Implementing Daily Salinity Models in the NSW Murray Darling Basin Tributaries

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Abstract: The NSW Salinity Strategy and Murray-Darling Basin Ministerial Council (MDBMC) Basin Salinity Management Strategy (BSMS) were developed to manage salinity in response to the findings of the 1999 Basin Salinity Audit. To understand and assess the linkage between land use change at the property scale, and the salinity response within the river system. A suite of landscape, instream, and socioeconomic modelling tools is being developed for this purpose. The instream component of the resultant modelling suite integrates salinity to the Integrated Quantity Quality Models (IQQMs) developed for daily water balance for the NSW Water Reforms and Murray Darling Basin Commission (MDBC) Cap. The objective was to produce a daily time series of salinities at key points within these river systems under current and future salinity management scenarios. The salinity modules of the IQQMs were implemented in three stages. The first stage included extensive quality assurance and refinement of the software, and a full assessment of available data. The second stage involved converting the prior work done for the salinity audit into the IQQMs, including revising the system schematics, and evaluating the results against observed data. A third conditional stage allows for model revision subject to the outcomes of this evaluation. This model implementation process has improved the understanding of, and linkages between, salt and water balance in the NSW tributaries, and set a platform to enhance capabilities in other areas of water quality modelling.

Keywords: Murray-Darling Basin, salinity modelling, IQQM,

1. INTRODUCTION

The increasing awareness of the magnitude and extent of dryland salinisation and associated water quality impacts in the Murray-Darling Basin (MDB) demands significant improvements in the modelling capabilities needed to understand and manage salinity. The information needs of natural resource managers at stages in the recent history of dryland salinity management in the MDB has largely determined the design and output of modelling work (Beecham et al., 2000). State and Basinwide strategies (NSWG, 2000; MDBMC, 2001) have specified the need to link landscape salinity management scenarios with in-stream impacts.

One component of this linkage is the implementation of salt transport models of the major NSW tributaries of the MDB. By integrating water quantity and quality, these models are designed to be able to link land based salinity management scenarios and impacts of water sharing policies, with outcomes at points of interest in the river systems.

This paper briefly reviews the background to the current modelling work, and presents the methods used to implement daily in-stream salt transport models of known reliability in the NSW part of the MDB. Stages in model implementation include software quality assurance (QA), assessing Electrical Conductivity (EC) data, introducing salt inflows to calibrated quantity models, and evaluating model results.

The model evaluation stage will report on the reliability of the model results for establishing a baseline salinity condition in the river system, and for assessing salinity impacts. The interpretation of these results will also guide how model reliability can be improved, by re-estimating model inputs, or changing model configuration, or through the collection of further data.

1.1. Background to current modelling

Modelling of in-stream salinity has a history extending back before the development of the MDBC 1987 Salinity and Drainage Strategy (SDS). Instream salinity assessment under the strategy was mostly in the context of irrigation induced salinity being perceived to be the principal cause of salinity increases in the Murray River. At a state level the modelling activities were at a local or semi-regional scale, and the results from these were assessed by the Murray-Darling Basin Commission (MDBC) for salinity impact in the Murray River, e.g. Beecham and Arranz (2001).

The complexity and scope of modelling dryland salinisation processes evolved in line with the information needs of natural resource managers, (Beecham et al. 2000). Concerns about the increase in the extent of dryland salinisation prompted an assessment of water quality data to look for evidence of a corresponding increase in in-stream salinities. The resultant Salt Trends study (Jolly et al., 1997) reported increasing EC trends over time in major and minor tributaries of the MDB.

The awareness from this study that the in-stream impacts of dryland salinisation were greater than perceived in the development of the SDS, prompted further investigations to provide information on the possible future magnitude of increased in-stream salinity. To this end, the MDBC coordinated a Salinity Audit of the whole MDB (MDBC, 1999). The methods adopted by NSW to produce these outputs linked statistical estimates of flow and salt load in tributaries of the MDB, with rates of groundwater rise in their catchments. The results of this study indicated that salinity levels in the NSW tributaries of the MDB would significantly increase over the next 20-100 years (Beale et al. 1999), with major associated economic and environmental costs.

1.2. Policy background

The NSW Salinity Strategy (NSWG, 2000) and the MDBMC BSMS (MDBMC, 2001) were developed in response to the outcomes of the Salinity Audit. The NSW Salinity Strategy adopted eight key tools to slow the rate of increase in salinity for the period to 2010. These key tools include: end of valley (EOV) salinity targets; market based solutions linked with business opportunities; improved regulation and catchment based planning; and government sponsored advice, information and scientific knowledge. This Strategy is linked to other mechanisms including Catchment Blueprints (www.dlwc.nsw.gov.au) and Environmental Services Scheme (www.forest.nsw.gov.au).

