa - 04[1]	14/10/2003	0.915	0.045	0.87	3.581	0.118	5.52	3.409	62%	9 gates at 0.49m, 1 gate at 0.47m
Goolwa - 05[1]	14/10/2003	0.915	0.045	0.87	3.581	0.118	5.52	2.816	96%	9 gates at 0.49m, 1 gate at 0.47m
Goolwa - 06[1]	14/10/2003	0.905	0.045	0.86	3.581	0.118	5.41	3.105	74%	9 gates at 0.49m, 1 gate at 0.47m
Goolwa - 07[1]	16/09/2003	0.625	0.555	0.07	3.581	0.118	1.51	1.807	-17%	1 gate negligible flow, 9 gates with 1 block removed
Goolwa - 08[1]	29/09/2003	0.855	0.605	0.25	3.581	-0.492	7.27	4.591	58%	10 gates open. All other gates 2 blocks removed
Goolwa - 09[1]	29/09/2003	0.855	0.605	0.25	3.581	-0.492	7.27	4.689	55%	10 gates open. All other gates 2 blocks removed
Goolwa - 10[1]	29/09/2003	0.855	0.605	0.25	3.581	-0.492	7.27	4.763	53%	10 gates open. All other gates 2 blocks removed
Goolwa - 11[1]	29/09/2003	0.855	0.605	0.25	3.581	-0.492	7.27	4.392	66%	10 gates open. All other gates 2 blocks removed
Goolwa - 12[1]	1/10/2003	0.9875	0.3375	0.65	3.581	-0.492	11.31	7.428	52%	12 gates open. 11 gates 1.1m depth, 1 gate 0.7m depth
Boundary Creek - 01[2]	13/12/2005	0.84	0.274	0.566	3.581	0.5894	0.97	0.50	95%	1 log open
Boundary Creek – 02[2]	13/12/2005	0.845	0.275	0.57	3.581	0.5894	1.00	0.54	86%	1 log open
Boundary Creek - 03[2]	13/12/2005	0.809	0.303	0.506	3.581	-0.325	7.63	7.13	7%	2 logs open
Boundary Creek - 04[2]	13/12/2005	0.803	0.32	0.483	3.581	-0.325	7.47	7.174	4%	2 logs open

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[1] WDS (2004)

[2] WDS (2006)

Barrage - gauging	Date	U/S WL (m AHD)	D/S WL (m AHD)	ΔH (m)	Width (m)	Sill (m)	Flow Calc. (m^3/s)	Flow Gauged (m^3/s)	Diff. (%)	Comment
Mundoo - 01[3]	Modelled	0.85	0.5	0.35	3.886	-0.965	325.33	140	132%	Mundoo model results: 26 gates open, total discharge
Mundoo – 02[3]	Modelled	0.85	0.25	0.6	3.886	-0.965	394.12	150	163%	Mundoo model results: 26 gates open, total discharge
Mundoo - 03[3]	Modelled	0.85	0	0.85	3.886	-0.965	442.87	163	172%	Mundoo model results: 26 gates open, total discharge
Mundoo - 04[3]	Modelled	0.85	-0.5	1.35	3.886	-0.965	507.07	165	207%	Mundoo model results: 26 gates open, total discharge
Mundoo - 05[3]	Modelled	0.85	0	0.85	3.886	-0.965	340.67	146	133%	Mundoo model results: 20 gates open, total discharge
Mundoo - 06[3]	Modelled	0.85	0.5	0.35	3.886	-0.965	187.69	100	88%	Mundoo model results: 15 gates open, total discharge
Mundoo - 07[3]	Modelled	0.85	0	0.85	3.886	-0.965	255.50	130	97%	Mundoo model results: 15 gates open, total discharge
Mundoo - 08[3]	Modelled	0.85	-0.25	1.1	3.886	-0.965	276.64	130	113%	Mundoo model results: 15 gates open, total discharge
Mundoo - 09[3]	Modelled	0.85	-0.5	1.35	3.886	-0.965	292.54	130	125%	Mundoo model results: 15 gates open, total discharge
Tauwitchere - 01[4]	2/10/2019	0.79	-0.042	0.832	3.886	-0.053	6.18	3.647	69%	1 gate at Pelican Point end
Tauwitchere – 02[4]	11/10/2019	0.82	-0.006	0.826	3.886	-0.053	6.32	3.345	89%	2 gate at Pelican Point end
Tauwitchere – 03[4]	18/10/2019	0.832	0.276	0.556	3.886	-0.053	4.41	3.846	15%	3 gate at Pelican Point end
Tauwitchere - 04[4]	22/10/2019	0.931	0.118	0.813	3.886	-0.053	5.47	3.631	51%	4 gate at Pelican Point end
Tauwitchere - 05[4]	30/10/2019	0.7805	0.0305	0.75	3.886	-0.053	6.14	2.88	113%	5 gate at Pelican Point end
Tauwitchere - 06[4]	12/11/2019	0.613	0.238	0.375	3.886	-0.053	3.36	2.354	43%	6 gate at Pelican Point end
Tauwitchere - 07[4]	14/11/2019	0.828	0.152	0.676	3.886	-0.053	4.86	3.146	55%	7 gate at Pelican Point end
Tauwitchere - 08[4]	3/12/2019	0.6475	0.2745	0.373	3.886	-0.053	3.40	2.675	27%	8 gate at Pelican Point end
Tauwitchere - 09[4]	14/01/2020	0.638	0.204	0.434	3.886	-0.053	3.66	2.368	54%	9 gate at Pelican Point end
Tauwitchere - 10[1]	18/09/2003	0.855	0.7215	0.1335	3.886	-0.053	2.18	3.814	-43%	Tauwitchere; 19 gates open. Different gate width reported (3.98m)
Tauwitchere - 11[1]	1/10/2003	0.942	0.633	0.309	3.886	-0.053	3.38	5.101	-34%	Tauwitchere; 1 gate open. Different gate width reported (3.98m)

