# Applying unsaturated zone modelling to develop recharge maps for the Murray-Darling Basin in New South Wales, Australia

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**Abstract:** Salinity models calculate how much salt is mobilised by surface runoff, subsurface flow and/or groundwater discharge within a catchment. They can be used to estimate salt exports under current land use conditions and the impacts of land use changes. These models are necessary for informing investment decisions and catchment planning activities so that intervention strategies (e.g. land use changes) are designed and implemented for maximum benefit. One aspect of such an integrated suite of models is the capability to predict recharge to groundwater under various land use and land management scenarios. This identifies areas where a land use change (e.g. tree planting) will have the highest impact on recharge. In this paper, two unsaturated zone models (PERFECT and HYDRUS 2D) are combined to produce recharge maps for the New South Wales portion of the Murray-Darling Basin under current land use and a generic land use change scenario. Inputs to the models include spatial data of soil hydraulic properties, climate, land use and topography. These maps are being incorporated into a range of decision support tools to identify priority areas for land use change and support investment decisions.

***Keywords:*** *Recharge, HYDRUS, PERFECT, Water Balance, Modelling*

## 1. INTRODUCTION

In eastern Australia, salinity planning is underpinned by the concept of a future salt target. They express desirable salinity conditions in our catchments at some future date (e.g. 2010), and lay the foundations for salinity management into the future. There are generally two types of salinity targets considered. Firstly, an end-of-valley target is a water quality target at the end of a river that expresses an overall salinity condition to aim for. Secondly, a within-valley target is a water or land-based target within a catchment that expresses the salinity level at that location.

Natural Resource Management policy under the New South Wales Salinity Strategy, Murray-Darling Basin Salinity Management Strategy and the National Action Plan guides investment decisions and catchment planning activities.

To support investment decisions, the contributions different intervention strategies make to achieving catchment targets must be quantified. Therefore, hydrological and salt balance models that predict the impacts of land use changes within a catchment on catchment salt exports are required. It is not suggested that these types of models will provide the final answer to prioritise salinity management options. Instead, models help to identify priority areas and to assess the relative merits of different management options. Output from these models is linked with other criteria such as social and economic impacts, biodiversity benefits, and other vegetation and water planning considerations.

These models are required at catchment, regional and statewide planning scales. The assessment of salinity management options at a property scale must be supplemented by on-site assessment and local data, for example, stream EC collected from rapid stream appraisals.

In the context of this paper, salinity models quantify the pathways of salt and water within a catchment. They calculate how much salt is mobilised by surface runoff, subsurface flow or groundwater discharge within a catchment. Salt exports under current land use conditions can be estimated and the impacts of landuse change scenarios of water and salt export from a catchment can be predicted.

Within New South Wales, the CATSALT suite of models is currently being developed and applied (Tuteja *et al.* 2003). One aspect of such an integrated suite of models is the capability to predict recharge to groundwater under various land use and land management scenarios. This identifies areas where a land use change (e.g. tree planting) will have the highest impact on recharge. In this paper, two unsaturated zone models (PERFECT and HYDRUS 2D) are combined to produce recharge maps for the New South Wales portion of the Murray-Darling Basin. These maps are being incorporated into a range of decision support tools to identify priority areas for land use change and support investment decisions in New South Wales

## 2. SIMULATION ANALYSES

### 2.1. Study area

The study area is the New South Wales portion of the Murray-Darling Basin in Eastern Australia. The area has particular significance for salinity studies as it has been identified as a major source of salts into the Murray-Darling River network (Murray-Darling Basin Ministerial Council, 1999). This causes a range of adverse impacts within the basin and ultimately affects Adelaide's water supply.

Dryland salinity is evident in upland areas of New South Wales exacerbated by land clearing in the past. As part of the National Land and Water Resources Audit approximately 150 000 ha were determined to be affected by shallow water tables and dryland salinity (Natural Heritage Trust, 2001). The Murray-Darling Basin Salinity Audit estimated up to three-fold increases in stream EC over the next 100 years.

Substantial government funding has been allocated to improve salinity in the basin. Information from a range of sources, including modelling, is required to ensure equitable allocation of funds and to target areas where funding will benefit a range of environmental services.

### 2.2. Model description

Selecting a model for a study like this is governed by maintaining a balance between model complexity and available data and, access to skills and computing performance.

The primary water balance model applied in this study to estimate recharge for various land management scenarios was the PERFECT model (Littleboy *et al.* 1992).

PERFECT was developed as a cropping systems model that predicts the water balance (runoff, infiltration, soil evaporation, transpiration and recharge) for crop/fallow sequences. It has been applied to estimate water balance for a range of perennial pasture systems and tree water uses in eastern Australia (e.g. Abbs and Littleboy, 1998) .

