Implementation of an Integrated Quantity and Quality Model for In-Stream Salinity in the Hunter Valley, NSW, Australia

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Abstract: Increases in in-stream salinity from dryland salinisation is a significant natural resource and environmental issue. An element of the NSW Salinity Strategy is to set end of valley and within valley targets for salinity management. The assessment of targets required prediction of future increases. Tools are available to estimate salt exports at point, hillslope and small catchment scales. However, to assess the contribution of tributaries to valley targets, an integrated river basin model is needed. The Integrated Quantity and Quality Model (IQQM) of the Hunter River provided a framework to meet this need. Salt loads and salinities were estimated for a number of tributaries, providing inputs to the IQQM from Glenbawn Dam (catchment area 1,300 km^2) to Greta (17,500 km^2). IQQM was calibrated on continuous observed data on the mainstream. A Current Conditions scenario applied river operations and development as at the year 2000 over the entire 1975-98 climatic period. The Current Conditions scenario was then used as a base case to compare future increases against. Salt loads from the tributaries for future conditions were based on hydrogeological analysis of groundwater level changes. The impacts of these changes on concentrations in the mainstream at key locations down the system were assessed. Results for IQQM calibration with observed data, current conditions base case, and changes are presented in this paper. There are some issues in the existing implementation of the Hunter IQQM that need to be addressed in the future to provide a more accurate representation of sources and magnitudes of salt. The future changes from dryland salinity only, produced a small increase from the base case mainstream salinities. The study highlighted the potential for salinity problems in some tributaries, although the extent is unknown due to lack of suitable data. The method used for modelling groundwater and surface water interactions created uncertainty in both current and future predictions that will be significant at lower flow ranges.

Keywords: Salinity, Hunter River, Groundwater, NSW Salinity Strategy, Model, IQQM

1. INTRODUCTION

Increases in in-stream salinity from dryland salinisation is a significant natural resource and environmental issue. An element of the NSW Salinity Strategy is to set end of valley and within valley targets for salinity management. The assessment of targets required prediction of future increases under the historic climatic period of 1975-98 [NSW Govt., 2000]. Sets of salinity export rates may be generated by various methods that are appropriate to point, hillslope and small catchment scales within a catchment. The contribution of salinity sources to end of valley and within valley targets is best determined using an integrated salinity basin model.

Previous work done for the major subcatchments of the Murray Darling Basin (MDB) estimated tributary salt loads. These were aggregated to a monthly timestep and transferred to end of system with a simple spreadsheet mass balance [Tuteja et al., 2000]. This method for estimating salt load contributions from tributaries has been adopted in the Hunter with minor modifications.

Shorter timesteps for transporting flow and salt are needed to account for individual tributary behaviour and dam operation on mainstream salinities. The daily Integrated Quantity Quality Model (IQQM) [DLWC, 1995] of the Hunter River provided a framework to meet this need. IQQM assumes fully mixed flow and uses short computational time steps to route salt [Javam et al., 2000].

The Hunter IQQM has been calibrated for current conditions, using recorded data for the period

1986–91. It has been used since 1998 to investigate options for modifying operations.

Much of the Hunter catchment has saline geology, and mines and power generators release saline water into the Hunter River as part of a managed discharge scheme [EPA, 1995]. This scheme involves real time monitoring and forecasting of flow and salinity to identify 'windows of opportunity' for saline water discharge. The Hunter IQQM has been used as a predictive tool to manage these discharges [Simons et al., 1996]. This modelling commenced in 1995 and only included the mainstream from Muswellbrook down to Greta. In order to use the water quality capabilities for longer term scenario runs, it was necessary to extend the modelling period, and also to subdivide the catchments to assess current and future cumulative impacts of tributaries.

This paper addresses model calibration on observed data for 1993-98, and model implementation for current and future scenarios for the climatic period from 1975-98. References to calibration in this paper, apply to the salinity calibration of the Hunter IQQM flow model.

2. METHOD

2.1 Overview

The Hunter valley sub-catchments used in this study are shown in Figure 1. Tributaries are defined as the area above a gauging station. The remaining ungauged area downstream is referred to as residual catchments (A to F). Individual sub-catchments range in size from 200-1900 km^2, except for the Goulburn River catchment (6,800 km^2). The total area modelled was 17,500 km^2.

