Data Driven Model Development for Estimating Salt Export from Irrigation Areas

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Abstract: Land and Water Management Plans (LWMPs) were developed for the Murray region irrigation areas in 1995 to improve economic and environmental sustainability. These LWMPs needed to be assessed under the Salinity and Drainage Strategy (SDS) to determine their effect on salinity in the Murray River. The assessment required estimating flow and salt exports for a number of scenarios. The LWMP areas are dominated by shallow watertables with an underlying rising trend coupled with climatically driven fluctuations. Salt is exported by two pathways: seepage of groundwater directly into drainage lines; and mobilisation of salt to the surface and subsequently in surface runoff. The assessment required the development of a robust modelling system to estimate changes in water levels over time, and estimate salt export by the major pathways. The assessment also had to be flexible enough to account for complex management changes described in the LWMPs. After initially adopting a complex integrated modelling system with limited success, a revised modular modelling approach was adopted where model components represent catchment hydrologic response in a simple manner, and encapsulate available data. Historical monthly groundwater levels were interpolated spatially resulting in a verifiable estimate of watertable behaviour, and simple assumptions were used to predict future watertable changes. These groundwater levels were used as inputs to surface runoff models coupled with simple estimates of salt washoff, and to estimate seepage of saline water into drains. The effect of assumptions in the model components were tested by sensitivity analysis.

Keywords: Salinity; Shallow watertables; Murray River; Modelling; IQQM

1. INTRODUCTION

Changes in salt and water exports from irrigation areas needed to be estimated for Murray-Darling Basin Commission (MDBC) salinity accounting purposes. The complex nature of the hydrologic systems and the need to provide reliable and robust estimates, required a comprehensive integrated modelling system.

1.1. The Study Area

The Murray Region irrigation areas and districts; Berriquin, Cadell, Denimien and Wakool, are located in the Southern Riverina area of New South Wales (NSW), and cover an area in excess of 8,000 km^2. The development of irrigation from the 1950's significantly changed the water balance in these catchments, resulting in large areas of land affected by high watertables from the 1980's. The catchments also experienced significant surface drainage problems, manifested in significant water ponding of productive agricultural areas.

1.2. Land and Water Management Plans

The deteriorating economic and environmental conditions combined with a privatisation policy in the early 1990's, highlighted the need for an integrated and comprehensive approach to manage the problems in these catchments. This approach took the form of Land and Water Management Plans (LWMPs), developed by the community in consultation with State and Local Government organisations. The LWMPs had the objective of managing land salinity, high watertables, and water ponding to ensure the agricultural productivity and environmental sustainability of the catchments [BLWMPWG, 1995].

The LWMPs had a range of elements for these purposes. These include structural elements such as improvements in surface drainage, sealing of leaky supply channels, and pumping from shallow groundwater, as well non-structural elements such as changes in irrigation scheduling, and recycling of irrigation tailwater. These elements were intended to reduce local recharge of water to the unconfined Shepparton aquifer, reduce the areas of high watertables, and reduce the incidence of water logging. However, these actions would also change the amount of salt and water leaving the catchments, and entering the Murray River.

1.3. Modelling Requirements

The LWMPs had to be assessed under the provisions of the MDBC Salinity and Drainage Strategy (SDS), as they were 'actions' that could significantly affect salinity in the Murray River. This assessment required estimating changes in flows and salt leaving the catchment as a result of elements in the LWMPs. The changes were relative to a 'base case', defined as the physical and management conditions that existed at 1/1/1988; the date the SDS was adopted. A preliminary assessment was carried out at the time the LWMPs were finalised, and the four plan areas combined were assessed as having an effect of increasing EC in the Murray R. at Morgan by 5 EC units. However, a more comprehensive assessment was needed.

The catchments had to be modelled for at least two scenarios: the 'base case' (BC), and the 'with plan' (WP) case. Additional scenarios were also modelled to provide information to make decisions on associated salinity accounting issues. Key processes that needed to be modelled included: shallow groundwater level behaviour; changes in this behaviour as a results of reductions in accessions from a range of plan elements; deep aquifer interactions; surface runoff and drainage; on-farm recycling; seepage of groundwater into drains; land salinisation; and salt washoff. The modelling assessment period was originally 1975-1985. For this project, the 1975-2000 climatic record was used to allow for a proposed extension of the assessment period by the MDBC.

