

Building more robust hydrological models underpinned by new regolith landform information

Craig Beverly¹, Mark Hocking², John Wilford³, Ken Lawrie³

¹Department of Sustainability and Environment, Victoria

²Hocking et. al. Pty Ltd, Victoria

³CRC LEME

Introduction

The expansion of land and water salinisation in the dryland landscapes of Australia is the result of mobilisation of stored subsurface salts arising from changed hydrological regimes. As such, the management of dryland salinity needs to describe the hydrological processes controlling the mobilisation of stored salts. This requires an integrated understanding of catchment surface water flows, groundwater dynamics, salt distribution and salt transport processes within different parts of the landscape.

This paper summarises contemporary techniques used to conceptualise and describe groundwater flow systems across the Australian landscape. The current 'standard' approach to describe catchment characteristics considers catchments as discrete zones and describes them in a relative context. This paper describes the method of sub-catchment generalisation approach and provides an alternative more detailed spatially explicit approach which better reflects the natural environment. The work reported assesses the impact of new regolith-landform information in the Loddon catchment (611,316 ha, 410-1170 mm/yr rainfall), using a linked biophysical surface and either lumped or distributed groundwater model. Results are presented at both the regional catchment scale and at the subcatchment scale.

The aims of the work reported in this paper are to:

1. to describe an enhanced groundwater flow system mapping technique
2. present two commonly used hydrological models used to predict salinity outcomes
3. to illustrate the benefits of the enhanced groundwater flow system mapping for developing improved conceptual frameworks and hydrological models

Method

Spatial data attribution: The Groundwater Flow Systems (GFS) approach (Coram *et al.*, 2000, Walker *et al.*, 2003) has been widely used in Australia to describe complex groundwater systems. This approach brings together groundwater information in a simple but structured manner and has used fifteen generic hydrogeological conceptual models to describe and map the groundwater processes of salinisation across Australia (Coram, ed. 1998). Each model incorporated the spatial extent of the groundwater flow system, and the geological structure, hydraulic estimates and the geomorphological/topographical setting.

A recent enhancement was made in the Loddon Catchment (Wilford, James & Halas 2007) to better understand the distribution and mobilization of salts. The result was the compilation of a series of thematic maps showing the detailed distribution of soils, regolith, rock types and bedrock structure. At a broad scale these themes, together with hydrological data, were used to identify major hydrological regions or groundwater flow system associations. These associations divide the landscape into regions with similar regolith, soil, bedrock, landform, hydraulic properties and salinity characteristics. For a whole-of-catchment perspective this classification identifies regions that require different salinity management approaches. These regions are linked to one or more conceptual models (e.g. 3D block models and cross-sections) that describe groundwater and salinity processes thought to operate within specific parts of the landscape. Below this a finer level of detail has been captured where the distribution of the individual components or the fundamental building blocks that make up the flow system are delineated. These include landforms (e.g. colluvial slopes, rises, floodplains), soils, regolith (degree of weathering, composition and thickness) rock types and structures

(e.g. faults, fractures, density of structures). At this level soil and regolith toposequences and associated weathering and geomorphic processes are identified and incorporated into the spatial attribution.

Modelling approach. The modelling approach used to predict the location and mobilisation of salt within the study region uses a combination of a suite of farming system models linked into a catchment framework with connection to either (a) a lumped groundwater model or (b) a distributed, multi-layered groundwater model. The model known as the Catchment Analysis Tool (CAT) explicitly links farming system models to account for land use, topography, soil type and climate with a series of groundwater models (Beverly *et al.*, 2005; DSE, 2007). In this paper the CAT was linked with both the generalised 2CSalt model (DPI, 2008, Gilfedder *et al.*, 2007) and with the fully distributed multi-layer groundwater model MODFLOW (McDonald and Harbaugh, 1988) to assess the robustness of each modelling approach when using the new-regolith data.

