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An integrated modelling approach to balancing trade-off issues in natural resource management

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Abstract: The south-west region of the Goulburn-Broken catchment (SWG) in northern Victoria is facing a range of natural resource challenges. High salt load export from the region affects water quality and contributes to stream degradation in the Murray River system. Traditionally, salinity management strategies have focused on increasing plant water use (e.g. tree planting). In recent years, however, there has been growing concern that the prevailing dry climatic conditions and revegetation are threatening the water supply and health of ecosystem. 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 satisfy human consumptive use and support in-stream and terrestrial biodiversity.

To explore the trade-offs for these two contrasting objectives, this study linked the 2CSalt model (Weeks et al., 2005) to CAT1D to investigate the effect of land use change and climate variation on stream flow and salt export in the SWG region. 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. The models were calibrated for all gauged catchments in the region. The risk and uncertainty analysis associated with the 2CSalt model was carried out by undertaking numerical and statistical simulations. The modelling explored and contrasted the impacts of a series of different focused revegetation and climate scenarios:

- Three biodiversity scenarios based on Ecological Vegetation Classes (EVC) coverage and landscape context scores
- Three revegetation scenarios focused on minimising salt export from the SWG region
- Three revegetation scenarios focused on minimising losses in catchment yield
- Three scenarios for climate change based on the outputs of CSIRO's regional climate models for high, medium and low IPCC emissions scenarios (CSIRO, 2007).

The results of this modeling work indicated:

- All three focused biodiversity planting scenarios approximately mapped along the linear baseline (i.e. the linear line between the current practice and 100 % tree cover scenarios) for stream flow, base flow and salt load impacts. This indicates that planting to satisfy biodiversity needs is unlikely to have any additional impacts on stream flow and salt load above random plantings across the SWG region.
- The three focused salt reduction scenarios are much more effective in reducing salt than that indicated by the linear baseline, while only slightly decreasing stream flows compared to the baseline. This result provides support for salinity management strategies while not disproportionately impacting upon flows.
- The focused stream flow retention scenarios are reasonably effective in minimising stream flow loss while at the same time being slightly less effective in reducing salt compared to the baseline. These results indicated that stream flow declines can be substantially lessened by targeting native and plantation forestry activities without significantly increasing salt export.
- Although the modelling revealed that the impacts of targeting vegetation are significant on stream flow and salt export, climate change scenarios will have an equal if not more significant impact on these issues over the next 70 years.

The modelling indicated that the impact of land use and climate change is complex. Analysis indicates that there is pronounced correlation between climate and mean annual stream flow, base flow and salt export, and these relationships appear to be non-linear. The knowledge gained through this study has informed a NRM trade-off decision process that aims to develop and prioritise NRM options.

Keywords: *Modelling, climate change, land use, water, dryland salinity, Goulburn Broken*

1. INTRODUCTION

The south-west region of the Goulburn Broken catchment (SWG) in northern Victoria is currently facing a range of natural resource challenges. It has been well-documented that high salt load export from the region contributes to water quality and stream degradation in the Murray River system (Cheng et al., 2004). Traditionally, salinity management strategies have focused on increasing plant water use (e.g. tree planting). There has been growing concern that dry prevailing climatic conditions and re-vegetation are threatening the water supply and health of the ecosystem in the region. While these measures can reduce recharge and lower watertables, they can also reduce stream flow and water resource.

In recent years, however, there has been a growing concern expressed by the stakeholders in the region, that drier climatic conditions pose a serious additional threat to the water supply and ecosystem health, especially if the conditions 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 satisfy human consumptive use and support in-stream and terrestrial biodiversity. This study aims to explore the functional relationships between land use, salt export and stream flow under various climate conditions in order to inform investigation of natural resource management trade-off issues in the SWG region

2. STUDY AREA

The study area is located in the south-west of the Goulburn Broken catchment in the south-eastern Murray-Darling Basin (Figure 1). It encompasses eight subcatchments including Gardiner Creek, Seymour area, Goulburn Weir area, Hughes Creek, Major Creek, Sugarloaf Creek, Sunday Creek and Whiteheads Creek, with a total area of approximately 3300 km^2. These sub-catchments mostly drain into the Goulburn River in an area from Trawool (south of Seymour) to the Goulburn Weir (north of Nagambie).