2. METHOD

2.1. History

Salinity assessment of the Murray Region Land and Water Management Plans was carried out in 1995, resulting in an interim listing for a 5 EC salinity effect for all the four plan areas combined. This assessment was done using a simple method, focusing on the additional volume of water from additional areas drained, as well as a GIS based method to estimate groundwater flow into the additional drains, over the climate period 1975-85.

The modelling to carry out this comprehensive assessment has evolved, from an integrated modelling system, to a decoupled version of this system with additional customised modules, to a data driven modelling system.

2.2. Integrated Modelling System

The modelling was initially attempted using Mike-SHE, a complex, physically based, integrated surface-groundwater hydrological modelling system [DHI, 1993], with a 2 km resolution. However, difficulties in validating the surface water outputs of the model, as well as conceptualising the modelling for the detail in the plans, prompted an external review of the method and results. The reviewers concluded that: more attention needed to be paid to measurement, analysis, and incorporation of existing data, the model was too complex for the intended purpose, and that this complexity had decreased the predictive ability of the model. The reviewers stressed that the model complexity had to be matched to available data. Alternatives to the modelling were suggested, and included decoupling the surface and groundwater components of the model.

2.3. Decoupled Modelling System

The approach taken to complete the task was to model the system using linked modules of a level of complexity appropriate to the data and our understanding of the system. Numerous assumptions were made in developing the modules. The significance of these assumptions was tested by sensitivity analysis. As will be seen, the salinity assessment results were not sensitive to some of the assumptions made, but were quite sensitive to other assumptions.

A model framework was designed that included the saturated zone (SZ) and unsaturated zone (UZ) components of the integrated modelling system, to take advantage of work already done. Decoupling these components allowed the modellers to focus on the outputs from each component independantly, and also decreased the run times of the model, even allowing for an increase in resolution from 2 km to 0.5 km. Separate model components were developed to model groundwater seepage to drains, as well as surface drainage. The models were linked as shown in Figure 1.

The advantages of separating the modelling system into modules allowed for better description of the subsystems. Each module attempts to reliably reproduce the behaviour of the subsystem. Changes could be made to any module without producing unforeseeable changes in other modules, and each module was calibrated with data where possible.

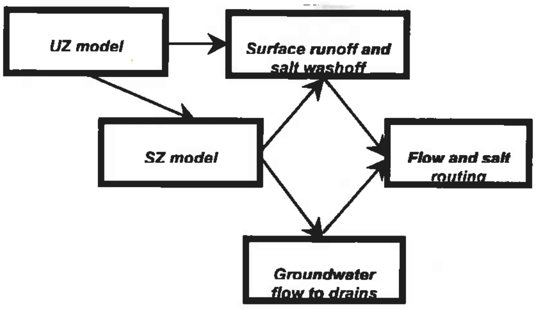

Figure 1. Decoupled modelling system.

2.3.1. Unsaturated Zone Model

The UZ model [DHI, 1993] used rain, PET, and irrigation estimates, and soil properties to produce time series of recharge and infiltration excess for the key combinations of: soil types, (sand, clay loam, and clay); land use types (dryland, annual crop, perennial crop, rice); detention storage depths (5 mm and 30 mm); and for shallow and deep watertable conditions. UZ runoff and recharge estimates were calibrated based on comparison with recorded data in the SZ model, and the surface runoff model.

2.3.2. Saturated Zone Model

The SZ model [DHI, 1993] used recharge from the UZ model as an input, with aquifer geometric and hydraulic properties, to simulate groundwater levels. Distributions of soils were based on published soil maps, and crop distribution was based on remote sensed imagery for one season. These were combined to match the UZ combinations. The SZ model parameter values were calibrated to groundwater levels that had been collected over a period of 25+ years at six monthly intervals for a bore network of several hundred bores.

2.3.3. Surface Runoff and Salt Washoff Model

The surface runoff model is a GIS based program that aggregates overland flow output from the UZ model to produce total infiltration excess for subcatchments. These programs were developed in-house. Water levels from the SZ model determined if the shallow watertable or deep watertable runoff sequence should be used. The total infiltration excess was multiplied by a drainage factor, estimated by field inspection, to produce a subcatchment surface flow time series.

