VALIDATING MODELLED DEEP DRAINAGE ESTIMATES FOR THE QUEENSLAND MURRAY-DARLING BASIN

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Abstract
Accelerated rates of drainage below the root zone can lead to rising water tables, which may in turn lead to land and stream salinity. Estimating rates of deep drainage is an important part of predicting salinity risk. Water balance modelling is widely used to estimate deep drainage. However, model outputs of deep drainage have rarely been validated in the past because of a lack of data. Estimates of deep drainage are now available for the Queensland Murray Darling Basin from several sources. This paper presents preliminary validation of modelled deep drainage against these data. Two daily water balance models, GRASP and PERFECT, were used for different soils and land uses, using 'default' parameter values.

Relationships of modelled water excess (runoff plus drainage) and average annual rainfall were similar to published relationships (Zhang *et al.* 2001), although modelled estimates give much greater differentiation between soils. Modelled drainage rates were of a similar order of magnitude to estimates determined from a transient chloride mass balance approach for native vegetation and cropping sites, and for a detailed catchment study. This improves confidence in drainage modelling, which is used to assess salinity risk in areas where measurement is impractical.

Additional Keywords: salinity, water balance, chloride balance, runoff

Introduction
Drainage of water below the root zone (described as deep drainage) can lead to rising water tables and lateral transfer of water and salt, which may in turn lead to land and/or stream salinity, through mobilisation of salts in the regolith. The measurement or estimation of deep drainage is therefore an important factor in predicting salinity. Water balance modelling is one of the techniques widely used to estimate deep drainage. These water balance models are useful for exploring the effect of climate, soil, land use and management practice on deep drainage.

Water balance models such as PERFECT and GRASP have been developed and used in Queensland for several decades. These models have been validated against measured runoff, soil water, yield and cover data in grazing and cropping systems (e.g. Littleboy *et al*. 1989, 1992, Silburn and Freebairn 1992, Day *et al.* 1997, Owens *et al.* 2003). However, there is little previous research on deep drainage in the Queensland Murray-Darling Basin (QMDB) and hence model outputs of deep drainage have been poorly validated.

Tolmie *et al.* (2003) have recently provided long term estimates of deep drainage for several soils and land uses in the QMDB using transient chloride mass balance. Sites were either long-term trial sites where crop, soil water and sometimes runoff measurements were available, or on-farm paired (native vegetation, crop) sites.

The aim of the current study was to validate modeled estimates of deep drainage occurring under a range of land uses and soil types in the QMDB. This will provide more confidence in using soil water balance models for drainage estimation to feed into salinity risk models. Drainage estimates from other methods combined with measured field data will increase confidence in modeled drainage rates.

Materials and Methods
The study area is the northern component of Australia's largest drainage system, the Murray-Darling Basin (Map 1). The modelling tools used were PERFECT (Littleboy *et al.* 1989) to represent cropping, and GRASP (Littleboy and McKeon 1997) to represent native pastures and trees.

Data sources
Sources of deep drainage estimates for different soils and land uses in the Queensland Murray-Darling Basin were:

1. General trends (Zhang *et al.* 2001)
2. Drainage estimates using soil chloride (Cl) methods (Tolmie *et al.* 2003)
3. Measured data at experimental sites

Zhang *et al.* (2001) collated results from 250 catchments worldwide, which showed good relationships between long-term average actual evapotranspiration (ET) and rainfall for two vegetation classes - forest and herbaceous plants. Static models built from these data are referred to in the literature as the Zhang curves. The transient chloride mass balance approach of estimating drainage compares time series or paired site chloride concentration profiles to infer the rate of water movement below the root zone (Tolmie *et al.* 2003).

Map 1. Queensland Murray Darling Basin (QMDB).

