Independent Review of the Source Model of the Murray and Lower Darling Rivers (SMM)

FINAL REPORT

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Disclaimer
This report was written by Professor Tony Jakeman, Professor Barry Croke, and Takuya Iwanaga for the Murray–Darling Basin Authority.

Table of Contents

Executive Summary

Several tasks were required by the MDBA to be addressed in this independent review of the Source model of the Victorian and New South Wales Murray Systems, the Lower Darling River and the South Australian Murray, known as the Source Murray Model (SMM). Here we summarise our major findings in relation to the specific terms of reference in Section 1.2. Our more detailed responses can be found in Section 3.

The model comprises the best available knowledge and information and is fit for purpose for estimating the Baseline Diversion Limits (BDL), and as part of the method for estimating annual permitted take in Water Resource Plans (WRPs). In this connection, the model structure contains appropriate system processes, water sharing and water accounting that will allow assessment of whether the rules in state changes to the Murray-Darling Basin (MDB) WRPs will still meet the relevant Sustainable Diversion Limits (SDL). It is largely extendable to support new policy and management initiatives. Concerns were raised regarding the workflow and usability but these are noted as largely being issues that could be addressed in the short-term, and do not compromise fitness for purpose. Continued use of the previous generation model (MSM-BigMod) for the WRPs cannot be described as a viable alternative as the SMM represents significant advances in understanding of the Murray/Lower Darling systems.

Overall, the model structure is fit for purpose and represents the water sharing arrangements for the Murray and Lower Darling System. The permitted take method has been developed in collaboration between MDBA and the three states using best available information and with consideration to MDBA Position Statement 3C. The climate period considered (1895-2009) contains a high degree of historic variability, so the modelling is robust with respect to that range of variability. As with all water resource modelling undertaken for planning purposes, there does however need to be continual assessment of the model performance and modifications added as new knowledge, information and data become available. Future modifications may involve changes to model inputs and/or parameterisation, and improvements to its overall usability to allow for more timely analyses to occur.

Largely the results shown indicate that the model is performing satisfactorily. Several improvements to model performance assessment processes are suggested and these would be a valuable addition to be considered over the next 18 months. Among these are practical methods of sensitivity analysis and uncertainty assessment. Wherever possible, performance should be assessed against observational data. In the longer term, methods could be used to identify and assess the worth versus cost of candidates (location and types) for additional data collection in terms of their value in improving predictive performance of the model.

Documentation of the modelling is considerable and is shared with the states but should be more complete, particularly where it is necessary to specifically understand model runs for WRP purposes. It can be part of the submitted WRP or at least available when WRPs take effect.

There will be benefit in ongoing work to improve some of the model inputs and model parameterisations over time. Above all, there is a valuable cohort of people working with and around the modelling that facilitates ongoing progress and healthy discussion. It is paramount, however, that both resourcing of the modelling and maintaining a critical mass of such expertise continue unabated as new demands and needs for improvements will continue to arise.

1 Introduction

1.1 Background to this Review

The MDBA has developed a Source daily time step model of the Victorian and New South Wales Murray Systems, the Lower Darling River and the South Australian Murray known as the Source Murray Model (SMM). This has included conceptualisation, calibration, testing and configuring the model to represent different levels of development.

An independent review into the adoption of the SMM was completed in March 2017 (Bewsher 2017). The MDBA has worked with Basin states since that time to implement the improvements outlined in the review, as well as to undertake further customisation to represent state requirements for water resource planning.

The MDBA believes the SMM is now the best available method to underpin an updated determination of some components of the Baseline Diversion Limit (BDL) estimate for the NSW, Victorian and South Australian Murray and NSW Lower Darling Sustainable Diversion Limit (SDL) resource units, and that it should be used for some components of the permitted take method brought forward by states for the relevant Water Resource Plans (WRPs).

As part of the WRP accreditation process the MDBA is reviewing the modelling provided by states in line with the requirements of the Basin Plan. As the MDBA is the developer of the SMM, an independent review was sought to undertake this task in relation to the SMM to maintain the impartiality of the process. The terms of reference for the review are in **Appendix A** and appear in part in Section 1.2 for context.

1.2 Terms of Reference for this Review

The review scope was limited to assessing whether the SMM is fit for use in generating BDL estimates and ongoing calculation of permitted take in the relevant SDL resource units, as a part of the wider process of WRP accreditation. The review is not intended to be as exhaustive as the process employed for model accreditation under the Cap. Specifically, the review focussed on whether:

1. the relevant recommendations of the previous independent review have been undertaken and adequately implemented within the model
2. the model has been adequately customised to represent state requirements
3. SMM is fit for purpose to re-estimate the quantity of water that was permitted to be taken under relevant components of the BDL, as defined under the Basin Plan
4. the permitted take method implemented in the SMM meets the requirements of the Basin Plan (as informed by MDBA Position Statement 3C – method for determining take – attached as **Appendix B**) and is robust under a range of climate conditions
5. any immediate corrections are required to meet the relevant WRP requirements of the Basin Plan
6. If while performing the above, the reviewer notes any future model enhancements or additional monitoring and data collection, that would improve the operation or the predictive capability of the model, these should be presented to the MDBA for further consideration.

1.3 Documentation of SMM

A comprehensive range of reports has been prepared by the MDBA throughout the establishment, calibration and initial implementation phases of SMM. These reports were provided to aid in the review process through eWater's wiki website ('the wiki'), with various documents also made available via email. Documents that were considered to be of most relevance are listed in **Appendix D**. The principal overview report is *Source Model of Murray and Lower Darling System* and is referred to as the **SMM Report** within this review.

The reports cover two broad stages reflecting the development and implementation of SMM. These documents are themselves in various draft and review stages. Such documentation has been made available to all jurisdictions throughout the model development and implementation process, and copies made available through the wiki. Leveraging the wiki platform has created opportunities for feedback and collaboration across the teams involved. This review endorses the collaborative and transparent approach that the MDBA has adopted in the development and documentation of SMM.

1.4 Liaison Undertaken During this Review

The review was undertaken from December 2018 to February 2019. It included various meetings, interviews and correspondence with the personnel listed in the following table:

Table 1. List of departments and personnel interviewed

Department/Organisation	Personnel and Role	Date(s)
Murray-Darling Basin Authority (MDBA)	Matthew Bethune, Director, Water River Systems Modelling, Science and Knowledge Division Alistair Korn, Director, Daily Model Development, Science and Knowledge Division Pradeep Sharma, Senior Director, Water Resources Group, Science and Knowledge Division Julianne Tanner, Director, Surface Water Management, Partnerships Division Tim Rossi, Policy Officer, Surface Water Management, Partnerships Division Marcus Finn, Senior Director, Water Resource Plans and Basin Plan Policy, Partnerships Division Ingrid Takken, Senior Hydrology Modeller, Science and Knowledge Division	10 December 2018 4 January 2019 24 January 2019 29 January 2019
NSW DoI/Water	Andrew Brown, Principal Modeller, Water Modelling	24 January 2019

SA DEW	Theresa Heneker, Principal Policy Officer, Murray Darling Basin Policy and Strategy Matt Gibbs, Principal Hydrologist, Science and Information Group Claire Simms, Senior Hydrologist, Science and Information Group	29 January 2019
Vic DELWP	Seker Mariyapillai, Senior Manager Surface Water Assessment and Modelling, DELWP Yong Li, Senior Water Resource Modeller, DELWP	15 February 2019

2 Background Issues Relating to SMM

2.1 Background to the Development of an MDBA Source Model

For a number of decades, the long-term planning of water resources in the Murray and Lower Darling Rivers has been well served through use of the hydrologic simulation model known as MSM-BigMod. Whilst this model has been continually expanded and upgraded to keep pace with changing requirements, the limitations of its older software and recognised shortcomings have meant that the Authority has been pursuing a formal replacement for MSM-BigMod since at least 2000.

The introduction of the Water Act 2007 (Commonwealth) has provided further impetus for the development of a new model. The Act requires the MDBA to build an integrated model of the Basin. The MDBA has committed to the eWater Source integrated modelling system (IMS) platform for this purpose. Further the August 2013 Implementation Agreement for the Basin Plan listed obligations for the Authority and the Basin States to *"Adopt eWater Source .... as water resource plans are brought forward for accreditation assessment or sooner if achievable"*.

Consequently, not only has the MDBA been working for some years to replace MSM-BigMod with one implemented with the Source IMS, but Victoria, NSW, South Australia and Queensland states are also building replacements for their existing models utilising the Source platform.

The key benefits of implementing Source models in the Basin have been recognised for many years and include:

- representing management and operational rules at a daily time step, including environmental flow processes;
- facilitating consideration of social and economic impacts of water trade and changes in water availability;
- better integration with Basin state models to enable more accurate modelling of interconnected systems, including water trade and delivery;
- greater transparency and efficiency, and better delivery and understanding by sharing a common modelling platform across the Basin;
- better model outcomes through a more visual and transparent modelling framework;
- application of contemporary software technology that meets current and future modelling needs and replaces existing legacy software.

2.2 SMM Model Purpose

The MDBA's Source Model of the Murray and Lower Darling (SMM) simulates hydrologic behaviour within the Murray River (from Khancoban to the barrages) and along the Lower Darling River (from Menindee Lakes to Wentworth). The principal modelling purposes to which SMM is being used are listed in Table 2. These reflect many of those purposes which MSM-BigMod was originally developed to fulfil. This requires that SMM has the necessary functionality to accurately simulate the principal hydrological processes of the River Murray and Lower Darling River systems and their water sharing arrangements at a daily time-step. This includes simulation of:

- flow and water quality;
- demand for water in the key regions throughout the system;
- individual water sharing plans that have been developed within each state to manage their share of the river system's water resources, including each state's allocations to individual water users;
- operation of various dams and structures including:
    - orders to meet forecast demands;
    - pre-releases from each storage for flood mitigation;
    - the allocation and use of environmental water;
- transfers required between storages to ensure that demands can be met; and
- unique interstate water sharing arrangements between NSW, Victoria and SA using the rules in the MDB Agreement.

In addition, because SMM will likely be used by a number of jurisdictions, water agencies and consultants, it has to be very clearly and comprehensively documented and must incorporate rigorous and accepted modelling practices. The model framework must also have the capability to be easily extended to support new policy and management initiatives as they arise.

SMM's functionality must also meet accountability and audit requirements in managing salinity, diversion limits, environmental and river system health issues for the Federal Government and each of the State Governments within the Basin.

Table 2. SMM – Model purpose and performance targets (adapted from Bewsher 2017)

Model Purpose	Component	Performance Targets		
		SHORT TERM – By June 2017	MID TERM – July 2017 to June 2019 (and current status)	LONG TERM – July 2019 to Dec 2025
Purpose 1: Understanding of Hydrological Processes within the River Systems Enhance understanding of flow and salinity behaviour. Evaluate the economic impacts of changes in these behaviours. Assess these behaviours and impacts under a variety of past, present and future conditions, and provide the capability to investigate alternative management scenarios.[1]	River flows River salinities Irrigation diversions and crop behaviours Groundwater interactions and river losses/gains Wetland, ecosystem waterings Economic analyses Water trade Water resource assessments Climate change scenarios	Simulation to similar or better standard than MSM-BigMod[2]	SMM to represent a significant improvement over MSM-BigMod Achieved - based on the findings of this review and results presented in various reports	Yet to be determined3[3]
Purpose 2: Legislative Responsibilities Fulfil the MDBA's modelling responsibilities under the Commonwealth Water Act 2007.	Cap[4] – model the long term average annual diversion and the annual diversion targets	Capacity to represent 'Cap'	Model of Cap conditions and differences between models explained On track – based on evidence of continued discussions between MDBA and relevant parties found through this review.	SMM does not need to calculate the Cap as this is done in MSM
	The Living Murray Initiative[5]	Capacity to simulate baseline conditions for TLM recovery	Model of TLM and differences between models explained.	Yet to be determined[3]

[1] Under Section 172(1)(ea) of the Water Act 2007, the MDBA has a legislated function to "*develop, in consultation with the Basin States, an integrated water model for the Murray-Darling Basin*" in order to fulfil its responsibilities under the Act.

