Approach for estimating salt export from the River Murray System to the Southern Ocean

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Contents

Background

Chapter 9 of the Basin Plan 2012 is a Water Quality and Salinity Management Plan (WQSMP). The Chapter sets out objectives and targets to ensure water quality in the Basin meets a range of objectives including those for water dependent eco-systems, human consumption, irrigation use, recreational water quality, maintains good levels of water quality and ensures that adequate flushing of salt occurs from the River Murray System into the Southern Ocean.

Section 9.09 of the Basin Plan sets out the salt export objective to ensure adequate flushing of salt from the River Murray System into the Southern Ocean. The salt export objective is expected to be achieved by the discharge of an average of 2 million tonnes of salt from the River Murray System into the Southern Ocean each accounting period (i.e. July to June). This is an indicative figure to assess adequate flushing of salt from the River Murray. The reporting requirement under the Section 9.09 of the Basin Plan is that the Authority:

1. must estimate the discharge of salt from the River Murray System into the Southern Ocean every water accounting period (Clause 4).

2. must assess, on an annual basis, achievement of the salt export objective by comparing the estimated number of tonnes of salt exported per year averaged over the preceding 3 years against the indicative figure of 2 million tonnes per year (Clause 5).

3. must publish each assessment on its website (Clause 6).

This report discusses relevant flow and salinity monitoring being undertaken and options for estimating salt export to the Southern Ocean from the River Murray System to meet the requirements of the Basin Plan. The report also discusses strengths and limitations of various approaches and recommends an approach for the short term and further work that could improve the accuracy of estimates in the long term.

Monitoring of flow and salinity

To allow an estimate of salt export to the Southern Ocean, two parameters need to be determined: namely the volume of water flowing from the River Murray going into Southern Ocean and the salinity of these flows. Figure 1 shows the Lower Lakes system and River Murray confluence with the Southern Ocean. To get a precise estimate of salt export to the Southern Ocean, both flow and salinity should be measured at this location (marked A on Figure 1). However any continuous flow or salinity measurements at this location would be meaningless as both flow and salinity are influenced by the interactions between the ocean and the estuary. As well, drainage flows from the South-East, which enter the southern lagoon of the Coorong, may also discharge to the sea. Therefore, any measurements at this location will not be representative of the salt export from the River Murray. To have any meaningful measurements of River Murray flows to the sea and its salt concentration, the measurements will have to be made further upstream. The flow and salinity monitoring system currently in place is discussed in the following section.

Monitoring programme currently in place
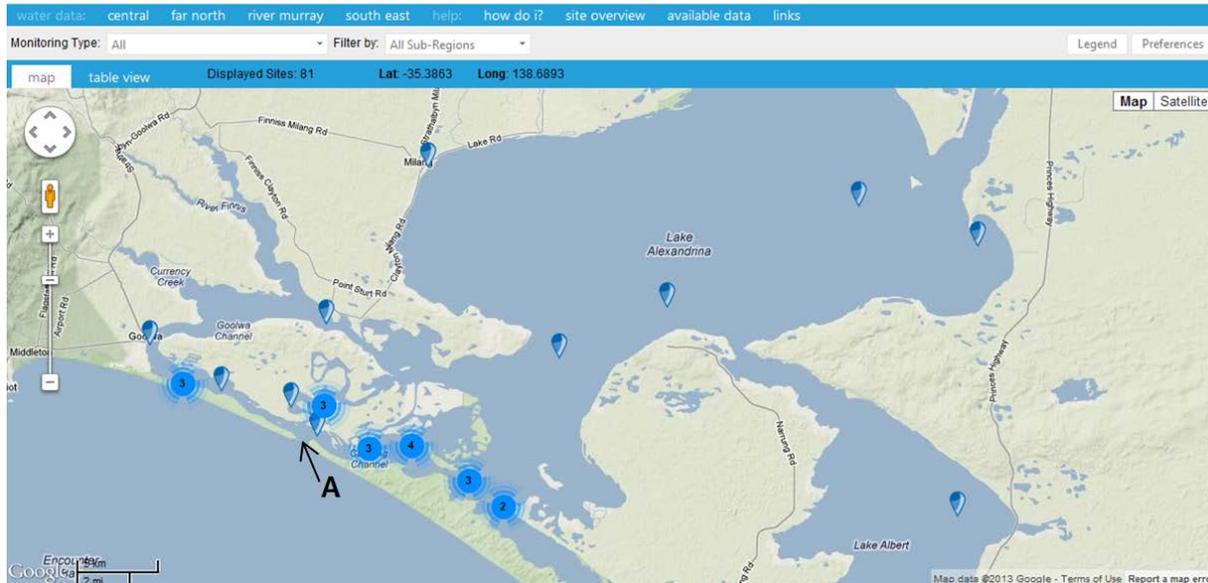
Figure 1: Level and salinity measurements near Murray Mouth

In addition to level and salinity measurements shown in Figure 1 for the Lower Lakes and Coorong, there are some long term and reliable salinity measurements available for the River Murray downstream of Lock 1.

Flow

Measurement of flows in the South Australian section of the river is a challenge considering that flows are affected by the locks and weir pools in this section of the river. However the measured daily flow data is available at the South Australian Border and flow estimates at Lock 1 are considered to be reasonably accurate.

Water level and salinity data

An extensive network of monitoring stations for salinity and water levels exists downstream of Lock 1 and in Lake Alexandrina and Lake Albert. For a number of these sites long term data is available which could be used for calibration and validation of model parameter values. The salinity and water levels are being monitored at:

- Upstream of Lock 1 – A4260902 (Salinity and Water Level)
- Downstream of Lock 1 – A4260903 (Water Level)
- Swan Reach (3 km downstream of Ferry) – A4261164 (Salinity and Water Level)
- Walker Flat – A4261163 (Salinity and Water Level)
- Mannum Town Wharf – A4261161 (Salinity and Water Level)
- Murray Bridge (Long Island) – A4261162 (Salinity and Water Level)
- Tailem Bend – A4261201 (Salinity)
- Wood Point – A4261126 (Salinity)