The associated salt washoff model is a grossly simplified representation of the process, as the data did not justify using a complex model Salt concentrations were estimated based on the soil type, land use type, depth to groundwater, and salinity of groundwater (1,000-20,000 mg/l). All runoff was assumed to have a salinity of 100 mg/l based on EC values of runoff hydrographs in the catchment, except for dryland areas with shallow watertables. These cases were assumed to have a concentration of 10% of the concentration of the underlying groundwater.

2.3.4. Groundwater Flow into Drains Model

The module estimating groundwater flows and salt loads into drainage channels uses a similar procedure to that in MODFLOW [McDonald and Harbough, 1985] based on Darcy's Law. This component was developed in-house. The module uses monthly series of groundwater levels from the SZ model for cells next to drains, the daily water level in the drains, soil type, and drain depths and widths. The water level in the drains was calculated from modelled flow using Mannings equation. Salt loads were estimated as the product of the groundwater flow, and the groundwater salinity.

2.3.5. Flow and Salt Routing Model

The daily time series of surface flow and salinity, and groundwater flow and salinity were inputs to the Integrated Quantity Quality Model (IQQM) river system model [DLWC, 1995]. IQQM aggregated and routed flow and salt to produce a time series of flows and salt loads at the end of the river system.

2.3.6. Outcomes of Decoupled Model

The modelling framework described worked well with the exception of the SZ component. Difficulties with getting a robust calibration were attributed to uncertainties in the input data: primarily the land use distribution, but also including soil distribution and properties. Land use was treated as a constant, whereas in reality the amount and distribution of different land uses would change from year to year. The cost of obtaining this data would have been prohibitive. Pressures to extend the time span of the modelling, and to extend this modelling to the remaining LWMP areas required a more reliable, and efficient way of modelling groundwater levels.

2.4. Data Driven Modelling System

2.4.1. Groundwater Levels

The groundwater measuring network provided the solution to representing groundwater behaviour. The network was reasonably dense, with a total of approximately three thousand bores across the four LWMP areas. The bores were generally set out in grid formation, with a spacing of approximately 2 km in the north-south direction, and 10 km in the east-west direction. Groundwater level maps interpolated from these points would provide a reliable representation of the piezometric surface of the Shepparton aquifer.

The other modules remained the same. However, as the recharge estimates are incorporated in the interpolations, the linkage with the UZ model was no longer needed (Figure 2).

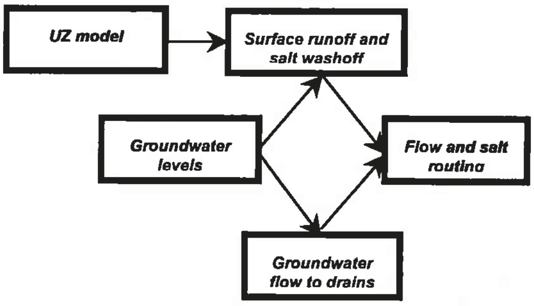

Figure 2. Data driven modelling system.

The observed bore readings were rigorously quality checked to remove suspect data, and then filled by correlation to produce a data set of monthly water levels at all bore locations. Different interpolation methods in ArcInfo [ESRI, 2001] were tested, and the best method chosen using generalised cross validation, as well as giving the best distribution of water levels compared with the bore data set, and lastly the results had to pass a visual test. The twenty-five years of monthly interpolations were organised into an animation using ArcInfo, and provided the modellers with insights into the groundwater behaviour.

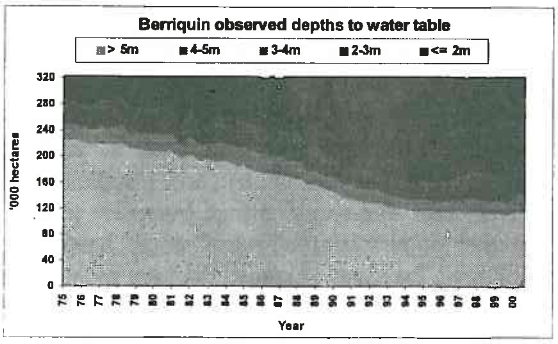

Figure 3. Depth to watertable behaviour in Berriquin LWMP area.

A summary graph of classes of depths to watertables in the Berriquin LWMP area is shown at Figure 3. The steady growth in shallow watertable areas from 1975 is apparent, as well as the large areas of shallow watertables in the late '80s and early '90s. Also of note are expansion of areas with depth to water of 2-3 m. As the aquifer behaviour has a rising trend of about 0.17 m/y superimposed with climatically driven fluctuations, these areas may be vulnerable to becoming shallow during the next wet period.