[2] This will be based on a qualitative assessment of the adopted model approach and reported metrics. Differences between the Murray Source and MSM-BigMod models will occur. The differences must be explainable and be accepted.

[3] Performance targets for model improvements will be set progressively as new data/knowledge/requirements are identified.

[4] As part of the implementation of a 'Cap' on diversions, the MDBA has responsibilities to develop and operate an analytical model of the 'designated valleys' known as NSW Murray, Victorian Murray and the Lower Darling Rivers. Refer subclause (4) and (5) of Clause 11 of Schedule E to Schedule 1 of the Water Act 2007.

[5] Modelling by MDBA to fulfil its responsibilities under subsection 18H(2) of the Water Act 2007.

Model Purpose	Component	Performance Targets		
		SHORT TERM – By June 2017	MID TERM – July 2017 to June 2019 (and current status)	LONG TERM – July 2019 to Dec 2025
			On track – based on evidence of continued discussions between MDBA and relevant parties found through this review.	
	BSM2030[6] – model the Benchmark Conditions, joint works and measures, State actions, and delayed salinity impacts. Maintain salinity registers.	Capacity to represent BSM2030 and other requirements under Schedule B	Model of BSMS conditions and differences between models explained On track – based on evidence of continued discussions between MDBA and relevant parties found through this review. Proposed to be submitted for accreditation as stipulated in Schedule B of the MDB agreement	Yet to be determined[3]
	BDL[7] – assess the baseline limit of take from each of the 6 surface water SDL resource units covered by the model	Model of BDLs	Model differences explained and accepted On track and undergoing assessment – SMM set up for BDL conditions and are being finalised in consultation with the States	Yet to be determined[3]
	SDL[7] – assess the annual limit of take from each of the 6 surface water SDL resource units covered by the model	Capacity to represent SDLs	Model of SDL conditions and differences between models explained On track – interim approach agreed and undergoing assessment.	Yet to be determined[3]
	WRP[7] – model the WRPs of each jurisdiction required under the Basin Plan	Capacity to represent each WRP	Model of each WRP On track – models for WRP conditions are being finalised in consultation with the States	Yet to be determined[3]

[6] The Basin Salinity Management 2030 (BSM2030), builds on the previous Basin Salinity Management Strategy (BSMS, 2001-2015). Under the BSMS and now under BSM2030, the MDBA has various modelling responsibilities. These include the development of a model to simulate salinity, salt load, flow regime and the economic effects on water users of these parameters. The MDBA's model must also be capable of predicting any salinity impacts of 'joint works and measures' and 'State actions', and any 'delayed salinity impacts'. Further the MDBA has a responsibility to maintain the salinity 'Register A' and 'Register B'. Refer Clauses 36, 38 and 39 of Schedule B to Schedule 1 of the Water Act 2007. Note also that the model used for the BSM2030 has to be reviewed at intervals of not more than seven years.

[7] Under the Basin Plan, prior to 1 July 2019, Water Resource Plans (WRPs) must be developed by NSW, Victoria and South Australia for all their WRP areas simulated within the coverage of the MDBA model. Each WRP area comprises one or more Surface Water Sustainable Diversion Limit (SDL) Resource Units. For each of these units, the Baseline Diversion Limit (BDL) is defined as the 'baseline limit of take' from an SDL resource unit calculated over the 'historical climate conditions' and using the legislated limits on take that existed at 30 June 2009. These BDLs will most efficiently be determined using the MDBA model. Further, after 1 July 2019, the water taken from each SDL resource unit is not to exceed the 'annual permitted take'. This take will also likely be determined annually using the MDBA model for each SDL resource unit covered by the model, consistent with the Basin Plan's proposed reduction in diversions across the whole Basin.

Model Purpose	Component	Performance Targets		
		SHORT TERM – By June 2017	MID TERM – July 2017 to June 2019 (and current status)	LONG TERM – July 2019 to Dec 2025
Purpose 3: Integrate Basin Water Resources Modelling Beyond the Murray and Lower Darling River Systems Link with surface and groundwater models in adjacent valleys to facilitate water resource management across the whole Basin.	Goulburn and Murrumbidgee	Provide linkages to allow integration of SOURCE models of these tributaries when developed by Victoria and NSW	Models linked and run concurrently Postponed – to be undertaken post June 2019	Yet to be determined[3]
	Barwon-Darling	Provide linkages to allow integration of SOURCE model of Barwon-Darling when developed by NSW	Models linked and run concurrently Postponed – to be undertaken post June 2019	Yet to be determined[3]
	Snowy	No formal linkage of models is proposed or required	Potential inclusion of Snowy into Murray Source Postponed – to be undertaken post June 2019	Yet to be determined[3]
	Groundwater	No explicit representation	Postponed – to be undertaken post June 2019	Yet to be determined[3]
	Ovens and Kiewa	Fully incorporated with MDBA's model	Fully incorporated with MDBA's model Interim solution completed – Regression equations implemented within plug-ins.	Fully incorporated with MDBA's model
Purpose 4: River Operations Facilitate day-to-day river operations in accordance with objectives and outcomes set by the Basin Officials Committee, including for interstate water accounting of past and future behaviour.	Interstate water sharing and accounts	Simulation to similar or better standard than MSM-BigMod	Simulation to similar or better standard than MSM-BigMod Interim solution completed and deemed fit-for-purpose	Yet to be determined[3]
	River operations and management	Simulation to similar or better standard than current spreadsheet models	Simulation to similar or better standard than current spreadsheet models Interim solution completed and deemed fit-for-purpose	Yet to be determined[3]
	Multi-history runs	Capability to undertake	Capability to undertake Interim solution completed and deemed fit-for-purpose	Yet to be determined[3]
	Salinity forecasts	Simulation to similar or better standard than current approach	Simulation to similar or better standard than current approach Interim solution completed and deemed fit-for-purpose	Yet to be determined[3]

3 Response to Terms of Reference

3.1 Implemented Recommendations from Previous Report

Independent reviews of the SMM were undertaken over the course of its development (Bewsher 2017; Bewsher 2015). The purpose of these reviews was to identify any shortcomings and to guide model development for initial use as a BDL model. Various model issues were identified with suggested tasks to rectify these (see Tables attached as Appendix E in Bewsher 2017).

The relevant general conclusion from the Bewsher (2017) report relates to progressing SMM to SDL and WRP models. The key additional capabilities for SMM identified were:

- Simulation of water recovery and the corresponding environmental watering proposals;
- Inclusion of SDL adjustment measures; and
- Any new water sharing arrangements proposed as part of a jurisdictions' WRP.

The majority of the personnel interviewed for this review indicated that the large proportion of high priority tasks and issues (see Table 3) with respect to the above capabilities have been acceptably resolved, although specific concerns surrounding the modelling process were raised. For example, the exact methods used to consider and calculate environmental take and carryover entitlements. Although important, these issues do not reflect a lack of capability within the Source modelling system. We find that progress is being made through effective collaboration between modellers and planners across the jurisdictions.

The availability of up-to-date documentation is still an ongoing concern and is partly addressed with the use of eWater's wiki site. Documents may refer to model results or other documentation that has not yet been included, made available, or updated. The difficulties involved in maintaining a consistent set of documents is appreciated but still needs to be a priority action for MDBA. This issue is further expanded on in the section entitled Assessment of SMM.

3.2 Customisation for State Requirements

NSW DoI/Water supports the customisation of the SMM for its purposes and is based on best available information (meeting with Andrew Brown, January 24, 2019). Several recommendations were made however that relate to the nature of the software and model runtimes (see also Section 3.6). Long model runtimes impact on model evaluation and could be shortened by exploring opportunities for speed increases and revising some of the coding. So-called plug-ins to the model can be made more generic, for example not pertain to a specific river valley only. It was also felt that there could be a resourced work program where the rules were more strongly connected to water managers and operators.

Discussion with SA DEW principally focussed on issues surrounding the implemented model assumptions and perceptions of incorrect model results and/or processes (as described in documents available to SA at the time). Missing, inconsistent, and unexplained values within the available documentation was cited as a major concern. This is understandable as SA, being downstream of all other States, are unable to set up a concrete version of the SMM model for South Australia without finalised input from the other States. One example – a mismatch in different components of water balance between SMM and MSM-BigMod – was explained as not so much as a discrepancy but an improvement in the understanding of these components through use of daily time step representation compared to monthly in MSM-BigMod (Sharma, pers. comm).

Updated documentation and model releases have been delivered in the intervening time between the meeting and the publication of this report which have given SA DEW the confidence that the

SMM is fit for the purpose of water resource planning, in that all the necessary functionality is available. Some issues raised in meeting with SA DEW, for example accreditation of the SMM and policy level discussions, were deemed to be outside the scope of this independent review, but is noted as a concern raised.

Victoria DELWP acknowledged the significant progress on the development of the SMM in close consultation with Victoria and indicated remaining actions required for use of the SMM as a fit for purpose tool for the Basin Plan compliance. Lack of transparency in the documentation and work around solutions implemented in the model plug-ins – with heavy reliance on prior knowledge of the inner workings of the SMM – was raised as a barrier towards timely verification of key outputs from the SMM. From their viewpoint, continuous verification and refinements with clear documentation are critical to aid in transitioning to the SMM. Modellers are also required to understand the reasons for differences between the SMM and MSM-BigMod results as the SMM is intended to be used for compliance purposes. To this end, clear documentation on the model, as well as the testing processes, is required. Focus and efforts are already placed at the technical level between Victoria DELWP and MDBA and are ongoing to resolve these concerns.

The method of implementation – use of plug-ins and other pragmatic design choices – were also raised as a point of concern. For example, the Victorian Murray resource assessment in SMM uses three runtime MDBA plugins and outputs from the MDBA Resource Assessment Model, and rather than using Source software core functionality, work-around solutions including plugins are used for storage releases in the SMM to simulate aspects of the River Murray system. Victoria is of the view that the processes represented should be moved to within the Source platform as part of its core functionality. Doing so may address to some degree the transparency of the model implementation, however we note that this is a workflow/process issue rather than a concern about the model itself.

Concern over the representation of irrigation district losses (in the Murray Valley and Torrumbarry Irrigation Districts) as a fixed percentage of deliveries was also raised. For the purpose of modelling water savings projects, it is important to improve the irrigation district loss modelling with explicit representation of component losses.

Victoria DELWP raised concerns about a number of outstanding JIRA[8] issue tickets raised in regard to the Source platform. Timely resolution of these issues is said to be critical. Run time issues were also raised as a major concern with a single run reportedly taking in excess of three hours. Such long runtimes, in their view, will constrain effective and timely analysis and responses, and hence compromises the intended use cases of SMM.

3.3 Fit for purpose (BDL and SDL estimation)

Overall, the model structure is fit for purpose and represents the water sharing arrangements for the Murray and Lower Darling System. It contains appropriate system processes that will allow assessment of whether the rules within state actions against their water resource plans will meet the relevant SDL. Of course, there will be benefit in undertaking ongoing work on improving some of the model inputs (as identified in the various SMM technical reports). Largely however, the results shown indicate that the model is performing satisfactorily. In Section 4 we provide details and comments on those results and make suggestions as to improvements that can be made in Section 5.

The currently published BDL estimates in the Basin Plan for the three Murray SDL resource units and Lower Darling were obtained using the MSM-BigMod model. These have been revised very recently as improved understanding of the hydrology of the system has accrued. This is reflected in the daily

[8] JIRA being the platform used to track issues raised

time step SMM that also now takes into account some improved calibration of the Lower Darling valley model Cap, detailed representation of The Living Murray Icon site works, and recalibration of some losses. Undoubtedly, such improvements will continue as new knowledge and data become available, especially upstream tributary inflow estimates, but presently the model and BDL estimates are based on best available information.

