Groundwater models of the South Australian River Murray for the Basin Salinity Management Strategy: A policy and modelling success

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Abstract: The River Murray in South Australia is prone to high salinity due to inflows of naturally saline groundwater. Land use changes have increased the flow of salt from groundwater to the river, as the watertable has been raised by the clearance of native vegetation and the introduction of irrigation. The Basin Salinity Management Strategy (BSMS) 2001-2015 continued policy measures established under the Salinity and Drainage Strategy (S&DS) 1988 and the Murray-Darling Basin Authority, to manage River Murray salinity, including the Salinity Registers, which record estimates of the salt load impact on the river of land use change and engineering works.

Since the BSMS was agreed, South Australia has developed a suite of groundwater models to provide impact estimates for the Salinity Registers. This has required long-running and close collaboration between state government groundwater modellers and policy officers and also representatives from SA Water and the Murray-Darling Basin Authority. By working together to understand the policy, data information and modelling needs, there has been progressive improvement to each model that has been recognised by independent model reviewers. The work has ensured the state can deliver on a range of obligations under the Murray-Darling Agreement (Schedule 1, *Water Act 2007* (Cth)), South Australia's Strategic Plan (2011), and Water for Good (2010) policies. The groundwater models are updated and reviewed on a five-year rolling basis, ensuring that the models and the Salinity Registers can continue to be refined as scientific understanding, modelling techniques and data acquisition improve.

Keywords: *Salinity, River Murray, Numerical model, Salt Interception Schemes*

1. INTRODUCTION

Salt is a natural part of the Murray-Darling Basin (MDB) landscape and rivers. These salts come primarily from rainfall, concentrated by evaporation over millions of years (Brown, 1989), possibly together with remnant salts from former inland sea sediments. Due to the natural geological structure of the Murray-Darling Basin, the River Murray in South Australia (SA) acts as a drain for salt out of the landscape (Brown, 1989). Agricultural practices have further mobilized salt from saline groundwater to the river. This affects the water quality of the River Murray for industrial, agricultural and potable use, including the water supply for metropolitan Adelaide. Increases in River Murray salinity can also lead to degradation of aquatic and floodplain ecological health. Rising river salinity levels are a significant issue for water supply in the state of South Australia because of the reliance of SA on the lower reaches of the River Murray.

Management of river salinity requires effective policy and management decisions which have been informed by the best available science. Successful outcomes have been achieved via long-running and close collaboration between state government groundwater modellers and policy officers and also representatives from SA Water and the Murray-Darling Basin Authority (MDBA).

2. HYDROGEOLOGY AND THE RIVER MURRAY IN SOUTH AUSTRALIA

The MDB is a closed groundwater basin (Figure 1) consisting of Cainozoic unconsolidated sediments and sedimentary rock (Evans and Kellett, 1989). It is wide but shallow, extending up to 900 km east–west and averaging 200 m thick, with a maximum thickness of 600 m (Brown, 1989). It includes a number of regional aquifer systems. Its surface waters and groundwater are connected to the sea only near the Murray Mouth. Salt from rainfall, surface water and groundwater has accumulated within the basin over the past half a million years (Brown 1989).

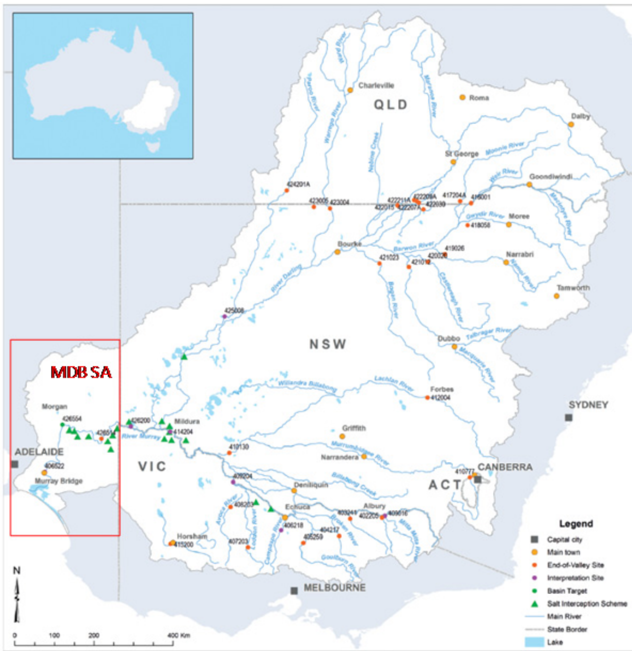

Figure 1. Locality map (after MDBA, 2013)