The SWG region has been extensively cleared for agriculture, mining, timber harvesting and urban development. The current predominant agricultural land uses are sheep and cattle grazing. About 24 % of the region remains wooded. Climate across the region is characterised by hot, dry summers and cool, wet winters, although winters in the last twelve years have been mostly quite dry. 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 SWG region comprises a significant area where the Central Victoria Highlands meet the Riverine Plain of the southern Murray Basin. The landscapes reflect several periods of regional uplift, erosion and valley incision, and the eventual backfilling of the major river channels. The major groundwater flow systems occurring in the region comprise local and intermediate flow systems in weathered and fractured sedimentary rocks, granites, basalts and Quaternary alluvial sediments (Cheng et al., 2004).

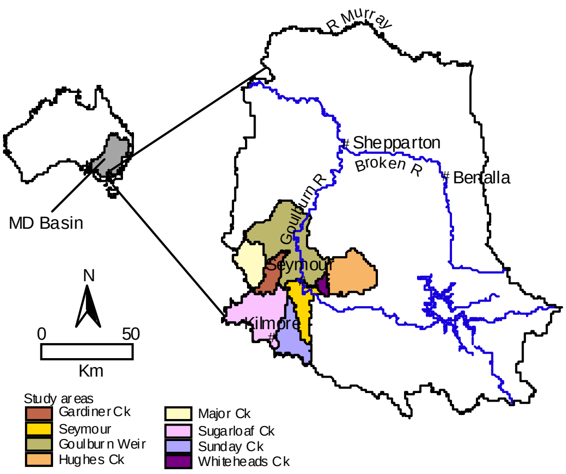

Figure 1. Location of the study area

3. MATERIALS AND METHODS

3.1. Overview of Modelling Approach

This study linked the modified 2CSalt model (Weeks et al., 2005) to CAT1D (PIRVic, 2005; Beverly et al., 2005) to investigate the effect of land use change and climate variation on stream flow and salt export at the subcatchment scale. The 2CSalt model was originally developed by the CRC for Catchment Hydrology (CRCCH, 2005) and later modified by Weeks et al. (2005). The modified 2CSalt model increased flexibility in pre-processing and post-processing and included an automatic parameter estimation technique.

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.

3.2. Calibration

The 2CSalt model was calibrated against measured 'end of stream' gauge information from 1975 to 2000 using an automated, constrained non-linear optimizer (The MathWorks Inc., 2007). The calibration criterion compares the stream monthly time series data with the simulated volumes derived using the 2CSalt modelling approach to calculate goodness of fit.

3.3. Uncertainty Analysis

The effect of uncertainty in model parameters was explored using numerical and statistical simulations adapted from Benke et al (2008). Metrics of uncertainty include standard deviation and error bars for output distributions. In the current investigation, five key parameters of interest in the 2CSalt model were represented by probability distributions and a series of Monte Carlo simulations were performed to assess the variability in streamflow predictions. Each parameter distribution was represented by the PERT probability density function (which is based on the Beta distribution), with specified mode (representing the calibrated fixed parameter), together with the upper and lower bounds on the latter. Five hundred parameter sets (comprising alpha, beta, lambda, omega, delta and evap_d) were randomly sampled and the model executed repeatedly in the simulation (i.e. equivalent to 500 iterations in a Monte Carlo simulation). The associated uncertainty metrics for the five distributions were the set of standard deviations given by $\sigma_{param} = [159.71, 7.84, 1.44, 1.60, 1.59, 0.76]^T$.

3.4. Development of Land Management and Climate Scenarios

To assist in resolving the essential NRM trade-off issue in the SWG region, a number of land management and climate change scenarios that present a range of possible futures were developed. These scenarios include:

- Three biodiversity scenarios (Bio1, Bio2, Bio3) with tree covers of 38 %, 53 % and 67 %, respectively
- Three salt reduction scenarios with similar percentage of tree cover to the biodiversity scenarios (Salt1, Salt2 and Salt3)
- Three flow retention scenarios with similar percentage of tree cover to the biodiversity scenarios (Flow1, Flow2 and Flow3)
- Three climate change scenarios were developed based on the outputs of CSIRO's regional atmosphere models (Hennessy et al., 2006). The three scenarios represent three key IPCC SRES emissions scenarios: A1F1 (high emissions), A2 (medium emissions) and B1 (low emissions) (IPCC, 2001).

