The Source Murray Model for NSW regional water strategies

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Abstract: The NSW Department of Planning and Environment (DPE) has been developing regional water strategies (RWS) across 12 NSW regions to enhance the management of water and improve water security. The Southern Murray Darling Basin covers two of these regions: Western and Murray regions. The project is a collaboration between partner organisations and stakeholders, led by DPE to integrate a suite of new and existing models for long-term analysis of water availability in the southern connected river systems (SCS). The RWS applies a consistent approach throughout the Murray-Darling Basin using three sets of climate data. These include 131 years of daily instrumental climate (1890-2021), 10,000 years of paleo-stochastic climate data (Leonard et al. 2022) and climate-change-adjusted stochastic climate. This information is used by runoff and river system models to assess hydrologic, economic and ecological risks and outcomes for baseline and a range of management and infrastructure options.

The Source Murray Model (SMM) is an integral part of the SCS integrated modelling, conjoined with the Upper Murrumbidgee, mid-lower Murrumbidgee. and the Snowy Hydro-electric scheme river system models. These models are separate, but they exchange information for inflows, water allocations, and other inputs and outputs related to water management rules. The exchange of information is complex as the models use a range of platforms running at different time steps (daily and monthly). This study adopted an iterative process to capture the interaction between models and ensure convergence (Trim et al. 2023). The DPE has developed Python scripts to manage the flow of information between the various models. The data exchange takes place between full-period simulations of the individual models. The Python scripts were executed by DPE to process Snowy Model outputs to SMM inputs, and vice versa. The scripts also processed Victorian tributary models for input to SMM.

The SMM uses information from the Murrumbidgee and the Snowy models. The model also takes inputs for the upstream contributions of Victorian tributaries and inflows to Menindee lakes. These include the NSW Barwon-Darling model and Victorian river system models of Kiewa, Ovens, and Goulburn-Broken-Campaspe-Coliban-Loddon Rivers. Some other inputs and South Australian demands are changed to monthly patterns or regression-based models for this project. The MDBA on behalf of NSW upgraded the existing SMM to create a new version of the SMM to support the integrated SCS modelling for the RWS project. The key upgrades included: updated urban water demand models and the snowy component.

As the project aims to secure future town water supply, the MDBA updated the urban water demand model with the latest high-resolution town water supply data, used to derive monthly and annual demands for individual towns. The model includes new climate stations, supply points and functionalities to demonstrably improve demand representation. The newly developed model has also created opportunities to analyse future water needs with respect to demographic and climate changes at an individual town level.

The snowy components of the SMM have been modified to align with the latest rainfall runoff modelling. Further, whereas the previous arrangement used the limited outputs from the 2002-conditions Snowy model to generate proxy information for simulating the effect of the 2011 Snowy Water Licence (SWL) changes, the SMM now accesses the current-conditions Snowy model outputs referred to in the SWL, and thus more faithfully simulates the Snowy-Murray interaction. Finally, the SMM now includes the callout provisions of the River Murray Increased Flow (RMIF) water, which provide greater flexibility on its use, and enhance its environmental benefit.

The collaborative efforts helped to develop an integrated modelling suite for the RWS project. The iterative process was effective in linking modelling inputs and outputs more accurately. The project also enabled SMM connection with the Snowy model outputs directly, which is an enhancement to southern basin modelling.

Keywords: *River system model, Source Murray Model, regional water strategies*

1. INTRODUCTION

The River Murray is Australia's longest river flowing through New South Wales (NSW), Victoria and South Australia (MDBA 2020). The river supports the livelihood of country towns and communities and is also home to unique native plants and animals with significant importance of ecological, sociological, and cultural heritage. The MDBA operates the river on behalf of the state governments, as set out in the Murray Darling Basin agreement (Schedule 1, the Water Act 2007), a binding document that gives MDBA control over the regulation assets, including Dartmouth Dam, Hume Dam, Yarrawonga Weir, Torrumbarry Weir, Lake Victoria and the locks and weirs from Lock 15 at Euston to Lock 7 at Rufus River (MDBA 2020). The physical operation of structures is managed by water authorities in each state. This includes Menindee Lakes on the Darling River, which contributes to water resource in the Murray system when its storage volume is greater than 480 GL (or 640 GL if coming out of NSW control) but is managed by the NSW Government. The MDBA does not operate the River Murray downstream of the South Australian border.