- 2 km downstream of Wellington Ferry – A4261159 (Salinity and Water Level)
- Poltalloch Plains – A4260575 (Salinity and Water Level)
- 4 km west of Pomanda Point – A4261158 (Salinity and Water Level)
- Near Mulgundawa – A4260574 (Salinity and Water Level)
- Beacon 90 – Offshore Raukkan – A4261133 (Salinity and Water Level)
- Milang Jetty – A4260524 (Salinity and Water Level)
- 3 km west of Point McLeay – A4261156 (Salinity and Water Level)
- West Clayton – Beacon 65 – A4261124 (Salinity and Water Level)
- Goolwa channel d/s of Hindmarsh Bridge – Beacon 23 – A4261123 (Salinity and Water Level)
- Upstream Goolwa Barrage – A4261034 (Salinity and Water Level)
- Downstream Goolwa Barrage – A4260525 (Salinity and Water Level)
- Upstream Mundoo Barrage – A4261042 (Water Level)
- Downstream Mundoo Barrage – A4261041 (Water Level)
- Upstream Boundary Creek Barrage – A4261045 (Water Level)
- Downstream Boundary Creek Barrage – A4261044 (Water Level)
- Upstream Ewe Island Barrage – A4261047 (Water Level)
- Downstream Ewe Island Barrage – A4261046 (Water Level)
- Upstream Tauwitchere Barrage – A4260527 (Salinity and Water Level)
- Downstream Tauwitchere Barrage – A4261048 (Water Level)
- Lake Albert near Waltowa Swamp – A4261153 (Salinity and Water Level)
- Lake Albert Meningi sailing club jetty – A4261153 (Salinity and Water Level)
- Lake Albert at 2km north of Warringee Point – A4261155 (Salinity and Water Level).

Barrages data

There are five barrages separating the Lower Lakes from the sea and the nature of control structures on these barrages are summarised in Table 1. The sill level of gates with stop logs depends on the number of stop logs removed and height of stop log removed which are not available currently.

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Table 1: Barrage Structure Data

Barrage	Number of gates	Sill Level
Goolwa	128 Gates, total open width = 128 x 3.581m = 458.4m Includes 2 fishways and 5 navigation bays All bays are stop logs	between -1.5 and -3.6 mAHD
Mundoo	26 Gates	6 spindles at -1.12 mAHD 9 stop logs at -1.12 mAHD 11 stop logs at -0.81 mAHD
Boundary Creek	6 gates	-1.12 mAHD
Ewe Island	61 radial gates and 50 stop logs	-0.05 mAHD
Tauwitchere	192 radial gates and 130 stop logs (includes 2 fishways)	-0.05 mAHD

Key issues

The key issues with the data available are:

- The salinity measurements immediate upstream of the Goolwa and Tauwitchere Barrages show that the salinity at these locations can vary significantly because of the sea water intrusions due to leakage during high tide effects and overtopping by wind driven waves (Figure 2). Thus, there can be salt and flow exchange from the sea into Lake Alexandrina even when the barrages are fully closed. The salinity measurements at further upstream locations in Lake Alexandrina are much steadier and variations in the salinity and water level are more influenced by wind seiche (Figure 3).

- There are no reliable flow measurements downstream of Lock 1 and all estimates of flow including flow over the barrages are estimated based on some gaugings, models or water balance calculations. The calibration and validation of the models can only be done for the water level data available for the river reach downstream of Lock 1 and for Lake Alexandrina and Lake Albert. There are major limitations with carrying out flow measurements downstream of Lock 1 under all flow conditions due to the interactions between lake levels, sea level, wind, local rainfall and evaporation, local tributary inflows and lack of free flow conditions most of the time.

- To improve estimation of the barrage flows based on measured water levels upstream and downstream of the barrages, the data collection would need to be improved by:

    a. Continuous recording of water levels both upstream and downstream of all the barrages,

    b. Recording the daily sill elevations of each gate at Goolwa, Boundary Creek and Mundoo barrages and storing records electronically, and

c. Conduct gaugings of typical gates for a range of different water levels and gate settings to assist in the development of more robust formulae for calculating the barrage flows.
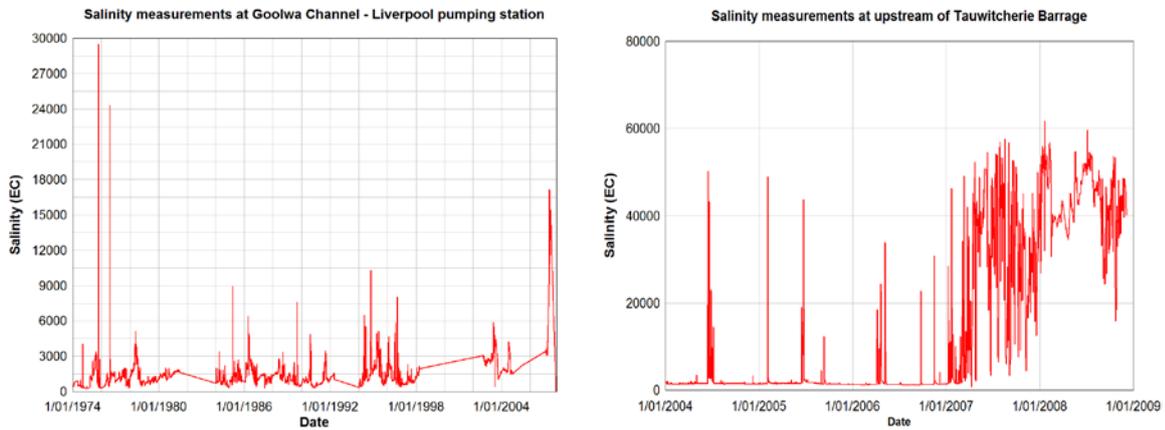