Modelled estimates of deep drainage for different soils and land uses in the QMDB
To obtain general trends of drainage across the QMDB, GRASP and PERFECT were run from 1900 to 2001, for 38 locations for 17 soils and 7 land uses. This covered most common combinations within the QMDB. The models were previously validated against hydrologic data across northern Australia (e.g. Littleboy *et al.* 1989, 1992, Silburn and Freebairn 1992, Day *et al.* 1997, Owens et al. 2003) but not for drainage. The drainage estimates from the matrix of model runs are based on representative soil profiles. As such, the drainage estimates have not been comprehensively validated at each location. However, results do indicate in relative terms the impacts of rainfall, soil type and land use on drainage. Results from this 'best bet' modelling (carried out before the drainage data were available) were compared, without calibration, with general trends (Zhang curves) and with drainage estimates obtained using the chloride method.

Site specific modeling at Greenmount
Water balance modelling was also tested in more detail at a site with long term cropping and water balance data, and an average drainage estimate for 1977-1996 from chloride (Tolmie *et al.* 2003). The runoff trial at Greenmount was established in 1976 on a black cracking clay soil or Vertosol (Freebairn and Wockner 1986). Runoff and soil erosion was previously modelled using data for 1976 to 1983 (Littleboy *et al.* 1989, 1992, Silburn and Freebairn 1992). Here the PERFECT model was run for the wheat-fallow treatment using measured soil, crop and management data from 1976 to 1996. Crop growth parameters were adjusted against measured crop yield, but otherwise parameters were measured (e.g. plant available water capacity, PAWC) or from previous modelling studies (i.e. for runoff, hydraulic conductivity and soil evaporation). The site was also modelled with general crop parameters and planting and tillage dates as used in the generic matrix of model runs, to see if acceptable results could be obtained without using detailed information like farm operations dates (eg planting, tillage and burning).

Results and Discussion

General trends across the QMDB
Long-term annual average ET and water excess (runoff plus drainage) derived using the GRASP model for native vegetation are in agreement, on average, with the Zhang model for forests (Figure 1). Long-term annual average ET and water excess derived using the PERFECT model for winter cropping agree, on average, with the Zhang curve for herbaceous plants (Figure 2). Keating *et al.* (2002) found similar results using APSIM for a red Earth at sites across the Murray Darling Basin.

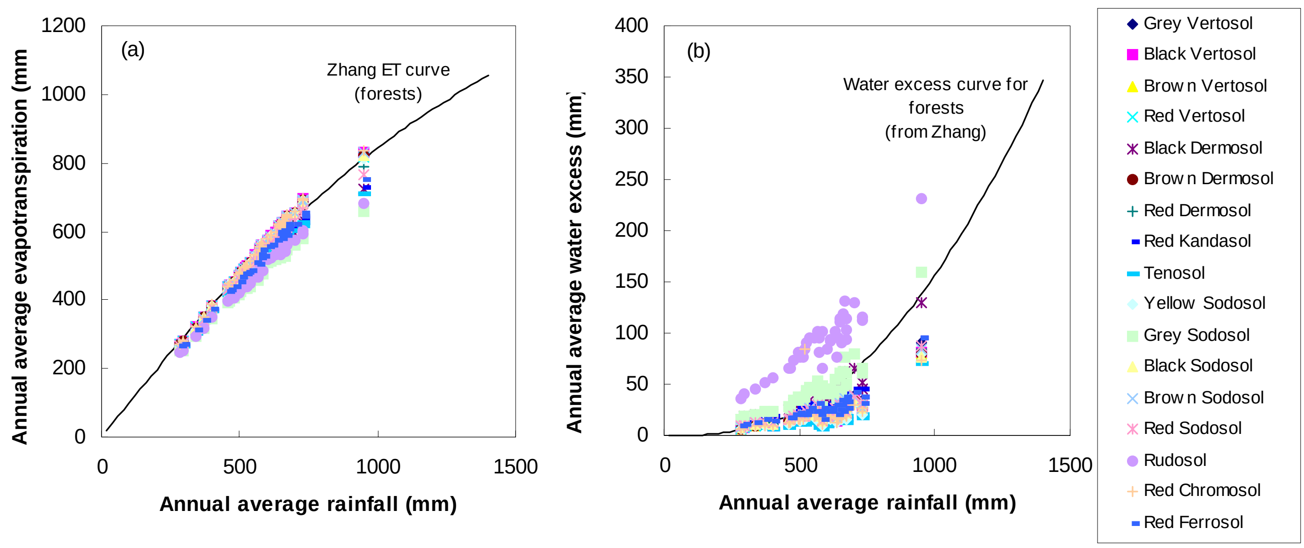

Figure 1. Predictions of average ET and water excess for native vegetation for 38 locations and 17 soils compared with the Zhang ET curve (forests).

