SOIL SCIENCE

Regional soil information for hydrological modelling in South Africa

Johan van Tol and George van Zijl explore the importance of regional soil information for hydrological modelling in South Africa.

Soils act as a first order control on hydrological processes by partitioning rainfall into overland flow or infiltration. The fate of the infiltrated water (e.g. storage, deep drainage, lateral flow etc.) is largely determined by soil properties and their spatial distribution. Although hydrologists agree that soils play a very important role in the hydrological functioning of landscapes, they often lack the skill to interpret existing soil information.

This problem is heightened by the fact that soil data has mostly been generated for agricultural purposes, such as land potential and fertilizer requirements, with little effort to make the soil data user-friendly for non-soil scientists. The consequence is that soil information is often misused in hydrological models and soil parameters are often only used for calibration of hydrological models.

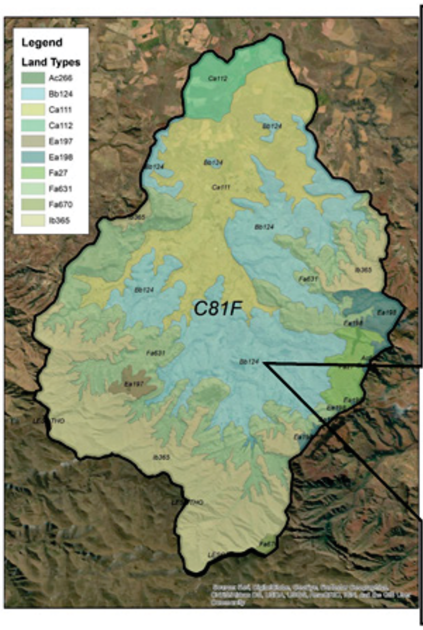
With enhanced computing power, spatially distributed hydrological models are capable of handling details of landscape heterogeneity better. Some models (e.g. SWAT) couple seamlessly with GIS interfaces, such as ArcMap and QGIS. The models typically rely on layers of the terrain, land use and soil information to delineate Hydrological Response Units (HRUs). The assumption is that a HRU is an area with homogenous hydrological response.

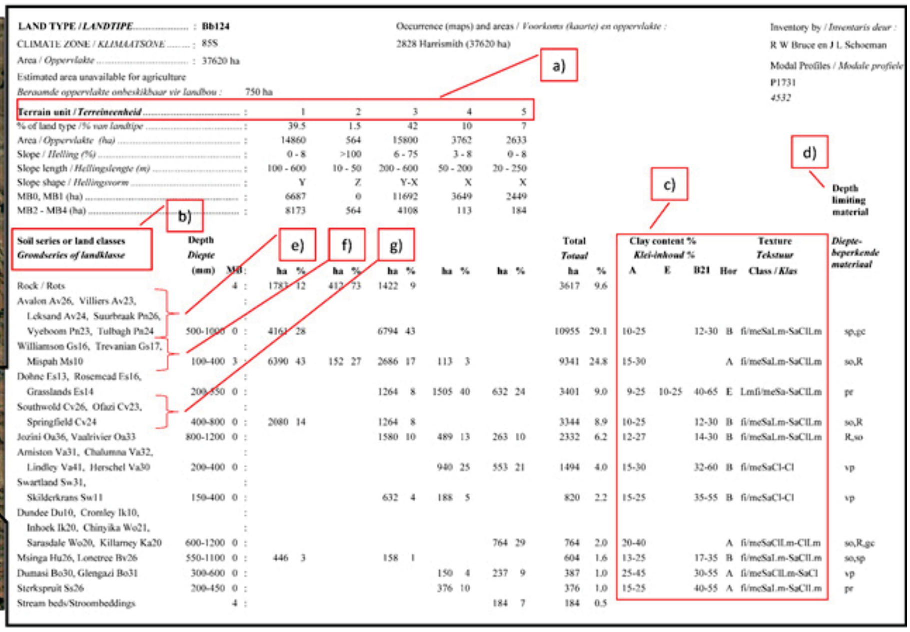
Terrain and land use data are freely available at an adequate scale for most hydrological modelling purposes in South Africa. Soil information, on the other hand, is typically not readily available for direct parameterisation of most models. Distributed models require not only the spatial distribution of the soils but also important soil properties which will determine the hydrological response of soil units. These properties include mostly physical properties, such as particle size distribution (% sand, silt and clay), depth of different soil horizons, hydraulic conductivity of the soil horizons and soil water retention characteristics. In more complex models, chemical properties of the soils are also included to determine nutrient uptake or the fate of pollutants from point and non-point sources.

