18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Grouping soil types based on soil properties- Impact on water balance modelling

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Abstract: The hydraulic properties of soils play important role on the overall water balance and flow partitioning from landscapes to stream. In this paper, the variability of three soil attributes (soil depth, plant available water capacity and saturated hydraulic conductivity) is modelled to classify soil into broader hydrological groupings. Soils are typically mapped using pedological classifications rather than soil hydrology. Many soils that exhibit similar hydrological behaviour may be classified as different soils. The New South Wales portion of the Murray-Darling Basin has 355 soil types as described in McKenzie *et al*. (2000) which are widely used in hydrological modelling. When overlaid with current land use mapping and climatic zones, there are 48280 combinations of land use, soil type, and climate across the New South Wales Murray-Darling Basin. Statistical analysis of output from water balance modelling has been used to group these 355 soil types into 29 hydrological soil categories. Reducing the number of soil groupings has major computational benefits for the spatial modelling of soil water balance. For example, reducing the number of soil groupings from 355 to 29 reduces the number of combinations for land use, soil type and climate from 48280 (355 x 136) to 3944 (29 x 136).

The new hydrological soil categories have been verified by comparing water balance differences between the neighbour soil categories and between soil types within one category. The results show that there are large differences between soil categories but few differences within one category.

Keywords: *soil type, grouping, modelling*

1. INTRODUCTION

The daily water balance model PERFECT (Littleboy *et al*. 1989) has been widely used in Australia to estimate soil water balance. The model was developed as a cropping system 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 trees water use in eastern Australia (e.g. Abbs and Littleboy, 1998). The model has been validated against measured runoff, soil water yield and land cover/vegetation data in grazing and cropping systems (Littleboy *et al.* 1989, 1992, Silburn and Freebairn 1992, Day *et al*. 1997, Owens *et al*. 2003, 2004).

PERFECT has been previously applied across the New South Wales Murray-Darling Basin using soil hydraulic properties derived for 355 mapped soils. Many of these 355 soils are hydrologically similar or identical soils that have been classified using different soil classification systems. The New South Wales Murray-Darling Basin water balance modelling uses 613 climate zones, 355 soil types and 13 land use types, a total of about 3 million combinations. Reducing the number of soil types has the potential to dramatically reduce the number of combinations resulting in substantial saving in computational time and data storage.

The aim of this study is to use the simulation results of water balance model PERFECT to group soils with the same or similar hydrological response.

2. MODEL DESCRIPTION AND DATA

The daily one-dimensional water balance model PERFECT is used in this study. Within PERFECT, simulation is performed on a daily time step based on daily climate 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 from 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).

Modelling is carried out for entire New South Wales portion of the Murray-Darling Basin which covers an area of 597,926 square kilometres. Mean annual rainfall across NSW Murray-Darling Basin (1975-2006) ranges from a minimum of 239mm/yr to a maximum rainfall of 1079mm/yr. There is a clear east-west rainfall gradient across the region, where rainfall is highest in the east and lowest in the west.

The model requires daily climate data (rainfall, maximum temperature, minimum temperature, potential evapotranspiration, and radiation), soil profile hydraulic properties and land use types as its inputs. The source of the climate data is the ‘SILO Data drill’ of the Queensland Department of Natural Resources and Water (www.longpaddock.qld.gov.au/silo/, Jeffrey *et al*. 2001). The SILO Data Drill provides daily rainfall and other climate variables for 0.05°x0.05° grids across Australia, interpolated from point measurements made by the Australian Bureau of Meteorology. These surfaces are grouped into climatic zones on the basis of average annual rainfall and rainfall seasonality. For each of the defined 628 climate zones, the SILO data closest to the centroid of each zone are used. Four land use types (pasture, crop, trees and bare soil) are used in this modelling. The soil types used in this study is a dataset with 355 soil types as described in McKenzie et *al.* (2000).

3. GROUPING METHODOLOGY

All 355 soil types along with a subset of 136 representative climate zones are modelled. The analysis of the simulation results are used to group soil types based on their soil water balances. The simulation analysis in the paper considers 48280 (355 x 136) combinations of soil types and climate zones across the New South Wales Murray-Darling Basin.

