MDBA Ref: D20/2587

19 May 2021

BSM Procedures – Modelling

DOCUMENT HISTORY

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11 June '19	Consolidated comments provided to Greg Holland to consider and revise
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17 July '19	Updated version provided to Tim Cummins for Review (unresolved issues highlighted in green)
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Review Cycle

Updates are implemented as required following any significant changes to the content, and the need for a review will be considered by the relevant advisory panel each year.

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Glossary

This glossary provides a summary of key terms and definitions relevant to these procedures. Where there are differences between definitions set out below, and Schedule B to the Murray-Darling Basin Agreement, Schedule B prevails.

Accountable Action – an action under Schedule B [Cl. 2(1)] that**:**

- Is undertaken after a relevant Baseline Date and
- The Authority has decided it will have a Significant Effect and
- The Authority has entered in a Register.

Accredited model – a model found to be fit-for-purpose and approved by the Authority (or its delegate), for a specified purpose under Cl. 38.

Action – any work or measure; and any alteration to, or cessation of, any work or measure relevant to the purpose of Schedule B [Cl. 2(1)].

Agreement – means the Murray-Darling Basin Agreement (Schedule 1 to the *Water Act 2007 (Cwlth)*)

Altered model – a change to an accredited model or associated data sets under Schedule B [Cl .38] that if applied to a relevant Register entry, will result in a change to the estimated salinity effect of at least 0.1 EC by the year 2100.

Aquifer – a geological formation, group of formations or part of a formation; able to receive, store and transmit significant quantities of water.

Authority – Murray-Darling Basin Authority.

Authority model – a model developed by the Authority to meet the requirements of Cl. 36.

Authorised works or measures – works or measures:

- Listed in Appendix 2 of Schedule B or
- Resolved by Ministerial Council to be included in Appendix 2 of Schedule B under Cl. 56(6) of the Agreement.

Base case – the predictive modelling run against which other modelling runs are compared to inform estimates of salinity effects.

Baseline conditions – the conditions that contributed to the movement of salt through land and water within the Murray-Darling Basin on 1 January 2000 [Cl. 2(1)].

Baseline date – the following dates as specified under Cl. 2(1):

- With respect to NSW, Vic and SA – 1 January 1988
- With respect to Qld and ACT – 1 January 2000

Basin Plan – the plan prepared by the MDBA for subparagraph 44(2)(c)(ii) of the *Water Act 2007 (Cwlth).*

Basin Plan Water – Commonwealth environmental water holdings or other held environmental water that is held by a State Contracting Government to offset the reduction in the long-term average sustainable diversion limit [Cl. 2(1)].

Basin Salinity Management Advisory Panel (BSMAP) – a committee established under subsection 203(1) of the *Water Act 2007 (Cwlth)*, to advise the Authority and the Committee on Basin salinity management in accordance with a formal Terms of Reference.

Basin Salinity Target – maintaining an average daily salinity at Morgan at a simulated level of less than 800 E.C. for at least 95% of the time, under the hydrological conditions of the Benchmark Period [Cl. 7].

Benchmark Period – the period from 1 May 1975 to 30 April 2000, or such other period as the Authority, on the advice of the Committee, may from time to time determine [Cl. 2(1)].

Best Management Practice (BMP) – "*the best achievable procedures and outcomes taking into account intended modelling purpose, and trade-offs in knowledge, data, resource and time constraints*" (Jakeman *et al* 2018).

BSM – Basin Salinity Management.

BSM2030 – Basin Salinity Management 2030 strategy.

Calibration – Process of adjusting the values of model parameters within physically defensible ranges until the model performance adequately matches observed historical data from one or more locations represented by the model (i.e., a match is obtained that is robust and fit-for-purpose).

Cl. – a clause or subclause of Schedule B unless explicitly referenced to another statutory or regulatory document.

Conceptual model – Documentation or schematic of the conceptual understanding of groundwater recharge and discharge processes, flow within a groundwater system, and the interaction of groundwater with surface water and dependent ecosystems.

Collective Account –information included in Register A under the heading Collective Account [Cl. 2(a)].

Committee – Basin Officials Committee (BOC) established under Part IV of the Agreement

Delayed salinity impact – a salinity impact which occurs after 1 January 2000, but which:

- In the case of NSW, Victoria or South Australia, is attributable to an action taken or decision made in that State before 1 January 1988
- In the case of Queensland or the ACT, is attributable to an action taken or decision made in that State before 1 January 2000 [Cl. 2(1)].

Delegate – a member of the Authority staff who has been delegated functions and powers under Cl. 199 of the *Water Act 2007 (Cwlth)* through the Instrument of Delegation of the Water Act and Murray Darling Basin Agreement (2019).

Estimates of salinity and salt loads under baseline conditions – estimates of the movement of salt through land and water within the Murray-Darling Basin on 1 January 2000 [Cl. 5].

Evapotranspiration (ET) — the total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies.

Fit-for-purpose model – a model assessed under Cl. 38(2) and found to be suitable for its intended purpose, and the finding endorsed by BSMAP.

Floodplain — generically defined as the land adjoining a watercourse that is periodically subject to overbank flow and inundation from the watercourse.

Gaining – a surface water feature where groundwater discharge contributes to flow or storage.

Groundwater – water contained within rocks and sediments below the ground surface, in the saturated zone predominantly, but including perched systems above the regional water table.

Input models – models that generate salt loads or flows used as inputs to downstream models.

Infiltration – the downward entry of water into the sub-surface.

Lead Agency – Australian or State Contracting Government responsible for developing or reviewing a model.

Losing – a surface water feature from which water is lost to the surrounding and underlying substrate via infiltration through the bed and banks.

Model – a method (or methods) used to estimate flows and salt loads that directly or indirectly have a salinity effect on the Murray River.

Model domain – the geographical area covered by a model, inclusive of the depth of modelled aquifers.

Murray River model – the most recently accredited model developed by the Authority under Cl. 36.

Other shared programs – programs (in addition to Authorised works or measures) that have been established and jointly funded under agreement between State Contracting Governments such as The Living Murray (TLM) and in some cases the Australian Government.

Partner governments – Contracting Governments as defined under Cl. 2 of the Agreement.

Peer assessment – an independent assessment of models undertaken by or on behalf of the Authority under Cl. 38.

Perched groundwater – an area within the unsaturated zone where the soil or rock may be locally saturated because it overlies a low permeability unit (e.g. Blanchetown Clay); perching occurs when the conductivity of a clay layer is sufficiently low that the flux (primarily from irrigation Root Zone Drainage) cannot move through the clay layer under gravity alone; the perched water table may grow vertically and laterally, causing the area of perched groundwater to spread, with possible losses to the surface via evapotranspiration and via irrigation drainage schemes.

Pre-intervention conditions – surface or groundwater conditions under one of the following base case contexts:

- at the baseline date, derived from the estimate of flow and salt loads
  - under baseline conditions minus
  - contributions from Delayed salinity impacts and Accountable Actions at 1 January 2000
- for Delayed salinity impacts, derived from the estimate of flow and salt loads prior to the commencement of that Action
- for the assessment of the incremental effect of an action relative to preceding actions, derived from the estimate of flow and salt loads
  - for the base case at the baseline date plus
  - contributions from Delayed salinity impacts and Accountable Actions that were determined to be accountable [Cl. 19(1)] and included on the Register [Cl. 22] prior to when the Accountable Action being assessed was (or is to be) included on the Register

Procedures – consistent with the meaning given by Cl. 40A(1).

Proposal – any proposal relevant to the subject-matter of Schedule B, for any action [Cl. 2(1)(a) & Cl. 17(1)].

Recharge – the infiltration or ingress of water to the saturated part of a geological layer. Infiltration of precipitation and its movement to the water table are a form of natural recharge. Other sources of recharge are from irrigation RZD and infiltration from streams and flooding.

Root Zone Drainage (RZD) – the residual of water volumes provided to a crop (including irrigation and rainfall) that passes beyond the root zone and is no longer available to plants.

Salinity accountability framework – the combined Basin and state policies and legislative instruments (including Schedule B) that collectively support application of the BSM guiding principle of accountability and transparency.

Salinity effect – a change in the average salinity at Morgan resulting from any action, as estimated by the Authority as defined in Schedule B [Cl. 2(1)(a)].

Salinity cost effect – a change in average salinity cost resulting from an action, as calculated by the Authority [Cl. 2(1)(a)].

Salinity cost functions – mathematical functions that relate river salinity to economic impacts on the various Murray River water users. They are used to the model the economic effects on water users of the simulated salinity, salt load and flow in the Upper River Murray and the River Murray in South Australia [Cl. 36(1)(b)].

Salinity impact – both the salinity effect and the salinity cost effect [Cl. 2(1)(a)].

Salt Management Basin – large evaporative basin used to concentrate saline water from salt interception schemes. Depending upon the basin, the salt is either harvested by commercial operations or gradually seeps back into the regional watertable

Saturated zone – the soil and rocks below the land surface where all spaces between soil/sediment/rock particles are filled with water; it encompasses all the soil and geological layers below the regional water table.

Salinity Registers – a credit and debit-based salinity accounting system which tracks all actions that are assessed to have a Significant Effect on river salinity, being a change in average daily salinity at Morgan which will be at least +/-0.1 EC by 2100 [Cl. 15]. The Salinity Registers provide a primary record of jurisdictional accountability for actions that affect river salinity.

- Register A contains details of any actions after the baseline date (1st January 1988) that are considered to have a Significant Effect, excluding those actions that have the express purpose of offsetting Delayed salinity impacts. Register A also brings forward information about works carried out under the former Salinity and Drainage Strategy.

- Register B records Delayed salinity impacts due to actions taken before the baseline date applicable to each state (the 'legacy of history' for which the Contracting Governments accept joint responsibility). It also contains details of the predicted future effects of actions aimed at addressing Delayed salinity impacts, including contributions from Authorised works or measures, and their salinity costs.

Scenario years – the years inclusive of 2000, 2015, 2030, 2050 and 2100 for which models are required to estimate salinity, flow and salt load [Cl. 36 & 37].

Schedule B – Schedule B to the Agreement.

Significant Effect – a change in average daily salinity at Morgan which the Authority estimates will be at least 0.1EC by the year 2100; or a salinity impact which the Authority estimates will be significant [Cl. 18(3)].

State Action – any Accountable Action that is designated wholly or partly as a State Action by the Authority in accordance with Cl. 20(1)(b) or 24(2(a).

State Contracting Government – any of the Governments of New South Wales, Victoria, South Australia, Queensland or the Australian Capital Territory [Cl. 2 of the Agreement].

State model – a model developed by State Contracting Government to meet the requirements of Cl.37.

Stress period – time interval within a model during which inputs remain constant.

Surface water – water that flows over or is stored on the land surface that includes: (a) water in a watercourse, lake or wetland and (b) any water flowing over or lying on land: (i) after having precipitated naturally or (ii) after having risen to the surface naturally from underground.

The Living Murray (TLM) – a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and the Commonwealth governments, coordinated by the Murray–Darling Basin Authority, which focuses on the recovery of 500 gigalitres of entitlement used to maintain the health of six sites along the Murray River.

Transfer function – a mathematical function that describes the relationship between the input and output of a system; in these procedures, the system is the unsaturated zone, the input is the irrigation accession flux, and the output is the recharge rate used by the groundwater model. A Transfer Function has been developed for the Mallee region to define a mathematical relationship between irrigation RZD and recharge to the regional water table that is representative of the influence of the unsaturated zone. The application of this Transfer Function will enable irrigation recharge to be computed directly from estimates of irrigation RZD.

Unaccounted salt loads – salt load estimates in modelled river reaches that are not fully explained by quantified input data.

Unsaturated zone – the soil and rocks between the land surface and the regional water table in which the pore space contains both air and water.

USDA – United States Department of Agriculture.

Validation – where observations and simulation results are compared using data that were not part of the calibration; a model is conditionally validated for a particular application and a successful validation in one example does not imply that the model is validated for universal use; a model that is conditionally valid is one that has not yet been falsified by tests against observational data; validation is a test of usefulness and not of truth in the sense that may be implied by the non-preferred but generically synonymous term of verification (Black *et. al*. 2011).

Water Table – the top of an unconfined aquifer which can be either perched or regional; it is at atmospheric pressure and, in a regional context, indicates the level below which soil and rock are saturated with water.

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- Dr Juliette Woods (SA Department for Environment and Water)
- Hugh Middlemis (HydroGeoLogic)
- Ray Evans (Salient Solutions)
- Greg Hoxley (Jacobs)

1 Introduction

1.1 Purpose of this document

This document sets out a series of procedures which may be formalised by the Committee [Cl. 40A] to guide the development, assessment and use of surface, groundwater and other mathematical models supporting Basin Salinity Management (BSM) and the associated salinity accountability framework.

The potential need for procedures specific to the development, assessment and use of models is envisioned in Schedule B [Cl. 41(h)] to the Murray-Darling Basin Agreement (the "Agreement"). BSM procedures complementary to these modelling procedures include:

- BSM Procedure – Introduction to the accountability framework
- BSM Procedure – Salinity impact assessment process
- BSM Procedure – Register entries
- BSM Procedure – Conducting reviews and assessments
- BSM Procedure – Environmental water accountability
- BSM Procedure – Register operations
- BSM Procedure – Monitoring
- BSM Procedure – Authorised works or measures
- BSM Procedure – Developing the Review Plan
- BSM Procedure – Independent audit and assessment
- BSM Procedure – Catchment salinity
- BSM Procedure – Elevated salinity events
- BSM Procedure – Reporting
- BSM Procedure – Review of BSM2030 and Schedule B

These modeling Procedures are intended to support appropriate levels of consistency [1] in implementing BSM2030 strategy and complying with the accountability requirements set out in Schedule B, while also enabling adaptive management and continuous improvement. Since the need for consistency changes over time, modelling and other complementary procedures may be updated from time to time.

[1] "Appropriate levels of consistency" includes 'a common method" referred to under Cl. 41(a) but may otherwise mean the concepts that give rise to the consistency principle in Section 3.3 of this document.

1.2 Background

A key element of BSM is the accountability framework that "*commits the partner governments to maintain agreed salinity levels and ensure that their actions that increase river salinity are offset by investing in actions to reduce salinity*". Schedule B to the Agreement formally sets out these arrangements for the management of long-term salinity impacts [linked BSM Procedure – introduction to accountability framework].

Models are powerful tools that play an important role in implementing this accountability framework. Within the BSM context, they are used for the purpose of estimating the long-term changes to river salinity and the salinity cost effect resulting from climatic variability, land use, and water use changes over time.

Elements of the accountability framework directly related to modelling include:

- A suite of models used to simulate a variety of processes within different hydrological and hydrogeological landscapes and for different purposes.
- The assumptions and policies guiding including the Benchmark Period which defines a climatic sequence (currently selected for the period 1 May 1975 to 30 April 2000) that is used consistently in models to take account of hydrological variability in the assessment of salinity impacts
- Governance arrangements that include the review of models according to the BSM2030 review plan, the requirements for peer assessment, the accreditation of new and amended models and the capture and management of metadata.

1.3 Procedure structure and scope

The salinity accountability framework covers the whole of the Basin. It directly, or indirectly, accounts for all actions, in any part of the landscape, that have a material impact upon the salt and water balance of the Murray River. Modelling underpins the framework by quantifying these impacts at various scales. Some of the procedures in this manual are pertinent to all models; others are specific to particular types of models or particular model functions.

The initial scope of modelling procedures sought, were derived from an interjurisdictional workshop (The Wedge Group Pty Ltd 2017). The procedures set out in this documented reflect subsequent advice on the different levels of detail sought by State Contracting Governments and the Authority for different model types (the various types are described in section 2.3). Some procedures are intended to be informative at a relatively high level – they explain the context or background to current Best Management Practices (as defined in this procedure) regarding different aspects of modelling. Other procedures are more prescriptive – they target issues where there is a consensus that more consistency is desirable, throughout the Basin, regarding specific aspects of modelling or modelling approaches.

To align with both the informative and the prescriptive roles, this document includes an overview of modelling in the context of the salinity accountability framework, followed by procedures set out in three parts:

Part 1: Procedures at the core of the BSM modelling framework

Part 2: Procedures applicable to all models that support salinity accountability

Part 3: Procedures applicable to specific types of models

The specific types of models covered by these procedures are:

- Mallee groundwater models
- Floodplain and environmental watering models.
- Irrigation delivery system models
- Irrigation drain flow and salt load models
- Upland groundwater models.

2 Overview of BSM Modelling

2.1 Purpose

This section provides an overview of the types of models used to support implementation of Schedule B, the integration of models essential to evaluating the salinity effects of actions on the shared waters of the Murray-Darling Basin, and the generic steps that underpin modelling-based assessments.

2.2 Background

Under the BSM accountability framework, modelling has the following applications:

- Estimating salinity and flows under baseline conditions [Cl. 37(1)].
- Supporting an evaluation of the salinity trends, predictions and risk profiles in tributary rivers [Cl. 33(3)].
- Predicting the salinity effects in each of the scenario years (2000, 2015, 2030, 2050 and 2100) from Delayed salinity impacts, and changes in land and water use, from conditions at the baseline date [Cl. 33(2), 36(2) & 37(2)].
- the economic effects on water users of the simulated salinity, salt load and flow in the Murray River [Cl. 36(1)(b)].
- Comparing the net salinity effect of all land and water management actions within the Basin against the Basin Salinity Target [Cl. 7(2)].