The MDB in SA lies in the south-western edge of the basin (Figure 1). For the MDB in SA, the key regional aquifer systems are the Loxton Sands, the Murray Group and the Renmark Group (Figure 2, where the Murray Group is depicted as three of its sub-units, the Glenforslan, Finniss and Mannum Formations). The channel of the ancestral River Murray is incised into the highland sediments of the regional aquifers. Within this channel, the semi-confined Monoman Formation aquifer has been deposited. The regional watertable aquifers are generally juxtaposed and hence hydraulically connect with the Monoman Formation. Groundwater salinity into the river valley is typically 22 000 – 30 000 mg/L (Telfer *et al.,* 2012) but may exceed 45 000 mg/L (Yan, Li and Woods, 2011). Under natural river conditions, many SA reaches of the River receive saline groundwater flow; due to the salinity, the salt flux can be high. Prior to irrigation development, only some SA reaches received high salt loads from groundwater. In recent years, investigations

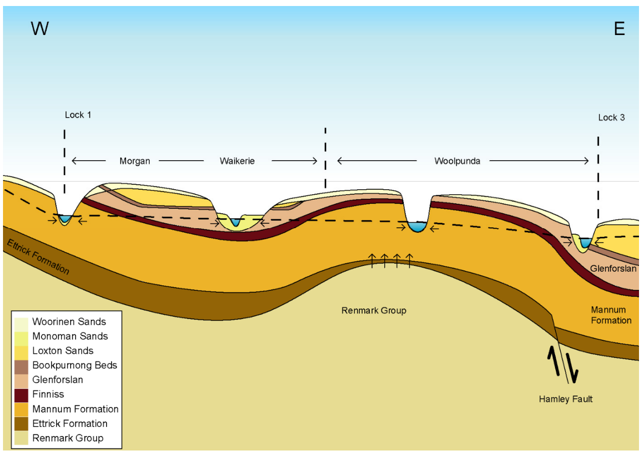

Figure 2. Conceptual Hydrogeological Cross-Section in the MDB SA (Yan, Li and Woods, 2012)

and model results indicate that total salt load entering the River Murray in SA can be up to a thousand tonnes per day.

Salt movement from the groundwater into the River Murray has increased since European settlement, due to changes in land use. Under natural conditions, the native mallee vegetation is highly water-efficient, so only 0.1 mm/yr of rainfall recharges the watertable aquifer (Allison *et al.,* 1990). Land clearance increases recharge by an order of magnitude (Cook et al. 2004) and irrigation areas have recharge rates of, e.g. 100 to 500 mm/yr (Yan, Li and Woods, 2012). Land clearance and irrigation in the SA Riverland has therefore greatly increased the total recharge and raised the watertable, forming groundwater mounds under irrigation areas (Figure 3). The raised gradient between the aquifer's potentiometric head and the river level has in turn increased the flow of saline groundwater induced salt into the River Murray and hence increasing the overall in-river salinity.

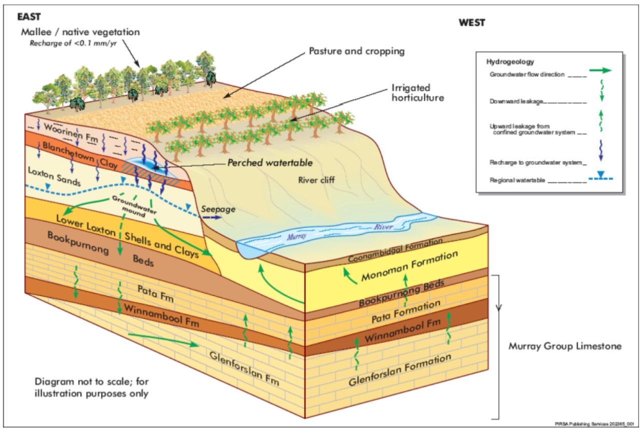

Figure 3. Elementary Conceptual Model of irrigation impact (Yan, Li and Woods 2011)

3. MDB SALINITY POLICY

The first governance model for the Murray-Darling Basin was the River Murray Waters Agreement, which was signed in 1914 by New South Wales, Victoria, South Australia and Federal governments and established the River Murray Commission in 1917. The Commission consisted of representatives from the Federal Government, as well as representatives from the three states through which the Murray flows. All development and works that were carried out on the Murray River were controlled by the Commission.