Soil properties analysis. There are 355 soil types as described in McKenzie *et al*. (2000) in New South Wales Murray-Darling Basin. Each soil type has been assigned three soil properties: plant available water capacity (PAWC), soil depth, and saturated hydraulic conductivity (Ksat). The three soil properties play important role on water balance modelling. Soils across the study area have been mapped using up to three different systems of soil classification. When identical soils with different soil classification names are grouped, the number of soil types reduces from 355 to 145. Consequently, the number of combinations of climate zone and soil types reduces to 19720 (145 x 136). This reduced set of combinations is used to group soil types according to soil’s hydrological behaviour.

Soil type grouping. Estimated average annual ET (plant water use plus soil evaporation), average annual surface runoff, average annual drainage below the root zone and average annual water excess (runoff plus drainage) are tabulated against average annual rainfall for all combinations of soil types and climate zones. Soil types that exhibit the same or similar hydrological behaviour are then grouped into different soil categories.

The table is sorted by ET to generate the distribution of ET from the highest to the lowest for 145 soil types. The distribution of ET then is divided into eight classes with the same ET interval. The number of ET classes was a compromise between a large number that would decrease the efficiency of grouping and a small number that would result in excessive variations of ET within one class.

Results are classified by runoff and drainage respectively, and divided into eight classes to generate new runoff, drainage indices. With this process, each of the 145 soil types is assigned an ET index, runoff index and drainage index.

Soil types with the same ET, runoff and drainage soil indices become one soil category. There are a total of 29 new soil categories derived in comparison to the original 145 soil types. The sequence of new soil categories is recorded according to the sequence of ET increase. Soil category 1 has the smallest ET while soil category 29 has the largest ET.

Soils are grouped based on their estimated water balances rather than their soil physical properties. The important soil properties for water balance modelling are water holding capacity, soil depth and hydraulic conductivity. If each of these three properties is grouped into the same number of classes used to group components of the water balance (eight classes), then there would be up to 512 (8x8x8) combinations of these properties and hence a maximum of 512 new soil groupings. Since the aim of this analysis is to reduce the number of soils into fewer classes, soils are grouped on their hydrological response rather than their soil physical properties.

4. RESULTS AND DISCUSSION

Hydrological behaviours of new soil category

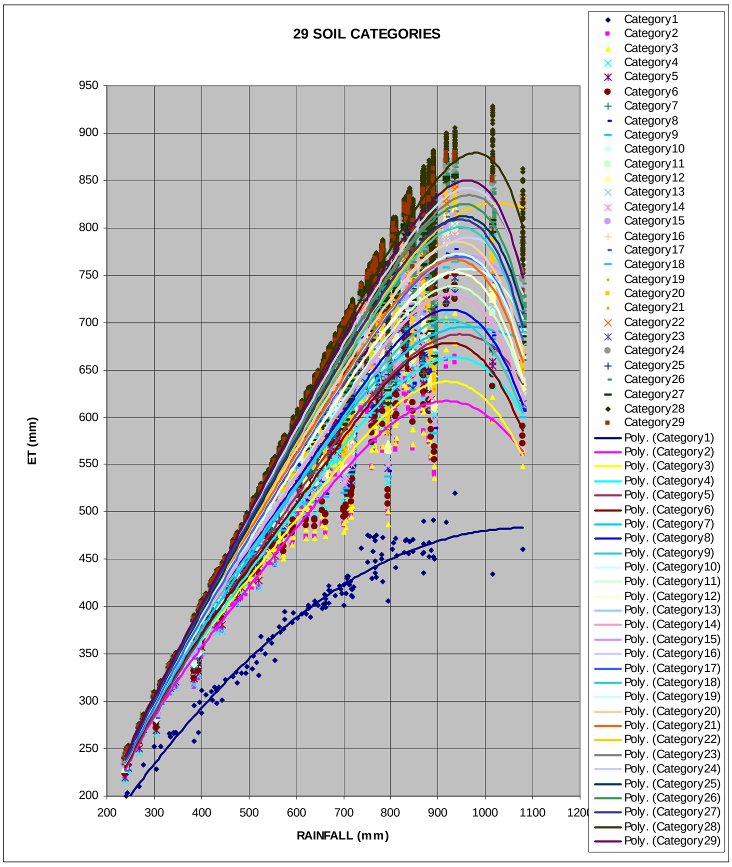

Figure 1. New soil categories' evapotranspiration distributions and their trend lines

The original PERFECT modelling results for 145 soil types are grouped into 29 new soil categories based on soil hydrological behaviour.

Figure 1 shows the evapotranspiration distributions and their trend lines for each of the 29 soil categories. The difference of annual average ET among 29 soil categories increases with the increase in average annual rainfall. Within each category, the difference of annul mean ET also increases with the increase in average annual rainfall. The ET trend lines of 29 soil categories separates from each other. This shows ET distribution patterns are different for each soil category. The new soil categories can reflect ET distribution behaviour.

