Effect of Landuse Change and Climate Variation on Stream Flow and Salinity in South-Eastern Murray-Darling Basin, Australia

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EXTENDED ABSTRACT

Several subcatchments in the south-west Goulburn Broken region in the south-eastern Murray-Darling Basin generate high salt loads to streams due to dryland salinity. This high salt export contributes to water quality and stream degradation in the Murray River system. While the main focus of salinity control is to increase plant water use (e.g. tree planting), this can also lead to reduced runoff. However, in recent years, there has been a growing realisation that drier climatic conditions pose a serious additional threat to water supplies and river health in the region. In this context, it will require a flexible and carefully balanced strategy to achieve the contrasting objectives of remediating land salinisation and reducing salt export while maintaining water supply security.

To explore the trade-offs for these two contrasting objectives, this study linked the 2CSalt model (CRCCH 2005) to CAT1D (PIRVic 2005) to investigate the effect of land use change and climate variation on stream flow and salt export at subcatchment scale. The CAT1D comprises a suite of farming systems models ranging in complexity from a simple crop factor approach to phenologically based crop and pasture modules (Beverly et al. 2005). It was used to estimate monthly surface runoff, evapotranspiration, subsurface lateral flow and recharge for various landscapes and farming systems which are required by the 2CSalt model as input data. The 2CSalt model was applied to quantify surface and groundwater contributions of salt to streams and predict the impacts of land use change and climate variation on monthly stream flow and salt load (CRCCH 2005).

The models were calibrated for all gauged catchments in the south-west Goulburn Broken region. A number of hypothetical land use and climate variation scenarios were simulated. The key findings from the study include:

- Climate variation can have significant impacts on stream flow, base flow and salt export. For example, a 20% reduction in rainfall could reduce stream flow by 40-58%, base flow by 32-60% and salt export by 25-58% in the catchments studied.
- Stream flow, base flow and salt export are also sensitive to land use change. For example, converting the entire catchment area to trees could reduce base flow and stream flow by more than 90% in some subcatchments.
- The magnitude of impact of both climate variation and land use change varies considerably from one location to another, reflecting the differences of landscape characteristics between locations in a catchment.
- The modelling results suggest that large scale tree planting may not be a viable option for salinity management due to its significant impact on stream flow and quality. However, effective salinity management can be achieved by strategic tree planting.
- There is a strong correlation between rainfall and stream flow, base flow and salt export, which appears to be non-linear.
- There is considerable uncertainty in the modelled results associated with model limitations and gaps in input data.

The findings from this study have improved the understanding of the hydrology and salinity processes at subcatchment scale in the south-west Goulburn region. The knowledge gained through this study will assist catchment managers to develop more appropriate salinity and water resource management strategies. Most importantly, it gives greater confidence to decision makers about the secondary impact of salinity management programs on water resource issues.

1. INTRODUCTION

Dryland salinity is one of the major environmental problems facing the Goulburn Broken catchment in the south-eastern Murray-Darling Basin in Australia. Several subcatchments in the south-west Goulburn Broken region generate high salt loads (Cheng *et al*. 2004). This high salt export contributes to water quality and stream degradation in the Murray River system. Traditionally, salinity management strategies have focused on increasing plant water use (e.g. tree planting). While these measures can reduce recharge and lower watertables, they can also reduce runoff

However, in recent years, there has been a growing realisation that drier climatic conditions pose a serious additional threat to water supplies and river health in the region if they persist or worsen as has been predicted. In this context, it will require a flexible and carefully balanced strategy to achieve the contrasting objectives of remediating land salinisation and reducing salt export while maintaining water supply security.

To explore the trade-offs for these two contrasting objectives, this study aims to improve the understanding of the hydrologic processes and assess the effect of land use change and climate variation on stream flow and salt export at subcatchment scale.

2. STUDY AREA

The south-west Goulburn region defined in this study has a total area of approximately 3300 km^2 and include subcatchments: Gardiner Creek, Seymour area, Goulburn Weir area, Hughes Creek, Major Creek, Sugarloaf Creek, Sunday Creek and Whiteheads Creek (Figure 1).

