The Application of Pedotransfer Functions with Existing Soil Maps to Predict Soil Hydraulic Properties for Catchment-scale Hydrologic and Salinity Modelling

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Abstract: Available soil information from a soil landscape map and a soil data base was used to predict the spatial distribution of soil hydraulic and salinity properties within the Little River catchment in central western NSW. The spatial distribution of individual soil types within individual soil landscapes was predicted using a DEM and terrain analysis. The soil landscapes were known to have defined toposequences of soils and so terrain analysis (FLAG UPNESS index) was used to identify individual landform elements and hence identify individual parts of the toposequence. This enabled the prediction of the spatial distribution of individual soil types. Using this process, 82 individual soil types were identified within the Little River catchment. Some properties of the individual soil types were known from the soil landscape maps including horizon depths, soil textures, soil structure and soil colour. With the use of some simplified PTFs, these basic properties were used to predict the soil hydraulic properties of the individual soil types including residual, 15 bar, 0.1 bar and saturated moisture contents, hydraulic conductivity and bulk density. As many of the 82 initial soil types had similar soil hydraulic properties these were combined into 14 basic soil hydrological soil types. These 14 hydrological soil types were then used to predict the spatial distribution of the soil hydrological properties in the catchment hydrological and salinity modelling.

Keywords: *Hydrologic and salinity modelling, pedotransfer functions, terrain analysis, soil maps.*

1. INTRODUCTION

Estimates of soil hydraulic properties across the landscape are a requirement for much of the hydrologic and salinity modelling that is currently being applied to the problem of dryland salinity. Hydrologic modelling provides a means of examining and evaluating the impacts of different land use options on catchment salt exports. While models vary in the degree and amount of information needed, most need some estimate of the water holding capacity and hydraulic conductivity of soils in the landscape.

Unfortunately, in many areas where hydrologic and salinity modelling are required, there is little direct data on soil hydraulic properties. Estimates of these properties have to be made using relationships based upon more routinely and more frequently collected soil property measurements. While a considerable amount has been written about the development of PTFs to relate various soil properties (McBratney *et al* 2002), less has been written about how they can be applied to catchments. This paper examines the use of PTFs and use of spatial prediction models for soils in a catchment where soil hydraulic property data are required for catchment salt and water balance. The catchment was the Little River Catchment in central west NSW. This paper outlines the methods for applying digital elevation models and PTFs to make use of available soil information from soil maps, data bases, and secondary sources of information such as geology maps. The methodology provided useable information on soil hydraulic properties for hydrologic and salinity modelling at the catchment scale.

A program to formally evaluate this methodology has begun. The program aims to test the distribution of individual soil types predicted by the DEM and the soil properties predicted by the PTFs. Preliminary tests confirm that the distribution of soil properties can be developed with this methodology.

2. STEPS TO APPLY PTF'S TO A CATCHMENT

A summary of these steps is given in Figure 1

1.Identification of soil landscapes within the catchment

As these map units were at a scale of 1:250 000, these were complex map units in which several soil types occurred in a defined way. Toposequences down a slope were the most common type of soil distribution within the soil landscapes of the Little River catchment.

2. Methodology to establish the spatial distribution of the soil type within each soil landscape

A digital elevation models (DEM) and terrain analysis using FLAG (Roberts *et al.* 1997) were used to predict the distribution of individual soil types within each soil landscape. In the case of toposequences, the UPNESS index from FLAG was used to identify landform elements in the toposequences (Summerell *et al.* 2003). Note that soil type is used to describe a set of soils that are grouped for a particular purpose.

3. Determination of the available soil properties for the soil types

Existing soil information included soil texture, particle size distribution, depth, structure, colour and sodicity. Estimates were made of the variability in these properties.

4. Selection / development of PTFs to be applied to the soil data to predict moisture contents at 10kPA and 1500kPa, hydraulic conductivity and bulk density

A number of existing PTFs were reviewed, as well as data sets that could be used to develop PTFs.