In developing the Water Resource Plans, the approach taken is to treat the environmental water delivery in the same pattern as the historical irrigation pattern, rather than building rules into the model determining when and where the allocated environmental water is used. As noted in Technical Report 2018/16, this is because the rules and approaches for use of environmental water are still evolving. The volumes of water supplied thus obtained are then scaled down for the water recovered for the environment. This is a necessary work around the issue, given the patterns of demand for environmental water use are still evolving, however it is understood that this method is still under discussion. The scaling is constant across all users and accounts and is therefore an equitable approach. The requirement is that the scaled annual average diversions across the climate scenario (based on the historical record) should be equal to or less than the SDL. It is also noted that the Victorian SDL units may be aggregated into effectively a single SDL unit for compliance purposes in accordance with the Basin Plan (s6.12). This is reasonable given the proximity of these SDL units, and allows for greater flexibility in the management of the water resource. To meet Basin Plan SDLs, the annual average diversions that occur after scaled environmental use are removed should be equal to or less than the SDL across the climate scenario (based on the historical record).

3.4 Robustness of Permitted take method under various climate conditions

The permitted take method has been developed in collaboration between MDBA and the three states using best available information and with consideration of the MDBA Position Statement 3C. The climate period considered (1895-2009) contains a high degree of historic variability, so the modelling is robust with respect to that range of variability. In the short term, this robustness could be further tested using simple unit tests (e.g. setting inflows to zero for a period) to test the response of SMM to changes in the input climate signal. In the medium term it would be strategic to augment this one climate series approach and ensure that the modelling is robust to plausible or anticipated future changes in climate, including precipitation and temperature/evapotranspiration. It is noted that the MDBA has recently released a Discussion Paper on climate change with respect to the Basin Plan.

3.5 Necessary corrections to meet relevant WRP requirements

While there are areas where the SMM model could be improved in the long-term, there does not seem to be any major corrections necessary to meet the current WRP requirements. The model is deemed fit for purpose and capable of future development to improve representation of the system.

3.6 Future enhancements

The current reported runtime of the SMM (examples given are within the range of two to four hours) was raised repeatedly as a concern as it hinders effective and timely analysis. Simplifying the model where appropriate, by lumping modelled processes for example, may alleviate these concerns to some degree. Computational performance of model components (including plug-ins) should be profiled to aid in identifying the areas that could benefit the most from improvements, and their proportionate effect on runtime be documented.

Uncertainty and sensitivity analysis can also aid in simplifying the model representation (which partly addresses model runtime issues) as well as providing helpful information towards

understanding the confidence in the model outputs. Here we are not suggesting an exhaustive formal analysis be conducted, but rather a targeted approach for identified model components of concern. This is further discussed in Section 4.8 and 5.2.1.

It may be the case, however, that the Source IMS itself requires improvements to achieve measurable decreases in model runtime, as opposed to the model implementations and assumptions. In this case it is understood that such improvements are outside the direct control of the MDBA but it is an area for further investments to be made. In addition to resolving issues of long runtime, documentation of the plug-ins developed in-house could be improved with a standardization of their functionality where possible. Through this process, common functionality could be identified and made generic, allowing these to be moved to within the Source IMS itself.

3.7 Practice Notes for Implementation of Source Models

MDBA has a suite of Practice Notes setting out the principles for developing models. This suite includes naming conventions, storing time series data, sourcing, quality assurance and infilling of data, developing a conceptualisation of a reach, modelling reach water balance and urban demand. One of the purposes of the Practice Notes is to provide consistency between models. These practice notes are concise documents giving recommendations for future model developments, and constitute a very useful resource. There is mention of calibration and uncertainty in the reach water balance modelling note, though this warrants expansion, perhaps into a separate practice note. Regarding uncertainty, this is included in general principle 8:

> *8. Uncertainty should be tested by using a reliable calibration and validation procedure so that the model is appropriate for use in water planning and management.*

Calibration is addressed in general principles 6, 9, and 11

> *6. A systematic approach should be used when calibrating a reach water model. The calibration should focus on periods with minimum data uncertainty for the different model components. Not all reach flux models need to have the same calibration period.*
>
> *9. The assessment of the final calibration of a reach water balance model is based on analysing flows at the downstream gauge or gauges. Representations of individual flux components may be calibrated to other data sources if available. However, the overall combination of fluxes should still be tested against an ability to replicate the flows at the downstream gauge(s).*
>
> *11. Reporting on the calibration of the reach water balance should include, an assessment of how suitable the model is for its intended purpose, and, how well the modelled flow matches the recorded flows at the downstream gauge (as defined by appropriate metrics).*

These are purposefully very broad statements as there seems to be no agreement among the states and the MDBA on calibration metrics; for example, due to variability in specific purpose of the model and geographic location. However, the statements could usefully be expanded in the Practice Notes to give modellers more guidance on how calibration and uncertainty analysis is best achieved. In terms of calibration and performance assessment, Bennett et al (2013) review the range of metrics and qualitative/graphical methods available for environmental modelling in general. These could be used to make more specific recommendations on objective functions to use in given situations. For example, Nash-Sutcliffe Efficiency (NSE) focuses on calibrating higher flows and log transformed NSE focuses on lower flows. The reason for this recommendation is that the documentation includes tables with three objective functions to show how the model is performing. However, these objective functions are not independent of each other (e.g. RSR can be calculated from NSE and vice versa), and this limits the information that is available to the reader.

There should be guidance on how to estimate uncertainty, and what sources should be considered. This should be a pragmatic approach to assessing uncertainty rather than narrow technical uncertainty approximation methods, which tend to be impractical in the context of this review. A mix of qualitative and quantitative methods would be appropriate as it can be impractical to assess uncertainty as quantitative estimates of bounds or probability distributions. There should also be a discussion and guidance on sensitivity analysis methods that could be used (bearing in mind the model runtime and the limitations this can cause), at least in order to qualitatively rank those uncertainties with a view to focussing attention on the critical ones.

It is noted that there does not, at time of writing, appear to be any formal guidance or commonly agreed convention on plug-in development and testing practices. Due to the stated concerns regarding model runtime and model transparency, it would be appropriate to give some guidance around plug-in development and how to measure the performance impact of these.

4 Assessment of SMM

The change from the monthly time scale MSM model to a daily time scale SMM model is certainly necessary for evaluating the impacts of both management and climatic conditions as daily variability in the rainfall and hence streamflow will have a significant impact on the response of the system.

Overall, the model structure is fit for purpose and represents the water sharing arrangements for the Murray and Lower Darling System. As stated on the wiki, this includes:

a. Flow and water quality
b. Water accounts using the rules in the MDB Agreement,
c. Resources available to the States under the Murray-Darling Basin (MDB) Agreement,
d. Allocation by States to individual water users,
e. Demand for water in the key regions throughout the system,
f. Transfers required between storages to ensure that the demands can be met,
g. Operation of various dams and structures including:
h. Orders to meet forecast demands,
i. Pre-releases from each storage for flood mitigation, and
j. The allocation and use of environmental water.

The model structure contains appropriate system processes that will allow assessment of whether the rules in state water plans will meet the relevant SDL. Whilst there are empirically-based functions in some parts of the model, the existence of these is necessary at this point in time to have a working model. These are unlikely to affect estimation of BDL and SDL values as the model is calibrated to observed flows at many points in the system.

The SMM is designed to be used for a range of purposes over time, including water resource planning, understanding of hydrological processes, legislative responsibilities and river operations. It is appropriate for these purposes and is largely extendable to support new policy and management initiatives. Thus, it can for instance support future links with: groundwater models and/or data where it is necessary to represent surface-groundwater interactions; and water quality modelling. Of course, there will be benefit in ongoing work to improve some of the model inputs. Above all, there is a valuable cohort of people working with and around the modelling that facilitates ongoing progress and healthy discussion. It is paramount, however, that resourcing of the modelling and

maintaining a critical mass of such expertise continue unabated as new demands and needs for improvements will continue to arise.

It is noted that the climate period considered (1895-2009) contains a high degree of historic variability, so the modelling is robust with respect to such variability. In the medium term it would be strategic to make sure that the modelling is robust to plausible or anticipated future changes in climate, including precipitation and temperature/evapotranspiration. In any case it is understood that the states are free to test such futures and model assumptions in general. It is also noted that the MDBA has released a Discussion Paper on climate change with respect to the Basin Plan.

The SMM model is based on available data, and where data are not available, is based on model results from MSM as a surrogate until the relevant functionality is built into SMM. This is a necessary step in order to have the model working for development of the currently required WRPs. Having this functionality in place is a key step in preparation for the next round of WRPs. Improvements can be found by considering the quality and uncertainty of data being used. The impact of these uncertainties on the SMM model output needs to be considered in order to assess main contributors.

Calibration of flow is done reach-by-reach, and some of the assessment is on that scale also. This is necessary for such a complex model, but there also needs to be documented comparisons between observed and full modelled values at each point in the network. Appendices C and D in Technical Report 2015/03 gives plots and tables for 17 locations showing how the model compares with observed flows in calibration and testing periods. Additional results appear in the body of that report (e.g. volumes for selected dams and lakes, flow exceedance curves for selected sites), but this needs to be more comprehensive in order to get a better view of where the deficiencies in SMM lie. Characterising and documenting performance of the calibration on independent periods will also assist in understanding inherent uncertainty of the model with respect to different climatic forcing.

Ideally, model sensitivity analysis should be carried out to identify critical sources of uncertainty. The run time of the model will however limit the capacity for this analysis, so sampling and evaluation methods selected for the analysis must be efficient.

In general terms, it is recommended that the opportunity be taken to develop and document a future practical framework for evaluating uncertainty. Examples on which this could be based include Refsgaard et al. (2007; Environmental Modelling and Software 22, 1543-1556) and van den Sluijs et al. (2005, Risk Analysis, 25, 481-492) but adoption of an appropriate framework will need to take account of the WRP context and constraints.

- Refsgaard et al. (2007) review 14 methods for uncertainty assessment and characterisation, and present a matrix for evaluating the sources of uncertainty, considering the context, inputs, model structure, parameter values and outputs. It should be noted that they recommend that this is not just something undertaken at the end of the modelling work, but should run from the outset and throughout the study, and involve the modeller, water managers and stakeholders.
- Van den Sluijs et al. (2005) present four examples of putting together a matrix for evaluating the “pedigree” of an environmental assessment, accounting for both quantitative and qualitative measures of uncertainty. This attempts to gain understanding of the uncertainties/limitations in the knowledge base of complex problems.

The model documentation is proceeding well but in the next section we offer suggestions for improvements. We also recognise the value in having Practice Notes and have made recommendations for future practices around sensitivity and uncertainty analyses.

4.1 Documentation

There is considerable documentation associated with the SMM model (see Appendix D) and this practice is being undertaken comprehensively, being essential for transparency reasons and efficient sharing of knowledge and information about what is a multi-faceted set of modelling exercises. Although this documentation will out of necessity always be in development, it can be more complete, and less contradictory in places.

A comprehensive review of the documentation was not possible within the time frame of this review as some were still being completed. As the model is still under development (and will continue to be so as data and knowledge improve in the future), it is impossible to have completed documentation. Examples of the evolution of the model can be seen in the documentation. Such an example is the area-allocation relationships for South Australia, where there are significant differences between Figure 14 in "Phase2-Crop water model for the Murray and Lower Darling.pdf" and Figure 17 in "Crop Water Model for the Murray and Lower Darling 2018.pdf". Maintaining the documentation will be an ongoing challenge for MDBA.

The value of the documentation would be enhanced if there were to be an index document that readers could search to find documents that are relevant to specific questions. This includes linking to the various questions in the attachment to Position Statement 3C: Method for determining take. This index document should include a glossary defining all the acronyms/jargon being used. This will aid in the transparency of the modelling. The wiki site currently in use to disseminate documents and model versions could be better leveraged for this purpose but requires specific concerted effort be made to maintain its relevance.

Additionally, it is recommended that special effort be made to clearly define and explain the various terminologies found in the SMM related documents and reports. Lack of explanation hinders cross-communication and training of those without the necessary historic contextual knowledge which many of the documents currently appear to presume. Including contextual descriptions will also aid cross-State discussions and future reviews. Some examples of terms used without context include:

- NSWRA (NSW Murray Resource Assessment) in 2018-16G NSW Murray Resource Assessment (p8)
- "Icon sites" – Environmental Demands Technical Report 2016-08E (p5 onwards)
- TLM (The Living Murray - various documents)

The wiki could be further leveraged and set up as a sort of 'one stop shop' for information on the SMM. In addition to providing information, historic records of the dialogue and commentary around the development and review process could also be made available. We note that the wiki is being used to this effect to some degree but should be further encouraged. Various incarnations of the SMM (with differing model/plug-in combinations) are made available via the wiki but these could be better organised. If collaboration across jurisdictions and modellers is expected, then access instructions, (code) contribution standards and testing processes could also be detailed there.

