# The 6th Kirkham Conference


**Brent Clothier**

**Chair, Committee S774 Kirkham Conferences Committee,**

**Soil Science Society of America**


Welcome to Skukuza in the Kruger National Park of South Africa for the 6th Kirkham Conference. Finally, after a two-year delay due to Covid-19, researchers are again able to meet up for this conference on "Soil Physics in Agricultural Production: Water Resources and Waste Management". I know you will enjoy the stimulation of the presentations and the many conversations with other participants in the stunning environment of Kruger National Park.

Who was Don Kirkham, and why are there Kirkham Conferences?

Don Kirkham (1908-1998), inspired and supported by his wife Betty, was an exceptional man. He influenced, more than anybody else, developments in the field of soil physics.

*Don & Betty Kirkham*

Students, friends, colleagues, family, and the Soil Science Society of America decided to commemorate this unique couple in a lasting way. Shortly after Don's death in 1998, they established the Don and Betty Kirkham Soil Physics Award and the Kirkham Conference Programs within the Soil Science Society of America, as a permanent tribute.

From the beginning, the late Don Nielsen, from the University of California in Davis, and a student of Don Kirkham, has been a key driver and funder behind the realization of the quadrennial Conferences. The late Rienk van der Ploeg, an erstwhile professor of soil physics at the University of Hannover, Germany, and also a former student of Don's, had a major influence through establishment of the Lena and Maria van der Ploeg Fund in memory of his late sister, Lena, and in honour of his wife, Maria. His permanent endowment to recognize scholarship in soil physics is used to support the Kirkham Conferences.

The Kirkham Conferences are topical meetings to encourage scientists to make organized, in-depth explorations of disciplinary and interdisciplinary subjects of soil physics in ways seldom possible at national or international meetings.

The first Kirkham Conference was held in Ames, Iowa in 2000. Don was a Professor of Soil Physics at the University of Iowa, in Ames. Then in 2004 the second Kirkham Conference was held in Logan Utah, followed by Davis, California in 2008. In 2012 it move offshore to Palmerston North, New Zealand, and then in 2016 to Sede Boqer in Israel. The 2020 Kirkham Conference was slated to be held at Skukuza, South Africa in 2020. However, Covid-19 intervened. A year later, to maintain the "Kirkham momentum" a virtual conference was held (https://vimeo.com/manage/videos/595965299 ). Now, two years after the original scheduling, the 2020 Kirkham Conference, can finally take place.

Welcome, and I am sure you will enjoy the many "… in-depth explorations of disciplinary and interdisciplinary subjects of soil physics" that will take place in Skukuza. The Kirkham tradition continues …

On behalf of Committee S774 (Kirkham Conferences) of the Soil Science Society of America, I wish to thank Simon Lorentz and his local team for their superb organisation of this meeting. And I also wish to thank Susan Chapman, Director of Member Services of the Tri-Societies, for her work in making this conference a success.

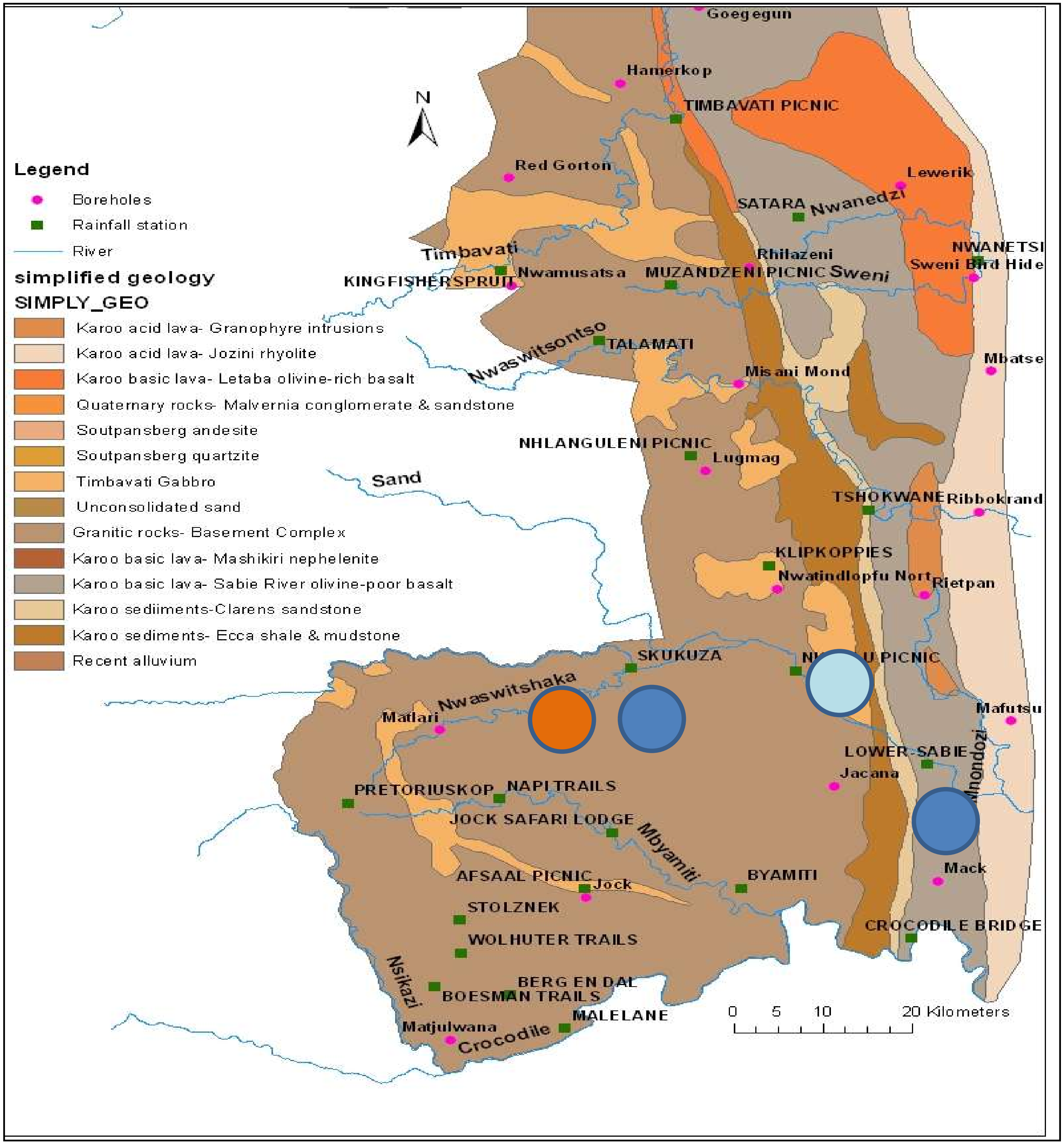
Best regards

Brent Clothier

Chair, Committee S774,

Soil Science Society of America

# Kirkham 2022 Field Excursion KNP 31 Aug 2022




KNP Supersites

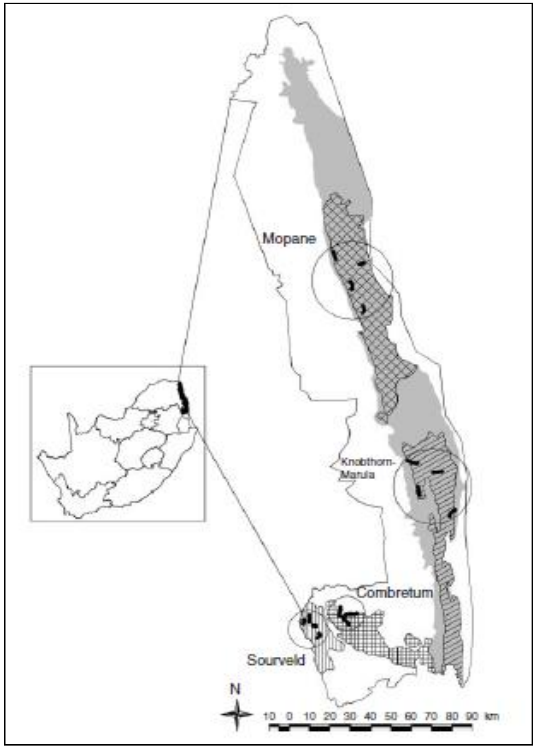
KNP Experimental Burn Plots

Long Term Experimental Exclosures

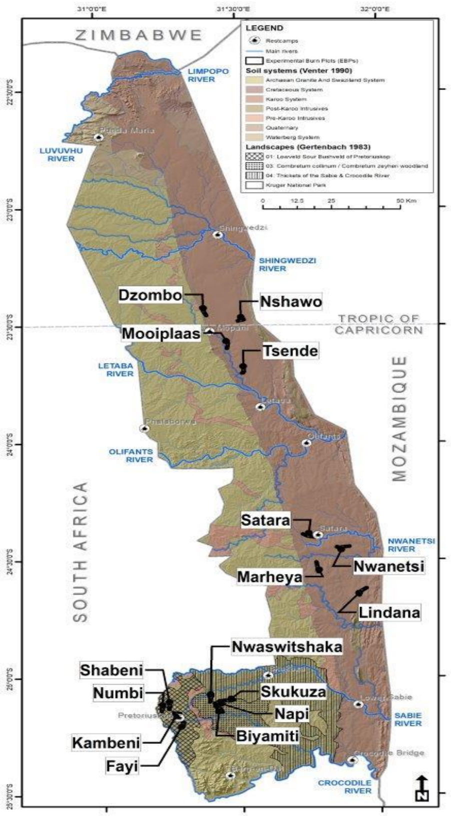
**Kirkham Conference 2022 – Skukuza, Kruger National Park**

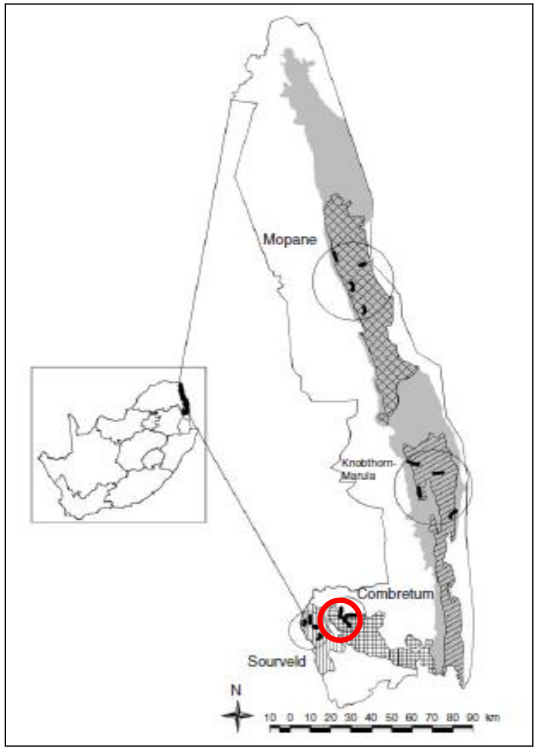
**Wednesday 31 August 2022**

*Field Visit - Experimental Burn Plots (Tercia Strydom)*




- The Experimental Burn Plots (EBPs) were initiated in 1954.
- They are replicated in four major vegetation landscapes in the park
- Geology- granites in the west and the basalts in the east
- Across rainfall gradient (~450-700 mm/annum)






- AIM: To determine the effect of varying fire frequencies and intensities on savannas
- 16 replicates
- Total of 208 burn plots, roughly 7 ha each (350 x 150 m)

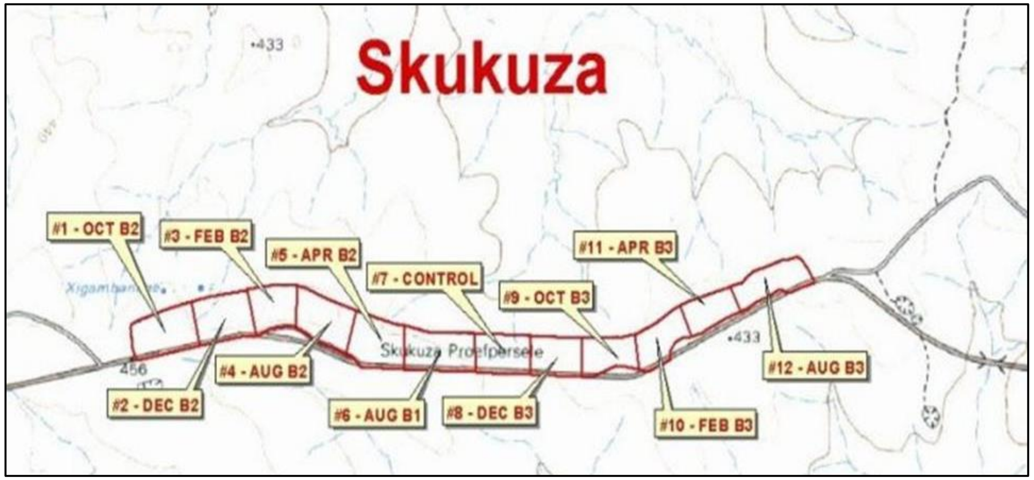
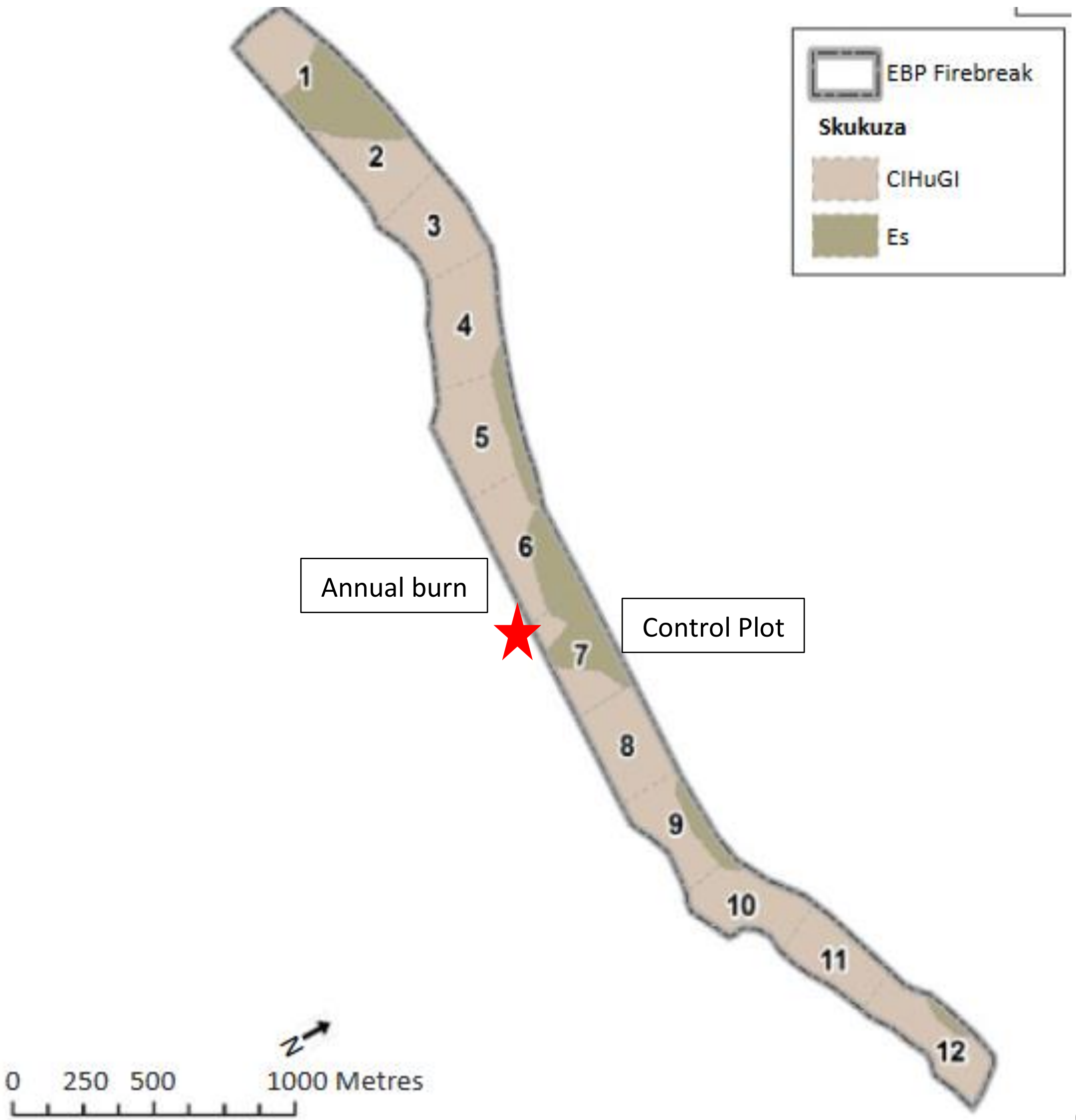


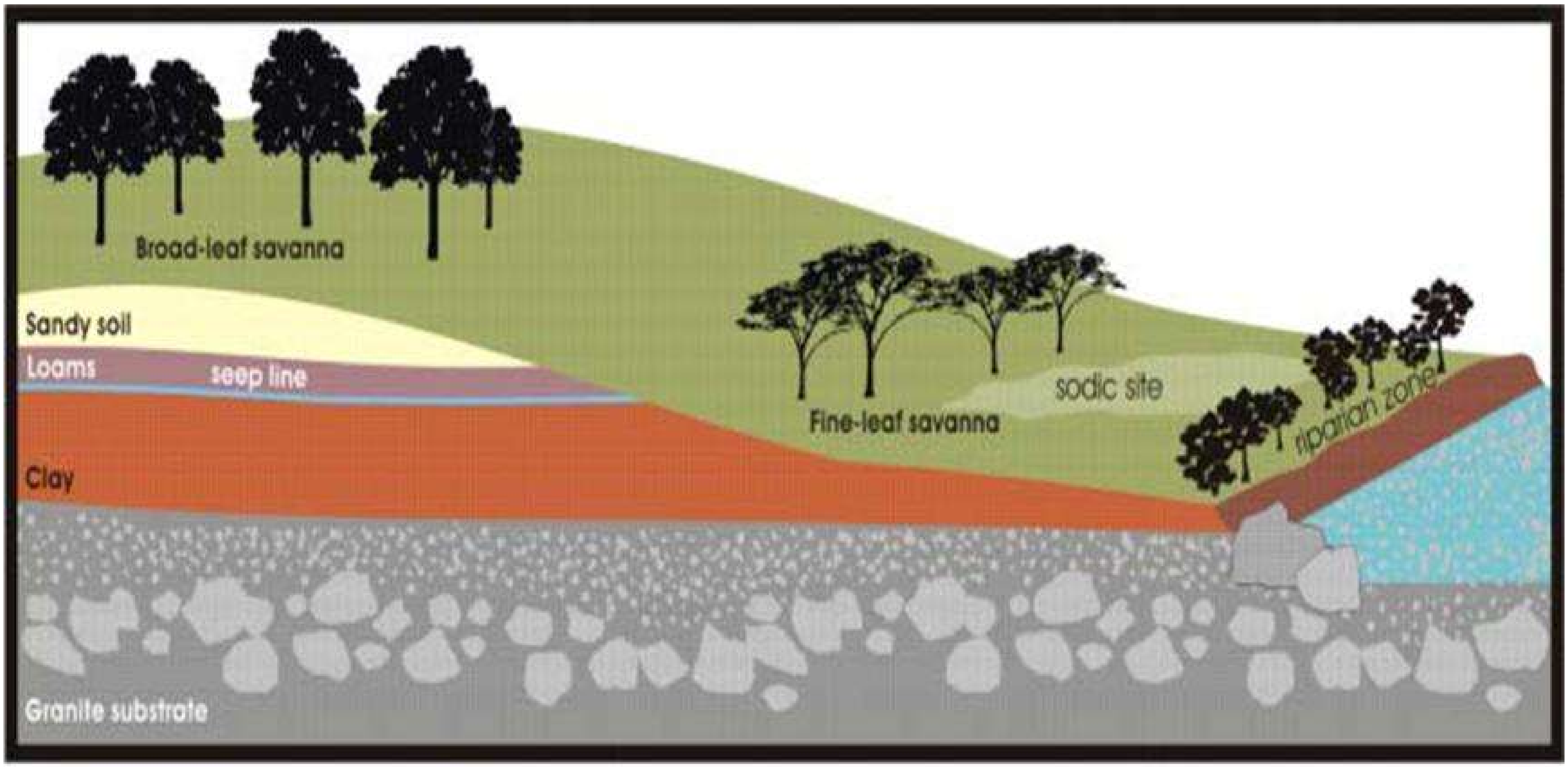
Table 1. Description of the treatments (frequency and season) in each vegetation type.

| **Sourveld** | **Combretum** | **Knobthorn- Marula** | **Mopane** |
|---|---|---|---|
| Oct B2 | Oct B2 | Oct B2 | Oct B2 |
| Oct B3 | Oct B3 | Oct B3 | Oct B3 |
| Dec B2 | Dec B2 | Oct B4 | Oct B4 |
| Dec B3 | Dec B3 | Oct B6 | Oct B6 |
| Feb B2 | Feb B2 | Dec B2 | Dec B2 |
| Feb B3 | Feb B3 | Dec B3 | Dec B3 |
| Apr B2 | Apr B2 | Feb B2 | Feb B2 |
| Apr B3 | Apr B3 | Feb B3 | Feb B3 |
| Aug B1 | Aug B1 | Apr B2 | Apr B2 |
| Aug B2 | Aug B2 | Apr B3 | Apr B3 |
| Aug B3 | Aug B3 | Aug B1 | Aug B1 |
| C | C | Aug B2 | Aug B2 |
| | | Aug B3 | Aug B3 |
| | | C | C |