The biodiversity scenarios were built on biodiversity/native vegetation objectives only, primarily based on Ecological Vegetation Classes coverage and landscape context scores, with no consideration of minimising water yield reduction and maximising salt reduction. Salt load reduction scenarios aim to effectively reduce salt export with minimum impact on stream flow, while the flow retention scenarios aim to minimize the loss in stream flow without other consideration. The methods for generating these scenarios were described by Cheng et al. (2009).

To assist the assessment of effectiveness of these possible future land use scenarios, the modeling exercise also simulated the current practice (tree cover estimated at 24 %) and 100 % tree cover scenarios which used to development the linear baselines for the impact of tree plantings.

The 2CSalt model was applied to eleven land use scenarios for the current climate condition (1975-2000) and three climate change scenarios (2000-2070).

4. RESULTS AND DISCUSSION

4.1. Model Calibration

Calibration of the 2CSalt model was performed for all gauged subcatchments in the SWG region. The model captured the stream data reasonably well for most subcatchments. The mean annual stream flow, base flow and salt export modelled by the 2CSalt model were very similar to those estimated from the gauged data, with differences generally less than 10 %. The flow and salt load duration curves and time series graphs also indicated reasonably good prediction of flow and salt loads. The modelled water and salt pathways also were consistent with the current understanding and knowledge. However, the magnitude of large stream flow events tends to be underestimated. An example of the 'end of stream' calibration for the Sunday Creek catchment is illustrated in Figure 2.

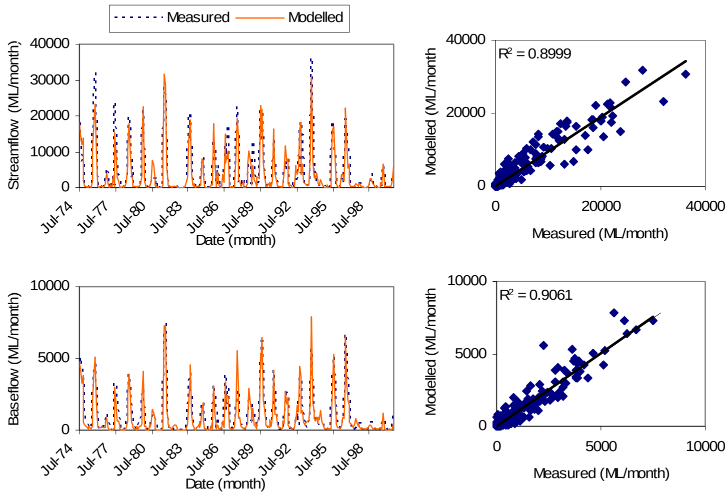

Figure 2. Comparison of measured and modelled streamflow and baseflow, Sunday Creek

4.2. Uncertainty Analysis

Uncertainty analysis on 2CSalt predictions was performed for the Sunday Creek catchment using the method described in Section 3.3. In Figure 3, the representation of uncertainty in monthly streamflows shows the mean and three sigma limits of model output distributions (closed circles and error bars), and also the monthly standard deviations (open squares). During the winter and spring months, the streamflow is very high relative to the summer months, and the uncertainty in the mean estimates is high in absolute magnitude. Also shown are monthly streamflow predictions for the calibrated parameter set for the Sunday Creek catchment (open circles). Predictions for this parameter set are well within the uncertainty bounds in the high streamflow months in winter (being greater than 8000 ML), but are borderline in the low streamflow months in summer (i.e. where streamflow is less than 3000 ML). This suggests the possibility of greater uncertainty in model predictions for the Sunday Creek catchment in the case of very low stream flows.

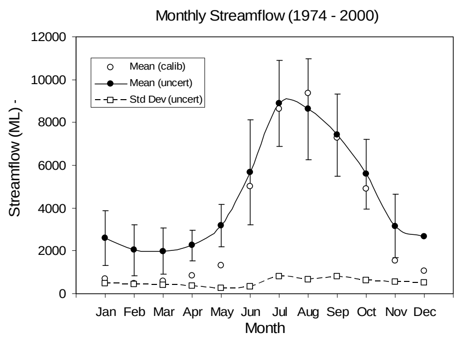

Figure 3. Uncertainty in mean monthly streamflow for the Sunday Creek catchment is represented by: a) mean and three sigma limits of model output distributions (●) and monthly standard deviations (□), together with streamflow predictions for calibrated parameter set (○).