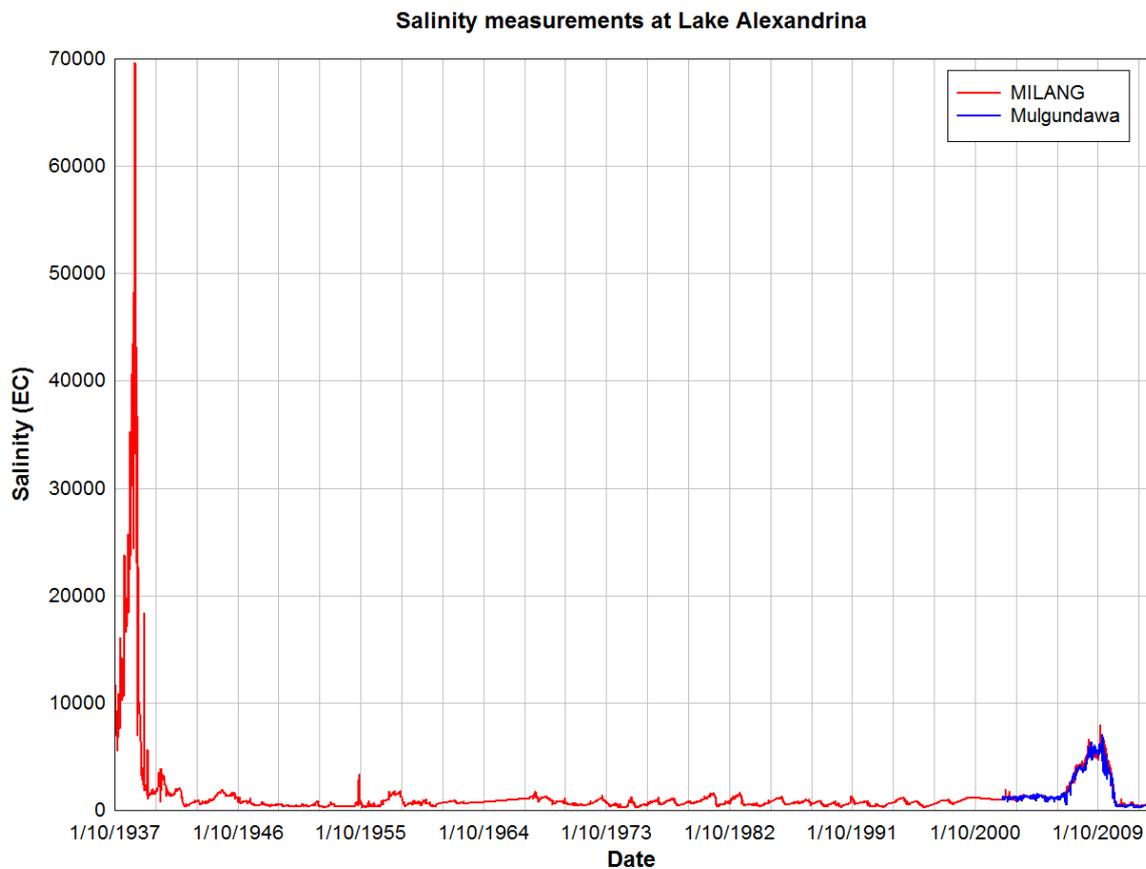**Figure 2: Salinity measurements upstream of Goolwa and Tauwitchere barrages**

Figure 3: Salinity measurements at Milang and Mulgundawa in Lake Alexandrina

Approaches for estimating salt export to the Southern Ocean

Salt export (tonnes of salt) from the River Murray System can be estimated by using average salt concentration (salinity) in Lake Alexandrina and the estimated water flow over the barrages or into the Southern Ocean. Due to the issues impacting on measurements of salinity near barrages as described earlier, it is proposed to use an average of observed salinities from Lake Alexandrina (using the Milang, Mulgundawa, Poltalloch Point and Point McLeay monitoring stations) to estimate salt concentration of water flowing over the barrages. The average salinity measured in EC can be converted into milligrams per litre (mg/L) using a conversion factor of 0.6 as per Section 9.17 of the Basin Plan. Therefore the following section mostly describes different ways to calculate barrage flows.

A typical rule of thumb often used by the barrage operators is that each gate discharges between 300 and 500 ML/d (BMT-WBM, 2011b). This rule of thumb is an approximate estimate and based on the review of available information. There are three key methods that could be used to provide a more accurate estimate for the barrage flows and therefore salt export. These three methods are:

1. **Observed data:** The barrage flows could be estimated using weir formulae with observed data for water levels at upstream and downstream of barrages, gate opening and sill levels.   These estimated barrage flows and observed average salinity for Lake Alexandrina could be used for estimating salt export over the barrages.   However, discharge coefficients of the weir formulae will have to be calibrated/derived using some observed data/gaugings to provide confidence in the estimates. As described earlier during high flows the barrages would drown out and calculation would be less accurate.

2. **BIGMOD model for Lower Murray:** BIGMOD is a daily flow and salinity routing model for the River Murray and Lower Darling system. This model could be used to predict flow over the barrages and the combination of this modelled flow and observed average salinity for Lake Alexandrina could be used for estimating salt export to the sea.

3. **BMT WBM 2-D hydrodynamic model:** BMT WBM (a private company) has developed a 2-D hydrodynamic model for the Coorong, Lower Lakes and Murray Mouth (CLLMM) area for South Australian Department of Environment and Natural Resources (DENR).   This model has been used to undertake a range of studies to improve the understanding of key environmental and hydraulic processes in CLLMM area. This model estimates both flow over the barrages as well as exchange of flow and salt between the Southern Ocean and Coorong.

The above three methods are discussed in further detail along with their strengths and limitations in the following paragraphs.

Method 1: Use of observed data

As mentioned earlier, the water levels at upstream and downstream of barrages, the number of gates open and salinity in Lake Alexandrina are currently recorded. However, to estimate the barrage flows, the discharge coefficients of weir formulae will have to be derived using some

observed data to provide confidence in the estimates. Three studies have derived weir formulae for estimating barrage discharge and all three studies have assumed barrages as a broad crested weir. However, all three studies have come up with different estimates of discharge coefficient in the weir formula. The three weir formulae derived by these studies and the approach adopted by them is summarised below:

DWLBC South Australia

Water Data Services Pty Ltd in September and October 2003 performed gauging's to measure the flow through two separate barrages for the Department of Water Land and Biodiversity Conservation, South Australia (DWLBC). The details of study and results are discussed in WDS (2004). It seems that all gauging's were under the conditions of downstream water level being lower than the sill level of the gate opening (i.e. not submerged conditions). These gauging's were undertaken over a range of upstream and downstream water levels and flow measurements for one gate out of a number of gates that were open at the time. However velocity checks were carried out for a number of open gates to see if they exhibit similar hydrological characteristics. The weir formulae derived for the Goolwa and Tauwitchere Barrages (note width of gate is part of the equation) were:

$$Q = 3.2 \times N \times H_1^{0.5}$$ - for Goolwa with one stop log removed ($0.2 < H_1 < 0.8$),

$$Q = 10.8 \times N \times H_1^{0.6}$$ - for Goolwa with two stop logs removed ($0.3 < H_1 < 0.8$),

$$Q = 8.7 \times N \times H_1^{0.4}$$ - for Tauwitchere radial gates ($0.5 < H_1$),

Where,

Q = discharge through barrage (m^3/s)
N = no. of gates open
H_1 = depth of upstream water level above sill level (m)

The study found that the external variations such as wind, marine growth and tidal currents caused variations in gate characteristics that resulted in different flows occurring in gates across the barrage. For more accurate ratings for each barrage and each gate many more streamflow gaugings would be needed at a number of locations. Despite such further gauging, it would be possible to improve the accuracy of estimates only up to a point, as effects of external variations would not be possible to account for in the weir formulae.