Within PERFECT, simulation is performed on a daily timestep based on daily weather data. Runoff is calculated as a function of rainfall, soil water deficit, surface roughness, surface residue and crop cover. Soil water is updated on a daily basis by any rainfall exceeding the daily runoff volume. For dry profiles this infiltration may flow directly into the lower profile layer/s using an optional soil cracking algorithm. Infiltration is redistributed through the profile using a linear routing method. Redistribution from the lowest profile layer is assumed lost to the system as drainage. Transpiration is represented as a function of potential evaporation, leaf area and soil moisture. Water is removed from the profile according to the current depth and distribution of roots. Soil evaporation is based on Ritchie's two stage evaporation algorithm (Ritchie 1972). Following rainfall, it is assumed that drying occurs at a potential rate to a user defined limit. When this Stage 1 limit is reached, the second and slower stage of evaporation commences.

PERFECT is a one-dimensional water balance model in that it predicts the water balance in a single column of soil. It does not predict lateral subsurface movement of water. Any excess soil water is assumed to move vertically only. Therefore estimates of drainage from PERFECT are actually a combination of subsurface lateral flow and vertical drainage.

In order, to partition excess soil water moving laterally and vertically, the HYDRUS 2D model (Simunek *et al*., 1999) was applied to develop a generic model of lateral water movement (See Rassam and Littleboy, 2003). This algorithm partitions lateral and vertical flow based on slope and soil hydraulic conductivity. The amount of lateral water movement is estimated from slope and contrasts in soil texture. Highest lateral partitioning occurs for soils with strong contrasts in texture occurring on steeper slopes. Lowest lateral partition occurs for uniform textured soils in flatter areas. When this simper model derived from the HYDRUS 2D analyses is applied to the drainage term from the one-dimensional PERFECT model, the remaining excess soil water after the lateral flow component has been removed is assumed to be recharge.

### 2.3. Data sources

PERFECT requires inputs describing the climate, soils, and land use. When coupled with the simplified lateral flow algorithm derived from HYDRUS 2D, slope is also required.

GIS datasets are required when applying PERFECT spatially. Spatial data sources used were monthly rainfall surfaces (1 km pixel) derived from ANUCLIM (Hutchinson, 1995); a soils map of New South Wales, consisting of the best available soils maps spliced together; the 25 m Digital Elevation Model of New South Wales; and the land use map (1 km pixel) from National Land and Water Resources Audit (Natural Heritage Trust, 2001).

## 2.4. Data analyses

Climate zones for New South Wales that reflect total rainfall and rainfall seasonality were defined by overlaying grids of average annual rainfall with rainfall seasonality defined by (June + July + August rain / total rain); ie proportion of annual rainfall falling in winter months. The following categories of average annual rainfall (mm) were used: 0-200, 200-300, 300-400, 400-450, 450-500, 500-550, 550-600, 600-650, 650-700, 700-750, 750-800, 800-850, 850-900, 900-950, 950-1000, 1000-1250, 1250-1500, 1500-1750, 1750-2000 and greater than 2000 mm. The proportion of winter rainfall was divided into 5% classes. For each climate zone, daily weather data were extracted from the Queensland Department of Natural Resources and Mines Silo dataset (Jeffrey *et al.* 2001). The climate file closest to the centroid of each climate zone was obtained.

Soil hydraulic properties (water content at air dry, wilting point, field capacity and saturation, and hydraulic conductivity) for each soil unit were obtained from a variety of sources including the New South Wales Department of Land and Water Conservation SALIS database, look-up tables based on soil group, data for Northcote groups from (McKenzie *et al.* 2000) and PAWCER pedo-transfer software (Littleboy, 1997).

The land use map contained a wide range of land use attributes. The data were reclassified into the following generic categories; pasture, trees, cropping, urban and other land uses.

For the analyses presented in this paper, pasture was simulated as a perennial system without significant grazing pressure. Potential tree water use was estimated by applying a crop factor to daily pan evaporation. Actual tree water use was estimated from potential tree water use and soil water availability on a daily timestep. Cropping assumed a winter rotation (wheat and canola).

Climate zones and soil polygons were overlayed in a GIS to divide the New South Wales Murray-Darling Basin into climate and soil combinations. For each combination the PERFECT water balance model was run to predict runoff and deep drainage for each polygon. Weather data for the period 1975-2000 were used for all simulations.

The lateral flow algorithm derived from HYDRUS 2D analyses was then applied to partition the deep drainage into lateral flow and vertical recharge. The ArcGrid and Spatial Analyst GIS software were used for all analyses. A 100m pixel resolution was applied across the NSW Murray-Darling Basin.