2.3 Types of models

The term “model” encompasses a significant diversity of mathematical tools used to support salinity impact assessments and implementation of the accountability framework. Diversity is apparent in both the function and mathematical form of models.

Functional types covered by Part 1 and Part 2 procedures (and in some cases Part 3 procedures) include:

- **Upper catchment models** – generate estimates of surface runoff for input to river models
- **Murray, tributary or irrigation system models** – surface water models that include the Murray River model and surface water models that generate inputs to the Murray River model
- **Irrigation drain models** – generate drain flow and salinities for input to Murray or tributary models
- **Recharge models** – generate estimates of groundwater recharge

- **Groundwater models** – generate groundwater flux estimates, which together with assumptions on groundwater salinity, provides estimates of salt loads to surface water models
- **Floodplain models** – depending upon the level of complexity, test the impact of actions that affect groundwater and surface water processes, and so contribute to estimates of salt loads to surface water models
- **Salinity cost effect models** – use salinity effects and salinity cost functions to estimate the cost of an Accountable Action or a Delayed salinity impact.

The form of these models includes empirical, analytical and numerical methods.

- **Empirical methods** typically use measured data and regression relationships rather than mathematical methods to guide natural resource management decisions
- **Analytical methods** involve highly idealised conceptual models, parameters and boundaries that are amenable to providing an exact solution to the governing equation and they are often relatively simple and efficient to obtain
- **Numerical methods** apply approximations to a governing equation to enable the division of space and time into discrete pieces. Numerical models accommodate varying boundary conditions, hydrological properties and water sharing and management arrangements. They provide opportunities for more complex, and potentially more realistic, representation of systems than analytical models.

For any specific purpose, one or more of these types of model may be adopted to support a salinity impact assessment consistent with the accountability framework. From an efficiency perspective, the most appropriate method type, is that which most efficiently and effectively meets the objective.

2.4 Modelling objective and design

The starting point for the development of a model is a clear purpose (Anderson *et al* 2015). In the BSM context, the purpose of models is to meet accountability objectives; support Register maintenance or assess progress against salinity targets.

In order to achieve its purpose, model design decisions are required. Decisions include the type of model (discussed above) and the level of detail required – recognising that all models are simplifications of complex hydrological and hydrogeological processes and settings (Grayson *et al* 2002; Anderson *et al* 2015).

In broad terms, the model types briefly described above, fall within one of the following three levels of complexity (modified from Middlemis (2001)):

- Basic model – a model suitable for preliminary assessment (simple calculations), not requiring substantial resources to develop
- Impact Assessment model – a moderately complex model, requiring more data and a better understanding of system dynamics
- Highly complex model – suitable for predicting responses to arbitrary changes in hydrological conditions.

Consideration of an appropriately level of complexity is one of a number of early modelling decisions and is implicit in the “confidence level” approach provided by Barnett *et al* (2012) to support groundwater model design which includes factors associated with data availability, calibration, prediction and ‘fit-for-purpose’ indicators.

Referencing Doherty (2011), Anderson *et al* (2015) state "*Defining the optimal compromise between simplicity and complexity is part of the art of modelling and is one of the challenges in modelling*". The merit of simple *vs* complex models included in the literature[2] include:

- If there is insufficient data to constrain modelling results – given that the predictive performance of a complex model may be no better than that of a simpler model (Figure 1)
- Whether, even with significant data gaps, complex models improve understanding by enabling contributing processes to be considered and parameterised through informed estimates.

Ultimately in model design, more complex processes and parameters should be included if they are essential to meeting the modelling objective (Anderson *et al* 2015). Support on what is "essential" in a BSM context is provided by BSM2030 Guiding Principles. Modelling Principles are provided within these procedures [linked procedure 3] to provide a modelling context to the BSM2030 Guiding Principles.

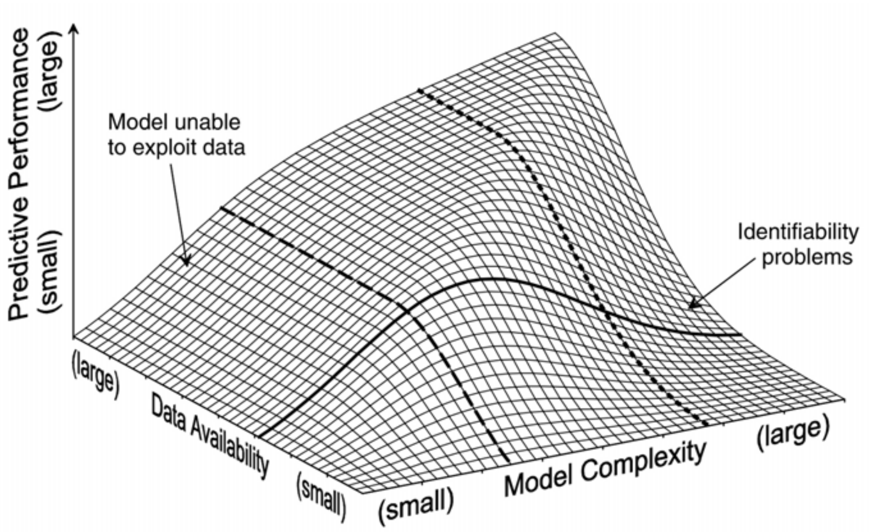

Figure 1: Schematic diagram of the relationship between model complexity, data availability and predictive performance (sourced from Grayson *et al* (2002) after Grayson and Blöschl (2000))

2.5 Model integration

Managing the salinity of the shared water resources of the Murray-Darling Basin (MDB) requires a whole-of-Basin approach. This means that the accountability framework incorporates the net contribution from climate, land use, and water use across the whole of the basin, to assess/manage salinity effects in the Murray River. The integration of models is critical to this whole-of-basin approach; it enables the output data from many of the functional types of models to be used to develop input files for other models.

This integration extends from the elevated upland landscapes (including in the northern Basin) to the mouth of the Murray. It allows the salinity effect downstream at Morgan in South Australia to be assessed using the salt and water balance estimates derived for the location of an Accountable Action anywhere in the Basin. This integration is schematically illustrated in Figure 2.

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[2] For example Black *et al* (2011)

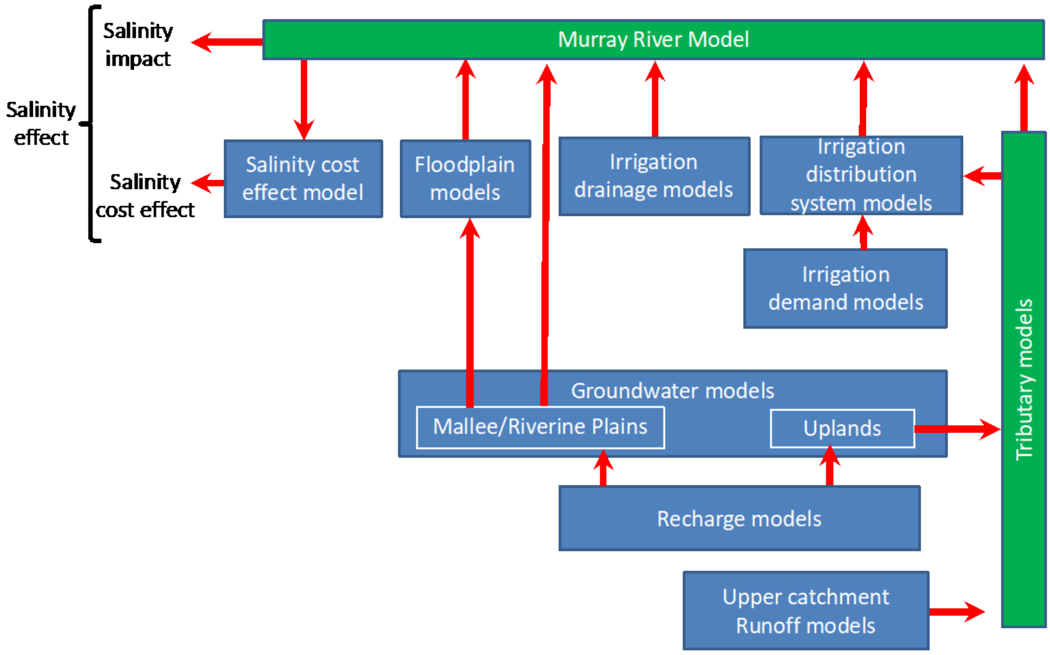

Figure 2: Examples of functional types of models and their integration across the Murray Darling Basin

2.6 Modelling steps

All modelling assessments are unique; each must address specific purposes, specific hydrological or hydrogeological environments, and specific risks. However, the eight generalised technical steps set out in Figure 3 are the key components of most modelling studies. This workflow is generally consistent with guidance documents available in the public domain[3], though the terminology, and the grouping of tasks within each step, may differ.

In following the modelling steps in Figure 3, the procedures set out in the following three parts of this document should be considered. This will guide the project towards appropriate levels of consistency (see section 3.3) and Best Management Practice (inclusive of governance and quality assurance).

[3] For example Anderson *et al* (2015) and Barnett *et al* (2012)

1. **Purpose –** define the purpose of the model including the key technical questions to be answered by the assessment. For example, is the model intended to:
    - Assess changes to surface water flows, and salt loads, entering streams resulting from changes in land use or water use?
    - Assess changes to groundwater discharge to streams or floodplains resulting from changes in land use or water use?
    - Quantify inputs to groundwater models?
    - Assess the Murray River salinity effect resulting from any, or all, of the above?
2. **Conceptualisation** – compile relevant data and develop a conceptual model that provides a level of understanding sufficient to inform the intended purpose of the model.
3. **Method selection –** select an assessment method that is suited to the model's purpose with due consideration given to the modelling principles and other relevant guidance set out in these procedures [linked procedure 3].
4. **Model development** – construct the model:
    - To achieve the intended purpose
    - To be consistent with the conceptualisation
    - In accordance with Best Management Practice in design, calibration, and sensitivity analysis.
5. **Model application and predictions** – undertake the assessment targeted towards answering the technical (including probabilistic) questions.
6. **Uncertainty analysis** – consider uncertainty throughout the process informing both the modeller and stakeholders of the limitations of the assessment and potentially identifying the need to review previous steps.
7. **Documentation** – document each step in the process and so inform stakeholders and peer assessors about progress and feedback on key assumptions and decisions.
8. **Reporting** – compile a final report clearly communicating key assumptions, predictions, results and uncertainties.

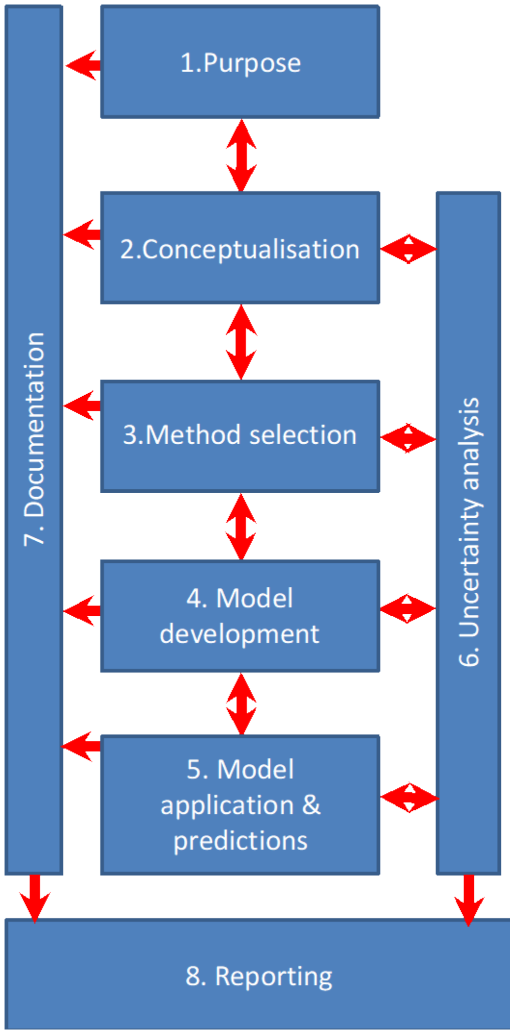

Figure 3: Typical steps in the development of (or alteration to) a model

The linear structure of Figure 3, suggests a sequential workflow. However, in practice, modelling is typically an iterative process with the modelling team progressing their understanding of the system, recognising gaps in the knowledge base, potentially modifying the methodology accordingly, and improving the model conceptualisation and/or performance.

PART 1: PROCEDURES AT THE CORE OF THE BSM MODELLING FRAMEWORK

3 Modelling Principles

3.1 Purpose

This procedure provides principles to guide all modelling undertaken under the BSM accountability framework.

3.2 Overview

Principles provide insight into what is expected and desirable from a modelling project. These procedures support:

- Innovation and flexibility – balanced with appropriate levels of consistency (see section 3.3)
- Continuous improvement.

The principles presented in this procedure draw upon the BSM2030 strategy guiding principles and other concepts applicable to modelling in general.

3.3 Application

The following principles should be considered during each of the modelling steps set out in Figure 3. noting that on some occasions, it may be necessary to balance one principle against another.

- **Accountability and transparency** – Models are integral to the salinity accountability framework, therefore the processes for developing, documenting, and applying a model must be consistent with the requirements of Schedule B, and demonstrate robust review and reporting arrangements.
- **Best Management Practice** – In keeping with the scale, the purpose, and the risk associated with an assessment, Best Management Practices should be used in developing and applying all models, including peer assessment to confirming fit-for-purpose.
- **Consideration of new knowledge** – In selecting a method and developing a model, new knowledge (including improvements to available data and improvements in assessment methods) should be considered and used as appropriate. New knowledge includes understandings gained from linked data sets from integrated models, and learnings from other modelling studies, particularly where they have been developed in similar hydrological and/or hydrogeological environments and for similar purposes and where they have been peer assessed and confirmed as fit-for-purpose.
- **Consistency** – "appropriate levels of consistency" means the application of consistency in assumptions where:
    - models have similar applications and are underpinned by a common modelling platform
    - the processes being modelled are common across multiple modelling domains
    - alternative assumptions have the potential to significantly alter predictions

Models that deviate from previously agreed levels of consistency should be supported by clear, documented rationale.

- **Cost-efficient and cost-effective** – When selecting and applying modelling approaches and methods, the selection criteria should include:
  - Cost effectiveness – Increased investment in a model should be rewarded with increased predictive performance (see Figure 1)
  - Cost efficiency – The concept of pursuing 'best bang for buck' which could include (where appropriate):
    - seeking a 'no borders' approach to modelling
    - sharing the costs of developing and reviewing models with water resource managers.
- **Effort commensurate with risk** – The effort invested in developing, applying, and documenting a model or elements of the modelling project, should be commensurate with the risks associated with the decisions that the model will inform.
- **Multiple lines of evidence** – to the extent practical, assumptions on model inputs should be supported by a qualitative 'weight of evidence' assessment. For example, using the available science to demonstrate through several independent means, an appropriate selection of a parameter value.
- **Precautionary principle** – Where significant knowledge gaps have implications for applying models, assigning confidence levels, and interpreting results, it is important to take account of the risks associated with over- or under-estimating the salinity effect. As an example, it may mean taking a carefully considered approach to:
  - adopting modelling assumptions
  - selecting the preferred modelling output from the range of possible predictions.

  The precautionary principle may not be applicable to all modelling situations however the obligation to bring forward debits to the Register earlier than is required of credits [see Cl. 22 and linked "BSM Procedure – Register entries"] is an example of the application of this principle to salinity assessments. How this principle should be applied in estimating model parameters, especially when the model includes both credits and debits, is a matter for ongoing consideration by both the technical and policy personnel responsible for salinity management, and it may include a form of uncertainty analysis [see linked procedure 6].

4 Modelling the Murray River and tributaries

4.1 Integrating models

4.1.1 Purpose

This procedure provides guidance on addressing the challenges of integrating input models with tributary models and the Murray River model.

4.1.2 Background

Contracting Governments must give to the Authority information on a Proposal or Accountable Action, which may assist the Authority accurately assess salinity impacts [Cl.19 & Cl.33] or for a provisional entry, the salinity effect [see Cl. 20A and linked "BSM Procedure – Salinity impact assessment process"].

The knowledge required by the Authority to assess salinity impacts in accordance with these requirements of Schedule B, is most commonly data generated from input models. Figure 2 conceptualizes the integration of the various input models noting that input models may inform the Murray River model either directly, or indirectly (through other input models).

Model integration, that is, applying the outputs of one model to the input needs of another model, may involve the following challenges:

- **Differing time steps** – Schedule B is prescriptive about estimating salinity, salt loads, and flow regimes on a daily basis for the Murray River model and tributary models. Some other jurisdictional models also operate on a daily time step. However, many input models have substantially longer time steps (or stress periods), in which case the output data cannot be used as a direct input to the linked river model.
- **River conditions** – Schedule B is prescriptive about simulating salinity, salt loads, and flow regimes over the Benchmark Period for the Murray River model and tributary models. Depending upon the nature of the input model (for example groundwater models), it may not be practical for rivers to be represented in a way that is consistent with the Benchmark Period [see linked procedure 15.7]
- **Inconsistencies between the linked water systems, and the linkages between integrated models** – the integration of linked models (Figure 2) may not fully reflect the hydrological linkages in the landscape. For example, the final node of a drainage model may be based on the location of a drainage monitoring station, rather than the location of the river outfall.