The NSW Government has invested in new climate datasets and improving hydrological modelling to inform the development of regional water strategies for the Murray and Western regions. The objectives are to understand the regions' climate and the effect of future climate change more accurately and enable analysis of the associated water-related risks to NSW communities and water users (DPE 2022).

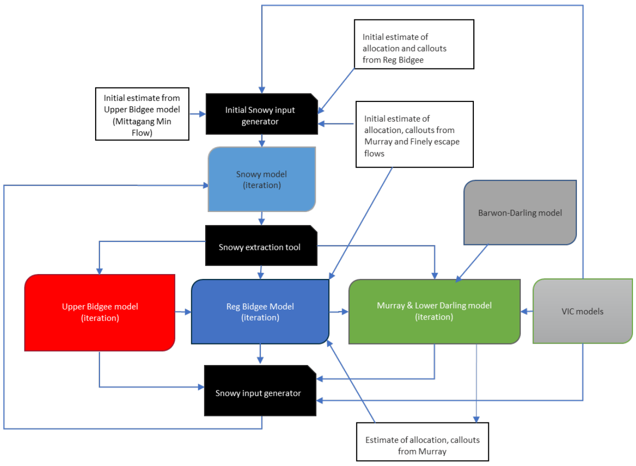

Figure 1. The Source Murray Model (Murray and Lower Darling model) within SCS platform (modified from Trim et al., 2023)

Working collaboratively with other state and territory governments, the MDBA, and Snowy Hydro Limited, for the first time this project brings together several separate hydrological models into an integrated modelling framework of the Southern Connected System (SCS) (Trim et al. 2023). The SCS framework combines the suites of models for the Snowy Scheme, the upper Murrumbidgee, the regulated Murrumbidgee and Murray systems models. These models run on a separate platform and for different time steps (daily, and monthly). The exchange of information has been facilitated through Python scripts.

Within the SCS framework the Murray Model interacts with Regulated Murrumbidgee and the Snowy Models. This paper details how the Murray Model has been upgraded and how the inter-connected system modelling helps to achieve the accuracy in sharing of information and greater transparency in modelling outcomes, which has been the key decision-making tool for this project.