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[3] WBM (2004)

[4] Castle (2020)

Barrage - gauging	Date	U/S WL (m AHD)	D/S WL (m AHD)	ΔH (m)	Width (m)	Sill (m)	Flow Calc. (m^3/s)	Flow Gauged (m^3/s)	Diff. (%)	Comment
Tauwitchere - 12[1]	7/10/2003	0.8445	0.418	0.4265	3.886	-0.053	3.88	6.31	-39%	Tauwitchere; 17 gates open. Different gate width reported (3.98m)
Rock Ramp – 01[5]	05/04/2016	0.565	0.093	0.472	3.886	0.45	0.0197	0.0201	-2%	Tauwitchere barrage rock ramp fishway
Rock Ramp – 02[5]	07/04/2016	0.57	0.141	0.429	3.886	0.45	0.0210	0.0212	-1%	Tauwitchere barrage rock ramp fishway
Rock Ramp – 03[5]	07/04/2016	0.574	0.22	0.355	3.886	0.45	0.0220	0.0214	3%	Tauwitchere barrage rock ramp fishway
Rock Ramp – 04[2]	3/11/2005	0.772	0.249	0.523	4.886	0.45	0.135	0.185	-27%	upstream ramp sloping section
Rock Ramp – 05[2]	21/11/2005	0.814	0.216	0.598	5.886	0.45	0.196	0.178	10%	upstream ramp platform
Rock Ramp - 06[2]	27/01/2006	0.662	0.081	0.581	6.886	0.45	0.102	0.075	36%	upstream ramp varying depth

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[5] Rowley (2016)

6 Discussion and Conclusions

The Barrage Calculator is considered to adequately represent discharge through the barrages for different gate configurations. Monthly totals correlate well to the monthly water balance after calibration of discharge coefficients and a seepage term. A comparison between the discharge calculated through an individual bay and available gaugings indicated that while there was some agreement, the calculator tended to overestimate the gaugings. The highest priority was given to replicating the monthly water balance as opposed to the instantaneous flow through individual bays, as the main purpose of the barrage calculator is to calculate the total flow occurring across all barrages.

The discrepancies between gauged data and theoretically derived flow may be in part due to the calculator being a generalised representation of the barrage bays. It is based on the assumption that all geometrically identical gates have the same flow, but in reality they will be differently affected by their location along barrage, operation surrounding gates and channel capacity (i.e. in the case of Mundoo). Furthermore, the physical and environmental constraints associated with gauging the barrage structures resulted in relatively high variance between individual gaugings, as outlined in Castle (2020). Nonetheless, the agreement with the monthly water balance over the period July 2015 – March 2020, including on two independent validation periods, provides some confidence that the total barrage flow can be represented by the Barrage Calculator under a range of conditions.