As there are multiple types of systems being modelled, and modelling types deemed appropriate to those circumstances, a prescriptive approach to how the outputs from one model are tailored to meet the input requirements of a river model is not appropriate. The guidance provided below in the keeping with the Accountability and Transparency principle [linked Procedure 3] through a clear methodology, and rationale for assumptions associated with this methodology.

4.1.3 Application

Where outputs from a model are to be used as inputs to a linked tributary model or the Murray River model, all assumptions and methods of conversion should be documented in ways that are guided by linked BSM Procedure – Tracking and managing salt load data.

4.2 Developing river models

4.2.1 Purpose

This procedure provides guidance on developing surface water models [Cl. 36(1) & 37(1)].

4.2.2 Background

Surface water models are informed by data from key monitoring points within the stream. They are also informed by the available data from input models.

Data sources will include time series data from continuous monitoring stations along the stream, through to occasional, or periodic, data arising from activities in specific reaches of the stream. Examples of the latter include periodic 'run-of-river' sampling and geophysical monitoring in the vicinity of salt interception schemes.

For some rivers and streams, there is also potentially regional scale information such as mapping of gaining and losing river reaches, and river corridor geophysical mapping by Geoscience Australia.

A range of Best Management Practice documents are available to guide model development through the key steps set out in Figure 3 e.g., Black *et al* 2011; Jakeman *et al* 2018. This procedure therefore focuses upon guidance on issues pertinent to BSM surface water models that are not covered by generic Best Management Practice documents, specifically:

- Model calibration and unaccounted salt loads
- Actions to be considered in estimating salinity, salt load and flow impacts under baseline conditions in surface water models
- Estimating baseline conditions.

4.2.3 Model calibration and unaccounted salt loads

Surface water models are calibrated and validated at key nodes, informed by the location of long-term monitoring records. Understanding changes to flow and salt loads within river reaches between these nodes should be informed by comprehensively assessing all the available data including outputs from models linking surface and groundwater systems (Figure 2).

The basis for assigning unaccounted salt loads to achieve a salt load balance between nodes in the calibrated model should be clearly documented.

4.2.4 Actions to be considered in estimating salinity, salt load and flow impacts under baseline conditions

The accountability arrangements for BSM rely on the adoption of the agreed estimate of baseline conditions across the Murray-Darling Basin. Baseline conditions are the conditions that contributed to the movement of salt through land and water within the Murray-Darling Basin on 1 January 2000. For New South Wales, Victoria and South Australia, the estimate of baseline conditions includes the salinity effect of Accountable Actions from 1988 to 2000.

The estimate of baseline conditions should include conditions pertaining to:

- Land use (level of development of the landscape)
- Water use (level of diversions from the rivers)
- Land and water management policies and practices (including diversions under the Murray-Darling Basin Cap[4] and any subsequent flow management agreements up to 1 January 2000)
- River operating regimes
- Salt interception schemes
- Run-off generation and salt mobilisation processes
- Groundwater status and conditions.

The relationship between these conditions and the salinity, salt load, and flow regime at End-of-Valley target sites and the Basin Salinity Target site is established by developing a model that simulates baseline conditions over the benchmark period.

[4] MDB Ministerial Council (1996)

4.2.5 Estimating salinity and salt load under baseline and current conditions

Using the calibrated model to develop model versions that represent baseline conditions and current conditions requires a review of the contemporary knowledge base on the status of salt loads and inflows at 1 January 2000 and since that time [Cl. 5(5)].

Appendix A provides an outline of how the unaccounted salt loads are estimated in the Murray River model for the baseline date, baseline conditions and current conditions.

Estimates of salinity and salt loads are set out in Schedule B, Appendix 1 for:

- Each End-of-Valley Target site
- At the Basin Salinity Target site at Morgan.

These baseline condition estimates for the river models are the Authority endorsed estimates [Cl. 5] however a State Contracting Government or the Authority may, from time to time, propose an amendment to these estimates using the best available information at the time the amendment is proposed.

Amendments will have implications for End-of-Valley targets [Cl. 5(1)] as salinities and salt loads listed within Schedule B, Appendix 1 are each expressed as a percentage of the estimated baseline conditions.

The process for the endorsement of revised estimates of salinity and salt loads under baseline conditions for the tributary valleys and the Murray River is set out in Cl. 5 including:

- The appointment of an appropriately qualified and suitably experienced panel to review and advise the Authority on the proposed amendment
- A decision to endorse or not endorse a proposed amendment
- Amendment of Appendix 1 to Schedule B
- Use of the revised estimates as a basis for salinity assessments.

Cl. 5 does not cover the endorsement of revised estimates of salinity and salt loads under baseline conditions for input models. These approvals are covered by the accreditation of the relevant model [linked procedure 6.5] and approval of the Register entry [linked procedure "BSM Procedure – Register entries"].

4.3 Sequencing actions in the Murray River model

4.3.1 Purpose

This procedure provides guidance on the sequencing of Delayed salinity impacts and Accountable Actions in the Murray River model.

4.3.2 Background

The MDBA's obligation to estimate the salinity effect of Delayed salinity impacts and Accountable Actions [Cl. 19] requires the use of the most recently accredited Murray River model [linked procedure 6.5]. Estimates are required for new Accountable Actions, and they are also required where reviews demonstrate changes to the flows and salinities arising from Delayed salinity impacts or Accountable Actions that are already on the Register.

The sequence in which the Delayed salinity impacts and Accountable Actions are individually assessed within the Murray River model affects the value of the salinity effect assigned to every Action that is subsequently assessed.

The approach to sequencing has implications for the number of Murray River modelling runs and hence the modelling resources required in maintaining the registers [linked BSM Procedure – Register operations].

The approach to sequencing can also affect the stability of the Registers. That is, sequencing can affect whether all entries are changed annually in response to an update of the Register entries reviewed during that year, or whether they are changed less frequently in response to a major update of the Register as a whole.

The sequencing approach should consider the following modelling principles [linked procedure 3]:

- **Accountability:**
  - The approach should meet the requirements of maintaining the salinity Registers [Cl. 1(2)] and provide relative stability to the Registers so as to be conducive to biennial auditing [Cl. 34(3)]
  - State Contracting Governments must keep their contributions to the Register in balance [Cl. 16], and they have invested significantly to meet this obligation. Hence the sequencing method should not enable an assessment to erode the credits, or increase the debits, of an Accountable Action that was included on the Register [Cl. 19(1) & Cl. 22] prior to the action being assessed.

- **Effort commensurate with risk** – Depending upon the modelling platform, the sequencing method may have implications for the required modelling effort. In keeping with this principle:
  - Significant effort in model sequencing may be warranted if risks arising from interpretations of the status of the Registers balance is high. For example:
    - at points in time when key investment decisions are required such as authorising a new Authorised work or measure [Cl. 12]
    - key policy decisions are required such as a comprehensive review of Schedule B [Cl. 35] or the Strategy [Cl. 35A]
    - on occasions when there are major shifts in the Registers [see linked BSM Procedure – Register operations]
  - Significant effort in model sequencing may not be warranted at other times, particularly if the Register is just providing a generalised understanding of each State's balance arising from a review scheduled within the Review Plan [linked procedure – Conducting reviews and assessments].

- **Cost-efficient and cost-effective modelling** – The adopted procedure should enable the Authority to undertake the salinity assessments in a cost-efficient and cost-effective manner.

4.3.3 Application

The following approach to sequencing seeks to balance the above principles:

- For the assessment of a new Register entry [Cl. 19(1)(f)], the assessment should be sequenced in the Murray River model after the assessment of all existing Register Entries.

- For the re-estimate of existing Register entries [Cl. 24(1)]:
    - Method 1 – For Actions where input models (Figure 2) provide salt loads to the Murray River model, the sequencing approach should be in accordance with the following steps:
        1. Calculate the difference in salt loads estimated in the review of the Register entry, from that identified in the previous estimate
        2. Using the Murray River model and the sequencing approach applied to a new Register entry, assess the salinity impact of the calculated difference from step 1
        3. Add the estimated salinity impact of the calculated difference (from step 2), to the previous estimate (i.e., the previously approved Register entry)
    - Method 2 - For Actions where input models (Figure 2) provide flow and salinity to the Murray River model, the sequencing approach should be as follows:
        1. Using the Murray River model and the sequencing approach applied to a new Register entry, assess the salinity impact of the flow and salinity estimated in the review
        2. Replace the previous estimate (i.e., the previously approved Register entry) with the new estimate (from step 1).

      Note that Method 1 cannot be validly applied to flow and salinity input data because in some timesteps, it would result in negative flow and salinity values

- For a full update of all register entries, each Register entry should be updated using the estimates of flow and/or salt load to the Murray River established as an outcome of "BSM Procedure – Salinity impacts assessment process" or "BSM Procedure – Conducting reviews and assessment" for a new Register entry, or a reviewed Register entry respectively. The assessment of the action should be in the chronological order in which the action was brought to the Register.

5 Salinity cost effect model

5.1 Purpose

To provide guidance on establishing or revising the salinity cost functions used in models that simulate the economic effects on water users of the simulated salinity, salt load and flow.

5.2 Background

Models are used to assess the economic costs that salinity poses upon consumptive water users [Cl. 36(1)(b)]. The major financial costs are considered to be:

- Urban: corrosion of water heaters, and the costs of water softening
- Industrial: water treatment, scaling of plant, more frequent replacement of water treatment infrastructure
- Agricultural: reduction in yield.

For this reason, a salinity cost effect model has been developed based upon the work by GHD (1999) and Allen (2004). The outputs of this model (from twenty-two Murray River reaches) are combined with the outputs from the salinity effect modelling to provide the evaluation of the salinity impact (Figure 2).

The current accredited cost effect model is based upon the following:

- Urban and industrial cost effects ($/unit X No units) calculated using linear equations

    - Examples of $/unit include $/household, $/kL, or $/ water boilers
    - Number of units based upon population and estimates of industry
- Agricultural salinity cost effects derived on the basis of the following
    - The Mass and Hoffman (1977) 'Bent stick' equations conceptualised within Figure 4. The "bent stick" assumes no yield reduction up to a threshold level of soil water salinity, and a straight-line reduction in yield with increasing salinity above the threshold. Soil water salinity (Figure 4) is estimated using irrigation season river salinity and leaching fractions
    - Threshold soil salinities are based upon research at the USDA Salinity Laboratory and rate of decline of yield varies from crop to crop
    - Other factors taken into account include:
        - Conversion of water salinity (inclusive of irrigation and rainfall) to soil water salinity using estimated leaching fractions, and estimated crop water requirements
        - Weighting for long term toxicity effects
        - Crop response functions from foliar injury from spray irrigation at threshold salinities.
- An economic model that combines the salinity/impact relationships above, with:
    - Agricultural data – average crop yields, land use and crop gross margins
    - Urban/industrial data – Number of users and estimated volumes of use.

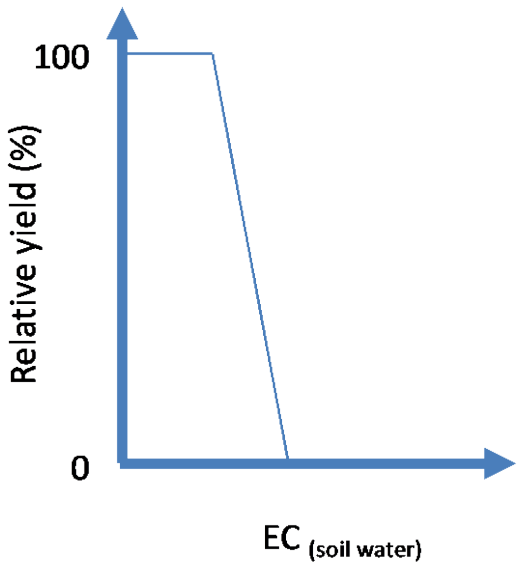

Figure 4: The "bent stick" conceptual model of yield loss with increasing soil salinity

The cost function model processes every run of the Murray River model and archives the salinity cost output on the model database. The cost function model does not quantify the environmental and social costs associated with salinity.

More detail is provided within GHD (1999) and Allen Consulting (2004).

5.3 Application

To meet the salinity cost effect modelling requirements of the Schedule [Cl. 36(1)(b)], the GHD (1999) and Allen (2004) cost functions must be used unless new cost functions developed and the altered model accredited [Cl. 38].

An alteration to the salinity cost effect model, should be subject to significant improvements in understanding and availability of supporting data necessary to update the salinity cost functions.

Data to be considered in updating the salinity cost functions and salinity cost effect model include:

- The distribution of different types of crops along the Murray River and lower Darling River
- The distribution of different types of irrigation systems (in the context of risk posed by over canopy spray)
- The relationship between salinity and yield
- Salt accumulation and soil salinity
- For permanent plantings, the relationship between the economic life of the plantings and exposure to high salinity water
- Average economic returns over the period that the cost functions are likely to apply.

6 Model governance

6.1 Purpose

This procedure sets out governance arrangements for developing, reviewing, assessing, approving and managing models

6.2 Background

For this procedure, governance is inclusive of:

- Responsibility for model development and related data
- Quality assurance of models
- Model accreditation.

Where the development or review of a model is to generate input data for tributary models or the Murray River model (Figure 2), governance arrangements set out in the following linked procedures should also be considered:

- BSM Procedure – Conducting reviews and assessments
- BSM Procedure – Salinity impact assessment process

6.3 Responsibility for model development, maintenance and review

6.3.1 Purpose

This procedure provides guidance on the assignment of responsibilities for models to Lead Agencies.

6.3.2 Background

Schedule B provides the following modelling obligations for models:

- To the Authority, for development and maintenance under Cl. 36, and review under Cl. 32(3):
  - Models used to simulate daily flow and salinity in the Murray River
  - Models used to estimate the salinity cost effect of Accountable Actions and Delayed salinity impacts [linked procedure 5]
- To each State Contracting Government, for development and maintenance under Cl. 37 and review under Cl. 32(3)
  - Surface water tributary models used to simulate daily salinity, salt load and flow, over the Benchmark Period
  - Groundwater models used to simulate salt load discharge to surface water

A range of other models are used to support implementation of the salinity accountability framework that are not explicitly covered by Cl. 36 and Cl. 37. For example:

- Purpose-built models that provide inputs to groundwater or surface water models
- Models that support an estimate of the salinity or flows relating to a single Register entry
- Generic modelling platforms that (subject to the availability of local data sets) are able to be applied by States as specific functional type models in meeting their accountability obligations: For example:
  - 2CSalt (Stenson *et al* 2011) applicable to upland unregulated catchments [linked procedure 19]
  - SIMRAT (Fuller *et al* 2005) and the Mallee Transfer Function (under development; Walker *et al* 2019) applicable to assessing recharge in the Mallee [linked procedure 15].

6.3.3 Application

Figure 5 provides a decision support framework for the assignment of Lead Agency responsibilities to models. Lead agency responsibilities are assigned as follows:

- To the Authority
  - Daily time step surface water models that simulate salinity, salt load and flow in the Murray River [Cl. 36(1)(a)]
  - Models to assess the salinity cost effect of Accountable Actions and Delayed salinity impacts (Cl. 36(1)(b)]
  - Generic functional type models developed by the Authority applicable to specific landscapes across multiple jurisdictions
- To State Contracting Governments
  - Daily time step surface water models, and groundwater models explicitly covered under Cl. 37
  - Models developed by states to generate inputs to surface water and groundwater models.

There may be situations where the decision support framework does not fully apply in which case negotiations between the Authority and State Contracting Governments may be required. For example:

- Where salinity effects of an Authorised work or measure is being assessed, model responsibility resides with the Contracting Government nominated by the Ministerial Council as responsible for construction, operation and maintenance in accordance with subclause 56(5) of the Agreement [Cl 19(3)(a)].

- Where the principle of cost-efficient and cost-effective modelling [see linked procedure 3] leads to sharing of a model (e.g., a no borders approach to the development of the Eastern Mallee model) [Cl. 19(3)(b)].
- Where salinity effects of a shared programs is being assessed where the Accountable Action is wholly or partly a State Action in respect of which salinity credits or debits will be attributed to the Collective Account – the Contracting Government determined by the Committee [Cl. 19(3)(c) & 21A(3].

Cost sharing arrangements will be negotiated as required between the Authority and one or more State Contracting Governments including where a nominated Lead Agency is responsible for the development or review of models that assess the salinity effects of multiple actions that cover more than one jurisdiction, include Authorised works or measures, or shared programs.