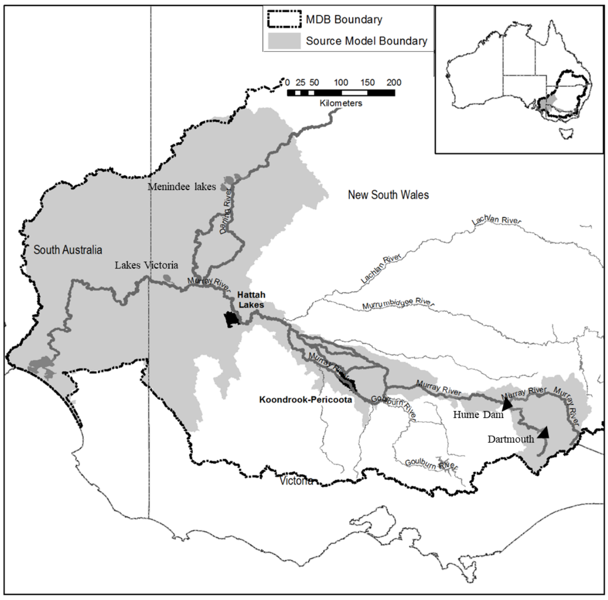

Figure 2. The Source Murray Model boundary

2. SOURCE MURRAY MODEL

The Source Murray Model (SMM) represents the Murray and Lower Darling River systems. The Murray River is about 2,530 km long, originates in the Snowy mountains about 40-km south of Mt. Kosciuszko and discharges into the Lower Lakes, at the sea barrages in South Australia. The model includes four major storages: Dartmouth Dam on the Mitta Mitta River, Hume Dam on the Murray River, Menindee Lakes on the Lower Darling and Lake Victoria (an off-river storage connected to the Murray River between the Darling River confluence and the South Australian border). The Menindee Lakes system forms the headwater of the Lower Darling River, which is modelled as four major lakes: Wetherell, Pamamaroo, Menindee and Cawndilla. In addition, there are thirteen weirs, ten locks, and several natural wetlands and floodplains in the model. The MDBA uses SMM to simulate the management of the River Murray through the operation of storages, weirs and regulators to deliver water to consumptive and non-consumptive water users along the river system according to the water sharing arrangements between New South Wales, Victoria and South Australia that are set out in the Murray Darling Basin Agreement (MDBA 2019).

2.1. Modelling concepts

The modelling process is undertaken in a series of phases; resource assessment, environmental flow prioritisation, constraints, ordering and flow. The resource assessment phase considers the stored resource, expected inflows and loss to determine allocations to water users. The environmental flow prioritisation phase considers the priorities of different environmental assets within the portfolio of available resource. The constraints phase is an upstream to downstream pass that determines the minimum and maximum flow constraints used to support decisions on the distribution of orders. The ordering phase accumulates orders from water users from downstream to upstream taking into consideration re-regulation, losses/gains and tributary inflow forecasts. The flow phase routes water from upstream to downstream and accounts for water regulation at structures, attenuation, losses and gains, diversions, extractions and return flows to and from the river system. The model operates on a daily time step and on a Windows PC takes about 2.0 hours to run for 100 years. Note this runtime has significant implications for running 10,000-year climate replicates.

The model maintains ownership between NSW and Victoria, with each state providing half of South Australia's entitlement flow. Clause 91 of the Murray-Darling Basin Agreement entitles South Australia to defer part of its entitlement flow for storage in the major dams. The management of this SA storage volume within the Murray-Lower Darling system is simulated via Source model functions.

2.2. Model scenarios

A consistent instrumental modelling period of 1/7/1891 to 30/06/2021 was adopted (Trim et al. 2023). Regional climate data used by the model and associated runoff generation models are used to inform the stochastic generation of 10,000-year replicates of regional rainfall, potential evapotranspiration, and temperature (Leonard at al. 2022). These climate replicates are also adjusted for NARCliM climate change projections to create a climate change scenario. This creates three specific climate scenarios referred to as instrumental, stochastic and NARCliM (Olson et al. 2016), which have been used in this study. NARCliM uses a total of 12 Global and Regional climate model combinations (4 GCM and 3 RCM) to produce a climate change ensemble over southeast Australia (Olson et al. 2016). NARCliM 1.0 outputs of three RCMs from CSIRO MK3.0 GCM have been used in this study.

2.3. Model inputs

The inputs to the model include inflows from other river system models. The Snowy Mountain Hydro-electric Scheme (SMHS) includes releases through the Murray 1 Power Station, spills and releases from headwater Snowy storages and aqueducts, and required annual release (RAR) and account information (NWS 2002). Victorian models provide inflows from Kiewa, Ovens and Goulburn-Broken-Campaspe-Loddon (GBCL). The GBCL also includes allocations. NSW models provide inflows from the Barwon-Darling to Menindee lakes, Talywalka Creek, Murrumbidgee and Billabong Creek. The Murrumbidgee also includes allocations and demands between Balranald and the Murray confluence. Other inputs included are return flows from irrigation drains and wastewater effluents.