(Venter & Govender, 2012)

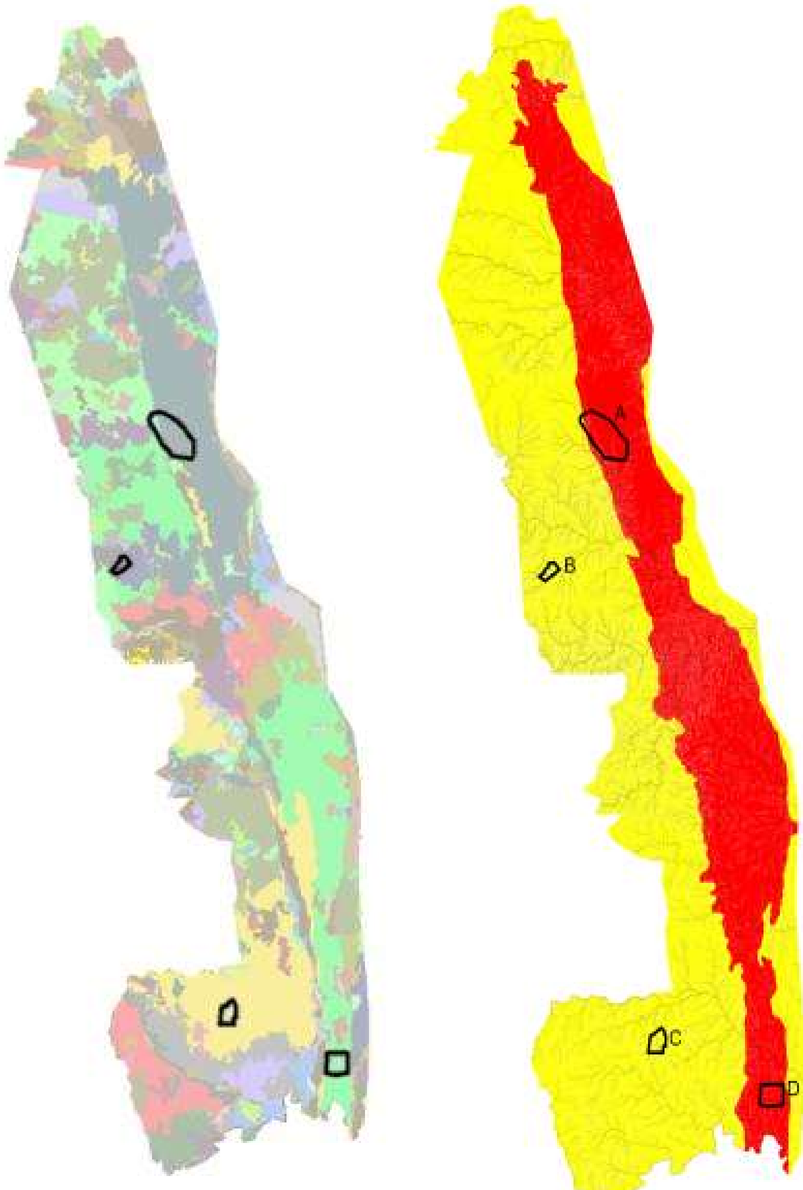
# Typical savanna catena showing the three elements




Savanna catena

diagram by Sharon Bernhardt

Cullum & Rogers (2011) A FRAMEWORK FOR THE CLASSIFICATION OF DRAINAGE NETWORKS IN SAVANNA LANDSCAPES. K5/1790




Perennial Rivers 600kms

Seasonal/Ephemeral 30000kms

## Super Research Sites Concept - Long-Term non-manipulated observatories

- Quantify the role of hydrological inter-connectedness between hydrological process domains.
- Determine the spatio-temporal variability of this interconnectedness in order to understand the hydrological fluxes that drive these savannah systems

## 4 key scales to the objective of the study:

**Intra Hillslope Connectivity**

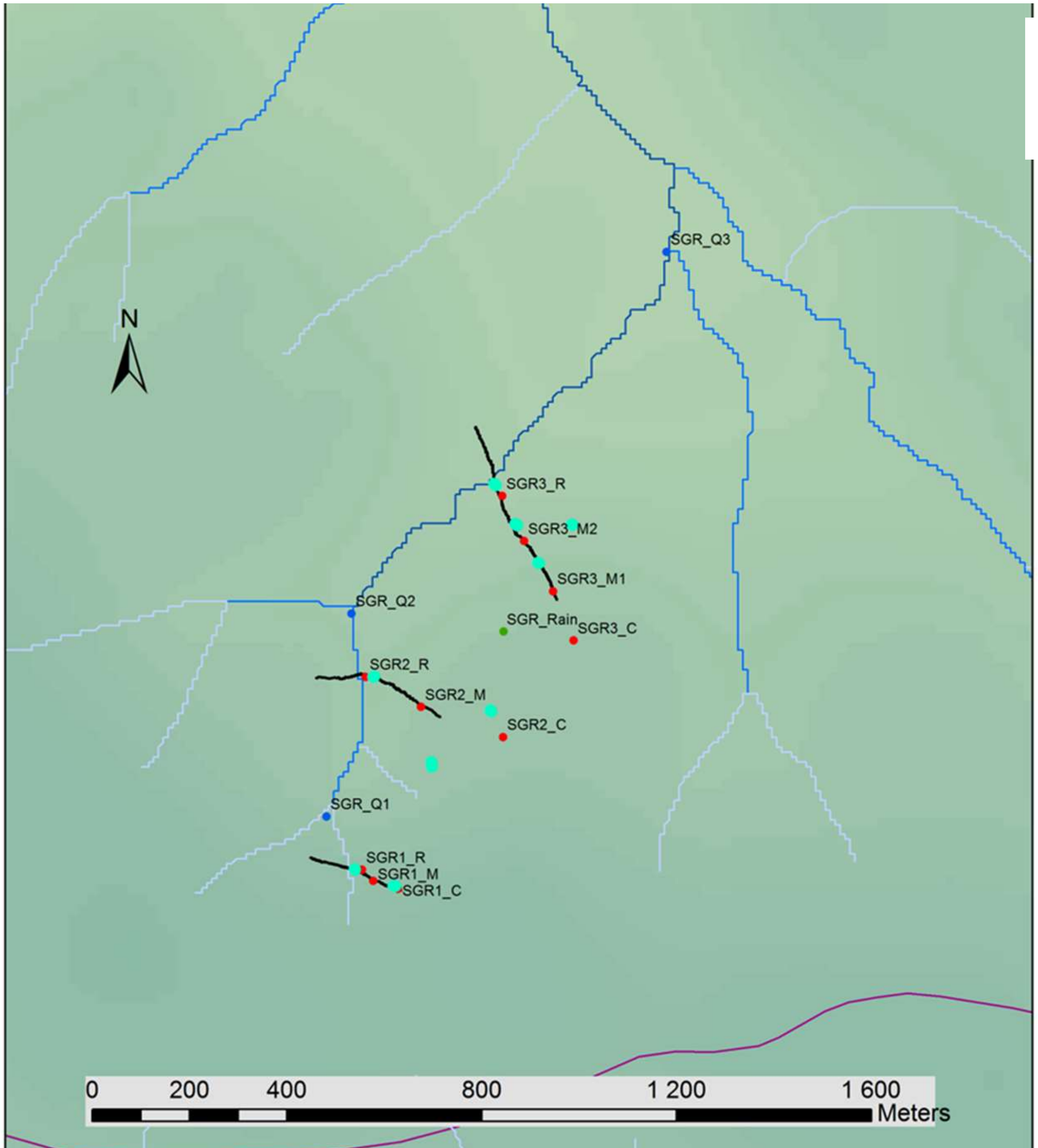
**Hillslope-Stream Connectivity**

**Stream Network Connectivity**

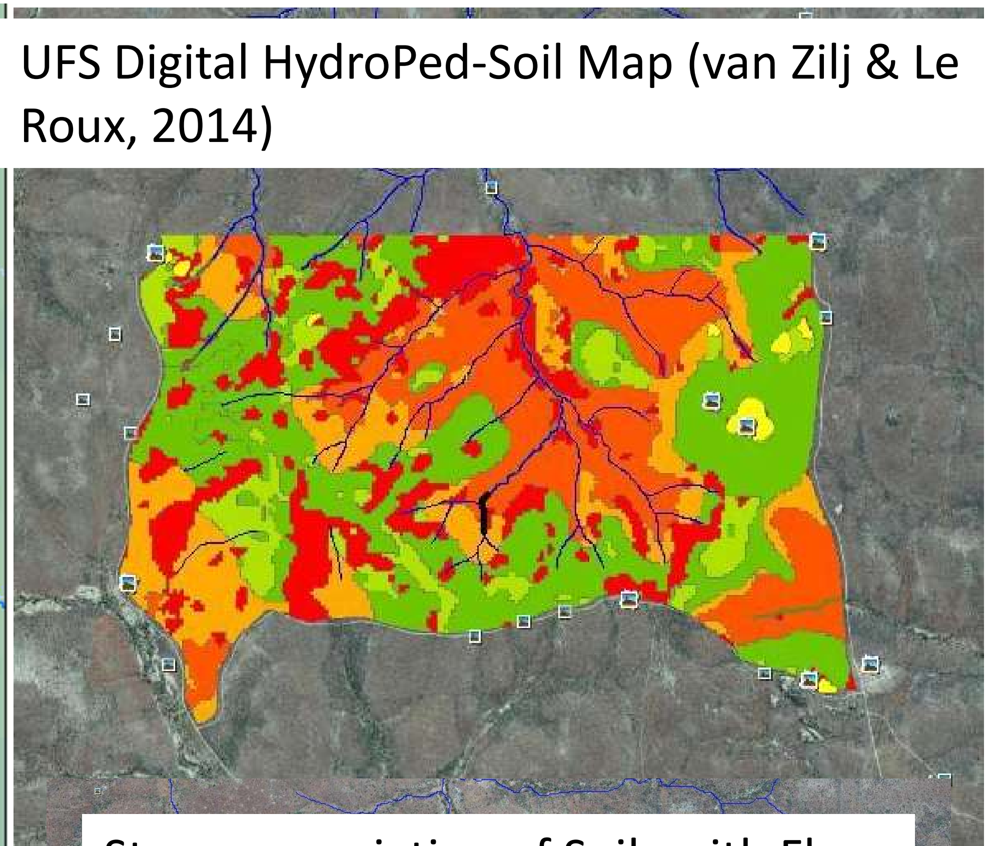
**Groundwater-Surface Water Connectivity**

**Hydrological Connectivity – Ecosystem/Landscape Processes**

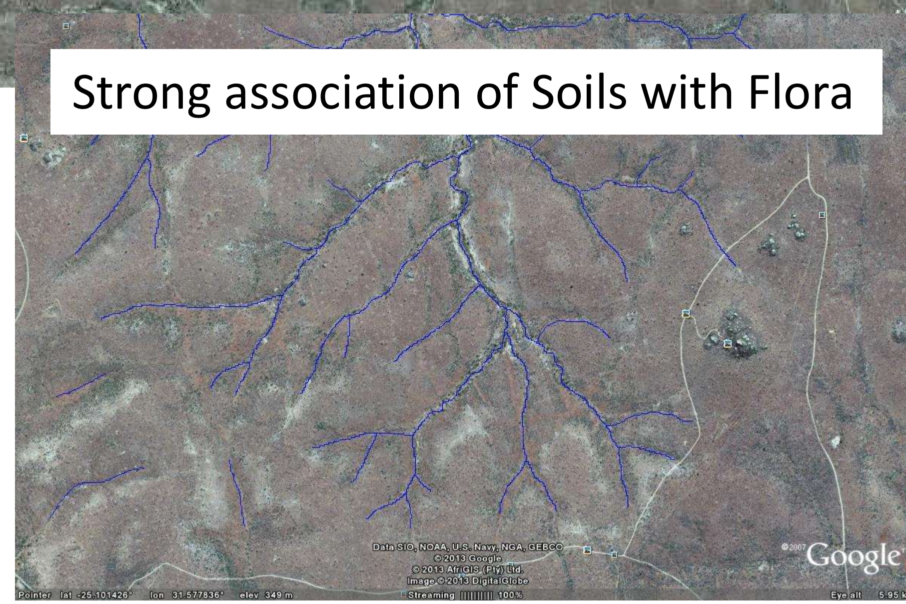
# Southern Granites




(red = soil moisture station, blue = streamflow gauge [SGR_Q3 includes integrated ALCO streamflow sampler], cyan = boreholes, small green = rainfall station, large green = DavisTM Weather Station)

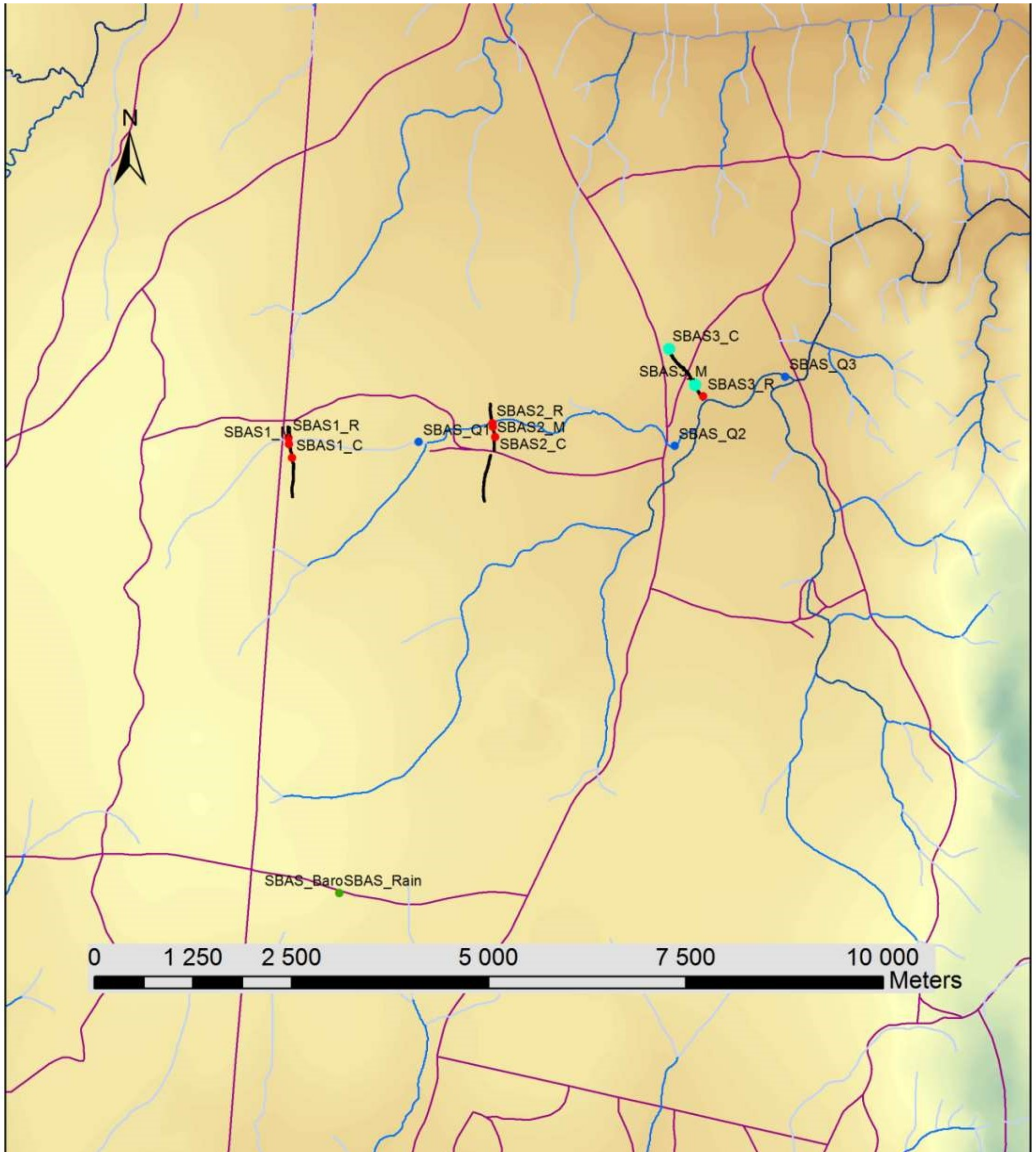


UFS Digital HydroPed-Soil Map (van Zilj & Le Roux, 2014)




Strong association of Soils with Flora

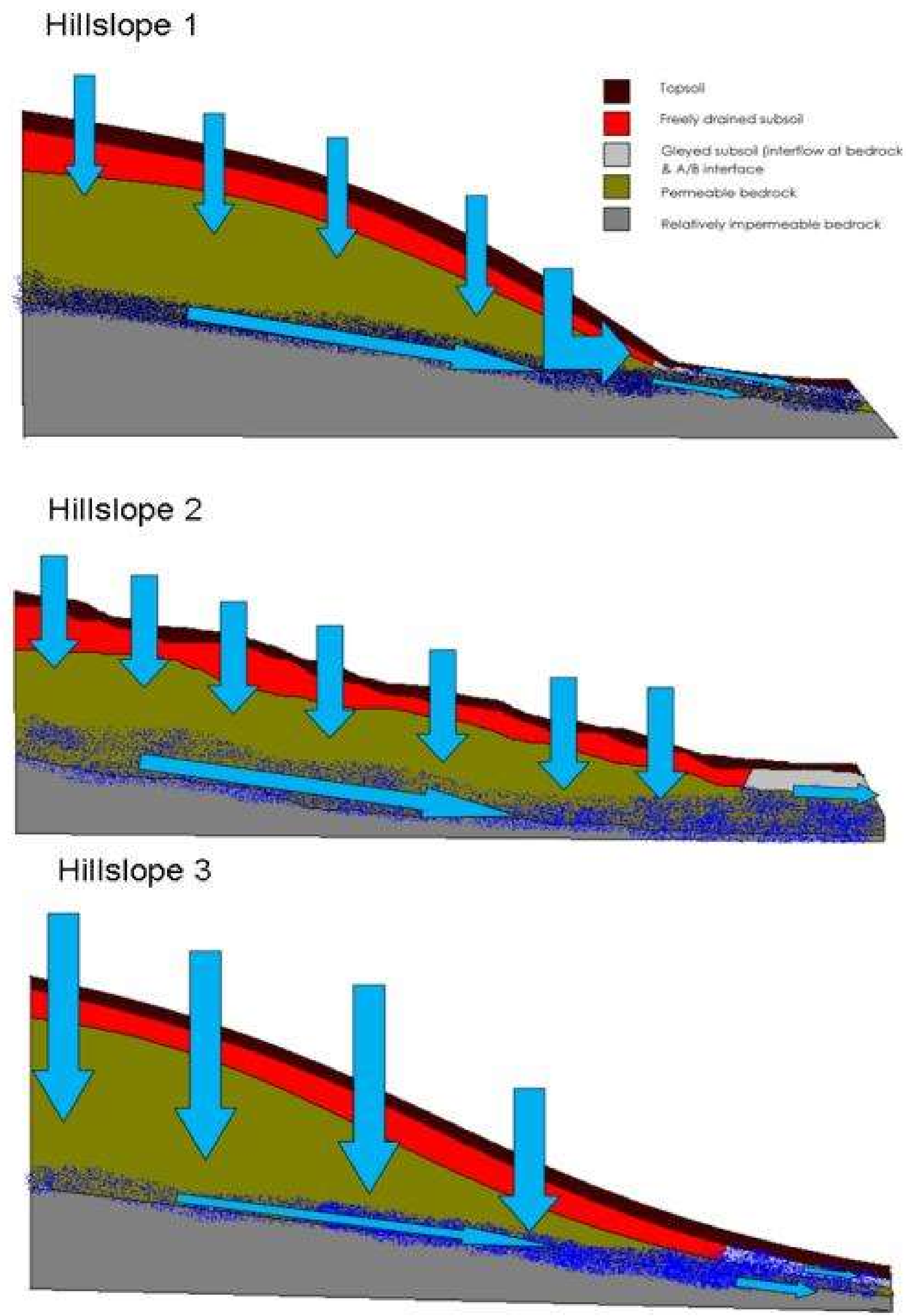
# Southern Basalts




Supersite (red = soil moisture station, blue = streamflow gauge, cyan = boreholes, small green = rainfall station, large green = DavisTM Weather Station).