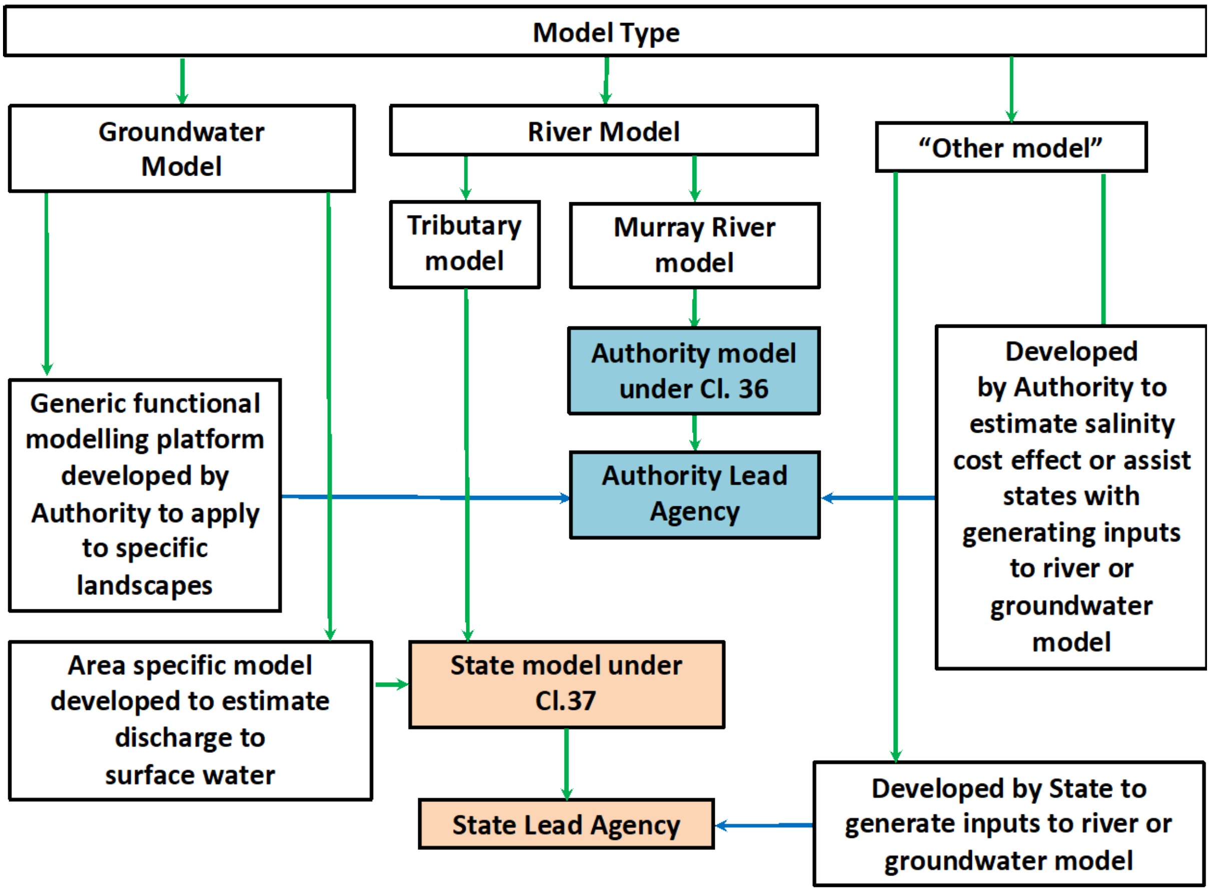

Figure 5: Decision support for assigning Lead Agency responsibilities for models.

6.4 Quality assurance of models

6.4.1 Purpose

This procedure sets out the processes supporting quality assurance in the development and alteration of models and data sets that are used to develop input files for use in the Murray River model.

6.4.2 Background

Clear processes for establishing and applying appropriate quality assurance processes provide confidence that models were developed, and are being maintained, in accordance with Best Management Practice [linked Procedure 3].

Quality assurance processes include:

- Internal quality assurance processes covering model development and data management
- External quality assurance processes managed by the Authority
- Model accreditation
- Management of output files that form the basis for input files to an integrated model (for example files provide to the Authority for salinity estimates with the Murray River model).

6.4.3 Application

6.4.3.1 INTERNAL QUALITY ASSURANCE

The scoping and specification documents developed prior to model development, or amendment, should include explicit requirements for quality assurance. Documentation should confirm that predictive modelling has been undertaken consistent with the assumptions applied to the accredited or otherwise fit-for-purpose model. Documentation should include version control and archiving requirements for the model and associated datafiles [linked procedure 13].

Guidance on archiving in accordance with best practice is provided by Black *et al* (2011).

6.4.3.2 EXTERNAL QUALITY ASSURANCE (PEER ASSESSMENT)

This procedure is intended to provide guidance on the peer assessment of models. Provisions for this procedure are explicit in the Schedule [Cl.38(1) & Cl. 41(h)] [see linked "BSM Procedure – Conducting reviews and assessments"].

The peer assessment is intended to provide professional scrutiny to the decisions that underpin both the conceptualisation and the mathematical model [see linked procedure 2.6] and so contributes both quality assurance and continuous improvement to the development and application of the model. The assessment is intended to be approached in the spirit of contributing to achieving long term incremental improvements in a model. However, peer assessment is not a substitute for the reviewer's appropriate and expected quality assurance throughout the project life cycle. Project proponents should consider the merits of including the peer assessor early in the project life cycle.

For models developed or altered by the Authority, the Authority will appoint a qualified and suitably experienced panel to independently assess the model [Cl. 38(3)]. For all other models the Authority is responsible for assessment under [Cl. 38(2)] and may engage the services of an Independent Peer Assessor[5] to advise the Authority.

[5] The term "Independent Peer Assessment" replaces the previously used term "Independent Peer Review" to better align with the use of terminology in the Schedule which:

- Uses the term "review" in the context of the process undertaken by Contracting Governments to update models (and Register entries and End-of-Valley Targets) under the Review Plan (Cl. 32).
- Uses the term "assess" In the context of quality assurance of models (Cl. 38) which is the focus of this procedure.

The scope of the independent assessment including an appropriate point for input into model development and the timing for engagement interactions with the modellers, will be dependent upon the scale and complexity of the modelling:

- For complex models, there are potentially a large number of decision points where timely input from the independent peer assessor enables the project to benefit from independent advice. Early feedback in the model development phase (i.e., before significant resources are committed) is critical for cost effective and cost-efficient management [linked procedure 3]. For example:
    - o The assessor (or panel) will gain an early understanding of the conceptualisation of the hydrological system (data, interpretations and gaps) and the proposed approach to mathematically represent this conceptualisation
    - o Provide feedback to the modelers. Timely input is essential to ensure consensus on the conceptualisation prior to the investment in the development of the mathematical model.
- For less complex models, the scope of the project may mean that cost effective and cost-efficient management is less dependent upon peer assessment input at the conceptualisation stage. In such cases it may be sufficient for the assessment to consider the "final draft" documentation, with comments considered in the final report.

The scope of the peer assessment will be defined by the MDBA. It typically involves:

- Confirming that there is a clear purpose for the model – a critical starting point given that an outcome of the independent assessment is that the model (or its application) is 'fit-for-purpose'
- Confirming that the modelling scope clear and aligned to the modelling principles, or supported by a rationale for balancing competing principles (Section 3)
- Evaluating the robustness of the knowledge review
    - o Have recommendations from previous reviews (and peer assessments) been considered?
    - o Have learnings from similar studies been considered? For example, models developed for similar purposes in similar hydrological or hydrogeological environments
    - o Have key knowledge synthesis documents developed collaboratively by the Authority and Contracting Governments been considered (e.g., Middlemis *et al*. 2017; Currie *et al*. 2017, Walker *et al* 2019)?
- Model development
    - o Taking into account scope:
        - – does model development align with the key modelling steps [linked procedure 2.6]?
        - – is it generally consistent with applicable Best Practice guidance documents e.g., Black *et al* (2011) and Barnett *et al* (2012)?
        - – For modelling steps (Section 2.6) that are identified as not relevant or modelling procedures that do not apply, is there a clear and justified rationale for the modelers' decisions?
    - o Are model assumptions consistent with any relevant procedure, or a rationale for deviation from the procedure?
- Alignment of predictive model with the BSM Accountability Framework
    - o Are model inputs impacted by climatic conditions represented in a way that is consistent with the intent of the Benchmark Period?
    - o Do model inputs include any Delayed salinity impact or Accountable Actions that impact processes within the model domain?
    - o Are model outputs able to meet the requirements for Base case and model scenario years consistent with requirements of the Schedule [see linked procedures 10 and 12]?
- Model version controls and archiving

- Does the model documentation identify version control and where the model is to be archived?

The checklist provided as Appendix C captures the elements of the scope of the Peer Assessment listed above, along with a range of other elements for consideration. For any given Peer Assessment, this checklist may require revision and amendment to aligned with the scope of the model being assessed.

The Peer Assessment should provide recommendations to the Authority and State Contracting Governments as to whether the model is fit-for-purpose and assign an uncertainty rating consistent with the approach for communicating uncertainty in Appendix B.

If the scope of the peer assessment includes the estimation of a Register entry, then consideration will also be necessarily given to the requirements of linked "BSM Procedure – Conducting reviews and assessments".

6.5 Model accreditation

6.5.1.1 PURPOSE

This procedure provides guidance on the accreditation of a model.

6.5.1.2 BACKGROUND

A model approved by the Authority or its delegate [Cl. 38(5)] for a specific purpose, is deemed to be an accredited model.

6.5.1.3 APPLICATION

In deciding whether to accredit a model, the Authority will consider:

- Any recommendation from an Independent Peer Assessment as to whether the model is fit-for-purpose [linked procedure 6.4]
- Recommendations from the Basin Salinity Management Advisory Panel.

6.6 Management of data from input models used by the River Murray model

6.6.1.1 PURPOSE

This procedure provides guidance on the process for providing the Authority with the information necessary to undertake a salinity assessment with the Murray River model.

6.6.1.2 BACKGROUND

To enable the Authority to undertake salinity assessments using the River Murray model, Contracting Governments must provide the Authority with output from the relevant input models [Cl. 19, 20A & 33].

6.6.1.3 APPLICATION

The supply of data for input to the River Murray model should follow the requirements set out in Linked "BSM Procedure – Tracking and managing data supplied to estimate salinity impacts using the River Murray model".

To the extent relevant, the process provided by this linked procedure should also be applied to models generating input data sets to other models e.g., tributary models (Figure 2).

PART 2: PROCEDURES APPLICABLE TO ALL MODELS THAT SUPPORT SALINITY ACCOUNTABILITY

7 Identifying and communicating uncertainty

7.1 Purpose

This procedure provides guidance on assessing and communicating modelling uncertainty so that the limitations of the model are clear, and so that this understanding is available to inform decisions based on model outputs.

7.2 Background

Identifying and communicating uncertainty:

- Provides transparency about how the modelling assumptions can affect model outputs. Clearly documenting uncertainty will demonstrate that there is no single "correct" prediction, rather, there is uncertainty around all predictions
- Informs the users of model outputs about how the assumptions influence predictions. For example, if modelling results are communicated in a way that transparently presents the range of likely or possible salt loads/flow predictions, this understanding combined with the precautionary principle [see linked procedure 3.3] may provide a defendable rationale for the selection of the most appropriate modelling run to generate a Register entry.

Uncertainty applies to all modelling results because even the most complex models are simplified representations of hydrological processes. This means there are limitations in how well processes are understood, how well they are represented within the conceptual model, and how well they are simulated within the mathematical model.

Reporting on model outputs should always provide some indication of uncertainty i.e., communicating to the decision maker that there is an "envelope" of possible results.

This procedure is intended to be enabling with the rationale for the approach to assessing and reporting uncertainty guided by the "Effort commensurate with the Risk" principle [linked procedure 3]. Options are provided below:

- Qualitative approaches –identify and document the rationale for assumptions and evaluate the implications for model predictions
- Quantitative approaches – sensitivity test or undertake stochastic analysis that either simply captures the upper and lower bands of probable modelling outputs, or with more effort, computes a detailed probability distribution to this range.

7.3 Application

Uncertainty should be considered and reported in all modelling projects irrespective of the scale. Characteristics of each step of the model development should take into account gaps and limitations that will inform the final assessment of uncertainty [linked procedure 2.6].

In documenting and reporting uncertainty, the minimum standards of reporting provided by Middlemis and Peeters (2018) should be considered, such as:

- Clear definition of the specific model outcomes sought
- Justification of the methods and assumptions applied, drawing upon modelling principles such as "Effort commensurate with risk" [linked procedure 3]
- Open, transparent and logical documentation of methods and results in a manner that is open to scrutiny.

Reporting should include

- The implications of decisions and assumptions on predictions.
- If a quantitative analysis is undertaken, the implications for the range and/or probability of predictions
- Predictions based on best estimates of the available input parameters.

Appendix B provides concepts that may inform the communication of uncertainty.

8 Modelling physical works and measures

8.1 Purpose

This procedure provides guidance on representing works and measures, and the management of those works and measures, in calibrated and predictive models.

8.2 Background

Factors affecting salinity outcomes in the river include climate and its impact on the natural environment, physical works and measures, and the human management decisions made about those works and measures. The accountable elements of these are changes to physical works and measures and changes to human management. Hence for:

- Physical works and measures – A change in the flow/salt mobilisation drivers of physical works and measures should be identified as part of the conceptualisation step
- Management decisions – The management of physical works and measures may be either constant over time, or variable, and, depending upon the nature of the works and measures, management may determine the extent to which the works contribute to a change in land and water management outcomes. Variable management may be a function of:
    - Seasonal conditions
    - Maintenance implications for operations
    - Changes to operating rules (policy)
    - Noncompliance with operating rules

It is therefore important to capture both physical works and measures, and management processes/decisions (including changes) as part of the conceptualisation [linked procedure 2.6].

If a calibrated model is developed, it should be consistent with the conceptualised climatic drivers, the timing of the development of physical works and measures, and the associated management decisions, that contribute to changes to flows and salt mobilisation.

If a predictive model is developed, then, depending upon its objectives, it may be required to be capable of separating the salinity effect of changes to works and measures, changes to management decisions, changes to climatic effects, and the individual contributions of separate Accountable Actions.

8.3 Application

Calibrations should be informed by the climatic record, the timeline over which works, or measures were implemented, and include any subsequent changes to management or operations.

For predictive modelling of Delayed salinity impacts and Accountable Actions, modelling of each scenario year:

- Should include:
    - Delayed salinity impacts or Accountable Actions that are already on the Register
    - Management assumptions associated with Delayed salinity impacts or Accountable Action impacts, noting that for physical works and measures, management/operating assumptions should align with operating rules
    - Impacts of rainfall consistent with the Benchmark Period
    - In groundwater models, representation of river levels [linked procedure 15.7.3.1] and natural flooding consistent with the Benchmark Period
    - The management response arising from a change in policy or a change in operating rules
    - Any noncompliance with operating rules.
- Should not include:
    - Operational response to climatic trends beyond that experienced within the Benchmark Period
    - Incapacitated operations arising from a major hydrological disruption
    - Shutdowns necessary to maintain works.

This procedure does not apply to any changes to operating rules for Authorised works or measures in situations where the Committee has agreed to test or trial different operating rules but have not agreed to adopt a “permanent” new policy position.

9 Conversion of electrical conductivity measurements to salinity concentrations

9.1 Purpose

This procedure provides guidance on the conversion of electrical conductivity measurements to salinity concentrations for use in modelling studies or for the reporting of salt load outputs from modelling studies.

9.2 Background

The measurement of electrical conductivity (EC) provides a cost-efficient and cost-effective indicator of salinity concentration. In most common circumstances, EC measurements can generally be converted to estimates of total dissolved salts (mg/L) by applying a simple conversion factor commonly lying between 0.55 and 0.75 depending upon the temperature of the water and the dominant ionic composition. However, at very high salinities, such as occur in salt disposal basins (see Williams 1986, SKM 2009, SKM 2011, Aquaterra 2011a), such conversions are not accurate and so hydrometer measurements and laboratory analyses may be required.

Section 9.17 of the Basin Plan (MDBA 2012) recommends conversion factors applicable to lower concentration situations throughout the Basin that may be appropriate to BSM modelling.

Some preliminary regional investigations have been undertaken, such as those in the Mallee (RMCG 2018), but they have not led to regionally specific recommendations for conversion factors.

9.3 Application

Recorded EC measurements used within modelling studies should be derived from equipment calibrated to a national standard and compensated to 25^{0}C.

The conversion factors presented in Table 1 are appropriate to informing BSM model development where the scope of the model does not include salt concentration within salt management basins. Where alternative conversion factors are considered appropriate, the technical rationale should be documented and the underlying science should be referenced.

Table 1: Conversion factors suitable for application to BSM surface and groundwater modelling

Basin Region	Conversion Factor (EC to mg/L)
Southern Basin (including Lachlan River)	0.6
Northern Basin	0.7
Paroo and Warrego Rivers	0.8

(Source: MDBA 2012)

10 Sequencing actions within input models

10.1 Purpose

This procedure provides guidance on the sequencing of multiple Register entries in input models that are integrated with tributary models or the Murray River model.

10.2 Background

This procedure applies to all input models used within the salinity accountability framework to generate flow and salinity time series data for the assessment of more than one Register entry.