2.4. Model simulation

The model runs on a daily time step and simulates: 1) state shares and bulk water accounting; 2) Allocation by each state to groups of water users; 3) Irrigation and urban water demands; 4) Required water transfers between storages for demand management; and 5) Operation of various dams and structures including water orders. The SMM has been calibrated separately. During the calibration, the model's input sets (inflows, allocations, and operational behaviours) are set to observed condition to simulate hydrologic processes. In this study, the model is set in planning mode, representing the 2019 level of development known as the Water Resource Plan (WRP) scenario. This scenario sets the state water management provisions and operational rules that are in effect on June 30, 2019. This is the scenario used for annual Sustainable Diversion Limit (SDL) accounting. Given its importance for this purpose, the NSW RWS study has used this WRP scenario to assess the potential long-term impacts of selected future climate sequences.

2.5. Model outputs

The Murray provides an extensive range of physical and management-based outputs that are used to inform RWS and as inputs to upstream SMHS and Murrumbidgee models. The Snowy model receives Dartmouth, Hume, Menindee Lakes and Lake Victoria volumes; Hume spills; water use; allocations; RMIF and drought callouts. The Murrumbidgee model receives flow at Wakool junction; SA surplus flow; NSW Lake Victoria volume; NSW Murray GS Effective Allocation; Finley Escape flow (fixed pattern).

3. MODEL UPDATES AND RESULTS

3.1. Inflows

As part of the RWS project the tributaries of the Upper Murray were modelled by a combination of rainfall runoff models and a corresponding reconceptualization of the Upper Murray configuration of the Murray Source model (Trim et al. 2023). The model included the Menindee and Bourke inflows and added Talyawalka Creek inflow from NSW's Barwon-Darling model as the inflows to the lower Darling River. The drain inflows at 25 locations have been replaced by monthly patterns converted from existing daily time series input data to annual average monthly values.

3.2. Urban water demand

Urban water demands in the SMM are modelled by taking account of 1) Critical human water needs (CHWN); 2) Seasonal variation in use in response to climate drivers, and 3) Variations in use in response to water restrictions, which is expressed as below.

$$TW_d = CHWN \times f(daily\ factor) + V_d \times f(daily\ factor) \times f(climate) \times f(restriction) \qquad Eq.\ (1)$$

Where, TW_d = Daily town water demand (ML/day); CHWN= Critical Human Water Need (ML/year); f(daily factor) = daily factor derived from monthly pattern; Vd = variable demand in response to climate seasonality and water restriction (ML/year); f(climate) = the ratio of rolling climate deficit and an average deficit; f(restriction) = function defining impact of urban restrictions on variable demand.

The Broken Hill urban water demand was modelled differently using a regression equation taking account of constant mining demand combined with a monthly pattern multiplied by population and constrained to treatment plant and pipeline capacities.

3.3. Snowy Water Licence

The Murray system is assured an annual nominal release of 1062 GL from the Snowy-Murray development. This requirement on the Snowy scheme effectively divides the Snowy Murray development water volume into below-target water (BTW) and above-target water (ATW). The annual nominal release is provided from BTW, while any surplus, discretionary releases are from ATW. The annual nominal volume is adjusted according to conditions in both the Snowy and Murray systems. For example, in dry periods, the Snowy system BTW shortage is encapsulated by the Dry Inflow Sequence Volume (DISV). The Snowy Water License (SWL) allows the nominal 1062 GL to be reduced while the dry period continues (DISV increases). During periods of DISV recovery (reduction), the recovery volume accrues first to the River Murray Drought Account, and then to the DISV Reserve Account. The Drought Account is reserved for extreme dry years, while the DISV Reserve Account is used to buffer the assured release against any subsequent DISV increase due to exacerbation of dry conditions. Once the Snowy scheme BTW is back on target, the DISV Reserve account is cancelled. The DISV Reserve mechanism tends to stabilize the Snowy scheme’s contribution to the Murray system resource during sustained dry periods.