Relationships were established between salt load and flow using observed data for each tributary. These relationships were then used to generate a daily time series of salt loads from flows for 1975-98. For catchments with no observed salinity data, salinity parameters were regionalised based on catchment characteristics. The mainstream calibration was done in IQQM against observed continuous data at 5 locations in the Hunter R., and 1 location on Glennies Ck. The calibrated salinity inputs from tributaries and groundwater contributions were then input to the IQQM Current Conditions model, producing daily time series of flow and salinity for the mainstream from 1975-98. The Current Conditions model applies river operation and development as at 2000 for the entire 1975-98 climatic period. Future scenarios were adopted by using the current conditions model, with the addition of predicted increases in salt load based on a hydrogeological analysis.

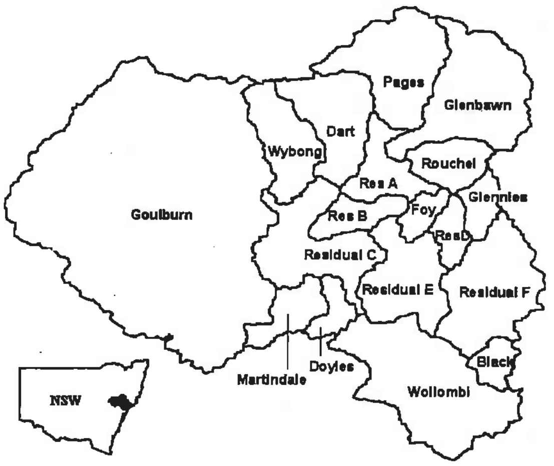

Figure 1. Hunter valley sub-catchments.

2.2 Data Available

Continuous flow records exist for most of the Hunter valley for the entire 1975-98 period. The missing flow data was filled using the Sacramento rainfall runoff model, or by correlation with another station. Electrical conductivity (EC) data was available for the 11 tributaries as follows: 7 tributaries had 3-8 years of continuous data (range 90-3500 μS.cm^{-1}), and 4 tributaries had 30-110 discrete data points (range 60-4000 μS.cm^{-1}). The remaining gauged tributary and the 6 residual catchments had no EC data. There were 6 mainstream calibration points with 7-9 years of continuous EC data (range 90-1500 μS.cm^{-1}). Continuous salinity data was extracted on an hourly basis and flow weighted to average daily values. Some continuous observed data was rejected based on quality codes of either flow or salinity.

2.3 Tributary Contributions

Details of the stochastic models used in the MDB audit are presented in Beale et al. [2000]. These were used in this study to characterise salt contributions from tributaries in the Hunter River system. In summary, they provide options for examining relationships between flow and salt load, flow and salinity using linear or non-linear regressions, and options for examining seasonal and time dependant effects. All models were tested with the data available. Inclusion of time dependence and seasonality did not add additional accuracy over the simpler regression models and so were not used for salt load or salinity generation.

Model choice was done by visual inspection of associated plots for the following; a) whether the data needed to be transformed (linear or non-linear model forms), b) the ability of the model to represent seasonality in salt load, c) the ability of the model to reproduce the cumulative probability distribution function of the daily salt load and salinity time series, d) scatter about the regression line and R^2 of observed verses estimated salt loads.

In the majority of cases, the model chosen performed the best in all the selection criteria. This was the non-linear and non-seasonal model IID, which transforms the data by the natural logarithm and fits parameters by regression. The simple linear model IIC was only used for some continuous 'extreme events' data, where there were few data points and less significant variations in salt washoff response. Detailed method and results for the tributaries are reported in Beale et al [in press].

2.4 Mainstream IQQM Calibration

The calibration points for the mainstream Hunter River were Muswellbrook, Denman, Liddell, Singleton, and Greta (Figure 2). Glennies Creek at Middle Falbrook was also used as a calibration point. The Hunter River at Greta represented the end of system for this study.

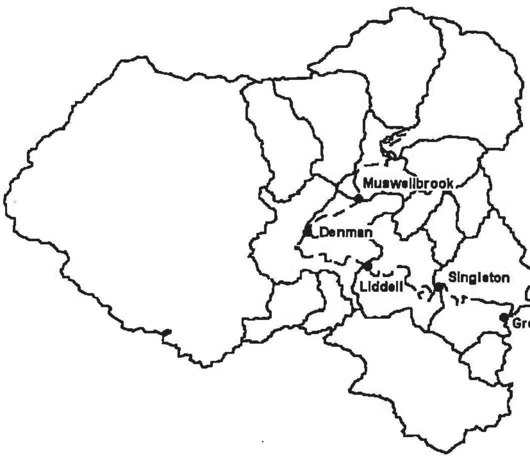

Figure 2. IQQM calibration points.