4.2 Previous Priority Tasks

This section begins with an overview of the WRP related requirements that SMM needs to meet. These requirements cover documentation, data analysis, model structure, calibration, verification/testing, prediction, sensitivity and uncertainty analysis, model improvements and quality assurance.

- **Documentation**: there is an extensive range of reports that have been generated. While these are mostly in a suitable condition, it should be noted that the model is still under

development, and will continue to remain in the future. As such, the documentation is continually being updated, and will naturally be slightly behind the model. Maintaining the documentation will require an ongoing commitment from MDBA. The main deficiency in the documentation at the moment is the lack of a map or directory of what information is in which document.

- **Data analysis:** The data used in the model are appropriate for use in the model.
- **Model structure:** While there are deficiencies in the implementation (some parts of the system are represented from MSM output rather than modelled with SMM, permitted take for environment being handled in a post-processing manner), the model conceptualisation is appropriate for generating SDLs, and therefore suitable for generating WRPs. The model is not perfect, but is the best currently available for estimating SDLs, and based on the available documentation, the model is suitable for estimating SDLs.
- **Calibration:** Calibration fits have been documented, though for only selected sites have the time series and frequency distributions been shown. The robustness outside the calibration period has been considered through use of a validation period, though noting the issue below concerning the selection of the validation period.
- **Verification/testing:** The model has been tested against observed and MSM-BigMod flows and storages. There is an issue with the selected validation period for the flows, with there being an overlap with the calibration period.
- **Prediction:** User manual information has not been assessed in this report. Regarding water balance, the model has been tested against observed long-term flow and storage data, as well as other sources.
- **Sensitivity and uncertainty analysis:** Based on the available information, this is the weakest part of the development of the SMM model. The lack of such analysis is due to the long runtime for the model. This is an area for future improvement.
- **Model improvements:** The documentation does include information on future improvements to the model. Where deemed necessary, the report indicates where additional improvements could be made.
- **Quality assurance:** Given the information in the documentation, it is not possible to determine whether there is enough information kept on model runs to recreate them. Also it has not been possible to verify that enough information is available to uniquely define other models that have contributed inputs to SSM, and their assumptions.

The MDBA, provided the information shown in Table 3 which lists identified priority tasks from the previous review (Bewsher 2017) and their current status. Each individual task listed may relate to number of issues raised by individual States. Of the 25 tasks listed, 11 are marked as completed; of which 8 of medium to high priority, and 3 marked as low priority. Of the remaining 14 tasks, 10 are listed as medium or high priority. All remaining tasks are listed as either awaiting further feedback or require details to be finalised before their completion.

Table 3. Status of priority tasks from previous review

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
1	High	Jan-17	Determine why SMM and MSM is over predicting the Victorian Allocation and complete	The MDBA has been in contact with GM-W and has a good understanding of the process used in the allocation process. Testing of the new methodology has been undertaken in a simple model and is currently being incorporated and tested in the SMM	Vic(3) Vic(35) NSW(56)	Ongoing. We believe we have a methodology which reflects the Victorian Murray allocation method as set out in Schedule 3 of the Bulk Entitlement (River Murray – Goulburn-Murray Water) Conversion Order 1999 and the NRVM Seasonal Determination document (https://nvrm.net.au/seasonal-determinations/how-allocations-work). This methodology largely suppresses LRWS allocations through establishing a larger reserve and reducing inflow assumptions	Revision 737 of River Murray repository (22/08/2017)	
2	Med	Jan-17	Temporary trade – additional work is required to test whether the adopted method for representing allocation trade can be used to support trade between the different States.	Has been tested. Will be included in updated report		Temporary trade works between the states. The adopted model prioritises intrastate state trade prior to interstate trade. Future improvements would be to incorporate temporary trade from the entire Southern Connected Basin (dependent upon development of Tributary models) and more detail on modelling restrictions e.g. above/below Barmah Choke. Due to SA assumptions on the use of their entitlement the plugin recognises that when SA uses their regression demands there can be no outward temporary trade from the state	Revision 672 of River Murray repository (20/01/2017) Revision 938 of River Murray repository (23/01/2019) Revision 952 of River Murray repository (12/02/2019) Changeset 948 MDBA Plugins repository (19/12/2018)	

[9] xx/xx in this column means the activity has not yet been scheduled

[10] Refer Appendix E in Bewsher (2017) for a description of the State Issues listed in this column.

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
3	High	Jan-17	Off-allocation – extend off-allocation behaviour to all NSW diverters who hold supplementary access entitlements. Currently only MIL has modelled supplementary access	Off-allocation configuration bugs addressed in Source v4.2.0, so work can now be done		Extended off-allocation to other NSW holders. NSW Murray TLM still not explicitly allocated to. Unlikely to have a major impact on model behaviour but may change the supplementary debiting behaviour	Revision 680 of River Murray repository (09/02/2017) Revision 723 of River Murray repository (05/06/2017) Revision 843 of River Murray repository (01/08/2018)	
4	High	Feb-17	The Murray SOURCE BDL model should include all improvements proposed by Barma (Barma 2012) for MSM BigMod configuration of BDL	Thought that recommendations are included. Need to check.	Vic(31)	Major recommendation was the Vic 50% carryover rule which is included	NA	
5	High	Feb-17	Investigate the underestimation of transfers between Dartmouth and Hume, and Hume and Lake Victoria generated by the Resource Assessment	Underestimation of transfers is primarily due to: · Some errors in the calculation of system transfers (calibration + BDL) · No inclusion of the TLM demands in the Resource Assessment (BDL) See Task 6	SA(6) SA(19)	Fixed a number of issues in the Murray Resource Assessment and we believe that the representation of the transfers between the storages is reflecting the current behaviour	Revision 678 of River Murray repository (06/02/2017) A number of revisions of the Assessment repository between October 2016 to April 2017	
6	High	Feb-17	Include the TLM Demands into the Resource Assessment: Step 1: Extend the Resource Assessment model to include the Lower Lakes and Chowilla Step 2: Include usage	Step 1 has been completed Step 2 is underway It is expected that Task 6 will resolve Task 5		Completed	revisions 610-623 of the Assessment repository between December 2016 to February 2017	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
			at Gunbower, Koondrook-Perricoota, Hattah and Lindsay/Mulcra into the RA					
7	Med	Feb-17	The TIS should be modelled as a separate ownership system independent of the Upper Murray	Better reflect the reality. May encounter configuration problems in Source. Would be good to complete before Task 8		Not necessary. Have included some change of ownership nodes to ensure there is a better representation of ownership in the system	NA	
8	Med	Feb-17	MDBA to provide DELWP with source of existing model entitlements from MSM		Vic(10)	Current BDL model has agreed BDL entitlements between Victoria and MDBA	Revision 847 of River Murray repository (14/8/2018) Revision 945 of River Murray repository (5/02/2019)	
9	Med	Feb-17	DELWP to confirm CHWN is urban only		Vic(11)	Not completed (potential minor impact on low allocations) Currently some of the CHWN is allocated to initial loss	NA	
10	High	Mar-17	Explicit inclusion of Victorian Irrigation loss relationships	For Murray Valley and Torrumbarry	Vic(13) Vic(16) Vic(36)	Not included. We believe functionality is now available in Source to represent loss in the manner Victoria would like. Victoria need to supply the information/parameters to define the loss relationships. Would be able to be included in an updated version of the model but would require recalibration of the Victorian Irrigation demand nodes	NA	
11	High	Mar-17	Undertake Review of TIS representation with Victoria	Task 7, Task 8 would ideally be complete before doing this		Not completed, the current representation is based on the REALM Kerang Lakes model. Redefining the conceptual behaviour of the TIS is unlikely to have a large impact on the behaviour	NA	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
12	High	Mar-17	Review Murray Resource Assessment Model with NSW to ensure common understanding on: · Terms, · derivation of formulas · relationships e.g. Inflow assumptions		NSW(81) NSW(82) NSW(83) NSW(84) NSW(92) NSW(93) NSW(106) NSW(110) NSW(129) NSW(130)	Ongoing as assumptions are finalised	NA	
13	High	Apr-17	Review Lower Darling Allocation and Accounting with NSW to ensure common understanding on: · Riparian releases · Trade · Losses · Allocation · Off-allocation · Trigger for reallocation · Inflow assumptions		NSW(157) NSW(158) NSW(159) NSW(160) NSW(161) NSW(172)	Ongoing as assumptions are finalised	NA	
14	High	Apr-17	Review NSW Murray Allocation and Accounting with NSW to ensure common understanding on: · Address concerns about how commitments/reserves e.g. CHWN are included in model · AWD after May · Representation of without debit (WOD) water in accounts		NSW(197) NSW(198) NSW(199) NSW(201) NSW(202-204)	Ongoing as assumptions are finalised	NA	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
			· Allocation process					
15	High	May-17	Update Individual Reports to include state comments and solutions compiled in state comments sections. Reports to update include: · Flow and Loss Calibration Report · Urban and Stock and Domestic Demands · Environmental Demands · Torrumbarry Irrigation Area · Murray Resource Assessment · NSW Murray Accounting · NSW Lower Darling Accounting · Vic Murray Accounting · SA Murray Accounting · Ownership and Operation Rules	Update for states comments identified in spreadsheet – State Comments v5.xlsx		Ongoing as assumptions are finalised	NA	
16	High	Jun-17	Update SMM Model Overview Report	Update for other improvements made to the model as a result of both model development and software development by eWater		Ongoing as assumptions are finalised	NA	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
17	Med	Jun-17	Include representation of the South Australian Storage right	Not required for BDL, though will be required for WRP		Mechanism is included, parametrisation still being confirmed	Significant number of changes to River Murray Repository from Revision 795 (27/02/2018) Also required significant development and changes to the SA Order plugin and MDBA Custom Functions plugins	
18	Med	Jun-17	Model Locks 1 to 5 in South Australia explicitly as weirs rather than storage routing reaches	Undertake in partnership with South Australia. Need to check available data, would be good to develop a practice not on configuration of weirs	SA(15) NSW(68)	Not critical for development of BDL, expected to occur under SDL adjustment project	NA	
19	Low	Dec-17	Update estimate of residual inflows once an agreed method is reached based on CSIRO practice notes project.	Will include in the Hume to Yarrawonga reach once methodology is finalised		Not done	NA	
20	Low	xx/xx	Currently the GW Loss custom function is being used to model losses using an antecedent moisture store. *Source* IMS groundwater functionality potentially has the capacity to replicate this functionality however it is not currently being used as it decreases	Dependent on eWater and NHMP development priorities		Not done	NA	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
			efficiency in using the platform and needs to be refactored. As such it has not been used but should be considered as an alternative in the future.					
21	Low	Undertaken as a capacity building exercise in plugin coding	The following demands in the model are not explicitly calculated in the model. These demand models need to be included, though they are largely separate from the model process it is unlikely they will impact the model results. o Finley Escape o Ovens Diversions o Kiewa Diversions	Currently still using output generated from MSM regression equations. The regressions are based upon climate data so they are independent of the SMM, however it would be good to generate the demand outside of MSM. Probably as a pre-calculated time series. Also question the importance of the Ovens diversions now that inflow is based at Peechelba		Included the regression equations as code in MDBA plugins repository. Therefore these can be generated outside of MSM relatively easy	Changeset 872 MDBA Plugins repository (27/7/2018)	
22	Low	xx/xx	Update calibration of the inflows from the Broken Creek	Revise the methodology used to derive Broken Creek Inflows and also look at incorporating modelled return flows from Broken Creek Escape		Wait until the daily GBCL model is more developed	NA	
23	Low	xx/xx	There is limited data available along the Edward-Wakool system to perform comprehensive calibration, though good metrics are achieved at Stoney Crossing. Further work could be done on the calculation of losses in this area particularly as knowledge of floodplain inundation increases	Joint project being undertaken by MDBA and CSIRO is looking at flood behaviour in the Edward-Wakool system. Information generated from that study to be used to inform calibration.		CSIRO have now handed back this project to the MDBA to complete. Once completed we will look at incorporating the learnings into SMM	NA	