2.5. Scenario Modelling

The model was used to assess the difference in flows and salt loads leaving the catchments for the WP scenario compared with the BC scenario. Physical and operational changes to the catchments were modelled using the 1975-00 climatic record as a basis for comparison.

The BC scenario simulation answers the question, 'what would be the flow and salt loads leaving the catchment, with the physical and operational conditions that existed in 1988, using the 1975-00 climatic record'. Similarly, the WP scenario uses the physical and operational conditions that existed in the plan, using 1995 conditions as a starting point.

The first step in either case was projecting water levels. The actual groundwater levels in 1988 and 1995 were used as initial groundwater levels for the BC and WP scenarios respectively. Subsequent water levels were calculated by adding the actual monthly changes from the period of record, starting in January 1975 (Figure 4).

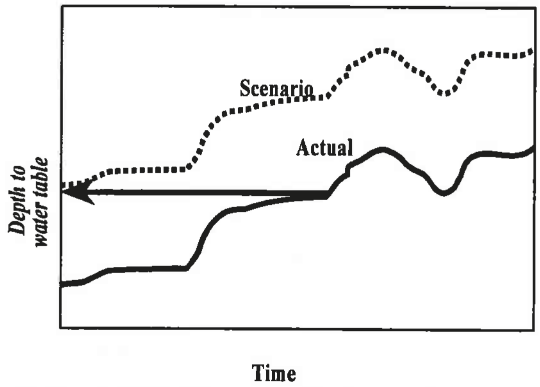

Figure 4. Projecting groundwater levels.

Adjustments were made for times when the watertable at a grid cell reached the shallow zone. Analysis of actual shallow bore level data showed that 90% of depth to watertable levels were greater than 0.8 m in summer, and 0.4 m in winter. These values were used to 'cap' water levels.

2.5.1. Modelling Plan Elements

Many of the plan elements were intended to reduce accessions to groundwater levels. These included sealing leaky supply channels, pumping from shallow aquifers, different irrigation practices, and land forming. Estimates of the changes in accessions were taken directly from the Plan document, and distributed spatially and temporally as described therein.

Volumetric accession changes were converted to water level changes based on estimates of specific yield.

Plan elements affecting surface water include: improvements in the drainage network, land forming, and irrigation drainage recycling. Subcatchment drainage factors were increased to account for the drainage improvements. The effects of land forming were simulated by decreasing detention storage in the UZ model. Drainage recycling was simulated using a simple IQQM setup with runoff, a storage, and an irrigation demand for a typical farm.

A further process that had to be simulated was the interactions from underlying Calivil aquifer. Excessive pumping from the Calivil formation had the potential to induce downward leakage from the Shepparton, and could effect simulated groundwater levels. This project used the results from a MODFLOW model of the Murray aquifer system to estimate this effect.

2.6. Sensitivity Analysis

The sensitivity analysis was done to see where our simplifications and assumptions would have a significant difference on the assessment, i.e., the difference between the BC and WP cases. Large variations from the adopted parameters were analysed, as this was a measure of our uncertainty in quantifying these processes. The results from this analysis could form the basis for future monitoring and data collection to improve future assessments. Changes made include:

(i) Reduce drainage factor by 5%;
(ii) Reduce overirrigation factor by 50%;
(iii) Increase all groundwater level by 0.5 m;
(iv) Increase assumed salinity of runoff from non-irrigated land with shallow watertables by 100%;
(v) Increase all other assumed surface runoff salinity by 50%;
(vi) Reduce minimum values to cap groundwater levels by 50%;
(vii) Use trend instead of actual values of 1988 and 1995 water levels as starting water levels; and
(viii)Use alternate estimate of Shepparton specific yield.

3. RESULTS

3.1. Calibration

Parameter values used in the models were calibrated by comparing the simulated flows and salt loads with the observed flows and salt loads in the river. The gauging station at Box Creek at Conargo Road (409058) has observed flow data from January 1986 and salinity data from 1986-92. Other gauging stations in these areas have data quality problems, or were affected by inflows from other sources and were not considered in the calibration process.

