Refinements to the River Murray Source Model in South Australia

Department for Environment and Water
June 2020

DEW Technical Report 2020/06

Government of South Australia

Department for Environment and Water

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ISBN 978-1-925964-34-9

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Preferred way to cite this publication

Department for Environment and Water (2020). *Refinements to the River Murray Source model in South Australia*, DEW Technical report 2020/06, Government of South Australia, Adelaide.

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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, regional 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

DEW acknowledges the following people whose input has been essential to the work presented in this report:

- Daniel McCullough for his support and input from hydraulic model runs;
- Andrew Keogh of the Murray-Darling Basin Authority (MDBA) for advice on weir nodes and developing the hydrological model of Chowilla Floodplain; and
- Alistair Korn of MDBA for the constructive comments as part of an external review of the report and the model, which has improved the document.

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Summary

A hydrological model of the River Murray and Lower Darling has been developed by the Murray-Darling Basin Authority (MDBA) using eWater Source (MDBA, 2013; 2015a), and is referred to as the Source Murray Model (SMM). The SMM is currently being used to develop water resource plans for the River Murray and a number of reviews have concluded that the SMM is fit for purpose and an improvement over previous models (Bewsher Consulting, 2017, Jakeman et al., 2019). The work outlined in this technical report has been undertaken to refine parts of the SMM in South Australia, with this refined model referred to as the SA River Murray Source Model. The refinements are to improve the capability to 1) assess various water quality, quantity and potential ecological changes within an environmental water planning and real-time operations support capability; 2) predict site and cumulative environmental risk and/or benefit under the suite of potential infrastructure operations within the SA section of the River Murray.

Significant elements such as: weirs (i.e. weir pools 1 to 5); key floodplains (i.e. Chowilla, Pike and Katarapko); and wetlands (i.e. Lake Bonney, Berri Basin, Gurra Gurra, Lake Merreti and Lake Woolpolool) were incorporated in the South Australian part of the SMM, as these nodes represent elements that are being manipulated more frequently to improve ecological outcomes, or in the case of some wetlands, can influence the water or salt balance. Furthermore, storage routing links utilised downstream of Lock 1 were re-calibrated for improvements to the SA River Murray Source Model.

Numerous scenarios were modelled using hydrodynamic models (MIKE FLOOD) to represent a wide range of conditions (flows and operational water levels) that had not been experienced in the historical record. Results from these hydrodynamic scenarios were used to parameterise and calibrate the hydrological model. Calibration was undertaken by adjusting routing parameters to provide accurate representations of the area and volume outputs simulated through hydrodynamic modelling. For the wetlands, conveyance relationships of wetland links were calibrated using the outputs of the hydraulic model scenarios to achieve the required water surface elevation between the river and storages. Subsequently, the calibrated parameters (i.e. rating curves, travel times, storage dimensions and conveyance relationships) were tested over a dynamic simulation over the period from 1977 to 2018 using observed inflow and climate data. The statistics demonstrate that the SA River Murray Source Model can simulate downstream flows at Lock 1 with high accuracy.

With this model, the capability now exists to simulate a range of operational scenarios considering weir pool manipulations and operation of floodplain infrastructure (currently under construction) that was not possible using previous hydrological models.

1 Introduction

1.1 Background

Simulation models underpin policy and management of the water resources of the River Murray and Lower Darling system. These simulation models are required due to the complex physical characteristics and water sharing rules defined in the Murray-Darling Basin Agreement. A hydrological model of the River Murray and Lower Darling has been developed by the MDBA using eWater Source (MDBA, 2013; 2015a), and is referred to as the SMM.

The level of detail represented in the SMM has been developed based on the MSM-Bigmod model (e.g., see MDBA 2014a), originally developed to represent historical river operations, and largely based on ensuring supply of water to consumptive users. The SMM can output all aspects of the water balance at each node and link such as flow, evaporation volume, rainfall volume, and seepage at each node and link, and has replaced MSM-Bigmod for water resource planning in the Southern Connected Basin of the River Murray.

DEW uses the South Australian section of the SMM (i.e. SA River Murray Source Model) for two main purposes:

- To inform operations of the Lower Lakes and barrages. This includes modelling over scales of a number of months to one year, based on a forecast of flow to South Australia, losses within South Australia, and different combinations of lake level or barrage flow releases.
- To inform annual environmental water planning. This modelling is used to align objectives and outcomes between a flow at the SA border for channel and floodplain outcomes and targeted barrage flow and Lake Alexandrina water levels at the end of the system.

As previously configured, the SA River Murray Source Model did not include a number of existing structures in South Australia, such as locks and weirs (with the exception of Lock 6). While historically these structures were operated to maintain a constant water level and thus had little effect on the water balance, more recently they are being managed to restore some natural variability in water levels. A model capable of representing the change in flow and additional losses from these actions was desirable. Additionally, construction of infrastructure on the floodplains for environmental benefits within the South Australian section of the Murray Darling Basin (SAMDB) was nearing completion, which was also desirable to represent in the model. Some examples of this within South Australia include:

- Only Lock 6 was explicitly modelled as a weir. The other weirs within SA were not represented in the model, as historically they have not been used to manipulate water levels, and as such have had a minimal impact on the downstream flow.
- Lock 6 was initially included in the model as part of representing The Living Murray works sites, which include the Chowilla regulator. The Chowilla regulator was represented in the SMM as one lumped weir representing the whole anabranch complex.
- The only other storages explicitly represented in the model were Lake Bonney, Lake Alexandrina and Lake Albert, and the effect of all other wetlands was implicitly represented in the relationship between flow and inundated area in the reaches with routing.
- There are a number of large-scale floodplain regulators at sites in the Pike and Katarapko Floodplains (South Australian Riverland Floodplains Integrated Infrastructure Program – SARFIIP sites) that are planned to be operated in 2020 which were not represented in the SMM.

Therefore, additional development and refinement of the SA River Murray Source Model was required to enable an integrated assessment of river operations within South Australia, including management of floodplain regulators at Chowilla, Pike and Katarapko as well as associated weir pool manipulations.

1.2 Scope

The purpose of this study was to undertake a number of hydraulic and hydrological modelling activities to expand the functionality of the existing SA River Murray Source Model, with the ultimate goal of integration within the SMM, as maintained by the MDBA.

The developments will improve DEW's capability to:

- Assess various water quality, quantity and potential hydro-ecological changes, enhancing environmental water planning and real-time operations support.
- Simulate site and cumulative environmental risk and/or benefit under the suite of potential infrastructure operations within the SAMDB, as represented by changes in variables modelled (for example, inundated area, flow rate and salinity).

Significant elements such as weirs and key floodplains (i.e. Chowilla, Pike and Katarapko Floodplains) and also important wetlands including Lake Merreti, Lake Woolpolool, Gurra Gurra Lakes and Berri Basin have been included in the SA River Murray Source Model explicitly as they represent regulating structures that can influence the water balance at the scale of river flows. There are many more wetlands that could be explicitly included in the model as storages, as opposed to integrated within the surface area of the relevant reach. Further wetlands were not included in the model to provide a balance between a parsimonious model that is quicker to run and one that provides the necessary level to detail to be able to account for cumulative changes along the river due to infrastructure operation.

2 Weir pool source models

2.1 Introduction

Weirs are structures built across rivers that are used to control water levels. Weirs are often accompanied by locks which allow river vessels to travel through a weir. There are six weirs with associated locks on the main channel of the River Murray in South Australia, with the combined structure colloquially referred to as the "lock". The locks have historically been operated to keep the water levels relatively stable and within the normal operating range. This has allowed for navigation and provide a reliable level of water for supplying critical human water needs, irrigation, recreation, stock and domestic purposes.

Prior to river regulation, water levels in the River Murray varied in response to changes in flow conditions driven by seasonal inflow conditions. The locks significantly influence the water levels and are operated as a series of relatively stable pools. Weir pool water level manipulation (WPM) involves use of the weirs to raise and lower water levels in a weir pool to connect floodplains and wetlands and mimic some of the natural variation in water levels in order to improve the health of the river. As WPM is being undertaken more regularly, across more weir pools and to achieve greater changes in water level, it has become necessary to represent the effect of these changes in water level on the volumes stored in the river, on the changes in inundation area to assess losses and to assess potential environmental benefits, to inform planning purposes.

Hydrodynamic modelling studies have been undertaken over recent years in four different sections of the River Murray in South Australia using MIKE FLOOD models, as shown in Figure 2-1. These models cover the South Australian part of the River Murray, including its floodplains downstream of Lock 6. Details of the hydrodynamic models are summarised in McCullough et al. (2017) and Montazeri and Gibbs (2018). Results from these hydrodynamic scenarios have been used to construct and calibrate the hydrological models representing five weir pools (i.e. Weir pool 1 to 5) using the eWater Source platform. The MDBA maintains a MIKE FLOOD model of Chowilla Floodplain as part of The Living Murray Program and has developed an updated hydrological model that represents weir pool 6 and the Chowilla floodplain. As such, it was not necessary for this section of SA to be considered further.

2.2 Data

The spatial extent of the Source model developed for each weir pool is illustrated from Figure 2-2 to Figure 2-6. Lakes, wetlands and floodplains were excluded when calibrating the upstream reach width and travel time for the weirs, i.e. 1) Lake Bonney was excluded in the Source calibration model of weir pool 3 (Figure 2-4); 2) Berri Basin, Gurra Gurra Wetlands, Katarapko and Pike Floodplains were not incorporated for weir pool 4 (Figure 2-5). Lake Woolpolool and Lake Merreti were excluded for weir pool 5 (Figure 2-6).

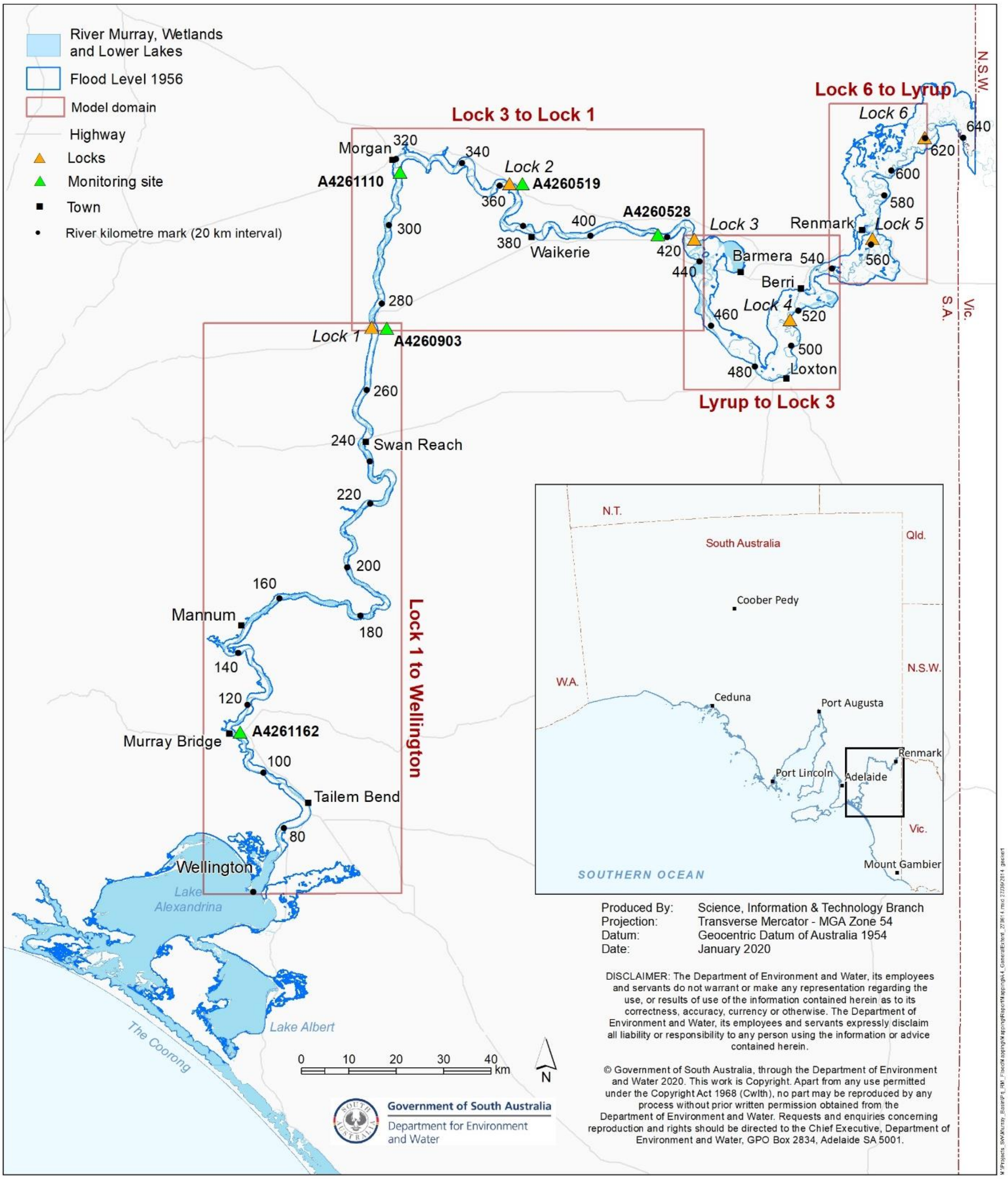
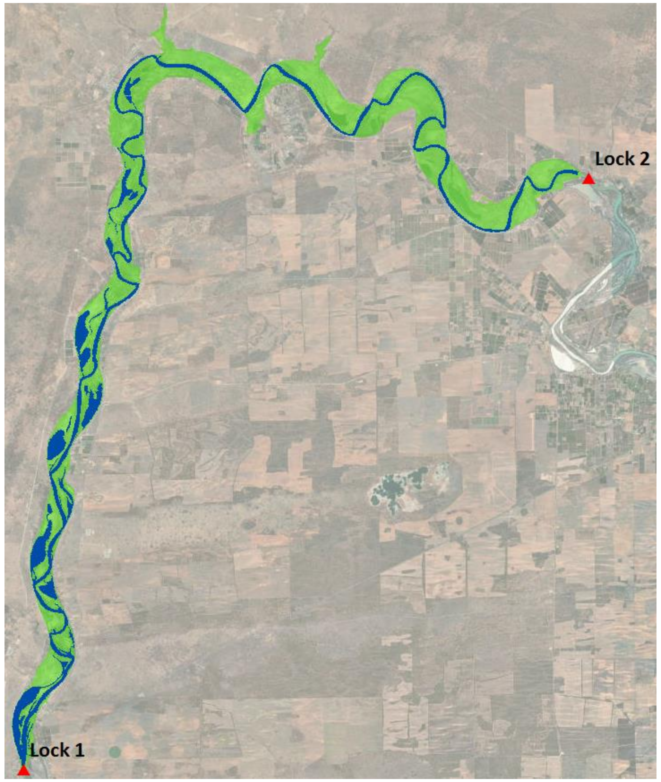


Figure 2-1 Hydrodynamic Model Extents



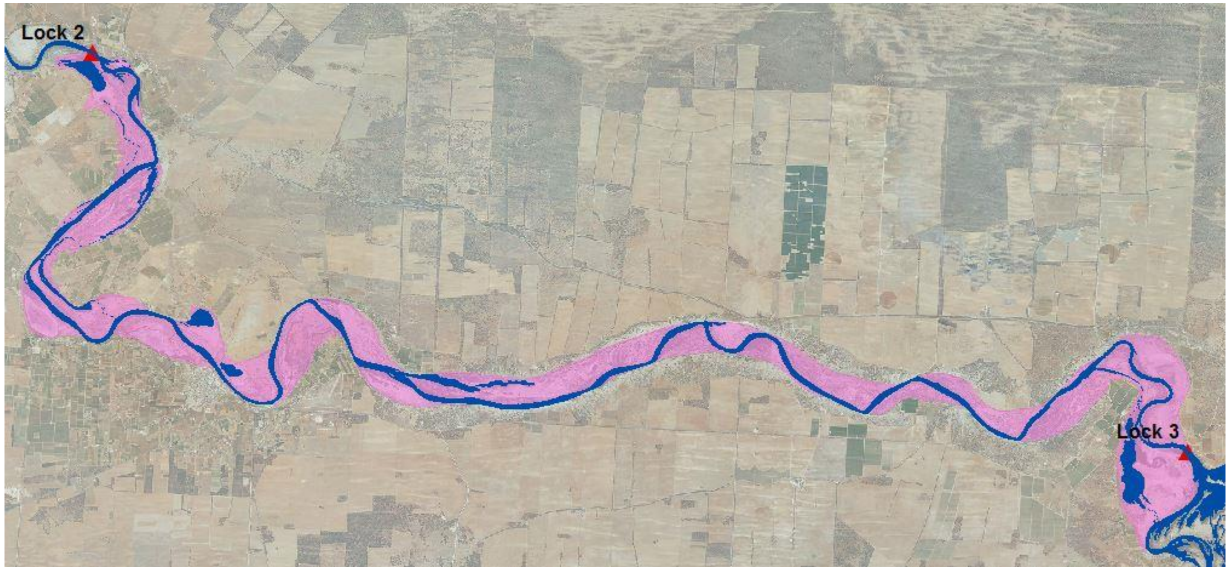
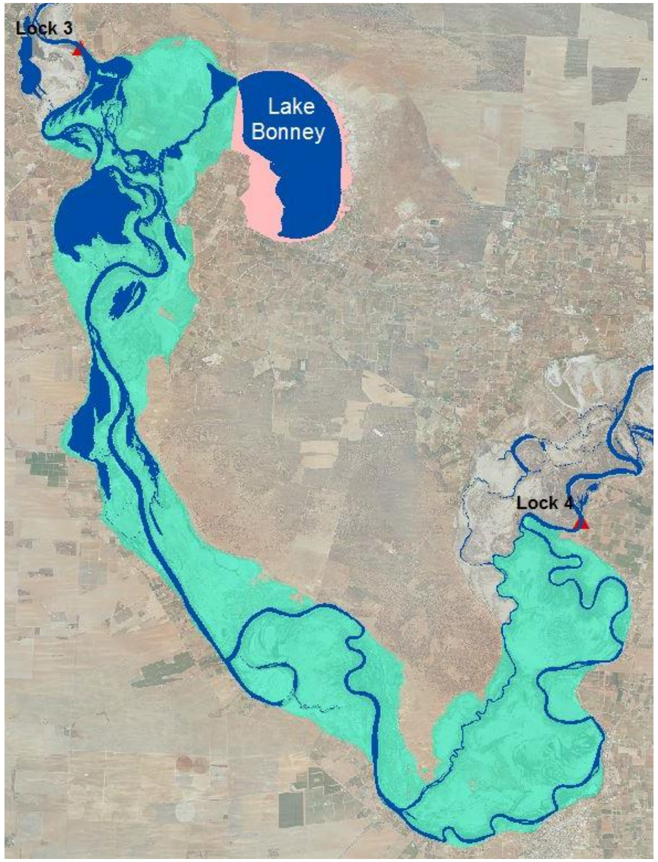
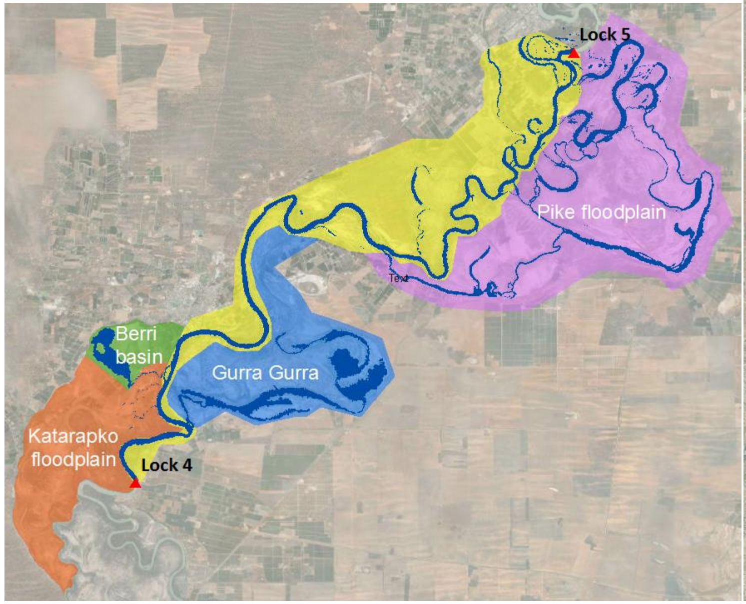


Figure 2-2 Source model extent of weir pool 1

Figure 2-3 Source model extent of weir pool 2





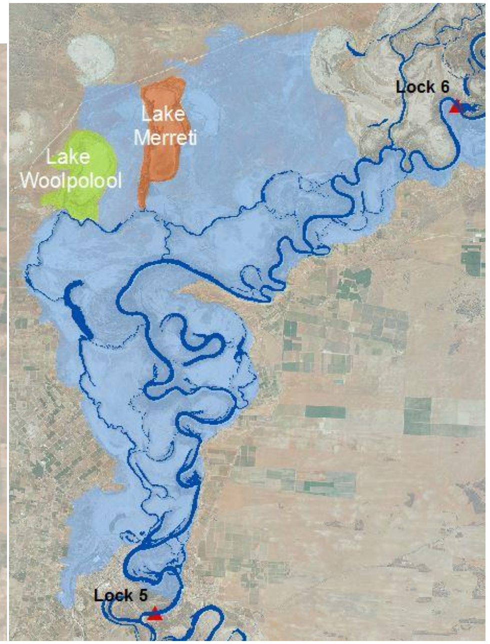


Figure 2-4 Source model extent of weir pool 3

Figure 2-5 Source model extent of weir pool 4 (yellow). The other shaded regions are represented as additional nodes.

Figure 2-6 Source model extent of weir pool 5 (blue). The other shaded regions are represented as additional nodes.

2.2.1 Bathymetry

Initial bathymetric information was derived from the 2-metre resolution digital elevation model (2 m DEM) using the geometry functions in ArcGIS. Depth-area-volume relationships for five weir pools are shown in Figure 2-7. Each relationship was generated according to the spatial extent presented in Section 2.2.

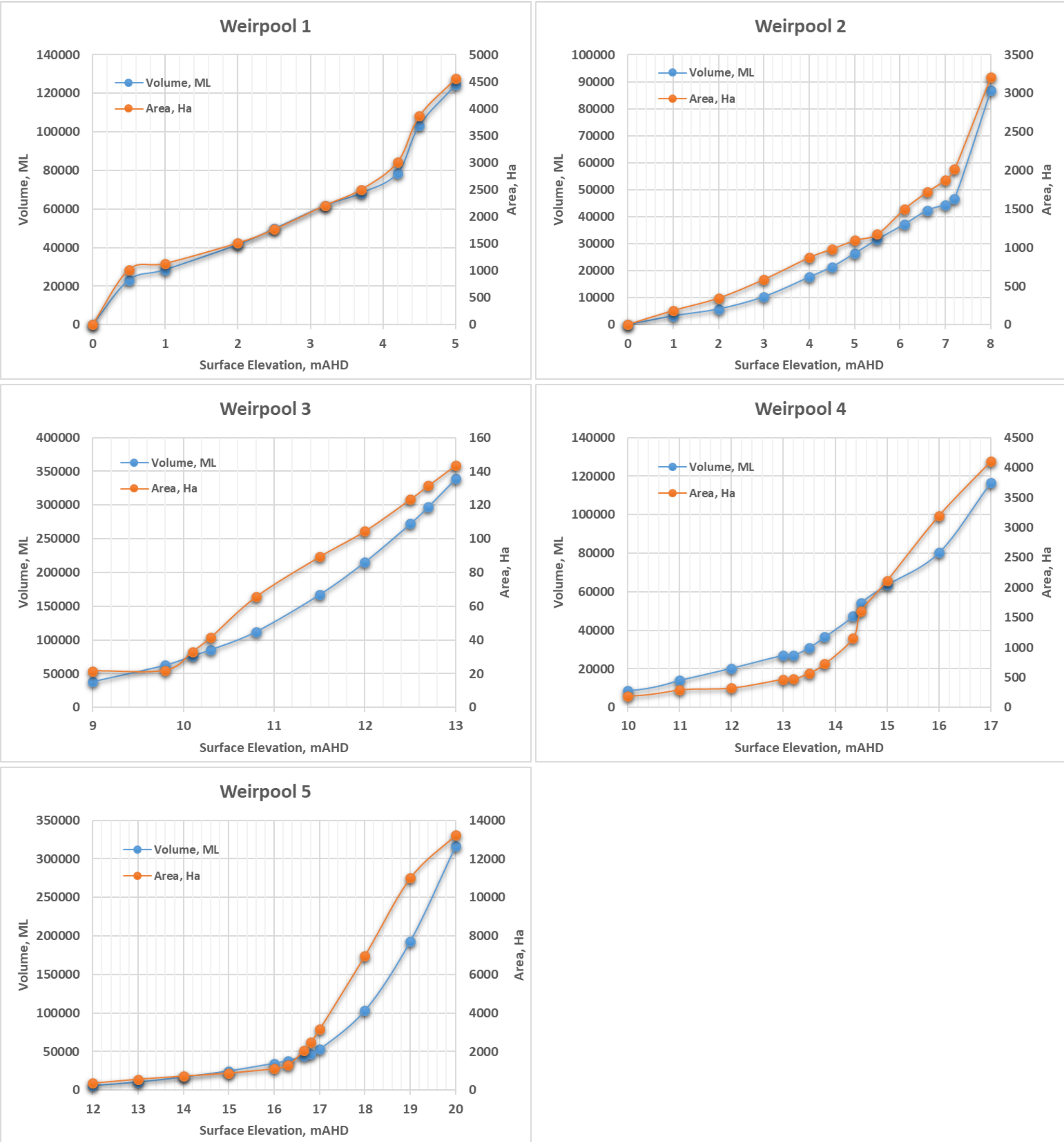


Figure 2-7 Bathymetry relationship for weir pools

2.2.2 Climate data

For the purpose of calibration against the hydrodynamic model outputs, climate data were used in the same manner in the hydrological model as was applied in the hydrodynamic model for a consistent comparison. Therefore, no rainfall was applied and a constant evaporation rate over the total inundated area of 9.5 mm/day was used to represent the maximum volume lost to evaporation per day.