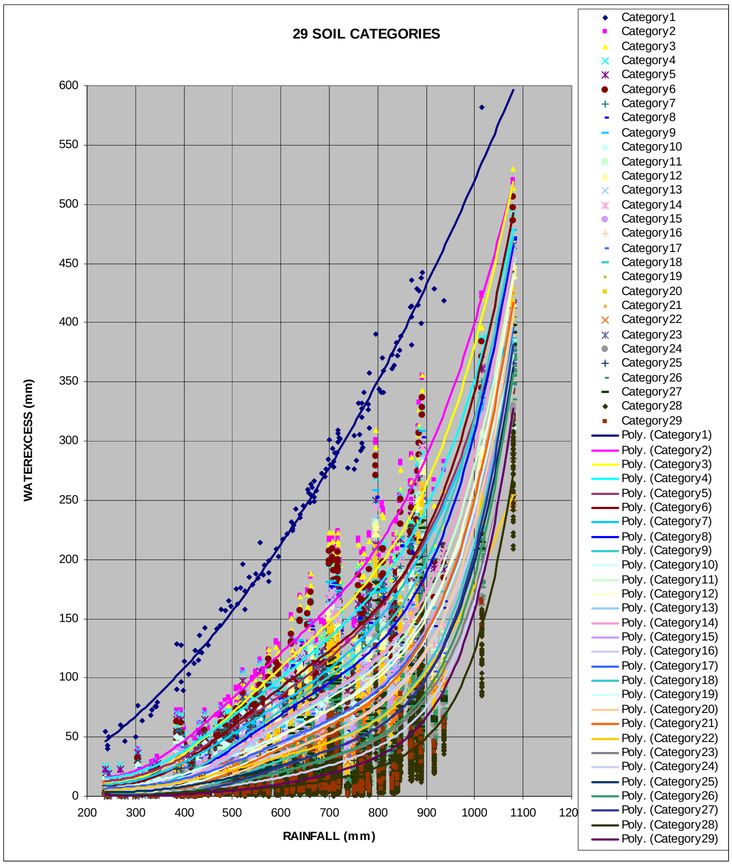

Figure 2. New soil categories' water excess distributions and their trend lines

Figure 2 shows the water excess distributions and their trend lines for the 29 soil categories. The difference of annual average water excess among 29 soil categories increases with the increase in average annual rainfall. Within each category, the difference of annul mean water excess also increases with the increase in average annual rainfall. There is a different water excess distribution pattern for each soil category. The new soil categories can reflect water excess distribution behaviour.

Verification of the soil type grouping

There are 136 climate zones and 145 soil types and hence 17290 points plotted in figures 1 and 2. It is very difficult to assess grouping validity based on the above figures only. Therefore, all neighbour categories' results are extracted to compare the difference between different categories and difference within one category since the grouping soil category is recorded according to the sequence of ET increase. The results show there are obvious differences between different soil categories but slight differences within one soil category. Here are some examples.

Category 2 and Category 3

The ET distributions for soil categories 2 and 3 are similar, but their distributions of other water balance elements are totally different (Figure 3). Category 2 has higher runoff and lower drainage. On the contrary, category 3 results in lower runoff and higher drainage. Therefore, they should belong to different soil categories based on hydrological behaviour. Soil type 230 and soil type 231 are grouped together to become category 2. When comparing the distributions of water balance between soil type 230 and soil type 231, they are almost identical. This shows that the difference is large between different soil categories but small within one category.