The BSMS also adopts EOV and basin targets, as well as other elements such as: managing tradeoffs with available in-valley options; assessing and implementing targeted salinity management actions, and ensuring Basin-wide accountability, monitoring, evaluating, and reporting. Salinity levels at 50th and 80th percentile non-exceedance probabilities and average annual salt loads are required at EOV sites for this reporting.

Both of these Strategies require computer models of salinity processes to assess the efficacy of salinity management scenarios such as reforestation, redesigned farming systems, salt interception works, and flow management. These models will improve our understanding of the links between catchment and in-stream salinity processes, and will allow us to assess the impact of scenarios on in-stream salinity levels.

2. MODEL DESIGN

The NSW Government and the MDBC have invested in the development of a suite of computer models to meet the needs of their respective strategies. The aim of the salt transport models is to provide daily time series salinity behaviour of the river systems under baseline conditions, and to assess the impact of salinity management scenarios on EOV targets.

2.1. Modelling framework

The salt transport models are a component of a modelling suite developed by the NSW DLWC. The other key biophysical modelling component is the CATSALT model. CATSALT is intended to provide estimates of salt loads and flows from catchments for salinity management scenarios such as reforestation and improved farming systems (Vaze et al., 2003). These flow and salt loads will then be transported through the river system using IQQM. CATSALT and IQQM combined will provide inputs to decision support systems that will allow the assessment of trade-offs between salinity management options.

2.2. Objectives

The key objective of this study is to develop salt transport models of the major NSW tributaries of the MDB that can estimate: (i) salinity concentrations and salt load at key locations under baseline conditions, and (ii) changes to these concentrations and loads levels resulting from salinity management actions.

These baseline conditions are defined as those existing at 1 January 2000, and include factors such as: (i) current salt inflows to the river system; and (ii) current water sharing policies, such as levels of irrigation development allowed under the MDBMC Cap and Water Sharing Plans.

This baseline condition will be assessed using a benchmark climatic period (1975-2000) to represent the range of climatic variability influencing flow and salinity levels.

A strategy was adopted to develop 'first cut' models using current estimates of flow and salt load, i.e., flows used in existing quantity models, and salt loads estimated for the 1999 Salinity Audit. These 'first cut' models will be progressively improved with better understanding of salinity processes.

A further objective is to clearly report the reliability of the outputs from the model, i.e., how capable are the models of meeting the key objectives. This recognises that we are still developing our understanding of salinity processes at scales from property to basinwide, and that the 'first cut' models are expected to improve. Besides assessing the reliability of the model results, the model evaluation stage of this project will recommend what parts of the model can be improved, either by: (i) improving the modelling; or (ii) improving the data describing the processes.

2.3. Geographic scope of modelling

Salt transport models are being developed for the following major NSW tributaries of the MDB: Border Rivers, Gwydir R., Peel R., Namoi R., Macquarie-Bogan-Castlereagh Rivers; Barwon-Darling R.; Lachlan R., and Murrumbidgee R. The IQQM schematisation relating to the current conditions was selected as the platform from which to develop the salt transport models.

2.4. Staged approach to salt transport modelling

A staged approach has been adopted to implement the salt transport models, with each stage providing a firm foundation for work in subsequent stages. The first stage was comprehensive testing and subsequent revision of the water quality modules in the IQQM software, and an assessment of the data available to develop the model. The second stage was inputting salt loads using the analysis from the 1999 Salinity Audit, and evaluating the model results against observed data. The third stage will be revision of model inputs and configuration as required.

3. SOFTWARE QUALITY ASSURANCE AND DATA ASSESSMENT

3.1. IQQM software

The IQQM software has been undergoing continual development for over ten years, and has been designed to simulate the key physical and management processes operating in regulated and unregulated river systems. These processes include inflows, water storage, flow routing, irrigation diversions, and water sharing rules (DLWC, 1995). The software has been applied to many large river systems in NSW and Queensland, and recently in the Mekong River Basin. Water quality modules have been incorporated from an early stage (Javam et al., 2000), and have been applied elsewhere in NSW for salinity (Gilmore et al., 2000).

3.2. Software QA

The tributary models together encompass most of IQQM's functionality, including complex water sharing rules. This complexity, the geographical scope and accountability for model results, warranted intensive QA of the software. The modellers had to be confident that undocumented software features (bugs) were eliminated from IQQM. QA tests were devised to ensure that the IQQM did not create or destroy mass, and that hydrologic routing was reflecting salinity behaviour recorded by continuous salinity probes along the major tributaries. Aspects of this work are discussed in Davidson and Salbe (2003).