Another adjustment to the annual nominal 1062 GL is for water savings on the Murray and Goulburn rivers as part of the Water For Rivers program (Productivity Commission 2010). Under this program, the twelve-months’ water savings to January 31 in the Murray, Goulburn and Murrumbidgee rivers are transferred to the Snowy scheme on May 1 for environmental use as SRIF (Snowy River Increased Flows), or RMIF (River Murray Increased Flows). The RMIF environmental account provides for environmental demands on the Murray below Hume Dam, while the water savings on the Murray and Goulburn allow the nominal 1062 GL release to the Murray to be reduced. The result of these adjustments to the nominal 1062 GL/y, and other adjustments detailed at Clause 12 of the SWL, define the so-called Required Annual Release (RAR) from the Snowy-Murray Development to the Murray system. Many of the RAR adjustments were formalised in the 2011 amendments to the SWL (NSW DPI 2015).

Separate to the RAR changes, the 2011 amendments also included a capacity for the Murray system to call out the Snowy RMIF account if the net ATW (ATW less River Murray and Murrumbidgee River drought accounts) exceeds 800 GL. Subsequently, this callout capacity enabled a proposal under the Sustainable Diversion Limit Adjustment Mechanism (SDLAM) program. This SDLAM proposal was underpinned by the *2013 Strategy for RMIF Increased Flow Rules*. This strategy proposes to manage the RMIF in MDBA storages through NSW and Victoria entitlements. In addition, the Snowy RMIF account incorporates two sub-accounts: Environmental and General RMIF. Each of these sub-accounts is further partitioned by state. The Snowy Environmental RMIF account has state sub-accounts for NSW and Victoria, while the Snowy General RMIF account has state sub-accounts for NSW, Victoria, and South Australia.

Under the RMIF callout provisions, the Snowy General RMIF account is credited through a substitution mechanism, which allows a state to meet a call on either the Snowy Environmental or General RMIF accounts from existing state resource in Hume, with a corresponding credit in the providing state's Snowy General RMIF account. Thus, a call on the Snowy Environmental RMIF account gives NSW and Victoria the option of increasing their respective Snowy General RMIF accounts. Similarly, any call on a state's Snowy General RMIF account can be met from either of the other two states, with a corresponding credit in the providing state's Snowy General RMIF account. This provides a mechanism by which South Australia can transfer to its Snowy General RMIF account any volume held in Dartmouth and Hume as deferred water under South Australia's Storage Right. For this NSW RWS project, the Snowy model did not include consideration of the RMIF general account. Therefore, the RMIF general account was disabled in the SMM used for this study.

Prior to the NSW RWS project, the standalone Murray model only had access to three outputs from a 2002-conditions Snowy model: Murray 1 Release, Tooma spills and Dry Inflow Sequence Volume (DISV). For current-conditions simulations, the standalone Murray model post-processes these outputs to account for changes that have happened since the 2002-conditions Snowy model, such as the 2011 SWL amendments. To this end, the Murray model used the 2002-conditions Snowy model's outputs to track the 2002-conditions RAR and ATW releases, which were used as proxies for the Snowy system information referred to in the 2011 SWL amendments.

For the NSW RWS project, the Murray model was configured to interact with a current-conditions Snowy model, with additional outputs to facilitate direct simulation of the SWL Schedule Four release requirements. The extra information included: 1) BTW volume in the Snowy storages, used to trigger cancellation of the DISV Reserve Account; 2) Snowy-Murray Development Forced Release volume, which triggers a spill from the River Murray Drought Account; 3) ATW reduction, which cancels RMIF water if there is no other ATW water against which to account evaporation; 4) RMIF reduction, which accounts for the impact on RMIF of any ATW to BTW transfer arising from Hume spill compensation release requirements, namely Within-Year Required Release and Wet Sequence Protection.

The Snowy-Murray development BTW volume is now used in the SMM to cancel the DISV Reserve. The operation of the DISV Reserve is shown for the instrumental dataset in Figure 3. This graph shows the period following a large initial rise in DISV.