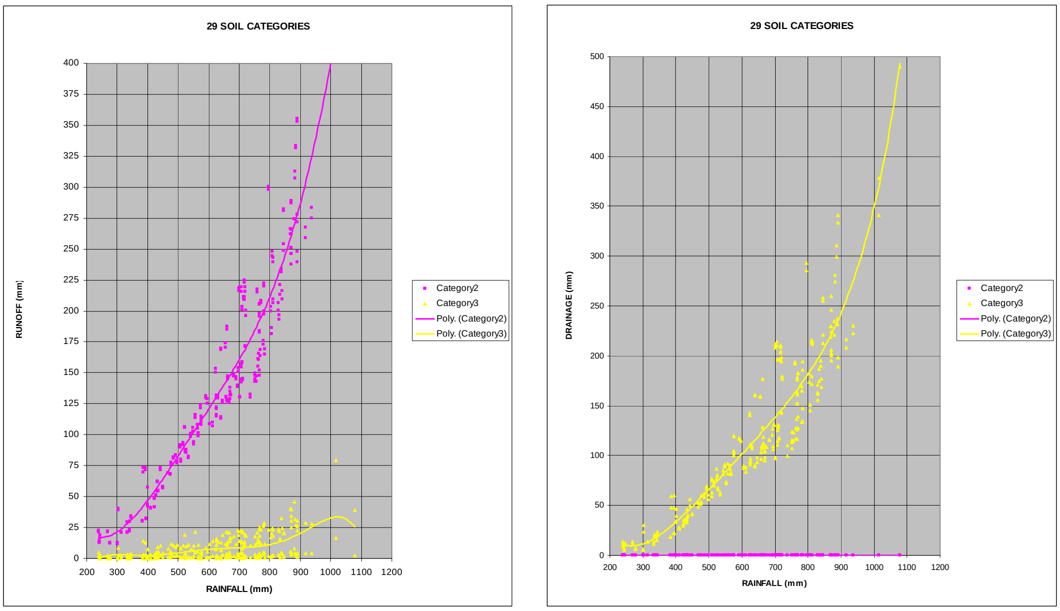

Figure 3. Runoff and drainage distributions for Category 2 and Category 3

Category 4 and Category 5

The distributions of ET and other water balance elements for categories 4 and 5 are similar, but there are about 25mm constant difference between the two categories' runoff, which is larger than threshold set to group soil types (Figure 4). Soil type 326 and soil type 95 are grouped together to become category 4. When the distributions of water balance between the two soil types are compared, the differences are much smaller than those between the two categories.

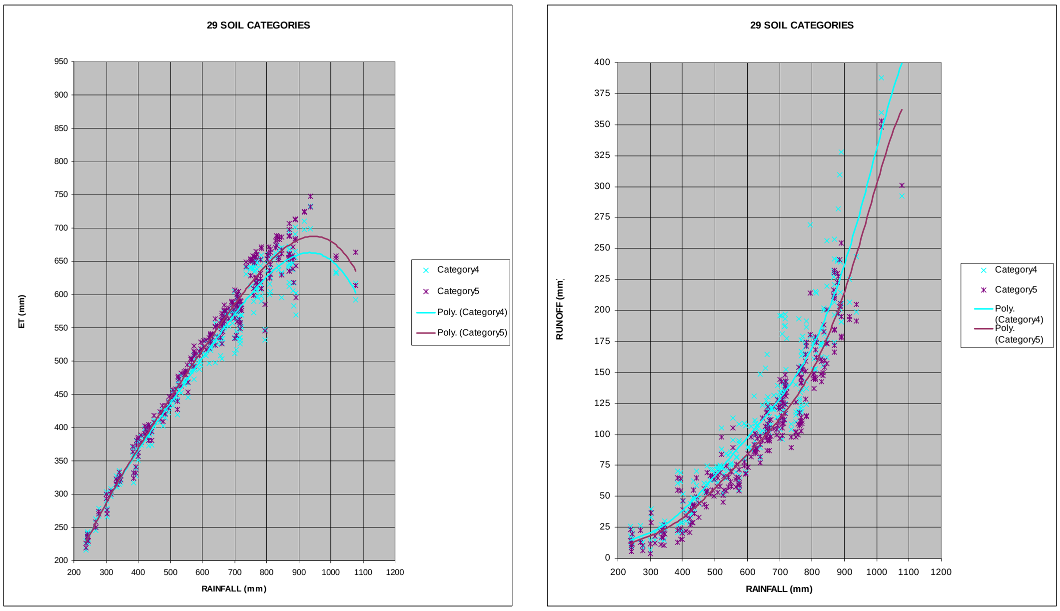

Figure 4. ET and Runoff distribution for Category 4 and Category 5

Category 26 and Category 27

The distributions of ET and drainage for categories 26 and 27 are similar, but there are large differences between the two categories' runoff and drainage (Figure 5). The differences of water balance between soil types within category 26 are a bit larger than those of previous categories, but still less than the criteria set to group the soils.