Climate across the region is characterised by hot, dry summers and cool, wet winters, although the last ten years has seen a reduction of wet winters. The average annual rainfall ranges from about 500 mm in the north to 1200 mm in the south-eastern part of the region (Cheng *et al*. 2004).

The geology of the region mainly comprises Silurian and Devonian marine sediments and granites. Minor Ordovician deep marine turbidites and Cambrian sediments and volcanics occur along the north-western boundary. These ancient rocks are partly overlain by younger volcanics and Quaternary and Tertiary alluvial sediments. The landscapes reflect several periods of regional uplift, erosion and valley incision, and the eventual backfilling of the major river channels (Cheng *et al*. 2004).

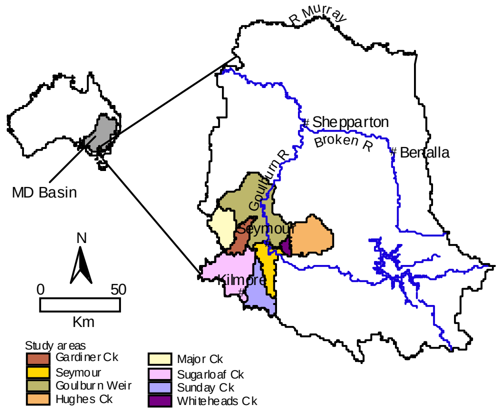

Figure 1 Location of the study areas

3. MATERIALS AND METHODS

3.1. Overview of modelling approach

In this study, the 2CSalt (CRCCH 2005) model was linked to a suite of unsaturated zone models, CAT1D (PIRVic 2005) to investigate the effect of land use change and climate variation on stream flow and salt export.

The 2CSalt model delineates two types of spatial units within a catchment - Hydrological Response Units (HRUs) and Groundwater Response Units (GRUs). HRUs represent the spatial mosaic of the climate, soil type, topography and land use within a catchment. GRUs are defined to represent the major groundwater units in a catchment. Each GRU is represented by an unsaturated zone store, a hillslope aquifer store and an alluvial mixing store. The model runs a mass balance of water and salt on a monthly time-step for each GRU to predict water and salt movement (CRCCH 2005).

The CAT1D comprises a suite of farming systems models ranging in complexity from a simple crop factor approach to phenologically based crop and pasture modules (Beverly et al. 2005). In this study, the CAT1D was applied to estimate surface runoff, lateral flow, evapotranspiration and recharge of each HRU on a daily time step. For integration into the 2CSalt model, the daily time series was accumulated to monthly time series.

3.2. Data collection and processing

The data required by the CAT1D and 2CSalt models was collected from various sources and processed to appropriate format for the study areas.

The DEM with a cell resolution of 20m, was sourced from the Victorian Government Spatial Information Infrastructure (SII) group. It was used to derive aspect and slope required by the CAT1D and to delineate HRUs and GRUs for the 2CSalt.

Long-term daily climate data was obtained from the SILO Data Drill, a web site belonging to the Queensland Department of Natural Resources and Mines.

This study utilises 1:100 000 scale land use data produced by the Bureau of Rural Sciences for the Murray-Darling Basin (BRS 2006). The land use map represents a snapshot in time.

The soils layer was sourced from CLPR (2002). The soil attributes required by the CAT1D were solely obtained from published data sources and pedo-transfer functions.

The values of hydrogeological parameters for GRUs were assigned based on hydrogeological attributes of GFSs as described by CLPR (2003).

Daily stream flow and salinity data was obtained from the Victorian Water Resources Data Warehouse over the period 1975-2000. Daily salt export has been calculated based on daily stream flow and salinity. Daily base flow has been estimated from the daily stream flow using the methods described in Arnold & Allen (1999). The daily stream flow, base flow and salt export were accumulated to monthly to match the time step of the 2CSalt model.

3.3. Calibration

The 2CSalt model was calibrated against monitored 'end of stream' gauge information from 1975 to 2000. The calibration criterion compares the stream monthly time series data with the simulated volumes of derived using the 2CSalt modelling approach to calculate goodness of fit. Calibration was achieved by using the technique of 'trial and error' adjustment of parameters.