# Le Roux et al: Hydrology of South African Soils and Hillslopes

# (HOSASH) - K5/2021




## Creating a conceptual hydrological soil response map for the Stevenson Hamilton Research Supersite, Kruger National Park, South Africa


George van Zijl[1]* and Pieter Le Roux[1]

[1]*Department of Soil, Crop and Climate, University of the Free State, Bloemfontein, 9301, South Africa*



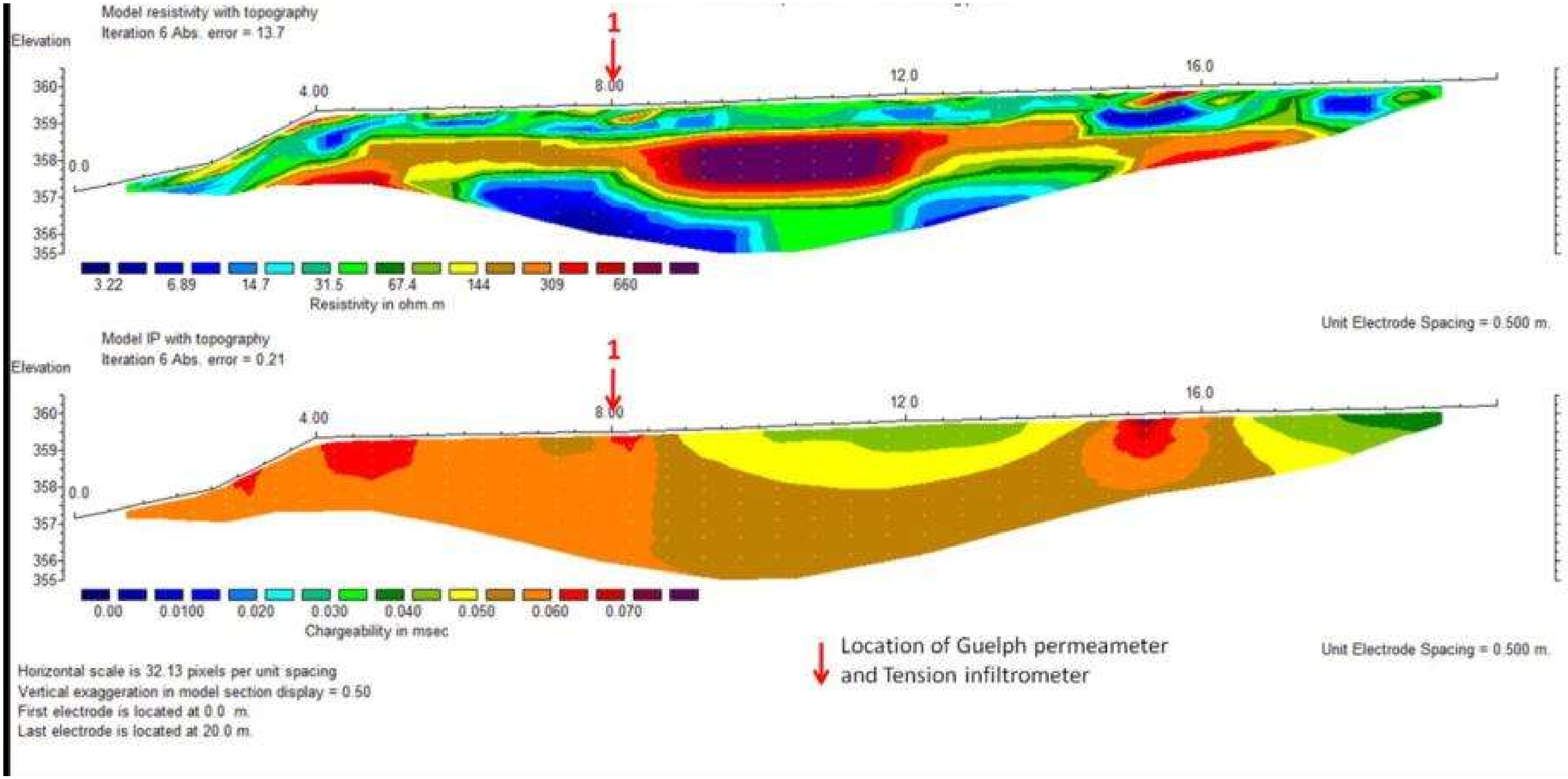
ABSTRACT

The soil water regime is a defining ecosystem service, directly influencing vegetation and animal distribution. Therefore the understanding of hydrological processes is a vital building block in managing natural ecosystems. Soils contain morphological indicators of the water flow paths and rates in the soil profile, which are expressed as 'conceptual hydrological soil responses' (CHSR's). CHSR's can greatly aid in the understanding of hydrology within a landscape and catchment. Therefore a soil map could improve hydrological assessments by providing both the position and area of CHSR's. Conventional soil mapping is a tedious process, which limits the application of soil maps in hydrological studies. The use of a digital soil mapping (DSM) approach to soil mapping can speed up the mapping process and thereby extend soil map use in the field of hydrology. This research uses an expert-knowledge DSM approach to create a soil map for Stevenson Hamilton Research Supersite within the Kruger National Park, South Africa. One hundred and thirteen soil observations were made in the 4 001 ha area. Fifty-four of these observations were pre-determined by smart sampling and conditioned Latin hypercube sampling. These observations were used to determine soil distribution rules, from which the soil map was created in SoLIM. The map was validated by the remaining 59 observations. The soil map achieved an overall accuracy of 73%. The soil map units were converted to conceptual hydrological soil response units (CHSRUs), providing the size and position of the CHSRUs. Such input could potentially be used in hydrological modelling of the site.