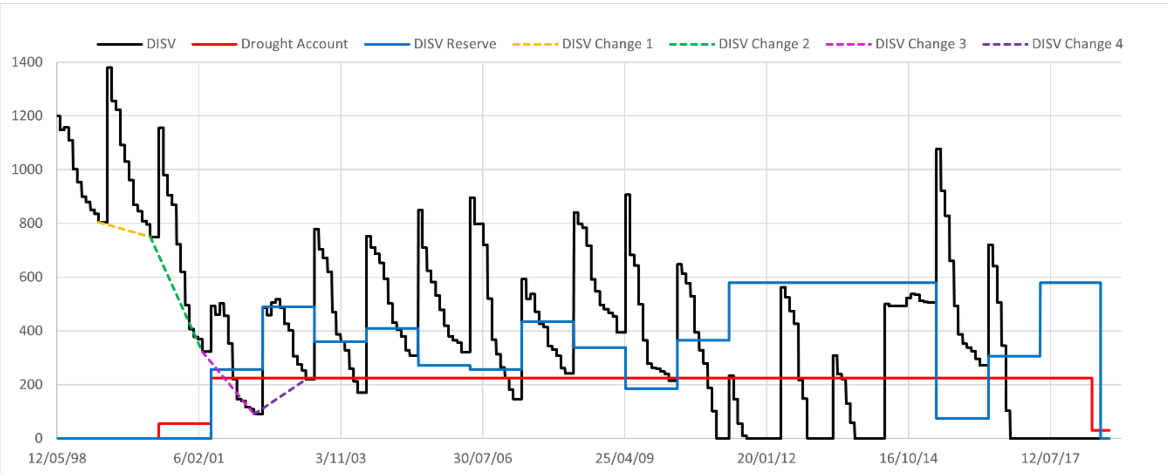

Figure 3. The operation of the DISV Reserve in the historical scenario (instrumental data set)

The impact of DISV on the Snowy water year's RAR is via the twelve-month change in DISV on March 1. Following the initial rise in DISV there is a modest reduction, denoted DISV Change 1. Two months later, at the start of the Snowy Water year in May, this 54.8 GL of DISV recovery is credited to the Snowy Murray Drought Account, to be called upon in extreme dry years. The next year sees a further 427.3 GL of DISV recovery denoted DISV Change 2, which credits the Drought Account to its maximum of 225 GL and establishes the DISV Reserve Account at 257.1 GL. The next year, DISV Change 3, there is 231.8 GL of DISV recovery, and this volume is credited to the DISV Reserve Account, which now stands at 488.9 GL. In the next year, there is a DISV increase of 128.1 GL. Because there is sufficient DISV Reserve Account, this DISV increase does not reduce the RAR; the DISV Reserve Account volume is reduced instead. Throughout the next fifteen years, the variations in DISV impact only the DISV Reserve Account, while the RAR remains unaffected by DISV fluctuations. Once the BTW storage in the Snowy-Murray development reaches target, the DISV Reserve Account is cancelled, and any subsequent rise in DISV will reduce the RAR correspondingly. Given the stabilizing influence of the DISV Reserve Account on the Snowy component of Murray resources, the capacity to cancel the account using conditions referred to in the SWL, rather than proxy modelled information, represents a significant improvement in the Source Murray Model's capacity to accurately capture the influence of the Snowy scheme on the Murray.

In addition to the extra outputs, the current-conditions Snowy model showed a more variable Murray 1 release than the previous 2002-conditions model, which was somewhat artificial in its uniformity. As a result, the transition to the current-conditions Snowy model brought to light an RAR adjustment that was missing from the SMM, the Within Year Release Requirement. This requirement stipulates that if Hume Dam has been spilling in the months May through October, then a certain portion of the RAR must be released in the December – April period of the Snowy water year. In the previous version of SMM, this requirement was always met via the 2002-conditioins Snowy model outputs. As part of configuring the SMM for NSW RWS, with the current conditions Snowy model, the Within-Year Release Requirement was implemented with four new model functions (Geoff Podger*, pers. comm.*).