## 3. RESULTS AND DISCUSSION

The derived recharge map under current land use is presented in Figure 1. Highest recharge was estimated for the eastern and upland parts of the Murray-Darling Basin. Recharge decreased to the west due to the declining rainfall westwards from the coast. Higher recharge tended to be predicted for the southern part of New South Wales, probably due to increased winter rainfall to the south. In winter months, rainfall exceeds potential evapotranspiration resulting in excess soil water in most years.

The data presented in Figure 1 are based on daily timestep water balance modelling that considers interactions between daily weather data, soil hydraulic properties and plant water uptake. There is a strong correlation between rainfall and recharge evident in the data. The spatial distribution of soil hydraulic properties and land use were also clearly evident. For example, the sharper delineated areas of higher recharge towards the west are due to highly permeable soils.

One possible scenario that can be considered from these datasets is the impact of planting trees on recharge. Figure 2 shows the reduction in recharge if trees are planted. Substantial reductions of up to 50 mm/yr were predicted for large parts of the eastern upland areas. In the northern parts of the State, the reductions were smaller. In the northern part of New South Wales, other intervention strategies such as changes in agronomic practice are being advocated. This shows that there is not a “universal” intervention strategy. The impacts of a range of intervention strategies on recharge will depend on the complex interactions between climate, soils, vegetation, topography and hydrogeology.

However, these results only describe the impacts of land use on recharge. It is not possible to quantify impacts on salinity by only considering recharge. This can only be achieved by coupling recharge estimates to models that describe water and salt movement within catchments.

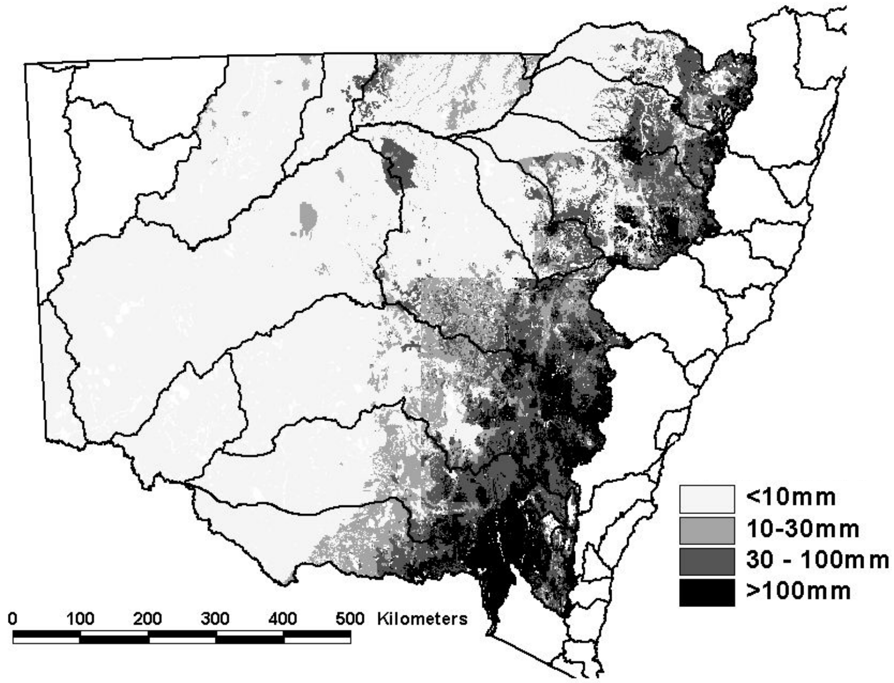

Figure 1. Estimated average annual recharge (mm) for the New South Wales Murray-Darling Basin