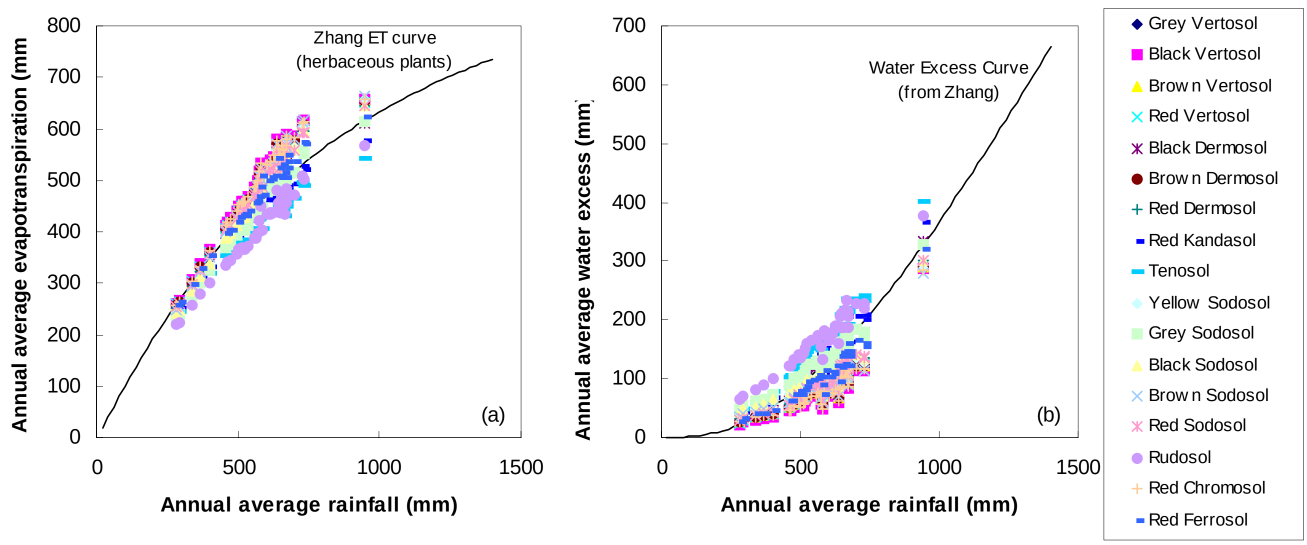

Figure 2. Predictions of average ET and water excess for winter cropping for 38 locations and 17 soils compared with the Zhang ET curve (herbaceous plants).

This is an independent validation of the GRASP and PERFECT models against observed data summarised by the Zhang curves. For each soil, average ET and water excess are related to annual average rainfall, following a curve similar to those of Zhang. However, there is considerable variation in water excess between soils due to soil properties. An extreme case is the Rudosol (shallow/skeletal soil) (Figure 1) where ET is considerably less, and the water excess is considerably greater, than the generalised curve. Soil water holding capacity is so low that larger rainfall events cannot be stored (for later use by ET) and become runoff and/or drainage. Water balance modelling for such soils is based on 8 years of measured hydrologic data (Owens *et al.* 2003).

Both average runoff and drainage increase as rainfall increases, with fairly consistent relationships for any particular soil (Figure 3). However, there are large differences between soils. The Tenosol (modelled here as a sandy soil) has the lowest runoff and highest drainage. The Kandosol and Ferrosol follow similar trends though with somewhat more runoff and less drainage. In contrast, Sodosols and Dermosols have the highest runoff and lower, but not the lowest, drainage, due to their low-moderate PAWC and lower subsoil permeability. Vertosols (cracking clays) have about average runoff but low drainage compared with the other soils, due to their high PAWC. The Rudosol has high drainage and about average runoff and thus has high total excess water, similar to the Tenosol.