In its current form, the barrage calculator represents the range of likely operating conditions, but does not incorporate all potential functionality of the barrages. If/when required, the following updates are suggested:

- Addition of multiple stop log options for Mundoo. The current representation is limited to the removal of 1 stop log only, however it is understood that the various bays can be operated at various heights (i.e. there is the option to remove multiple stop logs for each bay). Note that this has not been considered critical functionality as the stop log bays have not been operated since June 2011.
- More accurate representation of the rock ramp fishway at Tauwitchere. The rock ramp is expected to behave as a v-shaped weir, but is currently represented as a (rectangular) broad crested weir. It is expected that the difference in representation is insignificant given the proportionally small flow through the rock ramp fishway compared to a single gate. Additional gaugings at higher water levels are required to help refine the relationship.
- Subject to identifying a suitable gauging approach, additional gaugings for the following conditions would be valuable:
    - Radial gates at Tauwitchere located toward the middle of the barrage, to compare to those undertaken in Castle (2020) at the Pelican Point end of the barrage.
    - 1 and 2 stop logs open at Goolwa, to further evaluate the accuracy of the calculator for these settings; particularly for water levels differences between 0.2 – 0.8 m which were not covered by WDS (2004).
- Continue to undertake the comparison between the water balance and the barrage calculator, as different combinations of flow, water level differences and barrage gate settings occur over time.
- Consider other modelling tools that provide another additional line of evidence to support the fundamental calculations in the barrage calculator, such as Computational Fluid Dynamics modelling that is undertaken at a very high resolution, and accounts for additional dynamics such as the compressibility of water.
- Consider additional discharge coefficients as more data becomes available to support the additional calibration parameters. For example, different coefficients for each barrage, or coefficients that vary with flow.

7 Appendices

A. Calculation of evaporation rates

McMahon et al. (2013) recommends Morton's Lake evaporation (Mlake) as the preferred method for lakes (Morton, 1986). The inputs to the calculation of Mlake are minimum and maximum daily temperature, vapour pressure (derived from dew point temperature, derived from wet and dry bulb temperatures) and solar radiation.

To identify SILO stations that have observed data to calculate Mlake, the SILO Point Data website was inspected for sites that have observed temperature or pan evaporation data. Milang (24519) was also included, as this site has a long rainfall record and is used in the Source Murray Model. The quality codes for the sites identified and the relevant variables can be seen in Figure 6. Meningie (24518) has a long term record of the relevant temperature (and temperature derived, i.e. vapour pressure) variables, as well as stations on Hindmarsh Island (23849 followed by 23894). It should also be noted that vapour pressure is based on dew point at 9 am, as opposed to a daily average adopted in McMahon et al. (2013). Observed pan evaporation was available at Mundoo Barrage (23131), but this has been patchy since the late 1990s, and more recently closed. In comparison, the quality codes for rainfall data are presented in Figure 7.

It can be seen that none of the sites have observed solar radiation data. SILO derives solar radiation from remotely sensed cloud oktas at 9am and 3pm. Radiation estimates derived from 9 am and 3 pm cloud oktas will be discretised, as there are only nine possible values on the oktas scale (0-8). Consequently all possible combinations of 9 am and 3 pm values only admit 81 possible values of radiation. It is well known that Morton's calculations are sensitive to climate variables values, especially solar radiation (pers. comm., the SILO team, 8/7/2019). While this remotely sensed cloud oktas approach provides continuous coverage across Australia, it is less accurate than ground measurements of solar radiation.

Given this limitation in solar radiation data, the Mlake evaporation estimates have been recalculated using observed solar radiation data. Maximum and minimum temperature and vapour pressure data from Meningie (24518) have been used based on the observed data available in the SILO database. Observed solar radiation data is available from the NRM Weather Network at Narrung and Wellington East. These two sites were used to develop a continuous observed record of solar radiation starting from 1/1/2015, with the agreement between the two sites used as data validation, and the average of the two sites taken when good data was available from both stations. The resulting time series, and comparison to the solar radiation data provided by SILO, is presented in Figure 10. It can be seen that the SILO solar radiation tends to underestimate the peak solar radiation in summer each year, with a bias of approximately 6% (Figure 12). The lower resolution of the remotely sensed solar radiation data from SILO is apparent in Figure 12. This is in line with the accuracy expected from the remotely sensed derived solar radiation product, where the Bureau of Meteorology (the source of SILO data) state that (http://www.bom.gov.au/climate/austmaps/solar-radiation-glossary.shtml accessed 21/7/20):