2.2.3 Hydrodynamic model outputs

Numerous scenarios have been modelled using the MIKE FLOOD hydrodynamic models to provide technical information to support weir pool manipulation activities. Details of the hydrodynamic models are summarised in McCullough et al. (2017) and Montazeri and Gibbs (2018). The model runs included a range of flow rates between 5000 and 100,000 ML/day with current (i.e. with the locks controlling the water level for the range of flows where this was possible) and no structure conditions. The no structure condition represents the free-flowing river. Having no structure conditions was useful in quantifying the routing parameters for the free-flowing component of the weir nodes (see Section 2.4). Table 2.1 shows the range of weir settings that were simulated for each flow rate and Table 2-2 the downstream water level used for each no structure scenario.

In addition, results from high flow scenarios (i.e. flow greater than 100,000 ML/day) with all locks completely overtopped were used to describe the routing parameters and reach widths for these conditions. For these flows when the weirs are overtopped, weir pool manipulation is not feasible and therefore the rating curves and travel times were derived from the outputs outlined in Bloss et al. (2015).

Table 2-1 Weir pool level scenarios tested in this study

Weir	Lock 1	Lock 2	Lock 3	Lock 4	Lock 5
Normal weir level (m AHD)	3.2	6.1	9.8	13.2	16.3
Weir pool raising (m AHD)	3.7	6.6	10.1	13.5	16.8
	4.2		10.39	13.8	
				14.34	

Table 2-2 Water level (m AHD) for no structure conditions

Flow (ML/day)	Water elevation (m AHD)				
	Lock 1	Lock 2	Lock 3	Lock 4	Lock 5
5000	0.80	2.89	5.90	10.44	13.01
10000	1.13	3.36	6.35	10.97	13.34
20000	1.76	4.20	7.18	11.65	14.01
30000	2.36	4.98	7.92	12.24	14.63
40000	2.87	5.73	8.58	12.95	15.15
50000	3.54	6.50	9.16	13.59	15.62
60000	-	-	-	14.01	16.03
70000	-	-	-	14.25	16.31
80000	-	-	-	14.41	16.56
90000	-	-	-	14.54	16.76
100000	-	-	-	14.66	-

Outputs from the detailed hydrodynamic models, namely inundated areas and storage volumes, used for conceptualisation and calibration of the Source models are summarised in Appendix B. The methodology for including these hydrodynamic model outputs is outlined in the following section.

2.3 Model development

Weir nodes have been used to simulate the effect of the weir on the hydrology (flow, volume and area), which consists of a storage component due to the weir, and a free-flowing upstream reach component, due to the flow. The two components are combined assuming a triangular reach, as outlined by Close (2015). Figure 2-8 illustrates the assumption. The maximum storage on the weir has height (H), width (W) and the length of the reach (L). Areas are determined by estimating where the two plans have equal width and determining the upstream area from the flow-related area and the downstream area from the weir pool.

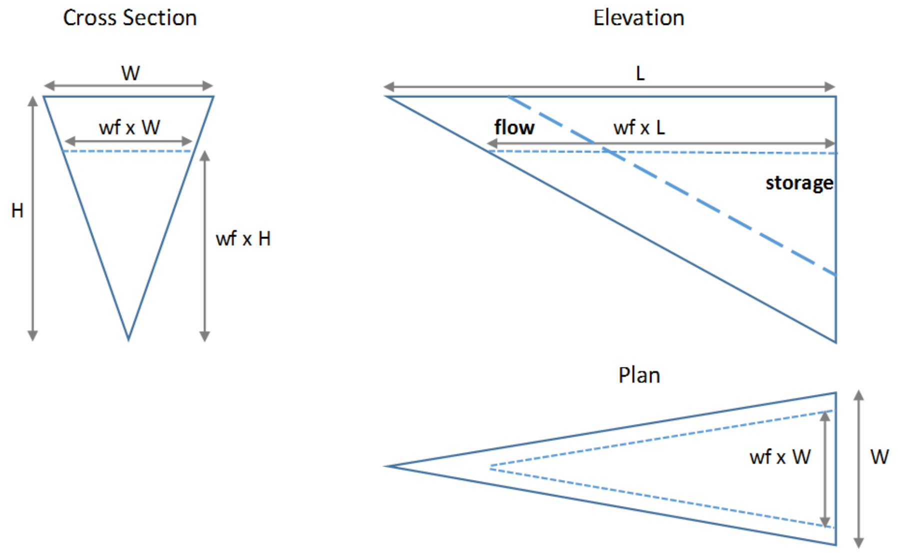


Figure 2-8 Triangular cross section representation of weir reach

Individual simple models were developed in Source (Version 4.4.2.7314_Beta) for each weir pool for the purposes of calibration. The models consisted of three nodes shown in Figure 2-9: a weir node representing each weir pool and their upstream reach, an inflow node to deliver a set of pattern of River Murray flows and a gauge node that enables weir discharge. The weir node in Source enables both the storage and upstream reach to be represented in the model.

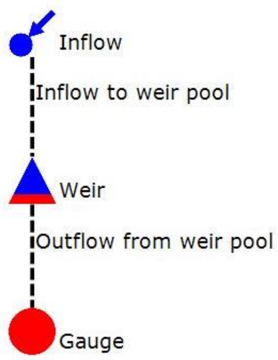


Figure 2-9 Schematic of a weir pool Source model

2.3.1 Static storage dimensions

The static storage dimensions for the weir nodes were assumed to be the 'no-flow', i.e. flat water surface, storage relationship as defined by a DEM and shown in Figure 2-7. Close (2015) noted that the triangular basin definition required specification of the maximum storage volume. As such, an additional point was included in these relationships to define the maximum volume and surface area at a level above the top of the weir structure. Figure 2-10 shows the static storage dimensions for weir pool 1 as an example.

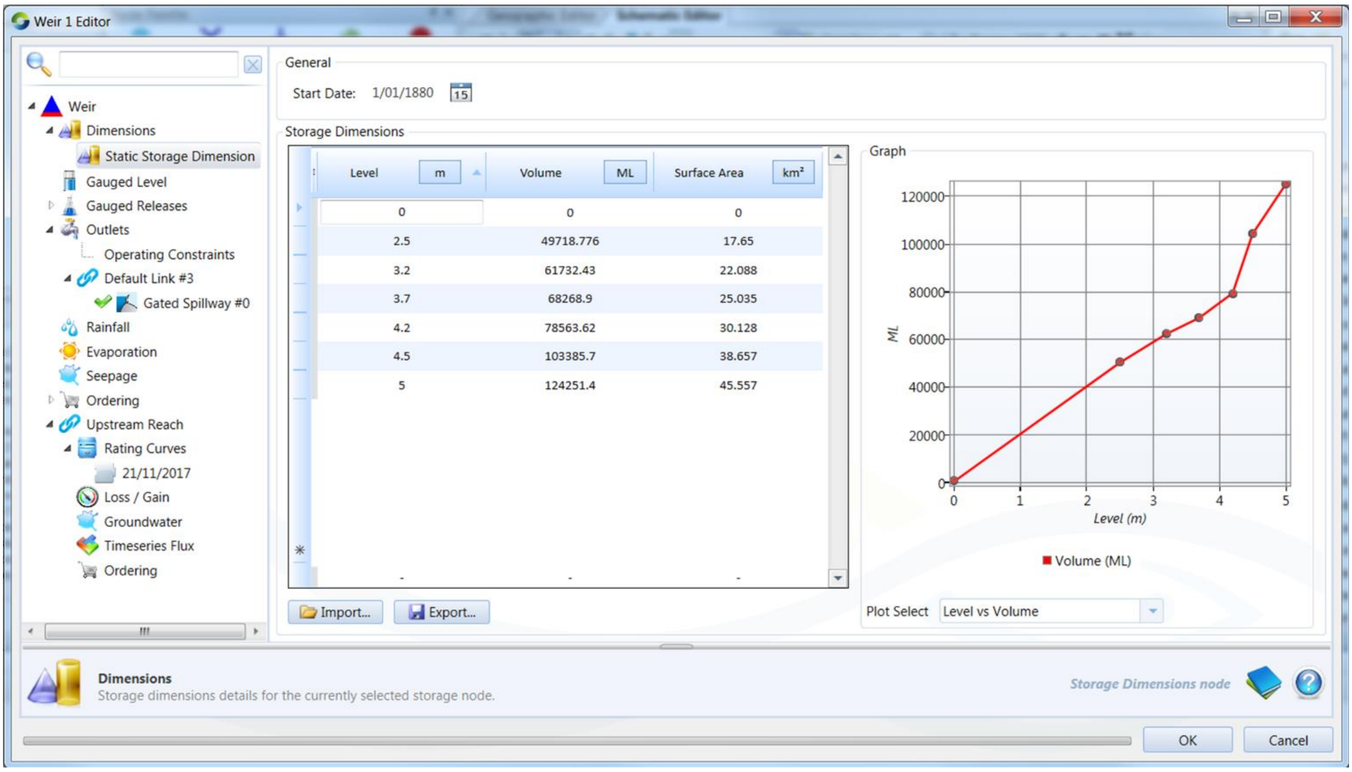


Figure 2-10 Static storage dimension of weir pool 1

2.3.2 Outflow from Lock

The gated spillways in the model were used to control releases by the operation of gates, or in practice, the stop logs within each weir. This allows a range of discharge rates up to the capacity of the river channel for a given water level. Outflow was controlled by the operation of a gated spillway which allows for a range of discharges for specified water levels. The flow and level relationships for gated spillways were developed from the observed downstream flow and water level data at each weir. Figure 2-11 shows the gated spillway parameters for Lock 1 as an example.

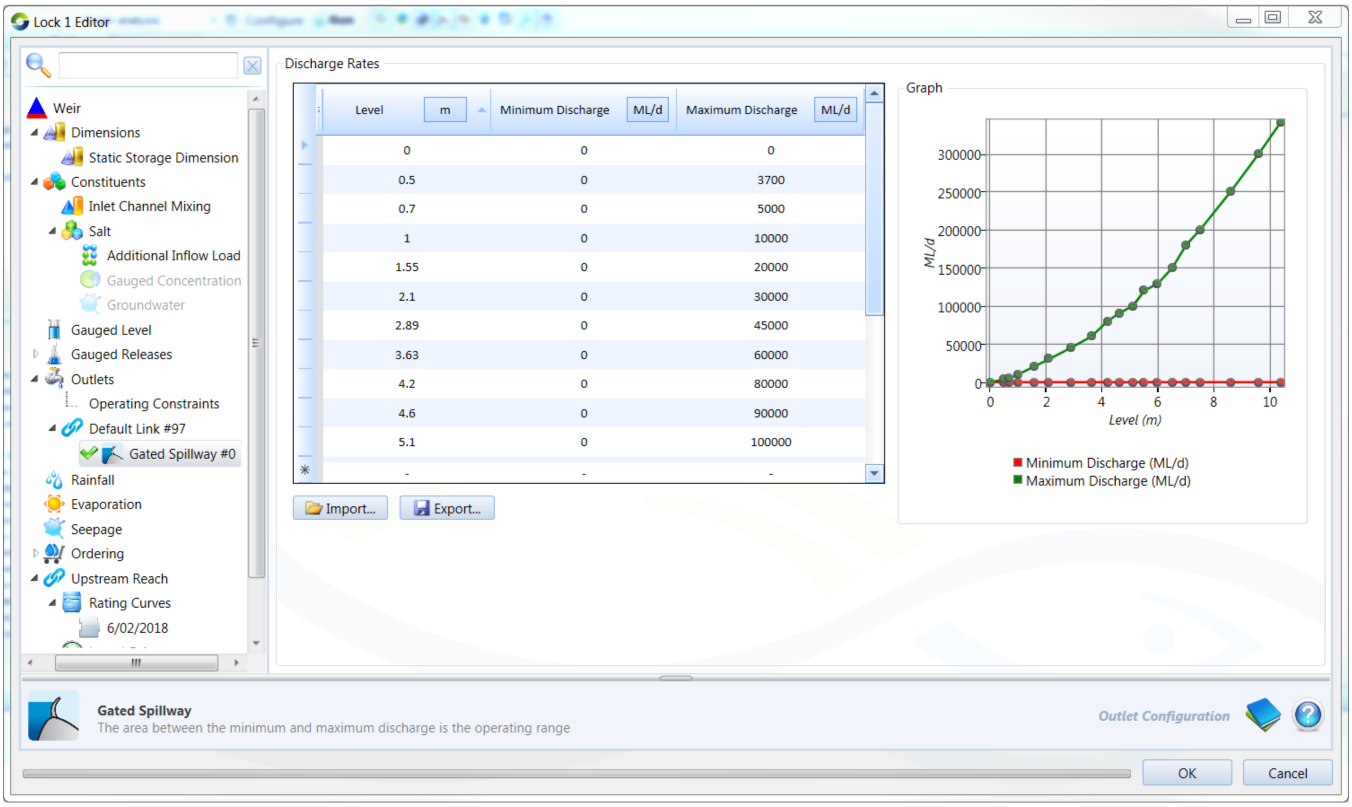


Figure 2-11 Gated spillway of weir pool 1

2.3.3 Upstream reach

The upstream reach represents the free-flowing part of the river reach. The travel time parameters were specified using a piecewise lookup table, with different travel times for increasing flows. The travel time relationship also defines the volume stored in the reach due to flow, and these volumes have been compared to the volumes from the MIKE FLOOD models.

The upstream reach also includes a rating curve that describes the relationship between flow and its inundated area, specified in Source as an average river width for the length of the reach as shown in Figure 2-12.

Initially, rating curves values (i.e. flow and surface width) and travel time values were derived from the outputs of hydrodynamic models for the 'no structure' scenarios, which represent the free-flowing river. For higher flow (i.e. flow rates of greater than 100,000 ML/day), the upstream reach width and travel times were derived from the results of previous hydraulic modelling study (Bloss et al., 2015). For the case of weirs where the total area and volume are a combination of the storage and reach components, the initial upstream reach values were adjusted to replicate the modelled inundated areas (by modifying the reach width) and volumes (by modifying the travel time) from the MIKE FLOOD models for a given upstream flow and downstream water level condition.

In order to account for the interaction between the storage components and reach components, as represented by the triangular weir assumptions in Source, other parameters must also be set for the upstream reach as shown in Figure 2-13:

- The reach length was set to the length of river between two locks, as defined by the Adopted Middle Thread Distance (river kilometre).
- The bias between inflow and outflow rate, allowing for flow attenuation, was set to 1.
- The number of reach divisions was set to double the longest travel time, which ensures numerical stability in the travel time calculations.

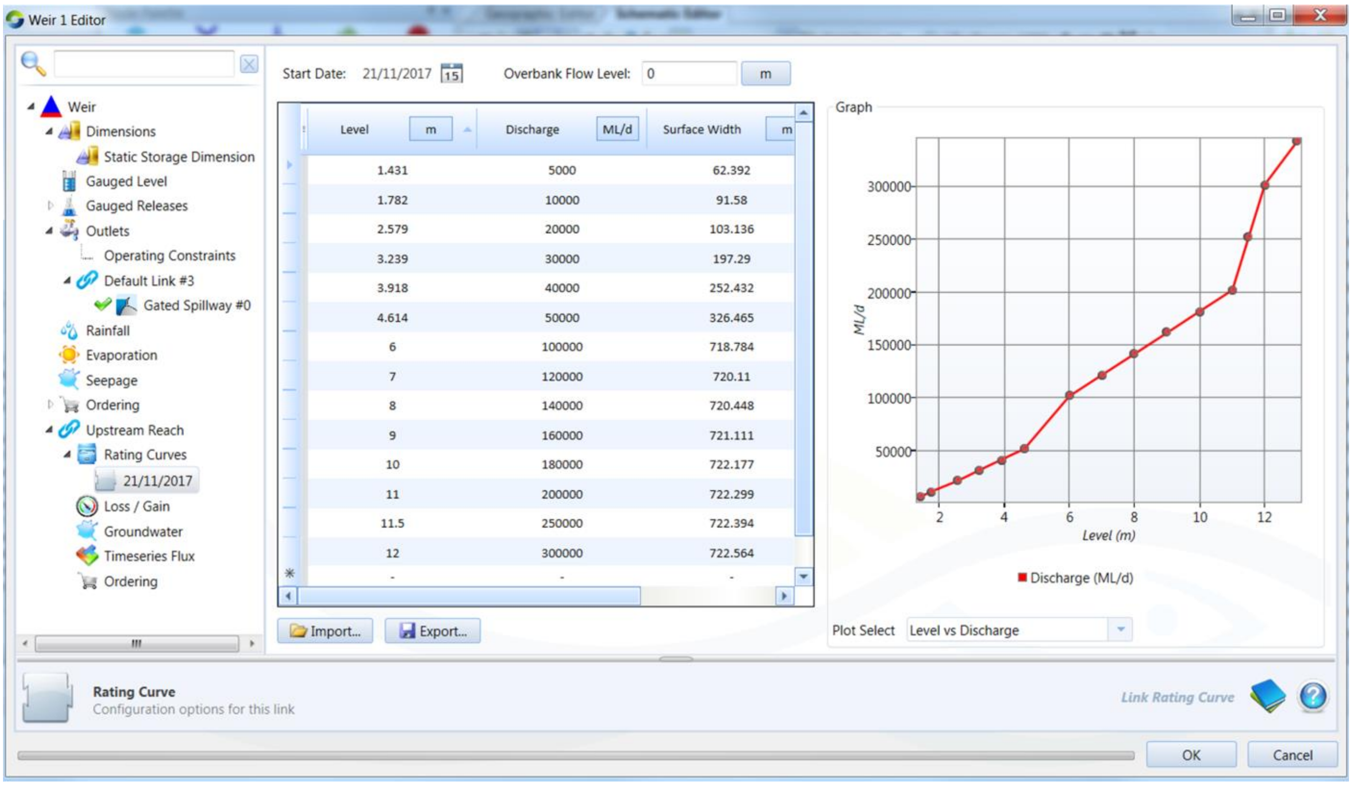


Figure 2-12 Rating curve of weir pool 1

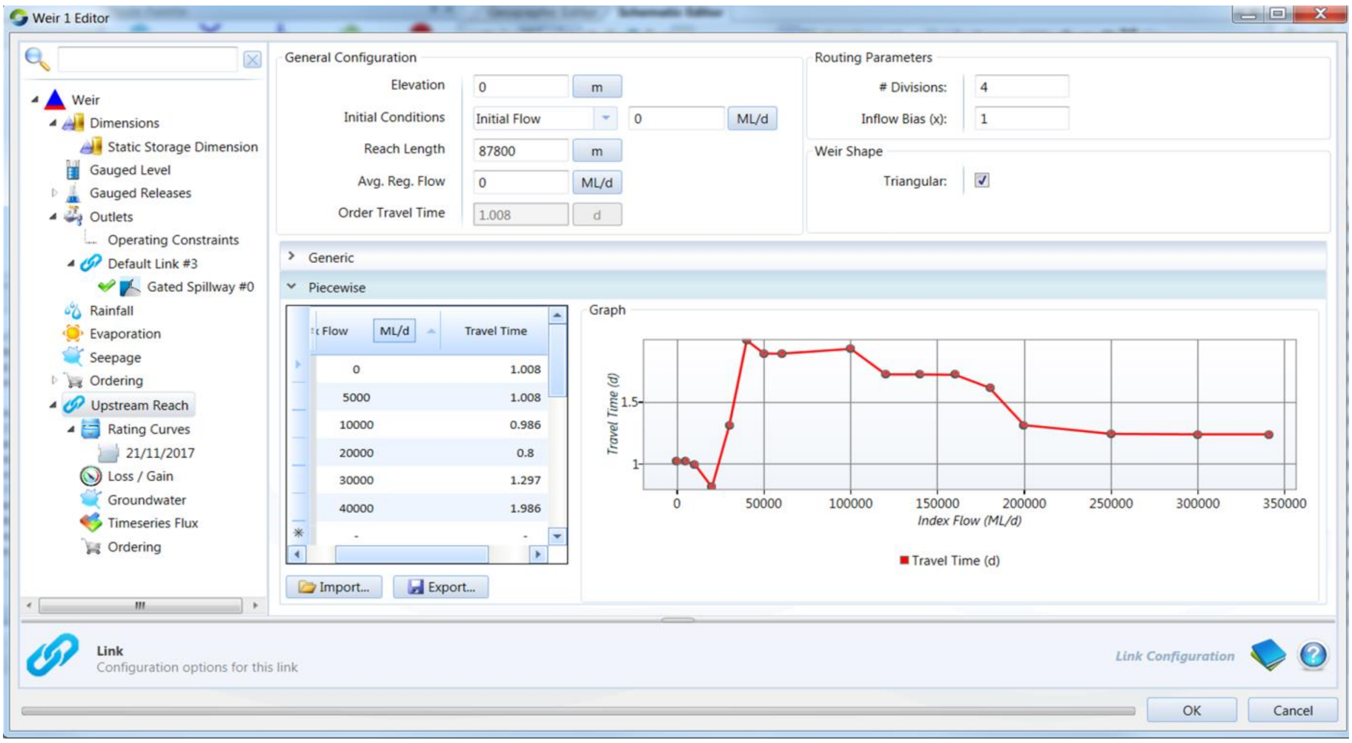


Figure 2-13 Piecewise function (i.e. routing parameters and travel time) of weir pool 1

2.4 Model calibration

Model calibration was undertaken by manually adjusting the rating curves, reach widths, travel-time tables and storage dimensions to provide the best estimates of the area and volume simulated through hydraulic modelling.

Prior to the calibration of the rating curves and piecewise function, the static storage dimension was adjusted for low flow condition as the backwater effects represented in the MIKE FLOOD outputs were not accounted for the method the bathymetry relationships were developed (Section 2.2.1). The adjustments were made for all normal pool level and weir pool raising scenarios. Then, upstream reach width and travel time were adjusted for subsequent flow rates to match the output from MIKE FLOOD, respectively, to provide a good representation across normal pool level and weir pool raising scenarios.

Travel times calibrated at lower flow rates have an effect to the travel time for higher flow rates, and thus, the values calibrated earlier were re-visited and re-adjusted if required when calibration was undertaken for increasing flow rates. All calibrated rating curves and piecewise storage functions are provided in Appendix C.

2.5 Results

Visual comparison of Source area and volume compared to that derived from MIKE FLOOD demonstrates that the results align well, as seen in Figure 2-14 to Figure 2-18. In these figures, the different colours represent different lock water levels, and within a colour the increasing area or volume corresponds to increasing flow.