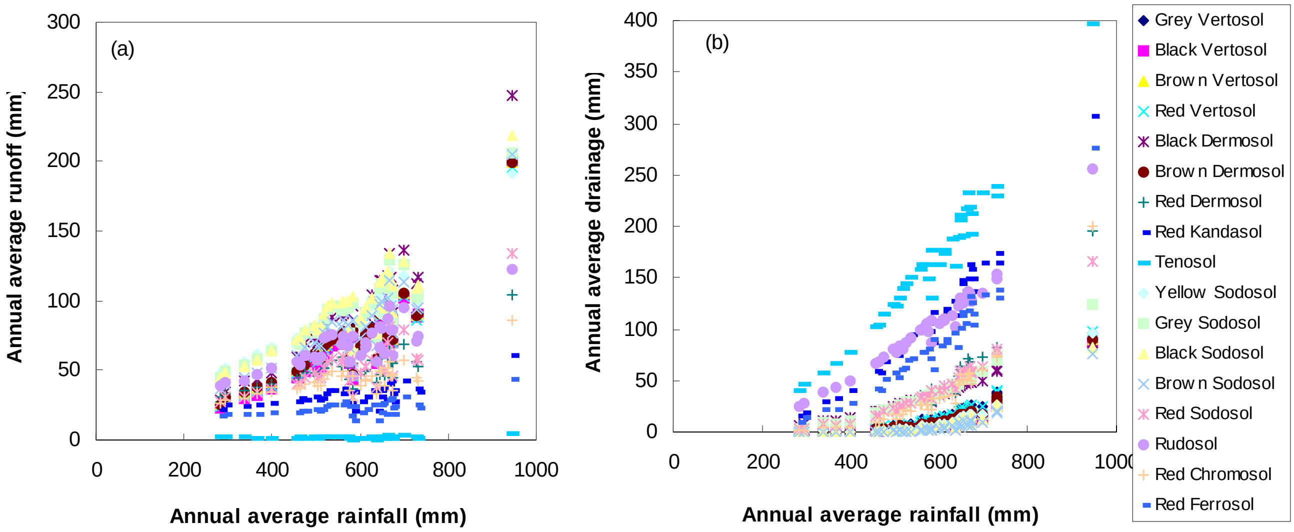

Figure 3. Average annual runoff and drainage for winter cropping for 38 locations and 17 soils in QMDB.

Thus there are quite large differences between some soils, in excess water in some cases, and in runoff and drainage partitioning, though on average they follow the Zhang curves. These differences occur because we have parametised the PAWC, runoff and drainage of these soils differently, based on what is known about them.

Comparison against transient chloride mass balance method

Tolmie *et al.* (2003) estimated drainage using soil chloride (Cl) for sites in the QMDB (Figure 4). To allow comparison and approach a long-term average, sites with 20-70 yrs cropping history that were dominantly under winter cropping-summer fallow and conventional tillage were selected. Long-term drainage modelling for these sites were selected from the generic matrix of model runs (without calibration) for a 'most like' soil. Modelled drainage compares favourably with estimates from the Cl method, in the same order of magnitude (Figure 4). Modelled drainage is higher than the Cl drainage at higher rainfall sites. One of these 'outlier' sites was modelled in detail (next section). When actual soil properties were used, modelled drainage was similar to drainage from Cl ('♦ Greenmount (site modelling)' in Figure 4). The soil chosen from the matrix in this case was simply not 'alike' enough.