The modelling platforms and processes used in developing time series input data for the Murray River model are highly variable across the suite of Delayed salinity impacts and Accountable Actions. The procedures set out below recognise this variability and so provide for flexible approaches to sequencing within input models.

The modelling principles and objectives for the Registers set out in the sequencing procedure for the Murray River model [linked Procedure 4.3] are also applicable to this procedure.

10.3 Application

When using input models in the assessment of salinity effects of more than one Accountable Action, decisions on sequencing should consider:

- The timing of each action being formally considered by the Authority
- The timeframe in which each action took (or is taking) place within the landscape
- The conceptual understanding of the processes and actions
- Any interaction between the Accountable Actions
- The potential for double accounting the salinity effects from an Accountable Action

- Whether the sequencing of actions could erode the benefits of previous or subsequent actions being modelled

The rationale for sequencing within input models should be documented including how modelling principles and objectives for the Registers set out in the sequencing procedure for the Murray River model [Linked Procedure 4.3] have been considered.

11 Description of data required from input models

11.1 Purpose

This procedure provides guidance on requirements for the supply of data from models that will be used as inputs to the Murray River model.

11.2 Background

The integration of models provides the basis for evaluating the salinity impacts for the Murray River from land and water management changes across the Basin (Figure 2). [See also linked procedure BSM Procedure – Conducting Reviews and Assessments]

Integration is practically achieved through monitoring and input model data given by the State Contracting Governments to develop and maintain the Murray River model [Cl. 36(3)] and for salinity assessments [Cl. 19(2), 20A(4) & 33].

To this end, data and documentation provided to the MDBA to undertake the assessment should meet minimum requirements.

11.3 Application

Requirements for Murray River model input files are as follows:

- Where input files are generated from groundwater models, salt load data (t/day) is required
- Where input files are generated from other integrated models (Figure 2), flow (ML/day) and salinity data is required
- For the assessment of actions that have continuous or regular material impact on the river, all input files must be provided as a daily time series data set for the period 1 May 1975 to 30 April 2000, or with advice on how data with longer time steps should be converted to daily time series data.
- State Contracting Government estimates of flow, salinity or salt loads required under the schedule [Cl. 19, 20A & 33] to enable Register maintenance [Cl. 1] and operations [Cl. 17], should be consistent with:
    - the estimate for each scenario year [linked procedure 12].
    - other expectations of these procedures such as the precautionary principle [linked procedure 3].

The rationale for selected input data and any processing of common datasets to achieve effective model integrated [see linked procedure 4.1] should be documented including:

- differences (if any) in the physical alignment of modelling domains (input model outputs relative to the Murray River model inputs)
- adjustments (if any) of input model outputs, to meet the requirements of the Murray model

Data management governance arrangements and the process for the submission of data to the MDBA for a salinity assessment should be consistent with the requirements of linked procedure 6.

12 Scenario year data requirements

12.1 Purpose

This procedure provides guidance on the requirements for the provision of scenario year data sets.

12.2 Background

Schedule B requires the Murray River model and tributary (input) models be capable of estimating or supporting the estimation of salinity impacts for each of the scenario years [Cl. 36(2) & 37(2)]. The supply of data from other input models [Cl 19, 20A & 33] should also be capable of supporting these estimates.

Accountable Actions that are strongly influenced by surface water processes (such as those for which the processes are simulated by irrigation distribution system models or irrigation drainage models) commonly have a direct conduit for flow and salt load to be transported to the river. For these short time lag situations, consistency in salt load mobilisation and flow data representations of current levels of development may be applicable to each scenario year (Figure 6 – blue stars).

Accountable Actions that drive groundwater processes, may drive relatively constant fluxes to the river over the long term, but due to the time lag before impacts materialise at the river, different salt load contributions may be applicable for each scenario year. Examples are changes to land use a long way from the river, or where the action increases rootzone drainage in areas with deep water tables (Figure 6 – black stars).

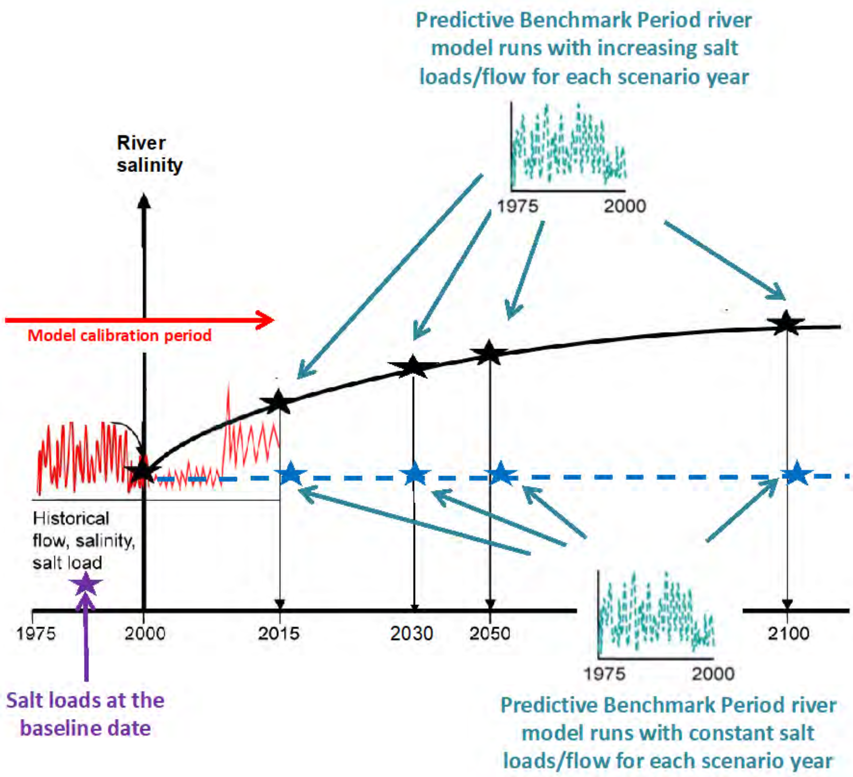

Figure 6: Conceptualisation of surface water model calibration with constant or increasing salt loads in scenario years (modified from MDBC 2005)

Actions that affect groundwater processes that are relatively close to the river may have intermediate time lags, and, depending upon management factors, they may lead to variable salt loads to the river.

Environmental watering, responsive management of SIS, and near-river irrigation are examples of actions that can lead to variable salt loads. Conceptualisation and/or modelling should be used to support a rationale for assuming either consistency or variability in salt loads at current levels of development for each of the scenario years.

12.3 Application

Lead Agencies responsible for providing information necessary for salinity assessments by the Authority, must provide data appropriate to each of the Scenario years.

For Accountable Actions that are relatively continuous over time, and for which the time frame from commencement to a material outcome at the river is short, a single input data file, applicable to each Murray River scenario year modelling run, may be appropriate. A documented supporting rationale should accompany the data, aligning with the conceptualisation of pathways to the river and the absence of a time lag.

For Delayed salinity impacts or Accountable Actions that are relatively continuous over time, but where there are time lags between the start of an Accountable Action and its impact materialising over the 100-year modelling timeframe, separate Murray River model input files should be provided for each scenario year. If Lead Agencies request to vary this approach (such as when doing uncertainty modelling and using salt loads other than the best estimate, or when holding salt loads from a given scenario year constant across other scenario years), a documented supporting rationale should be provided.

For other near-river Accountable Actions that affect groundwater processes, a documented supporting rationale should accompany the provision of either a single input data file or different data files for different scenario years. The rationale may include:

- Technical information such as the conceptualisation of pathways (and time lags) to the river and the rationale for estimating the salt loads for each scenario year such as where varying river levels are adopted [see linked procedure 15.7.3.2]
- Relevant principles informing the decision such as the Precautionary Principle [see linked procedure 3].

13 Documenting models

13.1 Purpose

This procedure sets out the expected minimum requirements for model documentation.

13.2 Background

In order to meet quality assurance and accountability requirements, documentation of each step of the modelling chain (linked procedure 2.6) is critical.

13.3 Application

Model documentation should be prepared guided by leading practice documents. For example:

- Groundwater models (Barnett *et al* 2012)
- Surface water models (Black *et al* 2012)

The required documentation will be dependent upon its purpose and the approach. Typically, it would be expected to cover the following:

- Model purpose
- BSM context
- Knowledge review
- Conceptualisation
- Model description, approach, and assumptions
- Salt and water balance, and uncertainty
- Quality assurance processes including response to independent peer assessment
- Application and related decisions
- Archiving
- Recommendations for future work

PART 3: PROCEDURES APPLICABLE TO SPECIFIC FUNCTIONAL MODELS

14 An overview of the priority landscapes in need of specific functional models

Actions within all landscapes in the Basin contribute to salinity in the shared water resources either through river regulation or by changing the inflow of salt or water. The salinity risks within these landscapes are primarily a function of natural salt inflows, the impacts of salt mobilised before the baseline date, and the impact of salt mobilised by Accountable Actions and Delayed salinity impacts. Reductions in flow regimes also have a significant effect (through reduced dilution), so they also require consideration.

As described within the General Review of Salinity Management (MDBA 2014), the Basin landscapes contributing most to the current salinity risk are the Mallee regions of New South Wales, South Australia, and Victoria (including the floodplain), as well as parts of the Riverine Plains of New South Wales and Victoria. There is significant variability in the threats posed by these landscapes, however their potential as sources of mobilised salt (and for some areas, changed flow regimes) mean that they are the priorities for careful ongoing management. Consequently, most of these procedures provide guidance towards consistency in the development of models in each of these landscapes [Cl. 41c].

These Part 3 procedures apply only to the following functional model types:

- Mallee groundwater models
- Floodplain models
- Irrigation delivery system models
- Irrigation drain flow and salt load models
- Upland catchment groundwater models

15 Mallee groundwater models

15.1 Overview

In the Mallee regions of South Australia, New South Wales and Victoria, highly saline regional aquifers have a very large impact on salt loads to the river. Consequently, there are many Accountable Actions within this region that require salinity assessment.

Numerical groundwater flow models (see section 2.3) are commonly used to undertake these assessments, and there are common technical and policy issues to be considered in their application.

The following procedures focus primarily on issues common to these models.

15.2 Representing Mallee dryland recharge

15.2.1 Purpose

This procedure provides guidance on the approach to representing dryland recharge in model calibration and in predictive modelling.

15.2.2 Background

The clearing of Mallee vegetation has led to increased rootzone drainage, which subsequently has increased groundwater recharge (Middlemis *et al* 2017). Increased recharge displaces highly saline groundwater to the river although these Delayed salinity impacts are not yet fully manifest. Groundwater models need to take into account the processes (including time lags) within the unsaturated zone following land clearing, recognising that:

- There are gaps in the data available to assess whether recharge is manifest, therefore calibration through history matching is often not possible
- Both the calibrated and predictive models require estimates of recharge, and therefore it is important to integrate recharge models (Figure 2) to estimate time lags.

15.2.3 Application

Recharge models should be used to support estimates of recharge that provide the inputs to numerical groundwater models as illustrated within Figure 2.

These models should be based upon the hydrological processes provided by Cook *et al* (2001; 2004).

Applied tools should be informed by the best available knowledge on the presence and thickness of clay layers so as to impose justified time lags between the time of clearing, and the time of recharge reaching the water table.

SIMRAT (Fuller *et al* 2005; Woods *et al* 2016) may be suitable for this purpose in dryland areas (Middlemis *et al* 2017).

15.3 Understanding irrigation intensity and irrigation efficiency

15.3.1 Purpose

This procedure provides guidance on compiling evidence of long-term changes in the irrigation intensity (including the expansion of irrigation in some parts of the Mallee and the retirement of irrigation in other parts) and changes to irrigation efficiencies. This understanding is used to inform the estimate of the distribution and magnitude of rootzone drainage, which then informs decisions on the distribution and magnitude of groundwater recharge [see linked procedure 15.4].

15.3.2 Background

In the older irrigation areas of the Mallee, historically poor irrigation practices led to large volumes of applied water seeping into underlying aquifers. Increased groundwater pressure displaces saline groundwater to the river. However, the modernisation of irrigation district delivery infrastructure, the adoption of pressurised on-farm irrigation systems and improvements to irrigation scheduling, have each reduced the extent to which root zone drainage beneath historically irrigated areas is contributing to recharge.

Whilst there has been some retirement of historically irrigated areas, the total area of irrigation has increased in the Mallee since the Baseline date. This has been enabled by water trade over the last 20-30 years. This expansion has increased the hydrological loading within the Mallee although as for the historically irrigated areas, substantially improved efficiencies have reduced the extent to which a unit area of irrigation, is contributing to recharge.

Notwithstanding these improvements in efficiencies, there remains a need for some rootzone drainage. This leaching is necessary to avoid salt accumulation in the crop rootzone.

15.3.3 Application to the development of the calibrated model

The understanding of irrigation footprint and associated irrigation efficiency should be informed by the best available knowledge on the history of irrigation. It requires a spatial and temporal representation of changes to the irrigated landscape over time and any available evidence of changes to efficiencies.

The following approach should be considered:

- Establish a chronology of irrigation system improvement policy and actions that have driven changes to irrigation intensity (including retirement) and on-farm irrigation efficiency improvements over time
- Develop best estimates of how this qualitative chronology of policies and actions translates into spatial and temporal changes to rootzone drainage.

This work may be informed by available data on cropped area and district- or farm-scale measurements of water use[6]. It may also be necessary to seek anecdotal evidence or community knowledge.

15.3.4 Application to salinity assessments

Representation of current irrigation intensity and efficiency requires the consideration of actual water use, and of the risks posed from irrigation development commitments, in the context of current allocation rules and benchmark period rainfall patterns.

The underlying assumptions should take account of differences between perennial crops and annual crops and pastures:

- Perennial crops – High establishment costs, and multi-year time lags between planting and full production, mean that irrigators are reluctant to dry-off perennial crops. In any year, the available water is likely to be prioritised to the most profitable of these crops. Hence the current area can be considered to be “permanent” in the context of salinity assessments for the scenario years.
- Annual crops and pastures – In times of water shortages and high-water prices, irrigators may choose not to plant annual crops and pastures. Also, some travelling irrigation systems are relocated between seasons, enabling rotational cropping. The spatial annual irrigated footprint is therefore variable. This variability needs to be considered in modelling assumptions on the representation of current levels of development in scenario years.

The following factors should be considered as an input into decisions on recharge in predictive models [linked procedure 15.4.3.5]:

- Current levels of irrigation intensity – supported by a rationale that takes into account:
    - The historic record (i.e., estimates of irrigation intensity and irrigation efficiency for years up to the current year) moderated to reflect water availability under

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[6] In many areas, significant historical and current aerial and satellite imagery data is available to support an understanding of changes in irrigation area over time. In some areas, such as the Sunraysia, aerial imagery is combined with land based data to build property scale understanding (see Argus 2018)

contemporary allocation rules and Benchmark Period rainfall patterns [linked procedure 8]
    - The area of land authorised for irrigation that has been developed – taking account of the areas retired from irrigation
    - Any practical constraints on delivering the volume of water necessary to irrigate the authorised area at the authorised level of intensity
- Current levels of Irrigation efficiency – supported by a rationale that takes into account:
    - Irrigation systems typically applied to "permanent plantings" and "annual plantings" in the area
    - The range of theoretical efficiencies across different irrigation system types (for example: Mushtaq and Maraseni 2011)
    - Any local water balance and rootzone drainage studies that provide indications of efficiency achievements

15.4 Representing irrigation recharge

15.4.1 Purpose

This procedure provides guidance on representing irrigation recharge beneath the irrigated area (see linked procedure 15.3) as part of model calibration and in predicting future salinity effects.

15.4.2 Background

In the Mallee region, irrigation recharge is a significant driver of increased river salinity, and substantial efforts have been made to reduce that impact through improved irrigation efficiencies and salt interception schemes. Confidence in the estimates of the recharge volume and of the time lag between irrigation commencing and the impact materialising at the water table, are therefore critical accountability issues requiring attention in groundwater models (Newman *et al* 2009).

Setting recharge parameters within a model commonly involves a forward modelling approach and/or an inverse modeling approach (Currie *et a*l 2017):

- A forward modelling approach uses the best available data to estimate likely recharge rates for inclusion in the model, with hydrogeological parameters varied during model calibration.
- An inverse modelling approach varies recharge during calibration, with minimal changes to hydrogeological parameters.

Irrespective of the modelling approach, assumptions about the adopted values should be supported by credible independent methods that take account of:

- An understanding of changes to irrigation intensity and irrigation efficiencies over time [linked procedure 15.3]
- Time lags consistent with depth to water table and overlying stratigraphy.

15.4.3 Application

15.4.3.1 OPTIONS FOR ESTIMATES INDEPENDENT OF NUMERICAL MODELS

There are a range of methods available to support estimates of recharge for model inputs, or as a basis for validating the estimates derived from model calibration. These include:

- District-scale water balances
- Recharge modelling tools.

Other options may also be available.

District-scale water balances take account of the distribution of irrigation, the intensity of irrigation, and an understanding of the temporal changes in the efficiencies of irrigation delivery infrastructure and on-farm irrigation methods over time. Account is also taken of the location of (and measurements from) drainage systems that capture and divert rootzone drainage.