MDBA

MDBA derived discharge coefficient for barrages by calibrating flows estimated using weir formulae against barrage flows estimated using BIGMOD. The procedure adopted for the estimation of barrage flows using BIGMOD is discussed later (more detailed explanation is available in MDBA, 2012). The calibrated weir formulae derived by the MDBA for the barrage flows are:

$$Q = 1.63 \times L \times N \times H_1^{1.5}$$ - for Goolwa, Mundoo and Boundary Creek

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$$Q = 1.23 \times L \times N \times H_1^{1.5} \qquad \text{- for Tauwitchere and Ewe Island}$$

Under submerged conditions equations derived are:

$$Q = 1.63 \times L \times N \times H_1^{1.5} \times (1 - (\tfrac{H_2}{H_1})^{1.5})^{0.385} \text{ - for Goolwa, Mundoo and Boundary Creek}$$

$$Q = 1.23 \times L \times N \times H_1^{1.5} \times (1 - (\tfrac{H_2}{H_1})^{1.5})^{0.385} \text{ - for Tauwitchere and Ewe Island}$$

Where,

Q = discharge through barrage (m³/s)

L = width of gate (m)

N = no. of gates open

H_1 = depth of upstream water level above crest level (m)

H_2 = depth of downstream water level above crest level (m)

BMT WBM for use in their 2D hydrodynamic model:

BMT WBM while developing CLLMM Forecast model developed a structure matrix that defines the barrage flow for a matrix of upstream and downstream water levels. To develop this matrix, BMT WBM deemed the barrages as a broad crested weir. The hydraulics of the broad crested weir (Bos, 1989) (including an allowance for drowned regimes) used for all five barrages was:

$$Q = 1.705 \times L \times N \times H_1^{1.5} \qquad\qquad \text{Not submerged conditions}$$

$$Q = 1.705 \times L \times N \times H_1^{1.5} \times (1 - (\tfrac{H_2}{H_1})^{1.5})^{0.385} \qquad \text{- Under submerged conditions}$$

Based on Hudson (2013), the discharge coefficient is a commonly recommended value from literature.

Discussion of method 1

The three studies carried out to estimate the barrage flows using weir formula show significant variation in estimates of the discharge coefficients for the weir formula. Further, gauging's carried out by South Australia show the challenges and limitations due to influence of external factors on predicting flows through all opened gates. However, by using appropriate weir formula and observed records for upstream and downstream water level, number of gates open, an operational estimate of barrage flows can be made in a short period of time and typically within one or two months after the end of the water year. These flow estimates along with the observed salinity data for Lake Alexandrina (i.e. average of stations not influenced by sea water intrusion) could be used to make a preliminary estimate of salt export from the system.

Method 2: BIGMOD model for the Lower Murray

BIGMOD is a daily model developed and maintained by the MDBA which simulates flow and salinity in the River Murray and Lower Darling systems. This model in conjunction with the Authority's monthly simulation model has been used over the last three decades for undertaking numerous modelling studies to inform major policy decisions. These models were also used for the development of the Basin Plan and to assess how well the environmental targets for the River Murray and Lower Darling system will be met under different levels of water recovery.   The estimate of barrage flows from this model were used as input to the Coorong model (Webster, 2006) to assess salinity changes in the Coorong for scenarios studied for the development of the Basin Plan.   This model is also used for assessing the salinity credits and debits under the accountability arrangements of the Basin Salinity Management Strategy for the Murray Darling Basin.

BIGMOD calibration for the estimation of barrage flows

The river reach between Lock 1 and the barrages is relevant for the estimation of the barrage flows. Therefore, this report only summarises the calibration methodology and results for this section of the river system. The detailed modelling methodology and its calibration are discussed in MDBC (2002).

For downstream of Lock 1, the evaporation rates are represented by twelve monthly values. The reach downstream of Lock 1 was recalibrated in 2009 (MDBA, 2009) using data from the recent drought period with no barrage flows. This data was ideal to carry out the water balances to estimate evaporation losses and derive an appropriate pan factor. This recalibration led to re-derivation of pan factor for estimating the evaporation losses from Lake Alexandrina and Lake Albert and inclusion of un-modelled components implicitly such as local inflows.   The water balances for the Lower Lakes for the period of no barrage outflows was carried out by BIGMOD model and by fixing the flows downstream of Lock 1 to the observed data and also fixing all known river diversions to the actual diversions and then comparing observed lake levels with the modelled water levels for different pan factors. It was found that a pan factor of 0.83 for river reaches and the Lower Lakes provided the best fit between observed and modelled data (R^2 of 0.938). Figure 4 shows the water levels at Lake Alexandrina using the updated pan factor and comparison against previous model results and observed water level data.
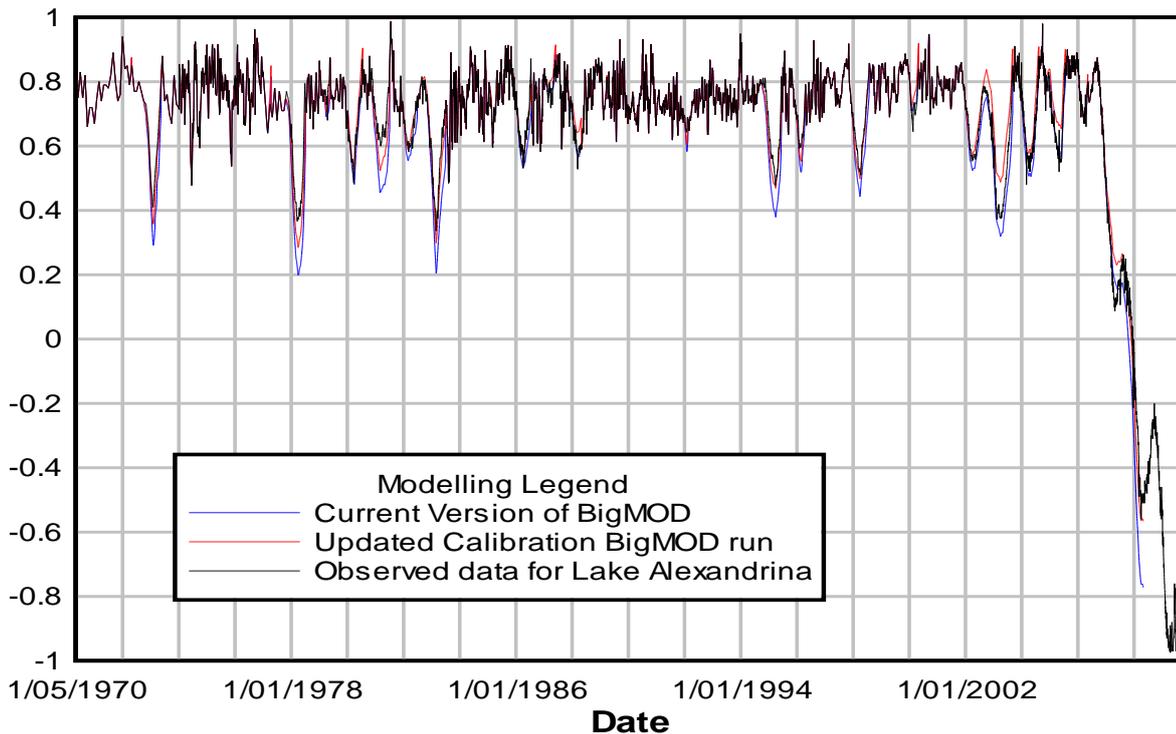
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Figure 4: Comparison of water levels (m AHD) at Lake Alexandrina between modelled and observed data (MDBA, 2009)