Hydrological soil information for South Africa

In South Africa, the only soil database that covers the entire country is the land type database. A land type is an area demarcatable at 1:250 000 scale with similar climate, geology and consequently soil distribution patterns. A total of 7 070 land types have been delineated between 1972 and 2006. Each of these land types are accompanied by a land type inventory (see example in Figure 1).

The land type inventory present the typical soils occurring on various Terrain Morphological Units (TMU's) (Figure 1a), gives an indication of the relative coverage of the TMU's in relation to the total area of the land type as well as the relative coverage of the soils covering the various TMU's (Figure 1b). The soils presented in the land type inventory reflect the soil series as in the first edition of the South African Soil Classification System (1977) – or the 'red book'. More than 30 years ago, Prof Roland Schulze made a remarkable effort to establish the hydrological response for each of these soil series.





LAND TYPE / *LANDTIPE* : Bb124
CLIMATE ZONE / *KLIMAATSONE* : 85S
Area / *Oppervlakte* : 37620 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 750 ha

Occurrence (maps) and areas / *Voorkoms (kaarte) en oppervlakte* :
2828 Harrismith (37620 ha)

Inventory by / *Inventaris deur* :
R W Bruce en J L Schoeman
Modal Profiles / *Modale profiele*
P1731
4532

Terrain unit / *Terreineenheid*	1	2	3	4	5
% of land type / *% van landtipe*	39.5	1.5	42	10	7
Area / *Oppervlakte* (ha)	14860	564	15800	3762	2633
Slope / *Helling* (%)	0 - 8	>100	6 - 75	3 - 8	0 - 8
Slope length / *Hellingslengte* (m)	100 - 600	10 - 50	200 - 600	50 - 200	20 - 250
Slope shape / *Hellingsvorm*	Y	Z	Y-X	X	X
MB0, MB1 (ha)	6687	0	11692	3649	2449
MB2 - MB4 (ha)	8173	564	4108	113	184

Soil series or land classes / *Grondseries of landklasse*	Depth / *Diepte* (mm)	MB	1 ha	%	2 ha	%	3 ha	%	4 ha	%	5 ha	%	Total / *Totaal* ha	%	Clay content % / *Klei-inhoud %* A	E	B21	Hor	Texture / *Tekstuur* Class / *Klas*	Depth limiting material / *Diepte-beperkende materiaal*
Rock / Rots		4	1783	12	412	73	1422	9					3617	9.6						
Avalon Av26, Villiers Av23, Leksand Av24, Suurbraak Pn26, Vyeboom Pn23, Tulbagh Pn24	500-1000	0	4161	28			6794	43					10955	29.1	10-25		12-30	B	fi/meSaLm-SaClLm	sp,gc
Williamson Gs16, Trevanian Gs17, Mispah Ms10	100-400	3	6390	43	152	27	2686	17	113	3			9341	24.8	15-30			A	fi/meSaLm-SaClLm	so,R
Dohne Es13, Rosemead Es16, Grasslands Es14	200-550	0					1264	8	1505	40	632	24	3401	9.0	9-25	10-25	40-65	E	Lmfi/meSa-SaClLm	pr
Southwold Cv26, Ofazi Cv23, Springfield Cv24	400-800	0	2080	14			1264	8					3344	8.9	10-25		12-30	B	fi/meSaLm-SaClLm	so,R
Jozini Oa36, Vaalrivier Oa33	800-1200	0					1580	10	489	13	263	10	2332	6.2	12-27		14-30	B	fi/meSaLm-SaClLm	R,so
Arniston Va31, Chalumna Va32, Lindley Va41, Herschel Va30	200-400	0							940	25	553	21	1494	4.0	15-30		32-60	B	fi/meSaCl-Cl	vp
Swartland Sw31, Skilderkrans Sw11	150-400	0					632	4	188	5			820	2.2	15-25		35-55	B	fi/meSaCl-Cl	vp
Dundee Du10, Cromley Ik10, Inhoek Ik20, Chinyika Wo21, Sarasdale Wo20, Killarney Ka20	600-1200	0									764	29	764	2.0	20-40			A	fi/meSaClLm-ClLm	so,R,gc
Msinga Hu26, Lonetree Bv26	550-1100	0	446	3			158	1					604	1.6	13-25		17-35	B	fi/meSaLm-SaClLm	so,sp
Dumasi Bo30, Glengazi Bo31	300-600	0							150	4	237	9	387	1.0	25-45		30-55	A	fi/meSaClLm-SaCl	vp
Sterkspruit Ss26	200-450	0							376	10			376	1.0	15-25		40-55	A	fi/meSaLm-SaClLm	pr
Stream beds/Stroombeddings		4									184	7	184	0.5						