**Keywords**: Digital soil mapping, terrain analysis, ecosystem services, conceptual hydrological soil responses, SoLIM

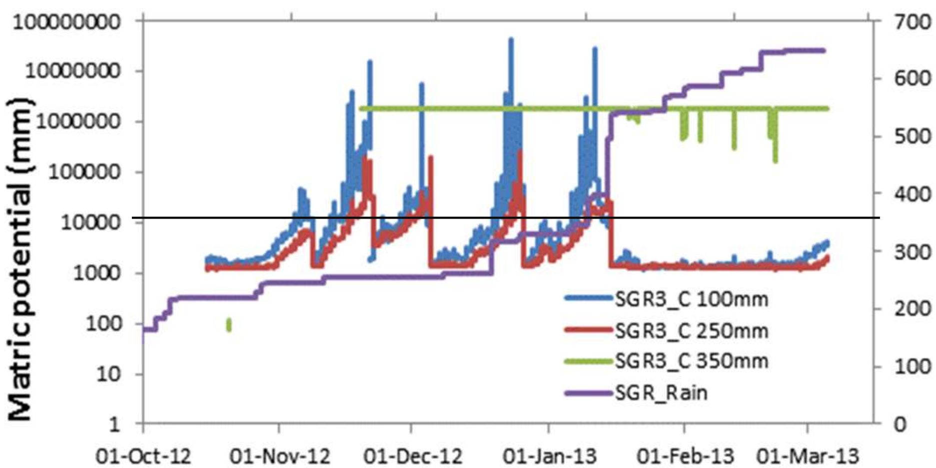
# Crest soils-Granite/3rd order

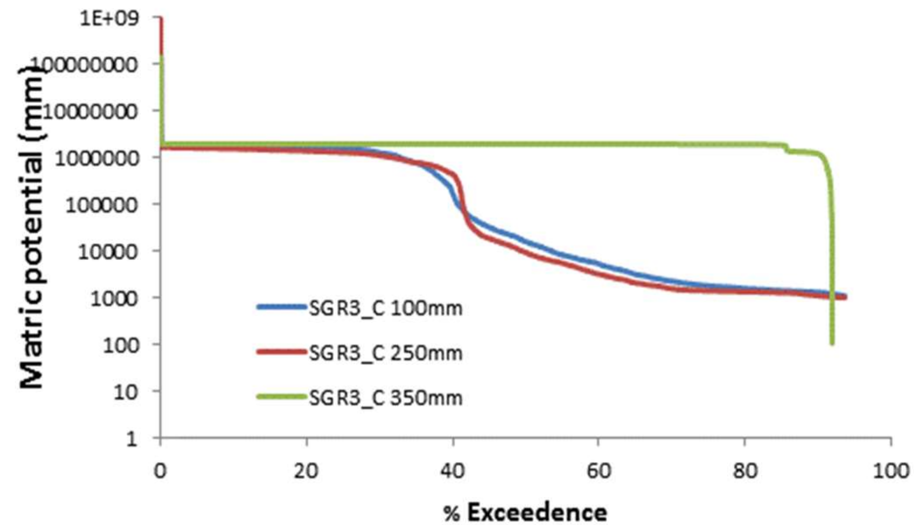



- Sandy soils
- Little clay content close to the surface

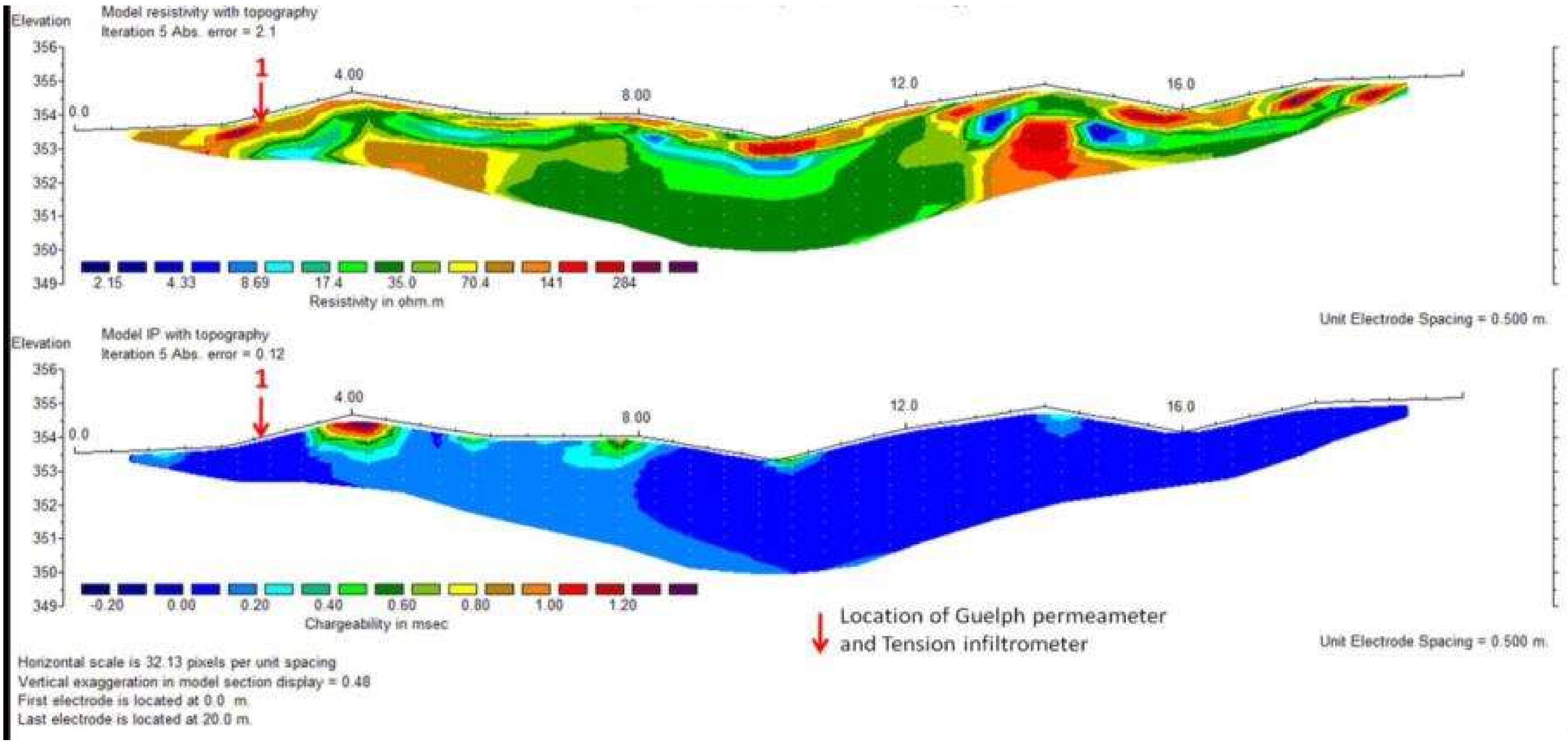
# Matric Potentials - Granites

Crest 3rd order



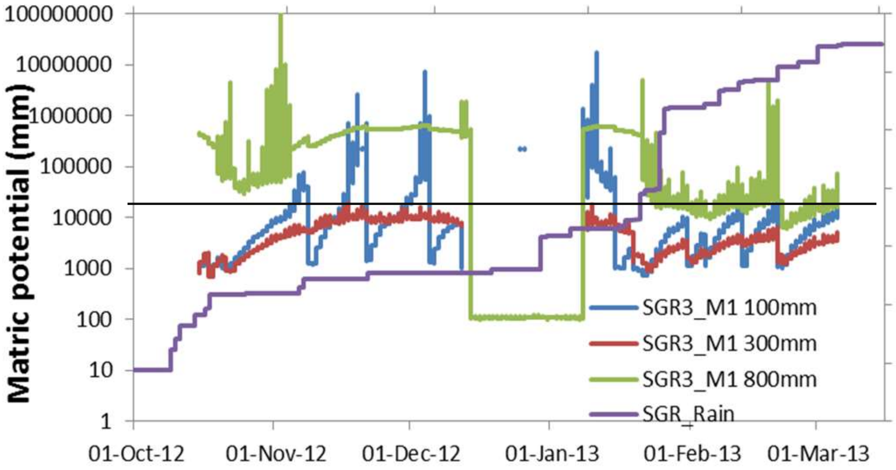



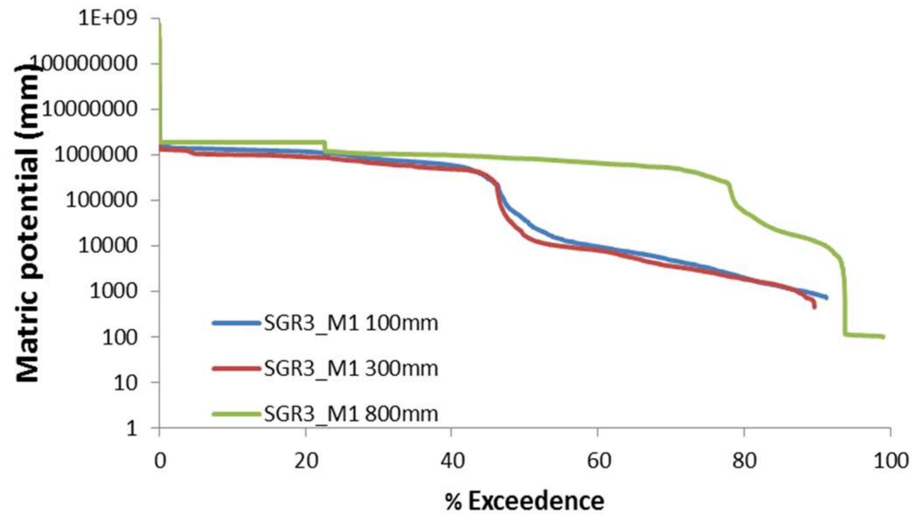
# Midslope-Granite/3rd order



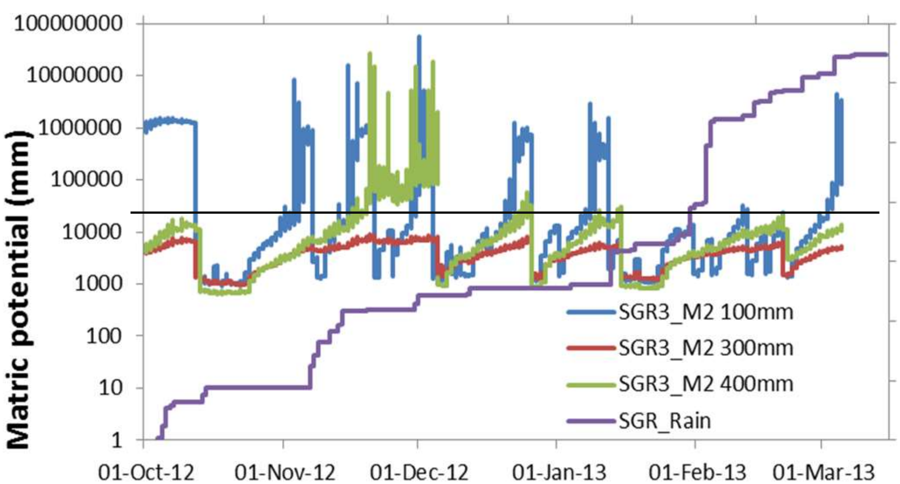

- Layers of clay in the subsurface
- Presence of duplex soils

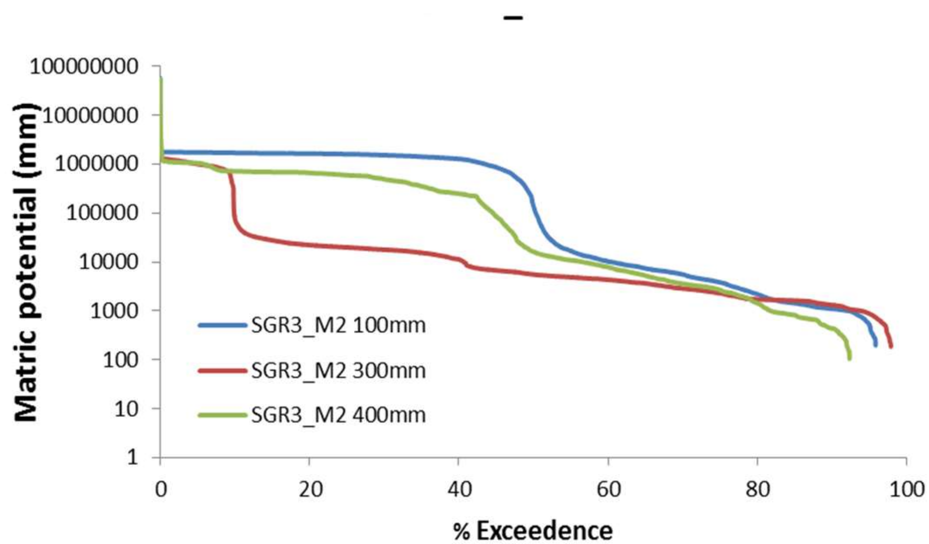
# Upper Mid-slope 3rd order



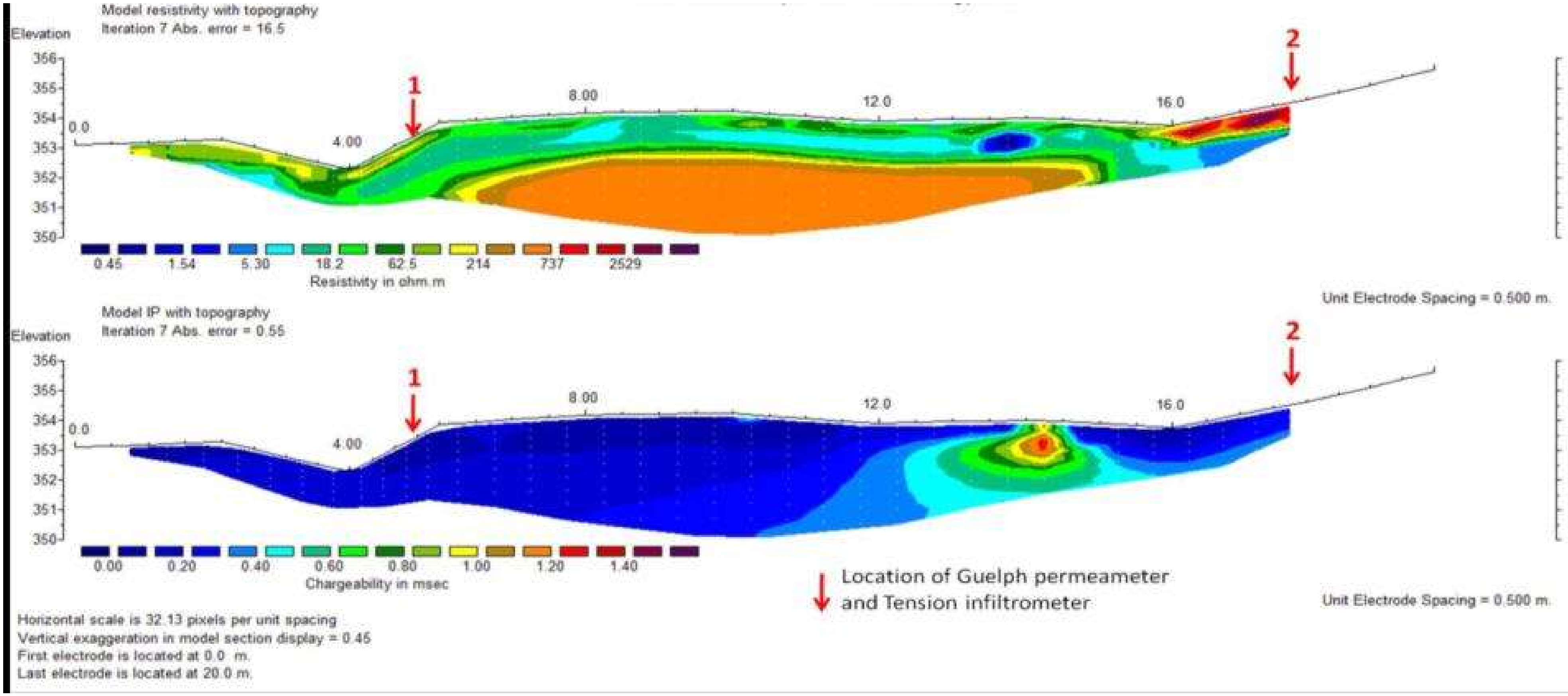




# Lower Mid-slope 3rd order



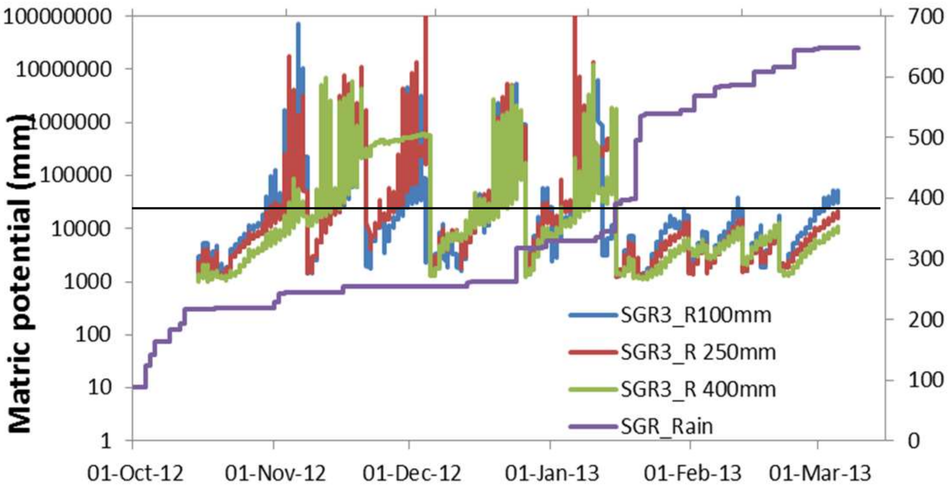



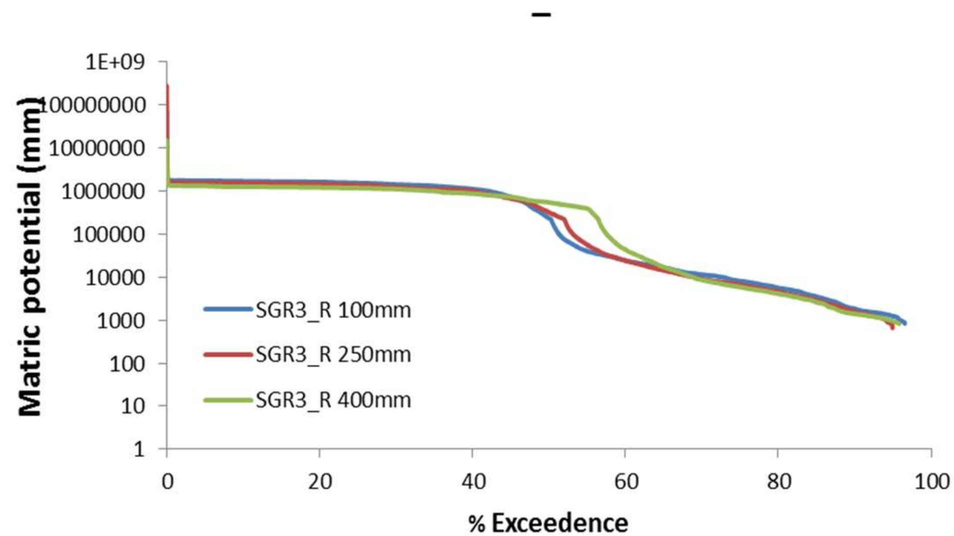
# Riparian soils-Granite/3rd order



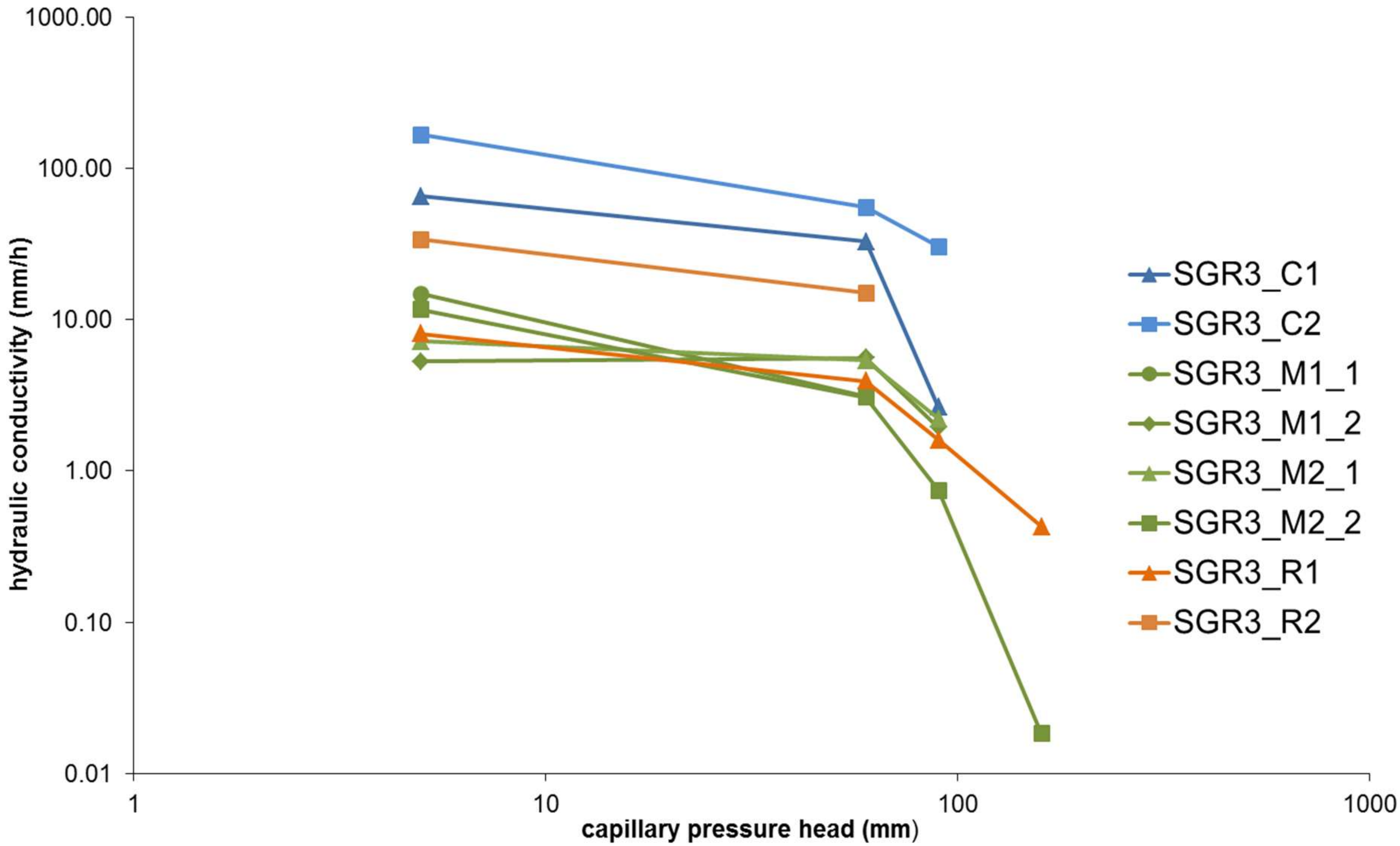

- Riparian soils mainly clays

# Riparian 3rd order



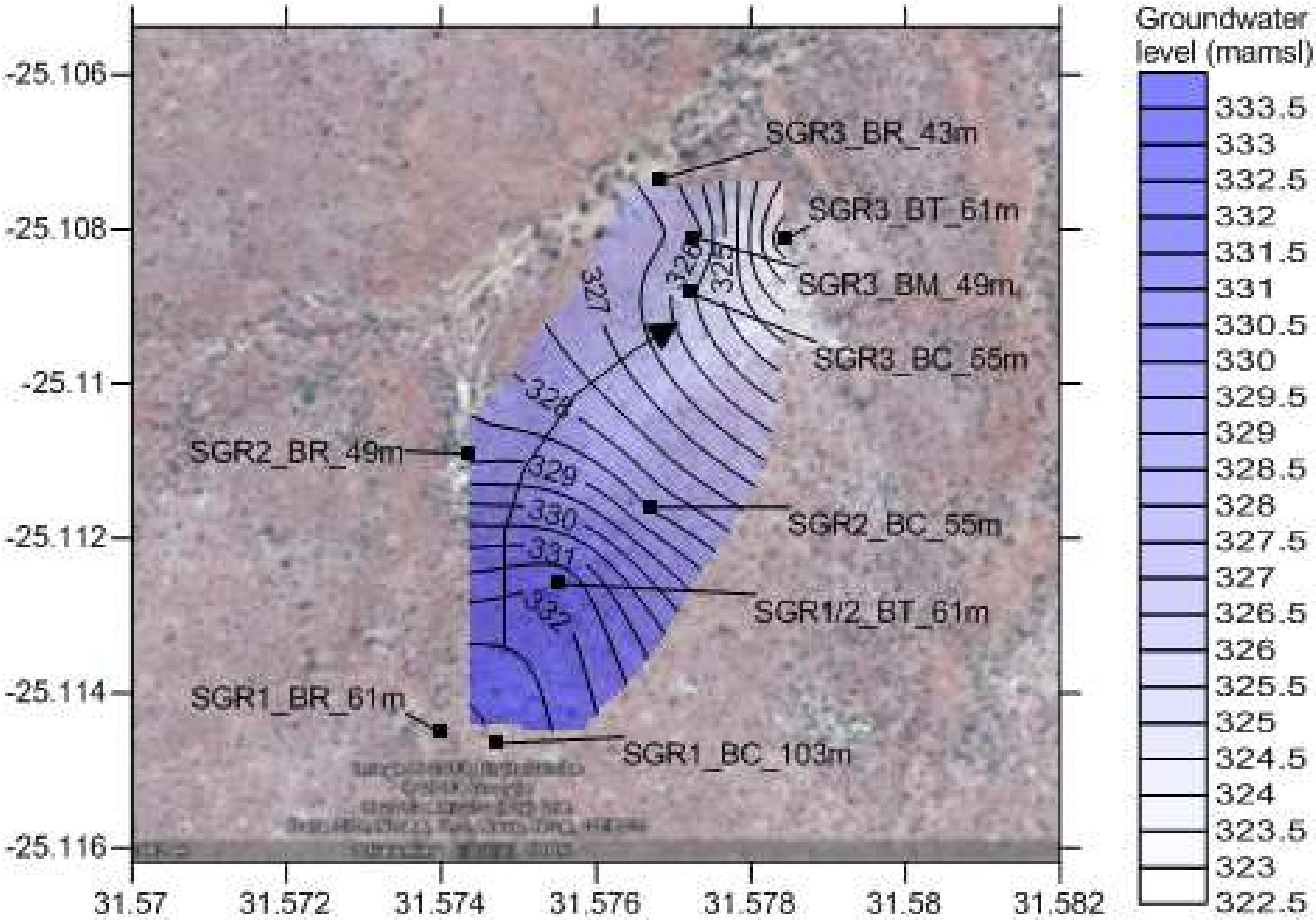
# Unsaturated hydraulic conductivity



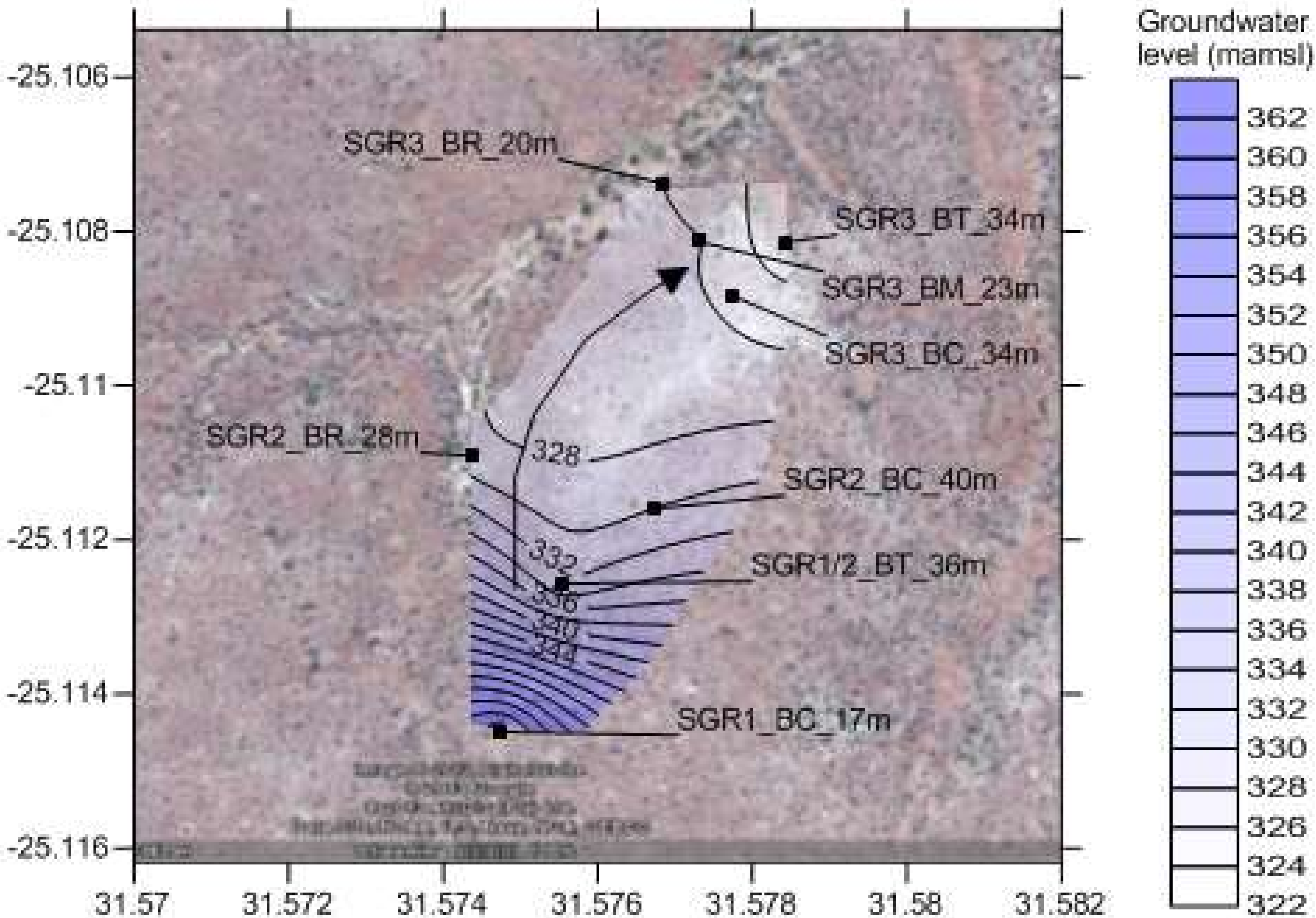

- High k on the crest- sandy soils, recharge
- Very low k on the midslope- duplex soils

# Spatial GWL map

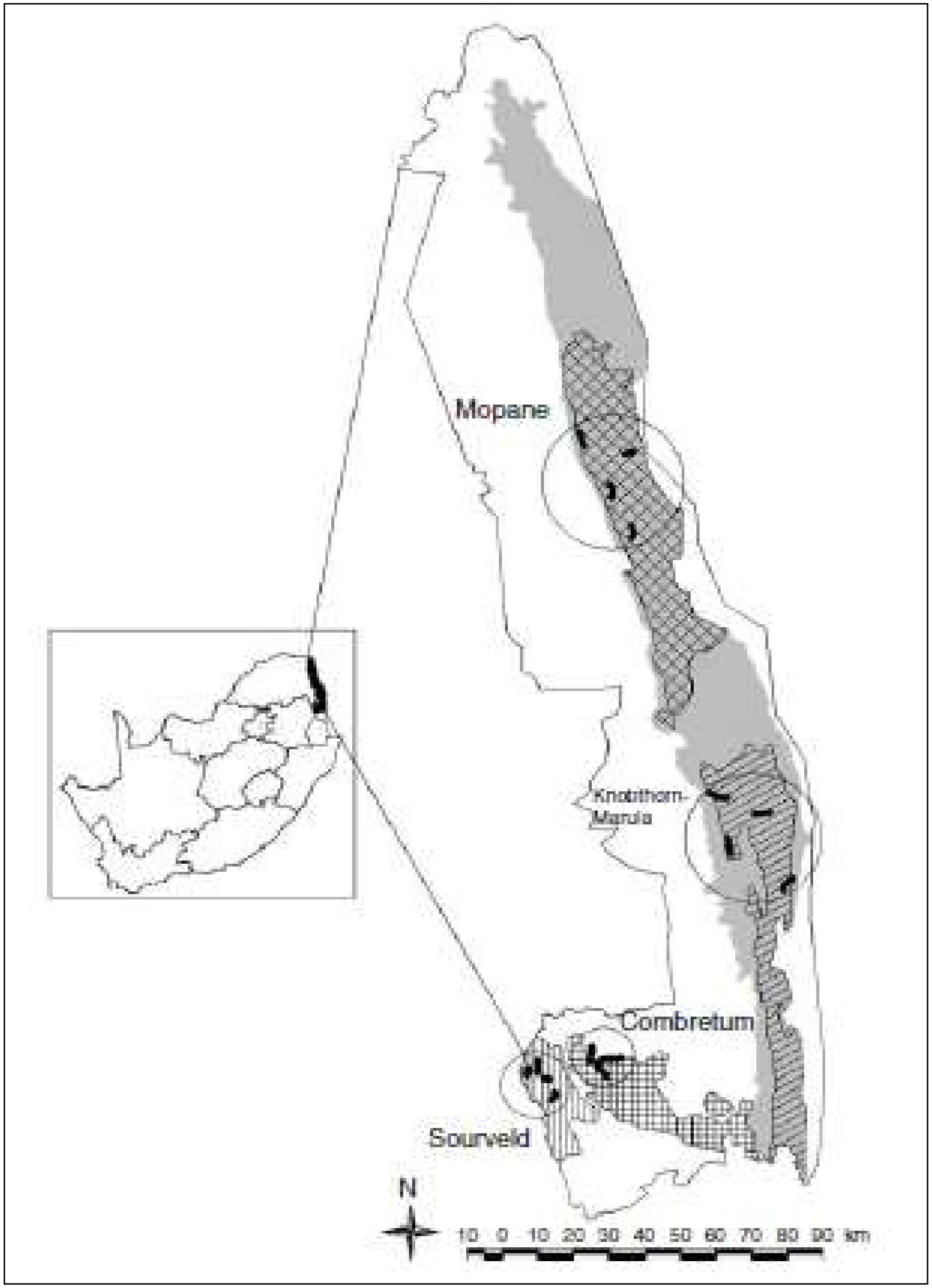
Deep GW



Shallow GW



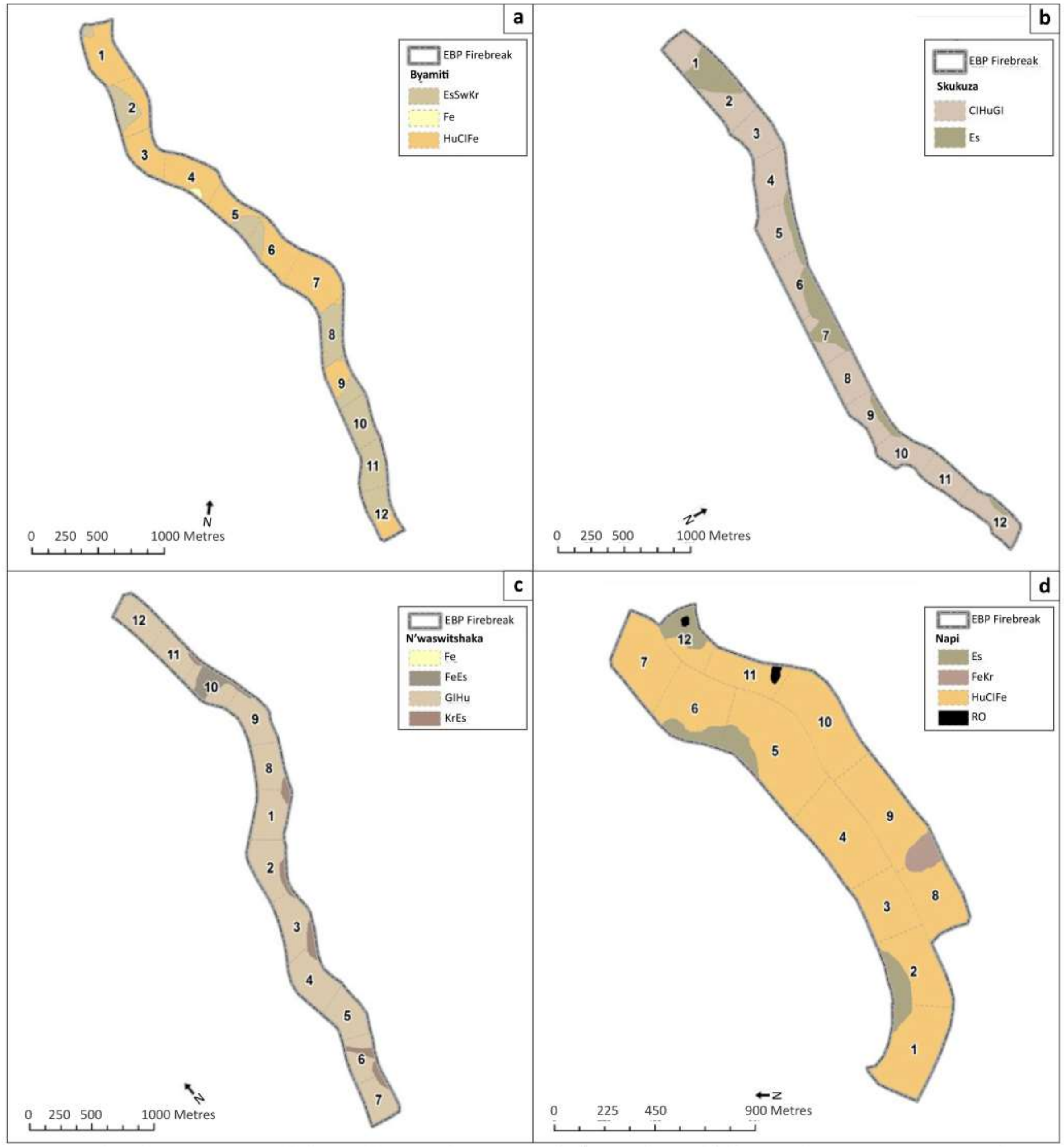
Groundwater level (mamsl)
362
360
358
356
354
352
350
348
346
344
342
340
338
336
334
332
330
328
326
324
322
SGR3_BR_20m
SGR3_BT_34m
SGR3_BM_23m
SGR3_BC_34m
SGR2_BR_28m
328
SGR2_BC_40m
332
SGR1/2_BT_36m
336
340
344
SGR1_BC_17m
-25.106
-25.108
-25.11
-25.112
-25.114
-25.116
31.57
31.572
31.574
31.576
31.578
31.58
31.582