Task No	Priority	Date mm/yy[9]	Task Description	MDBA Comment (Jan 2017)	State Issue ID[10]	MDBA Updated Comment 2019	Key repository revision	Complete
24	Low	Prioritised during 2017-18 in response to channel capacity issues arising out of horticulture development in the Sunraysia and Lower Murray	Revisit irrigation demand calibrations if/when better data is available	This is part of ongoing model improvement	SA(12)	Attachment D - Irrigation Demands on the Murray and Lower Darling Rivers included a substantial consolidation of the previous work and a repeatable method to produce consistent areas from the available crop survey data. While doing this work SA provided monthly irrigation data for the Renmark Irrigation trust and quarterly data for the Central Irrigation Trust. More detailed investigation, contained in Appendix C of the report, tried to address the concerns of SA in the previous irrigation demand report mainly that the crop models were overestimating summer demand and underestimating winter demand. This study concluded that there was justification for including a variable target soil depletion level in horticulture crops as irrigators applied excess water in winter for: Salinity Management - flush accumulated salt from the root zone, and help suppress the impact of frost. These parameters were adopted for the SA Irrigation demand models and did improve the behaviour from the previous reports. However, SA have chosen to adopt the previous crop regression models for the scenario modelling, so this work is not currently used.	Updated Irrigation demand Models and revised crop areas were incorporated into SMM in the following commits: Revision 860 of River Murray repository (7/09/2018) Revision 917 of River Murray repository (23/11/2018) Revision 942 of River Murray repository (29/01/2019)	
25	Low	See issue 24	Investigate impact on Irrigation demands of more variety in parameters for: · Root depth · Target depletion levels · Winter crop factors	Outcome of this will depend on development and agreement of crop modelling practice note	NSW(17) NSW(18) NSW(19)	See Issue 24. We have partly investigated this but given the resolution of data available to calibrate we do not believe it is a priority issue. Future model improvement particularly when irrigation diversion data is more widely available at sub annual timestep	NA	

4.3 Model Data

Overall, the data (climate, streamflows) used are the best available for the purpose. There are limitations in terms of the availability of data (e.g. inflows which are ungauged), but this is not a criticism of the implementation of SMM. In the longer term, methods could be used to assess the worth versus cost of candidates for additional data collection in terms of their value in improving predictive performance of the model.

4.3.1 Climate Data

The climate data (rainfall, potential evaporation) being used in SMM is from the SILO dataset. This is infilled and interpolated data, and therefore has the caveats associated with such data. The data are available at a 0.05 degree resolution, but the actual resolution of the information used in generating the data depends on the gauge density, which is commonly a lower resolution than this. That said, the SILO dataset is a widely used source of spatially distributed data for Australia, and is a suitable dataset for use within SMM.

4.4 Model Structure

As noted earlier, the model structure contains appropriate system processes, water sharing and water accounting that will allow assessment of whether state changes to the MDB Plan still meet SDLs. The SMM is designed to be used for a range of purposes over time, including water resource planning, understanding of hydrological processes, legislative responsibilities and river operations. It is appropriate for these purposes and largely extendable to support new policy and management initiatives.

4.5 Calibration of Routing and Loss Parameters for Flow Reaches

4.5.1 Flow and Loss Calibration

The model parameters are calibrated on a reach-by-reach basis, with inflows being set by the observed inflows rather than modelled inflows. This is the best available method for calibrating SMM. However, the sentence “This approach minimises the propagation of modelling errors downstream in the parametrisation of the model” can be a little misleading. The approach does not minimise the propagation of modelling errors; rather it minimises the propagation of errors in the parameter values of the model. Hence this approach minimises the covariance in the uncertainty in the model parameters between reaches.

4.5.2 Inflow Review

While there are known issues with the estimation of the inflows due to limitations in the network of gauges (with some inflows being infeasible to measure as well), the SMM model should perform better than the MSM-BigMod model in this regard. While there may be implications in terms of the derived BDL, the SMM model will give the best available estimate for this at this time, and hence is fit for purpose.

4.5.3 Residual inflows

The SMM model seems comparable to the MSM model in terms of handling residual inflows and losses. The unaccounted difference is recorded flow minus modelled flow. A positive value means that the reach is gaining, a negative means the reach is losing. This is partly a correction for interaction with groundwater, contribution from local runoff input (including ungauged catchments), and potentially correcting for errors (e.g. in rating curves). There is also potential for the residual flows to compensate for model errors.

However, the unaccounted streamflows are not included in SMM (Korn, pers. comm.) as these are a very small fraction of the total flow (see section 5: Suggested future developments). The

unaccounted salt flux is much more important. The question of whether SMM is robust to variations in the climate drivers depends on whether the unaccounted flows are sensitive to these drivers, and whether this is captured in the model. From what can be seen in Technical Report No 2016/16, the assumption is that the unaccounted salt fluxes are not sensitive to climate variations. While acceptable in the short term due to the long response times of the main groundwater systems in the region, longer term impacts (e.g. the Millennium Drought) may be significant in some locations.

4.5.4 Performance of SMM in reproducing observed flows

Appendix C in Technical Report No. 2015/03 shows plots for selected sites with exceedance curves, two largest flood events, annual time series and residual mass series plots. Comparison of the calibration and testing plots indicates issues with errors in the inputs in the testing phase, and shows how these errors can propagate downstream. Some sites are particularly problematic. For example, Mitta Mitta River at Tallandoon performs poorly under test, but gives good results when calibrating just the reach. In this case, the impact of the operation of Dartmouth Dam will be significant, and it is unlikely to be adequately modelled without detailed information on the operational decision-making process. The results shown in Appendix D of 2015/03 suggests that improvements to model inputs may help with modelling the flows down the River Murray, though the impact of these on the BDL and SDL estimates used in WRPs needs to be evaluated. This however is a longer-term improvement in the model.

There is also evidence of errors in the data for the River Murray at Barmah (Figure 53 in Technical Report 2015/03), where there is a sharp two-day duration decrease in flows during the largest flood event. It is highly likely that these data values are erroneous, and if so, they should be flagged and not used for calibration. The results suggest shown that these erroneous data values may have been used in calibrating the model for this particular reach. While this may not have a significant impact on the BDL and SDL estimates, this should be investigated immediately and, if they have been used in calibration the model, the model calibration should be checked.

4.6 Calibration of Demand Relationships

4.6.1 Urban Demand (Technical Report No. 2018/16 Attachment C)

Annual demand is disaggregated based on the long-term, mean historical monthly pattern of water use (i.e. percentage of annual use for each month). Demand is also broken into two components - “critical human water need” and a variable component. The CHWN is constant in time (i.e. not sensitive to climate and is based on a fixed consumption rate per person, allowing for transmission loss). The influence of climate is based on a 6-day rolling average of potential evaporation minus rainfall. This will do a reasonable job of capturing the impact of weather patterns over a time scale of a week, but not the impact of longer-term conditions. For urban water demand this should be reasonable as the demand will be based on human perception of need.

The estimation of CHWN is a little difficult to follow. The results in Tables 5 and 6 (2018/16, Attachment C) seem to indicate that the CHWN per capita for NSW is about 197 L/day, while for Victoria, it is approximately 485L/day. This difference seems a little strange and should be checked.

The testing of the model shows that in general the model performs well, giving generally a small bias (considerably less than 1%) for most regions of NSW accessing Murray River water, though as noted in Technical Report No. 2018/16 Attachment C, the model performs less well for Broken Hill. The report attributes this potentially to an issue with the local catchment inflows. At the moment, the local catchment inflows and storage for Broken Hill are not included in the model. This should be a focus for future development of the model.

There are some other less significant differences between the model and observed demands seen in the plots shown (e.g. Figure 8, where for the Wakool shire, the model seems to not capture the decrease in demand in the wet period from late 2010 to mid-2012). The model is also unable to

capture the rapid fluctuations in the stock and domestic demand (e.g. Figures 10 and 12 in 2018/16, Attachment C). The error in the Broken Hill urban demand may not be that significant as there are larger biases seen in the estimation of the Victorian urban water demand (Table 6). The impact of these differences should be explored in order to confirm what their impact will be on the overall model behaviour, particularly under the impact of climate variability.

Overall, while the urban water demand model has some issues, the approach is sound, and is fit for purpose, representing a substantial advance over MSM. The impact of the errors in the demand on the outputs of the model should be checked to evaluate the contribution to uncertainty in the derived values for BDL and SDL. This will enable decisions on where future work on reducing the model errors should be focused.

4.6.2 Environmental Demand (Technical Report No. 2016/08)

Within SMM, only the environmental demands for The Living Murray (TLM) icon sites and the Barmah-Millewa Forest Environmental Watering Allocation (B-MF EWA) are considered. As discussed in Section 3.3, the total environmental water demand is handled outside the model in a post-processing stage, with the permitted take correspondingly reduced.

The approach adopted within SMM uses a number of events at each site (type of event varies between sites and includes bird breeding, watering forests and wetlands, and maintaining water levels), with trigger levels based on time since last event, an indicator of flows and the available account balance. Events are triggered before the start of the season, to permit events to begin on the first day of the season (to allow for travel time).

4.6.2.1 Prioritisation

Prioritisation of event orders is achieved based on the time since last event using three levels of priority. The priority increases to level 2 once the time since the last successful event exceeds the required frequency. The priority is set to 3 once an event is triggered to ensure greater probability of successful events. The Lower Lakes, Coorong and Murray Mouth (LLCMM) have priority always set to 3 to ensure adequate operation (providing account limit does not operate).

4.6.2.2 Cost estimates

Estimated water requirement (or cost estimate) is scaled down based on the month to account for return flows and potential increases in the account balance. Maximum reduction is May and June (60% of estimated requirement is used), with July having 70%. All other months are 80%. No cost estimate is made for LLCMM orders to ensure these are always enabled and prioritised.

4.6.2.3 TLM account reduction

For Lindsay and Mulcra Island sites, there is an adjustment made to the use of water from the TLM account based on the flow levels and the return flows.

4.6.2.4 Assessment

Overall, the approach seems reasonable given the complexity of the system. However, it would be helpful in the long-term for the model to be able to capture and implement the actual operation plans for the icon sites. Other minor points that could be investigated, or better documented are:

1. It is not known from the reports what the relative importance of the different trigger requirements is. How frequently does the monthly flow impact on triggering an event? There is information given on the impact of the TLM account balance on triggering Hattah Lakes events, which only occurs in the years 1985, 2000 and 2006.
2. An issue with the transition from priority 1 to 2 occurring at the required frequency is that this will tend to result in exceedance of the required frequency if supply is limited. How often does this happen? One could introduce an intermediate priority to increase probability of not exceeding the required frequency? Also, in extended dry periods, if several sites have level 2 priority, which site is allocated first? Presumably this is hardwired into the model.

One could use a fractional priority to rank the sites? This would permit changing the order between sites relatively easily if this becomes desirable.

4.6.3 Irrigation Demand (Technical Report 2018/16 Attachment D)

Overall, the estimation of irrigation demands is reasonable, and suitable for use in SMM. A minor point to consider in the future is the selection of metrics that have been used to assess the model performance. While it is good practice that different metrics are being invoked, there can be improvement in choice of which to include, there being little difference between the metrics used here. There is a one-to-one relationship between R^2 (correlation coefficient of determination) and NSE (NSE=2-1/R^2, see Bardsley, 2013), under the condition that the slope of the relationship is close to 1, and intercept is close to zero. If using R^2, then the slope and intercept of the relationship between observed and modelled flows should also be reported as these will provide useful information on the systematic errors (bias and scale) in the model. Further, the RSR used is sqrt(1-NSE), and so can be calculated from NSE (and vice versa). So these three metrics simply present the same information in slightly different ways. It would be preferable to apply transformations of the observed and modelled data (e.g. using the Box-Cox transformation) to just one of these metrics.

4.7 Verification and Testing

The SMM model has been tested against MSM-BigMod as well as against observations. Testing against MSM-BigMod ensures that the model outputs are reasonably consistent, noting that there will be differences due to the change to a daily timestep for the entire model, as well as other modifications made. The testing that has been done indicates that the SMM model is fit for purpose.