Figure 4 shows that the new pan factor has improved the model's ability to replicate observed data reasonably well. However there were some occasions when modelled level is marginally over-predicted. This is probably due to use of monthly constant evaporation rates and not including local inflows from the Eastern Mount Lofty Ranges explicitly in the model. MDBA is intending to undertake further improvement to the BIGMOD calibration by incorporating local inflows and daily evaporation data from the SILO database.

Discussion of method 2

It is possible using BIGMOD to calculate barrage flows after setting up the model with Lock 1 flows being equal to the observed flows and all extractions downstream of Lock 1 being equal to the actual diversions. Further, levels of the Lower Lakes in the model would also be forced to the observed data too. With the routed flows to the Lower Lakes and twelve months observed levels at the Lower Lakes, BIGMOD would carry out water balance to estimate flow over the barrages. Therefore, this water balance method would not rely on water levels downstream of the barrages.

The key strengths and limitations of this method are:

- Cost effective (i.e no need to rely on external consultants);

- Model calibrations show that the model reproduces historical behavior of the Lower Lakes well and a rigourous and robust approach has been adopted to estimate evaporation losses. Consequently, confidence on barrage flow estimates should be high. However, BIGMOD works on a daily time step and cannot take into account the impact of wind on the lake level. Thus on a day to day basis the model predicted barrage flows could vary

by becoming negative or postive due to variations in levels caused by the wind. However, monthly totals of the modelled barrage flows which represent monthly water balance are considered to be reasonably accurate;

- Quick model run time;

- Since BIGMOD is a hydrological daily time step model, it is not possible to take into account some hydraulic characteristics such as:

  o Smaller time scale variations,

  o Fine spatial resolution, and

  o External forcing functions such as surface variation due to wind stresses; and

- BIGMOD does not include local inflows from the Eastern Mount Lofty Ranges explicitly. Therefore, recalibration of BIGMOD should be undertaken once this data becomes available. This should improve the model predictive capacity further.

Method 3: BMT WBM 2-D hydrodynamic model

BMT WBM has developed a CLLMM forecast model for the South Australian Department of Environment and Natural Resources (DENR) to undertake a range of studies to improve understanding of key environmental and hydraulic processes in the CLLMM area. This modelling tool consists of:

- 2-D hydrodynamic model called TUFLOW-FV for detailed calculation of hydraulic charateristics in the study area using a finite volume method which includes a scalar transportation module for salinity routing,

- Geo-morphological model (TUFLOW-MORPH) for sediment movement around Murray Mouth, and

- Wave model (SWAN) to bring ocean boundary conditions from offshore to nearshore area.

These three models simulate Lake Alexandrina, Lake Albert, Goolwa channel, North and South Coorong and coastal zone adjacent to the Murray mouth. This model could be used to estimate salt exchange between the barrage outflows, North Coorong and the sea. This is possible as the boundary condition of this model extends to the coastal zone adjacent to the Murray mouth.

Model setup and calibration process

Based on the calibration report (BMT WBM, 2011a), model setup and its calibration are summarised below:

1. Bathymetry data: As a 2-D hydrodynamic model, it requires depth information at every cell which was generated from a number of different sources including:

   o LiDAR data covering the fringes of water body,

   o Derived data from echo sounding, and

   o Surveyed cross-section data.

2. *Boundary conditions:*

   o Lock 1 flows and salinity were applied at Wellington which is approximately 200 km away from Lock 1. It was assumed that during periods of high flows transmission time between these locations is insignificant and extractions and evaporation losses have minimal impact. Period of calibration chosen was high flow period of 25/11/2010 to 1/5/2011.

   o SILO data was used to describe net evaporation losses.

   o Tidal data at Victor Harbour and modelled information purchased from BMT ARGOSS at offshore of Kangaroo Island were used to drive offshore water level boundary conditions.

   o Data from a weather station at Pelican Point was used to describe wind stress (direction and velocity).

   o Measured Salt Creek flows and salinity at Morella were used to describe inflows to South Coorong.

   o Inflows and salinity from local catchments (Finnis River, Currency Creek) were obtained from gauged data.

3. *Barrage representation:* In order to represent the barrages in the model, it used externally generated level-flow matrix using the weir formula described earlier which was included as a lookup table to derive flows once upstream and downstream levels are calculated. To describe opening of the barrages, recorded timeseries data was used so that the model could adjust sill levels of the structures.

4. *Initial conditions*: Initial conditions for water level, salinity and mouth bathymetry were set using the observed data. Averaged value of the gauged readings at the start day of the calibration period were used for the water level, For salinity, linear interpolation was used to distribute sparse observed data spatially and then later on it was adjusted to improve calibration results. Initial mouth bathymetry was based on surveyed data set from November 2010. To cover the entire computation domain, some assumptions were used where the survey doesn't extend fully (i.e. offshore beyond the mouth).