The exception to this good agreement was for high flow and high weir settings at some weir nodes. This is expected to be a limitation in the triangular weir assumptions used to combine the storage and reach information in the weir node. In the calibration process, priority was given to situations considered to be more common, normal pool level and weir pool raisings at lower flows (e.g. 20,000 ML/day and below). To improve the model agreement at high flow and high weir settings, the Source functionality could be extended to use a more flexible approach to combine the storage and reach information, for example allowing for input of a representative cross-section, as opposed to assuming a triangular representation. However, given the good agreement between Source and MIKE FLOOD in most cases, this extension is not considered necessary at this time.

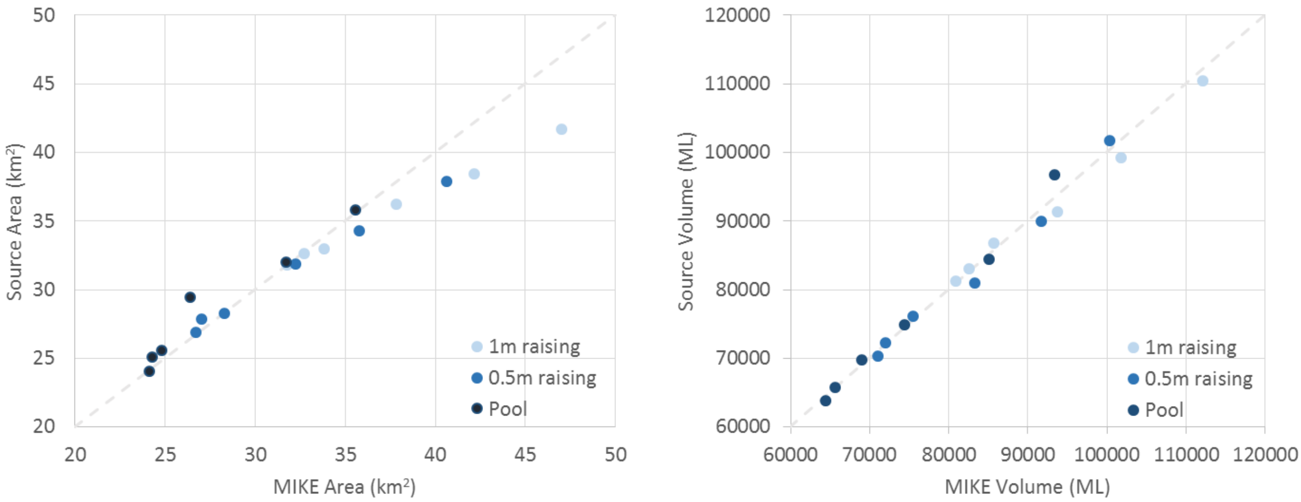


Figure 2-14 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for weir pool 1

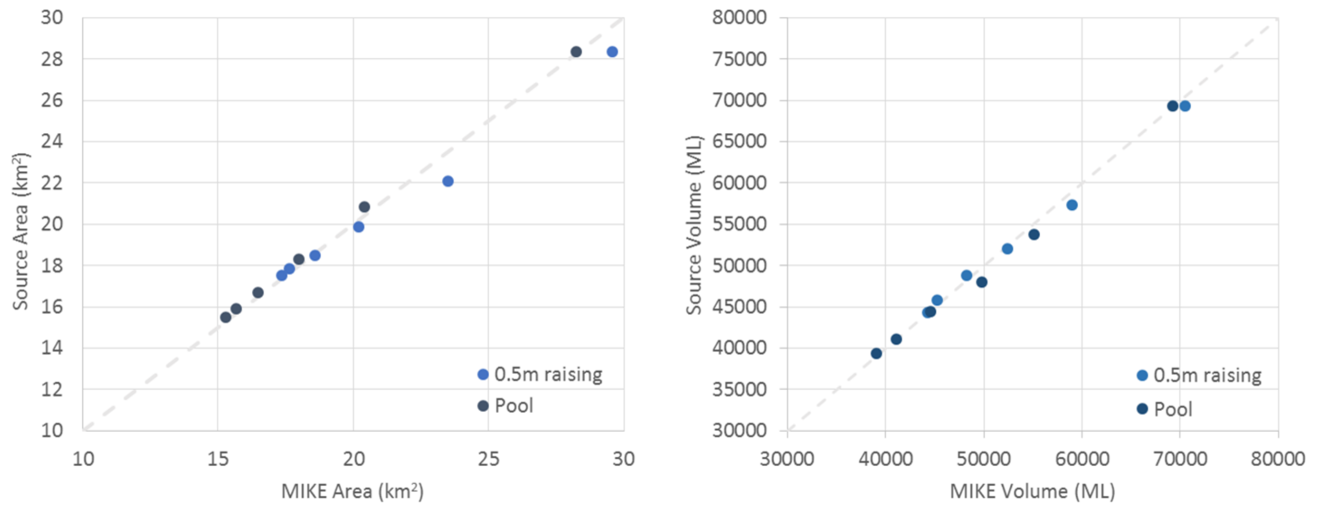


Figure 2-15 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for weir pool 2

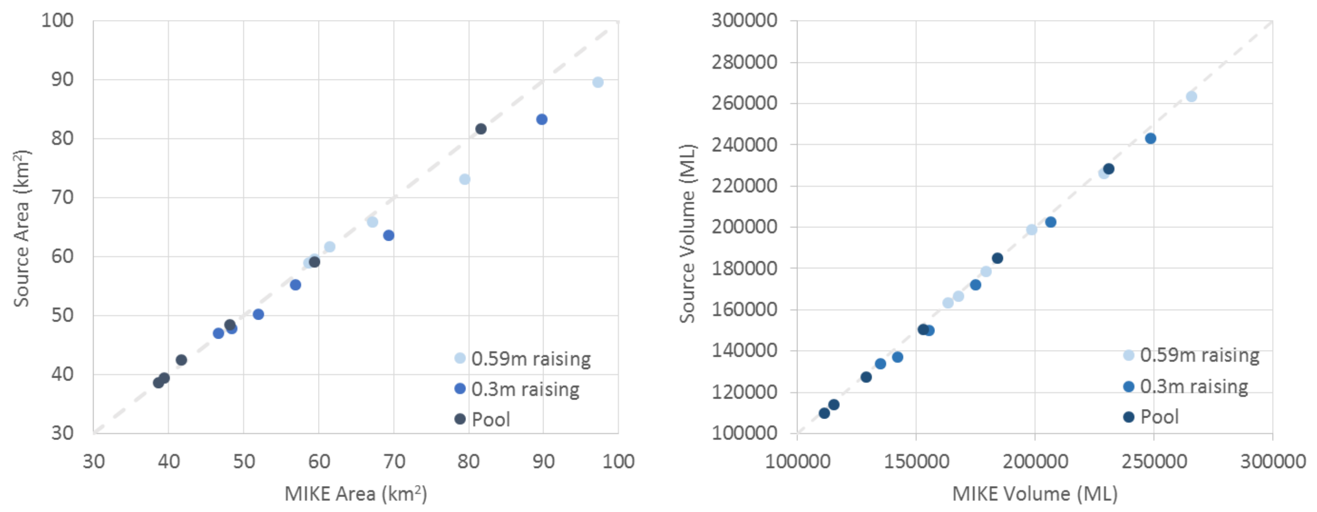


Figure 2-16 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for weir pool 3

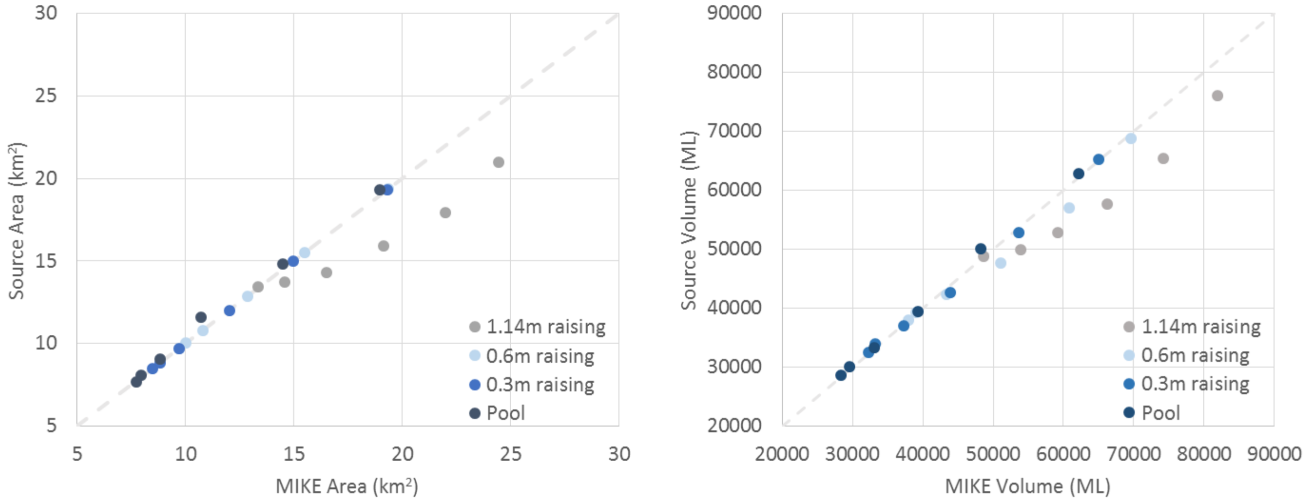


Figure 2-17 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for weir pool 4

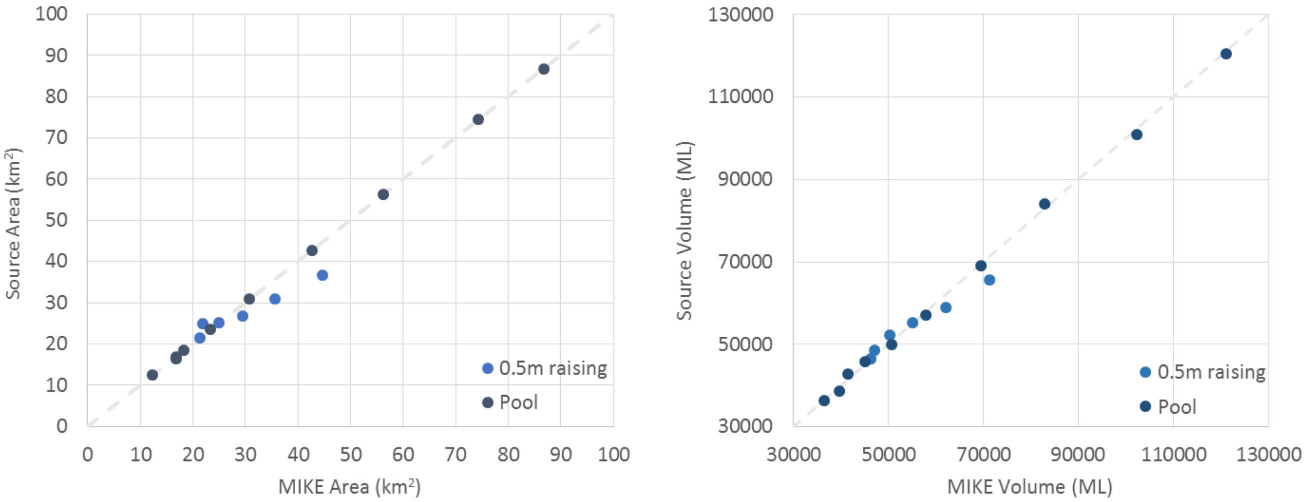


Figure 2-18 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for weir pool 5

3 Floodplain Source models

The purpose of this section is to document the development and calibration of hydrological models representing Pike, Katarapko and Chowilla floodplains.

3.1 Pike Floodplain

3.1.1 Introduction

The Pike Floodplain is an anabranch of the River Murray located in the vicinity of Renmark, South Australia. Its main inlets are located upstream of Lock 5, with return flows re-entering the River Murray on the downstream side of Lock 5. Figure 3-1 shows the main creeks and structures associated with the floodplain. Owing to the general degradation of the floodplain condition over time, the South Australian Riverland Floodplains Integrated Infrastructure Program (SARFIIP) has been undertaken to improve the flexibility of managing the system via new infrastructure and operational solutions.

Hydrodynamic modelling of the Pike Floodplain, using the MIKE FLOOD platform, was conducted as part of the investigations under SARFIIP, with specific scenarios designed to provide insights into a range of important design and management decisions, including: the location of blocking banks alignment; design of infrastructure; and potential benefits and risks associated with various managed and natural hydraulic scenarios. The details of the hydraulic models are summarised in McCullough et al. (2015a, 2016 and 2017).

Results from these hydrodynamic scenarios have been used to construct and calibrate a hydrological model of the Pike Floodplain using the eWater Source platform.

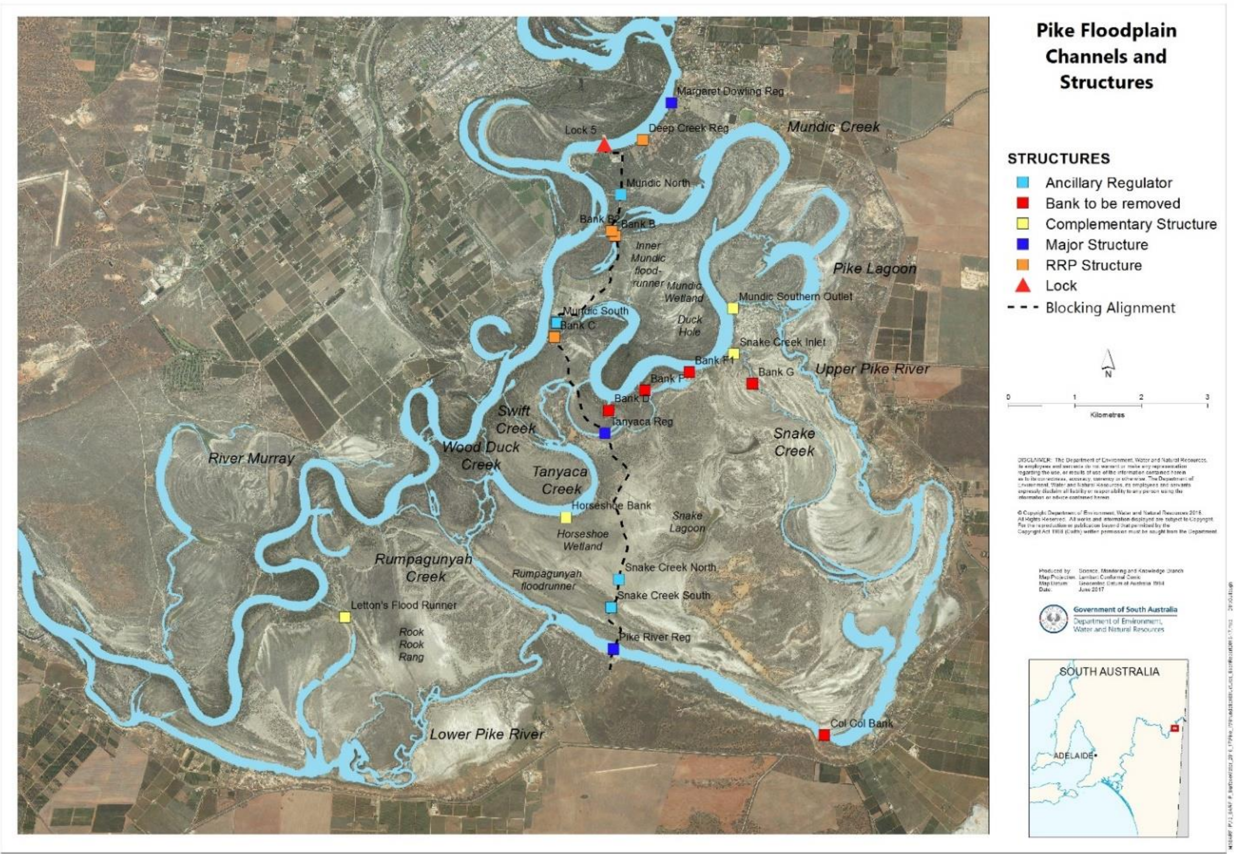


Figure 3-1 Pike Floodplain (McCullough et al., 2017)

3.1.2 Pike hydrology

The Pike Floodplain bypasses Lock 5 that presents the opportunity to manipulate water levels in the floodplain using artificial head difference created across the Lock. Under normal conditions, water permanently enters the Pike Floodplain upstream of Lock 5 through Margaret Dowling Creek and Deep Creek. Water also enters the Pike Floodplain downstream of Lock 5 via Banks B and C when flow at Lock 5 exceeds 35,000 ML/day and below the blocking bank through Wood Duck and Swift Creeks when flow exceeds 25,000 ML/day. Rumpagunyah Creek is permanently connected but can act as either an inlet or outlet depending on flow water levels between the floodplain and the River Murray. Further south, water also enters Lower Pike River via Letton’s flood runner when flow exceeds 35,000 ML/day at Lock 5.

The two main Pike environmental regulators (Pike River Regulator and Tanyaca Regulator) and blocking banks were designed through SARFIIP to retain operational control up to 16.4 m AHD to improve the ecological condition through increased inundation frequency and duration. To achieve this operational level, it is necessary to raise Lock 5, preferably to the top of its piers (16.8 m AHD), to maintain hydraulic grade during the peak of the operational hydrograph. Raising Lock 4 also provides additional inflows to the Lower Pike River below the blocking bank, by increasing the flow into the floodplain through Swift, Wood Duck and Rumpagunyah Creeks to provide additional dilution.

3.1.3 Data

3.1.3.1 Bathymetry data

Bathymetric information was derived from a 2 m DEM using the geometry functions in ArcGIS. Depth-area-volume relationships for two sections upstream of blocking banks are shown in Figure 3-2.

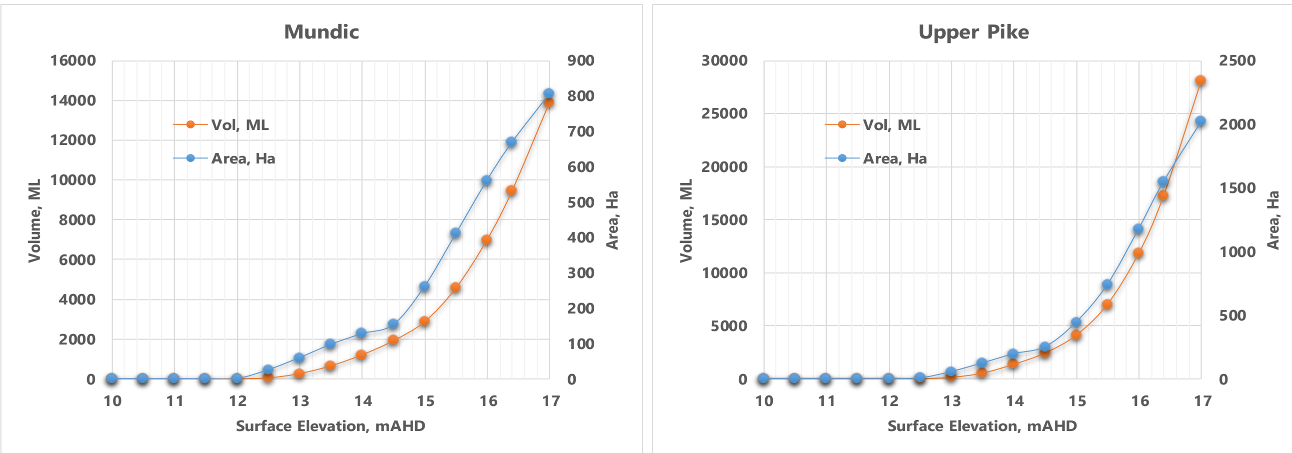


Figure 3-2 Bathymetry relationships for Pike Floodplain

3.1.3.2 Climate data

For the purpose of model calibration, climate data were used in the same manner as was applied in the hydrodynamic model for a consistent comparison. Therefore, no rainfall was applied and the maximum daily evaporation rate (9.5 mm/day for January from the nearest Bureau of Meteorology weather station at Loxton) was applied at a constant rate over the total inundated area to provide volume lost to evaporation per day.

3.1.3.3 Hydrodynamic model outputs

Numerous scenarios have been modelled using the hydrodynamic model MIKE FLOOD to provide technical information to support the investigation phase of SARFIIP. The detailed model runs have included a range of River Murray flows and operating levels at the environmental regulators and locks. A number of key outputs from the detailed hydrodynamic models used for construction and calibration of the Source model of the Pike Floodplain include flow and water level at the environmental regulators and Locks, as well as volume and inundation area within the areas impounded by the blocking bank alignments.

3.1.4 Model development

Model construction was a process of:

- Characterising bathymetry of the floodplain.
- Creating and parameterising nodes and links to represent the hydrological components.
- Defining the interactions between the various processes of the hydrological cycle included in the model.

The Pike Floodplain model has been constructed by defining three main sections: Mundic, Upper Pike and Lower Pike as shown in Figure 3-3. As discussed, two key environmental regulators have been designed through SARFIIP that manage flow and water level, together with blocking banks, throughout Pike Floodplain under all operational phases. Therefore, two nodes (a weir node representing Mundic and a storage node representing Upper Pike) are required to simulate the separate capacity and operations of these two regulators upstream of blocking banks. Depth-area-volume relationships for each section were derived from a 2 m DEM (see Section 3.1.3.1). The section downstream of blocking banks (Lower Pike) is represented by two controlled splitters that simulate movement of water through the complex of Swift, Wood duck and Rumpagunyah Creeks and also Lower Pike River.

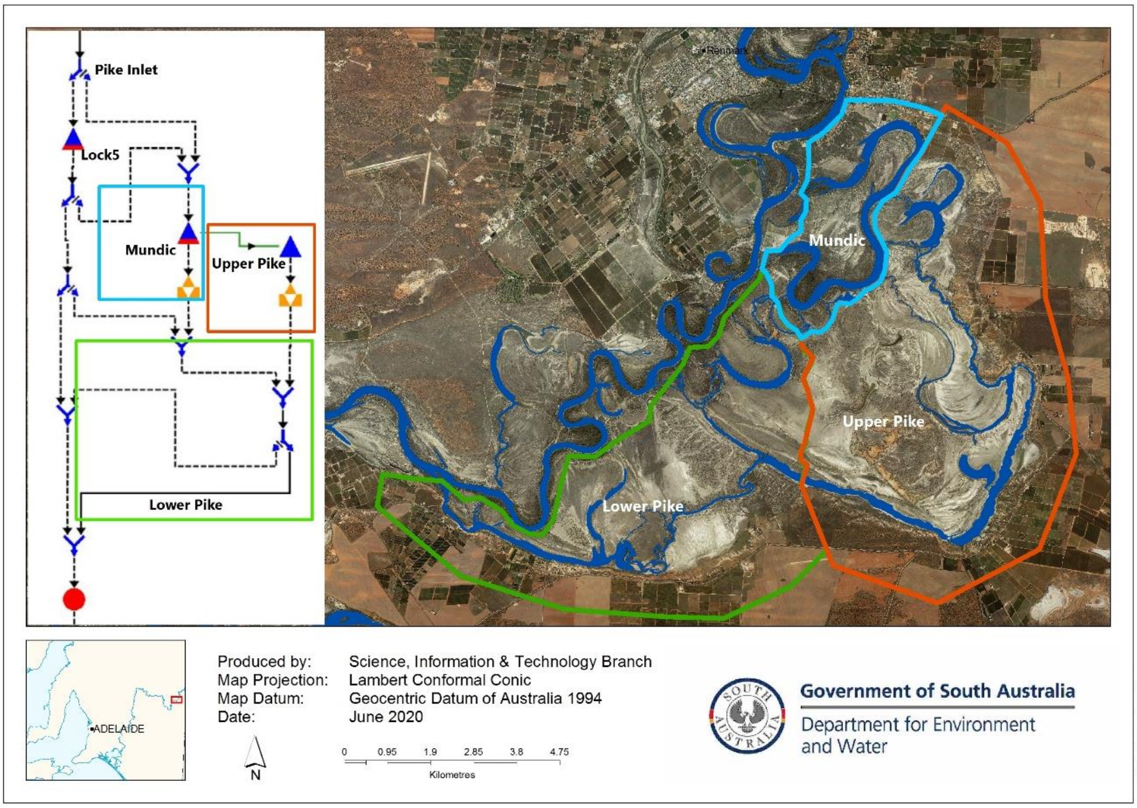


Figure 3-3 Schematic of Source model

3.1.4.1 Storage / Weir node

Storage nodes were used to simulate the water balance model for Lock 5 and floodplain regulators. Input data required for the water balance model include:

- Depth-area-volume relationship.
- Rainfall and evaporation data for the floodplain location.
- Loss rate from the floodplain.
- Operating details.
- Spillway and outlet capacity information.
- Routing Parameters (in the case of a weir node).