5. Application of the PTFs to the available soil information on each soil type to predict the soil hydraulic properties

3. RESULTS FOR LITTLE RIVER CATCHMENT

3.1. Geology/geomorphology and soil types in the Little River catchment

The Little River catchment is located in the central west slopes of NSW. The major soil

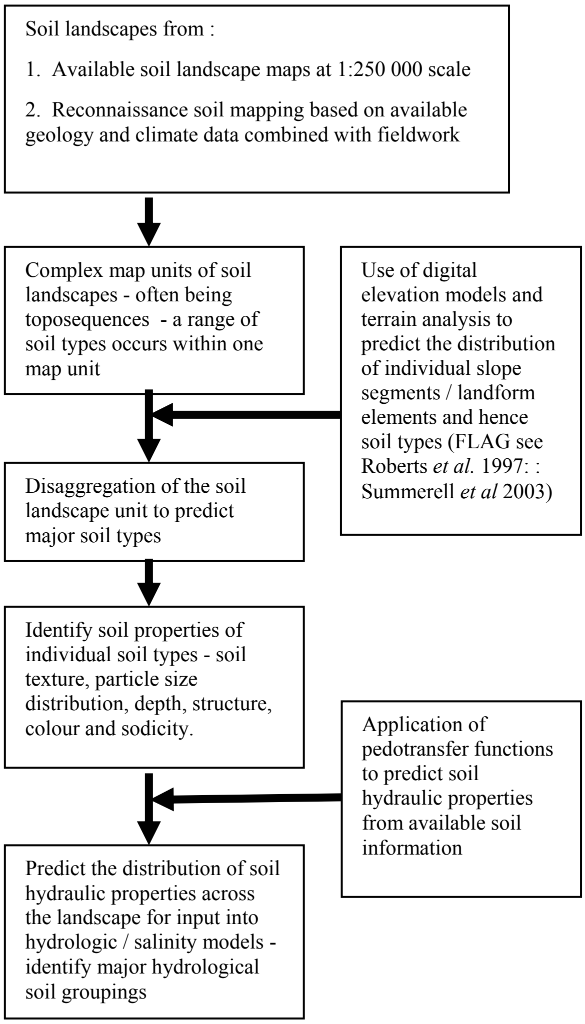

Figure 1. Steps in application of PTFs and terrain analysis to predict the spatial distribution of soil hydraulic properties

landscape/physiographic units and soil types are summarised in Table 1. This provided essential soil data for input to hydrologic models (see Tuteja *et al.* in press).

It also resulted in a map of the spatial distribution of soil hydraulic properties. Twenty-two soil landscapes were identified within the catchment (Murphy and Lawrie 1999). Each soil landscape is a complex soil mapping unit with a range of soil types. For the soil landscape units in the catchment the soil types are linked by forming a relatively consistent toposequence. For example, in the Gullengambell soil landscape on the siliceous phase of the Yeoval Granite, shallow sandy lithosols occur on crests and upper slopes, deeper siliceous sands occur on midslopes, and Yellow Sodosols occur on footslopes and in drainage depressions. This repeatable or

Geology/geomorphology	Major soil types
Yeoval Granite – siliceous phase (gg, gl, ox)	
Siliceous granite / adamellite	Siliceous sands (sandy Tenosols, S1 and S2), Yellow Sodosols (Y1) and Lithosols (Shallow Rudosols L2)
Yeoval Granite – granodiorite phase (yv)	
Granodiorite	Red (R1, R4) and Yellow (Y3) Chromosols
Dulladerry Rhyolite (yp, du, gd)	
Siliceous volcanics – rhyolite and dacite	Red (R3) and Yellow (Y2) Sodosols, Lithosols (L1), Red Chromosols (R2, R5)
Sedimentary rocks of the Cowra Trough (ar, mn, cu, sh, wc)	
Shales, mudstones, porphyry, limestones	Red Chromosols (red-brown earths and non-calcic brown soils, R1,R2, R5), Yellow Chromosols (Y3), some Yellow Sodosols (Y2) and Lithosols (L1).
Upper Devonian Terrestrial Sediments(na, tl, br, cs, my)	
Sandstones (lithic and quartzose), conglomerates, some shales	Lithosols (L1), Red Chromosols (red podzolic soils, R2, R5), Yellow Chromosols (Y3).
Recent alluvium (lr, mi)	
Alluvium from major streams including near-bank deposits and higher terraces	Layered alluvial loams and sands on near bank deposits and Red Chromosols (R1) and some Yellow Chromosols (Y3) on higher terraces

Table 1. Geology/geomorphology and major soil types of the Little River catchment.

predictable pattern in Little River enabled the use of DEMs and terrain analysis to predict the distribution of individual soil types in a soil landscape in a GIS system.