The calibration was done firstly, by forcing observed flows and salinities at the upstream gauge, and adding the tributary inputs and estimating the groundwater contributions at the downstream gauge for each river section. Secondly, the system was modelled from the top down, where cumulative model errors were assessed. The calibration period varies where continuous observed salinity and flow data was available, and was generally 1993-98.

Groundwater contributions are thought to be mainly where the Hunter River intercepts major fault zones, and were added as constant loads to the river for this study. The size of the constant loads was estimated by tracing dam releases and matching the observed salinity at the downstream gauge. However, groundwater and surface water interactions should be explicitly modelled in future studies.

2.5 Future Conditions IQQM

The hydrogeological analysis involved predicting the mass of additional salt discharging to the land surface at the target dates, based on observed rates of groundwater rise. Topographic effects were included using the FLAG model [Dowling, 2000], to estimate the maximum potential discharge area likely to contribute salt at the target dates. A more detailed explanation of the method and results are presented in Beale et al. [in press]. Calculated potential salt loads from groundwater discharging to the surface were assumed to transfer directly into the stream.

Future in-stream scenarios were adopted by using the current conditions IQQM, with the addition of predicted increases in salt load from the hydrogeological analysis. Two methods of transferring the salt were used; matching of the salt delivery to the flow and salt load distribution currently observed in stream, and a simple addition of a constant daily loading for each tributary. The first approximates the current build-up and wash-off characteristics observed, and the second assumes all increases will contribute to the streams as baseflow.

3. RESULTS AND DISCUSSION

Results for the IQQM reach by reach calibration, and the top down check of cumulative errors, are shown in Table 1. Mass % refers to the total mass or volume modelled, divided by the total mass or volume observed for the period, expressed as a percent.

The flow calibration period of 1986-91 being different from the salinity calibration period, (generally 1993-98) caused problems. The flow calibration was not adequate for salinity calibration for Liddell and Greta without modification, as significantly more baseflow was modelled than observed. This is an artefact of different calibration periods, and differing groundwater interaction behaviours over those periods. Since groundwater interactions are not modelled explicitly, an adjustment to the flow

Table 1. Results of IQQM reach calibration and top down calibration check.

River Reach	Period	No. points	Catchment Area km^2	Reach by Reach Calibration						Top down	
				Flow	Salt Load			Salinity		Salinity	
				Mass %	CD	CE	Mass %	CD	CE	CD	CE
Glenbawn Dam to Muswellbrook	1992-98	2341	4220	111	0.7	0.7	103	0.6	0.6	n/a	n/a
Muswellbrook to Denman	1993-98	1824	4530	87	0.9	0.8	101	0.8	0.8	0.5	0.3
Denman to Liddell	1991-98	2843	13400	102	0.8	0.8	101	0.6	0.6	0.6	0.6
Glenninies Dam to Middle Falbrook	1993-98	1859	466	93	0.5	0.4	102	0.4	0.4	n/a	n/a
Liddell to Singleton	1993-98	1942	16400	98	0.8	0.6	81	0.7	0.5	0.5	0.3
Singleton to Greta	9/1995-98	1198	17320	110	0.8	0.5	117	0.7	0.6	0.5	0.3

balance was done in the calibration of these reaches by mass balance, excluding differences due to timing problems. These adjustments did not affect the in-stream concentration as they were taken out in a similar manner to diversions. They represent less than 10% of the total flow over the calibration period, for both Liddell and Greta. The flow adjustments were not included in the 1975-95 current conditions run or future scenarios as they are period specific. This behaviour highlights the need for groundwater and surface water interactions to be modelled explicitly in the Hunter IQQM.

The results for the mainstream calibration were reasonable considering how little continuous EC data was available for the tributaries. Whilst individual events cannot be modelled well when tributary contributions were not measured, their contribution to mainstream behaviour is represented well. This is shown by salt load and salinity percent exceedence plots for the calibration periods (Figures 3-4). Model underestimation in Figure 3 in the 70-100 percent non-exceedence range is predominantly in 1992. There was no upstream or downstream data in 1992 to verify the observed data. It is not justifiable to adjust the calibration for 1993-98, on this 1992 deviation. This problem may be due to measurement errors or failure of the present audit model to represent all dominant processes contributing to the salinities at Muswellbrook. Further work on groundwater and surface water interactions may shed light on this apparent anomaly. The reasonable model fit for 1993-98 is because of the significant groundwater contributions of salt, and the tendency for regulated water from the dam to dominate the salinities observed at Muswellbrook.