3.4. Sensitivity analysis

To assess the uncertainty associated with the estimates of GRU and aquifer parameters, simple sensitivity analysis was undertaken. Firstly, all GRU parameters were tested and the effect of each parameter was analysed. Secondly, the effects of the parameters for terrain analysis were examined.

4. RESULTS AND DISCUSSION

4.1. Model calibration

Calibration of the 2CSalt model was performed for all gauged subcatchments in the south-west Goulburn region. Reasonably good representation of the hydrology was achieved for most subcatchments. The 2CSalt model predicted base flow and salt export particularly well (Figure 2). The mean annual base flow and salt export modelled by the 2CSalt model are very similar to those estimated from the gauged data, with differences generally less than 10%. The base flow and salt load duration curves and time series graphs also indicated reasonably good prediction of flow and salt loads (Figures 3 and 4).

However, the 2CSalt significantly over-estimated the stream flow for the Whiteheads Creek subcatchment, particularly for large flow events in the winter-spring period of drier years. The mismatch of modelled results and gauged data is possibly due to the following factors:

- The large proportion of missing data for the stream gauging station.
- The significant land use change in the catchment.
- The GFS and soil mapping is too coarse.
- As the 2CSalt assumes that evaporation from shallow watertables only occurs in the alluvial store, the model may have underestimated the total evaporation from shallow watertables in the catchment.