Recharge models (Figure 2) may be used to translate this spatial understanding of the source of recharge into an understanding of the quantum and timing of recharge. Examples include:

- SIMRAT, which can be used where there are time lags within the unsaturated zone – but it is not recommended for use where there is evidence of perched groundwater, which commonly occur under irrigated areas in the Mallee
- The Mallee Transfer Function model, which is currently under development (Walker *et al* 2019) and is intended for use where there is potential for perched groundwater.

In the event of a new recharge modelling approach being accredited [linked procedure 6.5], this procedure should be reviewed and updated.

15.4.3.2 USING INDEPENDENT ESTIMATES WITHIN A MODEL

The forward modelling approach uses recharge values from one or more of the independent methods [Linked procedure 15.4.3.1] as the basis for parameterising recharge inputs. It is most appropriate in situations where a close relationship between RZD and recharge can be demonstrated.

The forward modelling approach may be appropriate in situations where there is an adequate understanding of changes in irrigation intensity and efficiency over time and of the time lags in the sub-surface system.

15.4.3.3 DERIVING ESTIMATES FROM MODEL CALIBRATION

The inverse modelling approach derives recharge estimates through the calibration process, adjusting recharge until modelled groundwater levels match the historical record. Currie *et al* (2017) provides the following assessment of advantages and disadvantages of this approach:

- Advantage: it is not subject to the uncertainty arising from lack of data on parameter values in the unsaturated zone
- Disadvantages:
    - It integrates all potential errors into the derived recharge rate
    - It generates uncertainties because of gaps in observed water level data and from non-unique aquifer parameters, and recharge choices, between the various recharge zones
    - It is not readily applicable where there is no observed response in the water table i.e., long-time lag or no bore records at the appropriate time.

An inverse modelling approach may be appropriate where there is a clear groundwater response to irrigation recharge events.

Outputs from the inverse modelling approach should be validated against alternative methodologies (Section 15.4.3.1).

15.4.3.4 USING AN INTEGRATED/HYBRID APPROACH

Subject to the available data, recharge assessments based upon multiple methods (and potentially based upon the integrated use of these methods) should be considered. The application of multiple methods is consistent with the multiple lines of evidence principle [linked procedure 3], and it provides a means of addressing uncertainty [linked procedure 7].

Applied methods should make use of the best available spatial and temporal knowledge of irrigation intensity and irrigation efficiency [see linked procedure 15.3.4] and drainage schemes.

If recharge modelling tools are to be applied, the conceptualised understanding of the processes [linked procedure 2.6] including hydrological properties of critical stratigraphic units, and depth to water table should be used to guide tool selection.

15.4.3.5 USING RECHARGE ESTIMATES FOR PREDICTIVE MODELLING

For predictive modelling:

- The distribution of future recharge should be consistent with the understanding of the current irrigation footprint [linked procedure 15.3.4] with a rationale provided for any adjustments such as:
  - spatially variable annual cropping footprints (i.e., annual mobility centre pivots)
  - adjustments if there is evidence that the footprint has diminished due to climatic impacts on Murray River allocations that are not consistent with Benchmark Period conditions
- Estimates of the time taken for RZD from recent or new crops to reach the water table (i.e. the time lag) should be based upon either:
  - estimates established for, and applied within the calibrated model or
  - application of the Mallee Transfer Function model (e.g., Walker *et al* 2019) if and when it is accredited for this purpose.
- Constant recharge rates should be applied to each recharge zone from the point in time when recharge is estimated to reach the water table to 2100[7]
- The applied recharge rate should be based upon the five-year average annual recharge rates from calibrated model (therefore being consistent with rootzone drainage at contemporary levels of irrigation efficiency).

15.5 Representing groundwater evapotranspiration

15.5.1 Purpose

This procedure provides guidance on representing groundwater evapotranspiration in numerical groundwater models.

15.5.2 Background

Where the groundwater modelling domain is inclusive of areas with significant shallow water tables (such as are likely to occur on floodplains in the Mallee), groundwater ET is likely to be a significant component of the groundwater balance. This has important implications for the balance between salt accumulation on the floodplain and groundwater flux/salt loads to the river. Those implications must

[7] Beyond 2100 may be appropriate in some cases (e.g., 2113 as proposed in Table 3)

be considered under Baseline conditions, as a result of Delayed salinity impacts, and in response to Accountable Actions.

15.5.3 Application

Groundwater ET should be included within the conceptualisation of all groundwater models where there is a shallow water table (e.g. <10m depth) and there is potential for groundwater ET to make a significant contribution to the water balance. In the Mallee region, this will be most applicable within the floodplain where the watertable is shallower than across the broader landscape.

In the development of numerical groundwater models, the model domain should include the groundwater ET function except for areas where there are surface water bodies and at times when transient models are simulating inundation of normally terrestrial environments.

To the extent possible, estimates of groundwater ET should be validated against field-based measurements of floodplain transpiration. As the temporal and spatial availability of such data is likely to be limited, the comparison of point source measurements to estimates from models, will need to take into account variability in the health and density of vegetation which significantly impact upon ET rates.

15.6 Estimating groundwater salt loads to rivers

15.6.1 Purpose

This procedure provides guidance on estimating salt loads from groundwater systems to rivers.

15.6.2 Background

Groundwater salt loads to the river are a function of both volume (i.e., flux to the river) and salinity.

Software is available to combine solute transport with groundwater flux modelling. However, there are significant gaps in the data required to underpin the application of such models to the Mallee. Furthermore, the resourcing required to for their development makes it unlikely that their application is consistent with "cost-effective and cost-efficient modelling" or "effort commensurate with risk" principles [see linked procedure 3]. Therefore, this procedure does not provide guidance on solute transport modelling.

Under these procedures, an appropriate means of estimating groundwater salt loads to the river is by combining groundwater model estimates of flux to the river, with "appropriate" spatial representative groundwater salinity values for each reach.

A robust decision on which of the available data is "appropriate" is dependent upon a strong understanding of the groundwater-surface water processes which are in many reaches, both complex and dynamic. Factors that contribute to variability include the hydrogeological pathways from the primary source aquifer to the river, the geomorphology of the floodplain, flooding events, irrigation recharge, groundwater extraction from SIS, and groundwater ET. These factors spatially and temporally influence groundwater salinity through freshening, salt attenuation in the unsaturated zone, and salt release to the river.

The conceptualisation of source, processes and timeframe by which salt loads are reaching the river is therefore critical to the appropriate assignment of salinity values to groundwater fluxes.

This procedure is also informed by the modelling principles [linked procedure 3] with guidance on their application as follows:

- Cost efficient and cost-effective modelling –a pragmatic zonal scale assignment of assumed groundwater-river flux salinities that align with model water budget reporting.
- Precautionary principle – representative salinities should be consistent with the understanding of salt expected to reach the river over the 100-year BSM2030 accountability horizon, rather than from measurements affected by dynamic processes that have short to medium term impacts on groundwater salinity.
- Consistency – the salinity effect of Delayed salinity impacts and Accountable Actions is highly sensitive to the assumed groundwater salinity, and hence a common approach to zoning is recommended through the application of the procedure set out below.

15.6.3 Application

The approach to assigning salinities should be as follows:

- Review the available direct measurements (e.g., groundwater salinity data, run-of-river monitoring) and other relevant data (e.g. AEM salt storage mapping, NanoTEM measurements, unaccounted salt load estimates assigned within the calibrated Murray River model).
- Review any previous documentation applicable to the model domain that has assigned spatially variable groundwater salinities (i.e., an upper and lower salinity “envelope”) to inform estimates of salt loads to rivers. Previous assignments may be deemed to be “point of truth” representations (avoiding the need for re-analysis) if:
  - the assessment method
    - is consistent with this procedure
    - has been reviewed as part of an Independent Peer Assessment [linked procedure 6.4.3.2]
  - a clear rationale can be made that there is no new knowledge that would warrant revising previously defined zonal boundaries and the associated salinity envelope.
- If new or improved zoning is considered necessary, apply the following steps:
  - Conceptualise the groundwater-surface water interaction processes across the model domain, documenting the current understanding of how salt is reaching the river.
  - Where there are clear differences in conceptualised processes along the river, transition areas should be used as a basis for delineating “first pass” salinity zone boundaries. The need for further zonal divisions will be dependent upon variability assessed from, “appropriate” data sets.
  - Data identified as appropriate to setting upper and lower bands of the zonal envelope, should be data:
    - that is representative of hydrogeological units that play a significant role in the pathway of salt to the river
    - that is representative of groundwater that is the primary source of salt over the 100-year accountability horizon (i.e., where the salt entering the river is coming from).
  - Salinity values selected to compute salt loads should lie within the established salinity envelope for each of the defined salinity zone and be constant over time.
- If during validation of salt load estimates to the river, refinements to the adopted salinity estimates is considered necessary, refined values should be constrained by the assigned zone envelope boundary values.

15.7 Representing rivers

15.7.1 Purpose

This procedure provides guidance on representing rivers in calibrated and predictive Mallee numerical groundwater models.

15.7.2 Background

15.7.2.1 WHY RIVER LEVELS ARE IMPORTANT IN GROUNDWATER MODELS

In the Mallee region, the incised river channel interacts with the groundwater system with regional groundwater flow paths primarily towards the river trench. At a local scale however, a combination of landscape variability and land use, river regulation and the dynamics of climate-driven flooding events means that there is variability in the interactions between groundwater and surface water. These range from river reaches where water is almost always gaining from groundwater, reaches which are almost always losing water to the groundwater system, as well as reaches that fluctuate between gaining and losing.

Representation of rivers is therefore an important boundary condition within Mallee groundwater models with the associated assumptions potentially having significant implications for estimates of the magnitude and direction of fluxes.

Whilst river level monitoring data sets are relatively comprehensive (commonly daily), it is not practical for many groundwater models to have stress periods of a comparative frequency. Decisions are therefore required on an appropriate approach to represent river levels in a model that has longer/less dynamic stress periods. In deciding upon an appropriate approach, the following issues warrant consideration:

- Benefits of dynamic river representation to model calibration
- Relative contribution of an Action to the groundwater balance
- Mathematical validity in the application of models to the accountability framework

These issues are discussed in more detail below.

15.7.2.2 BENEFITS TO MODEL CALIBRATION

River level variability in reaches with high groundwater connectivity have a significant influence on the groundwater response. Hence in the development of the calibrated model, the setting of variable river levels over relatively short stress periods may be important to constraining estimates of near river aquifer parameters. This is of particular value where there is little other data to constrain groundwater fluxes in calibration (e.g., SIS pumping, salt load observations). Where river level variability is low (such as in a weir pool), then there may be limited benefit in considering dynamic river simulation.

15.7.2.3 RELATIVE CONTRIBUTION OF ACTION TO THE GROUNDWATER BALANCE

The extent to which the river should be dynamically represented within BSM modelling is a function of whether the river substantially changes its contribution to the groundwater balance between comparative modelling runs. For example, if the pre-intervention condition modelling run differs substantially from the modelling run that includes the Action, it may be appropriate to represent the river dynamically.

Representation of a dynamic river may therefore be considered essential for assessing the salinity effect of near river actions such as environmental watering but may not make a material difference to the assessment of a long-term change to a distant action such as the salinity effect of dryland clearing.

15.7.2.4 MATHEMATICAL VALIDITY IN THE APPLICATION OF MODELS TO THE ACCOUNTABILITY FRAMEWORK

Groundwater models are primarily used within the Accountability Framework to estimate the change in groundwater fluxes arising from an Action. Mathematics underpins both the models themselves and the calculation of "change" apparent from adding the action to the pre-intervention condition in the predictive model.

As the direction and magnitude of fluxes between groundwater and the river are a function of both the action's impact on groundwater level, and the assumed river level, there is potential for mathematical nuances to affect flux estimates. Therefore, they require consideration in these procedures.

The approaches to representing the river in a groundwater model that have mathematical validity implications are:

- holding the river level constant over the whole of the modelled period or
- incorporating temporal variability.

Table 2 presents alternatives to these settings in the application to the model calibration phase (Figure 3 – step 4), and the predictive phase (Figure 3– step 5).

Table 2: Alternative approaches to setting river levels in groundwater models

Approach	Calibrated model	Predictive model
1	Variable	Variable
2	Constant	Constant
3	Variable	Constant

Comparing salt loads with an Accountable Action with salt loads without the Action (Woods 2019) for each of the three approaches shows that the comparison is only mathematically valid if the net effect on groundwater fluxes arising from both the assumed river levels and the Action, is equal to the sum of the effect of assumed river level and the Action individually.

All three of the above approaches are mathematically valid if:

- The river is almost always gaining, because the assessment uses the difference in the magnitude of the salt load arising from the Accountable Action
- The river is almost always losing although such a situation would not require a salinity assessment because it means there is neither a Delayed salinity impact nor an Accountable Action to assess.

Approach 3 is not mathematically valid if the river is switching between losing and gaining, because not only is the magnitude of the salt load affected, but the amount of time it is gaining depends on both the river level and the Action. This situation (switching between gaining and losing) is common for many of the reaches in the Mallee. Hence, the salt load arising from the defined river levels will be different in the modelling run with the Action compared with the modelling run without the Action. That is, salt load is a non-linear function of the river level, if it is switching between losing and gaining.

15.7.3 Application

15.7.3.1 RIVER REPRESENTATION

Decisions about which Approach to take in representing river levels in groundwater models should be guided by the following:

- All available information on the river should be considered
- Consideration of modelling principles [linked procedure 3] particularly:
    - Accountability and Transparency – For example, a clear rationale for assumptions that have implications for calibration and mathematical validity of the model, noting that the model will need to be independently assessed as fit-for-purpose [linked procedure 6.5].
    - Effort commensurate with risk – For example, the risks associated with the action should be sufficiently high to justify the allocation of resources to a detailed representation of the river.
    - Cost-efficient and cost-effective modelling – For example, confidence in the model (i.e., its predictive capacity for its intended use) should be improved if additional effort is required to provide a more detailed representation of the river.
- A consistent approach to the setting river levels between the calibrated and predictive models is preferred to ensure the mathematical validity of the salinity assessment
- If different approaches to the setting of river levels are adopted between calibrated and predictive models, the change in the influence of the river must be similar with the Action as it is without the Action. Evidence of this requirement should be provided by demonstrating that:
    - Only a small proportion of the river switches between losing and gaining and/or
    - The change in salt loads due to the change in approach to the setting of river levels is very similar for all scenarios.

15.7.3.2 DERIVING SALT LOAD ESTIMATES FOR SCENARIO YEARS

The rationale for the selection of groundwater-river fluxes from the predictive model upon which to estimate salt loads to the river for each scenario year, should be documented.

Table 3 provides a suggested approach to guide estimates associated with long time lags

Table 3: Estimating average daily salt loads for actions with relatively continuous and long-term effects

Predictive model	If constant river level applied	If variable river level applied
Pre-intervention conditions	Constant salt load representative of conditions at: ▪ Prior to the commencement of the Action (for Delayed salinity impacts) ▪ Baseline date for Accountable Actions	Average salt load over Benchmark Period
2000	Average salt load in 2000	Average salt load over Benchmark Period
2015	Average salt load in 2015	Average salt load from 2003 – 2028
2030	Average salt load in 2030	Average salt load in 2018-2043
2050	Average salt load in 2050	Average salt load in 2038-2063

2100	Average salt load in 2100	Average salt load in 2088-2113

Table 4 provides a guide for actions with short time lags.

Table 4: Estimating average daily salt loads for actions with irregular and relatively short-term effects

Predictive model	If constant river level applied	If variable river level applied[8]
Pre-intervention conditions	Not applicable	Time series salt load without action over period of salt load response in scenario year
All scenario years	Not applicable	Time series salt loads (at stress period intervals) over period of salt load response

16 Floodplain models

16.1 Overview

In the lower Murray, floodplain processes are important to the conceptualisation and quantification of salt mobilisation from groundwater to the river. The processes associated with floodplain water movement and salt mobilisation are complex with flow paths being dependent on the topography, geomorphology, groundwater flow into the floodplain, evapotranspiration and minor watercourses on the floodplain and river height.

Groundwater gradients driven by recharge in the higher elevation regional landscapes to the incised river means that the water table is close to the surface beneath the lower elevation of the floodplain. Under pre-development conditions, when river levels were low, groundwater discharged to the river. During times of high river flow the direction of discharge was reversed, such that river water recharged the floodplain aquifer. With regional land use change, river regulation and locking, the dynamic equilibrium status of the pre-development era has been altered with the processes now more complex.

River regulation, irrigation adjacent to the floodplain, and the clearing of native vegetation from higher elevations collectively contribute to higher groundwater levels beneath the floodplain. This both increases the volume of saline groundwater discharging to rivers and allows evaporation and salt accumulation close to the surface of the floodplain. Salt accumulation affects the health of the floodplain, and it also provides the potential for salt to be flushed into the river during floods and thereby increasing in-stream salinity.

While these salt accumulation and discharge processes occurred naturally, the regulation of rivers by dams, locks and weirs and the diversion of water for consumptive uses have limited regular natural flushing of salt from the landscape and exacerbated salt accumulation in some locations.