Salinity in the River Murray first became a major concern to the Murray-Darling Basin States during the droughts of 1965-66, 1966-67 and 1967-68. At this time, other MDB management issues also required urgent attention, including water-logging and soil salinisation over large areas of well-established irrigation on the Riverine Plains in New South Wales. In response, the River Murray Commission conducted salinity investigations in the Murray Valley. The investigations ultimately led to an amendment of the River Murray Waters Agreement in 1982 and the broadening of the Commission's role to take account of water quality issues in its water management responsibilities.

In November 1985, a Ministerial Council comprising twelve Ministers from the Commonwealth, Victoria, New South Wales and South Australia was established to promote effective planning and management for the equitable, efficient and sustainable use of water, land and environmental resources in the Basin.

The coordinated management of the Basin's salinity and waterlogging problems was given a high priority by the Murray-Darling Basin Ministerial Council and resulted in a working group which led to the Salinity and Drainage Strategy (S&D Strategy), 1989, to be implemented through the recently established Murray-Darling Basin Commission. The S&D Strategy provided the framework for coordinated management of River Murray salinity, land salinisation and water-logging in the Murray-Darling Basin. A key feature of this strategy was the adoption of a Basin salinity target at Morgan in South Australia (see Figure 3 for location) and the establishment of the Salinity Registers system. The Salinity Registers track all actions that are assessed to have a significant effect on salinity, defined as a 0.1 EC change in modeled average daily salinity at Morgan over the Benchmark period (defined as 1975-2000). The Strategy established a shared legacy of history amongst the partner governments for salinity impacts resulting from actions prior to implementation of the Strategy resulting in a Joint Program of Works. Additionally, the Strategy required the basin states to assess, report and review management actions after 1988 that have a significant effect on salinity in the River Murray at Morgan and to maintain their share of the Salinity Register in a positive balance. That is, actions which decrease salinity in the River Murray at Morgan must outweigh the impacts of actions which increase salinity in the River Murray at Morgan.

This system of Salinity Registers was formalised into Schedule C of the Murray-Darling Basin Agreement (which replaced the River Murray Waters Agreement in 1987) and was subsequently renamed to Schedule B when the Murray-Darling Basin Agreement was incorporated into the *Water Act 2007*, (Cth).

Following the conclusion of the S&D Strategy, the Basin Salinity Management Strategy (BSMS) 2001-2015 was adopted by the Basin states and continues to implement the Salinity Registers.

Since the adoption of Schedule B to the Murray-Darling Basin Agreement, South Australia has developed a series of five numerical groundwater models to estimate salinity debits and credits for the Registers (Figure 4). The work has ensured the state can deliver on a range of obligations under the Murray-Darling Agreement (Schedule 1, *Water Act 2007* (Cth)), South Australia's Strategic Plan (2011), and Water for Good (2010) policies. Each model is capable of simulating part of the regional aquifer system for the South Australian River Murray area to:

- Improve the understanding of the hydrogeology of the regional aquifer system and processes to identify key areas to be targeted
- Provide estimated salt loads entering the River Murray from groundwater under different accountable development and management actions (100-year predictions from current year) for use as Salinity Register entries, specifically:
    - Mallee (i.e. native vegetation) clearance
    - Irrigation development
    - Improved irrigation practices
    - Salt interception scheme operation.
- Assist with the broad-scale planning for groundwater management schemes (e.g. salt interception schemes) that help to control the flux of saline groundwater and therefore salt load, entering the River Murray.