5. *Calibration*: The model was calibrated for the period 25/11/2010 to 1/5/2011. This time period was governed by the data availability at spatial and time resolution for the TUFLOW and SWAN models. Main focus of the calibration was reproducing measured water level and salinity as close as possible. In order to achieve this, a number of parameters were changed which included:

    o   Roughness parameter,

    o   Wind shear stress coefficient and

    o   Sediment transport scaling coefficient and sediment size distribution.

In addition, there were some changes made to initial salinity distribution and Lock 1 flow. The calibration report (BMT WBM, 2011a) noted that there are a number of inconsistencies in recorded time series data of barrage operations and lack of detailed information (the number and size of logs removed). Subsequently the time series data was altered to achieve better calibration.

Discussion of method 3

It is possible to use the weir formula as done by BMT-WBM and observed levels upstream and downstream of each barrage to compute flow over the barrages. These flow estimates combined with the observed salinity data from the Lake Alexandrina would be used to estimate salt export over the barrages. Alternatively, modelled barrage flows can be used for flow estimates.

To strictly comply with the requirement of the Basin Plan Chapter 9 (i.e. estimate the discharge of salt from the River Murray System into the Southern Ocean) then the best available estimate would be through running the TUFLOW-SWAN modelling suite for a period of more than 1 year (including a period required for warming up of model to get the initial conditions correct) and estimate salt fluxes to the Southern Ocean. However, this would require modelling approximation to account for fluxes between salt inflows and outflows from the Southern Ocean to the North Coorong and the component of salt export that may have come from salt inflow from the Upper South East Drainage.

Key strengths and limitations of this method are:

-   Large data requirements for setting up initial conditions for the model,

-   Computation time to run three hydrodynamic models for a one year period from Lock 1 to Southern Ocean including Northern and Southern Coorong is likely to be high unless spatial grid sizes are increased. Such an increase is likely to be at the expense of some loss in accuracy of the predictions.

-   If salt export is measured at the Murray Mouth where interactions between the estuary and the ocean are significant, it would not represent salt exported from the system.

-   In the model, it is possible to tag salt coming from the Upper South East Drainage and how it moves within the Coorong system vis-à-vis salt input from the River Murray system to apportion salt fluxes from the River Murray System, Coorong, Upper South East Drainage and the Southern Ocean.   This apportioning method, however, is only as

accurate as the model's accuracy which is difficult to quantify without measured data. This could have a significant influence on the reported estimate of annual salt export from the River Murray System.

- Cost of running the models and processing of model results for one year period.

- Ongoing financial commitment for future model improvement and maintainance.

- The accuracy or confidence limits on the estimate of salt export from the River Murray System to the Southern Ocean cannot be quantified.

- Among the methods assessed, this method is the only method capable of providing an estimate of salt export to the Southern Ocean from the River Murray System. All other methods provide an estimate of salt export over the barrages from the River Murray System.

Comparison of barrage flow estimations

On 31 May 2013, modelled data (6 months of data used for validation; BMT WBM, 2012) from BMT WBM was purchased so that the methods described in this report could be compared (Figure 5). Figure 5 shows that estimated barrage flows from the hydrodynamic model and the water balance method are closely matching even though flows from the water balance method exhibit more pronounced temporal variations in some months. Over the 6 month period, the difference of flows between these two modelling methods is roughly 2.6% (i.e., daily averaged flows are 28,929 ML/day from the hydrodynamic model and 28,166 ML/day using the water balance method). Given that averaged salinity at Milang over the period is approximately 530 EC, the difference of estimated barrage flows between these two methods leads to a discrepancy in salt export of less than 0.09 million tonnes over the 6 month period.

Figure 5 also shows estimated flows using two weir formulae (from MDBA and BMT WBM). Barrage flows are calculated with recorded information of barrage opening and measured (at half hourly intervals) water levels at upstream and downstream of each barrage (MDBA, 2012). These calculated flows are different only in their magnitude because the same formulae and data sets are used with different coefficients. The difference of flows is around 19%. It should be noted that especially during May in the 6 month comparison period these weir formulae calculated flows are underestimated compared to the modelled flows. This underestimation is caused by level measurement data of questionable quality at the site downstream of Goolwa Barrage during late April to early May. The recorded level is inconsistent with other level data and downstream levels are up to -0.5 m below sea level and jumps from -0.205 m to 0.535 m from 5th May 2011 to 6th May 2011. Considering the quality of level data for this period the major differences between the water balance calculations and weir formula are questionable.
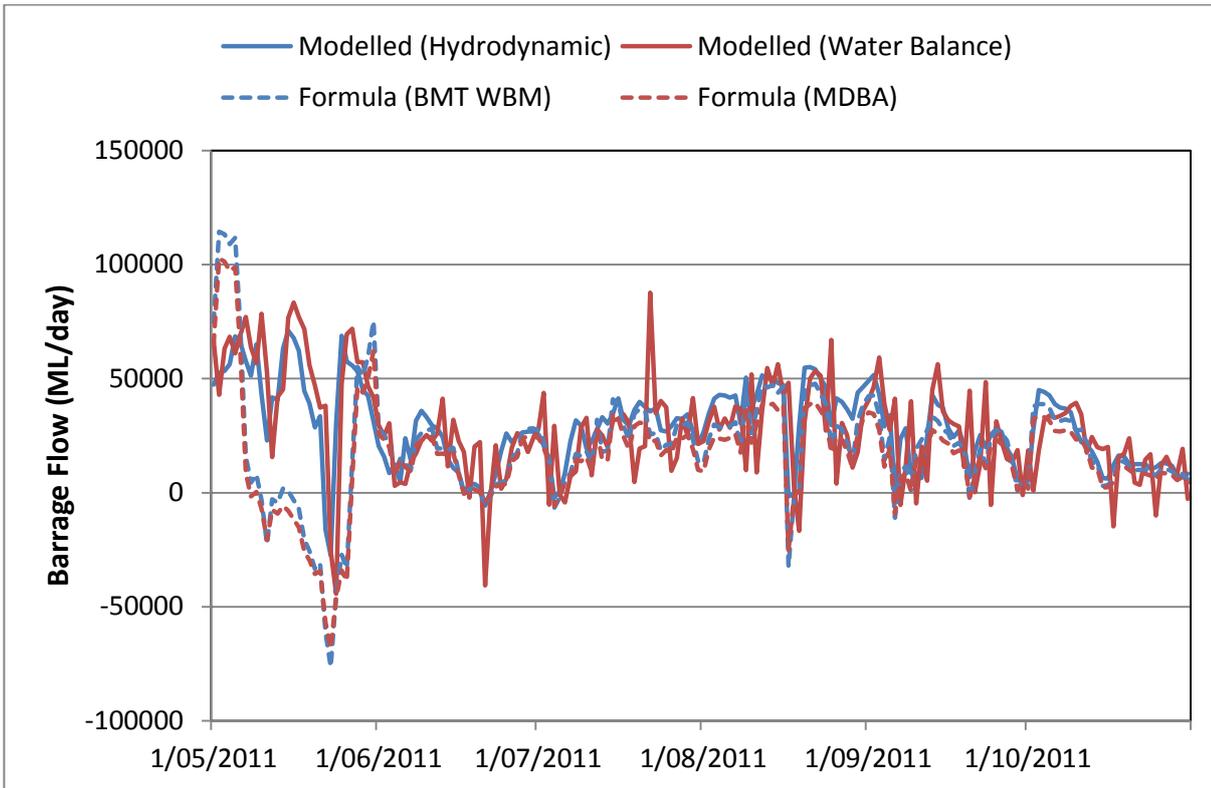
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Figure 5: Comparison of barrage flows calculated using BMT WBM's hydrodynamic model, BIGMOD water balance method, and two weir formulae.