Where mass balance and related statistics can be strongly influenced by individual events, the percent exceedence plots give a better indication of how the model performs overall. Deviations for the top down calibration appear firstly at Greta. These occur in the 0-10 and 90-100 percent ranges and so are not likely to impact the 50 and 80 percentile ECs reported for current and future conditions (Figures 5-6).

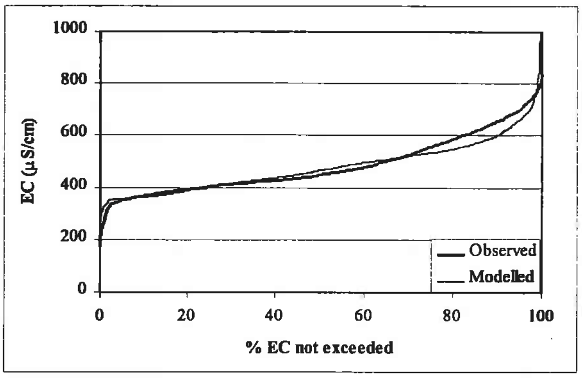

Figure 3. IQQM reach calibration of salinity for Glenbawn Dam to Muswellbrook, 1992-98.

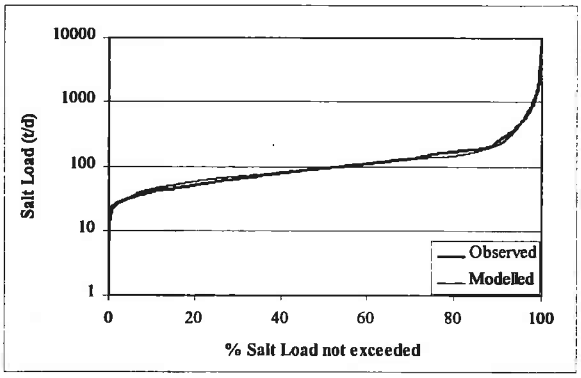

Figure 4. IQQM reach calibration of salt loads for Glenbawn Dam to Muswellbrook, 1992-98.

Salinity in the mainstream river at any point in time is determined by the amount of flow and the source area contributing. That is rainfall, runoff characteristics, and distance to the mainstream, are not distributed evenly over the whole catchment, and thus tributaries vary in their contribution and timing with each event. Accounting for contributions of flow and salt from ungauged catchments on a point basis rather than a distributed basis is difficult in a model such as IQQM. Flow source and time of arrival is significant for modelling in-stream concentrations.

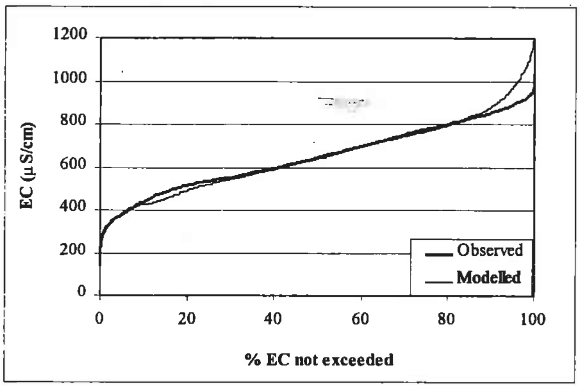

Figure 5. IQQM top down calibration check of salinity for Singleton to Greta, 9/1995 to 1998.

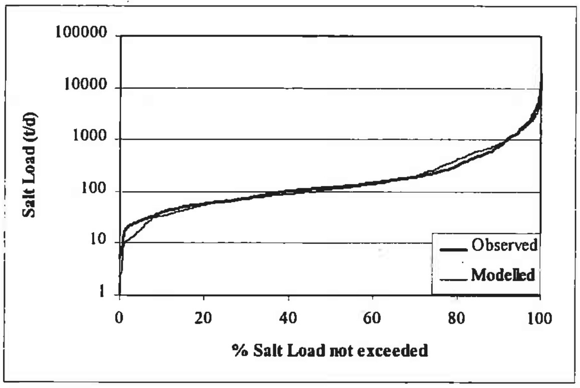

Figure 6. IQQM top down calibration check of salt loads for Singleton to Greta, 9/1995 to 1998.