- The Experimental Burn Plots (EBPs) was developed in the early 1950s.
- They are replicated in four major vegetation landscapes in the park
- Geology- granites in the west and the basalts in the east

# SKUKUZA EXPERIMENTAL BURN PLOTS

*Note following Slides from Pretoriuskop Granite but higher rainfall*



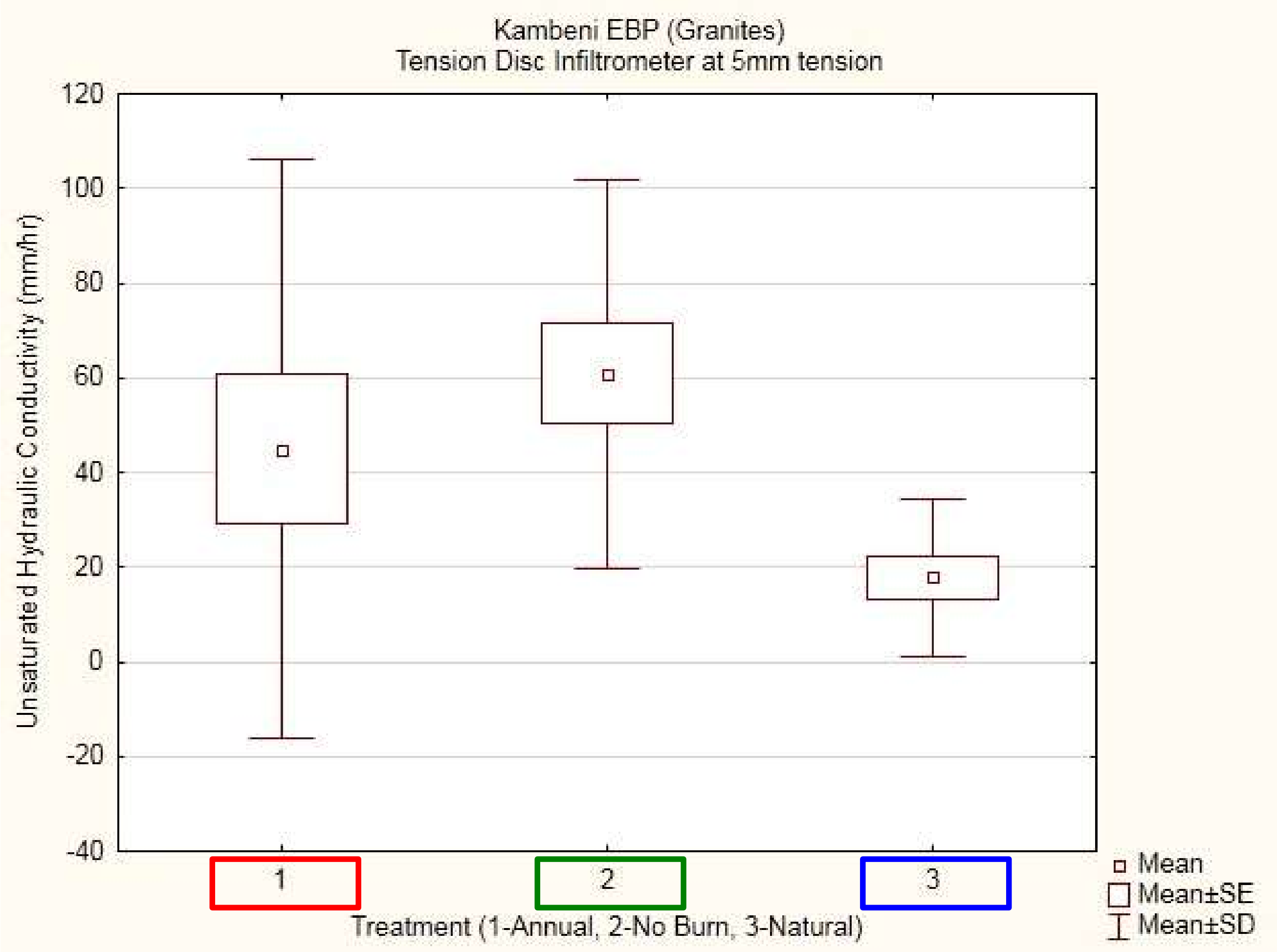

EBP, Experimental Burn Plot; EsSwKr, Estcourt–Swartland–Kroonstad; Fe, Fernwood; HuClFe, Hutton–Clovelly–Fernwood; ClHuGl, Clovelly–Hutton–Glenrosa; Es, Estcourt; FeEs, Fernwood–Estcourt; GlHu, Glenrosa–Hutton; KrEs, Kroonstad–Estcourt; FeKr, Fernwood–Kroonstad; RO, Rocky outcrop.

**FIGURE 3:** Description of the soils types on the Skukuza replicates (a) Biyamiti (b) Skukuza (c) N'waswitshaka and (d) Napi. For the complete list of soil names and abbreviations see Online Appendix 2.

Venter, F.J. & Govender, N., 2012, 'A geomorphic and soil description of the long-term fire experiment in the Kruger National Park, South Africa', Koedoe 54(1), Art. #1037, 10 pages. http://dx.doi.org/10.4102/koedoe.v54i1.1037

# GRANITES: Soil infiltration rates

H 1: Soil infiltration rates will be slowest on the **Annual** burn plot.

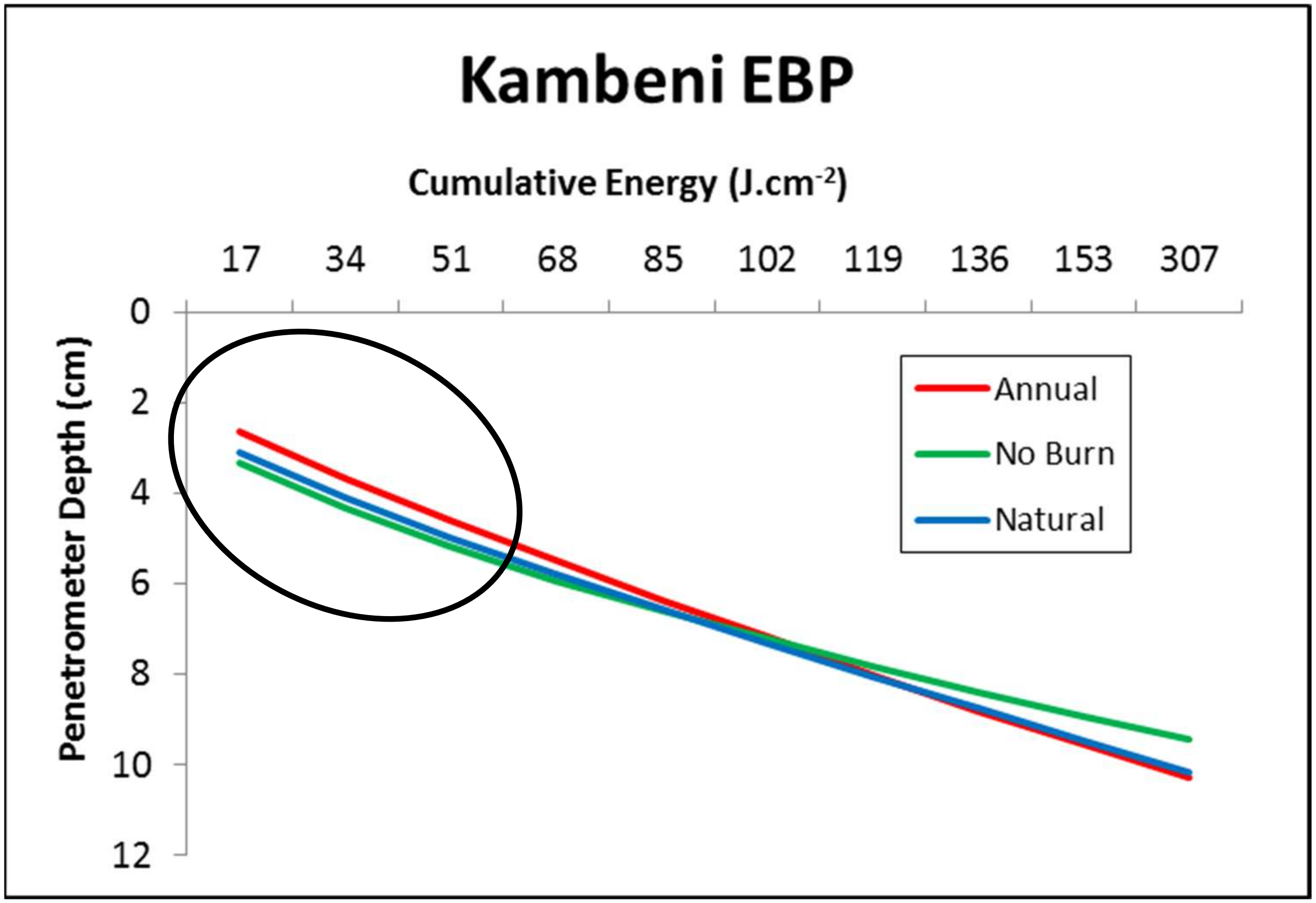



- Infiltration rates are slowest on **Natural** plot (p=0.003)

| | |
|---|---|
| ● | Annual (August, hot fire) |
| ● | No burn (Total fire exclusion) |
| ✖ | "Natural" (± 3 years) |

# GRANITES: Soil Compaction

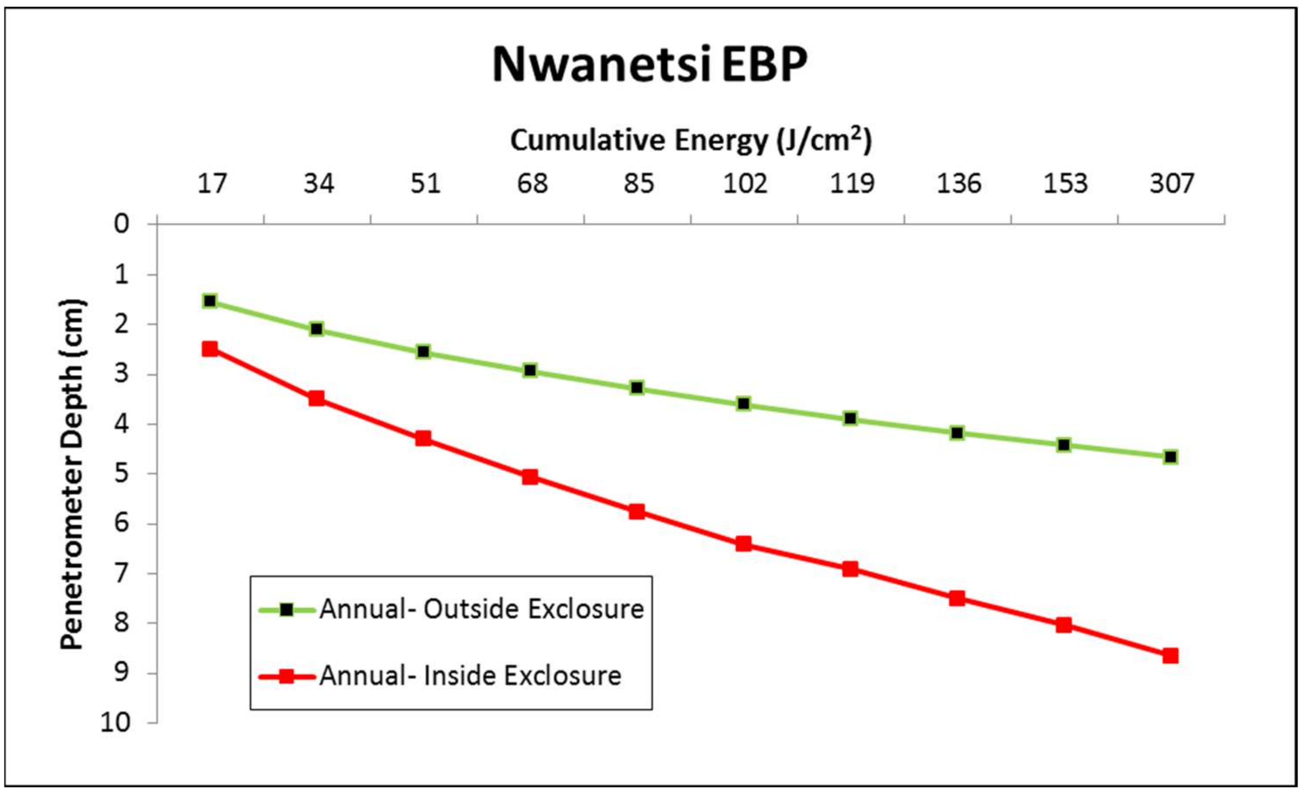
H 2: **Annual** burn plot will be the most compacted.




- **Annual** plot has significantly ($p < 0.008$) higher resistance to penetration- most *compacted*
- Effect of fire or herbivores?

# Soil Compaction

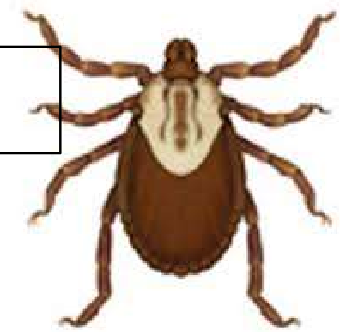
**FIRE** vs. **HERBIVORES**

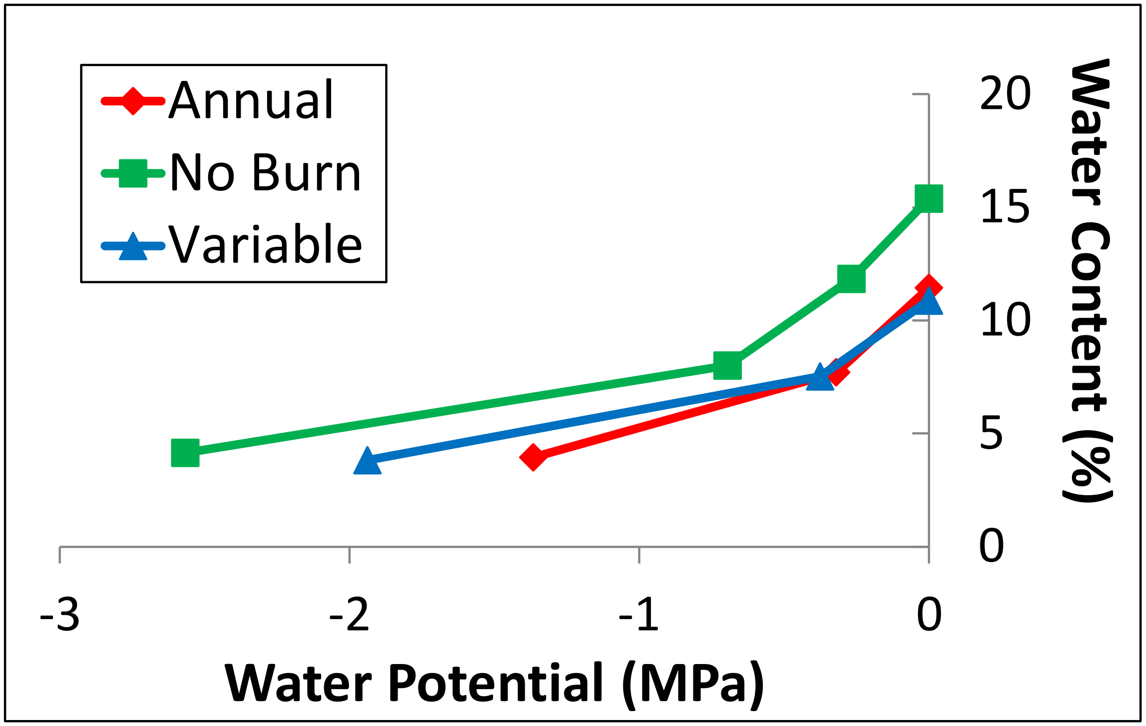



- With fire both outside and inside the exclosures, soils are significantly more compacted **outside** the exclosure ($p<0.05$).

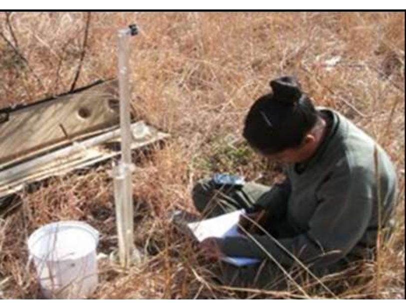
# Water Retention Capacity

H 3: Higher water retention capacity on the **No Burn** plot.



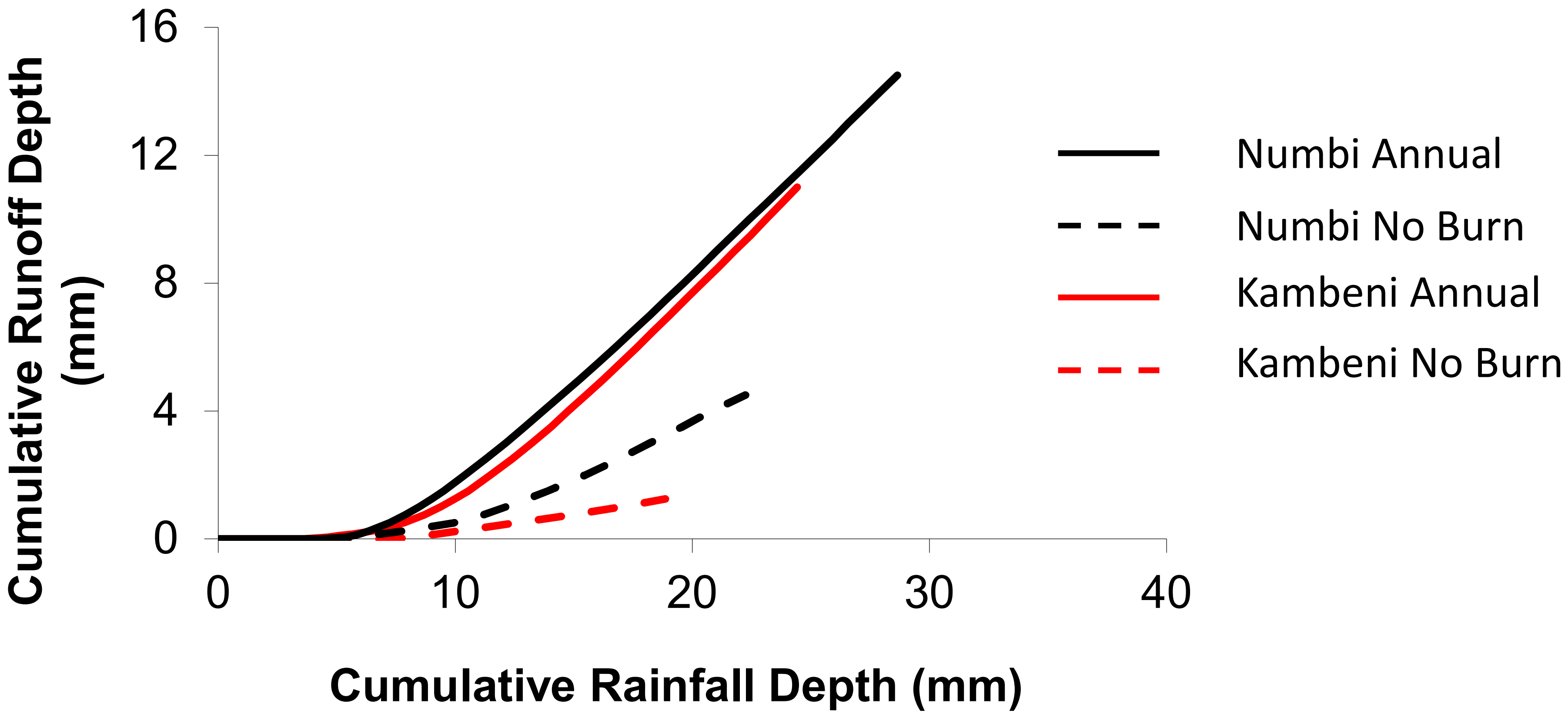



- Similar water contents- **No Burn** plot has a higher water retention capacity.
- Linked to higher biomass and soil organic matter (SOM)



# Surface Runoff

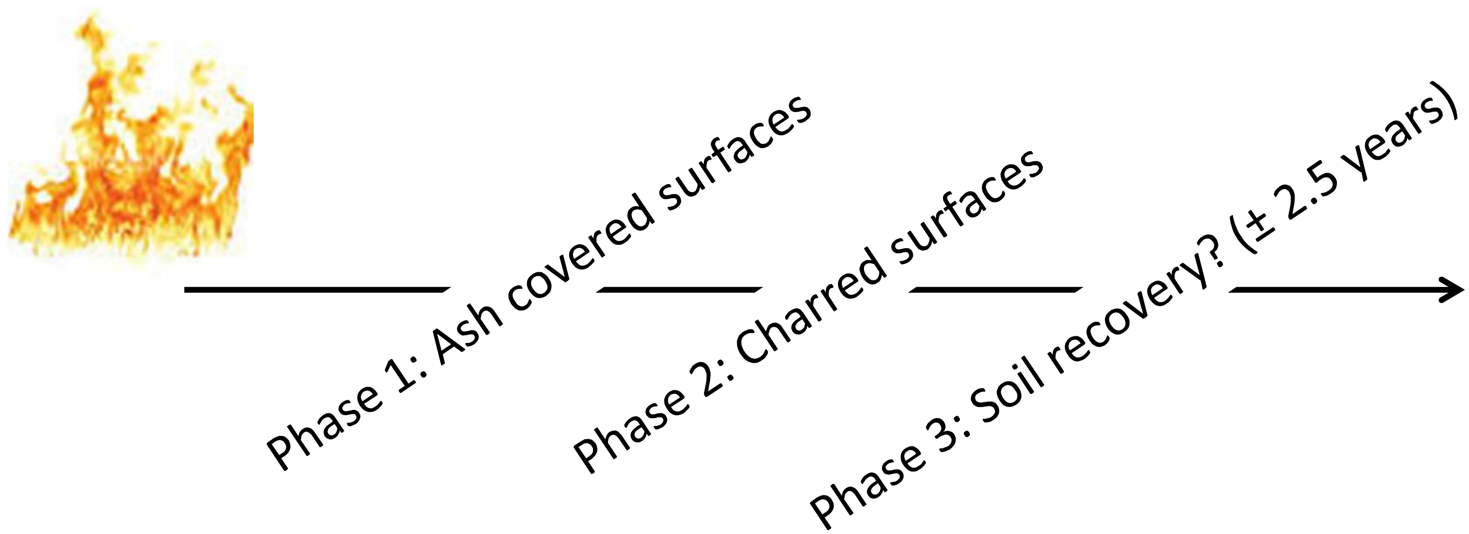
H 4: More runoff occurs on the **Annual** burn plot.