It should be noted that there are issues with the selection of the validation period (section 23 in Phase2-Crop water model for the Murray and Lower Darling.pdf). In Table 70, the calibration period is 1996 to 2012, instead of 1993-2012 as quoted in the text. The validation period should be as distinct as possible from the calibration period. If it is desirable to report the performance for the period from 1983 to 1999 inclusive, then that is best done using a third period to show a match with previous work on MSM-BigMod. The validation period should then be 1983-1995.

4.8 Sensitivity and Uncertainty Analyses

Sensitivity and uncertainty analysis are useful in helping to understand the confidence in the model outputs, as well as the components of the model that contribute most to the 'width' of that confidence interval. To date, formal application of sensitivity and/or uncertainty analysis methods to SMM is essentially absent. In terms of the SMM model being used for WRPs this is understandable and acceptable given the long model runtimes and the complexity of the model.

Longer-term development of the model would benefit from more detailed and systematic analysis of the model behaviour in a way that that pragmatically takes into account the complexity and purpose(s) of the model. This is discussed in Section 5 on the Future Improvements.

4.9 Salinity (Technical Report No. 2016/16)

Overall, the SMM model is fit for salinity purposes, and performs comparably to MSM-BigMod. There is a slight over-estimation (<5%) for high EC values at Morgan (Figure 11 in 2016/16) and Murray Bridge (Figure 12 in 2016/16). It is considered that these will not be significant in terms of the WRPs, but this should be confirmed. There are however some caveats regarding the treatment of salinity by the SMM model.

Unlike flow volumes, modelling salinity requires use of the unaccounted saline groundwater or surface water inflows (in this case, salt). This accounts for fluxes of salt from groundwater, but also

can correct for model errors (essentially a condition-dependent form of bias correction). This approach is fine when considering the historical climate and flows. Extending the model to consider future climate scenarios will require consideration of the impact of the scenarios on the fluxes, as well as the corrections that the unaccounted fluxes are applying.

A constant factor of 0.6 is used to convert from EC (micro Siemen/cm at 25deg C) to TDS. This coefficient is known to vary along the river (due to variations in chemistry) as well as with temperature, but a constant factor has been used for simplicity. This should not have a significant impact on the result as the error introduced by this will be balanced by the unaccounted fluxes of salt.

4.9.1 Example assessment of a register entry

To test the ability of SSM to estimate salinity impacts and compare this to MSM-BigMod, both models were run with the Woolpunda, Waikerie and Qualco SIS turned off. This only tests for consistency between the models, with SMM giving comparable median EC values to MSM-BigMod down to Murray Bridge (SMM slightly lower than MSM-BigMod), though the difference increases for Murray Bridge and Milang. SMM predicts high 95th percentile salinity, which as noted in Technical Report No. 2016/16 is not unsurprising given SMM is a daily model and will have higher variability in the streamflow compared to MSM-BigMod. It would be helpful to investigate whether this is also a cause of the under-estimation in the median EC values, or if it is due to recalibration of the model inputs.

4.9.2 Differences between SMM and MSM-BigMod

Converting the model to running entirely on a daily time step model has the potential for a significant improvement in the model performance. It would be informative to show how the monthly aggregated SMM results compare with the monthly values from MSM-BigMod.

4.10 Application of SMM to BDL and Without Development Scenarios

Currently, the SMM model is the best available for such applications. An issue with the “without development scenarios” for the salinity modelling is the impact that the development may have had on the bias corrections being applied, as there is no data available related to this. This is a point for future research.

5 Suggested future improvements

While the SMM model is assessed as being fit for purpose for establishing the current WRPs, there is scope for further development of the model over the time scale of about five years, which aligns well with the next planning horizon.

5.1 Shorter-term development

There are recommendations that could be addressed on the time scale of the next two years.

1. Conduct workshops with the states to qualitatively rank the contributions to uncertainties in the key SMM model outputs. This will help prioritise further model developments, including the recommendations listed below and share understanding of the modelling.
2. Inconsistent documentation should be addressed, including clear definitions of all terminologies used.
3. Documentation should be modified as necessary to clarify reasons behind changes to model parameter values – e.g. due to calibration studies.
4. Test whether recalibration of parameter values will address issues with estimation of inflows (as noted in the documentation, particularly for Broken Creek at Rices Weir in Technical

Report No. 2013/18). If not, then this leads to a longer-term development of the model to correct this issue.

5.2 Longer-term development

5.2.1 Sensitivity Analysis and Uncertainty Assessment

Sensitivity analysis can be used to prioritise the criticality of the various assumptions, inputs and parameters (often just called factors) to model predictions. It involves: sampling factors repeatedly within their range of possible values and running the model for each sample to generate model outputs for each sample; followed by evaluating an index of the change in model outputs for the change in each model factor. The larger the index for a given factor the more sensitive and important that factor is in influencing model output. The prospects for a detailed sensitivity analysis of the SMM model to identify critical factors are however not immediately strong due to the long runtime of the model (>~2hrs per run). Nevertheless, detailed analysis can be done on parts of the model. With the complete model, the analysis could be limited to a small number of scenarios with respect to assumptions and parameters, neglecting those that are presently known to not be critical. Thus there will need to be considerable care taken in selection of the scenarios to be used and the method of sampling to ensure an adequate exploration of the model's behaviour.

SMM is too complex and necessarily multi-faceted in its representation of processes to warrant undertaking formal uncertainty analysis that is designed to yield confidence intervals in model outputs. Uncertainty analysis in this regard can however be carried out on parts of the model that are amenable to such formality, whilst more qualitative methods including expert opinion can be used to judge uncertainty on other parts of the model. These types of analyses can be integrated into systematic documentation of the model evaluation process to share a common understanding of the strengths and weaknesses of a model. The work of van der Sluijs (see references) fashions such a process into a concept known as evaluating and documenting the model pedigree. It, or something similar adapted to the water planning context here, could well provide the foundation for systematically addressing and communicating the pedigree of the SMM.

5.2.2 Climate change influences on model behaviour

If the requirement for the model to be "robust under a range of climate conditions" includes future climate scenarios, then there will need to be further development of the model to achieve this. The SMM model (like MSM-BigMod) is set up using historical records. As such, the model appears to be robust (based on the available performance indicators) under those historical conditions which do already contain a great deal of climate variability. There is however a question of to what extent the model is robust under alternate climate scenarios not represented in the past record. Using the model to simulate the flow and salinity under alternate plausible climates requires having the model being able to predict the impacts of possibly greater variations in rainfall and potential evaporation. This includes addressing the impacts of changes in groundwater levels. This will require future modifications to the model, including being able to make use of recorded and simulated groundwater levels.

1. *Add variation in groundwater levels as an input to the model*. This should improve the simulation of the impacts of groundwater/surface water interactions, and thereby help with accounting for the impacts of groundwater extractions and droughts on surface water flows. There will be an impediment here due to a lack of long-term historical groundwater level data. This could be overcome in other ways such as using a cumulative net recharge (recharge minus losses) departure method, requiring the creation of a model to generate the net recharge. This will need to be verified against available groundwater level observations and/or more detailed groundwater modelling.

2. *Improve modelling of inflows* using rainfall-runoff models to capture the impacts of climate scenarios on possible inflows. This will add complexity to the model, but it will allow for exploring the impacts of alternate climate scenarios on modelled flows.
3. *Study gains/losses within each reach* to assess in each case whether improving the representation of these within the model is warranted.

5.2.3 Improve representation of GW-SW interactions

There might need to be improved consideration in the future of representing the effect of increased groundwater extraction and irrigation efficiency on return flows. For the moment the current representation would seem to suffice. It has been concluded in an independent report by Wang et al. (2017) that the "impacts of future extraction from within the BDL have not been further considered by MDBA, as it is believed that these should have already been incorporated in surface water management plans prior to the Basin Plan. The estimated impacts of the extraction of unassigned water have been further considered in the setting of the SDLs. The cumulative impact of the Draft Plan groundwater SDLs on streamflow had been estimated but were in the range of 75-150 GL/yr. As this level of impact was considered to be unacceptable (MDBA, 2012b), the groundwater SDLs were reduced to bring them into the acceptable range."

5.2.4 Residual inflows

The question of whether SMM is robust to variations in the climate drivers depends on whether the unaccounted flows are sensitive to these drivers, and whether this is captured in the model. From what can be seen in Technical Report 2013/18, the assumption is that the unaccounted fluxes are not sensitive to climate variations. This means there is potential for improving the representation of the residual inflows, both in terms of water and salt, particularly in areas that use simple empirically-based relationships.

5.2.5 Urban demand

In future versions of SMM, consider including additional catchment area and storages (e.g. Broken Hill). The question is whether these need to be explicitly represented in the model, or the impacts of these on inflows be better captured.

5.2.6 Environmental demand

Improve representation of actual operational rules for the icon sites in the model. It would also be valuable to have some measure of the effectiveness of these in terms of supporting the environment, but this is beyond the current scope of the model.

6 Summary

Overall, it is the view of the reviewers that the SMM model is an improvement on the MSM-BigMod model, and is fit-for-purpose to be used for the estimation of BDLs and in developing WRPs. There is still room for advances in the model as new information and data become available. This will be an ongoing requirement for MDBA, and includes the maintenance of the documentation of the model. The future development tasks suggested above in Section 5 are not repeated here. Whilst they are beyond the current needs for developing WRPs, investment in them is felt to be profitable for future uses of SMM in the planning space.

There are however some tasks that would benefit understanding and use of the SMM model. One is to have the considerable documentation related to SMM as up to date and consistent as possible (see section 4.1). This should also be supplemented by an index or meta-document which describes the contents and relationship among all the relevant documentation. This includes linking to the various questions in the attachment to Position Statement 3C: Method for determining take. This index document should include a glossary defining all the acronyms/jargon being used. This will aid in the transparency of the modelling. The wiki site that is currently in use to disseminate documents

and model versions could be better leveraged for this purpose but requires specific concerted effort be made to maintain its relevance. Additionally, it is recommended that special effort be made to clearly define and explain the various terminologies found in the SMM related documents and reports. Lack of explanation hinders cross-communication and training of those without the necessary historic contextual knowledge which many of the documents currently appear to presume. Including contextual descriptions will also aid cross-State discussions and future reviews.

A second task that would assist transitioning to SMM by the states also concerns documentation. There appears to be a need for more information about work around solutions implemented in the model plug-ins – there being reliance on prior knowledge of the inner workings of the SMM (see section 3.2). This was raised as a barrier towards timely verification of key outputs from the SMM. In the longer term, there is a clear demand from the states for plug-ins to at least be more generic and less numerous, and whenever possible to be incorporated in the core Source IMS platform.

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Appendix A: Terms of Reference

Statement of Contractor requirements

Terms of Reference – Independent Review of Source Murray Model for use as Permitted Take method

Background

1. The MDBA has developed a Source model of the Victorian and New South Wales Murray Systems, the Lower Darling River and the South Australian Murray known as the Source Murray Model (SMM). This has included conceptualisation, calibration, testing and configuring the model to represent different levels of development.
2. An independent review into the adoption of the SMM was completed in March 2017 (**Attachment C**). The MDBA has worked with Basin states since that time to implement the improvements outlined in the review, as well as to undertake further customisation to represent state requirements for water resource planning..
3. The MDBA believes the SMM is now the best available method to underpin an updated determination of some components of the Baseline Diversion Limit (BDL) estimate for the NSW, Vic and SA Murray and NSW Lower Darling SDL resource units, and that it should be used for some components of the permitted take method brought forward by states for the relevant water resource plans (WRPs).
4. As part of the WRP accreditation process the MDBA is reviewing the modelling provided by states in line with the requirements of the Basin Plan. As the MDBA is the developer of the SMM, an independent review is sought to undertake this task in relation to the SMM to maintain the impartiality of the process.