Spillways were configured based on hydrodynamic model outputs (i.e. modelled flow and water level downstream of regulators) to represent outlet capacity at different upstream water levels.

MIKE FLOOD outputs for each of the storages were interrogated to determine if a weir node was required, where water level alone was not enough to explain change in area and volume, and the effect of flow also needed to be taken into account, which was only the case for the Mundic section. In order to represent both total volume and inundated area upstream of the storages two further components were calibrated in each storage:

- A rating curve was used to describe the physical characteristics of the upstream reach and convert flow into a level and consequently to the inundated area.
- A piecewise storage function which specifies travel time for a range of index flows. This travel time influences the volume stored upstream of the blocking bank alignment.

Rating curves and piecewise storage functions used to calibrate the hydrological model are provided in Appendix C.

3.1.4.2 Controlled splitter node

The inlets to Pike Floodplain are regulated and as such can be controlled independently from river level and flow. Therefore, controlled splitter nodes were used to split the river flow and water diverting into the floodplain. These nodes distribute flow down main (River Murray) and effluent (floodplain inlet) branches according to a fixed percentage that can be a function of flow. Four controlled splitter nodes are used for Pike Floodplain. One splitter node represents the combined inflow from both Margaret Dowling Creek and Deep Creek, one represents the Bank B and C complex downstream of Lock 5 and two splitters were used to represent the complex downstream of the blocking banks.

3.1.5 Model calibration

Numerous runs of hydraulic models have been undertaken to develop sufficient information for calibration of the hydrological model. Model calibration was undertaken by adjusting the rating curves, piecewise storage function and routing parameters within storage nodes to provide the best estimates of the flow, water level, area and volume outputs obtained through hydraulic modelling. As these structures are under construction at the time of writing, there is no observed data available for the purpose of model calibration or validation. A visual comparison of model outputs demonstrates that the results are reasonable, as shown in Figure 3-4 and Figure 3-5.

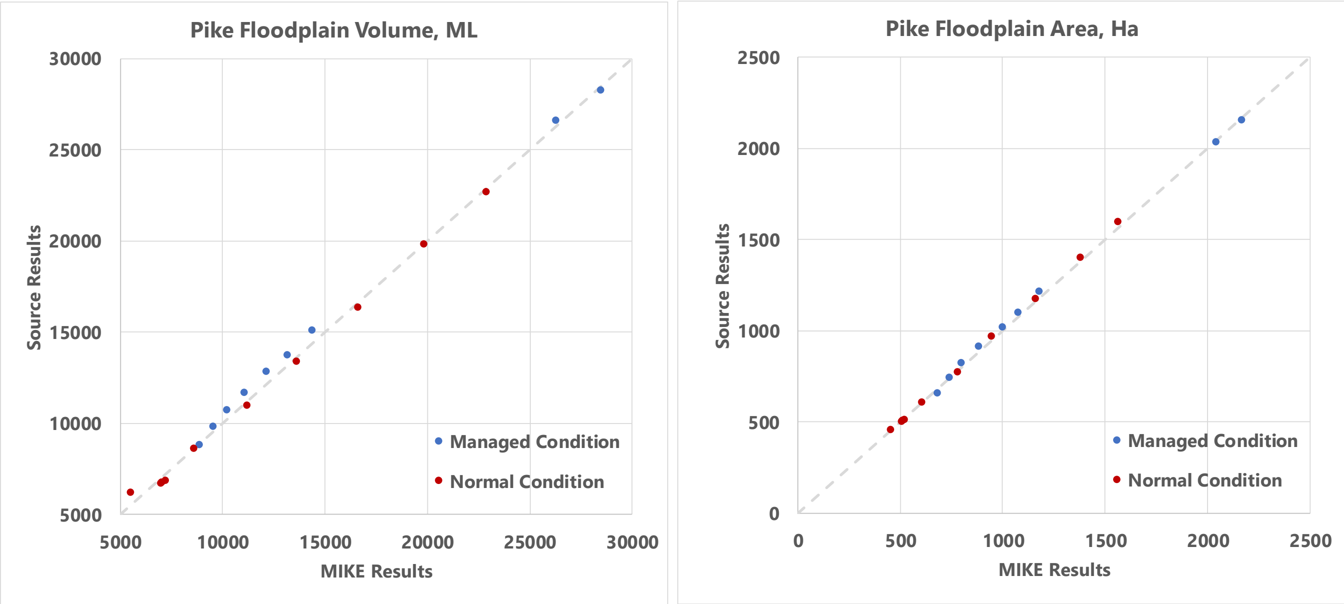


Figure 3-4 Comparison of MIKE FLOOD and Source model outputs – total inundated areas and storage volume upstream of blocking banks, for Pike Floodplain

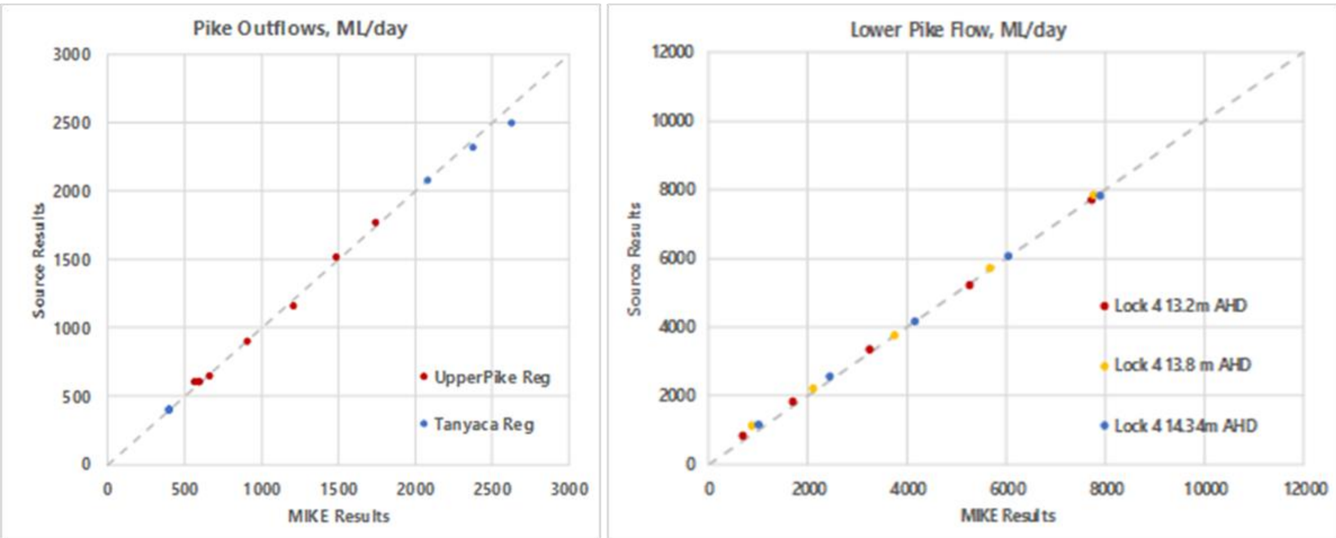


Figure 3-5 Comparison of MIKE FLOOD and Source model outputs – Pike Outflows through environmental regulators (left), flow at Lower Pike (right)

3.2 Katarapko Floodplain

3.2.1 Introduction

Katarapko Floodplain is an anabranch of the River Murray located in the vicinity of Loxton, South Australia. Its main inlets are located upstream of Lock 4, with return flows re-entering the River Murray on the downstream side of Lock 4 through Katarapko Creek. Figure 3-6 shows the main creeks and structures associated with the floodplain. A number of structures and banks have been constructed over the years, both internal and external to the floodplain, which have modified the natural hydraulics of the system and resulted in a general degradation of the ecological condition of the floodplain and associated wetlands.

Hydrodynamic modelling of the Katarapko Floodplain (using the MIKE FLOOD platform) was conducted as part of the investigations under SARFIIP, with specific scenarios designed to provide insights into a range of important design and management decisions, including the location of blocking banks alignment, design of infrastructure and potential benefits and risks associated with various managed and natural hydraulic scenarios. The details of the hydraulic models are summarised in McCullough et al. (2014a, 2014b and 2017).

Results from these hydrodynamic scenarios have been used to construct and calibrate hydrological model of Katarapko Floodplain using the eWater Source platform.

3.2.2 Katarapko Hydrology

The major inlets for the Katarapko Floodplain are Banks N, K and J which are upstream of Lock 4. Water flows from the main channel into Eckerts creeks via the North Arm, South Arm and the main Eckerts Creek. These flows bypass Lock 4 and then discharge into Katarapko Creek downstream of The Splash. Katarapko Creek leaves the main channel downstream of Lock 4 and then returns back to the River Murray. As Eckerts Creek Anabranch bypasses Lock 4 there is a head gradient of ~3.5 m between the main Eckerts Creek inlet (Bank J) and the confluence of Katarapko Creek and the River Murray. As a result of this hydraulic head, Katarapko Floodplain encompasses a range of diverse aquatic habitats incorporating permanent fast-flowing and slow-flowing creeks, in addition to backwaters.

The main environmental regulator (Splash Regulator) and blocking banks were designed through SARFIIP to retain operational control up to 13.5 m AHD to improve the ecological conditions through increased inundation frequency and duration. To achieve this operational level, it will be required to raise Lock 4, to at least 13.8 m AHD, to maintain hydraulic grade during the peak of the operational hydrograph.

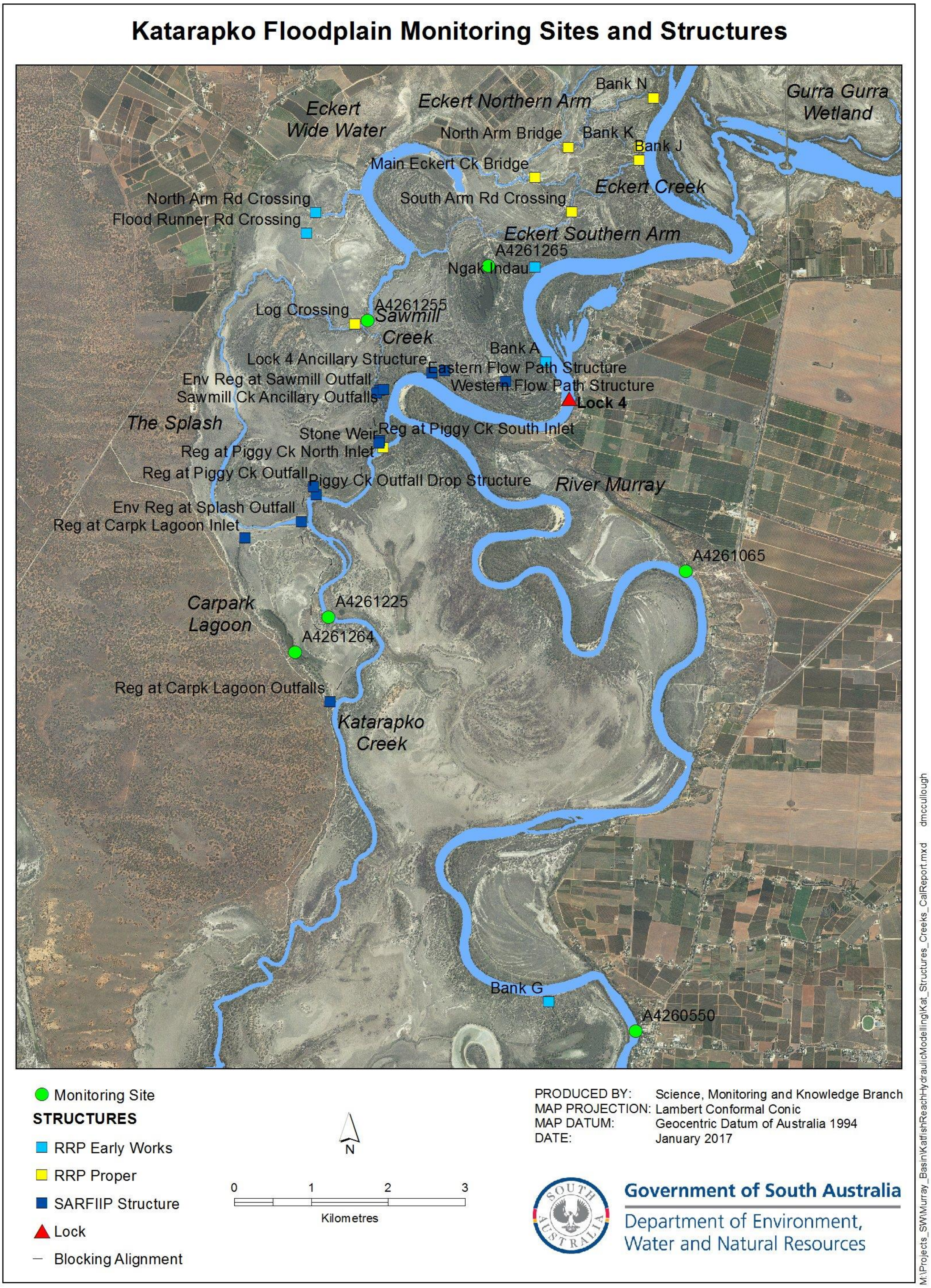


Figure 3-6 Katarapko Floodplain creeks and structures from McCullough et al. (2017)

3.2.3 Data

3.2.3.1 Bathymetry data

Bathymetric information was derived from a 2 m DEM using the geometry functions in ArcGIS. Depth-area-volume relationship for the floodplain upstream of blocking banks are shown in Figure 3-7.

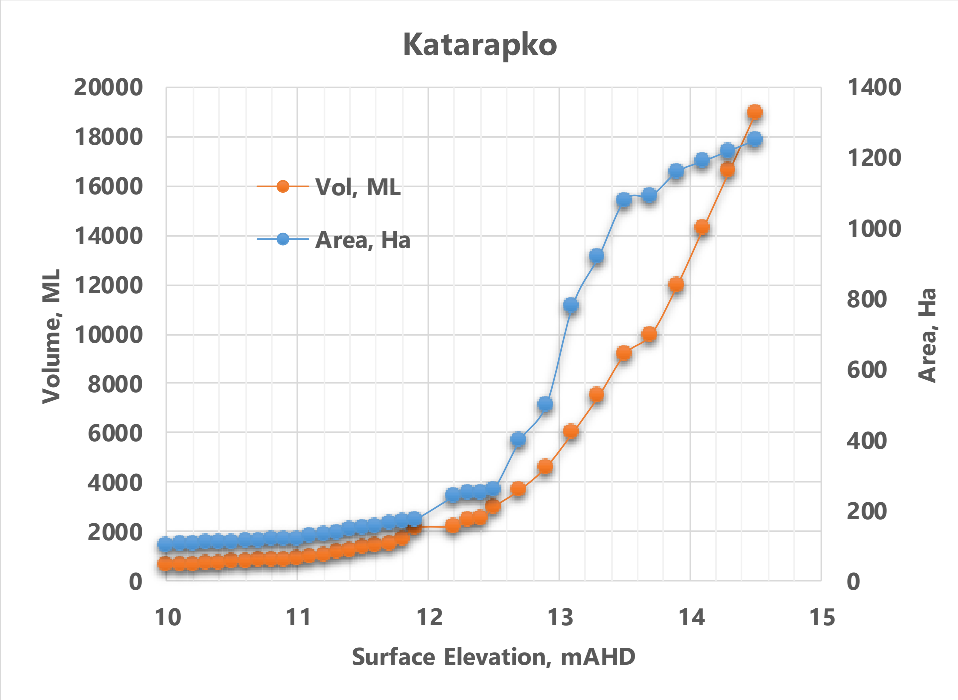


Figure 3-7 Bathymetry relationships for Katarapko Floodplain

3.2.3.1 Climate data

For the purpose of model calibration, climate data were used in the same manner as was applied in the hydrodynamic model for a consistent comparison. Therefore, no rainfall was applied and the maximum daily evaporation rate (5.3 mm/d for January from the nearest Bureau of Meteorology weather station at Lyrup) was applied at a constant rate over the total inundated area to provide volume lost to evaporation per day.

3.2.3.2 Hydrodynamic model outputs

Numerous scenarios have been modelled using the MIKE FLOOD hydrodynamic model to provide technical information to support the investigation phase of SARFIIP. The detailed model runs have included a range of River Murray flows and operating levels at the environmental regulators and locks. A number of key outputs from the detailed hydrodynamic models used for construction and calibration of the Source model for the Katarapko Floodplain included: flow and water level at the environmental regulator and lock, volume and inundation area within the areas impounded by the blocking bank alignments.

3.2.4 Model development and calibration

Model construction was a process of:

- Characterising bathymetry of the floodplain.
- Creating and parameterising nodes and links to represent the hydrological components.
- Defining the interactions between the various processes of the hydrological cycle included in the model.

The Katarapko Floodplain model has been represented by one weir node shown in Figure 4-2, for the floodplain upstream of the blocking banks shown in Figure 3-8.

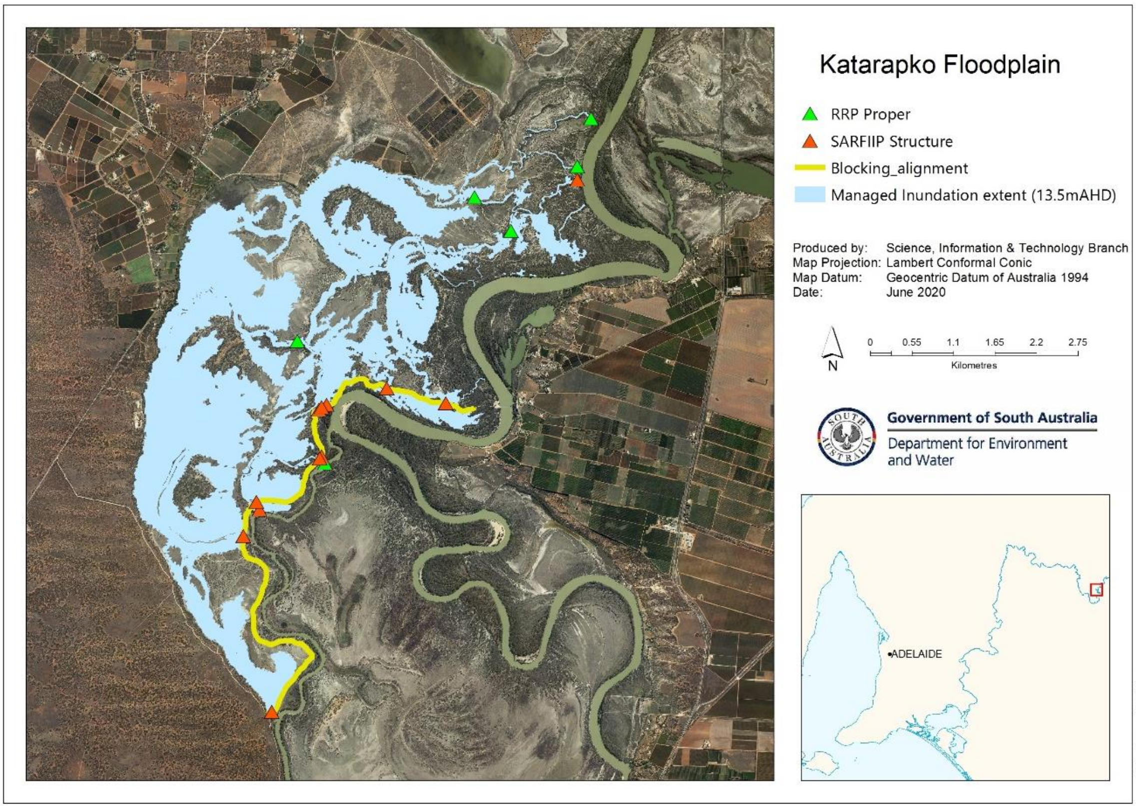


Figure 3-8 Katarapko Floodplain

3.2.4.1 Weir node

Input data required for the water balance model include:

- Depth-area-volume relationship.
- Rainfall and evaporation data for the floodplain location.
- Loss rate from the floodplain.
- Operating details.
- Spillway and outlet capacity information.
- Routing Parameters.

Spillways were configured based on hydrodynamic model outputs (i.e. modelled flow and water level downstream of regulators) to represent the combined outlet capacity at different water levels.

Once inflows to the floodplain were calculated, the model applied hydrologic routing to calculate level, volume and inundation area for each floodplain storage. In order to represent both total volume and inundated area upstream of the storage two further components were calibrated:

- A rating curve was used to describe the physical characteristics of the upstream reach and convert flow into a level and consequently to the inundated area.

- A piecewise storage function which specifies travel time for a range of index flows. This travel time influences the volume stored upstream of the blocking bank alignment.

Rating curves and piecewise storage functions used to calibrate the hydrological model are provided in Appendix C.

3.2.4.2 Controlled splitter node

The inlets to Katarapko Floodplain are regulated and as such can be controlled independently from river level and flow. Therefore, controlled splitter nodes were used to split the river flow and water diverted into the floodplain. These nodes distribute flow down main (River Murray) and effluent (floodplain inlets) branches according to a fixed percentage that can be a function of flow.

3.2.5 Model calibration

Numerous runs of hydraulic models have been undertaken to develop sufficient information for calibration of the hydrological model. Model calibration was undertaken by adjusting the rating curves, piecewise storage function and routing parameters within storage nodes to provide the best estimates of the flow, water level, area and volume outputs provided through hydraulic modelling. Visual comparison of model outputs demonstrates that the results are reasonable, as shown in Figure 3-9. The exception was for low level operations. Bathymetric information does not match model assumptions with inundation occurring closer to the blocking banks. Larger inundation areas were prioritised in the calibration, which correspond to planned operations and potentially larger magnitude errors.

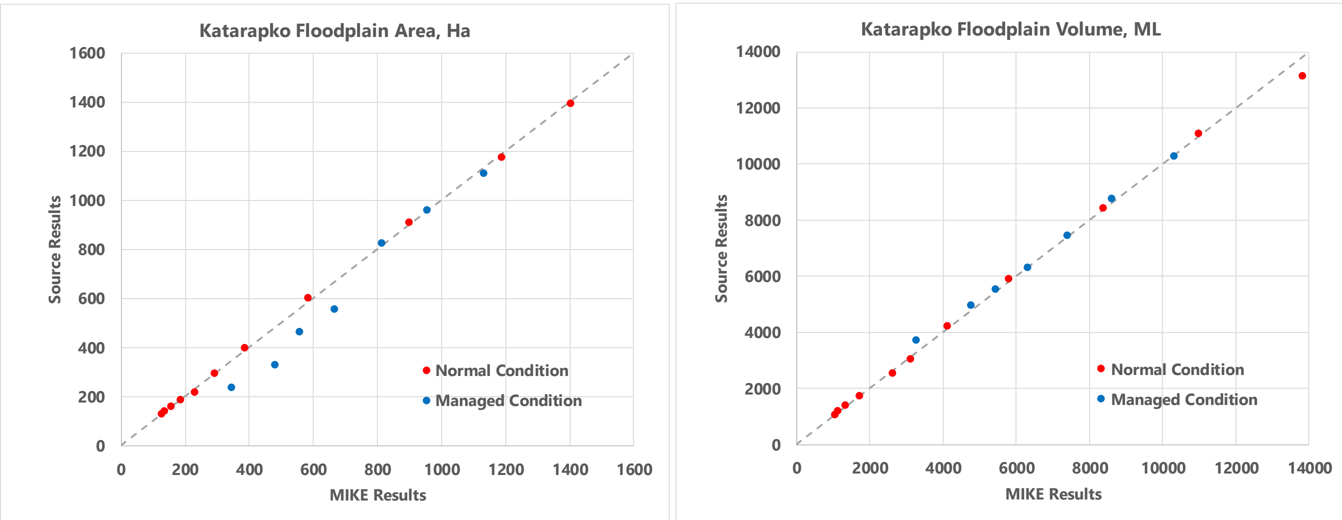


Figure 3-9 Comparison of MIKE FLOOD and Source model outputs – total inundated areas and storage volume upstream of blocking banks, for Katarapko Floodplain

3.3 Chowilla

MDBA (2014) developed a Bigmod hydrological model for the Chowilla floodplain for rapid calculation of losses and environmental objectives (e.g. turnover rate) to inform and evaluate operations. A source model of Chowilla Floodplain was also developed by MDBA, which replicates and updates the functionalities of the Bigmod model. This model has been incorporated in this SA River Murray Source Model, to refine the representation of the Chowilla floodplain. The following information is extracted from the MDBA draft report.