As one example of testing the satellite method of determining radiant exposure from the visible images from GMS-5 an intercomparison was undertaken using pyranometer data from 9 network sites from July and August 1997. On average the model agreed with the measurements to within 0.17% (around 0.04 MJ/m2 on a typical clear day) and the majority of measurements agreed within 6% (around 1.5 MJ/m2 on a typical clear day). The satellite method tends to slightly over-estimate the radiant exposure in wet, cloudy conditions, such as those present in Adelaide in the 1997 winter and to under estimate it in dry conditions such as those commonly present in Alice Springs. On the basis of these and subsequent intercomparisons *it is concluded that the satellite model provides useful daily global solar exposure estimates in all conditions, with an error of 7% or better in clear sky conditions and up to 20% in cloudy conditions.*

To determine the effect of the differences in the solar radiation data on the calculated Mlake evaporation rates, the Mlake calculation code used by SILO was obtained, and the Mlake data as provided by SILO were reproduced using this code. The resulting weekly evaporation rates can be seen in Figure 11, with a typical increase in evaporation rates of approximately 9% (Figure 12) based on the observed solar radiation data. However, this was not a consistent increase, where in some weeks the observed data resulting in lower evaporation than estimated from cloud cover (Figure 12). This weekly time step was adopted as Morton (1983) suggested a 5-day limit as the minimum time step for analysis of derived evaporation rates.

This revised estimate of Mlake evaporation was used in the Source model water balance to provide an estimate of monthly barrage flow volume to calibrate the barrage calculator weir equations to.