- At rainfall intensity of 200 mm/h, more runoff occurs on the **Annual** burn plots.

# Conclusion

- Not fire frequency but ***TIME*** following a fire plays a major role on changes to soil hydraulic properties.

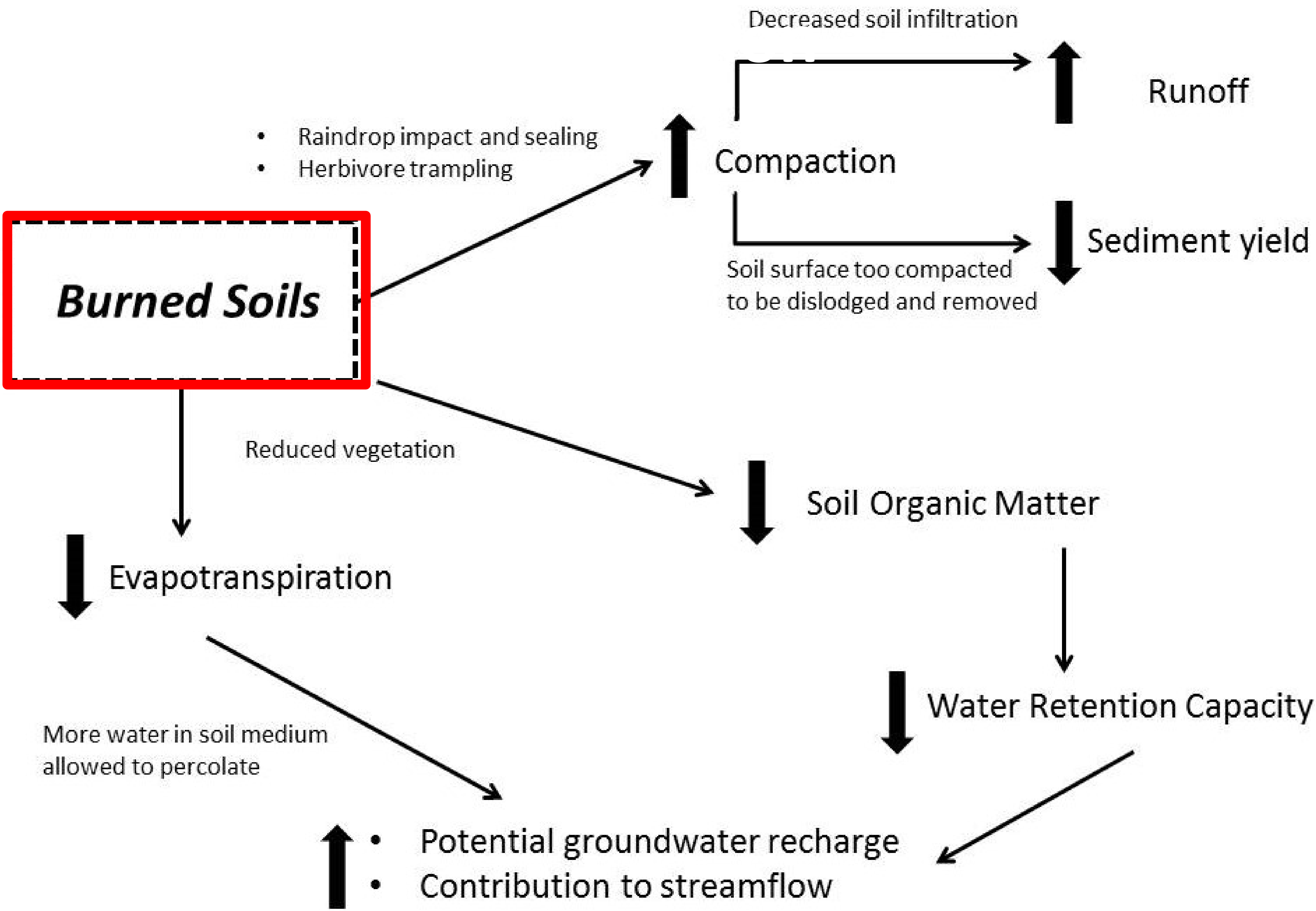



- Herbivore trampling exacerbates the effects of fire leading to more compacted soils.

# Conclusion

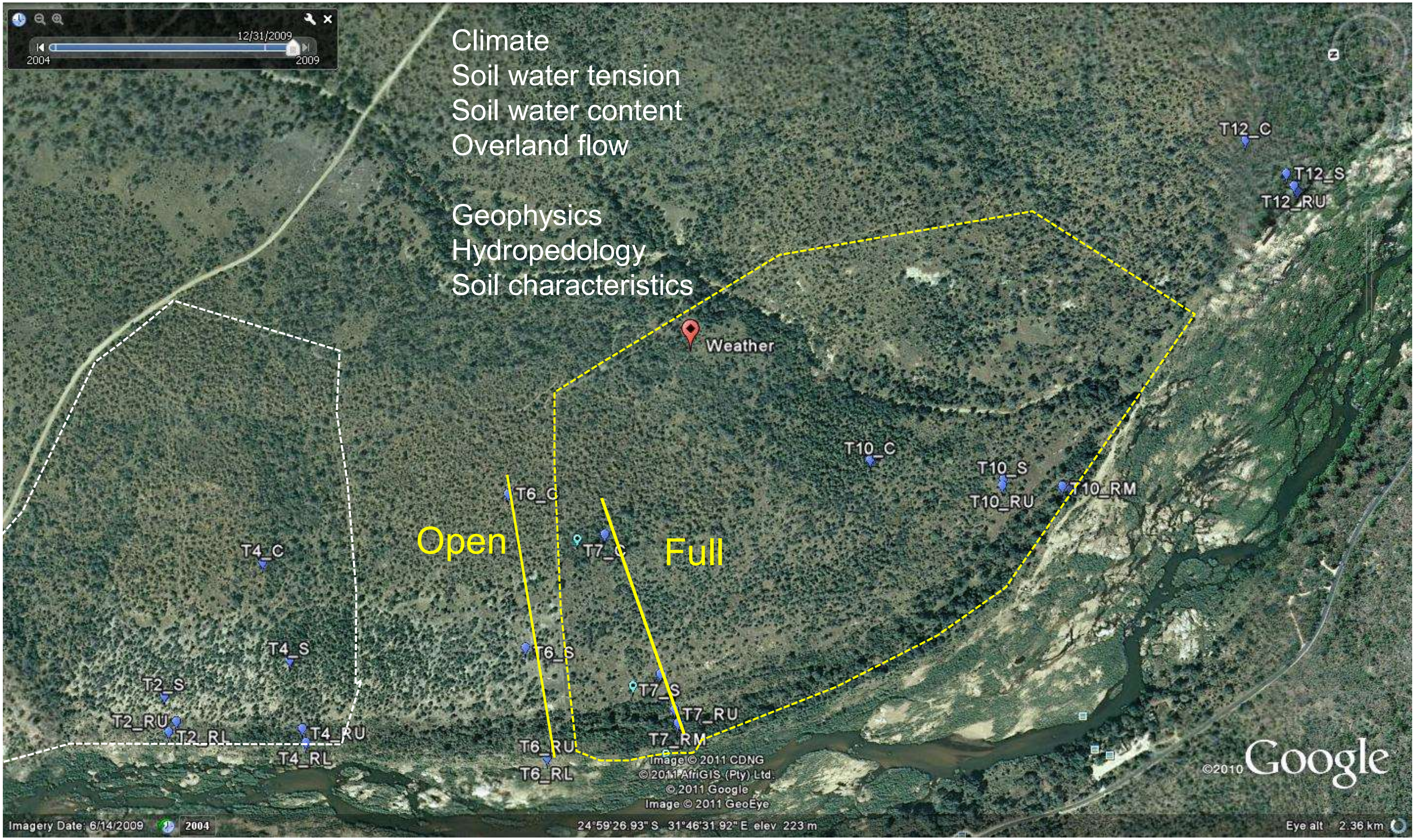
- Frequent fires consume organic matter and result in lower soil water retention capacities

- During extreme rainfall events, more runoff will occur on **Annual** burn plot.



Decreased soil infiltration
Runoff
Raindrop impact and sealing
Herbivore trampling
Compaction
Burned Soils
Sediment yield
Soil surface too compacted to be dislodged and removed
Reduced vegetation
Soil Organic Matter
Evapotranspiration
Water Retention Capacity
More water in soil medium allowed to percolate
Potential groundwater recharge
Contribution to streamflow

## Catena Hydrological Fluxes on Granite Hillslopes and Links to Distinct Vegetation Guilds within the Herbivore and Fire Exclusion Experiments




Google Earth, 2009 image

**Sabie Nkhuhlu Exclosures**

# Monitoring



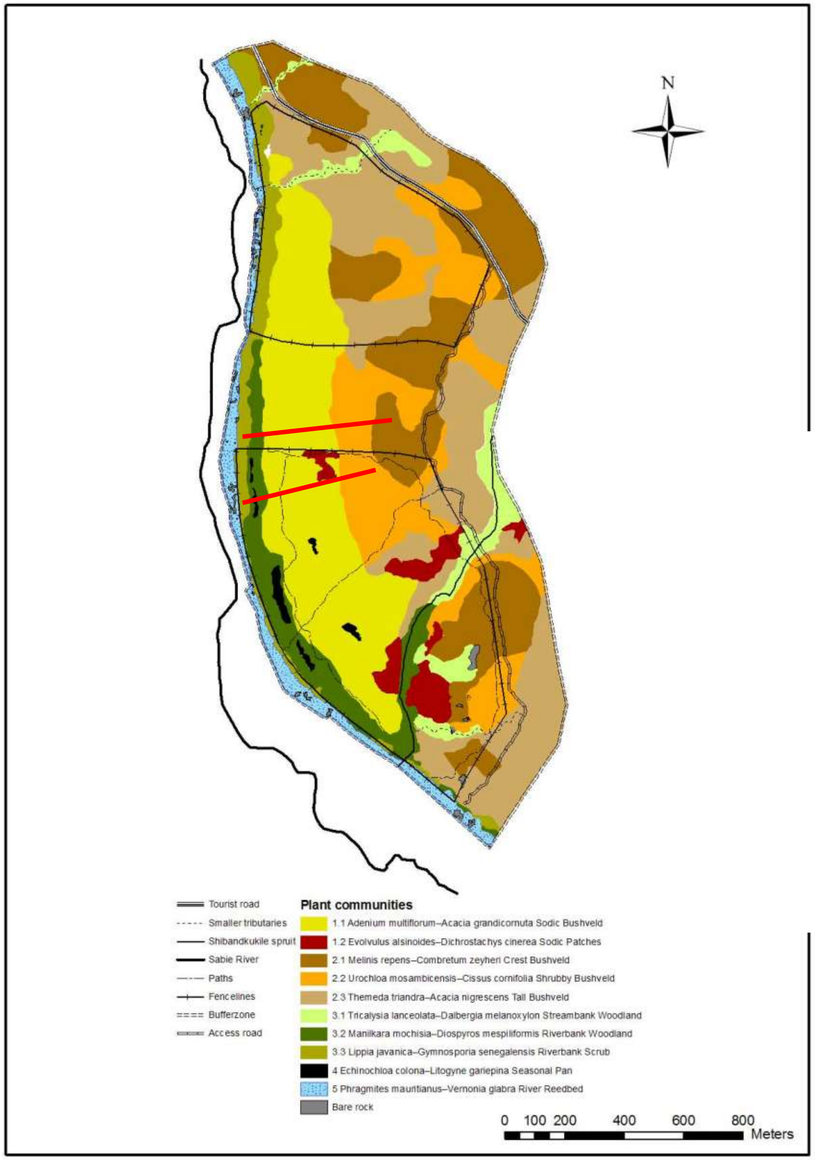


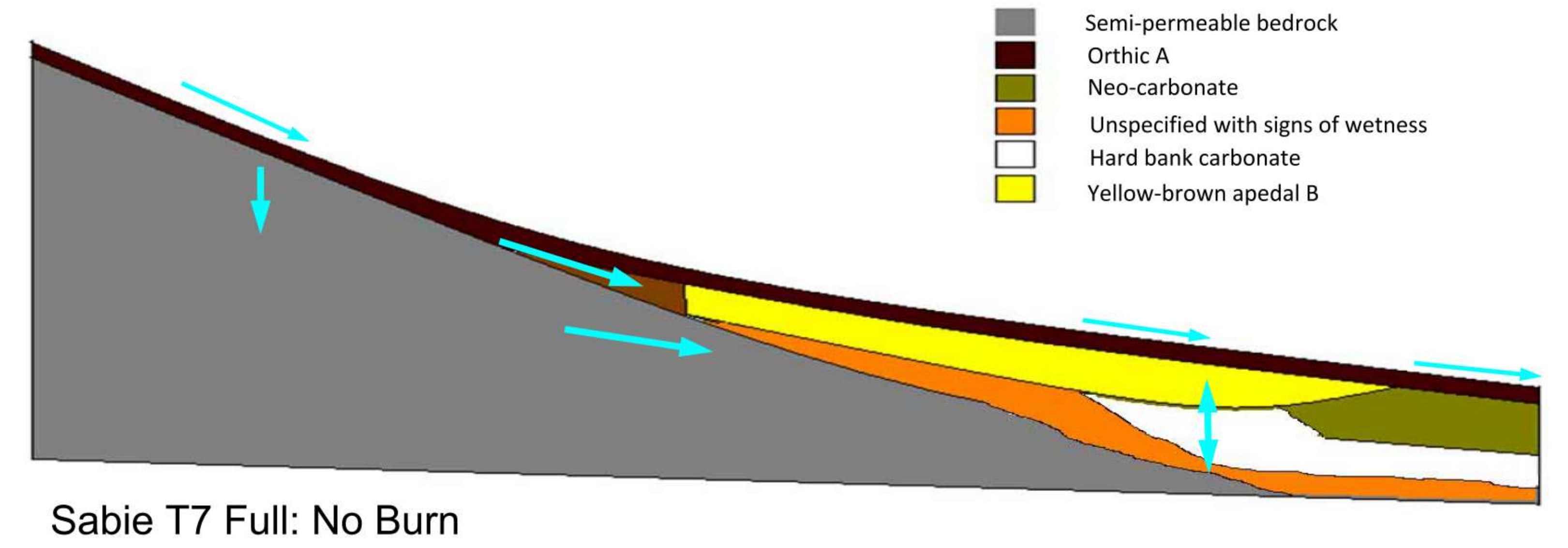


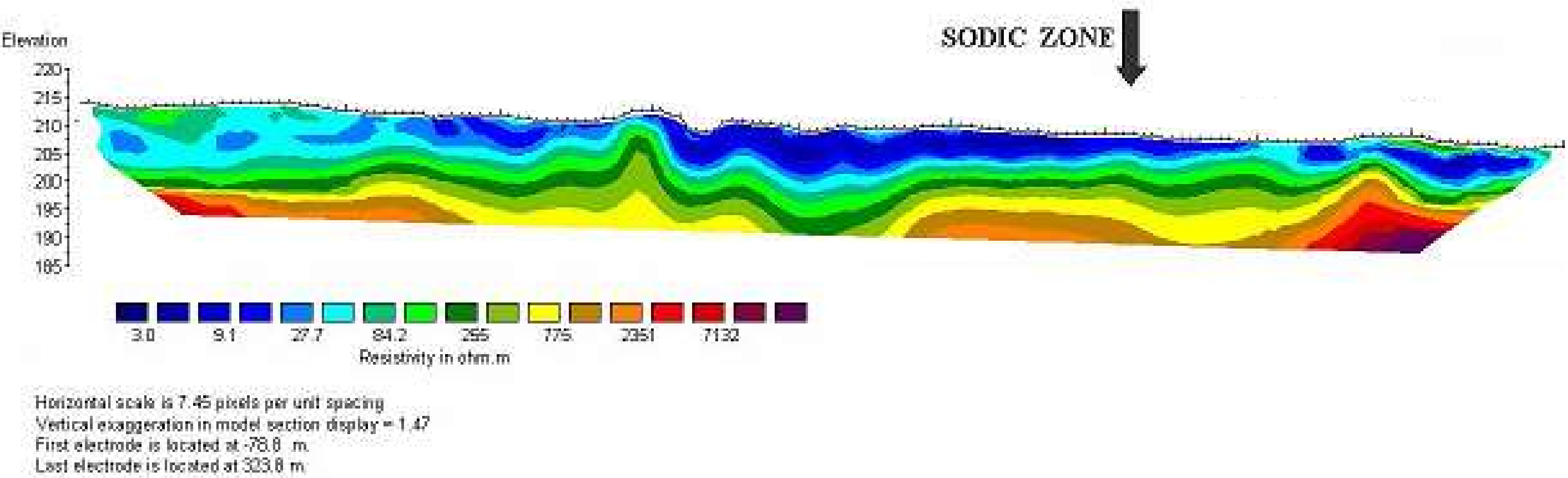
FIGURE 1
Vegetation map of the Nkhuhlu exclosure site