A detailed hydrodynamic model of the Chowilla floodplain has been previously developed and calibrated (MDBA, 2014). Numerous runs of this model have been undertaken to develop sufficient information for calibration of a simplified hydrological model in the MDBA hydrological model. The detailed model runs have included a range of River Murray flows, operating levels at the Chowilla Regulator and Lock 6 and flows through Pipeclay and Slaney Creeks. The hydrological model was constructed from the key hydrological components including:

- Lock 6 weir pool.
- Chowilla anabranch system.
- Chowilla Regulator and Chowilla floodplain.
- Chowilla wetlands (Lake Littra, Gumflat, Lake Limbra, Coombool Swamp and Werta Wert wetland).
- Woolshed Creek.
- Floodplain retention.

Structures included in the source model were at:

- Chowilla regulator and Lock 6, allowing manipulation of the upstream water level during an operational scenario.
- Pipeclay and Slaney Creeks, allowing manipulation of flows into these creeks.
- Woolshed Creek to allow manipulation of outflow from this creek back to the River Murray.
- Werta Wert wetland to retain water in the wetland following a watering event.

A number of key outputs from the detailed hydrodynamic model were used by MDBA for calibration of the hydrological model of the Chowilla floodplain including: flow and water level at the Chowilla regulator site; volume and inundation area within the Chowilla anabranch system, wetlands and floodplain; and within the River Murray upstream of Lock 6.

4 Wetland Source models

Key wetlands, namely Lake Bonney, Lake Merreti, Lake Woolpolool, Gurra lakes and Berri Basin, were explicitly included in the Source model as these wetlands are expected to influence flows or salinity of the River Murray. The details of how these nodes were parameterised is outlined in this section.

4.1 Lake Bonney

Lake Bonney is adjacent to the Riverland township of Barmera. The Lake is approximately 7 km long and 3.5 km wide with and average depth of one to two metres (Thwaites and Smith, 2010). The lake receives water from the River Murray through Chamber's Creek.

To represent the interaction between weir pool 3 and Lake Bonney in the Source model, a hydraulic connector and wetland link were used to model the interaction as shown in Figure 4-1. The discharge across the link depends on the conveyance function between Lake Bonney and the weir pool 3. The wetland link was set to be unregulated and bi-directional.

The conveyance relationship within wetland links are presented in Appendix C and are unchanged from the original SMM.

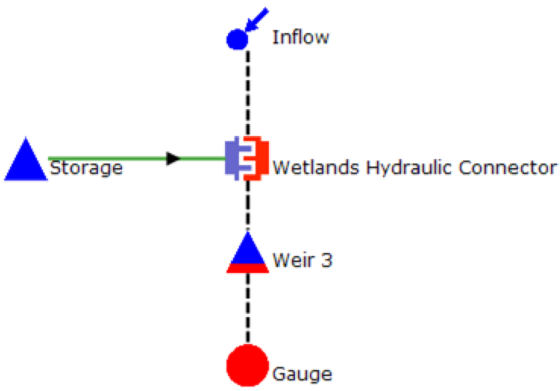


Figure 4-1 Schematic of Source model for weir pool 3 and Lake Bonney

4.2 Berri Basin and Gurra Gurra Wetlands

The Berri evaporation basin is part of the River Murray wetland system used for saline water disposal in the Riverland region of South Australia. It covers an area of 100 hectares and is located within the northern section of the Katarapko and Eckert Creek anabranch system, and its associated floodplain of the River Murray, which bypasses weir pool 4. The Berri evaporation basin is isolated from the river at pool level by Banks A, B and C which all have hydrological control structures.

Gurra Gurra Wetlands covers an area of 3000 hectares, stretches along the eastern bank of the River Murray to the east of Berri Basin. The flow regime of the wetland complex has been significantly changed since construction of weir 4, located immediately downstream of the wetland. The water level in the wetland is held at a raised level by lock, keeps the floodplain inundated and this water backs up to the pool immediately below Tortoise Crossing.

To represent the interaction between Berri Basin, Gurra Gurra Wetlands and the River Murray in the Source model, a controlled splitter node was used to represent the temporary Lyrup flow path that can flow into Gurra Gurra Wetlands at higher River Murray flows (approximately 35,000 ML/day), as shown in Figure 4-2. For the purposes of calibration, outputs of the hydraulic model scenarios were used to configure the controlled splitter nodes and set the inflow to Gurra Gurra Wetlands.

A wetland hydraulic connector node was used to connect Berri Basin to the main river network, to represent the water level at the connection point based on both the flow in the river and the water level at weir 4. Both Berri Basin and Gurra Gurra Wetlands were represented by a storage node connected by a wetland link. Flow in a wetland link can be in either direction. Flow that moves in the default direction (shown by the arrowhead) is represented by a positive number, while flow in the other direction is represented by a negative number. The conveyance relationships within wetland links were informed by outputs of the hydraulic model scenarios, and then calibrated to achieve the stable water levels between the river and storages. The rating curve for hydraulic connector and the conveyance relationship within wetland links are presented in Appendix C.

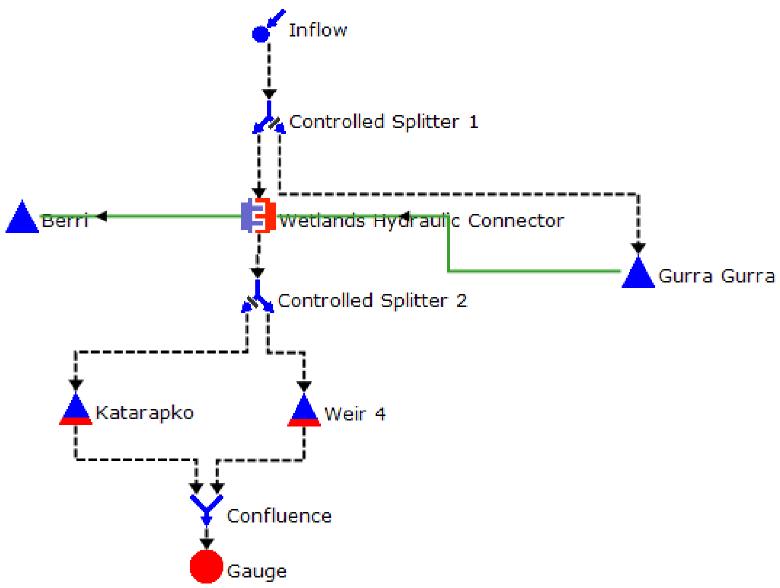


Figure 4-2 Schematic of Source model for weir pool 4, Berri Basin, Gurra Gurra and Katarapko

4.3 Lakes Merreti and Woolpolool

Lake Merreti is located approximately 20 km north of Renmark. The lake is a freshwater wetland and covers an area of 391 hectares. It is one of the largest regulated freshwater wetlands of the SA Riverland. Lake Merreti receives flows from Ral Ral Creek, which is a permanent anabranch of the River Murray with a regulated pool level of 16.3 m AHD. The lake has three inlets which have infrastructure to control inflows and outflow during floods. The bed of Lake Merreti has been surveyed at 15.2 m AHD. When the lake is at pool level, the water level is 16.3 m AHD with a maximum pool depth of approximately 1.1 m (Riverine Recovery, 2014).

Lake Woolpolool is located approximately 15 km north of Renmark. The lake is a saline temporary wetland and covers a total area of 330 hectares at pool level and is connected to the River Murray via the inlet channel from Ral Ral Creek. The creek provides an inlet and outlet for the water flowing between both Lake Woolpolool and the River Murray. It is recognised that the management of Lake Woolpolool must be linked with the management of Lake Merreti. Maintaining the water level of Lake Woolpolool above that of Lake Merreti may cause migration of the regional saline groundwater front toward Lake Merreti. Therefore, the water level in Lake Woolpolool will be operated at below the level of Lake Merreti to reduce the risk of salinising Lake Merreti by potentially reversing the groundwater gradient between the lakes (Riverine Recovery, 2013).

For the simulation in Source, both lakes were represented by a storage node connected to a hydraulic connector by a wetland link as shown in Figure 4-3. The rating curve for hydraulic connector and the calibrated conveyance relationship of the wetland link are presented in the Appendix C.

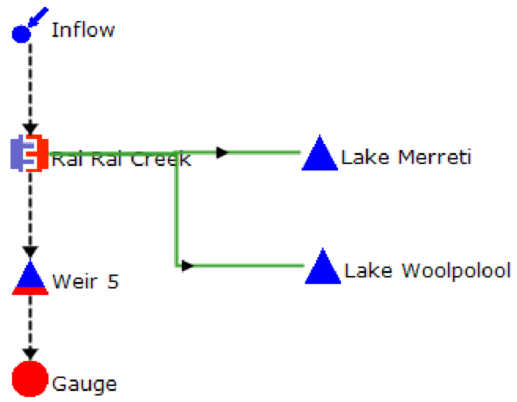


Figure 4-3 Schematic of Source model for weir pool 5, Lake Merreti and Lake Woolpolool

5 Routing links below Lock 1

In the SMM the River Murray downstream of Lock 1 to Lake Alexandrina was represented by six routing links, with Lake Alexandrina as a weir to use a target operating level, but with no upstream reach routing. Storage routing links model the movement of water through a length of river using a hydrologic routing method. They can represent the travel time of water through a reach, the attenuation of flow rates due to channel shape and roughness, as well as reach processes (i.e. net evaporation from the water surface).

Similar to the calibration process discussed in Section 2.4, various scenarios were modelled using the MIKE FLOOD models to provide outputs to calibrate the Source model, for flows between 5000 and 50,000 ML/day and were based on a downstream water level at Wellington of 0.75 m AHD. This level was selected as it represents a typical operating range for the Lower Lakes, noting there is a seasonal pattern in the lake levels, typically between 0.5 and 0.85 m AHD in recent years.

The results are shown in Figure 5-1, where it can be seen that changes in flow rate below 50,000 ML/day have minimal influence on the inundated area and volume from Mannum to Wellington, due to the backwater effect of Lake Alexandrina. Above Mannum, the inundated area and volume can be seen to increase with flow. These results were used to parameterise the travel time and rating curve information for the routing links below Lock 1, with values for flows above 50,000 ML/day adopted from the SMM where possible.

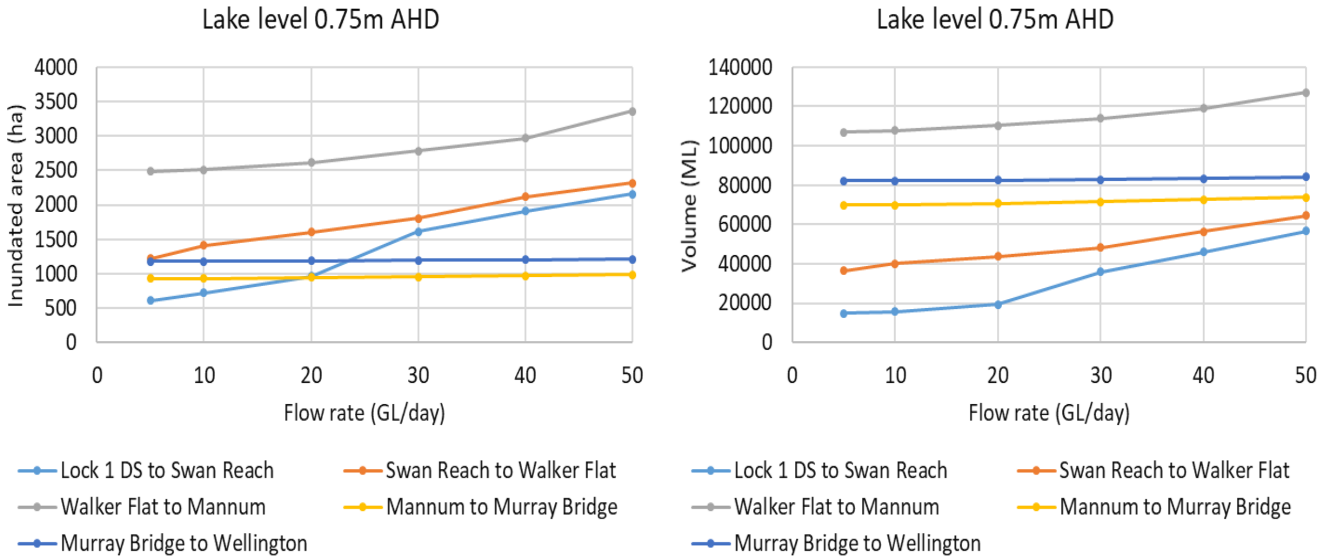
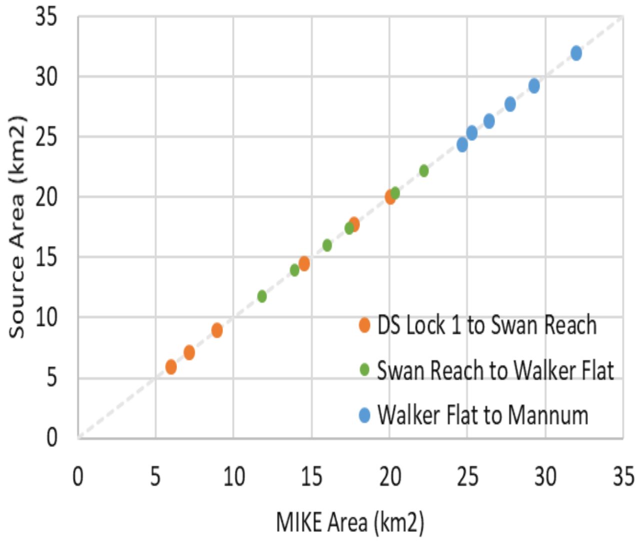


Figure 5-1 Inundated areas and volumes of reaches from downstream of Lock 1 to Wellington for a Lake Alexandrina level of 0.75m.

5.1 Results

For the two links below Mannum, the area and volumes were input to produce the area and volume seen in Figure 5-1 for a flow of 50,000 ML/day, noting that there is very little change in area and volumes for these reaches. For the remaining three reaches, visual comparison of Source area and volume compared to that derived from MIKE FLOOD demonstrates that the results align well, as seen in Figure 5-2, in which the different colours represent different reaches, and within a colour the increasing area or volume corresponds to increasing flow.



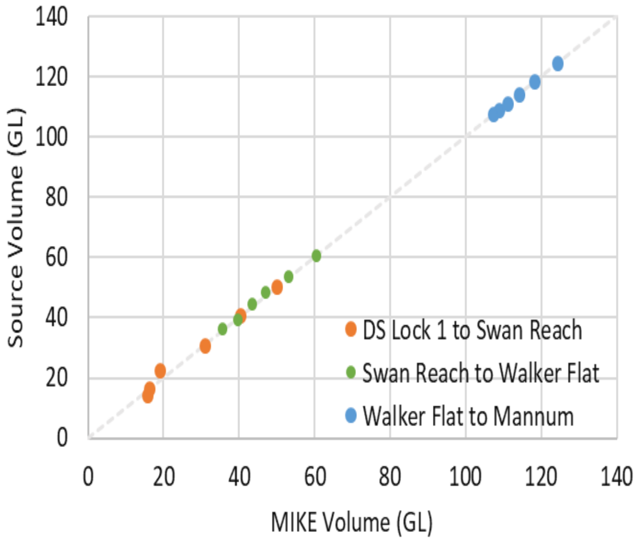


Figure 5-2 Comparison of MIKE FLOOD and Source model outputs – inundated areas and storage volumes for three storage routing links from downstream Lock 1 to Mannum

6 Dynamic calibration

The results presented thus far demonstrate good agreement between the individual Source model nodes developed and the steady state MIKE FLOOD hydrodynamic model results used to simulate a wide range of conditions. To ensure the SA River Murray Source Model was configured correctly for simulating longer time periods, the model was used to simulate the period from 1/7/1978 to 30/6/2018 and compared to observed flow, water level and salinity data. The data used to test the model is outlined below.

6.1 Input data

6.1.1 Inflows

Calculated Flow to SA, A4261001, was used as the inflow to the model. This record begins on 12/2/1977 and the initial data was used to initialise the storage levels before comparison of model outputs to observed data commenced on 1/7/1978. The simulation period represents a substantial flow range, including a number of high flow events between 60,000 ML/day and 100,000 ML/day and the low flow period of the millennium drought from 2001 to 2009.

6.1.2 Diversions

Estimates of diversions for Adelaide Metropolitan pipelines (Swan Reach – Stockwell, Mannum – Adelaide and Murray Bridge – Onkaparinga), country towns and non-urban (irrigation demands, as well as stock and domestic, recreation and industrial) demands were used as available in the original SMM. Time series were extended where required.

When configured to use historical demand, the SMM applied the non-urban demands time series as 61% occurring above Lock 1, and the remainder below Lock 1. When comparing the model results at Lock 1, this distribution in diversions may influence the results, as such this diversion fraction was updated based on recent diversion data. Based on annual reports over the period 2013/14-2017/18, Lower Murray Reclaimed Irrigation Area (LMRIA) diversions have averaged 15 GL out of a total 367 GL for all other purpose entitlements, or 4%. Angas Bremer Water management Committee (2018) indicates that diversions for the Angas-Bremer region are typically of a similar magnitude to LMRIA. A nominal 2% of the total estimated non-urban diversions was assumed for the Lower Lakes water user node in the model, with the remaining 90% extracted by the Riverlands water user node, distributed along the river above Lock 1. Stock and Domestic, Recreation and Industrial water user nodes were set to zero demand, as this use is part of the non-urban demand time series.

6.1.3 Climate data

SILO (Jeffrey et al., 2001) has been used for the observed climate data, rainfall and evaporation. Morton's Lake has been used for evaporation from open water bodies, as recommended by McMahon et al. (2013) and MDBA (2018). Monthly average rainfall and evaporation data has been used, to smooth out any unrealistic peaks in flow introduced by days of very high rainfall.

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. SILO derives solar radiation from remotely sensed cloud oktas at 9am and 3pm. While this approach provides continuous coverage across Australia, it is less accurate than ground measurements of solar radiation. In recalculating Mlake with observed solar radiation data around the Lower Lakes, Miller et al. (2020) found the remotely sensed solar radiation underestimated the observed solar radiation by 6%, which resulted in a Mlake estimates 9% lower than that calculated based on the observed solar radiation data. As such, the SILO derived estimates of Mlake have been scaled up by 9% for this comparison.

6.1.4 Water levels

The weirs included in the model have an operational target level that can be controlled. For the purpose of model calibration this operational target was set to the observed water level. A 30-day rolling average was applied to the observed water level, to smooth any local variations expected to be due to wind.

Additional testing included another scenario with the operational target to pool level, to test that the gated spillway settings resulted in realistic changes in water level, and hence modelled area and storage volume, at high flows (Section 6.5).

6.1.5 Salinity and additional salt loads

The upstream salinity into the model was set to observed salinity at upstream of Lock 6 (A4260510), as this site has a salinity record extending back to 1972. Salt also enters the river along the reaches, and the existing unaccounted salt load time series in the SMM was used to represent this process. This time series was calculated by comparing observed salinity in the river to the salinity modelled by the SMM, to determine the additional salt that must have entered the river each month. Modelled unaccounted salt load data was only available until 30/6/2012 at the time of modelling and, as such, this was the end date used for the salt constituent transport testing.

6.2 Observed data for comparison

6.2.1 Lock 1

The main flow record available to compare the model results is at Lock 1. Upstream of Lock 1 each lock has an anabranch that bypass the flow calculation, meaning that not all flow in the river downstream is recorded at these sites. Lock 1 is downstream of all of the nodes added to the model in the SA River Murray Source Model, and thus provides a useful comparison that the revised nodes provide a realistic representation of flow attention and losses along the river.

6.2.2 Salinity

The salinity modelled downstream of Lock 1 was compared to that recorded at Morgan, station A4260554, where the daily salinity records extend back to 1938, with the continuous sensor installed in 1997.

6.3 Flow results at Lock 1

Results for the modelled compared to recorded flow at Lock 1 for the full time series can be seen in Figure 6-1. It is difficult to see the detail in the daily flows over the 40-year record in Figure 6-1, so examples of a dry period and wet period are provided in Figure 6-2 and Figure 6-3, respectively. The statistics Table 6-1 indicate a good fit to the data, with model bias less than 6% across the flow ranges and periods.

A flow duration curve is presented in Figure 6-4, which also demonstrates the range of flows are simulated well, with some overestimate of flows below approximately 3,000 ML/day. However, as the recorded Lock 1 flow, as calculated based on weir equations within the program "QLock", underestimates gauged flows at Lock 1 at low flows (seen in Figure 6-5), it is unclear if this is due to errors in the model or in the calculated flow at Lock 1 for low flows.

Finally, the range in the differences in the monthly volumes at Lock 1 are presented in Figure 6-6, as the percentage difference as compared to the observed volume, and the volume difference for months with a total flow volume of less than 300 GL/month (i.e. average flow less than 10,000 ML/day). No obvious seasonal pattern can be seen in the differences, and as such Figure 6-6 and Table 6-1 suggest there is no long term over or underestimation of the observed Lock 1 flow in the modelled results.

Table 6-1 Statistics of model performance, over the whole period considered, and the last 20 years. Positive bias indicates the modelled volume is greater than the recorded volume.

	1978-2018			1998-2018		
Flow Range	Bias (%)	NSE	R2	Bias (%)	NSE	R2
All Flows	0.9	0.99	0.99	-2.7	0.99	0.99
Less than 10 GL/day	0	0.73	0.75	-5.4	0.85	0.86
10 - 40 GL/day	2.2	0.92	0.93	-4.3	0.95	0.96
40-100 GL/day	0.3	0.9	0.9	2.8	0.89	0.91

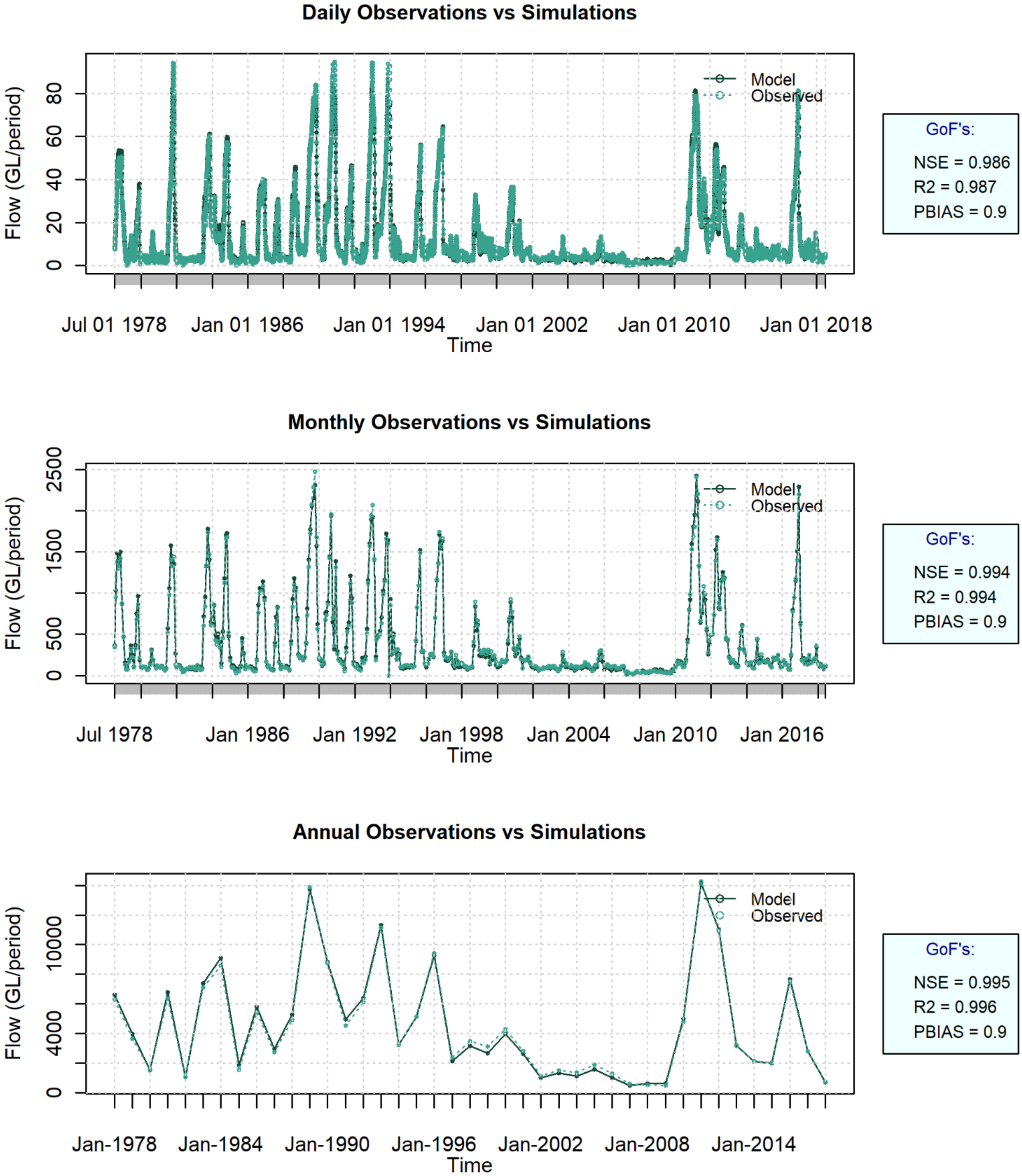


Figure 6-1 Time series and statistics of modelled vs recorded flow at Lock 1, at daily monthly and annual time scales.