Figure 1: Example of land types covering quantenary catchment (C81F) and the inventory for land type Bb124.

The land type inventory further provides estimated clay percentages and texture class for the A, E and B1 horizons of the different soil forms (Figure 1c) as well as description of the nature of the layer which will restrict root penetration (Figure 1d).

At this stage, land type information are mainly being used in 'lumped' format as presented in the South African Atlas of Agrohydrology and Climatology (Schulze et al., 2007). In this format, the land type is considered as a single unit, with average parameters representing the entire land type (in the Atlas the hydrological parameters are mainly those which are used in the ACRU model). Although treating land types as lumped entities is certainly useful for large scale modelling, we believe that this invaluable database can be used for so much more, permitted that certain limitations are addressed.

Limitations of using land type information for hydrological modelling

The land type survey was essentially done with agricultural potential in mind. The observation depth was limited to 1 200 mm. When a root limiting layer was observed, deeper layers were not described. In hydrology, the nature of the soil/bedrock interface plays a very important role in the hydrological response. This requires that land type data is carefully interpreted before direct incorporation for modelling purposes.

The majority of land types were described using the 1977 edition of the soil classification (the 'Red Book') and the remainder with the 1991 edition (Blue Book). Both of these editions are no longer in print creating a knowledge gap for upcoming modellers in terms of the data that they are using. The newest edition of soil classification was published in 2018, with a strong emphasis on soil as a natural entity (i.e. not only agriculture). Although this is a complete paradigm shift in the way soil scientist describe soils, it will require a dedicated effort to re-interpret existing soil information for hydrological purposes.

It is important to note that a land type is not a soil polygon but depicts soil distribution patterns. Considerable variation can therefore occur between soils on different terrain units.

Significant variation within a specific terrain unit is also possible – therefore, merely identifying terrain positions to disaggregate land type is not sufficient. In the example of land type Bb124 (Figure 1), TMU 1 is dominated by 3 distinctly different soil associations. A total of 28% (Figure 1e) of this terrain position are occupied by soils with plinthic layers (see Figure 2a), 43% (Figure 1f) by shallow soils (Figure 2b) and 14% (Figure 1g) by freely drained soils (Figure 2c). The hydrological response of these soil groups will differ considerably, where lateral flow at the soil/bedrock interface is likely to be dominant on the plinthic soils (Figure 2a), overland flow due to storage excess on the shallow soils (Figure 2b) and vertical drainage and recharge on freely drained soils (Figure 2c).