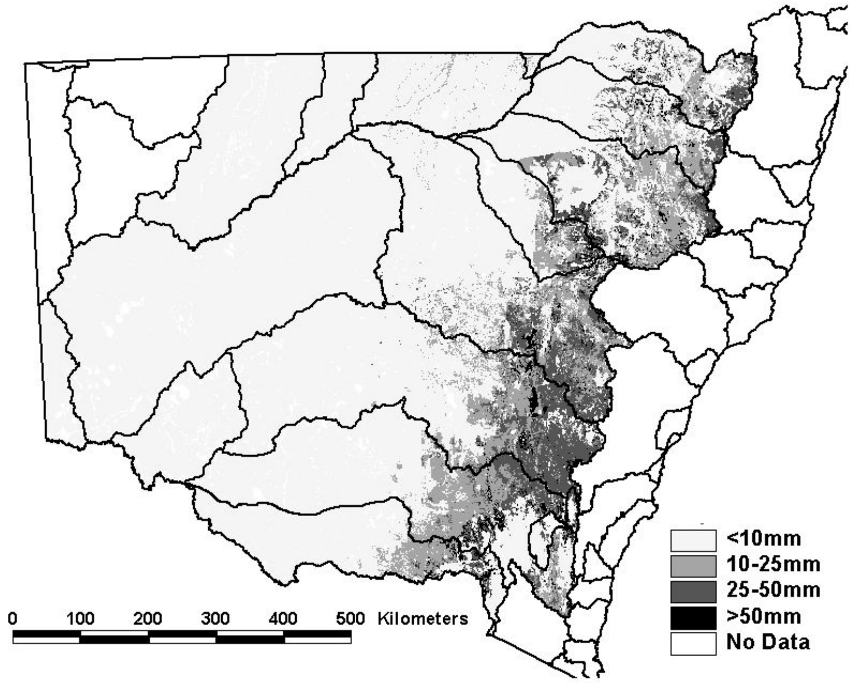

Figure 2. Estimated reduction in average annual recharge (mm) if trees are planted for the New South Wales Murray-Darling Basin

An example of a study that uses recharge modelling as one data layer to predict water and salt movement within catchments and stream EC at the catchment outlet is described in Tuteja *et al.* (2003).

The validity of output from such a spatial modelling exercise is impossible to completely determine. The validation of any model can be quantitative or qualitative. Qualitative validation is based on subjective comparisons of model performance such as expert opinion. Quantitative validation utilises statistical tests to compare model output with either field measurements or expert opinion. An underlying assumption of the model validation process is that the field data or expert opinion represents reality. It is generally assumed that a model is valid if it can adequately mimic the field data or expert opinion. The main outcome from model validation is an increased level of confidence and trust in a model. Greater confidence in model output can be obtained through the validation of a number of prototypes of a model.

Extensive validation of PERFECT for numerous soils, climates, and farm-management options has been performed and published in the scientific literature. In eastern Australia, validation has been undertaken using data from at least ten locations, 20 soils and 48 farm-management options (e.g. different crops, tillage practices and fertiliser options). These represent approximately 450 years of experimental data. In addition, there are numerous publications describing the validation of models that were later to become a submodel of PERFECT. Some examples of submodels of PERFECT that have been compared with field data include the CREAMS water balance model (Silburn and Freebairn, 1992), various soil erosion models (Freebairn *et al.*, 1989), and the wheat submodel (Woodruff and Tonks, 1983; Hammer *et al.*, 1987).

Confidence in a model will be enhanced if the model is found to be robust over time and space. The success of this previous validation of PERFECT has increased the confidence in applying PERFECT for spatial modelling of soil water balance.

The results presented in this paper are the initial estimates of recharge across the New South Wales Murray-Darling Basin. In this study, only three generic land uses (trees, pasture and winter cropping) were considered. Further analyses are currently underway to increase the number of scenarios simulated including a range of tree covers, pasture management strategies and cropping systems.

In addition, improvements in the collation and analyses of available soil mapping data will provide enhancements in the quality of soils data required to undertake spatial modeling of soil water balance.

This modelling is currently being linked to a range of decision tools under development to support salinity management across a variety of spatial scales. One example is the Land Use Options Simulator (Herron and Peterson, 2003).

## 4. CONCLUSIONS

This study successfully coupled a generic relationship derived from complex water balance modeling with HYDRUS 2D with a simpler cascading bucket model. This permitted the application of a simpler water balance model to estimate lateral movement of water. This captures some of the complexity of physically-based soil water models while overcoming many of the data limitations which limits the spatial application of complex soil water models such as HYDRUS 2D.

Estimated average annual recharge under current land use ranged from near zero in drier parts of New South Wales to greater than 100 mm in wetter high altitude areas. Average annual recharge typically ranged from 10 to 100mm in the eastern areas of the New South Wales Murray-Darling Basin where dryland salinity is more evident. In these areas, the modelling estimates that average annual recharge could be reduced by between 10 and 50 mm if trees are planted.

## 5. ACKNOWLEDGEMENTS

This project was funded under the New South Wales State Salinity Strategy. The authors wish to acknowledge the Department of Land and Water Conservation soils group at Parramatta for providing the soil mapping used in these analyses. We would particularly like to thank Dr Brian Murphy from Department of Land and Water Conservation in Cowra for assistance in deriving soil hydraulic properties, and the numerous experts who have provided comments to the project team on these products. Finally, Peter Dykes undertook some of the GIS analyses presented in this paper.

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