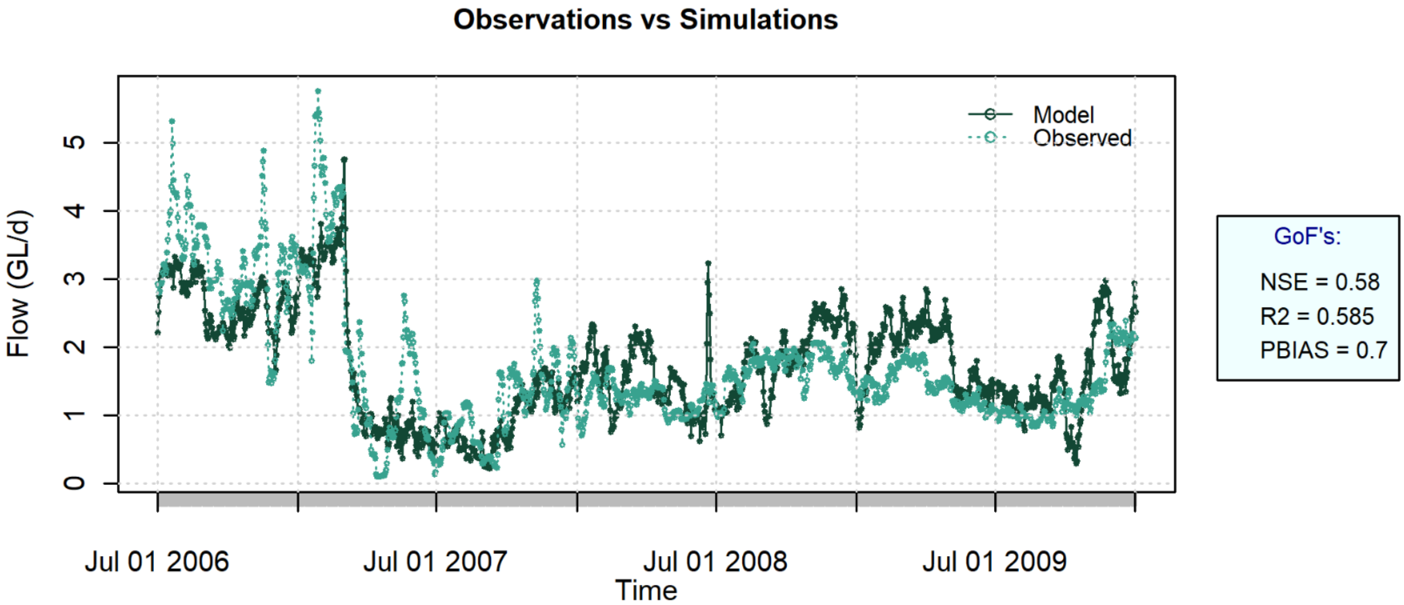


Figure 6-2 Comparison of the modelled downstream flow to observed data at Lock 1 – three years during millennium drought

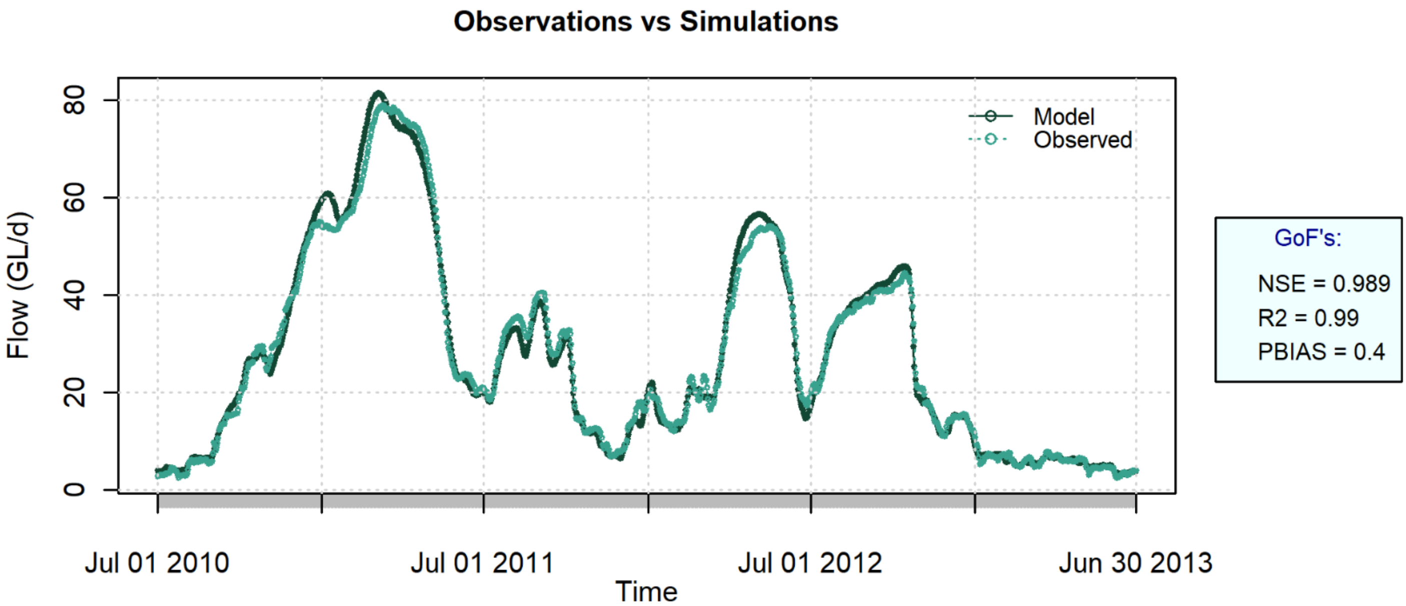


Figure 6-3 Comparison of the modelled downstream flow to observed data at Lock 1 – three years of high flow event

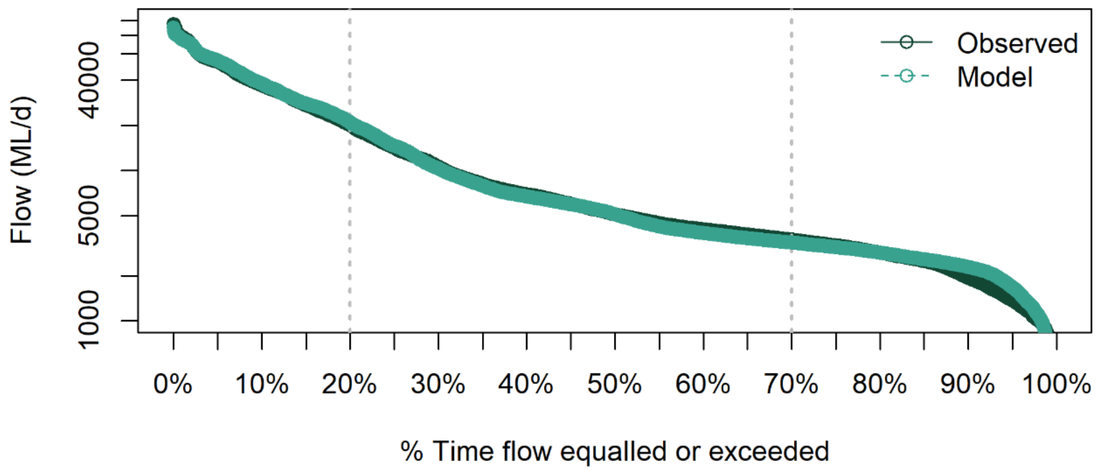


Figure 6-4 Flow duration curve of modelled vs observed flow at Lock 1.

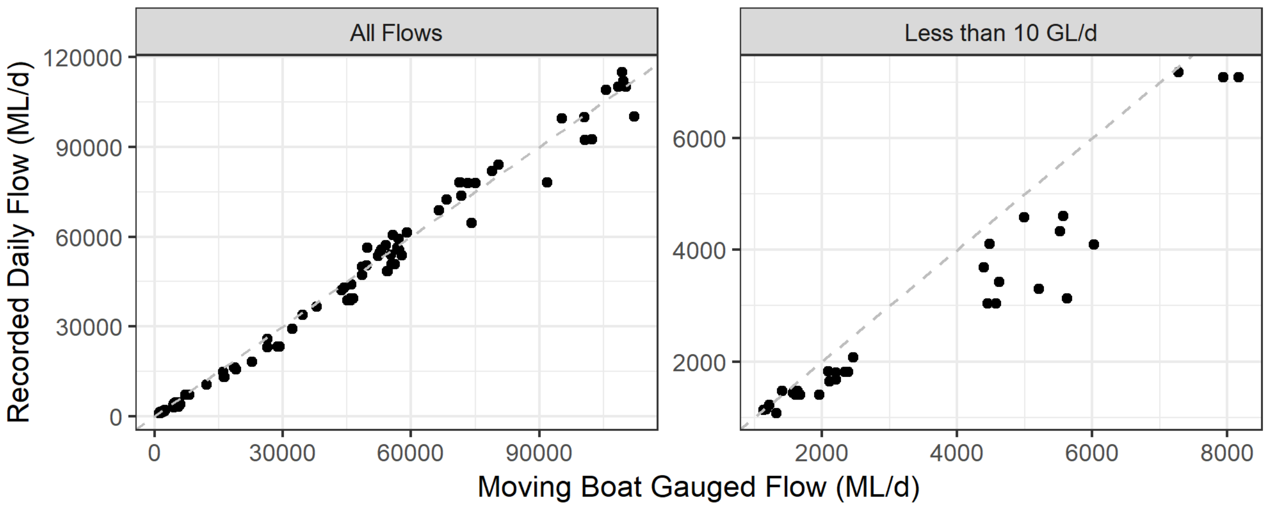


Figure 6-5 Comparison between measured flow (obtained using a moving boat gauging) and the recorded daily flow, as calculated by "QLock".

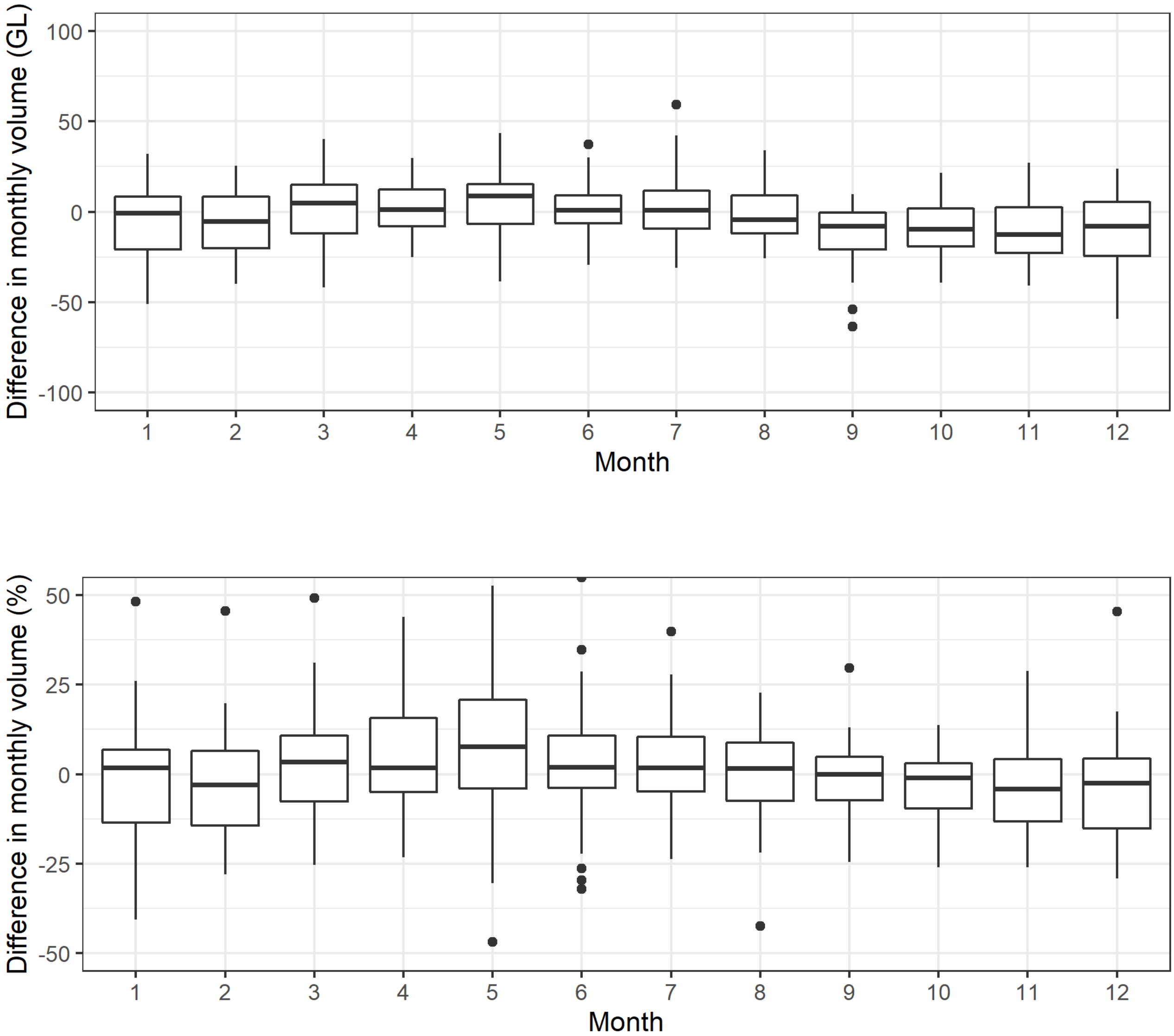


Figure 6-6 Differences between monthly volumes at Lock 1, as a volume difference for months with less than 300 GL/month and percentage of the observed volume for all months.

6.4 Salinity attenuation

A comparison of modelled and observed salinity at Morgan (based on modelled salinity upstream of Lock 1) is presented in Figure 6-7. It can be seen that the modelled outputs were underestimated in comparison to the observed salinity, especially earlier in the salinity record. However, the modelled salinity is dependent on the unaccounted salt loads used as inputs to the model, which are in turn calculated by comparing the model outputs to recorded salinity data. Given the updates to the model, in particular the change from storage links with dead storage to weir nodes that explicitly include this storage, it is anticipated that the unaccounted salt loads will also need to be updated, which will by definition correct this underestimate in the modelled salinity.

The main test for the SA River Murray Source Model at this stage is to ensure that the salinity events are moving through the model realistically. Bigmod, and the SMM, use a dead storage volume in the storage routing links to represent the salinity travel time, as the transport of salt is slower than the wave front measured as a change in flow. In this SA River Murray Source Model, the weir pool volume is now explicitly represented in the weir nodes, and it is expected that this volume will mean that the dead storage is no longer required. The results in Figure 6-7 and

Figure 6-8 indicate that this is the case, where the timing of peak salinity events, and recession from these high salinity events are well represented by the model.

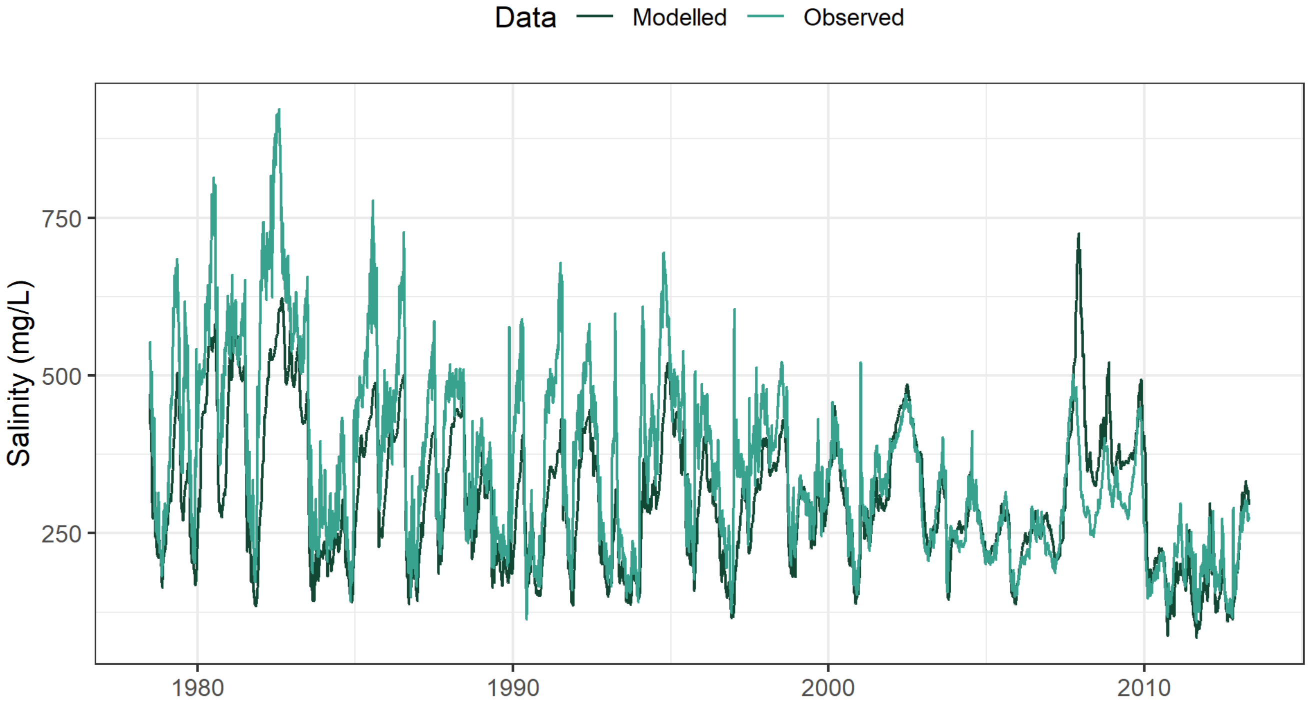


Figure 6-7 Comparison of the modelled output to observed data – salinity at Morgan (upstream of Lock 1)

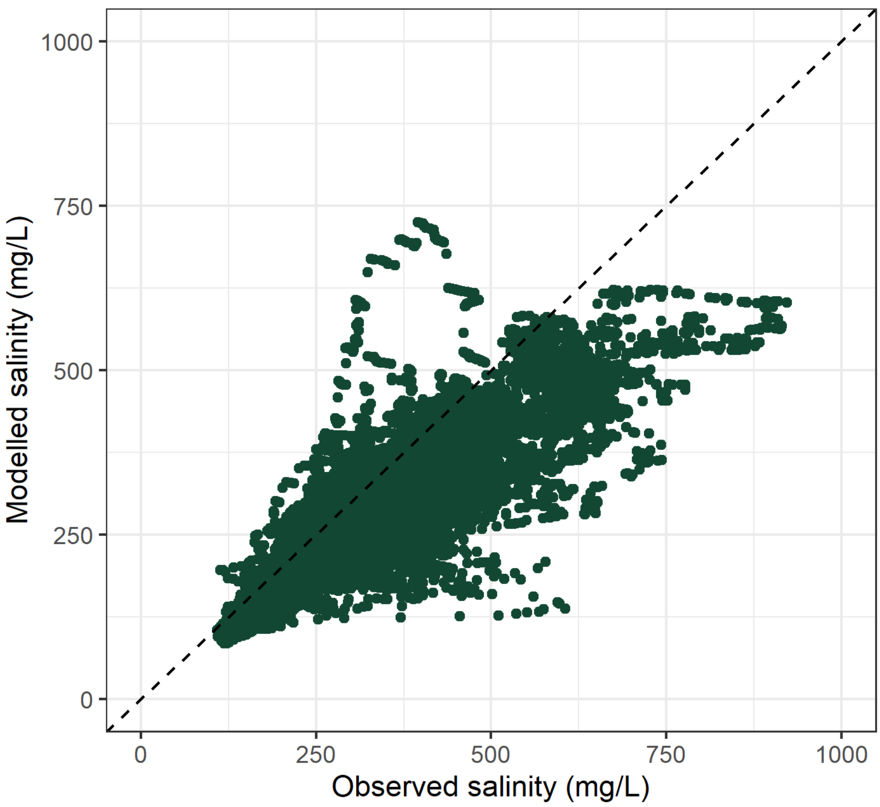


Figure 6-8 Correlation between the observed and modelled salinity at weir pool 1

6.5 Function of gated spillways

The gated spillways in the model were used to control the maximum possible releases by the operation of weirs. A maximum flow for a given water level is specified, and if the inflow to a weir exceeds this capacity, the water level of the weir will rise accordingly. This functionality allows inundation due to high flows to be represented, where the water level and corresponding surface area and volume will increase irrespective of the operational target of the weir node. To ensure the gated spillways were configured correctly, the water level target was set to pool level at each weir, and then the simulated level was compared to the observed. The results can be seen in Figure 6-9, showing that the modelled water level increases to the correct level in line with the high flow events that have occurred over the period simulated. This simulation did not include weir pool manipulation events that have occurred historically, and as such these events are not represented in these results (e.g. since 2014 at Lock 2). While the model does have this capability to represent these weir pool events, this is not the purpose of this particular simulation.

6.6 Model stability for very high flow events

In the above tests, the SA River Murray Source Model was simulated from 1/7/1978. The flows over this period are less than 120,000 ML/day, far below the highest flows experienced in the modelling period typically used in the River Murray (i.e. from 1895 onwards). To ensure the model stability for extreme conditions, especially the flood event that occurred in 1956, the model was used to simulate the period from 01/07/1895 to 30/06/2009 using inflows to SA from the Baseline Diversion Limit (BDL) model. Outputs from the SA River Murray Source Model were compared to the SMM BDL model outputs, as shown in Figure 6-10.

As can be seen from Figure 6-10, the SA River Murray Source Model can effectively replicate these high flow events through the system to Lock 1. Calculated correlation between the two sets of outputs presented in Figure 6-11 shows that the SA River Murray Source Model is relatively robust under dynamic conditions (i.e., drought and flood events). It should be noted that the purpose of this test was to ensure flow events greater than 120,000 ML/day, not captured in the earlier testing, can be simulated. The model was not configured to represent the BDL conditions exactly (e.g. diversions were not adjusted), and as such the results are not expected to exactly match the simulated flows at Lock 1 in Figure 6-10 and Figure 6-11.