3.3. Data assessment

EC data has been collected in NSW for thirty or more years at several hundred locations, mostly corresponding to stream gauging stations. The majority of data sets are discrete, with intervals between observations typically 1-2 months. In recent years, a number of continuous EC probes have been installed along the major tributaries at key locations. The EC data on the minor tributaries was used to estimate salt inflows to the salt transport models. EC data from sites on the main rivers is being used to test how well the model reproduces observed results.

Processes affecting water quality are more complex than those affecting quantity alone. However, we have orders of magnitude less water quality data to analyse and estimate these processes. Therefore, any conclusions on model reliability need to consider how much data there is to assess model results.

The available data was matched to locations where model results were reported. These data sets were then screened to eliminate unreliable results; either outliers tested in-situ, or by comparing with results at other stations. This screening removed less than 1% of discrete data points, and up to 10% of continuous data. Cases where continuous EC data was rejected are such as that shown in Fig. 1, where the initial flow peak (upper plot) was not accompanied by an expected corresponding reduction in salinity (lower plot).

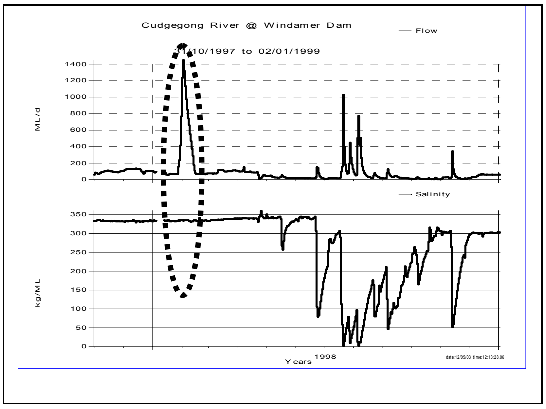

Figure 1. Example of Flow v EC reliability check showing EC data error

Data sets accepted as reliable were then tested for how well they represented hydrologic variability over the benchmark climatic period. A data set that only sampled part of the flow regime (e.g., low flows), or only sampled a short period over the 25 year period, would not be as good an evaluation data set as one that sampled all parts of the flow regime and for a longer period. In-stream levels of salinity are affected by a number of factors, including: geographical source of streamflow; whether it is from baseflow or surface runoff; seasonality; degree of flow regulation; and antecedent conditions. EC data has then to adequately represent these factors to provide a data set good enough to test the model results.

Measures of the accuracy of the salinity data levels then included: (i) comparing the flow distribution on the days EC was observed against the flow distribution of the benchmark period: (ii) number of EC measurements; (iii) period over which the EC data was collected; (iv) seasonal distribution of EC data; and (v) total number of months EC data was collected. The last test was used to account for the serial correlation of data implicit in continuous data. Comparison of the flow distributions for the example in Table 1 shows that the distribution of flows when EC data is collected is lower than the distribution flows for the benchmark climatic period for all flow ranges.

Table 1. Summary statistics of flow for all benchmark period and flow with EC data

Flow range	Data set	Flow (ML/d)			
		Mean	**SD**	**Min**	**Max**
Low	All	140	59	6	342
	EC data	*125*	*63*	*9*	*298*
Medium	All	866	583	227	2389
	EC data	*755*	*551*	*231*	*2352*
High	All	6098	8339	2391	120784
	EC data	*4792*	*2639*	*2465*	*14467*
ALL	All	1768	4345	6	120784
	EC data	*1370*	*2064*	*9*	*14467*

4. MODEL DEVELOPMENT

4.1. Salt inflows to quantity IQQMs

The 'first cut' model strategy used estimates of salt loads reported in Beale et al. (1999) as inflows to the daily salt transport models. These salt loads were estimated at inflow points corresponding to those used in the quantity IQQMs, using statistical relationships between salt loads and flow. The salt balance for the river systems were then calculated using monthly spreadsheets of flows and salt loads.

The same statistical relationships were used to estimate daily salt loads to the salt transport models. IQQM was enhanced to allow direct input of model form and parameters reported in Beale et al. (1999). Modifications were made based on regionalised parameters where catchment delineation in IQQM differed from that used in the previous study. For the case of the Barwon-Darling IQQM, EOV outflows from the Border Rivers, Gwydir R., Namoi R., and Macquarie-Bogan-Castlereagh Rivers models will be used as the model inputs, along with inputs estimated by Queensland.