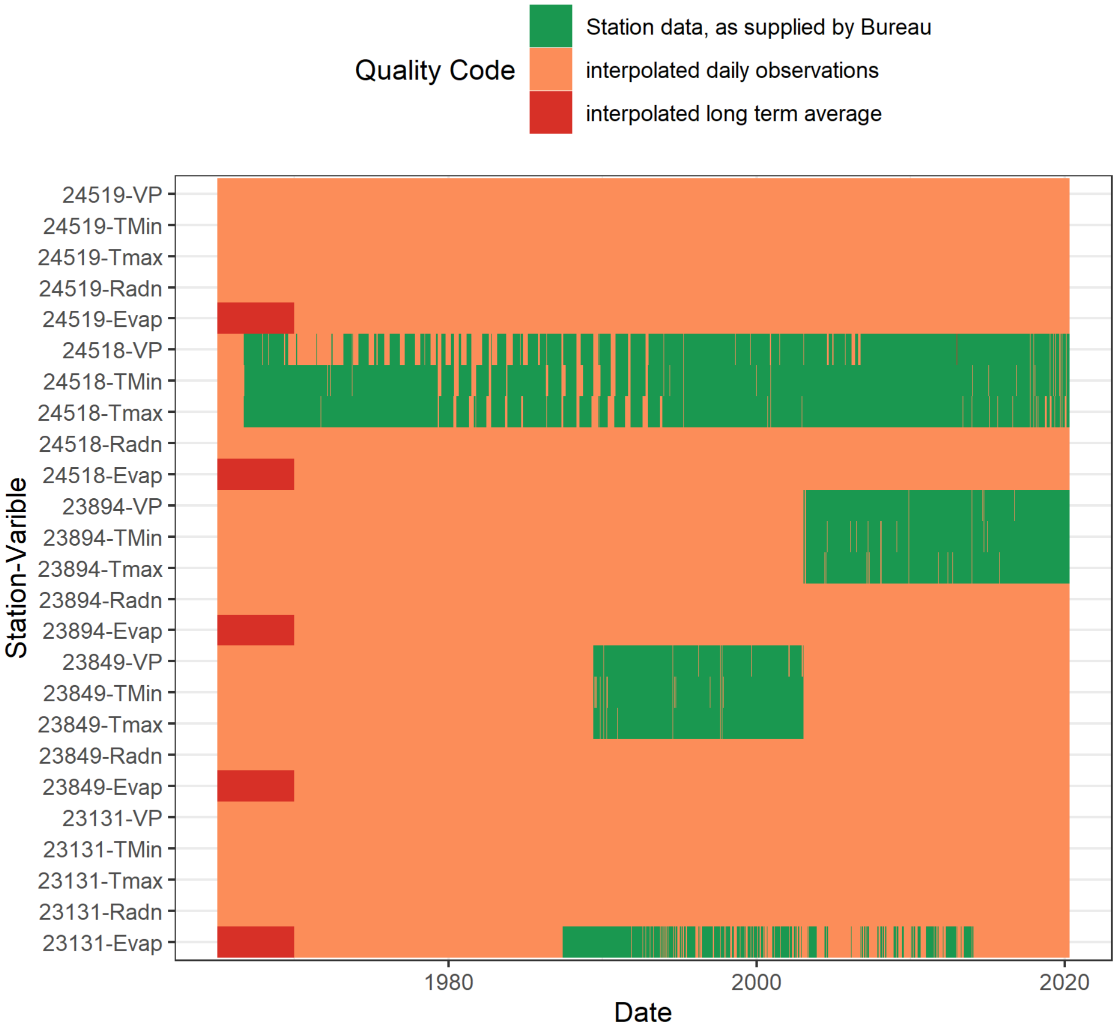

Figure 8 Quality codes of SILO data for variables related to Morton's Lake evaporation, as well as measured pan evaporation (Evap)