It is not possible to compare long term behaviours of the hydrodynamic model with the other methods of barrage flow calculation given that its modelled results are only available for a six month period. However, monthly estimates from the water balance method and the MDBA's weir formula are compared at Figure 6 over the last 27 years. This figure shows that the correlation between these two is quite high when monthly flows are less than 1500 GL (r^2=0.87) but the weir formula tends to overestimate when flow is greater than 1500 GL/month with significant differences in some months. Given that it is likely to export adequate salt from the system when flow is high, the weir formula is calibrated against the water balance method for low to medium flows.

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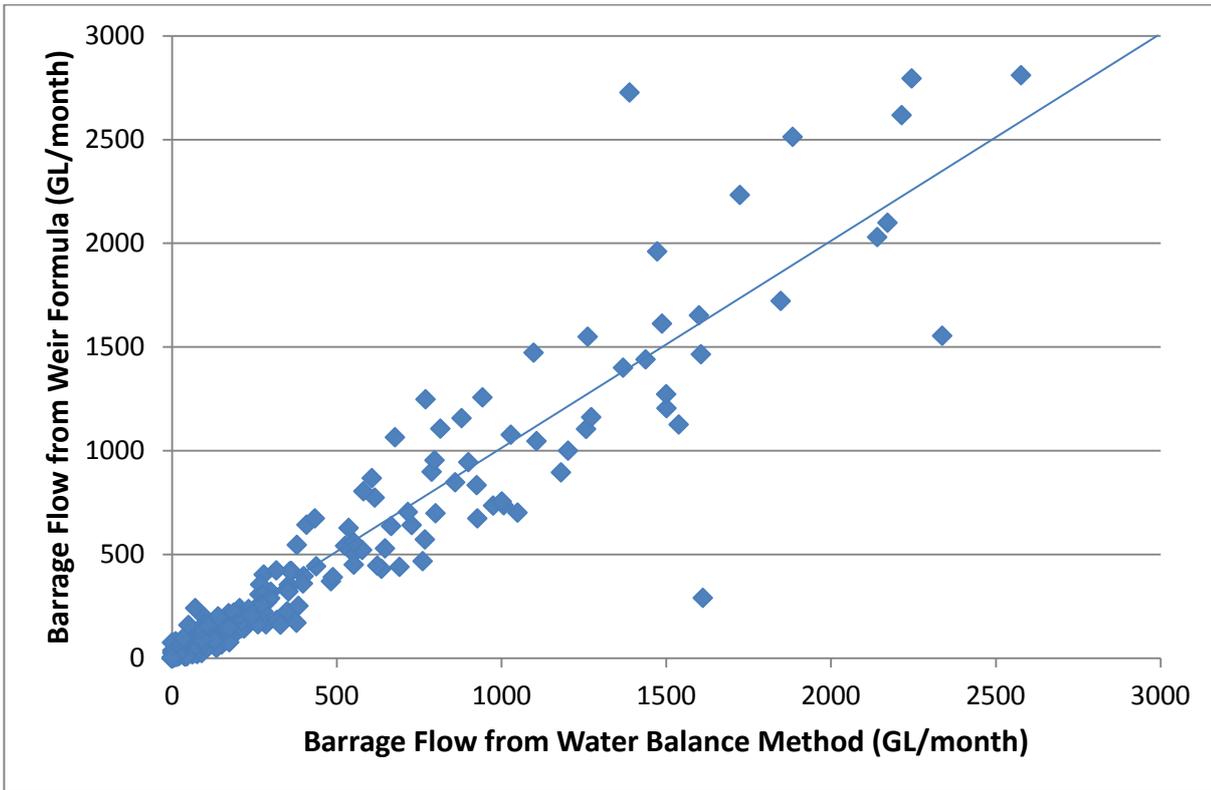
(a)
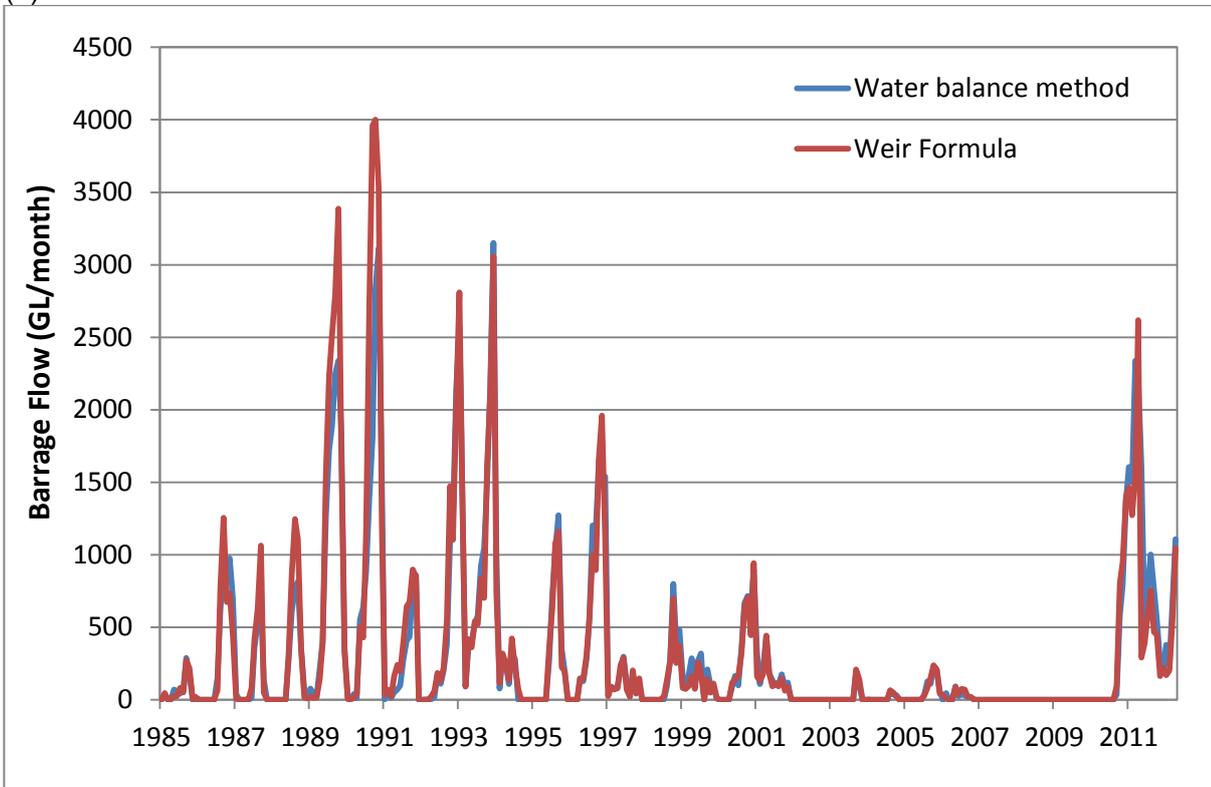
(b)