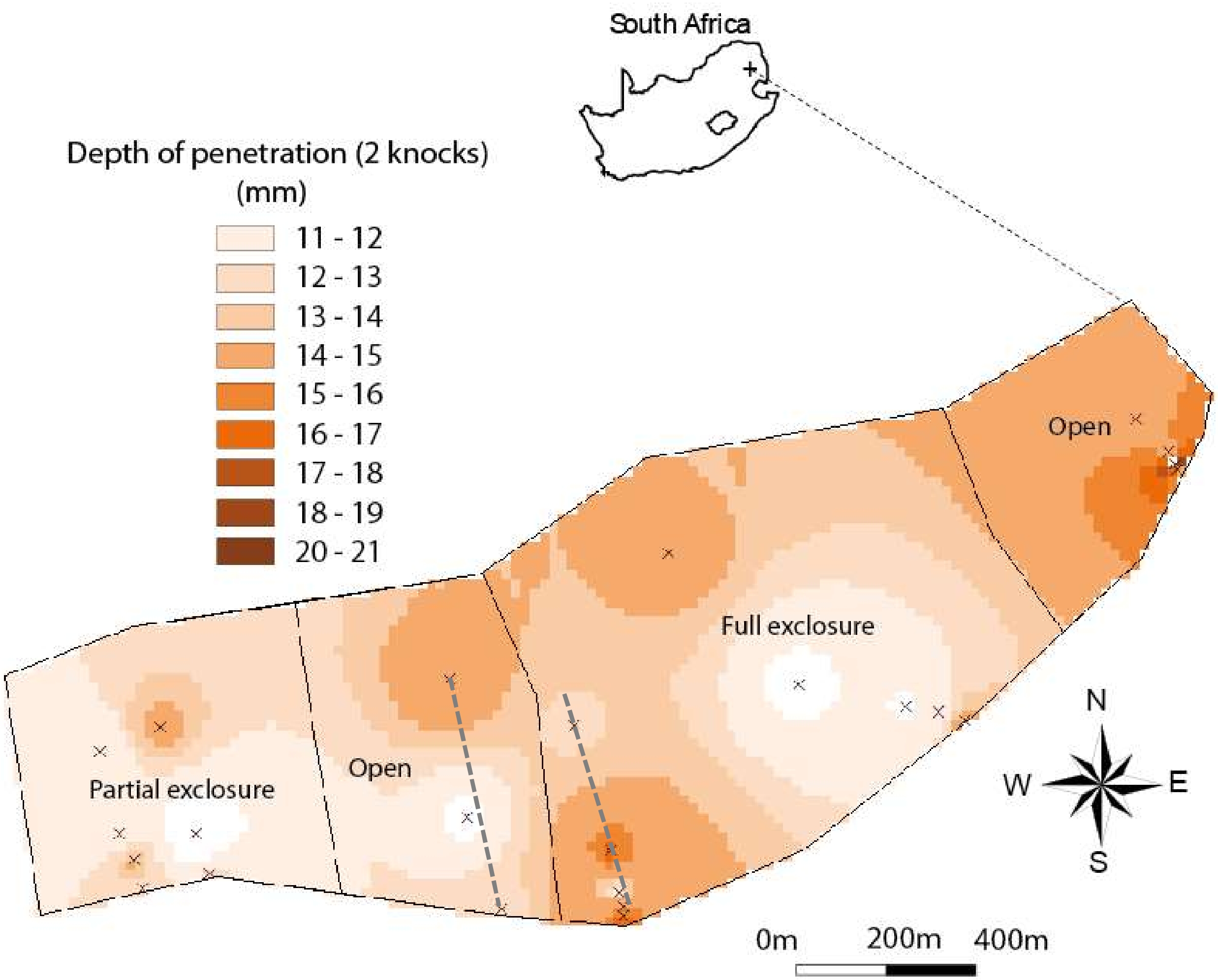
Siebert & Eckhardt, 2008
Koedoe Vol 50 (1), p126-144