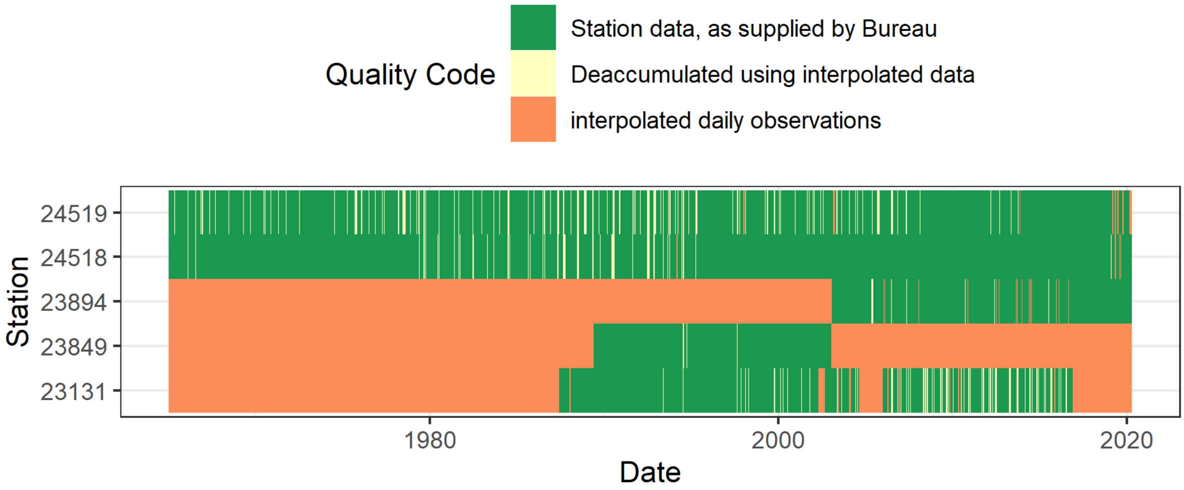

Figure 9 Quality codes of SILO data for rainfall data, from 1970-2020

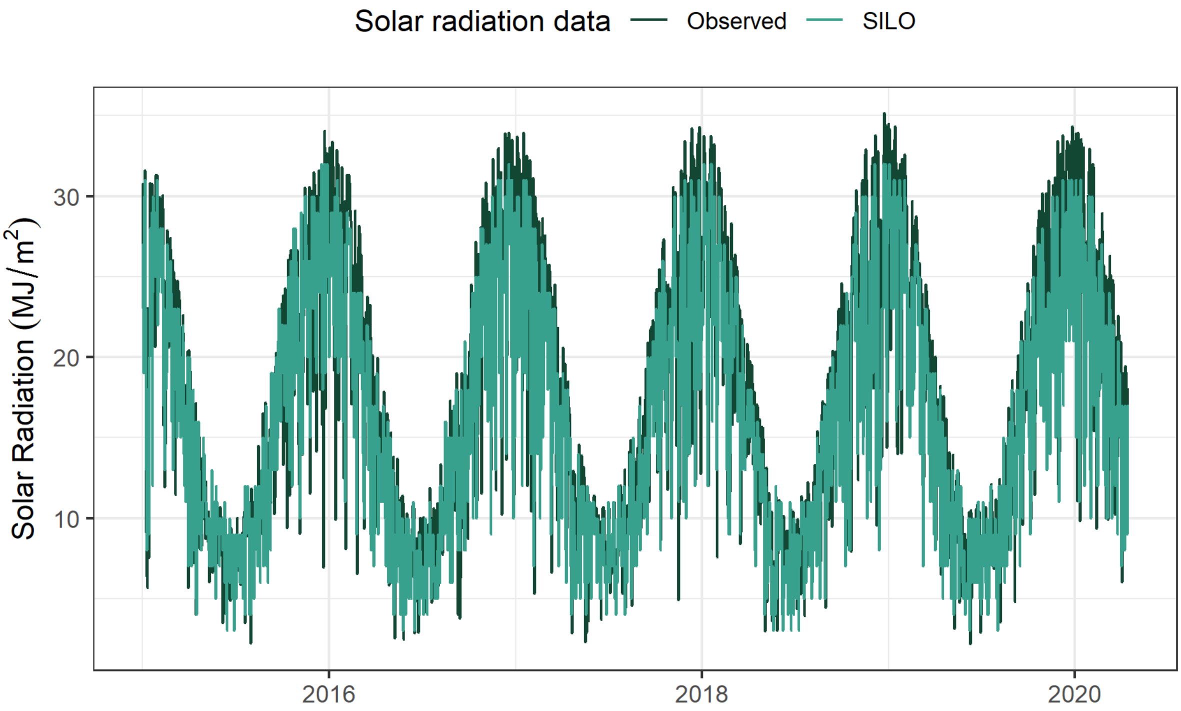

Figure 10 Solar radiation data from SILO (Meningie, 24518) and observed based on the NRM observation network at Narrung and Wellington East

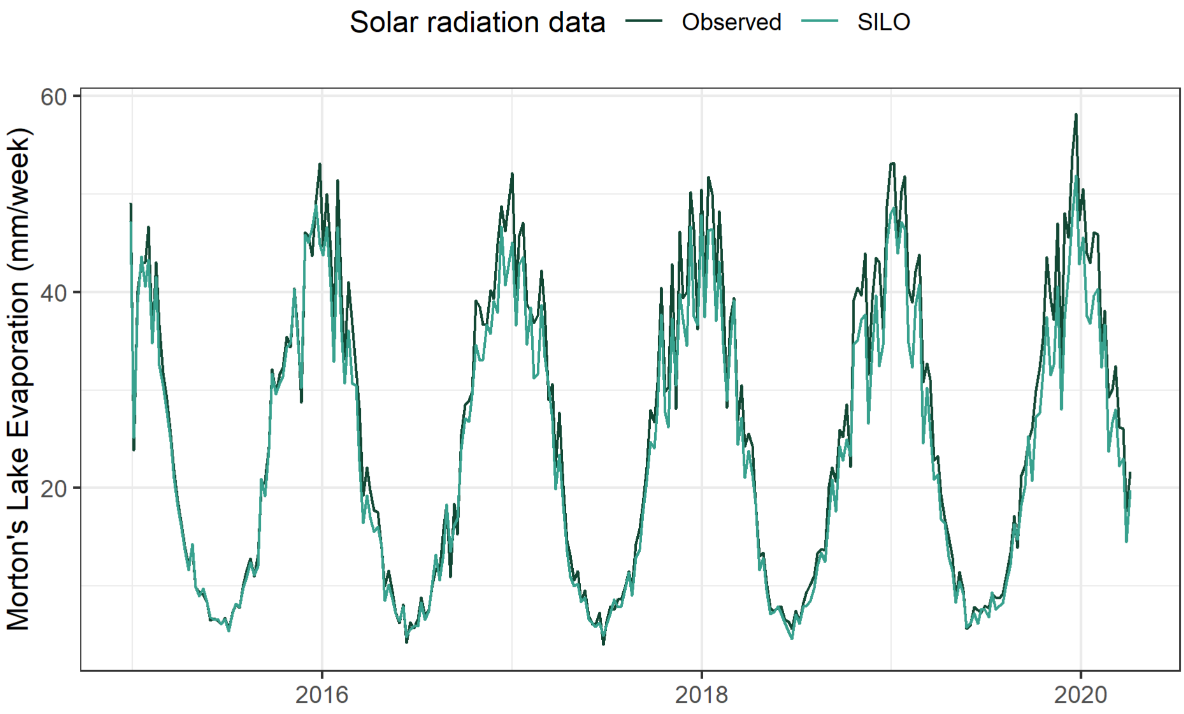

Figure 11 Weekly Morton's Lake evaporation, based on the two difference sources of solar radiation data