Basic soil hydrological groupings are also shown (Table 2)

3.2. Terrain analysis to predict the distribution of soil types within soil landscapes – intersection of FLAG based land form element map and soil landscape map

The UPNESS Index of FLAG was considered to be able to predict soil types within a soil landscape because it divides the landscape into landform elements on the basis the area of land contributing water and weathered materials and deposited materials to a point in the landscape. The assumption has to be made however that the soils are in an erosional landscape with a sequence of bedrock, colluvial and alluvial soils from essentially the same parent materials. This was the case for the Little River catchment. In areas of ancient landscapes, dunes and swales and other geomorphological types of landscapes such as aeolian or young volcanic, FLAG Upness may not be as applicable. FLAG was calculated using the DEM for the entire Little River catchment (Summerell *et al*. 2003). This was then used to divide the landscape into four major landform elements (Figure 2):

I – drainage depressions and floodplains
II – footslopes
III – midslopes
IV – upper slopes and crests.

An intersection was made between the soil landscape map and the FLAG based landform element map (Figure 3). This composite map then gave an approximation to the distribution of individual soil types within the Little River catchment. Each combination of soil landscape/FLAG based landform element was assumed to give a unique soil type. This resulted in 82 initial soil types (Figure 4) with a defined set of soil properties for each soil horizon including depth, texture, colour and soil structure. These properties were derived from the field descriptions of the soils in the soil landscape map.

3.3. Use of a simple pedotransfer function to predict the soil hydrological properties of the soil types in the Little River Catchment

A simple pedotransfer function based on soil texture and soil structure was used to predict the soil hydraulic properties of the 82 initial soil types Standard soil texture groups were used with modifications for soils that were sodic or strongly structured. The simple set of pedotransfer functions was based on general relationships developed between soil texture and structure and the soil hydraulic properties in Schaap *et al.* (1998), Geeves *et al*. (1995), Geeves *et al*. (2000) and Williams *et al*. (1983). The soil hydraulic properties predicted included residual moisture content, saturated moisture content, moisture at 10kPa and 1500 kPa, and saturated hydraulic conductivity. All of these are required for the modelling of water flows and salt loads in the catchment. Other soil hydraulic properties estimated included residual moisture content, saturated moisture content, bulk density and the relative proportions of clay, silt and sand. The soil properties were predicted for four soil layers, 0 to 20 cm, 20 to 40 cm, 40 to 70 cm and 70 to 100 cm for application to the HYDRUS and PERFECT models for the Little River catchment.

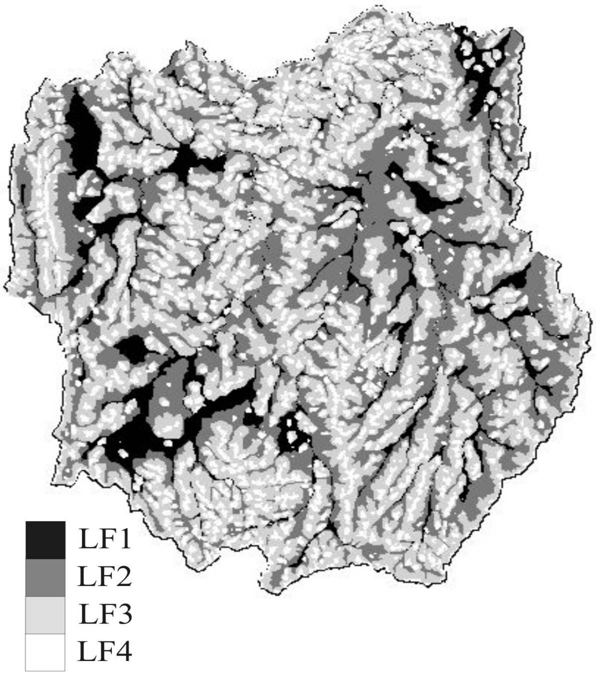

Figure 2. FLAG based landform element map – LF4 = crests and upper slopes, LF3 = midslopes, LF2 = footslopes and LF1 = depressions and floodplains.