Scope of review

5. The scope of this review is to assess whether:
    a. the relevant recommendations of the previous independent review have been undertaken and adequately implemented within the model
    b. the model has been adequately customised to represent state requirements
    c. SMM is fit for purpose to re-estimate the quantity of water that was permitted to be taken under relevant components of the BDL, as defined under the Basin Plan
    d. the permitted take method implemented in the SMM meets the requirements of the Basin Plan (as informed by MDBA Position Statement 3C – method for determining take – Attachment B) and is robust under a range of climate conditions
    e. any immediate corrections are required to meet the relevant WRP requirements of the Basin Plan
6. If while performing 5 (a-e) the reviewer notes any future model enhancements or additional monitoring and data collection, that would improve the operation or the predictive capability of the model, these should be presented to the MDBA for further consideration.

Contractor requirements:

7. The MDBA requires the services of a contractor to undertake an independent review of the SMM for the purposes of Basin Plan compliance. The contractor should have:

a. extensive knowledge and experience in water resource management and policy at a river system and basin scale
b. extensive knowledge of hydrological modelling processes, and their representation within managed river system planning models.
c. knowledge of the resource assessment, entitlement types and allocations processes in all relevant areas of the Murray Darling Basin.

Independent review approach

8. The review should:
    a. review available documentation, including the last review of the SMM
    b. hold bilateral meetings with NSW, Vic and SA regarding the SMM, its implementation and representation of state policies
    c. assess whether the SMM has used the best available information and was developed according to "good modelling practices" (giving consideration to position statement 3C), and hence its suitability for use in re-estimating the BDL and to determine the permitted take
    d. assess the model water balances and if any changes from previous estimates are justified and reasonable
    e. report on these findings to the Basin states and MDBA.

Deliverables and proposed timeframe

9. It is estimated that the review will take around 13 working days, including travel to bilateral meetings. Expected project milestones are:
    a. review inception meeting with MDBA – early Jan 2019
    b. bilateral meetings with Basin states (New South Wales, South Australia and Victoria) – January/early February 2019
    c. draft report shared with states and MDBA for comment – 8 February 2019
    d. final report submitted to MDBA – 28 February 2019.

Governance and oversight:

10. The Project Steering Committee will work with the independent reviewer to further define the scope of the review, milestones and set work level standards as required.
11. The Project Steering Committee (the Committee) will consist of:
    a. Director, Surface Water
    b. Senior Director, WRP and Basin Plan policy
12. All invoicing and payment enquiries to be forwarded to Tim.Rossi@mdba.gov.au.

Reference details of associated reports

13. Material required to support the review will be provided to the states and the independent reviewer through a "wiki" based document sharing site. This site allows the states to provide comments on technical reports, which can feed into the independent review.

14. Additional reports will be provided to the independent peer reviewer upon engagement to support the review, including:
    a. revised and updated MSM-BIGMOD model report (MDBA Ref. D15/58979)
    b. independent peer review report of MSM-BIGMOD model (MDBA Ref. D15/58618)

Appendix B: MDBA Position Statement 3C

Basin Plan
Water Resource Plan Requirements
Position Statement 3C
Method for determining take

POLICY ISSUE	**How will models included in the method to determine permitted take or the method to determine actual take be assessed?**
REFERENCES	Basin Plan s10.10, s10.12, s10.15, s10.45 and s10.49

MDBA POSITION STATEMENT

1. If a WRP uses a model to determine permitted or actual take, the model must meet the requirements of s 10.10 (for permitted take) and s 10.15 (for actual take) of the Basin Plan.
2. Models will be assessed using the criteria listed in Attachment 1. The criteria are based on requirements under the Basin Plan for a model used for the purposes of s10.10 or s10.15.
    a. Guidance notes are provided in Attachment 1 for each criteria to explain the supporting evidence sought.
    b. Providing the supporting evidence assists in demonstrating how the model development has been based on best available information (s.10.49).
    c. MDBA will review the model, based on the assessment criteria, and provide the State with feedback via an assessment report.
3. It is not a requirement to provide a BDL model, however, the guidance notes include consideration as to whether the SDL model also supports a demonstration of BDL.
4. It is desirable to have models in SOURCE but it is not an essential requirement.
5. Where a model is used to determine actual take by estimating the quantity of water taken by a form of take, the estimate of actual take:
    a. must be done consistently with the method to determine permitted take under s10.10;
    b. be able to demonstrate how it will use the best available information, at the time each year, in order to estimate the quantity taken (s10.15(2)), and
    c. be able to demonstrate how it will account for any growth in use in a form of take included in the model (including under s10.13).

6. Where a model is provided as the method for determining actual take, the water resource plan must specify measures for maintaining, and the timeframe for improving where practicable, the proportion of take that is measured, where practicable (s10.45).

Rationale

Assessment Criteria (Item 2)

The assessment criteria listed in Attachment 1 are based on requirements under the Basin Plan for a WRP. The guidance notes are in the form of questions directed at establishing whether the criteria have been met. They are included to assist in the development of best practice models. They also indicate what information will be sought by MDBA in order for it to be satisfied that the criteria have been met, when it is assessing a WRP for the purposes of making a recommendation to the Minister about accreditation.

Assessment Report (Item 2c)

An assessment report will be provided to the State for review once MDBA has assessed the model against the criteria. The assessment process for SDL models is a bilateral process, whereby each State and the MDBA work together to ensure the State's WRP model will meet the requirements of the Basin Plan, as outlined in the criteria checklist in Attachment 1. The State will have the opportunity to explain any issues of concern to the MDBA or modify the model if required before the MDBA makes a recommendation about accreditation of the WRP.

BDL Model (Item 3)

Where the method for permitted take includes a model it is a requirement to provide an SDL model. The MDBA does not require a BDL model to be developed to meet this requirement; however where a State does develop a BDL model to support its demonstration of meeting the SDL guidance notes are provided in Attachment 1 for how the BDL will be considered.

SOURCE Model Practice Notes (Item 4)

The MDBA is developing, in collaboration with the Basin States, a set of practice notes for the development of models in SOURCE. These can be used as guidance to be followed for various elements of the SOURCE model development. If a SOURCE model provided to the MDBA does not follow the practice notes, MDBA will request an explanation of the reason for this. SOURCE practice notes are available separately < HP Ref: D15/60850>.

Actual Take (Item 5)

Using a model for estimating actual take is acceptable where actual take is not measured, and an estimate is based on the best information available at the time. If a model is used for estimating actual take it must be consistent with the method or model accredited under s10.10 for determining permitted take.

It is noted that a determination of actual take must be made on the best information available at the time, and that it is expected that over time, measuring methods will improve. It is a requirement of s 10.45 for a WRP to specify measures for maintaining and improving, where practicable, the proportion of take that is measured.

Where a determination of actual use for a form of take is to be made by estimating the quantity of water actually taken, the MDBA will seek evidence that establishes that the model will use the best available information in order to estimate the quantity taken (s 10.15(2)), including evidence that demonstrates that any growth in use in a form of take will be accounted for in the estimate. The type of evidence that might need to be provided would be discussed with the State at the time of assessing a WRP submitted for accreditation. Methods such as

comparing water balance models of observed flow with modelled flow, conducting surveys or using satellite imagery, might be adequate.

Additional Issues to note

The way forward with cap factors may result in a broader discussion with States about their planning assumptions, in preparation for 2019. This planning assumptions work may bring forward aspects of the model accreditation work earlier than the current timetable for model accreditation.

Appendix C: SDL Models - Evaluation Criteria

(Note for the purposes of WRP assessment, a 'model' is assumed to be the software engine, system files, and all the input data used to operate to model).

BASIN PLAN CHAPTER 10		***ASSESS***	***ASSIST***	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
		• *these criteria <u>must</u> be met as they are requirements for the models specified in s10.10, s10.12, s10.15, and;* • *these criteria demonstrate the use of best available information as required under s10.49.*		• *these guidance notes are included to assist in the development of models which meet the requirements under the Basin Plan; and the development of best practice models.* • *these guidance notes also indicate what information will be sought by MDBA in order for it to be satisfied that the criteria have been met, when it is assessing a WRP for the purposes of making a recommendation to the Minister about accreditation.*
S10.10		***ANNUAL DETERMINATIONS OF WATER PERMITTED TO BE TAKEN***	**1**	***DOCUMENTATION AND MODEL OVERVIEW***
	s10.10(1)	Is the method – for determining the maximum quantity of water that the plan permits to be taken for consumptive use during a water accounting period – a model?	1.1	Has a complete model report been provided which documents all the matters necessary to allow peer review consistent with the Basin Plan and these evaluation criteria?
	S10.10(2)	• Does the WRP set out the method, for example, by reference to a model report?	1.2	Has sufficient effort been directed to documentation? (i.e. is the model report readable and clear?)

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			1.3	Where previous reports, including any peer reviews, are essential to evaluation of the model, have copies of these reports been provided?
			1.4	Is there a clear statement of objectives in the report? Do the objectives include use of the model to compute SDL(s) (and BDLs) consistent with Chapter 10 of the Basin Plan?
			1.5	In the model report, has the definition of SDL in Schedule 2 of the Basin Plan been correctly interpreted and documented? Where interpretations or assumptions have been made concerning the application of Schedule 3, have these been documented and are they appropriate?
			1.6	Have the WRP area(s) and the SDL resource unit(s) to which the model has been applied been clearly and accurately defined? If the model is applied to only part of these area(s) or resource unit(s), have the areas of application been clearly defined?
	s10.10(3)(a) s10.12(1)(a)	Has the model accounted for all forms of take from the SDL resource unit and all classes of water access right?	1.7	Is there a clear statement, in the model report, which specifies the 'forms of take' that are included in the model and those which are not?[11] Should other forms of take have been included in the model, given its coverage and application within the WRP(s)?

[11] Refer to the seven components of the 'form of take' defined in Section 1.07 of the Basin Plan. It will be important that the modelled forms of take are clearly stated in the report so that the WRP's managers can ensure there is no double-counting of take (refer Section 1.11 of the Basin Plan).

BASIN PLAN CHAPTER 10		***ASSESS***	***ASSIST***	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
	s10.10(2)	Has the model been designed to be applied after the end of the relevant water accounting period, having regard to the water resources available during the period?	1.8	Has the model report established that the model can be used to provide a practical and reliable method to determine the annual permitted take in a water accounting period (for the forms of take to which the model is applied)?
			1.9	If these models were independently reviewed (e.g. when the model was applied as a cap model), have the recommendations of these reviews been considered in formulating the SDL model? If not, have the reasons been documented and are they appropriate?
			1.10	Have the diversion results been individually reported for each form of take simulated in the model? Where the model covers more than one surface water SDL resource unit, have the diversion results been reported for each SDL unit, and for each form of take simulated in the model?
	s10.10(1)	As per 10.10(1) above	1.11	Are the model report's conclusions and recommendations reasonable and supported by evidence?
S10.49		***BEST AVAILABLE INFORMATION***	**2**	***DATA ANALYSIS***
	s10.49(1)	Is the model based on the best available information?	2.1	Have all relevant data been collected and analysed? (surface water, groundwater, land use, diversions, climate, etc)
			2.2	Has information on the spatial and temporal extent, together with the quality of the relevant data, been provided?

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			2.3	Has the recorded diversion data (for the forms of take simulated in the model) been analysed and reported in sufficient detail to allow calibration/ validation of the model? Are the accuracy/ limitations of this diversion data adequately described?
			2.4	In respect of the relevant surface water, groundwater and climatic data used in the model, has the process of infilling data gaps and extending data beyond the period of record been properly documented? Where these data extensions relied on separate modelling, has this modelling been documented and provided for review?
			2.5	Has the process of infilling gaps and extending data been carried out appropriately?
			2.6	Have all locations been identified where recorded flow data already includes for upstream take (e.g. from runoff dams, groundwater usage or diversions from unregulated systems)? Have appropriate procedures been included to allow for this upstream take?
S10.10 S10.12		***ANNUAL DETERMINATIONS OF WATER PERMITTED TO BE TAKEN. MATTERS RELATING TO ACCOUNTING FOR WATER.***	**3**	***MODEL STRUCTURE***
	s10.10(3)(b)	Is the model consistent with the other provisions of the water resource plan?	3.1	Is there a clear description of the model structure and its spatial coverage? Is the model structure and coverage appropriate for SDL assessment?