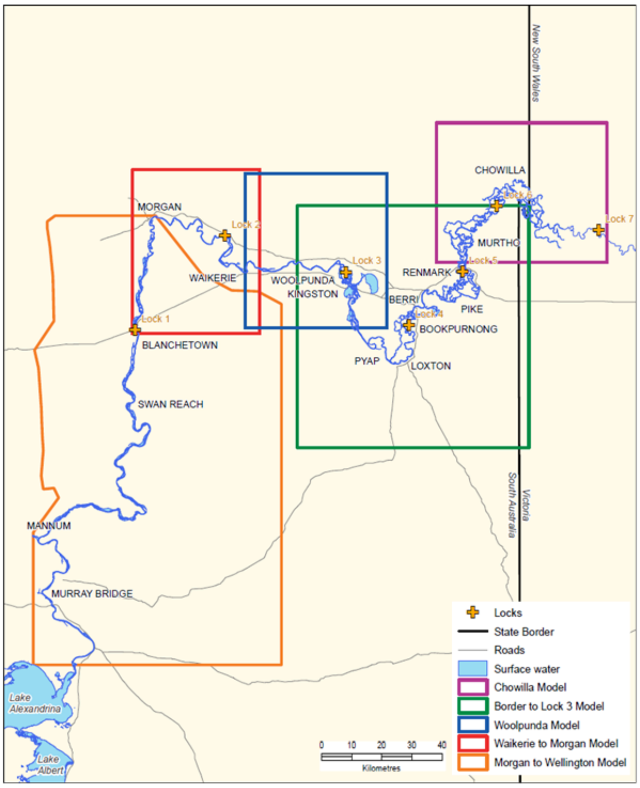

Figure 4. Extent of Numerical Groundwater Models for Salinity Registers (Woods *et al.* 2013)

4. INTEGRATING MODELLING AND POLICY

Schedule B sets out the responsibilities and accountabilities of jurisdictions that are party to the Murray-Darling Basin Agreement in regards to salinity management, which include:

- assigning credits or debits to all land or water management actions that will have a significant salinity effect on the River Murray and recording these impacts in the Salinity Registers; and
- five-yearly technical reviews of each tributary river valley and each Salinity Register entry to ensure that the credits or debits on the register are continually updated over time.

In SA, these requirements are met primarily using the Salinity Register numerical groundwater models which are reviewed and accredited as fit for purpose through a process of independent review. The groundwater models are updated and reviewed on a five-year rolling basis, ensuring that the models and the Salinity Registers can continue to be refined as scientific understanding, modelling techniques and data acquisition improve. Each of the five-yearly technical reviews involves:

- collation of new knowledge, information and data for the years since the last review, e.g. potentiometric head observations, SIS pumping rates, irrigation data, recent aquifer test estimates of aquifer properties,
- collation of historical datasets which have been substantially improved since the last review, e.g. since 2011 an improved, more detailed methodology has been used to provide landuse data and recharge estimates,
- a review of the datasets and an update, where necessary, of the conceptual model
- changes to the design and input files of the numerical model to reflect the above
- numerical model calibration, including sensitivity tests
- review of scenario design to meet the policy requirements
- scenario simulation, including uncertainty analysis
- use of the model results to provide entries for the Salinity Register, and
- model platform upgrades.

The challenge is that the model must be both scientifically sound and fit for policy purposes. Assumptions and simplifications are required to meet the policy requirements. For example, a key assumption imposed on the numerical groundwater models to enable the output required by Salinity Register is to use the river at a constant level (i.e. normal operating pool level) during the scenario runs. Whilst the numerical groundwater model is calibrated to actual conditions, which includes a variable river level less than1 meter 75% of the time, the assumption of a constant river level is employed within the scenarios to remove the overlap of salt mobilized as a result of climatic variability and anthropomorphic activities. In order to remove the confusion of 'natural variability' a constant river level is held during scenario runs.

To ensure assumptions and simplifications are appropriate, both scientifically and for policy purposes, a Five-Year Review Modelling for Salinity Registers Project Team (the Project Team) was formed and meets regularly to discuss policy requests, data and information sources, model development, assumptions, simplifications and limitations, and scenarios. The Project Team includes groundwater modelers and policy officers from the SA Department of Environment, Water and Natural Resources (DEWNR), representatives from the Murray-Darling Basin Authority (MDBA), and Salt Interception Scheme operators. Hydrogeologists familiar with the model site are invited to join the Project Team meetings during the data collation and conceptual model review stages. Model and scenario design decisions are presented and discussed in a timely fashion so that modelling and policy issues are resolved quickly. As a result of this process, the Salinity Register models are consistent in their assumptions and usage.