Groundwater models attribution: The 2CSalt model groundwater attribution was based on spatially averaged GFS mapping (Figure 1). In contrast, a single layer and a six-layer MODFLOW groundwater model was developed based on the original and revised groundwater flow system stratigraphical delineation. The single layered MODFLOW model adopted the same initial attribution as the 2CSalt model. In the case of the six layer model enhanced GFS mapping was used to better define the spatial extent of the following defined aquifers; (1) Quaternary Alluvium and Pliocene Sand, (2) Newer Volcanics, (3) Calivil/Renmark Group, (4) Deeply weathered basement, (5) Devonian granite and (6) Palaeozoic basement. All MODFLOW groundwater models adopted a uniform grid of 100 m resolution.

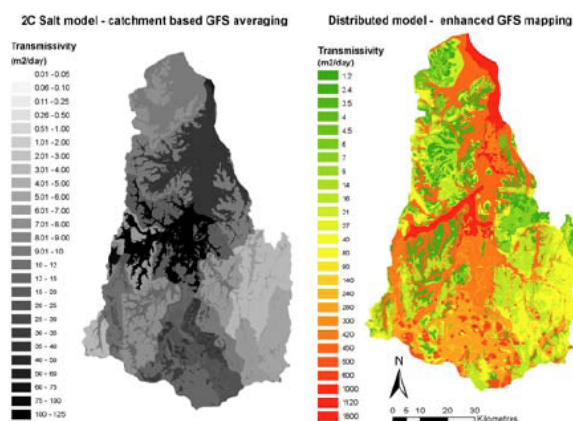


Figure 1 Groundwater transmissivities assigned as either spatially averaged (left for 2CSalt) or based on the revised (right) GFS mapping and incorporated into MODFLOW models.

Model calibration: The groundwater model calibration criteria were based on matching mapped salinity extent, depth-to-watertable estimates and baseflow volumes. A total of 298 groundwater observation bores were used for calibration of the distributed models.

Results

Model calibration. The 2Csalt model adopts a parameter estimation approach to match observed monthly flow and salt exports and does not simulated depth-to-watertable. In the case of the regional MODFLOW single layer model the calibrated model had a scaled rms error of 3.85% and an absolute residual mean of 3.50m which was considered acceptable with respect to the scale and hydrogeological complexity of the catchment. Table 1 summarises the error estimates associated with the different GFS mapping approaches derived within the BetBet sub-catchment.

Model sensitivity: A range of sensitivity analysis was undertaken on each model to assess the robustness of the model to changes in key input parameters. Figure 2 shows the impact of changes in hydraulic conductivities on baseflow. The response trajectory reflects the

sensitivity of the model and uniqueness of the model predictions.

Table 1 Comparison of GFS mapping results in the Bet Bet Catchment Original GFS mapping Enhanced GFS mapping

		Original GFS mapping	Enhanced GFS mapping
Single layer MODFLOW	Scaled RMS	2.25 %	2.10 %
	Mean sum of residuals	4.31 metres	4.11 metres
	Median watertable at mapped salinity sites	1.72 metres	1.60 metres

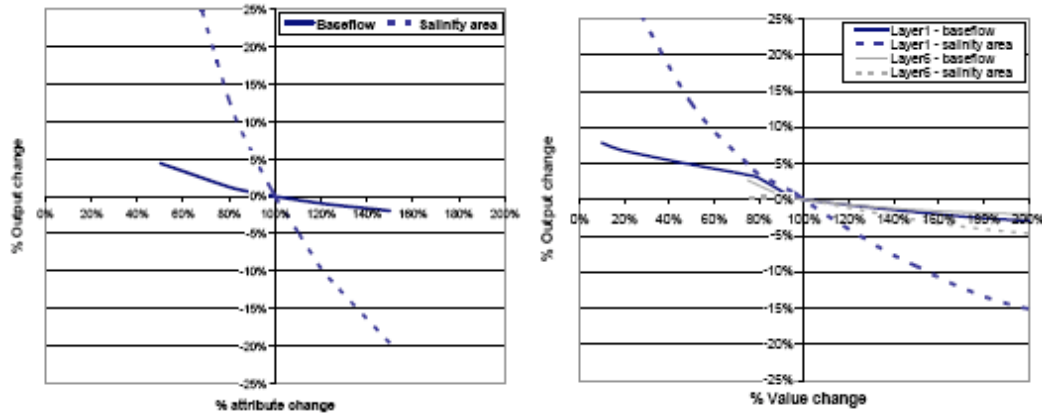


Figure 2 Typical sensitivity analysis applied to each model (top=2CSalt and 1 lay MODFLOW, bottom=6 lay MODFLOW) showing impact on baseflow to changes in hydraulic conductivities.