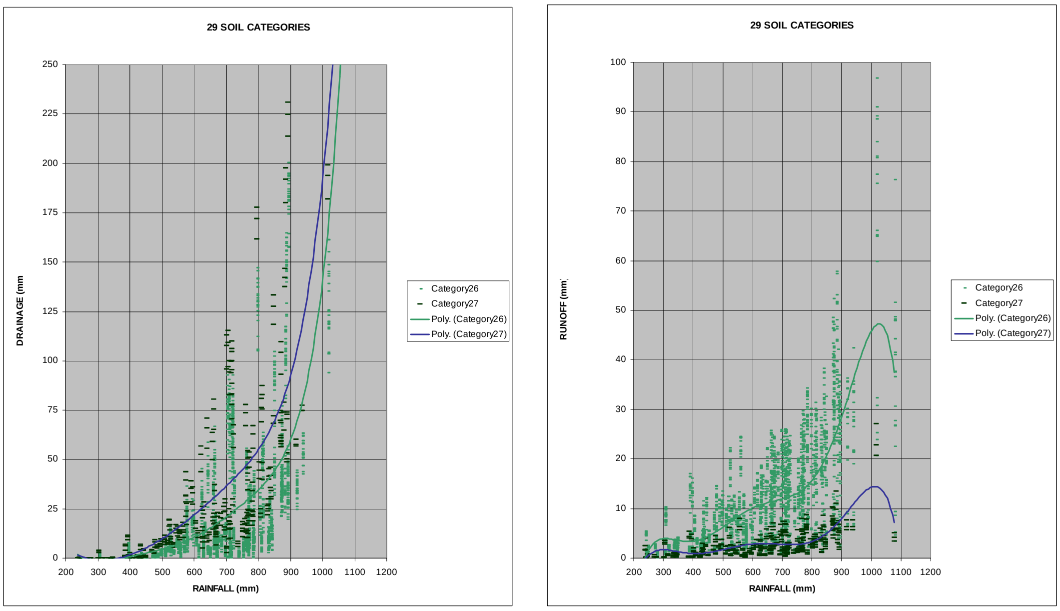

Figure 5. Runoff and drainage distributions for Category 26 and Category 27

5. CONCLUSIONS

Simulation results from water balance model PERFECT are used to group soils with the same or similar hydrological response. A total of 355 soil types along with 136 climate zones are modelled.

Soil attributes PAWC, soil depth and Ksat are used in hydrological modelling. Soil types with the same three attributes but different names are treated as one soil types. There are only 145 different soil types remaining after this procedure. The number of combinations of soil type and climate zone reduces to 19720 (145 soils x 136 climate zones).

Mean evapotranspiration, runoff and drainage of simulation results are used to classify the category of ET, runoff and drainage. Based on this, each soil type will have its new ET, runoff and drainage category indices. Soil types that exhibit the same ET, runoff and drainage category indices are grouped into one new soil category. There are a total of 29 new soil categories instead of 145 soil types.

The grouping results are verified by comparing the water balance differences between neighbour categories and within one category. The results show that the differences in water balance are large between new soil categories but small within each category.

Reducing the number of soil types considered in any spatial modelling of the water balance will have many benefits in terms of execution time and file storage. Reducing the total number of soil types modelled from 355 to only 29 will reduce both execution time and file storage requirements by greater than an order of magnitude (10 fold).

The results from this grouping can also be used to further improve the predictive capability of Zhang type relationships as described elsewhere in these proceedings (Ji *et al.*, 2009).

ACKNOWLEDGMENTS

The authors would like to thank Dr. Jai Vaze from CSIRO for his comments and suggestions. This study is supported in part by the CRC for Future Farm Industries.

REFERENCES

Abbs, K. and Littleboy M. (1998), Recharge estimation for the Liverpool Plains, *Australian Journal of Soil Research*, **36,** 335-357.

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)

Jeffrey, S.J., Carter J.O., Moodie K.M. and Beswick A.R. (2001), Using spatial interpolation to construct a comprehensive archive of Australian climate data, *Environmental Modelling and Software*, **16,** 309-330.

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).

McKenzie, N.J., Jacquier, D.W., Ashton, L.J. and Cresswell, H.P. (2000), Estimation of Soil Properties Using the Atlas of Australian Soils. CSIRO Technical Report 11/00

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.

Owens, J.S., Tolmie P. E, Silburn, D.M. (2004), Validating modelled deep drainage estimates for the Queensland Murray-Darling Basin, 13th international soil conservation organisation conference, Baisbane, 2004

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.

Ji, F., Littleboy, M., Summerell, G. (2009), Water Balance Modelling – Impact of land use, soil properties and rainfall seasonality, submit to 18th World IMACS / MODSIM Congress.