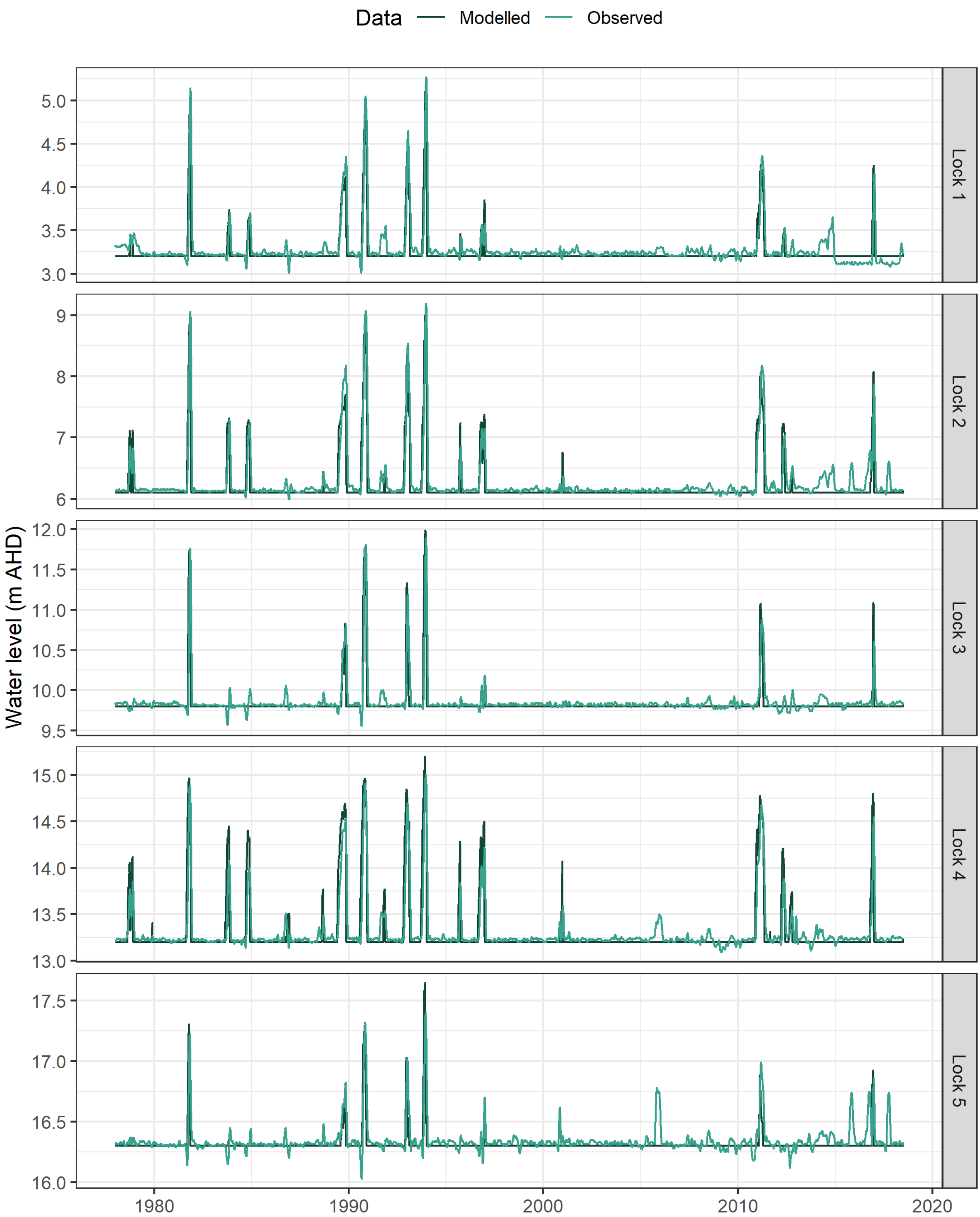


Figure 6-9 Comparison of the modelled output to observed data – upstream water level at each weir

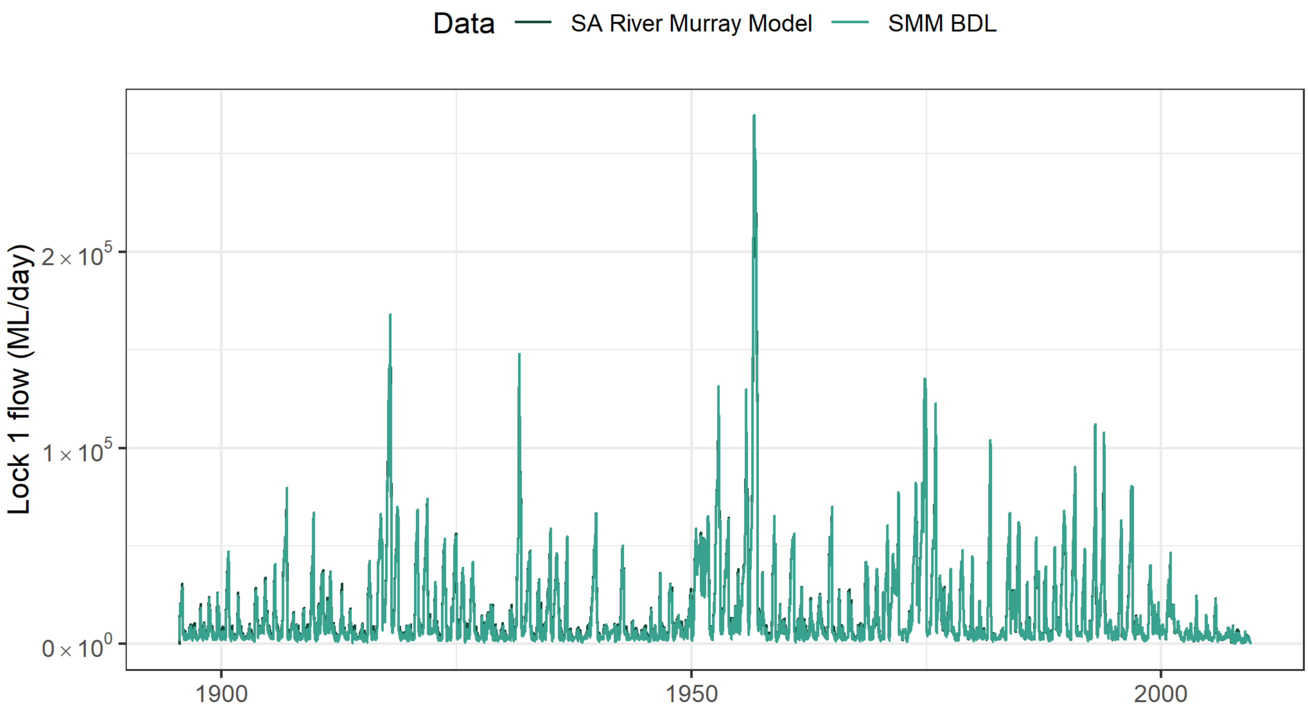


Figure 6-10 Comparison of flow modelled by the SMM and the SA River Murray Source Model (downstream of Lock1)

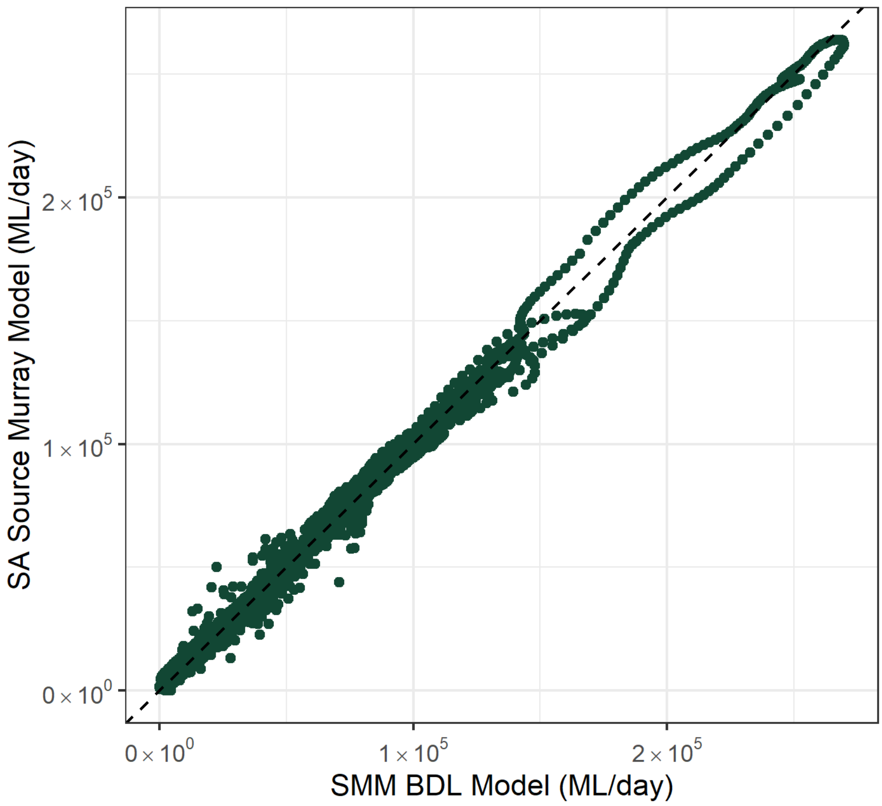


Figure 6-11 Correlation of the flow modelled by the SMM and the SA River Murray Source Model (downstream of Lock1)

7 Conclusions and recommendations

Planning for the variable operation of existing structures (most notably weirs) and the construction of new floodplain infrastructure, have necessitated improvements to the hydrological models of the River Murray in South Australia to explicitly represent these structures and proposed (planned) operations. This report has outlined these model improvements, by calibrating weir nodes to represent each of the weirs and the large floodplain infrastructure at Chowilla, Pike and Katarapko Floodplains.

The refinements to the SA River Murray Source Model will enable the effects of river operations on a number of changes in the river to be assessed, including:

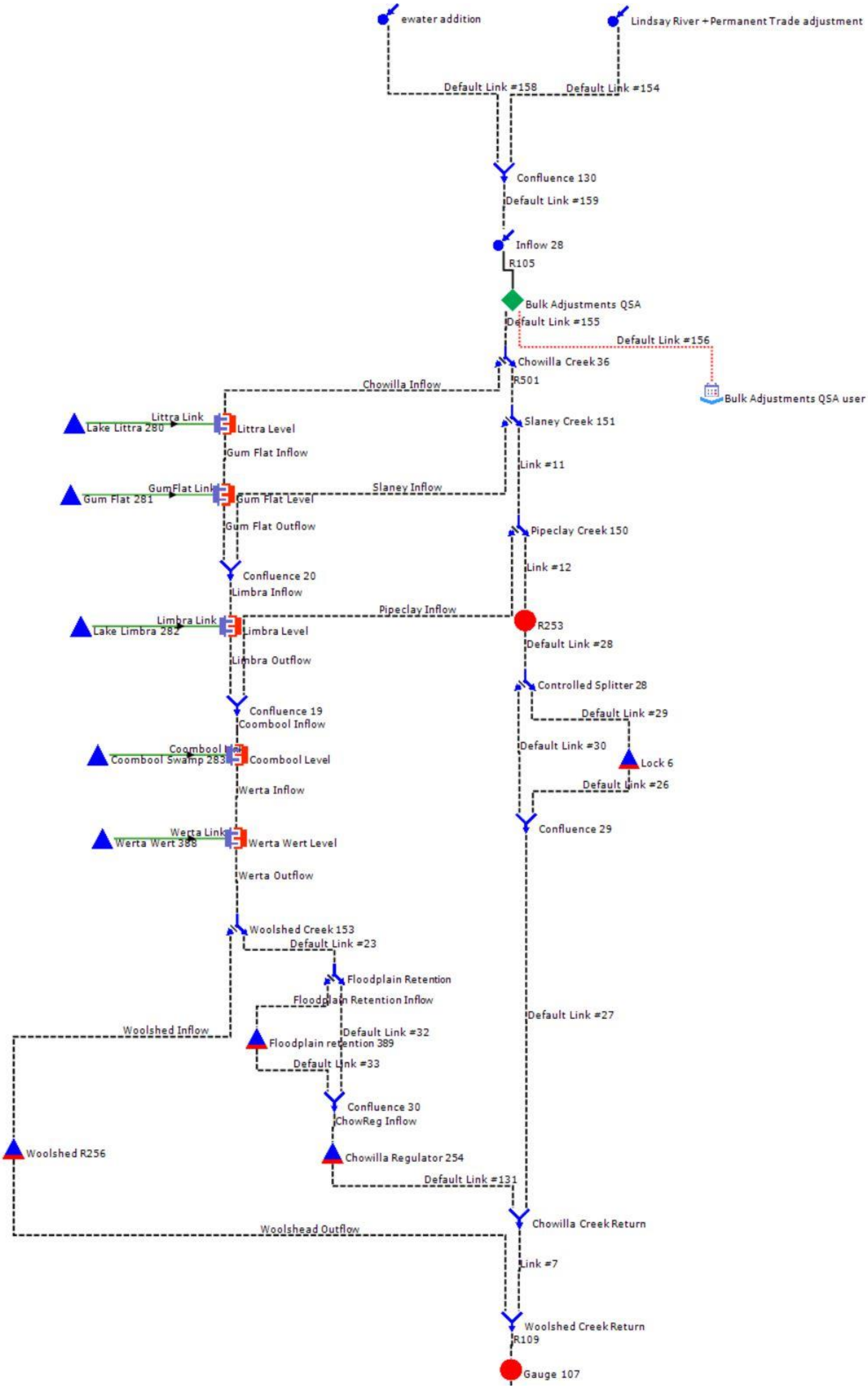
- Inundated area, to improve calculation of additional losses from operations, and infer ecological changes due to changes in inundation
- Volume, where cumulative operations may influence the retention and release of flow along the river
- Salinity, where changes in the flow for dilution can be represented, as well as the influence of explicitly modelled storages such as Lake Bonney and Gurra Gurra Lakes on the in-river salinity.

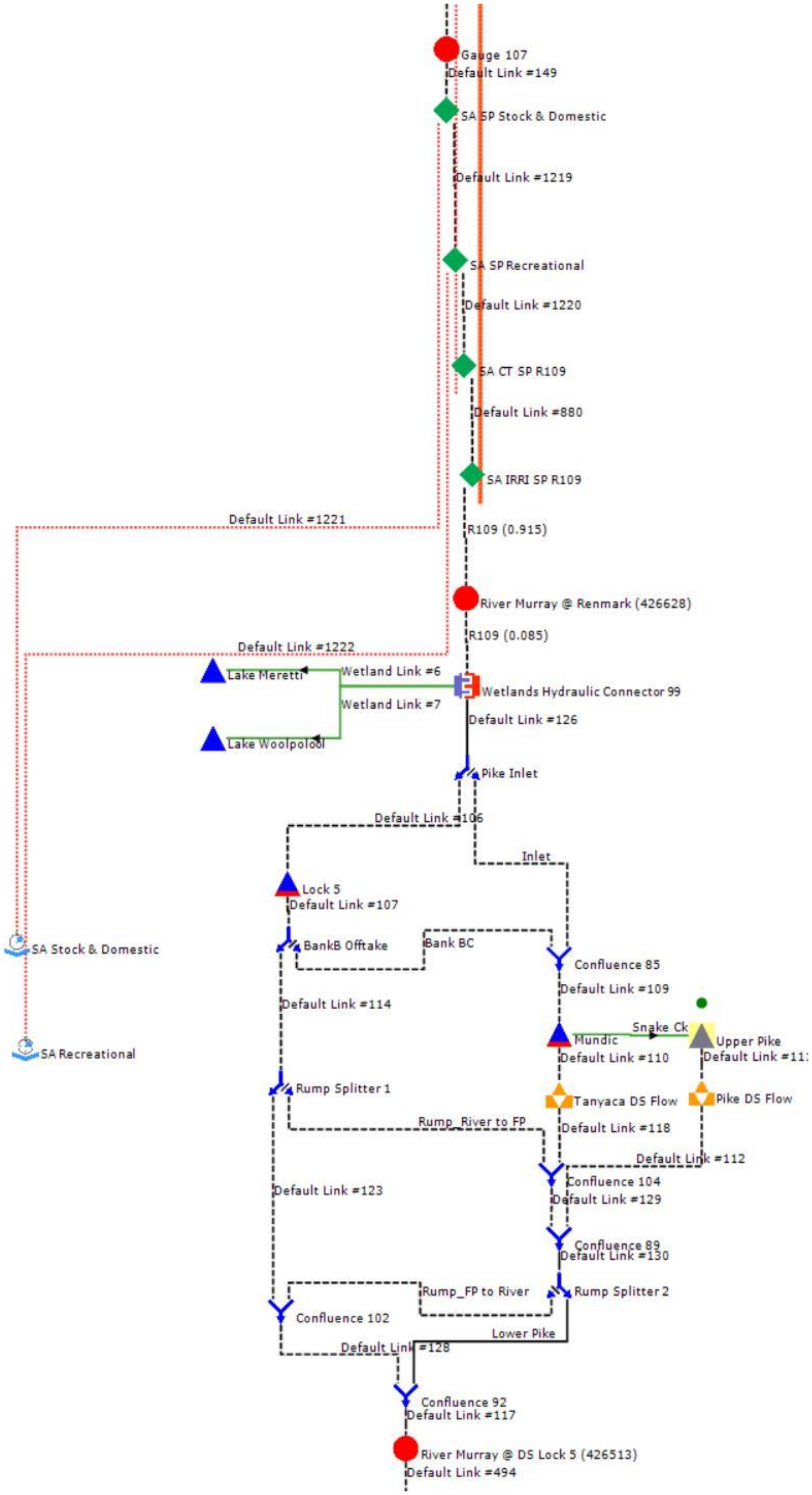
Two recommendations for further improvements to the model have been identified through undertaking this work. These are:

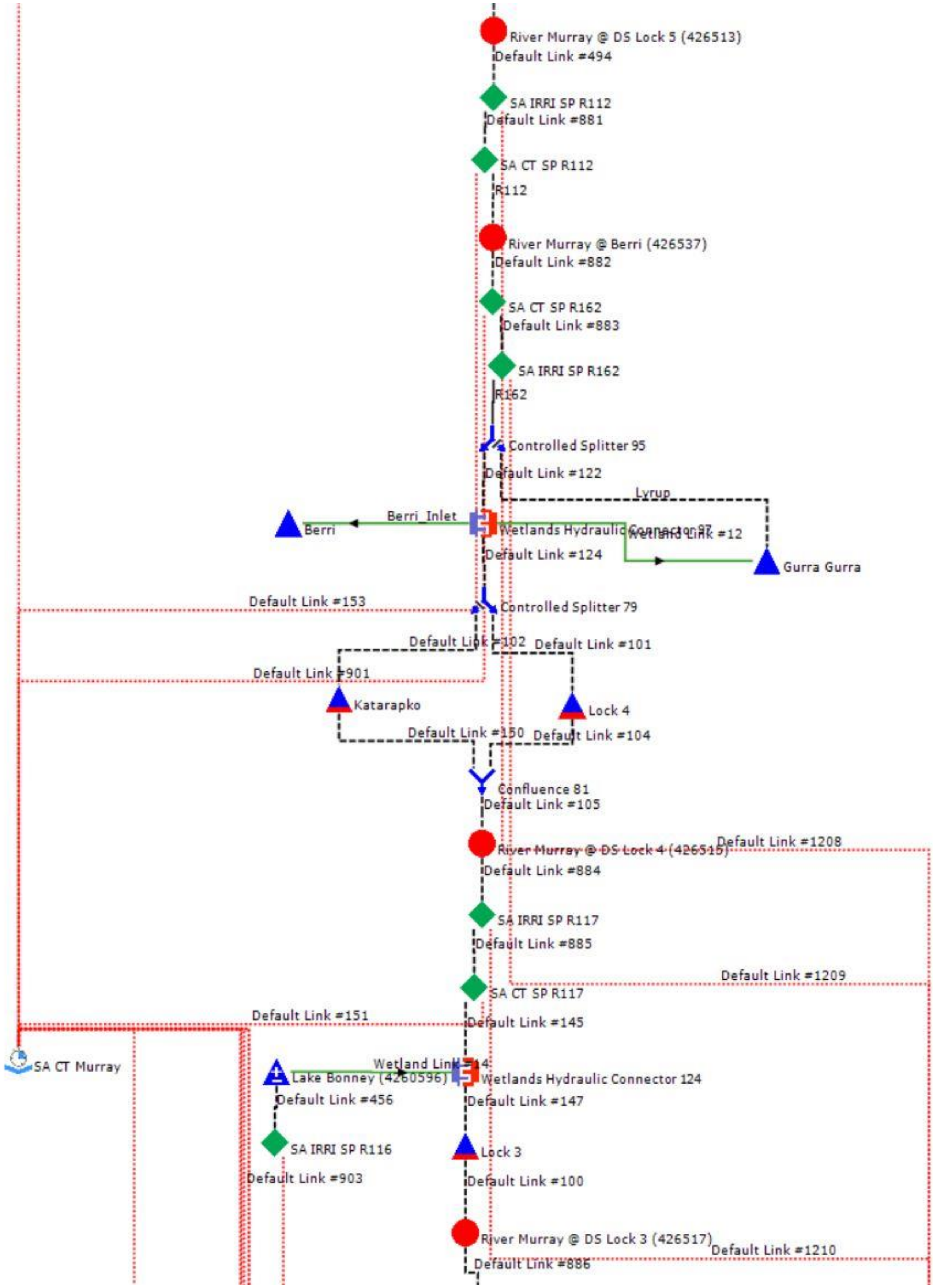
- Recalculate the unaccounted salt loads due to changes in travel times and weir storage relationships compared to the SMM.
- Review Qlock calculations at Lock 1 against gaugings, particularly for flows below 10,000 ML/day.