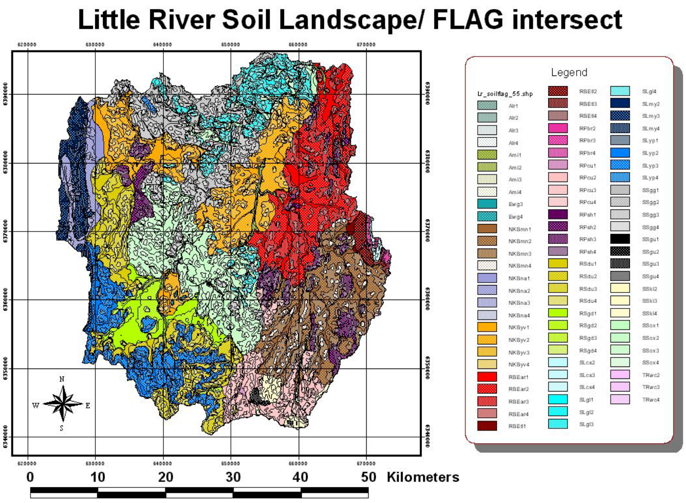

Figure 3. Intersect of soil landscapes and FLAG UPNESS units to give 82 initial soil types.

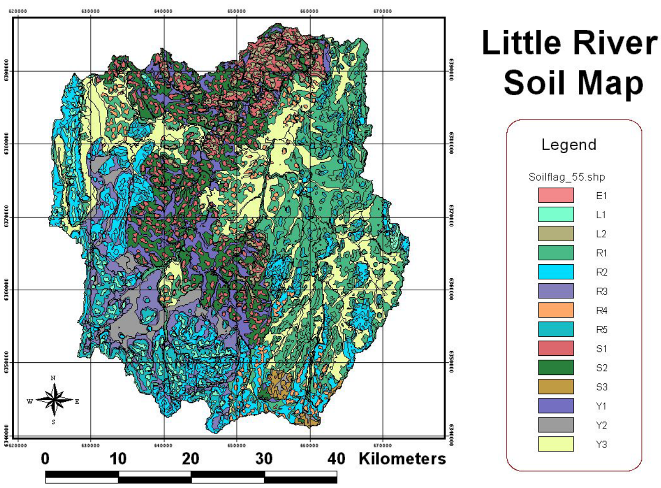

Figure 4. Main soil hydrological hydrological groupings for the Little River catchment

Predicted soil properties of R1 soil hydrological type				
Red Chromosol on more mafic parent materials				
Soil hydraulic properties	0 to 20 cm	20 to 40 cm	40 to 70 cm	70 to 100 cm
Area	44 958 ha (22.5 % of catchment)			
Field texture	sl to fsl	sl to lc	lc to mc	lc to mc
Ksat mm/day	300	180	35	35
Residual mc %	5.6	9.0	12.6	12.6
15 bar mc %	8.3	16.3	24.6	24.6
0.1 bar mc %	27.4	34.4	42.0	42.0
Saturated mc %	39.8	45.4	51.3	51.3
Sand %	74	52	29	29
Silt %	11	17	23	23
Clay %	15	31	48	48
Bulk density t/m^3 (forested timber)	1.30	1.44	1.61	1.61
Bulk density t/m^3 (agricultural)	1.50	1.56	1.61	1.61
Total soil carbon % (forested timber)	1.75	1.17	0.40	0.40
Total soil carbon % (agricultural)	0.90	0.65	0.40	0.40

Table 2. Predicted soil properties of R1 soil hydrological type - Red Chromosol on more mafic parent materials

Once the soil hydraulic properties of the 82 initial soil types were available, these were then grouped into 14 basic soil hydrological types (Table 2, Figure 4). The grouping of soils was based on general profile features and the predicted soil hydraulic properties. Examples of the soil hydraulic properties predicted by the pedotransfer functions are given in Table 2. A limited number of soil hydrological groupings were desirable to limit the number of combinations of landuse, climate and soil types to be modelled.