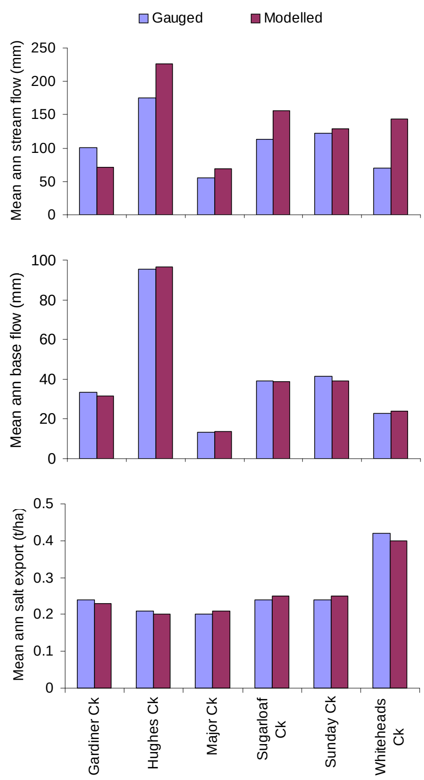

Figure 2 Comparison of modelled and gauged mean annual flow and salt export

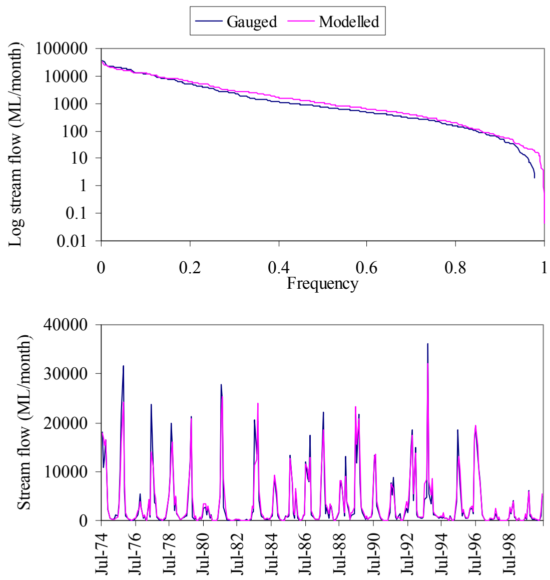

Figure 3 Comparison of modelled and gauged monthly stream flow, Sunday Ck

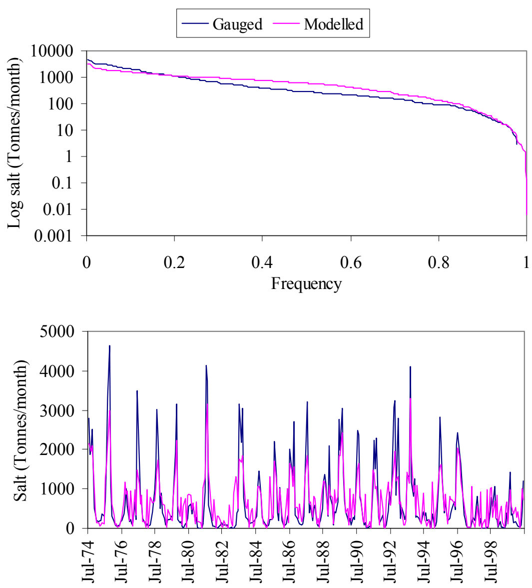

Figure 4 Comparison of modelled and gauged monthly salt export, Sunday Ck

4.2. Climate and land use change scenarios

Five hypothetical and current land use scenarios were modelled to investigate responses to climate variation and land use change for all eight subcatchments studied:

- Current practice (tree cover estimated at 28%)
- 10% reduction in daily rainfall for the period of simulation (from 1957 to 2000)
- 20% reduction in daily rainfall for the period of simulation
- entirely convert the subcatchments from their current land use to trees
- 51% tree cover targeting high salt yield areas
- 53% tree cover targeting recharge areas.

The two rainfall reduction scenarios assumed that all climatic conditions (e.g. temperature and potential evaporation) remained the same. These scenarios intended to test the effect of rainfall variation on stream flow, base flow and salt export rather than predict the impact of future climate change.

The 100% tree cover scenario does not represent a practical level of land use change, but indicates the maximum effect that could be achieved by changing land use. It also provides spatial information regarding the effectiveness of tree planting on stream flow, base flow and salt export.

The 51% tree cover scenario aims to effectively reduce salt export with minimum stream flow reductions. The spatial information on the effectiveness of tree planting derived from the 100% tree cover scenario was used to identify locations for targeted tree planting across the south-west Goulburn region that would produce long-term salt reductions.

The 53% tree cover scenario was developed based on existing tree cover, depth to watertable, topographic characteristics and distribution of groundwater recharge (SKM 2004b). This was one of the most effective scenarios identified by SKM (2004b) in terms of salt export reduction. Simulation of this scenario intended to compare the effectiveness of different tree cover options.

Response to reduction in rainfall

The model results indicated that a 20% reduction in rainfall significantly reduced stream flow (by 48%), base flow (by 45%) and salt export (by 34%) in all the subcatchments, while a 10% reduction in rainfall only resulted in 8-16% reduction in flow and salt export (Table 1). There seems to be no simple relationships between rainfall and stream flow, base flow and salt export. A preliminary analysis of the gauged data in the Hughes Creek subcatchment indicates that there is strong correlation between mean annual rainfall and mean annual stream flow, base flow and salt export and the relationships appear to be non-linear (Figure 5).

In both rainfall scenarios, the reductions in stream flow are greater than those in salt export in percentage terms. This indicates that dry conditions not only reduce stream flow, but also elevate stream salinities.

Table 1 Effects of land use and rainfall reduction scenarios on modelled mean annual stream flow, base flow and salt export in the south-west Goulburn region

	Change related to current practice (%)		
Scenarios	Stream flow	Base flow	Salt export
10% rainfall reduction	-16	-14	-8
20% rainfall reduction	-48	-45	-34
51% tree cover	-22	-37	-34
53% tree cover	-27	-34	-29
100% tree cover	-75	-84	-63

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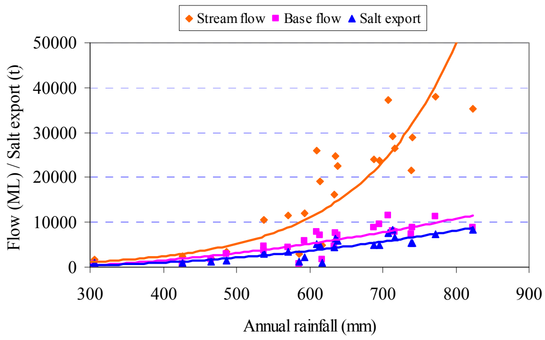

Figure 5 Annual rainfall vs. gauged annual flow/salt export for the period of 1975-2000 in the Hughes Ck subcatchment

It was also found that the significance of the impact varies from one subcatchment to another, probably due to differences in their landscape, hydrological and hydrogeological characteristics (Figure 6). As shown in Figure 6, a 20% reduction in rainfall could result in a 40-58% reduction of mean annual stream flow, a 32-60% reduction of mean annual base flow and 25-58% reduction of mean annual salt export from the studied subcatchments.