To be able to deliver the best model and results on time to support policy and management decisions, there is also a stringent model review process. Expert, independent reviewers are selected by the MDBA and evaluate the model revisions at several stages so that their comments can be incorporated before the model is finalised. Once a draft model report is prepared, it is further reviewed by another independent hydrogeologist and groundwater modeller who were not previously involved in model development. Detailed information about the modelling is also presented to two groups comprising representatives of the MDBA and three state governments (NSW, VIC and SA): the Technical Working Group on Salt Interception and the Inter-juristictional Expert Panel for 5 Year Reviews of Salt Interception Schemes. Some review comments may be considered out of scope for the current models, but are considered for action for later numerical models, as they are contingent on further data collation, advances in hydrogeological understanding, or improved modelling capabilities.

To ensure the detailed technical information and policy applications been properly documented, two reports are prepared. One exhaustively documents the model design, inputs and outputs prepared by modellers. The other documents how the model outputs from the scenarios are used to develop the entries for the Salinity Register as developed by policy officers in consultation with the modellers.

5. MODEL RESULTS AND POLICY IMPLEMENTATION

The model results have been used to:

- improve understanding of the issues and groundwater systems

- Assist in design and construction of salt interception schemes
- Calculate benefits and cost sharing for salt interception schemes
- Inform operation of the salt mitigation schemes (e.g. SIS and Chowilla Regulator)
- Improve the estimation of credits and debits which can be used to assist policy and management decisions; and
- Support management and policy development. (this sounds like a repeat of the above)

Since the BSMS was developed, the salinity mitigation works such as SIS and improvements of irrigation practices, have resulted in a substantially lower river salinity at Morgan than if no further intervention was undertaken (Figure 5; MDBA, 2013).

Most importantly these modelling projects have established a collaborative process in which modellers and policy officers work together. This process has led to better models to support policy which improves salinity management.

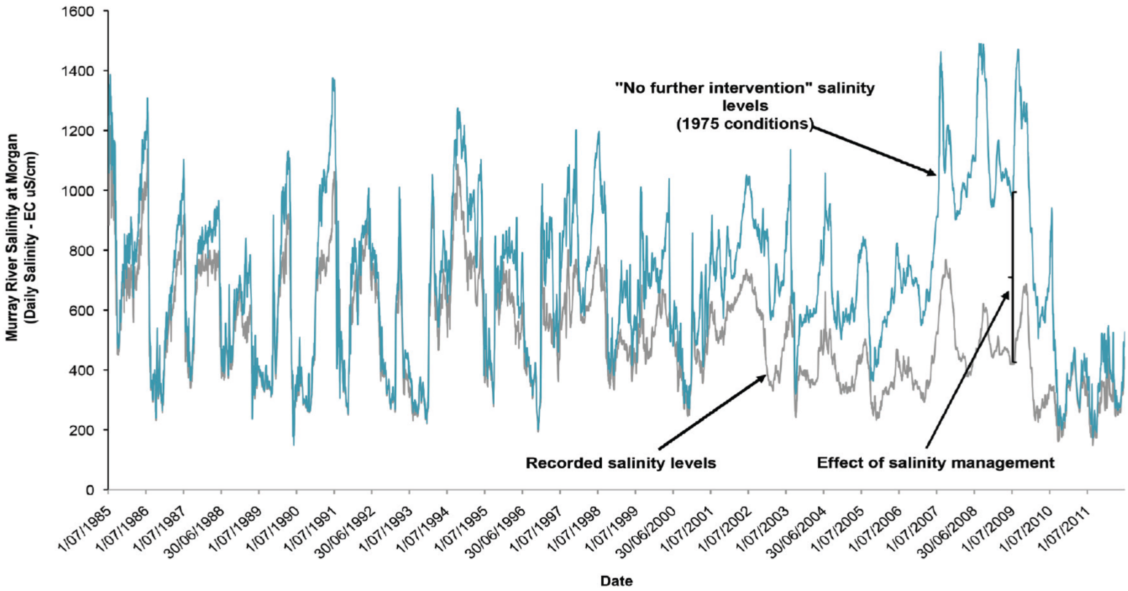

Figure 5. Comparison of recorded salinity levels (with SIS) and modelled salinity (levels without SIS) (MDBA, 2013)

ACKNOWLEDGMENTS

The projects were funded by the South Australian State Government and the MDBA.

The authors would like to thank Phil Pfeiffer, Asitha Katupitiya and Phil Cole of MDBA, Peter Forward of SA Water and Chris Wright and Judith Kirk of DEWNR for their significant contributions to the Salinity Register modeling projects.

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