4.3. Response to the Biodiversity Scenarios

Modelling results indicated that all three biodiversity scenarios have significant impacts on stream flow, base flow and salt load under current climate condition. As shown in Figure 4, the effectiveness of all three biodiversity scenarios in salt/base flow/stream flow reduction approximately map along the linear baseline (straight lines between the current practice and 100 % tree cover scenarios). This implies that planting to satisfy biodiversity needs is unlikely to have significantly greater impacts on stream flow and salt load than random plantings across the SWG region. For example, an increase in tree cover from 24 % (current practice) to 38 % (Bio 1) for biodiversity needs results in an approximately 15% reduction on current stream flow, while Bio 2 (53 % tree cover) reduces stream flow by 30 % from the current level. This equates to an average of 1 % loss in stream flow for each percentage point increase in tree cover. This level of impact is very similar to the average for the 100 % tree cover scenario which is 1.02 %.

The model results also indicated that reduction in stream flow, base flow and salt load would be significantly greater for current practice and all three biodiversity scenarios under any of three climate change scenarios than those under current climate conditions over the next 70yrs. For example, an increase in tree cover from 24 % (current practice) to 53 % for biodiversity needs results in a 30 % loss in stream flow by 2070 under current climate conditions, while the same biodiversity scenario results in a 53 % loss in stream flow under a medium emission climate scenario.

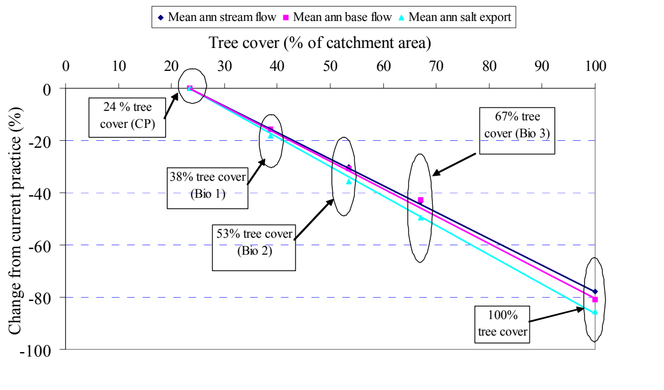

Figure 4. Effect of biodiversity driven scenarios on mean annual stream flow, base flow and salt export under current climate conditions in the south-west Goulburn region.

4.4. Response to the Salt Reduction Scenarios

The targeted salt reduction scenarios have more significant impacts on stream flow, base flow and salt load than those indicated by the linear baseline (Figure 5). More importantly, these scenarios are more effective in reducing salt than reducing stream flow (13-15 % greater depending on scenarios). Under current climate condition, 38 % tree cover for salt reduction needs (Salt 1) generates 14 % less salt export than that indicated by the linear baseline with flow reduction similar to the linear baseline, while 53 % tree cover (Salt 2) generates about 15 % less salt export with only 3 % additional flow loss. This result not only implies that annual mean stream salinity would be reduced by increasing tree cover, but also provides support for salinity management strategies while not disproportionately impacting upon flows.

The functional relationships for the salt reduction scenarios are clearly non-linear (Figure 5). It appears that the effectiveness of salt reduction scenarios in reducing salt is initially much greater than that indicated by the baseline and decreases with increasing tree cover. However, the response of stream flow to increase in tree cover does not seem to correlate with that of salt reduction and the functional relationship is less clear. For example, under current climate conditions, 38 % tree cover for salt reduction needs (Salt 1) achieved 1.95 % salt reduction (almost twice as much as that indicated by the linear baseline) with 1.04 % flow reduction (similar to that indicated by the linear baseline) for each percentage point increase in tree cover. For the scenario Salt 3, the effectiveness of tree planting in reducing salt drops to 1.04 % (slightly less than that indicated by the linear baseline) for each percentage point increase in tree cover, while the level of effectiveness in reducing flow slightly increases to 1.21 % for each percentage point increase in tree cover (slightly greater than that indicated by the baseline).

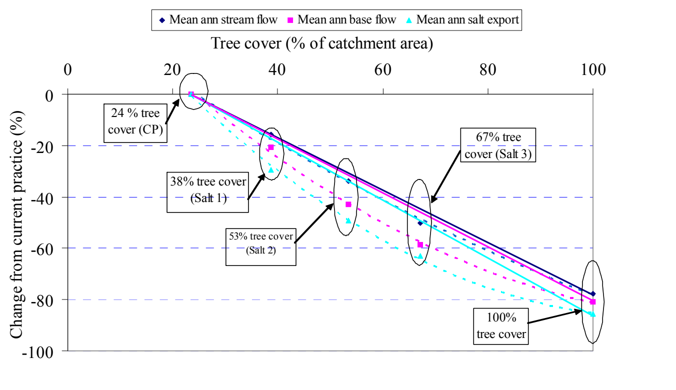

Figure 5. Effect of salt reduction driven scenarios on mean annual stream flow, base flow and salt export under current climate condition.