The reduction in rainfall also has a significant impact on flow duration and salt load duration as well as hydrological and salt pathways. For example, the proportion of time with no flow can increase significantly in some subcatchments by reducing rainfall by 20%.

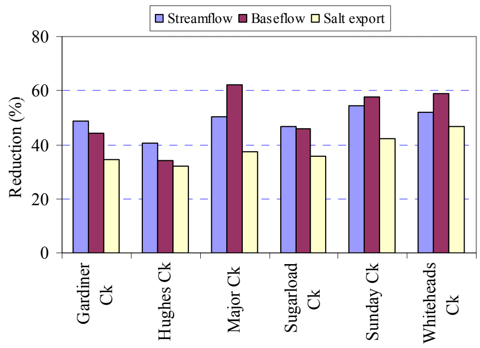

Fig. 6 Effect of a 20% rainfall reduction on mean annual stream flow, base flow and salt export in six gauged subcatchments

Response to land use change

As expected, the impact of converting the catchment entirely to trees is extremely large (Table 1 and Figure 7). Figure 7 reveals that it almost eliminated base flow (up to 99.5% reduction in mean annual base flow) and severely depleted stream flow (up to 92% reduction in mean annual stream flow) in the subcatchments with lower rainfall (e.g. Gardiner Creek and Major Creek), although it also significantly reduced salt export. This scenario indicated the maximum impact of tree planting. However, in reality it is highly unlikely that planting of this magnitude will occur in the region, particularly in the lower rainfall areas.

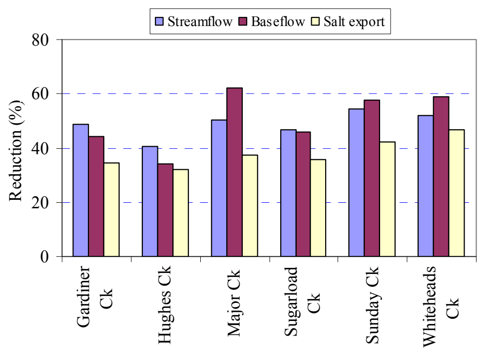

Fig. 7 Effect of 100% tree cover on mean annual stream flow, base flow and salt export in six gauged subcatchments

Although the 51% tree cover and 53% tree cover scenarios produced less salt export reduction than the 100% tree cover scenario, they are more effective and achievable (Table 1 and Figure 8). In the 51% tree cover scenario, additional 23% tree cover produced a 34% salt export reduction while stream flow was only reduced by 22% (i.e, relative to the current practice scenario). As shown in Figure 8, this scenario resulted in a much greater salt export reduction and slightly less stream flow reduction per unit of increased tree cover compared to the 100% tree cover scenario. By contrast, the 53% scenario was slightly less effective in reducing salt export, although it produced good results.

The results of these tree cover scenarios demonstrate that the relationships between either stream flow and tree cover or salt export and tree cover are not linear at the scale of the south-west Goulburn region. The effects of tree cover can vary significantly reflecting topographic and hydrogeological differences between locations in the catchment. For the same percentage of tree cover, different distributions of trees in a catchment may have significantly different impacts on stream flow, base flow and salt export. This suggests that more effective tree planting for salt reduction can be achieved by identifying appropriate locations.

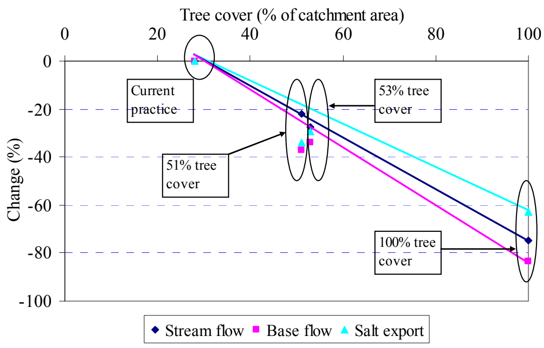

Fig. 8 Effect of tree cover scenarios on mean annual stream flow, base flow and salt export in the south-west Goulburn region