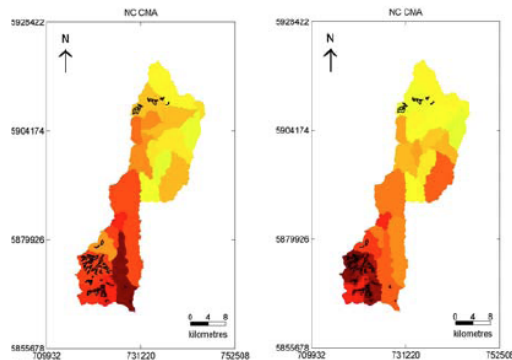


Figure 3 Simulated salt export rates (dark=high, light=low) for discrete zones based on the broad scale (top) and revised (bottom) regolith and bedrock information.

Salt export: The differences in estimated salt export from the Loddon catchment derived using the three models were negligible and in agreement with measured data. This is not unexpected as the 2CSalt model is calibrated to measured salt export data. However a significant difference in the spatial distribution of salt export was evident between the original and revised regolith information as shown in Figure 3. This figure shows the predicted salt loads derived within the Bet Bet subcatchment and clearly shows that the revised GFS attribution aligns the predicted high salt loads to the south-western corner of the catchment which is consistent with the mapped saline discharge regions within the study area.

Discussion

The significant limitation of the original GFS mapping approach was that it attempted to infer subsurface processes from surface information such as surface geology and landform mapping. Although these were the best available surrogates for delineating subsurface processes at the time the groundwater flow systems approach was developed, they only provide an approximation of the possible subsurface processes controlling dryland salinity. The new GFS layer incorporates the key components of bedrock, regolith and landforms to describe the different hydrological systems operating within the catchment. These components are defined from both existing datasets (e.g. geology and soil maps) and

interpretations based on aerial photographs, geophysical modeling (airborne magnetics and gamma-ray spectrometry) and digital terrain analysis techniques (automatic landform delineation). These components are compiled and aggregated across a range of landscape scales to define hydrological system operating across regional scales and time frames to short-term hillslope surface and through flow processes. Spatial autocorrelation was derived to describe the variability of the old and enhanced GFS mapping. In the case of the two mapped transmissivity layers a correlation coefficient of 0.59 was derived implying a weak relationship between the two data sets. Incorporation of these new data sets into a catchment modelling framework is shown to identify specific areas of the landscape requiring implementation of remediation strategies.

Evaluation of the simulated watertable surfaces between the original and enhanced GFS mapping layers show that the enhanced GFS mapping has provided a measurable improvement of simulated watertable level of approximately 7% and a 22% improvement in predicted salt export when compared to measured. Additionally a comparison of the impact of hydraulic conductivity on baseflow and predicted extent of land salinity as derived using the sensitivity analysis suggests that shallow watertable area should be a primary calibration target and groundwater baseflow a secondary target. The lumped modelling approach does not estimate shallow watertables nor adequately capture the enhanced GFS mapping attribution with the exception of the improved soil salinity layer.

Conclusion

This paper describes the enhanced understanding of catchment dynamics derived through application of a hierarchical, multi-scaled and multi-disciplinary mapping approach to help characterise different hydrological landscapes. The paper concludes that the enhanced spatial data sets derived using the hierarchical mapping approach when coupled to a spatially explicit physically based biophysical model provides a significant improvement in landscape process understanding and more credible predictions of the likely hazard and onset of dryland salinity.

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