Future improvements in catchment contributions to account for the spatial and temporal delivery of salt instream, particularly for ungauged catchments, could be integrated in IQQM. Improvements would need to be made by breaking the catchment into smaller parts, and accounting for system losses and groundwater interactions, for which, sufficient data and techniques have not yet been available. Including improved salinity information would probably require recalibrating the existing flow model. Basic data constraints and lack of a suitable catchment model means time variant washoff characteristics could not be included. Rising and falling limbs, time of concentrations, different soil types, geologies, topography, land use, antecedent conditions, and recharge/discharge characteristics all contribute to salt washoff processes.

Significant groundwater contributions occur in specific reaches where the river intersects major geological fault lines. During lower flows, when median to higher ECs are typically experienced, these groundwater fault zone interactions are the dominant influence on the salinity in the main stream. During higher flow events, salinity in the main stream is dominated by wash off from the tributaries. Which catchment is contributing and the timing of each contribution is significant. The significance of any particular sub-catchment to the mainstream concentration reduces progressively downstream since the relative contribution of the tributaries becomes smaller.

Flows in the 1993-98 period are representative of flows in the 1975-98 period in the 10-85 percentile exceedence range. The 1993-98 has lower frequency of larger events, and higher frequency of low flows. The low flow difference is affected by regulation and groundwater recharge/discharge. Stochastic models fitted to discrete salinity data for the Hunter river at Muswellbrook, Denman, and Liddell for the early period, compared reasonably with the observed salinity distribution in the later period. Whilst the build up and wash off processes for the larger events in the early period will differ, it is not known by how much since they were not sampled for salinity. The limited salinity data suggests that for the majority of the time, the 1993-98 period is representative of the 1975-98 period on the mainstream.

The constant groundwater load added represents an average contribution for the observed data period. The recharge and discharge characteristics will change over time due to climatic variations, and will significantly effect EC percentiles in the future. It was also assumed that these groundwater contributions have no trend into the future, which has not been studied. Since these have been identified as being significant, groundwater interactions should be accounted for explicitly in the IQQM.

The method chosen to transfer the future groundwater potential salt load to the stream had only a small impact on the mainstream salt load, but made a considerable difference to the predicted distribution of salinity. The current distribution method resulted in slightly higher estimates of salt load than the constant load method, but returns lower median and 80th percentile salinities. The current distribution method is more realistic, and these results are presented in Table 2. These results compare salinities at the target dates to those for the current condition, and are reported to a greater accuracy than they can presently be measured.

The trends in salinity predicted as a consequence of dryland salinity processes only are not great. The mainstream salinity values are not predicted to rise by more than 10% over the next 100 years for the most likely case. Change predicted in some tributaries will be greater, with a 10%, 13% and 33% change over 100 years predicted for Wybong Creek, the Goulburn River and Dart Brook respectively. Water users across the catchment are already experiencing the management risk implications of the salinity levels identified in the study. Surface water salinity already presents threats to the wine industry, power generation and town water supplies. The trends show a gradual worsening of these current threats.

Table 2. Current and Future median and 80th percentile salinities ($\mu S.cm^{-1}$) 1975-98.

Location	Percentile	2000	2010	2020	2050	2100
Muswellbrook	50th	485	500	510	520	525
	80th	625	640	655	670	675
Denman	50th	565	580	590	605	615
	80th	775	795	810	830	840
Liddell	50th	720	730	745	765	780
	80th	940	960	975	1005	1025
Glennies Ck at Fal	50th	445	450	450	455	455
	80th	570	575	575	585	585
Singleton	50th	670	680	685	705	715
	80th	925	935	945	970	980
Greta	50th	670	680	685	700	710
	80th	905	915	925	945	955

4. CONCLUSIONS

Calibration of salinity in the Hunter IQQM for the observed period 1993-98 was adequate for assessing future impacts of dryland salinity. The Current Conditions model results for the 1975-98 climatic period provided a base case to which future salinity increase scenarios could be compared. Comparisons for various increases in dryland salinity from the tributaries showed only a small increase from the base case mainstream salinities.

The study highlighted the potential for salinity problems in some tributaries, although the extent is unknown due to lack of suitable data. Continuous salinity and flow data, and more detailed bore information, would help to understand processes in those catchments, and thus allow better predictions to be made.

Groundwater and surface water interactions were assumed to have no trend, and not be influenced by climatic conditions. This created uncertainty in both current and future predictions that will be significant at lower flow ranges.

5. REFERENCES

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