4.3. Sensitivity analysis

Sensitivity analysis was carried out for the Gardiner Creek subcatchment. The analysis indicates that the model was very sensitive to changes in discharge depth threshold for the alluvial store (AS TH) and hillslope store (HS TH). The annual mean and seasonal fluctuation of modelled stream flow, base flow and salt export significantly increased with increasing AS TH value (Figures 9 and 10). Base flow appears to be more sensitive than stream flow to the GRU parameter (AS TH). This is probably due to the fact that a large proportion of stream flow was directly generated from the CAT1D. Changing the HS TH value also has a significant effect on annual mean and seasonal fluctuation of simulated base flow and salt export.

Changes in other GRU parameters can also have significant effects on modelled results. For example, changing the storage-discharge coefficient of the hillslope aquifer (HS β) has significant impacts on the seasonal fluctuation and the annual mean of modelled base flow.

The effects of changing the GRU parameter values are influenced by other factors such as alluvial area and hydraulic properties of aquifers (e.g. hydraulic conductivity). In general, the larger the alluvial area and the hydraulic conductivity of the aquifer, the greater the base flow.

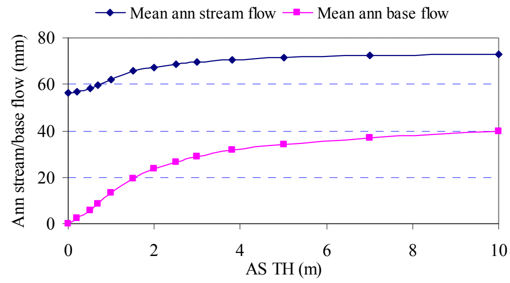

Figure 9 Effect of changing AS TH on modelled mean annual stream flow and base flow.

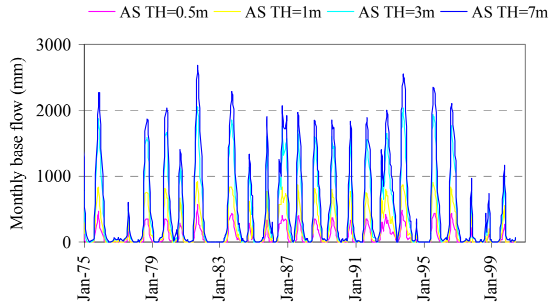

Figure 10 Effect of changing AS TH on modelled mean monthly stream flow and base flow.

5. CONCLUSION

In this study, good representation of the hydrology was achieved by the modelling exercise. The model reasonably estimated base flow and salt export in all subcatchments studied, although it slightly over-estimated stream flow in some subcatchments (e.g. Whiteheads Creek subcatchment). The modelled water and salt pathways were consistent with the current understanding and knowledge. The model also identified key areas contributing to stream flow, base flow and salt export at GRU scale.

The results from the two rainfall reduction scenarios and analysis of stream gauged data indicated that stream flow, base flow and salt export decrease with decreasing rainfall. However, their relationships appear to be non-linear. The reduction of rainfall can also elevate stream salinity and reduce flow duration. These effects of rainfall reduction also vary significantly from one subcatchment to another, probably due to differences in landscape, hydrological and hydrogeological characteristics.

The results of the tree cover scenarios indicated that planting trees can significantly reduce stream flow, base flow and salt export. For example, converting the catchment entirely to trees can reduce stream flow, base flow and salt export by approximately 90% in the subcatchments with lower rainfall (e.g. Gardiner Creek and Major Creek). This magnitude of reduction in stream flow suggests that large scale tree planting is not a viable option in the south-west Goulburn region.

However, this study found that the effects of tree planting can vary significantly between locations in the catchment. Targeted tree planting can be much more effective in reducing salt export and maintaining stream flow.

This study also found that the considerable uncertainties in the modelled results are associated with model limitations and gaps in input data.

The knowledge gained through this study will assist catchment managers to develop more appropriate salinity and water resource management strategies. Most importantly, it gives greater confidence to decision makers about the secondary impact of salinity management programs on water resource issues.

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