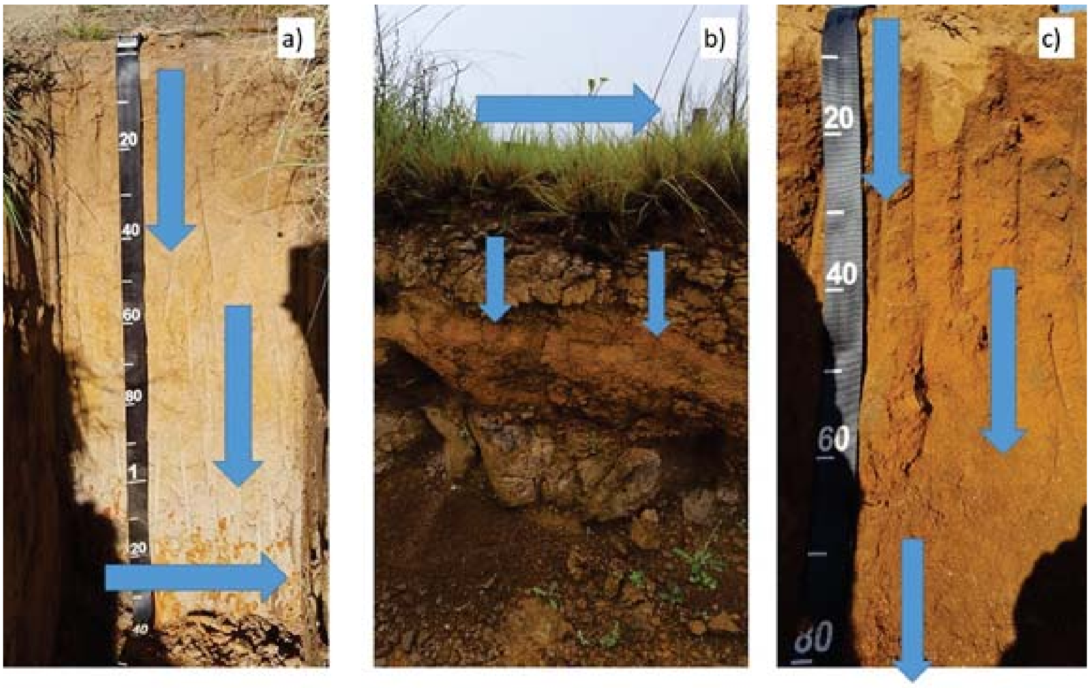


Figure 2: Soils occurring on a single terrain unit in land type Bb124 a) interflow soils, b) shallow responsive soils and 3 recharge soils. The variation in hydrological response emphasise the importance of accurate disaggregation of land type information for hydrological purposes.

Hydrological soil information for South Africa

The advances in Digital Soil Mapping (DSM) have paved the way for remapping soil legacy data at finer scales and better accuracy. In the past few years significant progress has been made to map soils through machine learning, expert knowledge and disaggregation of land types approaches into soil polygons, also for hydrological purposes in South Africa. These approaches also allow for the creation of soil associations/groups with similar hydrological response. A great advantage of the DSM derived maps are that a measure of uncertainty accompanies them, which could be built into the models.

There is a need to use the DSM methods to create user-friendly hydrological soil maps for the whole of South Africa. Such maps should also be accompanied by hydrological properties of the dominant soils for parameterisation of a range of hydrological models. These properties should either be directly measured or derived from locally developed PedoTransfer Functions (PTF's) which is applicable for our environmental conditions. These maps must also be accompanied with dedicated field campaigns where the accuracy of the maps are determined (for quantification of model input accuracy) and description of the nature of the soil/bedrock interface.

Sustainable water resource management in the highly variable water regime of South Africa becomes increasingly important as the demand for this resource increase. Accurate hydrological modelling to forecast the impacts of climate and land use change on this resource are pivotal to sustainable management. In this day and age, we simply cannot allow that the efficiency of modelling output is jeopardised by outdated, inadequate soil information, while new methods exist with which the spatial distribution of soil classes and properties could be accurately determined, together with the accompanying uncertainty on the distribution.

Examples of DSM-related projects for hydrological purposes in South Africa are:

Disaggregation of land types:

- *Flynn, T., van Zijl, G.M., Van Tol, J.J., Botha, C.C., Rozanov, A., Warr, B., Clarke, C., Comparing algorithms to disaggregate complex soil polygons in contrasting environments. Geoderma 352, 171-180.*

Expert knowledge:

- *Van Tol, J.J., Van Zijl, G.M., Riddell, E.S., Fundisi, D. 2015. Applications of hydropedological insights in hydrological modelling of the Stevenson-Hamilton Research Supersite, Kruger National Park, South Africa. Water SA 41, 525-533.*

Machine learning:

1. *Van Zijl, G.M., Van Tol, J.J., Tinnefeld, M., Le Roux, P.A.L. 2019. A hillslope based digital soil mapping approach, for hydropedological assessments. Geoderma. https://doi.org/10.1016/j.geoderma.2019.113888*