The two Basin environmental watering initiatives under TLM and the Basin Plan, have the potential to further modify these natural processes both by:

- Moderating the salinity impact (through the dilution effects of water delivery)
- Increasing the salinity impact through:
  - Salt wash-off
  - Floodplain recharge displacing increased groundwater to the river.

In those parts of the floodplain where environmental watering initiatives have the potential to contribute either on its own or cumulatively with similar actions or projected similar future actions to

[8] See linked procedure 16.3

have a Significant Effect [Cl. 18(1)], a salinity assessment is required. This suite of procedures provides guidance on the modelling associated with both the delivery and use of environmental water.

These procedures cover:

- Distributing the volume and frequency of delivery and use of TLM and Basin Plan water over the Benchmark Period
- Estimating salt mobilisation arising from floodplain inundation for an environmental watering site [linked procedure 16.3]
- Interpreting floodplain model salt load estimates for application to environmental water use assessments within the Murray River model [linked procedure 16.4].

16.2 Distributing the volume and frequency of delivery of TLM and Basin Plan water over the Benchmark Period

16.2.1 Purpose

This procedure provides guidance on assumptions about the volume and frequency of environmental water deliver and use over the Benchmark Period.

16.2.2 Background

The water available and used for environmental watering varies from year to year; it is a function of climatic conditions, held water entitlements, allocation rules, watering rules and constraints, and the priorities of environmental assets to be watered under TLM and the Basin Plan. These dependencies are as follows:

- Climatic conditions – impacts upon both unregulated flows and water in storage
- Held water entitlements – depend upon the volumes of water recovered through the relevant program
- Allocation rules – vary between river systems, entitlement types and jurisdictional policies
- Carryover – depends upon watering decisions in previous years
- Watering rules and constraints – depend upon point-in-time, works in place, and river operating rules
- Environmental priorities – coordinated through a planning process that involves the MDBA, the Commonwealth Environmental Water Holder and the States.

Priorities for applying the available environmental water are largely based upon *priority assets listed in long-term watering plans, watering strategies outlined in the Basin wide environmental watering strategy, watering proposals from States, hydrological conditions, third party risks and river operational priorities* (SCBEWC 2018). This prioritisation process provides the basis for documenting operational scenarios that *align environmental watering needs with the MDBA River Operations Annual Operating Plan flow forecasts*. This forms the basis for identifying opportunities to maximise environmental water outcomes through the coordinated delivery of all water in the system (SCBEWC 2018).

While the prioritisation process may collectively consider water from both the TLM and Basin Plan programs, separate salinity accountability requirements apply [linked procedure BSM Procedure – Environmental water accountability]. Consequently, this procedure provides for separate watering programs for calculating separate Register entries over the Benchmark period.

16.2.3 Application

Salinity assessments of the delivery and use of environmental water should be guided by the following:

- Be consistent with the sequencing procedure [linked procedure 4.3]. For salinity assessments of environmental watering, this means that the pre-intervention conditions should include all land and water management (including river operating rules) in place at the time that the environmental watering initiatives were authorised by the relevant government(s). The relevant dates are:
    - For TLM water delivery and water use Register entries – development and operations in 2003
    - For Basin Plan water delivery and water use Register entries – development and operations in 2009
- Estimate the volume and frequency of environmental water delivery and use over the Benchmark Period based upon:
    - "Point-in-time" assumptions on entitlements available, allocation rules, water delivery constraints and rules
    - Prioritisation of watering regimes provided by long-term watering plans.
- Provide the technical and or policy rationale for unpacking the salinity impacts of environmental watering actions where the salinity effects of delivering/using pooled entitlements is required to be reported across multiple programs or responsibilities.

16.3 Estimating the salt loads mobilised by floodplain inundation at environmental watering sites

16.3.1 Purpose

This procedure provides guidance on estimating salt mobilisation from floodplain inundation in order to support salinity assessments of environmental watering within the Murray River model.

16.3.2 Background

The salt mobilised by environmental watering can be modelled to varying levels of complexity [see linked procedure 2.4]. Examples include:

- Floodplain numerical groundwater models
- Simple Darcian-based analytical groundwater models
- Simple area-based salt 'wash-off' models
- Semi-quantitative risk assessment methods (Aquaterra 2011b; Currie *et al* 2016).

For a given set of input assumptions, the more complex numerical methods will generate time series salt load recession curves, whereas simple methods will generate a single number.

16.3.3 Application

Subject to the principles of "effort commensurate with risk" and "cost effective and cost-efficient modelling", assessments of floodplain salt mobilisation resulting from environmental water use should seek to provide (at a minimum) the following:

- Time series estimates of the salt loads mobilised during the period from pre-intervention conditions (i.e. prior to the commencement of inundation), until the time when salt loads inputs return to those conditions
- Documented assumptions relevant to the use of the output data as inputs to the Murray River model such as:
    - River levels in the groundwater model assumed to represent pre-intervention conditions
    - Time series river levels and maximum areas of inundation considered to be appropriate assumed for the flooding events
    - River condition ranges appropriate to the use of the data to inform the estimate of salt load inflows to the river.

16.4 Interpreting floodplain model salt load estimates for environmental water use assessments with the Murray River model

16.4.1 Purpose

This procedure provides guidance on the use of estimates of salt mobilisation from floodplain watering in Murray River salinity assessments.

16.4.2 Background

The outputs from floodplain modelling must be used as inputs to the Murray River model to estimate salinity impacts. Because groundwater fluxes (and hence salt loads) to the river are a natural process within the landscape, Murray River modelling must remove the contribution that pre-intervention conditions were making to the post flood salt recession curve and so only evaluate the incremental effect of the watering action.

16.4.3 Application

The following steps provide a guide to the estimation of salt load inputs from an environmental watering event:

1. From the Murray River model, for years representative of pre-intervention conditions (for TLM or Basin Plan), review unaccounted salt loads for the relevant reach of the river and evaluate what proportion of this salt load is expected to be sourced from groundwater
2. Compare the results of step 1, with floodplain estimates of salt loads prior to the watering event [linked procedure 16.3] and reach a decision on pre-intervention condition salt loads
3. For each flooding scenario provided from the floodplain model [linked procedure 16.3], subtract pre-intervention condition salt loads from the salt mobilisation estimates
4. Check the step 3 salt loads attributed to the environmental watering event to ensure that any negative salt loads are consistent with the understanding of surface-groundwater gradients and are not an artefact of differences between average values from the groundwater assessment, and daily values in the model. Adjust estimates if appropriate
5. Apply the step 3/step 4 estimates of salt load mobilisation (duration and magnitude) to the River model input files for the Benchmark Period consistent with the frequency schedule derived under linked procedure 16.2.

17 Irrigation delivery system models

17.1 Overview

Within intensive irrigation areas, regional-scale water-delivery systems convey water to properties across the landscape. Throughout the distribution network, these systems interconnect with the broader hydrological system. The flow and salt loads within these systems will be variously affected by interaction with groundwater (to or from the water delivery network), salt interception schemes (such as the Pyramid Creek SIS in Victoria), outfalls to drains, bank leaks and seepage, unaccounted losses through meters, and finally, return flows to the river.

Regional-scale delivery networks are complex, and with the exception of parts of the Torrumbarry Irrigation Area in northern Victoria, the salinity impacts of changes are for the most part, assessed through the drainage system [see linked procedure 18].

17.2 Status of procedures

No procedures have been prepared to date for this model type.

18 Irrigation drain flow and salt load models

18.1 Overview

Within intensive irrigation areas, regional drainage systems have been constructed to provide a conduit for surplus irrigation water, rainfall and salt loads to reach the river or to be stored in evaporation basins.

Across the southern Riverine plains, the earliest surface drainage systems were constructed around 100 years ago, with drainage improvements in some areas continuing up until the present day.

For the Riverine Plains of the southern connected Basin, the dominance of surface water processes, the extensive variability in both surface water and groundwater processes, and data gaps have meant that complex models have not been developed. To date, analytical and empirical models have been applied.

18.2 Representing irrigation intensity in irrigation drain and salt load models

18.2.1 Purpose

This procedure provides guidance on representing estimates of irrigation water use in irrigation drain flow and salt load models.

18.2.2 Background

Within the southern Basin, profound changes to the salt and water balance in irrigated areas have occurred over the last two decades. These are a result of changes in seasonal rainfall, water trade, water recovery for the environment and continuing improvements in irrigation management.

Recognising changes in land and water use as an Accountable Action, the IAG-Salinity (MDBA 2018) recommended that "*the MDBA and jurisdictions should consider the development of an approach to assessing the salinity impacts of irrigation that better represents actual water use; particularly in* *relation to the reduction in irrigation water use in some established irrigation areas in the southern basin*".

18.2.3 Application

Accountability for changes in water use should be representative of the long-term trends in land and water use.

In the development of the conceptual model, consideration should be given to all available data. For example:

- Remote sensing data indicating land use
- Field based measurements. For example
  - Drain flows and salinities
  - Drain diversions
  - Irrigation deliveries
  - Irrigation system leaks and outfalls to drains
  - Water tables
  - Groundwater extractions
- Research conclusions regarding actual efficiencies and potential efficiencies
- A chronology of physical events and policy drivers for changes in the irrigation footprint, crop types and irrigation efficiencies. For example:
  - MDB Cap on diversions (from 1995)
  - Introduction of water markets and the revealed value of water
  - Implementation of farm-based extension programs encouraging Best Management Practice
  - The long-term impacts of the millennium drought on land use
  - On-Farm Irrigation Efficiency Projects to further water recovery for the environment under the Murray-Darling Basin Plan
  - Major shifts in cropping systems that have implications for the timing and volume of water use.

19 Upland catchment groundwater models

19.1 Overview

The unregulated upland catchments of the MDB include the hills and mountains around the margins of the Basin and the alluvial valleys below. These catchments are dominant in the northern and eastern parts of the northern Basin (Queensland and NSW), the western slopes of the Great Dividing Range in NSW, and western and northern slopes in Victoria. These landscapes contain thinner lenses of saline groundwater than the Riverine Plains, but in some areas contain a significant salt store, including in the water table zone that dynamically transitions between saturated and unsaturated conditions. In the southern connected Basin, these upland landscapes are the primary source of regular flows to the Murray River.

During the early years of the Basin Salinity Management, gaps in modelling tools meant that predictions were based largely upon trend analysis, however since that time, substantial improvements in fit-for-purpose tools provide the capability for more robust assessments (MDBC 2007).

19.2 Selection of modelling tools

19.2.1 Purpose

This procedure provides guidance on the selection of modelling tools to support salinity assessments in upland catchments.

19.2.2 Background

Modelling groundwater-surface water interaction in upland landscapes is challenged by the absence of detailed monitoring data, requirements for predictions at a catchment scale, and the time lag between land use changes that affect the groundwater balance and their impacts on stream flow and salt loads.

To meet these challenges, the 2CSalt modelling platform provides a consistent approach to assessing the salt mobilisation impacts of land use change in upland sub-catchments (Stenson *et al* 2006). The model has been peer assessed (SKM 2005) and deemed fit-for-purpose (BSMSIWG 2005).

Attributes of 2CSalt include:

- It sources inputs from integrated 1D models such as recharge models, and so supports the assessment of land use change on the salt and water balance.
- It operates on a monthly timestep at a sub-catchment scale
- It is able to be calibrated against stream flows in gauged catchments.
- Its outputs are able to be integrated with tributary models as conceptualised in Figure 2
- It has been tested in sub-catchments in each of the eastern states of the MDB

Notwithstanding the availability of 2CSalt, this procedure is intended to be enabling, allowing States to pursue innovative alternatives.

19.2.3 Application

2CSalt is the endorsed modelling platform to support salinity assessments in the Upland catchments.

Alternative groundwater modelling approaches may be considered but will require peer assessment [see linked procedure 6.4.3.2].

Models used to estimate recharge inputs to upland groundwater models should be documented and may require review if used to inform Register entries [linked procedure BSM Procedure – Conducting reviews and assessments] but are not considered to be models under Cl. 36 or Cl. 37.

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Appendix A: Estimating unaccounted salt loads under baseline conditions

Purpose

This Appendix is intended to document the process for deriving unaccounted salt load inflows to the Murray River model under baseline conditions. Unaccounted salt inflows include saline groundwater accessions, unmeasured drain inflows and salt mobilised from the floodplains during high flow events.

Background

The estimate of baseline conditions must include an estimate of unaccounted salt loads needed by the Murray River model to achieve the best fit to the observed salinity data and thus "unaccounted" salt inflow includes all groundwater inflows and unaccounted surface water discharges.

The process for deriving unaccounted salt loads for inclusion in the estimated baseline conditions has two practical applications in BSM2030 modelling:

- The "one off" estimate that supports the development of the accredited Murray River model, which is used to estimate the salinity effects of Delayed salinity impacts and Accountable Actions
- The "annual estimate" used in the assessment of progress against the Basin Salinity Target.

This Appendix summarises the approach set out in the MDBA (2016) report[9]. Key elements of the process include:

- The removal of the net impact of salt loads from actions in the calibrated model that are not part of the estimate of baseline conditions
- Refining the above estimate of salt loads under baseline conditions to remove anomalous negative salt load gains.

Methodology

The calibrated model is used in the calculation of the daily unaccounted salt inflow (historical). This explains the difference in salinity measurements between an upstream and downstream location – after accounting for all known salt inputs and extractions in the reach as well as accounting for flow and salinity travel times.

The steps in the process are below with progression towards the calculation of a final estimate of river salt loads summarised under baseline conditions illustrated within Figure 7 for the Lock 5 to Morgan reach:

1. Daily raw salt loads are calculated using the calibrated model in salt calculation mode. At some points along the river, this calculation may result in estimates of negative salt inflows if the measured salinity at the downstream site, is lower than the upstream measured salinity with no freshwater contribution. Calculations of negative salt inflows could be due to errors in salinity measurements, errors in modelling the travel time of water, or limitations in the accuracy of salinity recorders. It is also possible that corrections applied to salinity measurements for temperature and scaling on salinity probes or point salinity measurement may not be representative of the cross-sectional river salinity profile.

[9] An alternative more complex approach provided in Appendix B of MDBA (2016) is not considered to be cost effective (see linked procedure 3) given the amount of additional modelling effort required.

2. Daily salt load inflows are aggregated to monthly values in a first attempt to smooth out the fluctuations of positives and negatives (Figure 7 – "Aggregated mthly from calibrated model").
3. The monthly representation of salt load is used to derive the pre-intervention conditions at the baseline date by subtracting/adding (as relevant) the impact of contributions from Delayed salinity impacts and Accountable Actions up to 1 January 2000 from the date they were determined to accountable [Cl. 19(1)] and included on the Register [Cl. 22].

   For example, between Lock 5 and Morgan, salt interception schemes constructed under the Salinity and Drainage Strategy influence historical salt load calculations for part of the modelled period. Hence, they are effectively "turned off" by removing their influence from the historical unaccounted salt loads for the relevant part of the modelled period, to derive "Pre-intervention" salt loads. Thus the "pre-intervention" salt loads (Figure 7 – "Adjusted to 1988 base case") are higher than the historical unaccounted salt load estimates (Figure 7 – "Aggregated mthly from calibrated model") for this reach.
4. The "Current Conditions" salt loads are generated from "Pre-Intervention" salt loads generated in Step 3 by adding/subtracting (as relevant) impacts of delayed salinity impacts and Accountable Actions for the entire modelled period (Figure 7 – "Adjusted to current conditions").

   This step can also generate negative salt loads for some reaches in some months that are unrealistic – given that the available data shows increasing salt loads down the river at the modelled reach scale. In these situations, further refinement is required.
5. A smoothing function "Saltzeros" is applied to these "current conditions" salt loads. This program systematically steps through each modelled reach for each of the groundwater modelled scenario years, adjusting salt load inputs to ensure they are not less than the minimum required to avoid a negative salt inflow along that reach. Smoothing occurs between adjacent reaches from Hume to Murray Bridge (MDBA 2016). In the Murray Bridge to Milang reach the smoothing takes place between positive salt inflows in the adjacent months.

   Salt load contributions under "Baseline conditions", with negative anomalies removed, are generated by adding/subtracting (as relevant) back the salt subtracted in Step 3 for the entire modelled period to generate a smoothed BSMS "Baseline Conditions" salt inflow.