4.2. Model evaluation

The objective of the model evaluation is to report how reliable the model results are for the intended purpose, i.e, estimating baseline salinity conditions, and estimating instream impacts of salinity management actions. Further, interpretation of the model evaluation results will guide improvements to model upgrades beyond the 'first cut' version.

The model results will be evaluated by comparing against the accepted observed data sets for different flow ranges: High (0-20% exceedance probability over the benchmark climatic period); Medium (20-80%); and Low (80-100%). Flow exceedance probabilities are used as an indicator of the as yet unknown salinity exceedance probabilities required for BSMS reporting. By taking this approach we can make a statement that, as an example, a model might estimate low flow salinities well, but overestimates medium flow range salinities.

The models used are configured to reflect current water sharing conditions and do not necessarily reflect the actual water balance at the time an EC observation was made. This created an issue for comparing model salinity results against observed data. Differences in flow between simulated and observed will change salt loads and resultant concentrations, making it difficult to differentiate between errors from water balance and other errors. The model configuration was refined for the purposes of evaluation to match as closely as possible the observed water balance. This included forcing inflows to and releases from the storage.

Statistical tests were used to provide measures of model performance by comparing for each flow range simulated and observed: (i) loads into storages ; (ii) patterns of increasing or decreasing concentrations in storages; (iii) flow adjusted salt loads in-stream; (iv) mean in-stream concentrations; and (v) standard deviation of in-stream concentrations.

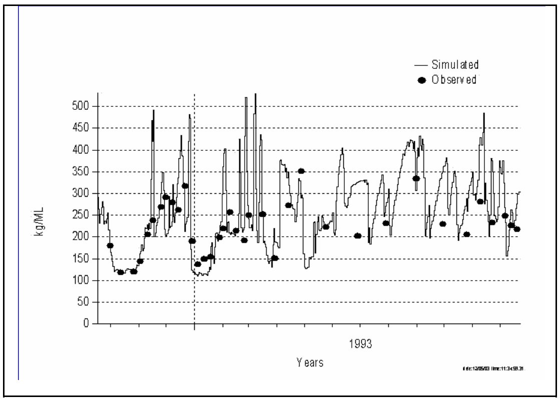

Figure 2. Initial results of simulated v observed salinity concentrations at 418013.

At the time of writing, the model results are being evaluated. Preliminary indications are that results are variable, models reproduce observed salinity quite well across all flow ranges in some cases, and others are systematically under or overestimating salinities. A plot of *simulated v observed* salinity is shown at Fig. 2, with close matches in the earlier period, and less matches for the later period. Summary statistics for the full data set are reported in Table 2.

Table 2. Preliminary results for salt concentrations for Station 418013

Flow range	Data set	Salinity (mg/l)			
		Mean	**S.D**	**Min**	**Max**
Low	Obs	294	84	167	482
	Sim	*365*	*120*	*185*	*702*
Medium	Obs	232	97	95	518
	Sim	*214*	*80*	*90*	*470*
High	Obs	136	53	79	269
	Sim	*137*	*45*	*85*	*226*
All	Obs	228	101	79	518
	Sim	*234*	*116*	*85*	*702*

5. DISCUSSION

The tests for model reliability will inform natural resource managers how well the model simulates salinity behaviour for different flow ranges at key locations in the river system. Interpretation of these results is expected to guide revisions of the modelling. This stage of the modelling is currently underway. We anticipate that there will be areas of the ‘first cut’ modelling that can be improved over time. Possible causes for systematic differences that may need to be addressed include the estimates of salt inflows, estimates of flows from ungauged catchments, and un-modelled groundwater interactions.

6. CONCLUSION

The implementation of these daily instream salt transport models at this scale and geographic scope is a key component in implementing the NSW Salinity Strategy and the BSMS. The salt transport models provide the key linkage between catchment salinity management actions, and impacts on in-stream salinity, as well as being able to assess impacts of water sharing policies on salinity.

Water quality modelling capabilities have been substantially enhanced in the process of implementing these models. Water quality modelling has not been attempted at this scale and detail. Several new procedures have been rigorously developed to provide transparent implementation of the models, and evaluate the results in a meaningful manner to natural resource managers. The testing and enhancement of the water quality modules of IQQM will provide a reliable platform for modelling other water quality constituents.

These procedures have been peer reviewed at regular stages in the implementation by key users of the model results, both internally within the department, and also by the MDBC. This review process is important for acceptance of the model results.

The water balance has been shown to be crucial to producing reliable water quality results. The models could not have been developed to the current extent without the substantial work that has gone into implementing daily water balance models of the river systems.

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