Figure 6: Comparison of barrage flows from water balance method and MDBA's weir formula ((a) scatter plot and (b) monthly plot)

Conclusions and recommendations

The Basin Plan requires (Section 9.09) the Authority to estimate the discharge of salt from the River Murray System into the Southern Ocean every water accounting period. The studies carried out in the past for estimating River Murray flows over the barrages and to the Southern Ocean and its salinity have been reviewed.   The key conclusions from this review are:

1. The TUFLOW-SWAN model is the only method assessed that is able to estimate salt export to the Southern Ocean from the River Murray System and Coorong. However, it would not be possible to quantify the accuracy of the estimate as it is not possible to measure flows near the Murray mouth due to constantly changing gemorphology. Further, assumptions will be needed to apportion annual salt export to the Southern Ocean between salt export from the River Murray versus the component attributable to Upper South East Drainage and sea water exchanges with the North Coorong as well as with the Lower Lakes close to barrages.

2. Over the longer term (i.e. multiple years), it is possible to use a salt balance calculation with frequent measurements of the volume of water being held in the Coorong and salinities at a number of locations for quantifying the accuracy of the TUFLOW-SWAN model. As this calculation cannot take into account salt contribution from outside of the system, its usage for estimating salt export is limited.

3. Compared with the accuracy of estimates of salt export from the Murray Mouth, the export of salt over the barrages can be estimated with reasonable accuracy in a cost effective and timely manner. The accuracy of estimates can be improved over time by reviewing data collection programs and refining the methodology.

4. Salt export over the barrages is a necessary and appropriate surrogate for salt export to the Southern Ocean.

5. It would be possible to provide a preliminary estimate of salt export over the barrages in a short time frame, typically within a couple of months after the end of the water year, by using appropriate weir formulae with observed water levels, barrage openings and salinity data. As MDBA (2012) calibrated its weir formula against the BIGMOD water balance method, this weir formula is likely to provide better estimates. When the recording of gate and stop log status and other better quality data are available, discharge coefficients of the weir formula should be recalibrated.

6. The BIGMOD model can be used for carrying out water balances on the Lower Lakes and to estimate the barrage flows. The predictive capacity of this model can be further improved by explicitly modelling inflows from the Eastern Mount Lofty Ranges and these improvements are currently being investigated.

7. The TUFLOW-SWAN model, when used to calculate flow over the barrages produces similar magnitudes and patterns to the water balance method using BIGMOD.

8. The monitoring programs for water levels, barrage openings and number of stop logs could be improved. Additional flow gaugings in the future could improve the accuracy of estimates of flow over the barrages.

It is recommended that:

1. Due to issues associated with estimating water quantity and quality at the Murray Mouth, in the short term, salt export to the Southern Ocean is based on the estimate of River Murray flows over the barrages and observed average salinity in Lake Alexandrina. Reassessing this approach should be carried out as better predictive capacity is explored to assess feasibility of estimating salt export from the River Murray System to the Southern Ocean.

2. MDBA make an operational estimate of salt export over the barrages using the MDBA's weir formula and observed water level and average salinity data for Lake Alexandrina. These estimates should be published on the MDBA website, and would typically be available within one or two months after the end of the water year, as a range of operational estimates of annual salt export from the River Murray System.

3. The operational estimates be reviewed using a water balance method on the river reach downstream of Lock 1 using the BIGMOD model. The updated estimate of barrage flows and the observed average salinity for Lake Alexandrina be used for reviewing the salt export estimate. This method should be applied as soon as historical data is available including diversions by users downstream of Lock 1, hydrographically corrected flow, water level and salinity data which may take 3-4 months after the end of the water year.

4. The data collection and its processing systems currently in place should be improved as soon as possible by:

   - Continuous recording of water levels both upstream and downstream of all the barrages,
   - Recording the daily sill elevations of each gate at Goolwa, Boundary Creek and Mundoo barrages and store records electronically, and
   - Conduct gaugings of typical gates for a range of different levels and gate settings to assist in the development of more robust weir formulae for calculating the barrage flows.
   - Updating MDBA River Operations spreadsheets to compute the barrage flow and salt export estimates using electronically downloaded data.

5. Undertake a "fit for purpose" assessment to consider further improvements to the method involving incorporating Coorong salt fluxes and the cost benefit provided by either a salt mass balance calculation or the TUFLOW-SWAN modelling approach. Based on the recommendations of this work, the salt export assessment approach for the long term may be reviewed.

6. The estimation of salt export using different methods may be undertaken for a few years to assess the relative differences by different methods. The reasons for the differences may be explored.

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