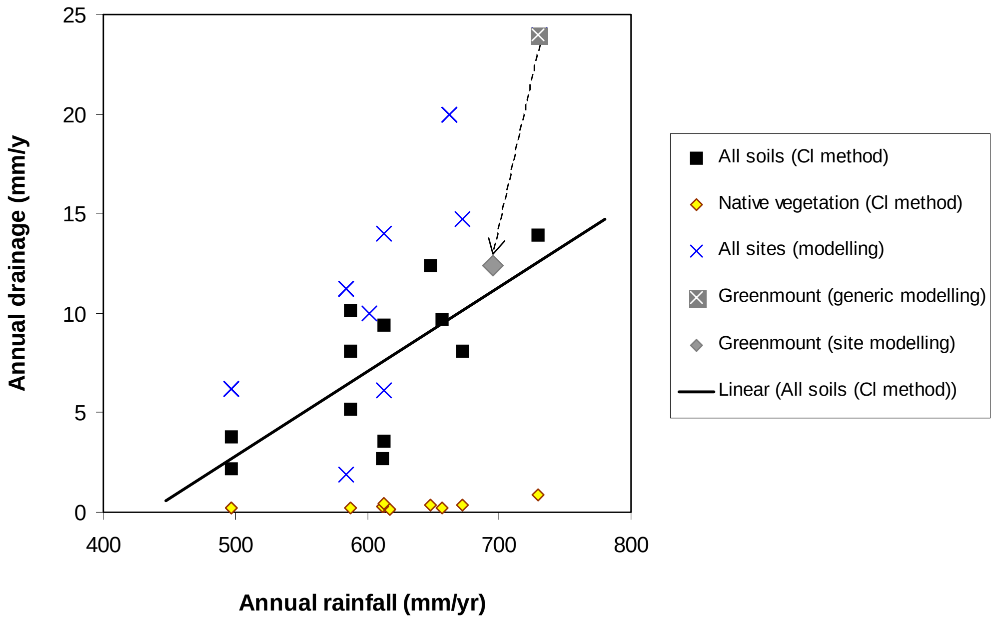

Figure 4. Drainage (at 1.5 m) related to average annual rainfall for long-term winter crop sites using the soil chloride method (Tolmie *et al.* 2003) and modelling.

Under native vegetation, Tolmie *et al.* (2003) found drainage rates were typically low (e.g. <1 mm yr^{-1}), averaging 0.3 mm yr^{-1} for the soils they studied (Vertosols and Sodosols). Long-term drainage modelling for these sites and soils under native vegetation show very low or no drainage. Modelled runoff and drainage rates are low for most (but not all) soils and locations under native vegetation (Figure 1).

Comparison against data from the Greenmount experimental catchments

Tolmie *et al.* (2003) reported drainage of 14 mm/yr for the period 1977 to 1996 at Greenmount. Modelled drainage for the same period was 12 mm/yr (Figure 5). Soil water was predicted well through time (Figure 5) (modelled soil water deviates from the measured data in 1985-86 because the crop died due to drought). Runoff was predicted reasonably well, similar to previous modelling of this site (Littleboy *et al.* 1989, 1992, Silburn and Freebairn 1992). When the site was remodelled with general crop parameters and planting and tillage dates, as are used for long-term runs in the generic matrix, average drainage was 16 mm/yr for the period 1977 to 1996, with reasonable predictions of crop yield, runoff and soil water. This illustrates that a reasonable prediction of long-term drainage is probably achieved without exact farm operation dates, so long as the main features of the cropping system (e.g. summer or winter crop) are captured.