8 Appendices

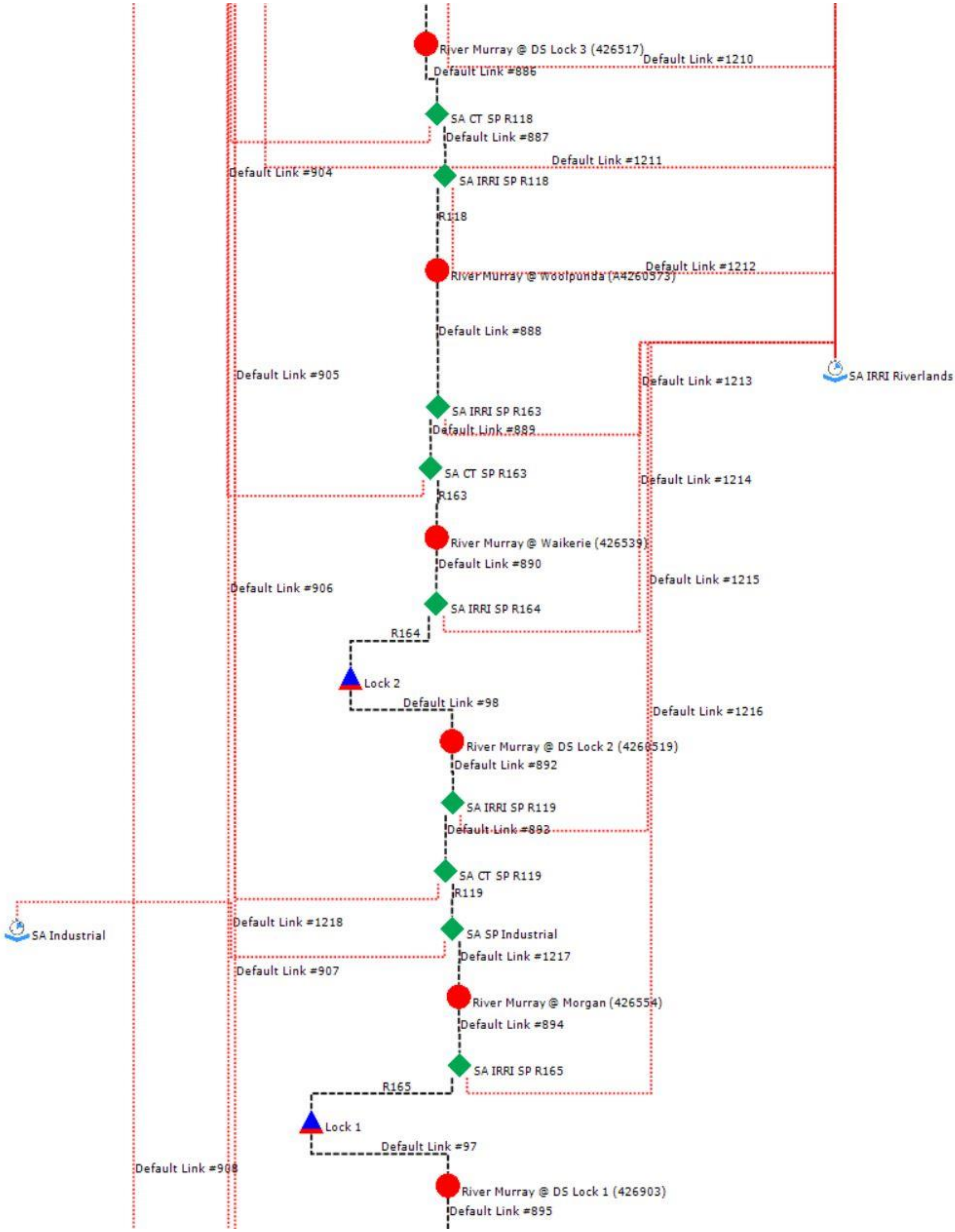
A. SA River Murray Source Model

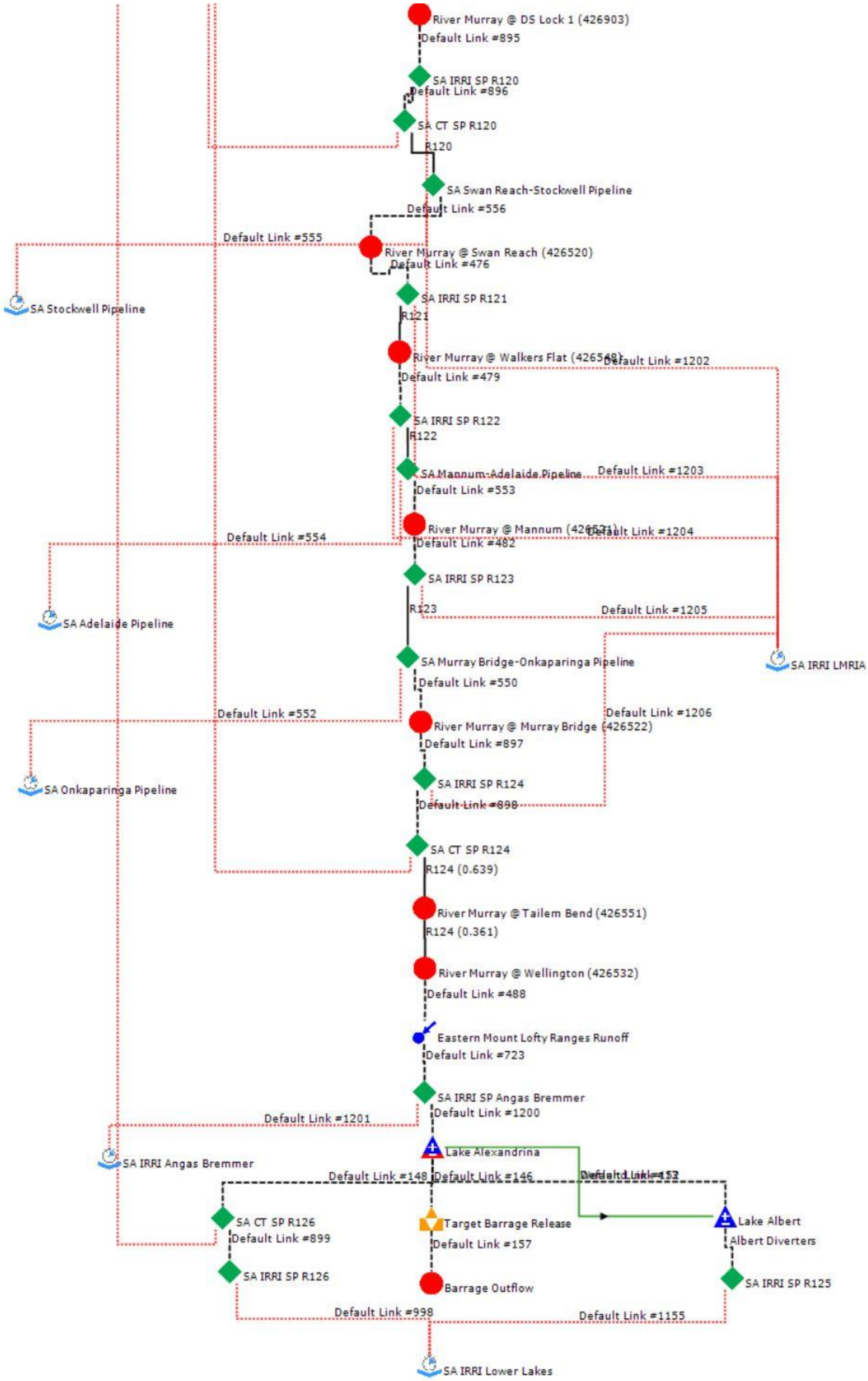

ewater addition
Lindsay River + Permanent Trade adjustment
Default Link #158
Default Link #154
Confluence 130
Default Link #159
Inflow 28
R105
Bulk Adjustments QSA
Default Link #155
Default Link #156
Chowilla Creek 36
R501
Bulk Adjustments QSA user
Chowilla Inflow
Littra Link
Lake Littra 280
Littra Level
Slaney Creek 151
Gum Flat Inflow
Link #11
GumFlat Link
Gum Flat 281
Gum Flat Level
Slaney Inflow
Gum Flat Outflow
Pipeclay Creek 150
Confluence 20
Link #12
Limbra Inflow
Pipeclay Inflow
Limbra Link
Lake Limbra 282
Limbra Level
R253
Default Link #28
Limbra Outflow
Controlled Splitter 28
Confluence 19
Default Link #29
Coombool Inflow
Default Link #30
Coombool Swamp 283
Coombool Level
Lock 6
Werta Inflow
Default Link #26
Confluence 29
Werta Link
Werta Wert 388
Werta Wert Level
Werta Outflow
Woolshed Creek 153
Default Link #23
Floodplain Retention
Floodplain Retention Inflow
Default Link #27
Woolshed Inflow
Default Link #32
Floodplain retention 389
Default Link #33
Confluence 30
ChowReg Inflow
Woolshed R256
Chowilla Regulator 254
Default Link #131
Chowilla Creek Return
Woolshead Outflow
Link #7
Woolshed Creek Return
R109
Gauge 107


Gauge 107
Default Link #149
SA SP Stock & Domestic
Default Link #1219
SA SP Recreational
Default Link #1220
SA CT SP R109
Default Link #880
SA IRRI SP R109
Default Link #1221
R109 (0.915)
River Murray @ Renmark (426628)
R109 (0.085)
Default Link #1222
Lake Meretti
Wetland Link #6
Wetlands Hydraulic Connector 99
Wetland Link #7
Lake Woolpolool
Default Link #126
Pike Inlet
Default Link #106
Inlet
Lock 5
Default Link #107
SA Stock & Domestic
BankB Offtake
Bank BC
Confluence 85
Default Link #109
Default Link #114
Mundic
Snake Ck
Upper Pike
SA Recreational
Default Link #110
Rump Splitter 1
Tanyaca DS Flow
Pike DS Flow
Rump_River to FP
Default Link #118
Default Link #112
Default Link #123
Confluence 104
Default Link #129
Confluence 89
Default Link #130
Rump_FP to River
Rump Splitter 2
Confluence 102
Lower Pike
Default Link #128
Confluence 92
Default Link #117
River Murray @ DS Lock 5 (426513)
Default Link #494



River Murray @ DS Lock 5 (426513)
Default Link #494
SA IRRI SP R112
Default Link #881
SA CT SP R112
R112
River Murray @ Berri (426537)
Default Link #882
SA CT SP R162
Default Link #883
SA IRRI SP R162
R162
Controlled Splitter 95
Default Link #122
Lyrup
Berri_Inlet
Berri
Wetlands Hydraulic Connector 97
Wetland Link #12
Default Link #124
Gurra Gurra
Default Link #153
Controlled Splitter 79
Default Link #102
Default Link #101
Default Link #901
Katarapko
Lock 4
Default Link #150
Default Link #104
Confluence 81
Default Link #105
River Murray @ DS Lock 4 (426515)
Default Link #1208
Default Link #884
SA IRRI SP R117
Default Link #885
Default Link #1209
SA CT SP R117
Default Link #151
Default Link #145
SA CT Murray
Wetland Link #14
Lake Bonney (4260596)
Wetlands Hydraulic Connector 124
Default Link #456
Default Link #147
SA IRRI SP R116
Lock 3
Default Link #903
Default Link #100
River Murray @ DS Lock 3 (426517)
Default Link #1210
Default Link #886


River Murray @ DS Lock 3 (426517)
Default Link #1210
Default Link #886
SA CT SP R118
Default Link #887
Default Link #1211
Default Link #904
SA IRRI SP R118
R118
Default Link #1212
River Murray @ Woolpunda (A4260573)
Default Link #888
SA IRRI Riverlands
Default Link #905
Default Link #1213
SA IRRI SP R163
Default Link #889
SA CT SP R163
Default Link #1214
R163
River Murray @ Waikerie (426539)
Default Link #890
Default Link #1215
Default Link #906
SA IRRI SP R164
R164
Lock 2
Default Link #98
Default Link #1216
River Murray @ DS Lock 2 (4260519)
Default Link #892
SA IRRI SP R119
Default Link #893
SA CT SP R119
R119
Default Link #1218
SA SP Industrial
SA Industrial
Default Link #1217
Default Link #907
River Murray @ Morgan (426554)
Default Link #894
SA IRRI SP R165
R165
Lock 1
Default Link #97
Default Link #908
River Murray @ DS Lock 1 (426903)
Default Link #895



River Murray @ DS Lock 1 (426903)
Default Link #895
SA IRRI SP R120
Default Link #896
SA CT SP R120
R120
SA Swan Reach-Stockwell Pipeline
Default Link #556
Default Link #555
River Murray @ Swan Reach (426520)
Default Link #476
SA Stockwell Pipeline
SA IRRI SP R121
R121
River Murray @ Walkers Flat (426548)
Default Link #1202
Default Link #479
SA IRRI SP R122
R122
SA Mannum-Adelaide Pipeline
Default Link #1203
Default Link #553
River Murray @ Mannum (426521)
Default Link #1204
Default Link #554
Default Link #482
SA IRRI SP R123
SA Adelaide Pipeline
R123
Default Link #1205
SA Murray Bridge-Onkaparinga Pipeline
SA IRRI LMRIA
Default Link #550
Default Link #552
Default Link #1206
River Murray @ Murray Bridge (426522)
Default Link #897
SA Onkaparinga Pipeline
SA IRRI SP R124
Default Link #898
SA CT SP R124
R124 (0.639)
River Murray @ Tailem Bend (426551)
R124 (0.361)
River Murray @ Wellington (426532)
Default Link #488
Eastern Mount Lofty Ranges Runoff
Default Link #723
SA IRRI SP Angas Bremmer
Default Link #1200
Default Link #1201
SA IRRI Angas Bremmer
Lake Alexandrina
Default Link #148
Default Link #146
Default Link #152
SA CT SP R126
Target Barrage Release
Lake Albert
Default Link #899
Albert Diverters
Default Link #157
SA IRRI SP R126
Barrage Outflow
SA IRRI SP R125
Default Link #998
Default Link #1155
SA IRRI Lower Lakes

B. Hydrodynamic model outputs

Table 8-1 Weir pool 1 Hydrodynamic model outputs

WP1	Without Development		Pool Level - 3.2 mAHD		Raised Level - 3.7 mAHD		Raised Level - 4.2 mAHD	
Flow (ML/day)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
5000	1331	32975	2414	64456	2675	71062	3180	80859
10000	1250	37577	2430	65662	2704	71947	3271	82589
20000	1432	47469	2483	69035	2831	75510	3383	85710
30000	1908	60527	2640	74406	3227	83326	3782	93721
40000	3007	80648	3171	85117	3579	91644	4214	101718
50000	4008	98571	3560	93404	4063	100347	4700	112095

Table 8-2 Weir pool 2 Hydrodynamic model outputs

WP2	Without Development		Pool Level - 6.1 mAHD		Raised Level - 6.6 mAHD	
Flow (ML/day)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
5000	1007	23047	1529	39101	1735	44290
10000	1066	27224	1567	41084	1765	45281
20000	1194	34607	1649	44596	1857	48210
30000	1341	41100	1797	49758	2021	52435
40000	1886	52141	2043	55124	2349	58944
50000	2885	70496	2826	69206	2957	70533

Table 8-3 Weir pool 3 Hydrodynamic model outputs

It should be noted that these results only represent the weir pool area in Figure 2.4, i.e. Lake Bonney is not included.

WP3	Without Development		Pool Level - 9.8 mAHD		Raised Level - 10.1 mAHD		Raised Level - 10.39 mAHD	
Flow (ML/day)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
5000	3124	55292	3870	111159	4667	134828	5864	163360
10000	2768	58045	3937	115381	4843	142079	5941	167504
20000	2809	72486	4169	128910	5197	155439	6151	179173
30000	3292	96685	4815	152719	5688	174935	6718	198527
40000	3794	122633	5951	184057	6930	206324	7952	228732
50000	6674	193863	8168	230980	8973	248402	9727	265623

Table 8-4 Weir pool 4 Hydrodynamic model outputs

It should be noted that these results only represent the weir pool area in Figure 2.5, and separately shaded floodplain areas are not included (e.g. Gurra Gurra Wetlands).

WP4	Without Development		Pool Level - 13.2 mAHD		Raised Level - 13.5 mAHD		Raised Level - 13.8 mAHD		Raised Level - 14.34 mAHD	
Flow (ML/day)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
5000	648	14678	771	28305	837	32237	965	37983	1335	48697
10000	709	18764	796	29550	860	33203	993	39075	1459	53899
20000	806	25520	881	33089	969	37200	1125	43359	1651	59158
30000	974	33376	1072	39313	1193	43953	1449	51110	1915	66255
40000	1403	46335	1448	48245	1602	53573	1816	60806	2200	74158
50000	2018	65677	1897	62104	1982	65013	2119	69613	2446	81930

Table 8-5 Weir pool 5 Hydrodynamic model outputs

It should be noted that these results only represent the weir pool area in Figure 2.5, and separately shaded floodplain areas are not included (e.g. Lakes Woolpoolol and Merreti).

WP5	Without Development		Pool Level - 16.3 mAHD		Raised Level - 16.8 mAHD	
Flow (ML/day)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
5000	620	31108	1238	36422	2095	46459
10000	666	38871	1274	37285	2151	47033
20000	769	50618	1413	40383	2208	47880
30000	1092	58467	1713	45379	2658	52888
40000	1539	73482	2263	51440	3211	59006
50000	2556	101399	3253	60751	3947	67004

Table 8-6 Hydrodynamic model outputs for downstream of Lock 1 to Wellington

Flow (ML/day)	Reach	Area (Ha)	Volume (ML)
5000	Swan Reach	597	15942
	Walker Flat	1184	35723
	Mannum	2467	107414
	Murray Bridge	897	66156
	Tailem Bend	728	53692
	Wellington	416	30681
10000	Swan Reach	714	16385
	Walker Flat	1388	39714
	Mannum	2530	108817
	Murray Bridge	901	66360
	Tailem Bend	731	53858
	Wellington	418	30776
20000	Swan Reach	893	19008
	Walker Flat	1600	43453
	Mannum	2636	111209
	Murray Bridge	919	67028
	Tailem Bend	746	54400
	Wellington	426	31086
30000	Swan Reach	1453	30964
	Walker Flat	1741	46997
	Mannum	2777	114164
	Murray Bridge	938	67821
	Tailem Bend	761	55043
	Wellington	435	31453
40000	Swan Reach	1770	40540
	Walker Flat	2035	53208
	Mannum	2927	118411
	Murray Bridge	948	68472
	Tailem Bend	769	55572
	Wellington	439	31755
50000	Swan Reach	2003	50183
	Walker Flat	2218	60556
	Mannum	3197	124499
	Murray Bridge	958	69166
	Tailem Bend	777	56135
	Wellington	444	32077

C. Calibration parameters

Table 8-7 Calibrated travel time and upstream reach width for weir pool 1

Flow (ML/day)	Weir pool 1	
	Travel time (day)	*Upstream reach width (m)*
5000	0.42	52.39
10000	0.50	60.58
20000	0.85	70.14
30000	1.70	145.29
40000	2.50	240.43
50000	2.00	335.46
60000	4.50	580.50
70000	1.50	675.00
80000	1.50	735.00
90000	1.10	750.00
100000	1.00	805.78
120000	0.90	825.78
140000	0.80	835.78
160000	0.70	845.78
180000	0.60	865.78
200000	0.60	865.78
250000	0.50	865.78
300000	0.50	865.78
341000	0.50	865.78

Table 8-8 Calibrated travel time and upstream reach width for weir pool 2

Flow (ML/day)	Weir pool 2	
	Travel time (day)	*Upstream reach width (m)*
5000	0.66	55.32
10000	0.67	59.89
20000	1.20	122.11
30000	1.80	192.40
40000	1.60	288.95
50000	3.20	486.00
60000	4.30	655.00
70000	2.50	770.00
80000	2.50	840.00
90000	3.00	890.00
100000	1.60	947.93
120000	1.25	994.45
140000	1.25	1062.19
160000	1.35	1072.51
180000	1.35	1076.51
200000	1.00	1076.51
250000	1.25	1076.51
300000	0.65	1076.51
341000	0.75	1076.51

Table 8-9 Calibrated travel time and upstream reach width for weir pool 3

Flow (ML/day)	Weir pool 3	
	Travel time (day)	*Upstream reach width (m)*
5000	0.30	271.27
10000	0.60	282.44
20000	1.00	325.16
30000	2.00	455.50
40000	3.50	647.43
50000	4.00	997.03
60000	4.50	1250.00
70000	4.50	1520.00
80000	4.50	1630.00
90000	4.50	1632.00
100000	4.50	1633.00
120000	4.50	1635.00
140000	4.50	1635.00
160000	4.50	1636.00
180000	4.50	1637.00
200000	4.50	1638.00
250000	4.50	1639.00
300000	4.50	1640.00
341000	4.50	1640.00

Table 8-10 Calibrated travel time and upstream reach width for weir pool 4

Flow (ML/day)	Weir pool 4	
	Travel time (day)	*Upstream reach width (m)*
5000	0.55	126.28
10000	0.45	133.49
20000	0.73	154.54
30000	1.14	215.87
40000	1.38	313.75
50000	1.95	411.84
60000	2.35	555.50
70000	1.35	650.50
80000	0.60	700.00
90000	0.70	715.50
100000	0.85	740.36
120000	0.34	716.80
140000	0.49	765.55
160000	0.49	783.96
180000	0.47	867.93
200000	0.37	927.46
250000	0.36	1055.16
300000	0.30	1055.29
341000	0.30	1055.30

Table 8-11 Calibrated travel time and upstream reach width for weir pool 5

Flow (ML/day)	Weir pool 5	
	Travel time (day)	*Upstream reach width (m)*
5000	0.81	87.99
10000	0.85	200.07
20000	0.47	208.96
30000	0.47	255.30
40000	0.73	375.16
50000	1.30	529.35
60000	1.94	745.00
70000	1.52	980.00
80000	2.00	1300.00
90000	2.00	1510.00
95000	1.50	1580.00
100000	1.00	1700.00
120000	1.03	2004.48
140000	1.06	2009.69
160000	1.03	2024.60
180000	1.09	2044.13
200000	0.84	2153.22
250000	0.74	2370.93
300000	0.60	2430.04
341000	0.60	2433.80

Table 8-12 Calibrated travel time and upstream reach width for Mundic

Flow (ML/day)	Mundic	
	Travel time (day)	*Upstream reach width (m)*
0	3	2
500	3	2
1000	1	10
2000	0.7	*
3500	0.6	*
4000	2	*
5000	2	50
6000	2	50

***linear interpolation of widths inside Source**

Table 8-13 Calibrated travel time and upstream reach width for Katarapko

Flow (ML/day)	Katarapko	
	Travel time (day)	*Upstream reach width (m)*
0	1	30
200.00	1	30
728.35	1	30
809.57	1	50
864.86	1	60
970.27	1	80
1327.10	1	90
2091.74	1.5	95
3192.48	*	150
4901.47	1.2	500
6661.44	1.3	950
7000.00	1.3	950

***linear interpolation of widths inside Source**

Table 8-14 Calibrated travel time and upstream reach width for downstream of Lock 1 to Wellington

Flow rate (ML/day)	Travel time (day)						Reach width (m)					
	D/S of Lock 1 to Swan Reach	Swan Reach to Walker Flat	Walker Flat to Mannum	Mannum to Murray Bridge	Murray Bridge to Tailem Bend	Tailem Bend to Wellington	D/S of Lock 1 to Swan Reach	Swan Reach to Walker Flat	Walker Flat to Mannum	Mannum to Murray Bridge	Murray Bridge to Tailem Bend	Tailem Bend to Wellington
0	0.45	0.60	0.50	1.39	1.12	0.64	0	0	0	0	0	0
5000	0.45	0.60	0.50	1.39	1.12	0.64	272	263	429	245	263	263
10000	0.45	0.60	0.25	1.39	1.12	0.64	326	309	440	245	263	263
20000	0.70	0.40	0.20	1.39	1.12	0.64	409	355	458	251	263	263
30000	1.00	0.40	0.35	1.39	1.12	0.64	664	387	483	260	263	263
40000	1.00	0.60	0.57	1.39	1.12	0.64	809	451	509	271	272	272
50000	0.90	0.80	0.60	1.39	1.12	0.64	915	493	556	281	272	272
70000	0.90	0.80	0.80	1.39	1.12	0.64	1002	559	600	502	355	355
80000	0.90	0.80	0.80	1.39	1.12	0.64	1131	623	681	545	395	395
100000	0.90	0.80	0.80	1.39	1.12	0.64	1163	738	787	607	454	454
300000	0.90	0.80	0.80	1.39	1.12	0.64	1257	869	896	761	824	824

Table 8-15 Rating curve of hydraulic connector connected to Lake Merreti and Lake Woolpolool

Water elevation @ weir pool 5 (m)	Flow rates (ML/day)								
	0	5000	10000	20000	30000	40000	50000	102000	181800	341000
15.00	15.00	15.00	15.06	15.29	15.60	15.94	16.28	19.60	20.30	21.30
16.30	16.30	16.32	16.39	16.62	16.93	17.26	17.60	19.60	20.30	21.30
16.80	16.80	16.81	16.86	17.02	17.26	17.53	17.81	19.60	20.30	21.30
20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.30	21.30

Table 8-16 Rating curve of hydraulic connector connected to Berri Basin

Water elevation @ weir pool 4 (m)	Flow rates (ML/day)								
	0	5000	10000	20000	30000	40000	50000	100000	300000
12.0	12.00	12.00	12.02	12.08	12.15	12.30	13.00	15.39	18.00
13.2	13.20	13.21	13.22	13.29	13.39	13.52	14.06	15.39	18.00
13.5	13.50	13.50	13.52	13.58	13.66	13.77	14.04	15.39	18.00
13.8	13.80	13.80	13.82	13.87	13.94	14.04	14.16	15.39	18.00
14.34	14.34	14.34	14.34	14.41	14.46	14.52	14.61	15.39	18.00
22	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00

Table 8-17 Conveyance relationship of the wetland link connected to Lake Bonney

Reduced Level (m)	Modified Conveyance
9.70	0.00
9.75	0.10
9.80	20.91
10.00	23.79
10.50	25.32
12.00	29.58
16.00	39.20
17.00	41.37
18.00	43.44

Table 8-18 Calibrated conveyance relationship of the wetland link connected to Berri Basin

Reduced Level (m)	Modified Conveyance
12.90	0.00
13.00	1.00
13.20	8.65
13.50	25.00
13.89	32.17
14.30	48.53
14.75	60.38
15.18	76.81
16.00	120.00
17.00	150.00
18.00	180.00

Table 8-19 Calibrated conveyance relationship of the wetland link connected to Gurra Gurra Wetlands

Reduced Level (m)	Modified Conveyance
11.13	0.00
13.00	15.00
13.50	16.20
14.00	32.00
14.50	48.00
15.00	56.00
16.00	100.00
17.00	200.00
18.00	220.00
19.00	240.00

Table 8-20 Calibrated conveyance relationship of the wetland link connected to Lake Merreti

Reduced Level	Modified Conveyance
15.00	0.00
15.50	5.00
16.28	54.86
16.38	55.64
16.52	56.78
16.73	57.44
16.93	59.02

Table 8-21 Calibrated conveyance relationship of the wetland link connected to Lake Woolpolool

Reduced Level	Modified Conveyance
15.20	0.00
15.70	5.00
16.28	50.86
16.38	51.64
16.52	51.78
16.73	52.44
16.93	53.02

Table 8-22 Percentage of intake controlled by the splitter to Gurra Gurra

Water elevation @ weir pool 4 (m)	Flow rates (ML/day)											
	0	20000	25000	30000	35000	40000	45000	50000	55000	60000	65000	70000	341000
12.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
13.2	0%	0%	0%	0%	0%	1%	2%	4%	9%	14%	32%	38%	100%
13.8	0%	1%	1%	2%	2%	3%	6%	10%	21%	33%	55%	60%	100%
13.95	0%	2%	2%	2%	3%	4%	7%	12%	24%	38%	64%	69%	100%
14.34	0%	4%	5%	6%	7%	8%	13%	21%	30%	48%	93%	100%	100%
22	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

9 Units of measurement

A. 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 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} 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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