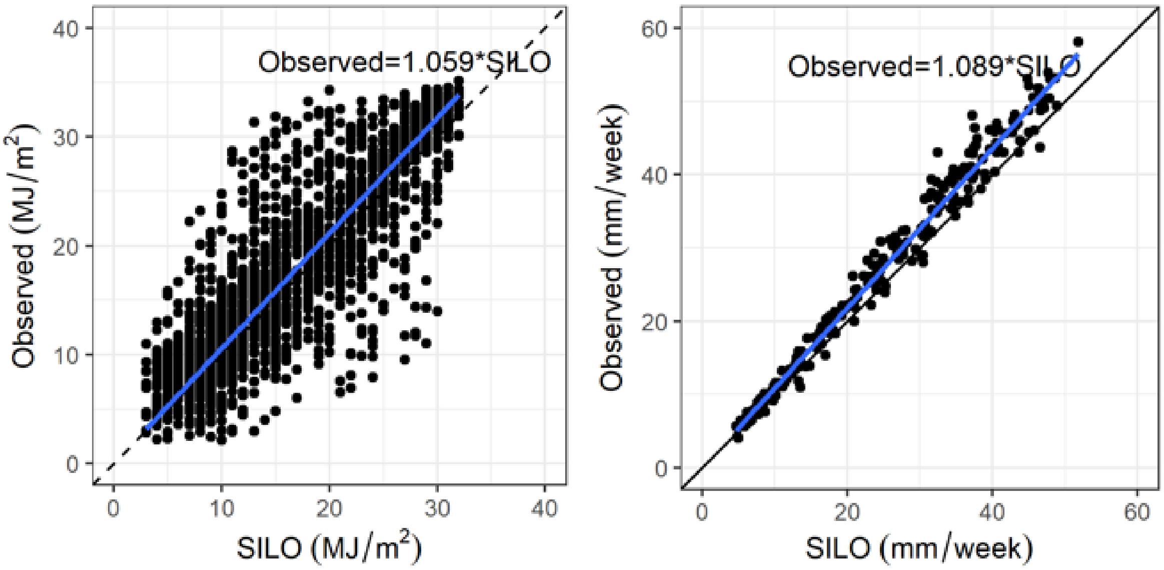

Figure 12 SILO derived and observed daily solar radiation (left) and the resulting Morton's Lake evaporation for the two difference sources of solar radiation data (right)

B Water balance results

In Table 10 barrage flow has been calculated based on both evaporation time series and as a product of a monthly water balance (i.e. Lock 1 + EMLR – diversion – loss – Storage Change) and also as the spill from the Lake Alexandrina node when the modelled water level exceeds the observed water level. The difference between the modelled and the water balance estimates is expected to be due to the travel time from Lock 1 to the barrages, which is not included in the water balance calculation.

Table 10 Water balance terms (GL/month) with SILO derived and observed solar radiation data as input to the calculation of Morton's Lake evaporation

Month	Lock 1	EMLR	Diversions	Loss		Storage Change		Barrage flow				
								Water balance[1]		Model[2]		Calculator
				SILO	Obs	SILO	Obs	SILO	Obs.	SILO	Obs.	
Jul-15	218	9	8	-30	-33	71	71	177	181	165	168	224
Aug-15	196	9	9	8	7	19	20	169	170	172	172	193
Sep-15	203	3	16	52	47	12	12	126	132	108	113	155
Oct-15	250	1	22	123	124	12	11	94	94	90	89	104
Nov-15	167	1	21	128	116	-21	-18	40	50	64	74	68
Dec-15	100	0	25	170	170	-109	-112	14	17	8	11	7
Jan-16	120	0	24	144	156	-72	-78	24	17	7	0	5
Feb-16	188	0	23	105	116	28	33	32	17	18	3	31
Mar-16	150	0	19	81	94	-43	-40	93	77	99	83	86
Apr-16	130	0	16	58	61	13	14	43	39	48	43	23
May-16	71	1	11	3	4	17	16	40	40	41	41	9
Jun-16	80	5	9	-16	-18	78	79	13	15	14	16	4
Jul-16	264	68	4	-57	-57	109	109	276	276	198	198	236
Aug-16	780	18	5	23	19	17	17	753	757	701	705	768
Sep-16	944	67	5	-53	-58	17	19	1043	1046	997	1000	1004
Oct-16	1180	57	6	80	85	-80	-82	1232	1228	1178	1175	1510
Nov-16	1405	3	8	120	124	-50	-49	1330	1324	1279	1274	1468
Dec-16	2204	4	10	116	132	128	126	1954	1939	1812	1797	1779
Jan-17	592	1	10	136	145	-46	-45	494	483	860	849	602
Feb-17	181	1	8	100	109	-62	-62	137	128	159	149	150
Mar-17	194	1	12	106	113	-112	-113	189	183	170	164	211
Apr-17	138	2	6	11	18	20	20	103	96	116	110	76
May-17	204	2	5	2	0	46	47	153	153	144	144	132
Jun-17	141	2	5	14	8	38	38	85	92	82	89	112
Jul-17	250	7	7	-27	-27	27	26	250	250	232	232	234
Aug-17	151	71	5	-21	-24	16	16	223	226	245	248	231
Sep-17	153	33	6	43	48	9	8	127	122	135	130	113
Oct-17	191	3	9	98	106	-21	-19	108	99	105	96	96
Nov-17	214	2	9	99	108	46	45	61	53	30	23	90
Dec-17	366	1	16	123	135	-17	-17	245	232	232	220	269
Jan-18	137	1	20	162	170	-94	-94	50	43	91	83	69