Flow was calibrated for the different flow components during different times of the year, using both the flow and salinity record. A part of the total record was set aside for validation. Rainfall-runoff was calibrated in winter to ensure irrigation did not influence the flow record. Groundwater inflow was calibrated during winter during periods of no rainfall. Overirrigation was calibrated during the irrigation system. The flow calibration results (Figure 5) were acceptable, with modelled flows within 15% of observed, and an r of 0.66 on a daily basis. The calibration of salt load is shown at Figure 6. The results were within 6% over the whole period, with an r of 0.80 on a daily basis.

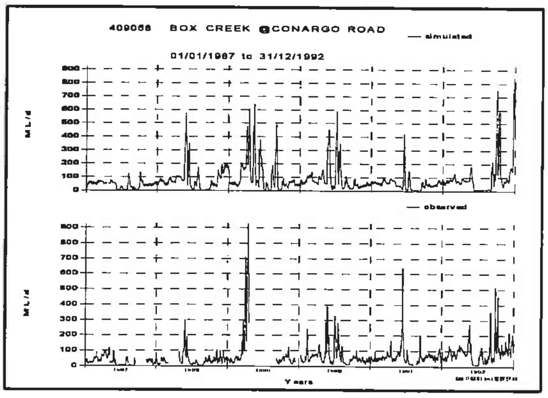

Figure 5. Flow calibration result at 409058.

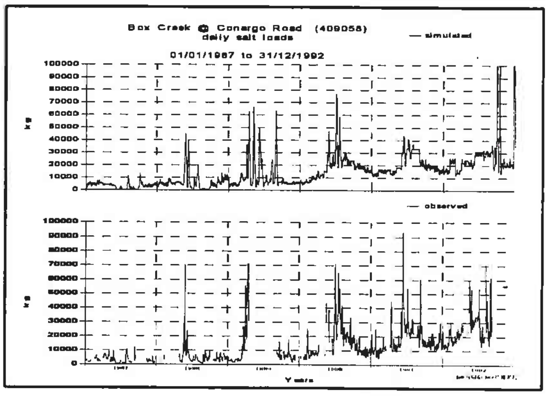

Figure 6. Salt load calibration result at 409058.

3.2. Scenarios

The two scenarios desribed were run using the 1975-2000 climatic record, and IQQM outputs were aggregated to an annual basis and compared. Average annual flows and salt loads are presented for the Berriquin catchment in Table 1.

What is apparent from these results is that there is about double the amount of flow and salt leaving the Berriquin for the WP scenario compared with the BC scenario. This increase is for the most part because of the large increase in the amount of surface drains in the catchment.

Table 1. Average annual simulated flows and salt loads for Berriquin salinity assessment.

	Flows (GL/y)	Salt loads ('000 t/y)
Base case		
Surface	81.8	9.8
Groundwater	3.8	15.7
Total	85.6	25.5
With plan		
Surface	161.5	24.6
Groundwater	5.6	24.2
Total	167.1	48.8

3.3. Sensitivity analysis

The sensitivity analysis results are presented in Table 2 as the % variation of the difference between the BC and WP scenarios for salt loads (23,300 t/y), as this is the crucial outcome of the project.

Table 2. Sensitivity analysis results.

Sensitivity run	Change in salt load difference (%)
(i)Reduce drainage factor by 5%	-6
(ii) Reduce over-irrigation factor by 50%.	-2
(iii) Increase all groundwater level by 0.5 m.	-22
(iv) Increase salinity of runoff from non-irrigated land with shallow watertables by 100%.	34
(v) Increase all other surface runoff salinities by 50%.	13
(vi) Reduce minimum values for depth to watertable by 50%.	-8
(vii) Use trend instead of actual values of 1988 and 1995 water levels.	-31
(viii) Use alternate estimate of Shepparton specific yield.	-10

The sensitivity analysis shows that the results are significantly sensitive to some of the assumptions, whereas others are not so crucial. What is also important to note is that these results overstate the sensitivity, as the models were not recalibrated with these new assumptions.

The two most crucial results of concern were for the estimate of washoff salinity of salinised land (+34 %) and by using the trend instead of actual values of starting water levels (-31 %).

The former indicates a need to better understand and quantify the salt buildup-washoff process, and should focus additional data collection. This information would then be used in future revisions of the salinity assessment. The latter is a sampling problem; the early 90's was a wet period, and the high groundwater levels at that time has affected the results.

4. CONCLUSION

The modelling developed for salinity assessment evolved from a complex method to simpler representations of the key processes. The simpler methods have proved to be more robust and flexible, and allowed for better focus on the important detail of the salinity assessment.

5. REFERENCES

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