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			3.2	Has a complete link-node diagram or other representation been provided to identify all the components of the model within each reach?
	S10.10(3)(a) s10.12(1)(b) (c)(d)(g)(h)(i) s10.12(2) s10.12(3)	Does the method account for all matters in s10.12 of the Basin Plan?	3.3	Are all the system conceptualisations appropriate for a SDL model (and consistent with the WRP) when properly calibrated, including those required under Basin Plan s 10.12? This includes, but is not limited to, conceptualisation of: • principle water inputs and outputs, flow routing, transmission losses/gains, storage operations, diversions for each form of take, permanent and temporary trade, water sharing rules, resource assessments, other management rules, procedures to manage HEW, carryover, return flows, water used for aquifer recharge and Is the model time step(s) appropriate?

BASIN PLAN CHAPTER 10		***ASSESS***	***ASSIST***	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
	s10.12(1)(e)	Has the model accounted for water resources which have a significant hydrological connection to the water resources of the SDL resource unit?	3.4	Where there are water resources with a significant hydrological connection to adjacent systems (including groundwater systems), has the structure of the model been prepared appropriately? If this inter-connection has not been simulated, has the likely impact on model results been assessed? Is the model appropriately structured to interface with other SDL models (surface water and groundwater), both upstream and downstream? Where the model interfaces with other SDL models (upstream and/or downstream) are the linkages to these other models clearly described and appropriately established? Have the upstream models been independently reviewed and accredited?
	s10.12(1)(f)	Has the model accounted for circumstances in which there is a change in the way water is taken or held under a water access right?	3.5	Has the conceptualisation of held environmental water (i.e. managed by CEWH, TLM, VEWH, OEH, Water for Rivers and others, if any)[12] been sufficiently described? Is this conceptualisation appropriate for this SDL model, when properly calibrated?

[12] Some SDL models may need to simulate operations under 'cap', or held environmental water recognised in baseline modelling (i.e. The Living Murray, Water for Rivers and Wimmera-Mallee Pipeline Project) in order to fulfil the requirements of Schedule 3 of the Basin Plan. CEWH = Commonwealth Environment Water Holder, VEWH = Victorian Environmental Water Holder, TLM = The Living Murray, OEH = NSW Office of Environment and Heritage.

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
	s10.10(4)	Does the model demonstration relates to the SDL of each resource unit in such a way that, if applied over a repeat of the historical climate conditions, it would result in meeting the SDL for the resource unit, including as amended under section 23B of the Act?	3.6	Is the model flexible enough to demonstrate it will meet the SDL, including an adjusted SDL? Is a reason provided why, if this is not currently the case?
			3.7	Is the model operated over historical climate conditions consistent with the requirements of the Basin Plan, for each form of take simulated in the model?
S10.49		***BEST AVAILABLE INFORMATION***	**4**	***CALIBRATION***
	s10.49(1)	Is the model based on the best available information?	4.1	Every model has different components that can be calibrated. These usually involve some or all of the following: flow calibration, storage calibration, diversion calibration and planted area calibration. For each of model components requiring calibration, has the calibration period been specified? Are the climatic and resource conditions over each of these calibration periods, described? Is the selection of these periods appropriate?
			4.2	Has sufficient effort been expended to obtain data for calibration of each model component?

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			4.3	Has the calibration 'fit' been documented for each model component requiring calibration? Have an appropriate range of statistics of the 'fit' and time series plots of observed and predicted values been provided? Have the model parameters that were 'forced' during each component of the calibration been documented?
			4.4	Is each component of the model sufficiently calibrated against spatial and temporal observations? Are the calibrated values plausible and resultant 'fit' appropriate?
			4.5	If the calibration components share a sufficient common period, has the overall calibration been reported? What is the quality of the resultant 'fit'?
			4.6	Has the robustness of the model to operate outside the calibration period been considered? What is the robustness likely to be having regard to the variability of climatic and other factors during the calibration periods?
S10.49		***BEST AVAILABLE INFORMATION***	**5**	***VERIFICATION/ TESTING***
	s10.49(1)	Is the model based on the best available information?	5.1	Where appropriate, have all reasonable avenues for verifying and testing the model been undertaken and documented? Alternatively if verification or testing has not been undertaken, have the reasons been documented and are they appropriate?
			5.2	Have the climatic and resource conditions over the validation period, been described? Is the selection of this period appropriate and has its duration been maximised?

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			5.3	Have the initial conditions for the validation been documented and appropriately set? Has the extent of any other 'forcing' been described and justified? If present is such 'forcing' appropriate.
			5.4	Have an appropriate range of statistics of the 'fit' and time- series plots of observed and predicted values been provided for all relevant model parameters? What is quality of the resultant 'fit'?
			5.5	For periods when the development limits[13] are sufficiently similar to the historical infrastructure and management rules, has the model been run to compare annual take with the recorded take? Have these results been compared statistically? What is quality of the resultant 'fit' and what confidence can be placed in the resultant SDL (and annual take) determined by the model?
S10.49		***BEST AVAILABLE INFORMATION***	**6**	***PREDICTION***
	s10.49(1)	Is the model based on the best available information?	6.1	Has the procedure for establishing the initial conditions for a model run been described? Is this procedure appropriate?
			6.2	Where the model relies on outputs provided by other SDL models, have the appropriate data sets been used?

[13] This will include for each form of take, the 'development limit' and the period over which the take has to be simulated. The term 'development limit' is used in this review to refer to past state water management laws or other management conditions which determine the opportunities and constraints on take. For watercourse diversions and take by runoff dams (excluding basic rights), the development limit is based on the State water management law that was in existence by a particular date (usually 30 June 2009). This generally refers to a limit established by a water resource plan in place at the time.

BASIN PLAN CHAPTER 10		***ASSESS***	***ASSIST***	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
			6.3	Has the BDL and SDL estimate (for each form of take) been compared with that estimated by the Authority when developing the Basin Plan in 2012? Are the reasons for the differences documented? Are the differences plausible?
			6.4	Has a water balance been provided which defines the magnitudes of all principal model inputs and outputs? Has a satisfactory water balance been achieved?
S10.49		***BEST AVAILABLE INFORMATION***	**7**	***SENSITIVITY AND UNCERTAINTY ANALYSES***
	s10.49(1)	Is the model based on the best available information?	7.1	Have the potential uncertainties in the model inputs been identified? Have the potential errors in the modelling processes been discussed?
			7.2	Have the potential uncertainties in the model outputs been estimated, and in particular, the simulated annual take and SDL?
S10.49		***BEST AVAILABLE INFORMATION***	**8**	***MODEL IMPROVEMENTS***
	s10.49(1)	Is the model based on the best available information?	8.1	Where model development has been constrained by limitations in the available data, have these been identified?
			8.2	Have the model's limitations been considered and has a potential list of improvements been prepared? Are these limitations and improvements appropriate?
			8.3	Is it necessary to collect more data or obtain further information to improve the model? If so have these been documented and scheduled?
			8.4	Where any model improvements are considered essential within a specified timeframe, has this timeframe been documented?

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
S10.49		***BEST AVAILABLE INFORMATION***	**9**	***QUALITY ASSURANCE***
	s10.49(1)	Is the model based on the best available information?	9.1	Has the model run number, the software version and all relevant model input been defined to enable the SDL model run to be repeated, at a later date, if required?
			9.2	Where the model relies on input data generated by other models, have sufficient details been provided to uniquely define those other models and their operating assumptions. Has the source and date of supply of those other models' results been documented?
S10.15		***DETERMINATION OF ACTUAL TAKE MUST BE SPECIFIED***	**10**	***DETERMINATION OF ACTUAL TAKE***
	10.15(3)	If the determination for any form of take is to be made by estimating the quantity of water actually taken, is the method for making the determination consistent with the method set out in the WRP in response to the requirement in s10.10(1)?		

BASIN PLAN CHAPTER 10		*ASSESS*	*ASSIST*	
Principle section	**Related section(s)**	**REQUIRED UNDER BASIN PLAN**	Guidance note #	**GUIDANCE NOTES**
	10.15(4)(a)	Does the model demonstrate that the quantity of water taken includes water that was held environmental water which was disposed of and then used in the SDL resource unit for consumptive use?		
	10.15(4)(b)	Does the model demonstrate that the quantity of water taken excludes water sourced from the Great Artesian Basin and released into and taken from a Basin water resource?		

Appendix D: Principal documents examined

Documents accessed via the eWater Wiki:

Files which have not been updated

Report	Title	Description
2015/03	Model Overview - Source Model of Murray and Lower Darling System	This report described the Source Murray Model
2013/18	Review of Murray Modelled Inflow Data	Summarises the sources of data used to generate inflow data for different scenarios. This includes methods adopted to fill gaps, extend data sets and synthesise data to ensure that inflow data sets are continuous over the required modelling period.
2016/07	Irrigation demands on the Murray and Lower Darling Rivers	Describes how irrigation diversions are represented on the Murray and Lower Darling system. Includes model calibration and comparison with previous modelling approach
2016/08	Environmental Demands	Describes how environmental demands are represented in the SMM
2016/03	Torrumbarry Irrigation Area	Describes the representation of the Torrumbarry Irrigation Area, as included in the SMM
2015/03	NSW Lower Darling accounting	Describes how SMM represents the process NSW uses to hold reserves, allocate water to users and accounts for use on the Lower Darling
2016/16	Configuration of Salinity in the Source Murray Model.pdf	Describes the configuration of salinity in the SMM

Files which have been/are being updated

Report v2	Filename	Description
2018/16	Source Murray Model - Main Document.pdf	File named Main Document, but this should be “Source Murray Model – Method for determining permitted take – DRAFT report This report only describes the BDL and WRP scenario configuration and the method for determining permitted take.
Attachment C	Urban Demand on the Murray and Lower Darling System.pdf	Describes how urban, local water utilities, stock and domestic, riparian and industrial demands are included in the SMM. It includes an assessment of model performance.
Attachment D	Crop Water Model for the Murray and Lower Darling 2018.pdf	Describes how irrigation diversions are represented on the Murray and Lower Darling system. Includes model calibration and comparison with previous modelling approach
Attachment E	Modelling Environmental flows in the Source Murray Model.pdf	Describes how environmental demands are represented in the SMM
Attachment F	Murray Resource Assessment-V2.pdf	Describes how the SMM determines total available water, conveyance and minimum reserves and distributes the available water resources between the states
Attachment G	NSW Resource Assessment.pdf	Describes how SMM represents the process NSW uses to hold reserves, allocate water to users and accounts on the NSW Murray
Attachment I	South Australia Resource Assessment.pdf	Describes how SMM represents the process SA uses to hold reserves, allocate water to users and accounts for use on the South Australian Murray
Attachment J	Victorian Resource Assessment.pdf	Describes how SMM represents the process Vic uses to hold reserves, allocate water to users and accounts for use on the Victorian Murray

Practice Notes	https://www.mdba.gov.au/publications/mdba-reports/hydrologic-modelling-practice-notes	The suite of Practice Notes detailing agreed upon modelling conventions. This is being continually expanded and updated.

Documents provided via email:

Document	Comments
State Comments-v4.xlsx	
Plugins used in the Murray Source model	Table displayed on eWater wiki
08 8578 MSM Cap Model Audit Report - June 2008.pdf	
2018-16 Source Murray Model - Main Document.docx	
2018-16C Urban and S&D Demands.docx	
2018-16D Irrigation Demand.docx	
2018-16E Environmental Demands.docx	
2018-16F Murray Resource Assessment.docx	
2018-16G NSW Murray Resource Assessment.docx	
2018-16H Lower Darling Resource Assessment.docx	
2018-16I South Australian Resource Assessment.docx	
2018-16J Victorian Resource Assessment.docx	
Copy of D18 20521 Bewsher (2017) Issues Table 3 - Tracker.XLSX	

D18 19928 Review of SMM - Bewsher's Draft Report - 10 March 2017.pdf	
Interim Review of Murray Source - Bewsher Draft Report - 21 September 2015.pdf	
SMM Main Document_NSW and SA comments.pdf	
Potential impacts of groundwater Sustainable Diversion Limits and irrigation efficiency projects on river flow volume under the Murray-Darling Basin Plan	Independent review conducted by University of Melbourne and Grounded in Water