3.4. South Australia – metro Adelaide demands

SA water demands for Metro Adelaide have been replaced by a regression model. A multiple linear regression was undertaken for threee sites: 1. Murray Bridge – Onkaparinga (MAMBONK), 2. Mannum – Adelaide (MAMANAD), and 3. Swan Reach – Stockwell Pipeline (SRSTOCK). The pumping at these sites was regressed monthly against Morton Lake evaporation and rainfall. Regression was considered against current month, 1-3 months lag, previous 3-month total and year to date (YTD). A least squares fit was found for each calendar month across the three sites. Where the Pearson's correlation was less than or equal to zero the long-term average mean was used for that month. The total across the three sites results in a bias of 3.14%.

3.5. SDLAM projects

Two of the projects included in the Sustainable Diversion Limit Adjustment Mechanism (SDLAM) were included in the SMM for the RWS. They were the change in operating rules on Barmah-Millewa Forest Environmental Water Allocation (BMFEWA), and the rule of flexible rates of fall in river levels downstream of Hume Dam.

3.6. Broken Creek inflows

A hydrological study for the RWS project recommended that the flow at site 404210 Broken Creek @ Rices Weir be represented as a regression equation, rather than the historical time series (HARC 2021). This is necessary for simulation of the hypothetical climate sequences of RWS.

3.7. Impacts on inflows and allocation

Several changes have been made to the Murray Model from its original WRP scenario. Additional time series were added and the changes in Snowy impacted the inflows and water allocation, which is considered to be acceptable (Table 1).

Table 1. Water balance impact due to changes in the model

Scenarios	Base model	RWS model	Difference (RWS less base)
System inflow			
Darling (inflow to Menindee Lakes)	1,704.2	1,769.5	65.3
Murrumbidgee (Balranald)	1,261.5	1,261.8	0.3
Murrumbidgee (Darlot)	311.0	311.0	0.0
SMHS releases	1,103.8	1,064.4	-39.4
Broken Creek inflows	171.1	141.6	-29.4
Allocations			
Mean NSW High Security Allocation	98.9	99.0	0.0
Mean Other NSW Gen Sec Allocation	63.9	68.3	4.4
Minimum Other NSW Gen Sec Allocation	0.0	0.0	0.0
Mean Victoria Feb Allocation %	146.4	156.6	10.3

3.8. Urban water demand model validation

NSW DPE collected daily or monthly water use data from town water supplies (total 26 towns) on the Murray and Lower Darling rivers. Data was used to estimate annual demands and monthly demand patterns for each entitlement. Data was not available for some towns, where it has been filled by surrogating data from other sites. The results are quite acceptable, as indicated by the bias (PBIAS) results of Table 2.

Table 2. Water balance impact due to changes in the model

User group	Albury	Berrigan Shire	Federation Council	Murray Shire*	Wakool Shire*	Wentworth	Deniliquin	Euston	Pooncarie
PBIAS (%)	6.3	9.7	-3.3	13.1	16.7	9.3	12.6	12.0	8.6

Note: *Jointly Murray River Council

3.9. Remarks on Snowy and RMIF modelling output

The snowy water modelling is complex. MDBA's stand-alone Murray model post-processes the 2002-conditions Snowy model outputs to simulate the 2011 license changes and the RMIF callout provisions. The Within-Year Release Requirement as specified at Clause 11 of the Snowy Water License was satisfied in the stand-alone implicitly. With the updated Snowy model for current conditions, it is necessary to explicitly add the Clause 11 component of the RAR. With a more realistic and variable-release Snowy model comes the requirement to explicitly consider Clause 11.

4. CONCLUSION

MDBA updated the Source Murray Model for the NSW Regional Water Strategies project to enable long-term simulation of ten thousand years of climate replicates for stochastic and NARCliM scenarios. After a rigorous process of dynamic modelling, a robust suite of models was obtained. The several feedbacks runs (four in this case) gives an accurate estimate of inputs for the models. The collaborative efforts have helped MDBA, for the first time, to connect the Murray model with Snowy model outputs directly, which is a significant improvement. The approach can be strengthened for basin wide modelling.

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