Month	Lock 1	EMLR	Diversions	Loss		Storage Change		Barrage flow				
								Water balance[1]		Model[2]		Calculator
				SILO	Obs	SILO	Obs	SILO	Obs.	SILO	Obs.	
Feb-18	137	1	16	128	139	-55	-55	50	38	32	20	46
Mar-18	125	1	17	108	113	-90	-91	91	87	81	77	37
Apr-18	120	1	14	71	70	7	11	29	25	30	26	19
May-18	86	2	8	-1	-1	29	25	51	55	47	51	13
Jun-18	121	2	7	-7	-7	85	85	39	39	35	35	19
Jul-18	213	2	16	-3	-2	127	127	75	75	56	57	44
Aug-18	139	6	15	8	11	-9	-9	131	128	152	148	128
Sep-18	112	2	16	62	66	-11	-11	46	43	46	42	45
Oct-18	153	1	22	96	106	-17	-21	53	47	34	27	49
Nov-18	146	0	19	95	112	-18	-18	51	33	63	45	38
Dec-18	167	0	22	131	143	-18	-17	32	20	13	0	24
Jan-19	161	0	23	184	197	-76	-76	29	17	39	27	41
Feb-19	137	0	20	130	143	-54	-55	42	30	25	14	12
Mar-19	179	0	25	98	112	-3	1	59	42	51	34	29
Apr-19	153	0	22	60	64	-7	-6	78	74	84	80	57
May-19	82	0	11	-36	-36	65	65	43	43	47	46	20
Jun-19	113	1	14	-14	-14	39	39	74	74	68	68	55
Jul-19	152	10	8	-6	-4	72	71	89	88	62	60	58
Aug-19	147	9	14	-11	-9	26	27	128	124	158	155	137
Sep-19	155	4	16	44	45	2	3	96	94	62	60	76
Oct-19	368	2	20	100	107	51	50	198	192	185	178	236
Nov-19	117	0	20	124	138	-79	-78	52	38	93	78	39
Dec-19	96	0	22	162	185	-106	-127	20	17	12	9	9
Jan-20	142	0	22	147	171	-64	-68	37	17	19	0	5
Feb-20	140	1	11	86	96	26	38	17	-4	21	0	9
Mar-20	100	1	15	94	106	-49	-38	41	18	39	17	15

[1] Water balance barrage flow calculated as: Lock 1 + EMLR – diversion – loss – Storage Change

[2] Modelled barrage flow is calculated using Source as the flow out of Lake Alexandrina after targeting the observed water level. The difference between the model and the water balance is due to the travel time from Lock 1 to the barrages, which is not included in the water balance.

8 Units of measurement

8.1 Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	$10^{6}\ \mathrm{m}^{3}$	volume
gram	g	$10^{-3}\ \mathrm{kg}$	mass
hectare	ha	$10^{4}\ \mathrm{m}^{2}$	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	$1\ \mathrm{m}^{3}$	volume
kilometre	km	$10^{3}\ \mathrm{m}$	length
litre	L	$10^{-3}\ \mathrm{m}^{3}$	volume
megalitre	ML	$10^{3}\ \mathrm{m}^{3}$	volume
metre	m	base unit	length
microgram	µg	$10^{-6}\ \mathrm{g}$	mass
microlitre	µL	$10^{-9}\ \mathrm{m}^{3}$	volume
milligram	mg	$10^{-3}\ \mathrm{g}$	mass
millilitre	mL	$10^{-6}\ \mathrm{m}^{3}$	volume
millimetre	mm	$10^{-3}\ \mathrm{m}$	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

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