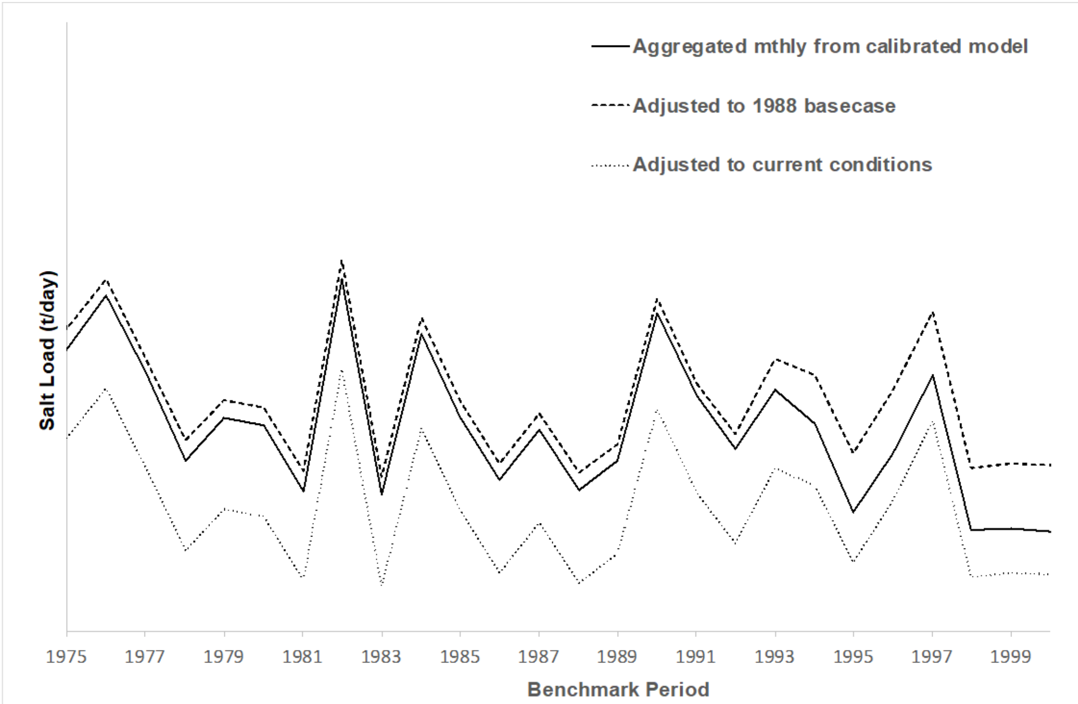


Figure 7: Illustration of transformation of Benchmark Period salt load inputs from Lock 5 to Morgan for the calibrated model, to the 1988 base case, to 2016 conditions using the MDBA (2016) methodology to derive Baseline conditions.

Steps 1 to 5 are undertaken annually to update the model to the previous year, and so inform progress against the Basin Salinity Target as illustrated by Figure 2 in MDBA (2018).

Additional information on the methodology described in this Appendix is provided within MDBA (2016).

Appendix B: Communicating modelling uncertainty

The purpose of this Appendix is to provide additional advice and insight to the reporting and communication of uncertainty analysis.

The importance of effectively communicating modelling uncertainty is highlighted in an experience related by Peeters (2017).

"*It allowed to very quickly assess the both strong and weak points in the analysis, which, in combination with the plain English discussion of model choices and assumptions, improved their confidence in the overall modeling approach, a crucial component in stake-holder engagement. Moreover, it provided the clients with a clear priority list of knowledge and data gaps which in turn allows for much more focused further research*".

Depending upon the scale and type of uncertainty analysis, reporting can be:

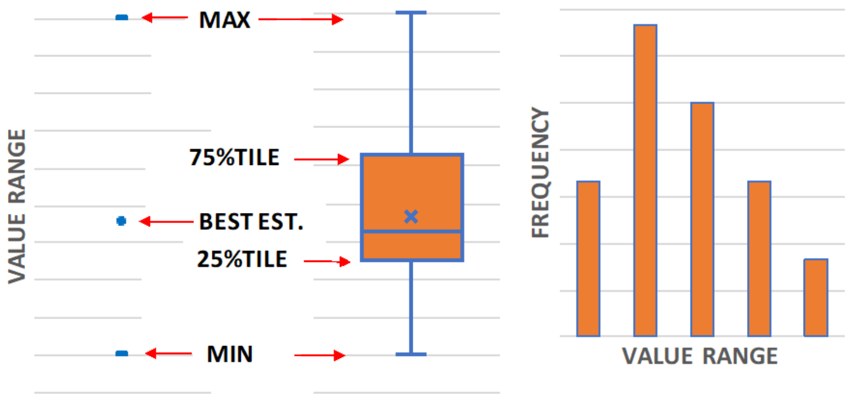
- Simple – inclusive of assumptions, the range of possible outcomes that would arise from different assumptions (an example provided in Peeters (2017))
- Complex – a detailed analysis of the probability associated with the range of outcomes (examples provided in Appendix to Middlemis and Peeters (2018)).

The extent to which probabilistic results can be reported is dependent upon the adoption of deterministic or stochastic approaches. Both methods are capable of providing insight into the uncertainty range in predictions.

- Deterministic applications employ a single value for each input parameter or boundary condition; this yields a single output value, time history or spatial distribution of the required output parameter
- Stochastic applications use a statistical approach on either analytical or numerical methods, which, when used appropriately, generate equally probable models honouring all available data and knowledge of the water system.

Simple illustrations of graphical approaches to reporting on uncertainty are provided by Figure 8:

a) Deterministic "best estimate" output based upon adopted conceptual model but with upper and lower bounds from alternative conceptual models
b) A whisker plot illustrative of the distribution of model outputs (e.g., salt loads) from stochastic modelling using the range of possible input parameters
c) A frequency distribution plot illustrative of likely model outputs grouped into specific ranges (e.g., from low salt loads to high salt loads), given the range of possible input parameters.



a) Deterministic b) Whisker plot c) Frequency distribution values

Figure 8: Examples of simple quantitative presentation of the range of model predictions.

Opportunities should be sought to present the results of uncertainty analysis in a way that is meaningful to decision makers, such as outlined below:

- Assigning a qualitative confidence rating based upon an evaluation of uncertainty in the conceptual model. For example:
  - High confidence – Few gaps in critical data. Strong evidence underpinning conceptualisation.
  - Moderate confidence – Moderate gaps in data. Different conceptual models possible but evidence generally supportive of adopted option.
  - Low confidence – Significant gaps in data. Range of quite different conceptual models possible.
- Assigning a quantitative confidence rating based upon a stochastic analysis. For example:
  - High confidence – Narrow range of possible outcomes.
  - Moderate confidence – Range of possible outcomes but probabilistic analysis indicates likelihood of narrower range.
  - Low confidence – Wide range of possible outcomes with similar probabilities across the range.

Appendix C: Independent Peer Assessment checklist

This checklist of evaluation criteria has been developed to support the peer assessment of models (Section 6.4.3.2).

A number of matters are pertinent to this checklist:

- Some of the criteria will apply to all model assessments, irrespective of the type or form of the model.
- Some of the criteria may not apply to the model being assessed.
- In applying this checklist, a starting point should be to review each of the criteria as to its applicability to the model being assessed. Then, based upon professional judgement/experience, refinements may be made (providing justification is given if changes may be contentious), by:
    - excluding those that are not applicable, and
    - adding additional criteria or refining existing criteria if appropriate.

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
1.0	**PRELIMINARY**			
1.1	List the reports that have been used as the basis for this assessment.			
1.2	Purpose • Is the purpose(s) of the model clearly stated as it relates to Schedule B? • Does this purpose include supporting cross jurisdictional accountability?			
1.3	Governance • Was the model oversighted by a steering committee? • Does the steering committee adequately represent the stakeholders? • Is Lead Agency responsibility for the model clearly documented? Is this assignment aligned with the modelling procedures?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
1.4	Model setting - do reports adequately document the following? • What part of the Basin is being modelled – northern basin, southern Riverine Plains, southern uplands, Mallee? • What is the primary hydrological system being modelled – river, irrigation supply system, irrigation drainage, groundwater, floodplain? • Is the model dependent upon other models for inputs? • Which models use the outputs from this model?			
2.0	**CONCEPTUALISATION**			
2.1	Knowledge review • Has a review of readily available knowledge been undertaken and documented? • Have learnings/recommendations from previous reviews (and associated independent assessments) been considered and the response to recommendations documented? • Has the knowledge and assumptions for similar types of BSM models in comparable landscapes been reviewed and relevant learnings been identified?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
2.2	Processes and parameters • Are the key flow and salt mobilisation processes and parameters explained with narrative and diagrams? • Is the narrative supported by evidence from the knowledge review? For example is there justification for: o The extrapolation of empirical understanding (either data or anecdotal) across modelled zones? o Interpreting short sequences of temporal data beyond the period of record and infilling data gaps? • Are the flow and salt load inputs/outputs between this conceptualisation and the conceptualisation of integrated models (Procedures Figure 2) explained?			
2.3	Constraints & Limitations • Have major reinterpretations of changes to the conceptualisation/assumptions from previous modelling of the landscape been adequately explained? • Are the implications of knowledge gaps explained in terms of model uncertainty? • In the context of knowledge gaps, have alternative conceptualisations been considered and the rationale for the preferred conceptualisation explained? • Taking into consideration modelling procedure principles, is the conceptualisation fit-for-purpose to inform development of mathematical model that will answer the key technical questions identified in the project purpose statement?			
3.0	**MATHEMATICAL MODEL**			

<table>
<tr><th></th><th>MODEL EVALUATION CRITERIA</th><th>ASSESSMENT
Missing / Deficient / Adequate / Very Good / Yes/No</th><th>COMMENTS
Recommended Improvements
• Critical or Urgent?
• Useful in medium term
• Useful in longer term e.g., for next five-year review</th><th>ACTION?</th></tr>
<tr><td>3.1</td><td>Model type
• What is the form of the model –empirical, analytical, numerical, other?
• Were other methods considered?
• Is the rationale for the preferred method documented?
• If yes, is this rationale guided by the BSM modelling procedure principles?</td><td></td><td></td><td></td></tr>
<tr><td>3.2</td><td>Consistency with conceptual model
• if the model is intended to represent hydrological and salt mobilisation processes, is the model type/approach consistent with the conceptualisation?
• If not, which important processes (if any) are not represented?</td><td></td><td></td><td></td></tr>
<tr><td>3.3</td><td>Model domain
• Is the spatial extent of the study area or river clearly defined?
• Is the targeted landscape adequately represented by the model domain?</td><td></td><td></td><td></td></tr>
<tr><td>3.4</td><td>Parameterisation:
• Are the model parameters:
o Consistent with evidence from the knowledge review and documentation within the conceptualisation?
o appropriate for application to that part of the landscape, river or aquifer zone?</td><td></td><td></td><td></td></tr>
</table>

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
For river or irrigation delivery system models				
3.5	Are all the principal flow/salt inputs and outputs included?			
3.6	Are all the relevant flow/salt routing processes included and documented?			
3.7	Does the model integrate flows and salinities of input models?			
3.8	Are the number and size of sub-catchments appropriate?			
For Mallee groundwater models				
3.9	• If the model is a Mallee groundwater model: • Is the model setup consistent with procedures relating to: o Dryland recharge? o Representing irrigation intensity and irrigation efficiency? o Representing irrigation RZD and recharge? o Representing groundwater evapotranspiration? o Estimating groundwater salt loads to rivers? o Representing rivers and surface water features? • Are there other assumptions or actions that have significant potential to impact predictions? Is there potential for guidance on these assumptions by new procedures?			
3.10	Time steps and stress periods • What are the time steps and stress period increments for the simulations, and rationale? • Given the type of action being assessed and relative distances from model boundaries, would decisions on different boundary conditions or stress periods be expected to substantially change the predictions?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
3.11	Processes and Boundary conditions • Which assumptions have the most potential to affect the predictive capacity of the mathematical model? o Flow/salt mobilisation processes? o Boundary conditions? o Parameters?			
For irrigation drain and flow salt load model:				
3.12	• In the estimation of irrigated area and water use has all readily available data been considered? • In the estimation of irrigation efficiencies: o Has the most recent data/research been considered? o Are assumed changes over time consistent with the chronology of physical and policy events that have influenced water management, documented and justified? • Are there other assumptions or actions that have significant potential to impact predictions? Is there potential for guidance on these assumptions through development of new procedures?			
Model calibration and validation				
3.13	History matching / Calibration: • Are model outputs "history matched"? • If no calibration/validation – is there a rationale that is aligned with modelling principals?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
3.14	For Calibrated models, calibration consistent with Best Practice modelling guidelines (e.g. Black et al 2011; Barnett el al 2012) • Does the calibration period include the Benchmark Period? • Is the calibration informed by climatic record, the timeline over which the Delayed salinity impacts and Accountable Actions were implemented, and changes to land and water management over time? • What are the calibration measures used in the model and are they consistent with best practice guidance? • Has the calibration process been sufficiently documented? Have an appropriate number and range of time-series plots and statistics of the observed and modelled data been provided? • Is the calibration fit adequate temporally and spatially? • What are the free variables used in the calibration? • Has calibration produced “believable” distributions of model parameters?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
3.15	Model validation • Have relevant and available validation criteria been used? e.g. o For a river model – a time series flow and salinity data reserved for validation post calibration? o for a groundwater model – groundwater levels / salt loads to the floodplain and river • Does the model provide plausible results over the model domain and the temporal extent envisaged? • Have model non-uniqueness issues been considered or addressed (sensitivity testing/uncertainty analysis) • If the model has not been validated, is there a justification/rationale for the outcomes that is consistent with the modelling principles?			•
3.16	Salt and water balance • If the model is a process model: o are all of the major processes identified in the conceptualisation, included in the model? o Are the contributions or each process to salt and water balance captured for the calibration period? • Is the scale of water balance zoning adequate to generate predictions at the sub-regional scale consistent with its purpose? • Is the net salt and water balance for the modelled system reported for the calibration period?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
3.17	Sensitivity analyses: • Has the sensitivity of the calibration been tested to other probably parameter settings?			
4.0	**MODEL APPLICATION AND PREDICTIONS**			
4.1	• If a tributary or Murray River model, does the model meet the predictive requirements of Cl 36 (1) & (2) or Cl 37(1)(a) & (2) with respect to time steps and salinity, salt load and flow under Baseline Conditions over the Benchmark Period? • Is there a clear and justified basis for the estimate of baseline conditions including addressing unaccounted salt loads?			
4.2	• If a groundwater model developed by State lead agency, does the model meet the predictive requirements of Cl 37(1)(b)?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
4.3	Status of actions • Are the predictive modelling assumptions on the operating status of works or measures consistent with the agreed or approved operating rules? • If not, does the documentation explicitly recognise the need to formally align the operating rules consistent with the proposed assumptions in the predictive model? • Is the data for actions sufficient for the use of the model in the estimate of the salinity impact for the pre-intervention conditions and scenario years? • Is the model capable of assessing the cumulative salinity effect of similar past actions or project similar future actions?			
4.4	Sequencing • Are the pre-intervention conditions clearly defined and consistent with the definition set out in the procedures? • Is the sequencing from the baseline date, consistent with the modelling procedures? • If not, is there a clear and logical rationale for the adopted approach?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
4.5	Predictions • Are deterministic outputs generated for the pre-intervention conditions and each scenario year based upon best estimate inputs? • Is the net salt and water balance for the modelled system reported for the pre-intervention conditions and one or more scenario years? • For input models, if only a single scenario run is provided, is there a clear rationale as to why this is applicable to each of the scenario years?			
4.6	Uncertainty • Have the net implications of uncertainties in the conceptual model and mathematical model been considered in the reporting of scenario predictions. • Are uncertainties communicated qualitatively or quantitatively? • Does the form of reporting effectively communicate to decision makers the extent of the uncertainty and possible implications for the use of model scenario predictions?			
4.7	Process of modelled data • Is the basis for any conversion of EC to concentration documented? • For input models, is there documentation of how the outputs from the input model, have been adjusted (if required) to meet the requirements of integrated model (Procedures Figure 2)?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
4.8	Management of model outputs • Is the internal QA process for modelling runs documented? • Does documentation capture: the purpose of each modelling run, a unique model run identifier, the Accountable Actions assumed, the key parameter settings held constant or changed? • Is there evidence that each modelling run has been archived and is able to be tracked to the storage location? If not, what improvements are required? • Is communications and data transfer between the modellers and MDBA office clearly documented?			
5.0	**MONITORING**			
5.1	Improving knowledge • Is there other knowledge that could be pursued to improve the model? • Is there new monitoring that could be undertaken to improve the model?			
6.0	**OVERALL**			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
6.1	Quality assurance • Internal o Is the internal QA process documented? o Has the model been subject to other review with the findings made available? • External o Did this peer assessor have opportunity for discussion with the development team, and comment during model development? • Is the process for data management and model archiving adequately documented?			
6.2	Reporting standard • Does the overall content of the report broadly match the content expectations of the modelling procedures? • Assessment of overall quality of the detail and clarity of the documentation? • What are the main shortcomings that should be addressed in the next review?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
6.3	Modelling principles Taking all matters in consideration, how effectively does the model (development and application) balance the following principles set out in the modelling procedures: • Accountability and transparency? • Best Management Practice • Consideration of new knowledge • Consistency • Cost-efficient and cost effective • Effort commensurate with risk • Multiple lines of evidence • Precautionary principle			
6.4	Recommendations • Does this Peer Assessment generally agree with the recommendations provided in the report? • What additional recommendations should be considered?			

	MODEL EVALUATION CRITERIA	ASSESSMENT Missing / Deficient / Adequate / Very Good / Yes/No	COMMENTS Recommended Improvements • Critical or Urgent? • Useful in medium term • Useful in longer term e.g., for next five-year review	ACTION?
6.5	Improvements • Based upon the experience in undertaking this peer assessment, provide succinct advice on potential areas for improvement in the modelling procedures (or new procedures) that would support improvements in model development or reviews • Is the model modular and/or flexible enough to be expanded or refined with the availability of more data in the future and availability of new data or flow/salt process models?			