The impacts of the climate change scenarios when combined with the salt reduction scenarios are similar to their impacts when combined with the biodiversity scenarios. Stream flow, base flow and salt load reductions will also be significantly amplified under any of the climate change scenarios with 65 % reduction on current loads assuming a medium emissions scenario at 53 % tree cover (Salt 2).

4.5. Response to the Flow Retention Scenarios

The targeted stream flow retention scenarios are reasonably effective in minimising flow loss, while at the same time being less effective in reducing salt. Under current climate conditions, these three scenarios achieve about 7-12 % less loss in stream flow than that indicated by the linear baseline, while at the same time also resulting in 4-9 % less salt reduction. For example, 53% tree cover for flow retention needs (Flow 2) achieves about 12 % less loss in stream flow with 7 % less salt reduction (Figure 6). These results indicate that stream flow decline can be substantially minimised by targeting native and plantation forestry activities if salt reduction is not considered.

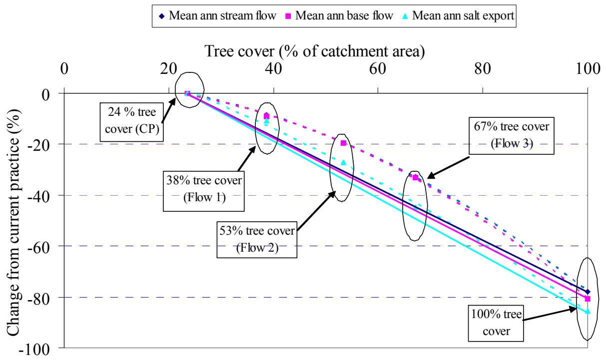

Figure 6. Effect of flow retention driven scenarios on mean annual stream flow, base flow and salt export under current climate condition.

The functional relationships between salt/flow reduction and tree cover indicated by these flow retention scenarios also depart from a linear one (Figure 6). The average stream flow loss and salt reduction are initially low (much lower than that indicated by the baseline) and increase with increasing tree cover. For example, under current climate conditions, 38 % tree cover for flow retention needs (Flow 1) only has 0.55 % flow loss (approximately a half of that indicated by the baseline) and 0.71 % salt reduction (well below the level indicated by the linear baseline) for each percentage point increase in tree cover. When tree cover increases to 67 % (Flow 3), the effectiveness of tree planting for salt reduction increases to 1.32 % (slightly higher than that indicated by the baseline) for each percentage point increase in tree cover, while at the same time average loss on flow also increases to 0.98 % (only slightly less than that indicated by the linear baseline) for each percentage point increase in tree cover.

The impacts of the climate change scenarios under the salt reduction scenarios are also similar to their impacts under the biodiversity scenarios. Stream flow, base flow and salt load reductions will also be significantly amplified under any of the climate change scenarios with 49 % reduction on current loads assuming a medium emissions scenario at 53 % tree cover (Flow 2).

4.6. Using Modeling Results to Inform NRM Trade-off Issues

To ensure best use of the modeling results to inform NRM trade-off issues, a number of workshops were held within the SWG region and a Working Group was formed. The critical NRM trade-off issue discussed essentially involves the integration of a range of strategies and programs including salinity management, river health, biodiversity, and land use planning to optimise the overall outcome as measured in resource condition targets. Three options were considered for development of NRM strategies in the region:

- Option 1: Maintain existing tree cover (i.e. permanently accept existing shortfalls in EVC woody vegetation coverage) but enhance grassland EVCs.
- Option 2: Enhance tree cover to minimum biodiversity requirement (15 % EVC) but restrict to low catchment yield zones and preferentially target high salt load zones. Use external trade to build biodiversity requirements where these conflict with high yield zones in the SWG.
- Option 3: Again enhance tree cover to minimum biodiversity requirement (15 % EVC) but restrict to low catchment yield zones and preferentially target high salt load zones. However to achieve this outcome allow the substitution of well represented tree cover from high yield zones to new plantings of equivalent or better biodiversity value in low yield zones. Use external trades where biodiversity objectives are still not met.