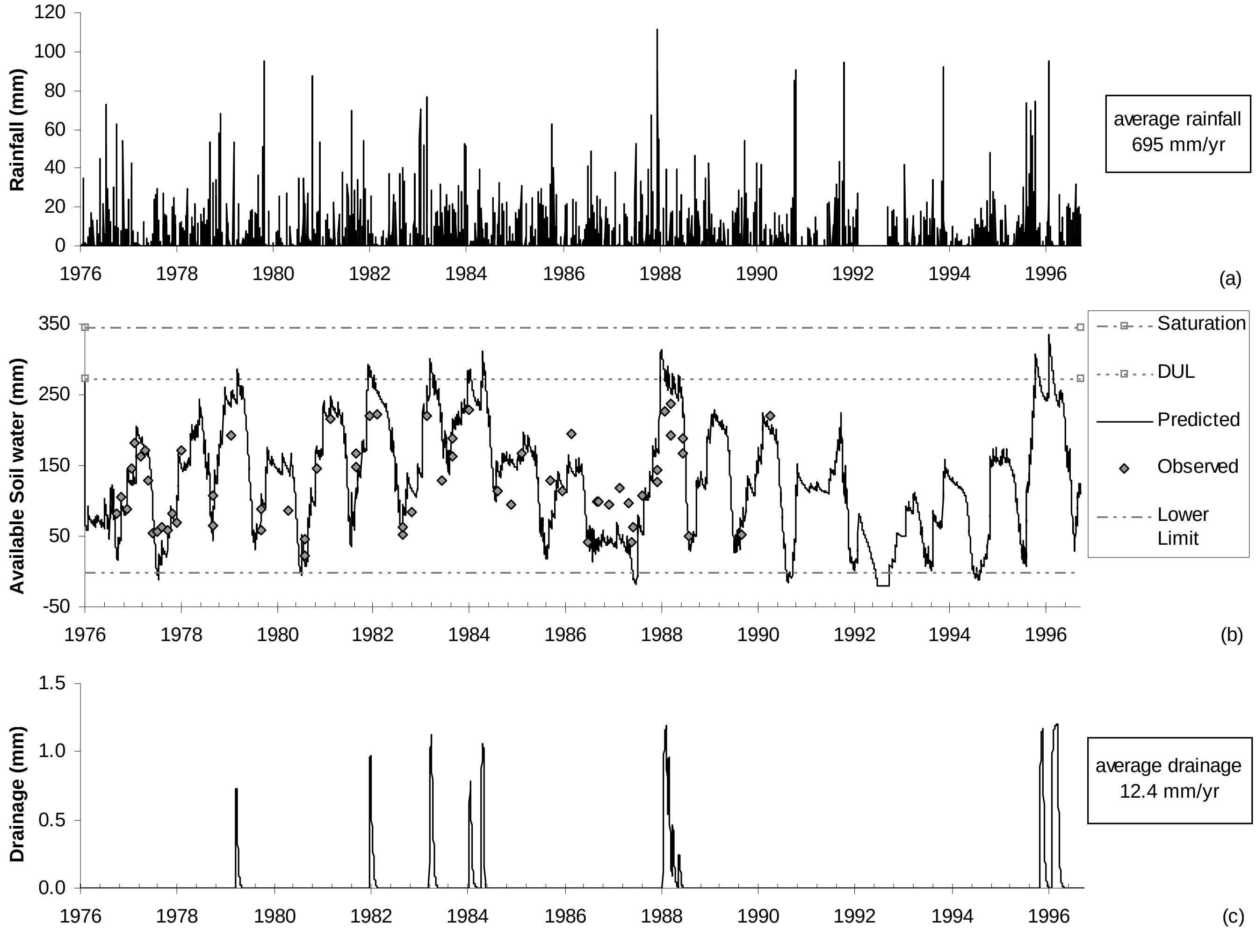

Figure 5. Rainfall, modelled available soil water and drainage at Greenmount using site management data.

Daily patterns of rainfall, soil water and drainage are useful for working out when drainage occurs (Figure 5). Drainage and runoff occurs when soil water is near field capacity (DUL) because little extra water can be stored in the soil. For example, the soil profile was 'full' in April to July of 1988 (Figure 5b), which coincides with high rainfall and runoff before planting, and drainage in the same period (Figure 5c). More or less no drainage occurred for the next 7 years. Drainage only occurred in 6 out of 21 years and 80% of drainage occurred in 9 months. These data, and other long-term modelled drainage, illustrate the temporal variability of drainage in this subtropical, semiarid environment. Drainage events are even uncommon and scattered under perennial vegetation such as pasture or native vegetation, a real challenge to measuring a sensible long-term average.

At least at this site, hydrologic model parameters that were derived from rainfall, runoff, soil water and soil and crop data (Littleboy *et al.* 1989, 1992, Silburn and Freebairn 1992), without drainage data, appear to have characterised the water balance well enough to give a reasonable estimate of drainage. Similar model testing is underway for other hydrologic/chloride study sites.