3.4. The use of electrical conductivities (EC) of soils within the soil landscapes to predict the spatial distribution of EC

The soil landscape map was used to allocate known values of soil electrical conductivities across the landscape. Some soil landscapes were known to have higher values of EC (1:5), averaged to 1 m, than others (see Figure 5). The EC values of saline sites were also measured. These values were then used to map the expected soil EC (1:5) to 1m in the catchment as described in Tuteja *et al*. (in press). The resultant map of EC is shown in Figure 5.

4. DISCUSSIONS AND CONCLUSIONS

A methodology that makes use of limited available data to predict the soil hydrological and salinity properties for catchment modelling has been developed and applied to the Little River catchment in Central western NSW. The methodology makes use of available soil landscape maps and soil morphological data to predict the spatial distribution of soil properties. The method is potentially applicable across broad areas. However, while field experience in the area, a comparison to existing soil profile data and a field reconnaissance through the catchment supported the predicted soil type distribution, further formal testing of the predicted soil distribution and is required. Further testing is also required of the soil hydraulic properties predicted by the PTF's. This is currently being done.

In this study use was made of the FLAG Upness index to disaggregate complex soil landscapes into soil type, but this is only one of several potentially useful methods of terrain analysis to do this. Other methods may be more effective, and be more applicable for different kinds of soil landscapes. This is a potentially very productive avenue for future investigation into the use of GIS to predict the spatial distribution of soils.

In applying data generated by this method, care needs to be exercised. For broad scale modelling and catchment scale modelling, the predictions would appear to be a reasonable approximation to the soil distribution in the catchment. They are not applicable for predicting soil types and soil properties for purposes requiring site specific information, although they may provide limited guidelines of expected properties.

A critical component of this methodology is the application of PTF's so the development of the methodology is dependent on the success of PTF's. Generally soil moisture holding properties can be reasonably be predicted by PTF's, but the most difficult properties to predict are bulk density and hydraulic conductivity (McBratney *et al*. 2002)

5. ACKNOWLEDGMENTS

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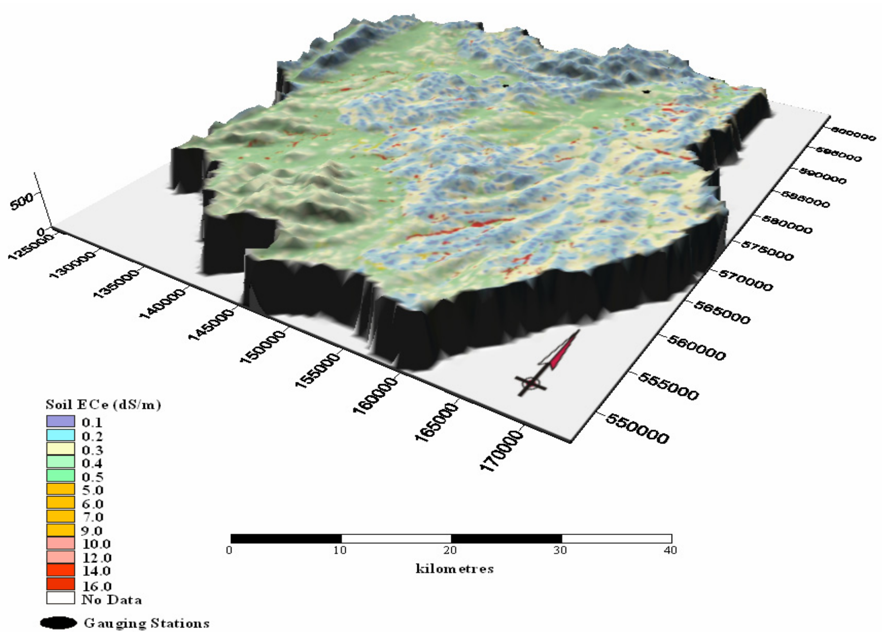

Figure 5. Predicted spatial distribution of EC in the Little River catchment.

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