Option 2 is an integrated approach that provides for biodiversity targets to be achieved whilst minimising impacts upon catchment yield and salinity. This option is innovative in that where biodiversity targets cannot be achieved without compromising yield; the mechanism of external trade (with neighboring regions) could be used. In contrast Option 1 would retain the status quo in catchment yield, but only some biodiversity EVC targets would be attained and net gain in biodiversity would be limited. Option 3 would be contingent upon a more radical approach of substituting (clearing) mature biodiversity from those EVCs that have high existing areas of coverage in high yield impact areas with new plantings of EVCs that have low existing areas of coverage on low impact. This option might be worthy of further research and assessment, especially if the impact of climate change was to be more severe than currently anticipated.

5. CONCLUSIONS

The modeling approach provided reasonable estimates of stream flow, base flow and salt export in all subcatchments studied. The approach also identified key landscape settings contributing to stream flow, base flow and salt export across the SWG region. The modeling results revealed that the climate change scenarios will have significant impact on stream flow, base flow and salt export for all land management scenarios over the next 70 years. Even the low emission climate scenario (B1) would reduce stream flow, base flow and salt load by more than 20 % over the same period if current land use continues. The magnitude of the impact varies depending on the landscape, tree location, hydrological and hydrogeological characteristics of each sub-catchment.

Change in land management also has a significant impact on stream flow and salt export, although the significance varies depending on tree location. The biodiversity scenarios almost equally reduce the stream flow, base flow and salt load and the magnitudes of the reduction are close to the average impact of random plantings. The salt reduction scenarios are particularly effective in reducing salt export with only marginal impacts (albeit a reduction) on stream flow compared to the random planting scenario. Although the impacts of all three flow retention scenarios for salt/base flow/stream flow reduction were much less significant than the impacts of biodiversity and salt reduction scenarios on stream flow and salt export, their impacts on stream flow were still significant. These findings offer new hope that effective salinity management can be achieved by strategic tree planting and confirm that large scale tree plantation can severely deplete stream flow. The knowledge gained through this modeling process has been used to inform an NRM trade-off decision process that aims to develop and prioritise the various NRM options available.

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REFERENCES

Benke, K.K., K.E. Lowell, and A.J. Hamilton, (2008), Parameter Uncertainty, Sensitivity Analysis and Prediction Error in a Water-Balance Hydrological Model, *Mathematical and Computer Modelling*, vol 47, pp 1134-1149.

Beverly, C., M. Bari, B. Christy, M. Hocking, and K. Smettem, (2005), Predicted salinity impacts from land use change: comparison between rapid assessment approaches and a detailed modelling framewater. *Australian Journal of Experimental Agriculture*, vol. 45, pp. 1453-1469.

Cheng, X., M. Reid, C. Daamen, and G. Hoxley, (2004), Integrated salinity study in the South West Region of the Goulburn Broken catchment. In Proceedings of the 9th Murray-Darling Basin Groundwater Workshop. 17 19 February 2004, Bendigo, Australia.

Cheng, X., A. Weeks, B. Christy, and M. Cotter, (2009), Effect of landuse management and climate variation on stream flow and salinity in the south west Goulburn region. Research Report. Department of Primary Industries, Victoria.

CRCCH (2005) User guide for 2CSalt. Cooperative Research Centre for Catchment Hydrology.

CSIRO (2007) Climate change projections for Victoria. Prepared for the Victorian Department of Primary Industries. CSIRO Atmospheric Research brochure.

Hennessy, K., C. Page, P. Durack, and J. Bathols, (2006), Climate Change Projections for Victoria. CSIRO Marine and Atmospheric Research, Aspendale, Victoria.

IPCC (2001), Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report (TAR) on the Intergovernmental Panel on Climate Change (IPCC), Houghton J., Y. Ding, D. Griggs, P. Noguer, P. van der Linden, X. Dai, K. Maskell, and C. Johnson, editors. Cambridge University Press, Cambridge.

PIRVic (2005) Technical Manual Catchment Analysis Tool, Version 14. Primary Industries Research Victoria, Department of Primary Industries Victoria.

The MathWorks Inc, (2007), Optimisation Toolbox 3 User's Guide. Available at http://www.mathworks.com

Weeks, A., C. Beverly, B. Christy, and T. McLean, (2005), Biophysical Approach to predict salt and water loads to upland REALM nodes of Victorian catchments. In Zerger A. and R.M. Argent (eds) MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 2776-2782.