Soil parameters obtained from modelling drainage at Greenmount, and other hydrologic/chloride study sites in the region, are useful for extrapolating to similar soils in the QMDB. These represent valuable 'point of truth' in modelling exercises such as salinity risk assessment, where drainage estimates are required for all soil-landuse-climate combinations in a spatial coverage.

Conclusions

Validation of modelled drainage against two other methods has greatly improved our confidence in modelling drainage in the QMDB. Drainage predicted using GRASP and PERFECT were similar to those derived from the Zhang curves and the chloride method. The Zhang curves provide a generalised response at a catchment scale that would often include a complex of land uses and soils, whereas the daily water balance models represent a single hydrologic response unit. The results derived in this study are based on historical time-series of climate data and consider land use, soil type and land management. The models used differentiate a large variation in runoff and drainage between different soils and hence provide a description of the natural variability that exists within the QMDB. They do however require considerable knowledge about vegetation and soil characteristics. Drainage estimation from soil chloride methods, applicable to longer time scales, appears suitable for this environment where drainage events are highly episodic and for testing models of drainage under these conditions.

Modelling at specific sites in conjunction with measured data greatly improves prediction of drainage, especially if measured soil water, runoff and crop management data is available. We plan to model all experimental sites where drainage has been estimated using the chloride method. This will provide increased confidence in using water balance models for predicting drainage and provide soil and plant parameter values for modelling similar soils. Modelled drainage for different soils, land uses and locations presented will be useful to inform natural resource managers of the likely impact of land use change on the water balance within the QMDB.

Acknowledgements

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References

Day, K.A., McKeon, G.M., Carter, J.O. (1997). Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final report for Rural Industries and Research Development Corporation project DAQ124A. (Queensland Department of Natural Resources: Brisbane)
Freebairn, D.M., Wockner, G.H. (1986). A study of soil erosion on vertisols of the eastern Darling Downs, Queensland. I. The effect of surface conditions on soil movement within contour bay catchments. *Australian Journal of Soil Research* 24, 135-158.
Keating, B.A., Gaydon, D., Huth, N., Probert, M.E., Verburg, K., Smith, C.J., Bond, W. (2002). Use of modelling to explore the water balance of dryland farming systems in the Murray-Darling Basin, Australia. *European Journal of Agronomy* 18, 159-169.
Littleboy, M, Silburn, DM, Freebairn, DM, Woodruff, DR, Hammer, GL (1989) PERFECT: A computer simulation model of productivity, erosion, runoff functions to evaluate conservation techniques. Bull. QB89005 (Qld Department of Primary Industries: Brisbane)
Littleboy, M, Silburn, DM, Freebairn, DM, Woodruff, DR, Hammer, GL, Leslie, JK (1992) The impact of soil erosion on sustainability of production in cropping systems. I. Development and validation of a simulation model. *Australian Journal of Soil Research* 30, 757-774.
Littleboy, M., McKeon, G. (1997) Subroutine GRASP: Grass production model, Documentation of the Marcoola version of Subroutine GRASP. Appendix 2 of 'Evaluating the risks of pasture and land degradation in native pasture in Queensland'. Final Project Report for Rural Industries and Research Development Corporation project DAQ124A. (Queensland Department of Natural Resources: Brisbane).
Owens, J.S., Silburn, D.M., McKeon, G.M., Carroll C., Willcocks J., deVoil, R. (2003) Cover-runoff equations to improve simulation of runoff in pasture growth models. *Australian Journal of Soil Research* 41, 1467-1488.
Silburn, D.M., Freebairn, D.M. (1992) Evaluation of the CREAMS model. III. Simulation of the hydrology of vertisols. *Australian Journal of Soil Research* 30, 547-64.
Tolmie, P.E., Silburn, D.M., Biggs, A. (2003) 'Estimating deep drainage in the Queensland Murray-Darling Basin using soil chloride.' QNRM03020. (Department of Natural Resources and Mines: Coorparoo, Queensland).
Zhang, L., Dawes, W.R., Walker, G.R. (2001) Response of mean annual evapotranspiration changes at catchment scale. *Water Resources Research* 57, 701-708.