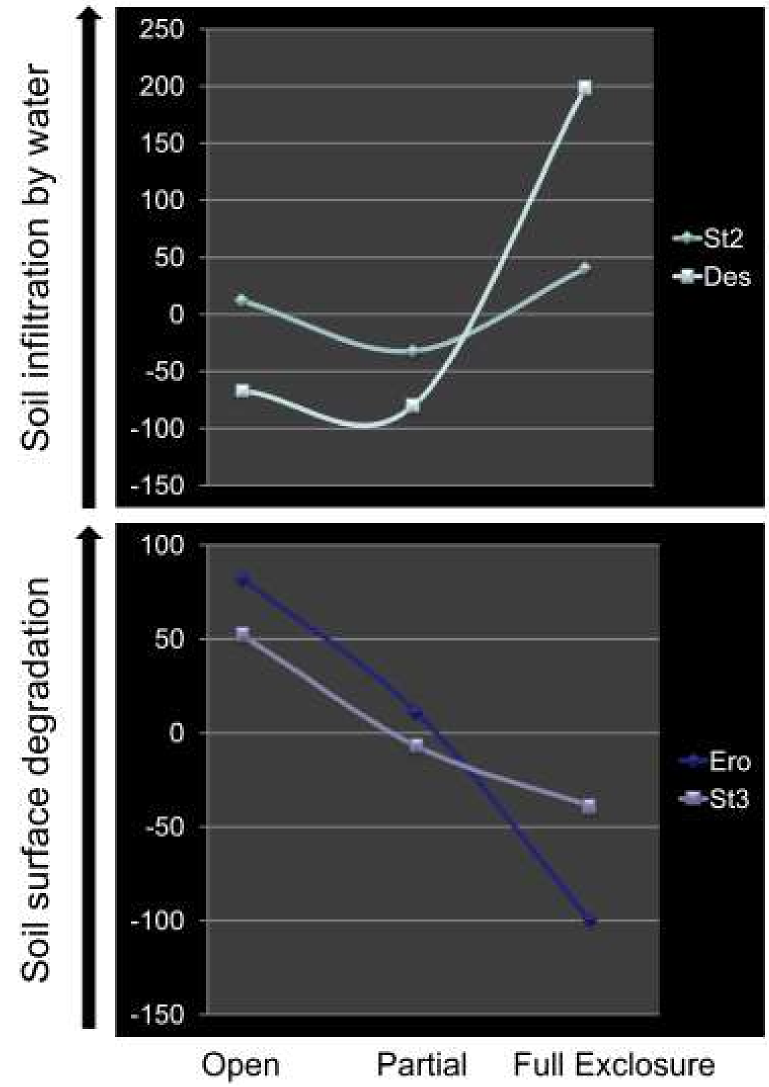
# Characterisation



# Characterisation

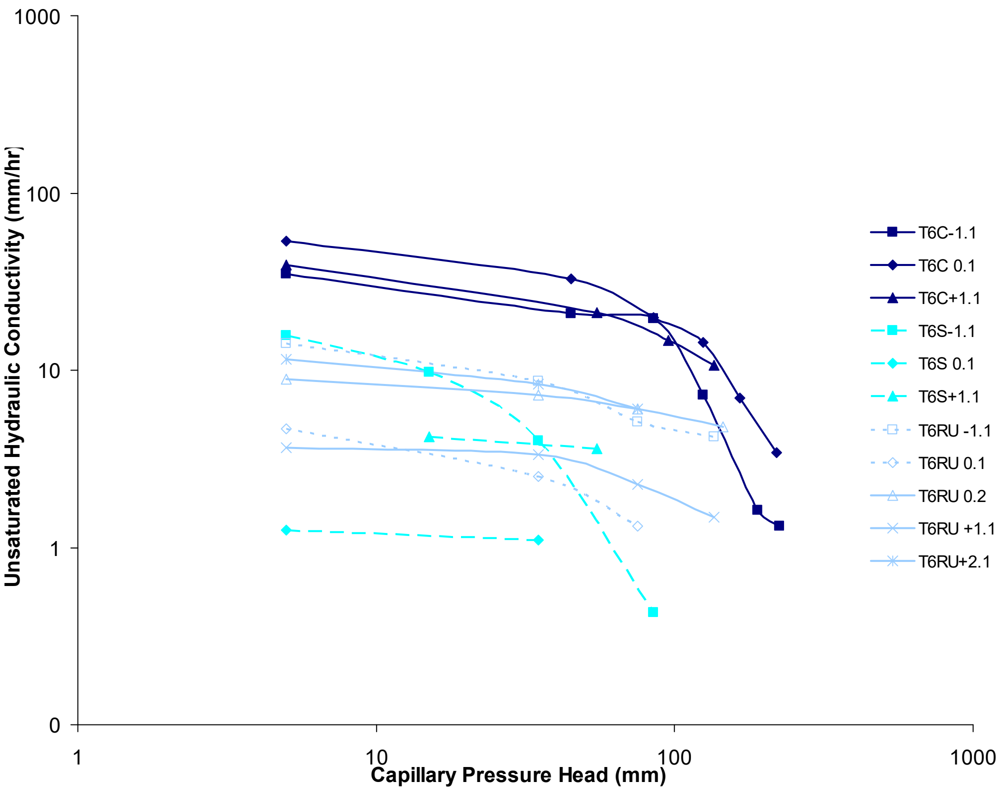


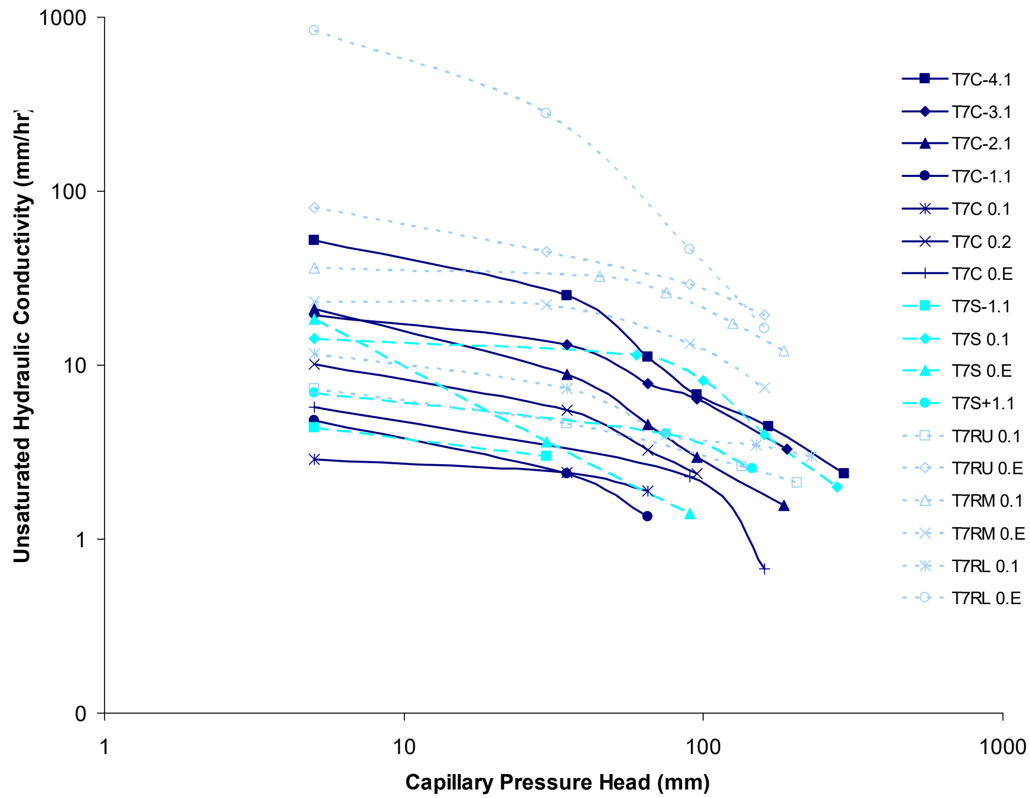

cone penetrometer: spatial variations of penetration depth

# Characterisation

## $K_{unsat}$



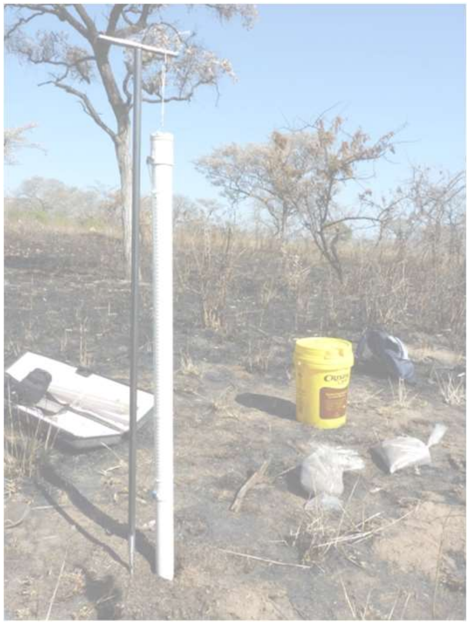

**T6 Open**

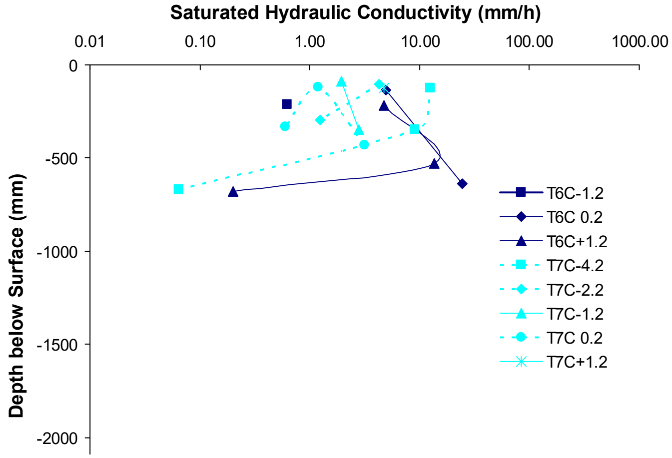



**T7 Full**

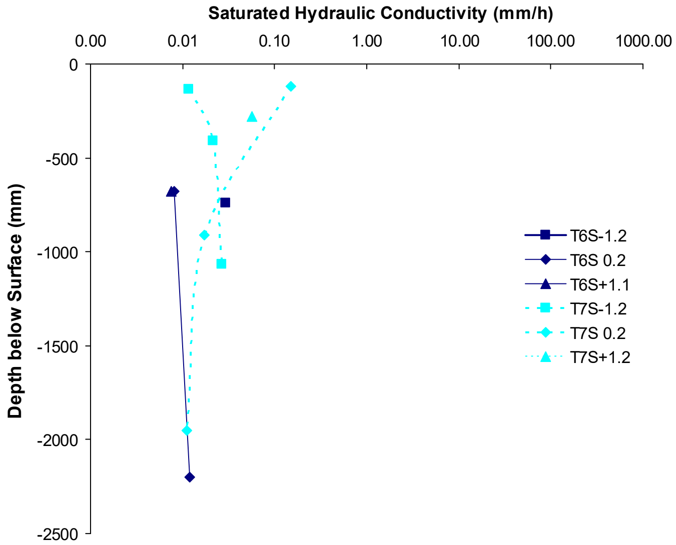
# Characterisation

## $K_{sat}$

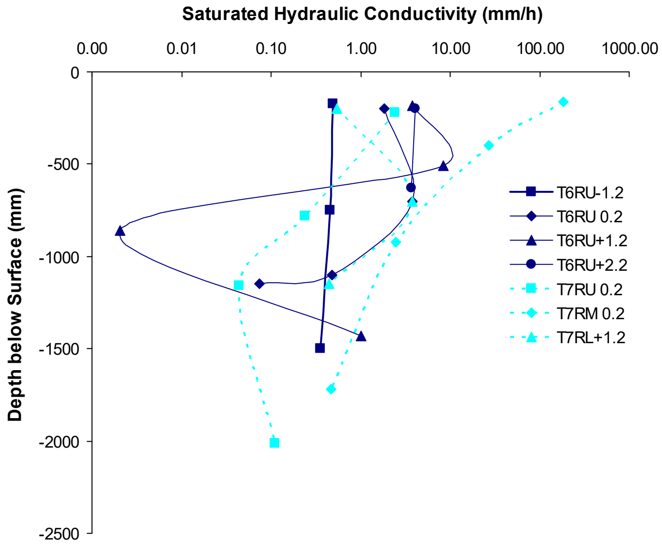





**Crest**



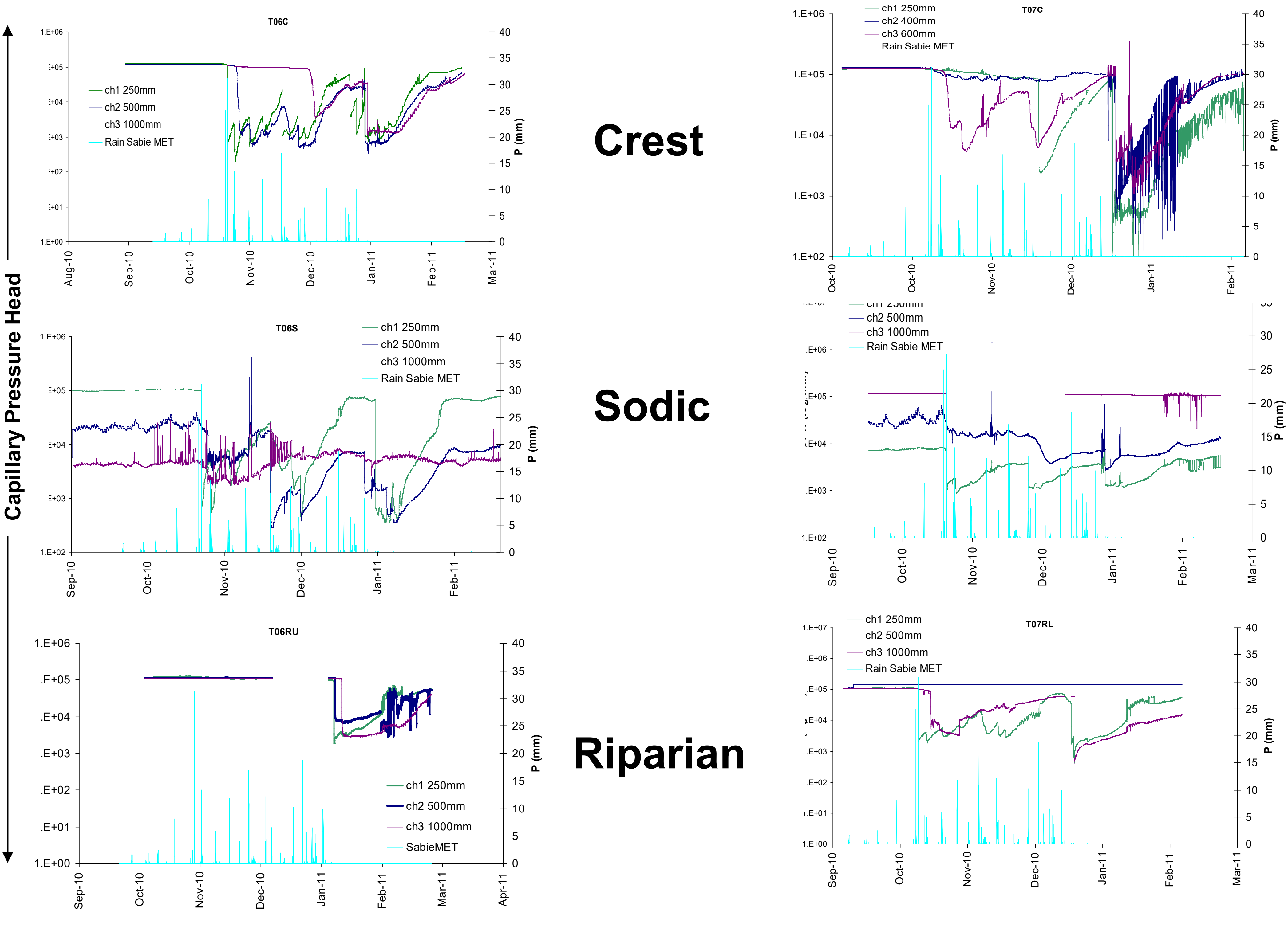

**Sodic**

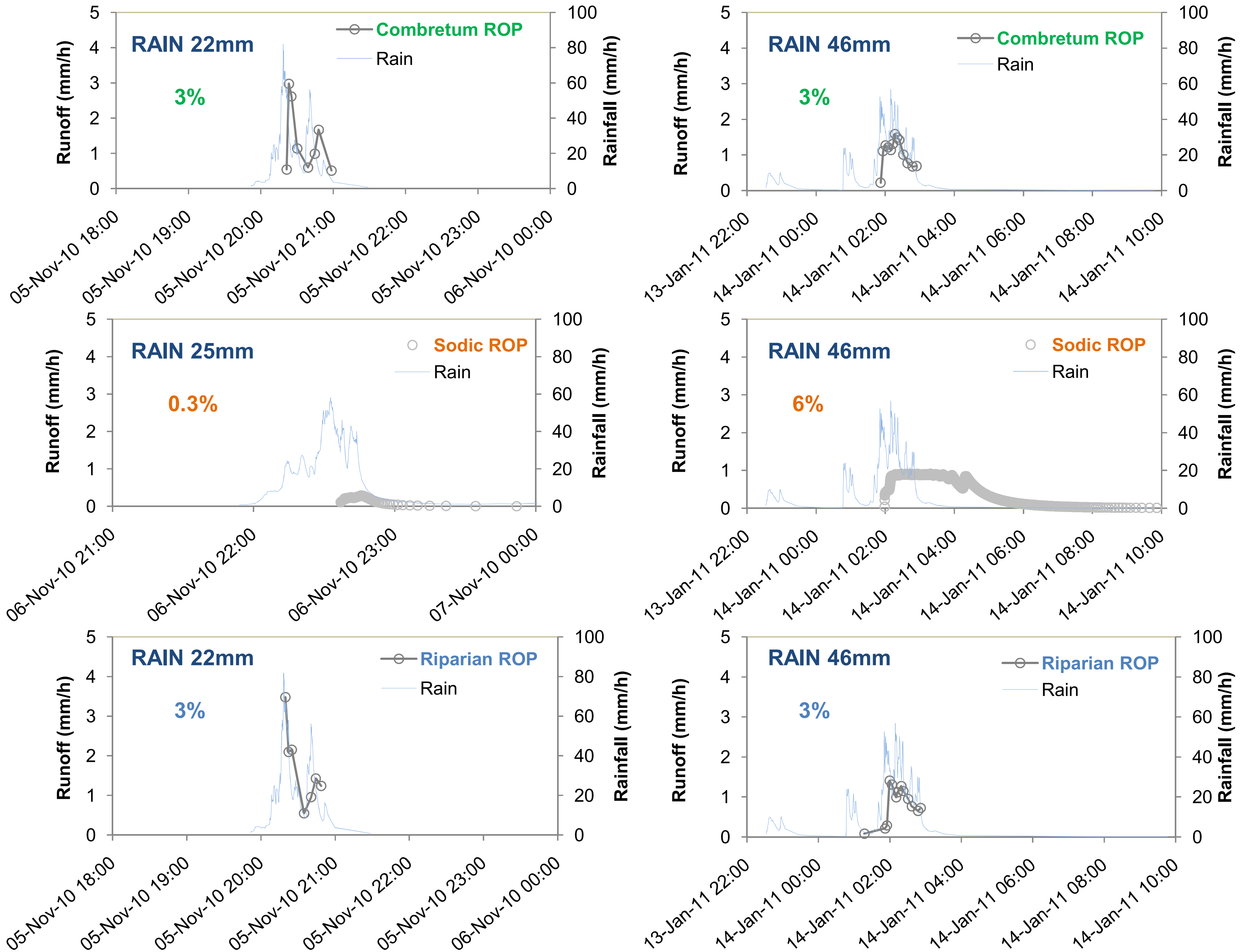



**Riparian**

# Soil Moisture 2010-2011

**T6** **T7**

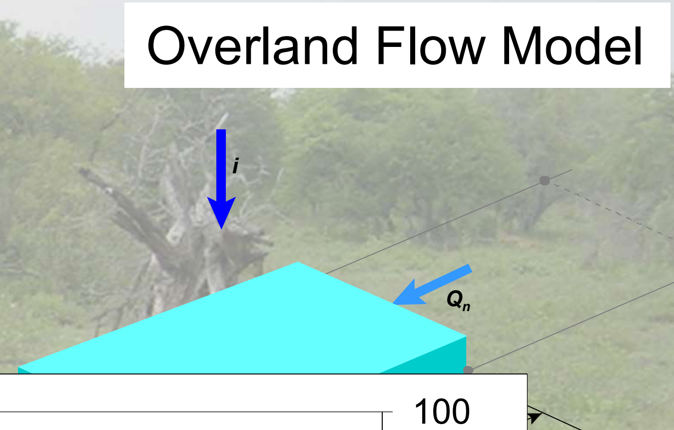


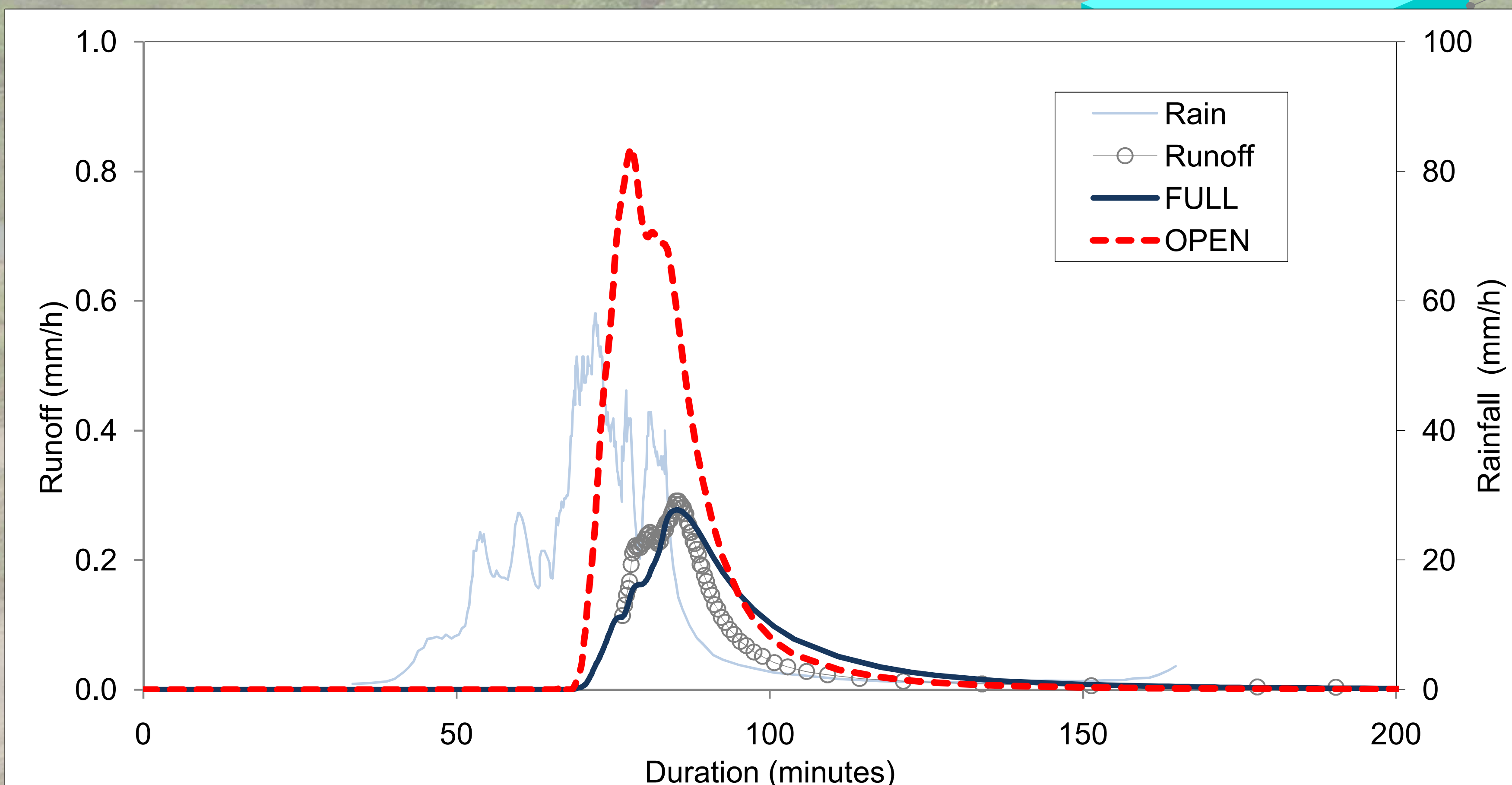


RAIN 22mm
3%
Combretum ROP
Rain
Runoff (mm/h)
Rainfall (mm/h)
05-Nov-10 18:00
05-Nov-10 19:00
05-Nov-10 20:00
05-Nov-10 21:00
05-Nov-10 22:00
05-Nov-10 23:00
06-Nov-10 00:00
RAIN 46mm
3%
Combretum ROP
Rain
13-Jan-11 22:00
14-Jan-11 00:00
14-Jan-11 02:00
14-Jan-11 04:00
14-Jan-11 06:00
14-Jan-11 08:00
14-Jan-11 10:00
RAIN 25mm
0.3%
Sodic ROP
Rain
06-Nov-10 21:00
06-Nov-10 22:00
06-Nov-10 23:00
07-Nov-10 00:00
RAIN 46mm
6%
Sodic ROP
Rain
RAIN 22mm
3%
Riparian ROP
Rain
RAIN 46mm
3%
Riparian ROP
Rain

# Responses and Connectivity

| | FULL | OPEN |
|---|---|---|
| Ksat (mm/h) | 10 | 5 |
| Roughness | 0.2 | 0.1 |



## CONCLUSIONS

- A combination of characterisation and observation allows assessment of typical responses and connectivity
- Full exclosure infiltration and retention characteristics better than open
- Overland flow increases during the season in sodic zones
- Subsurface lateral flow and connectivity is poor

# Securing the Nation's Water Supply and Livelihoods through Sustainable Soil Management: A South African Narrative

**Stanley Liphadzi**

Research and Development Branch, Water Research Commission, Bloukrans Building, Lynwood Bridge, Lynwood Manor, Pretoria, 0182, South Africa

*Stanleyl@wrc.org.za*

**Abstract**

Water is one of the limited resources in many regions of the world, and poor management of this resource has exacerbated water related challenges in the developing countries. As a water scarce country, South Africa socio-economic development and growth is intertwined with its water security status and risks. This paper is aimed at illustrating the connection and interdependencies existing between water security and the catchment activities. Special focus on the Maloti-Drakensberg water catchment area showed the impact of soil or land management on securing water resources to increase water security in South Africa. Soil erosion studies have warned about the huge amount of topsoil removed and mobilized as sediments to rivers and dams or lakes. The eroded soil from upstream catchments don't only impoverish agricultural fields (and farmers), but also reduce the water storage capacity of river's pools, dams or lakes located downstream. Dam siltation or sedimentation contributes to dam wall's degradation which compromise the safety of dams. The demand for water has become higher than the supply in many parts of South Africa due to the increasing population and increasing economic activities. The case studies showed that the best way to improve water security is to protect water at its source. South Africa has delineated and mapped sites that are called *Strategic Water Source Areas*. In addition, there are research and development projects and programmes implemented to protect these strategic water sources areas, which this paper will present.

## Keynote: Linking Soil Structure and Soil Function.

Hans-Jörg Vogel

Soil hydraulic conductivity in the state of non-equilibrium

Hans-Jörg Vogel, Annelie Ehrhardt, Horst H. Gerke, Robert Mietrach, Thomas Whöling and René Zahl

It is a well-known phenomenon of water dynamics in soil that during transient situations the equilibrium between water content and water potential according some well-defined water retention characteristic cannot be taken for granted. Especially during heavy rainfall on relatively dry soil water is flowing through easily accessible macropores long before the less accessible smaller pores are invaded by water. This leads to preferential flow and non-equilibrium depending on the hierarchical pores structure formed during pedogenesis and/or soil management.

Following first experimental evidence in the 1970s a number of model concepts were developed to account for this non-equilibrium. A more classical approach is based on the separation of two different domains having different hydraulic properties. Another, more general approach is to decouple water content and water potential during transient situations while the striving towards equilibrium is described by some first-order kinetics. In In all these approaches, it has never been considered how to describe the hydraulic conductivity during non-equilibrium. Either the conductivity is described as a function of water potential or water content. The first choice allows to reproduce preferential flow, the second allows to reproduce the overshoot of water potential during infiltration or drainage.

In this contribution we show that neither of these choices can be physically justified and we propose a physically based concept how to calculate the hydraulic conductivity during non-equilibrium. Based on numerical experiments we demonstrate the plausibility of the new approach.

# Variably saturated flow into and through fractured rock: physical experiments and contributions

MA Dippenaar

Hydrogeology no longer only relies on understanding of phreatic systems. Highly heterogeneous and anisotropic conditions in soil and rock comprising intergranular, fractured and karstic porosity affect groundwater vulnerability, recharge rates, drainage and dewatering practices, soil corrosivity, natural attenuation of contaminants, and integrity of infrastructure, to name a few examples. Movement of water at partial and highly variable saturation is very complex, depending on very small-scale variations in ground conditions as well as very subtle changes in moisture content. In contributing to this, a number of research projects were conducted, focused around physical experiments in the laboratory or mimicked in the field, and subjected to differing conditions pertaining to gravitational acceleration to scale the vertical dimension. Studies contribute to flow mechanisms and flow regimes of variably saturated soils and rocks, as well as the interface between, and link available theoretical understanding and empirical approaches to physical experiments and field verification experiments. Where possible, hydraulic parameters are estimated to improve the quantification of said parameters at discreet scale rather than assuming single values for bulk systems. Obvious limitations and assumptions are understood to the extent that updated flow scenarios are proposed to contribute to variably saturated flow systems. Behaviour is inferred for fractures of changing orientation, changes in medium from soil to rock, and for alternation between wetting and drying of different media. Selected experiments will be presented to highlight novel findings and the way forward. The presentation will focus on findings and contributions rather than the experiments itself, as these are all published in peer-reviewed literature.

## Vertical anisotropy and hydromechanical properties of the unsaturated saprolite in the complex intermediate vadose zone

**D. Swart**

Hydromechanical properties of the soil profile are important parameters to consider when assessing the vulnerability of groundwater to pollution and the movement of moisture laterally to streams and return flow to surface horizons. This seepage through a soil profile is primarily dependent on the hydraulic conductivity (K) and effective porosity. However, at very low moisture contents, the influence of grading and subsequently the surface area available for wetting become increasingly important in dictating imbibition and drainage, or the retention versus seepage of moisture in soil. Saprolite defines the transitional horizon between transported layers and bedrock and is referred to as the intermediate vadose zone. The thickness and characteristics of the saprolite is dependent on the parent rock, climate, topography, and vegetation cover. The behaviour of the saprolite is determined by the grading, relict parent structure, mineral occurrence, and pore fillings. Studies in this field usually assume homogeneous isotropic K throughout the profile, or anisotropic K but restricted to vertical and horizontal directions. The saprolite, which controls the preferred pathway of water after percolating through the shallow soil horizons (Van Tol, 2020), are generally vertically heterogeneous to the extent that, at larger scales of observation, they become anisotropic with a discrepancy between vertical and horizontal parameters. Most flow models are based on simplified, well-sorted, horizons, which are typical of transported soils but are not applicable to predict scenarios in the saprolite. Disregarding the influences saprolite has on a ground profile could be detrimental to progress in the study of groundwater / surface water interactions (Dippenaar 2012). This study will present accepted and hypothesised water flow models that occur within silty saprolite and discuss the governing factors thereof.

## The Unexplored Role of Preferential Flow in Soil Carbon Dynamics

Yan Jin and Shane Franklin, University of Delaware

Soil exhibits enormous heterogeneity, serving as the fundamental driver of nonlinear and heterogeneous hydrological processes and biogeochemical interactions at all scales. The so-called preferential flow, defined as the uneven and rapid infiltration and distribution of water, is perhaps the best know manifestation of soil heterogeneity. Preferential flow leads to nonuniform water flux, which has important consequence not only on water content and distribution in a soil but also on the transport of contaminants and nutrients. As a result, preferential flow has been a major research focus by the soil physics community, on its mechanisms, measurements, and modeling, since the early 1980s. These efforts generated significant insights into the physical and associated hydrological properties of preferential flow paths: they occupy small percentages of the soil matrix but can account for disproportionally large amount of infiltrating water, as well as all that are carried with it (solutes, nutrients, carbon, etc.). However, the possible role of preferential flow in biogeochemical processes has received very little attention to date. In this presentation, we discuss how preferential flow may serve as a framework of reference for the spatially and temporally heterogeneous biogeochemical cycling of soil carbon. Often associated with well-connected macropore networks (>300 µm Ø), preferential flow path regions offer a unique balance between water availability, nutrient delivery, and re-oxygenation upon drainage. The combination of these factors makes these locations optimal for high rates of microbial activity. Through literature review and our recent laboratory experiments, we will highlight the importance of combining current knowledge of pore-scale carbon dynamics with an appreciation of connected networks of hydraulically active pores/paths within the soil profile. Such combination opens new possibilities for upscaling pore-scale processes with the inclusion of resource heterogeneity at the macroscale and provides insight for the mechanistic representation of hotspots and hot moments (i.e., spatially and temporally isolated large pulses) of $CO_2$ after rewetting or thawing events. We will identify knowledge gaps and stress the critical need of linking soil physical structure, water flow and distribution with microbial activities and associated biogeochemical processes to mechanistically understand soil functions.

## Soil carbon and soil water content: comparing organic and conventional: The Mandela Trials.

Raymond Auerbach & Catherine Eckert.

Kirkham Conference, Skukuza 2022

The Mandela Organic Farming Systems Research Trials compared organic and conventional farming with cabbages, sweet potatoes and cowpeas in rotation and also with mono-cropped cabbages. In the first two years, soil life improved and soil acidity decreased in the organic treatments; however, the yield gap was larger after the second year (organic 31% lower yields) than the first (20%). Low available soil phosphate was then addressed using rock phosphate before planting the third cycle of crops. The yield gap was closed after the third year, with organic crops out-yielding conventional. A wide range of soil improvements was measured, including soil micro-organisms (diversity and quantity), soil organic carbon, soil water content and soil chemistry. Soil water content was consistently better in the organic farming system, as was soil organic matter and soil acidity. In the fourth year, crop rotation yields were significantly better than mono-cropped cabbage yields.

References; Auerbach RMB (editor): Organic Food Systems: Meeting the needs of Southern Africa (CABI, 2020). Chapters 18-22 deal with the base-line study, water use efficiency, biological and chemical pest and disease management, biological soil health indicators and soil fertility and yields over the first four years of the Mandela Trials.

## Findings from the North American Project to Evaluate Soil Health Measurements: Indicator Selection and New Pedotransfer Functions

D. Bagnall

The North America Project to Evaluate Soil Health Measurements (NAPESHM) included 124 long-term, replicated sites across Canada, the U.S., and Mexico and uniformly sampled over 30 soil health indicators in 2019. This presentation will present the effects of soil health management practices (reduced tillage, addition of organic nutrient sources, cover crops, crop rotation, residue retention, and rotation diversity) on water-related indicators of soil health and discuss indicator selection. Indicators considered were saturated hydraulic conductivity, soil organic carbon, aggregate stability, bulk density, water retention at permanent wilting point, water retention at field capacity using both intact cores and disturbed samples. Additionally, NAPSHM data were used to create new pedotransfer functions for permanent wilting point and field capacity. These new equations showed effects of calcareousness and demonstrated greater response to soil organic carbon than do previous equations due to the use of intact cores for field capacity measurements and the unique dataset that included the effects of management.

# Evaluation of water distribution on sandy soils with ultra-low flow drip irrigation and Nadorcott mandarin citrus.

Dr JE Hoffman and JH van der Merwe

Department of Soil Science, Stellenbosch University.

Citrus cultivation on sandy soils with a low water holding capacity is difficult to schedule. Since the development of low flow drip irrigation by NETAFIM, there is new potential for irrigating sandy soils for Citrus production.

The University of Stellenbosch is currently conducting a research project investigating the cultivation of Nadorcott mandarins with three different drip irrigation delivery rates on sandy soils in the Worcester district. Three drip delivery rates of 0.4, 0.7 and 1.6 L/hour are investigated where all the treatments receive the same amount of water daily. The water content is measured continuously with each treatment and the data is stored on a data recorder. The daily water content, the water distribution pattern through the soil profile, root distribution as well as plant parameters are determined.

During the growing season, the 0.4 L/h was on average wetter, in the topsoil, than the 0.7 and the 1.6 L/h, respectively. The two-dimensional water distribution patterns of the 0.4 L/h droppers were smaller than those of the 0.7 which were also similar in the root distribution of the treatments. At 0.7 L/h, the Citrus Roots developed deeper. The 1.6 L/h drippers were spaced closer together and consequently resulted in a strip of wetting. Interesting water distribution patterns occurred at both low flow droplets during the day. The yields of the different treatments did not show any significant differences over two seasons and the research is continued.

# Pan-African High-Resolution Simulations for Agriculture using Terrestrial Systems Modelling.

**Bamidele Oloruntoba, Stefan Kollet, Carsten Montzka, Harry Vereecken, Harrie-Jan Hendricks Franssen**
Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

**Abstract**

The lack of spatially sufficient observation datasets including atmospheric data and soil information over Africa makes land surface modelling important for Agricultural development in Africa. Most land surface modelling studies over Africa however have been performed at coarse spatial resolutions ($0.1^{o}$ x $0.1^{o}$ to $1^{o}$ x $1^{o}$) leading to lack of locally specific information about the simulated domains . We assessed the impact of different meteorological forcings and soil information over the African domain at continental, regional and local scales for the period between January 2013 and December 2014. The reanalysis products CRUNCEPv7, GSWPv3, and WFDE5 were used to force CLM5 simulations, and these have different temporal resolutions of 6 hours, 3 hours and 1 hour, respectively. Two different inputs for soil texture were used, namely from the FAO and SoilGrids250m. In addition, three different upscaling methods to upscale the SoilGrids information, available at 250m resolution to the model grid resolution of 3km, were evaluated. We found that 1) variation in the meteorological forcing product has a higher impact on the variability of evapotranspiration than variation in the soil texture input; 2) the soil texture information source (FAO or SoilGrids) impacted results stronger than the soil texture upscaling method; and 3) higher temporal resolution WFDE5 forcings result in higher surface runoff and also differences in simulated ET compared to lower temporal resolution atmospheric forcings, and in this case also differences appear between different soil information upscaling methods.

# Physical properties at the soil surface mediate water dynamics and subsequently yields in a USA Piedmont tillage study

Mathers, C

With projected increases in global temperatures and changes in regional climate, understanding the impact of soil management choices on yield stability is critical for farmer decision-making and agricultural resiliency. Because no-till and conservation tillage have had variable yield effects depending on crop and location, system-specific studies are necessary to gauge potential benefits. Yield and weather data from a long-term tillage study (28 years) in the Piedmont of North Carolina (U.S.) were analyzed to determine the effect of various conservation tillage practices on corn (*Zea mays* L.) and soybean (*Glycine max* L.) productivity and stability under a variety of growth conditions. Mean yield and yield stability (coefficient of variation) varied depending on the intensity of tillage and weather conditions, particularly during growth stages vulnerable to stress. However, soil health tests conducted in 2015 were unable to differentiate tillage treatments, and overall soil health scores were not correlated with yield. A soil moisture study was conducted over two growing seasons to examine if differences in soil water dynamics (water storage, rates of evaporation and infiltration) which are not directly captured by soil health metrics could explain the historic yield differences. Three tillage treatments (no-till, chisel, moldboard plow/disk) were selected to represent a spectrum of tillage intensity and instrumented with soil moisture sensors. Additional soil characteristics including hydraulic conductivity and crusting were also evaluated. Analysis indicates that soil water availability was higher and crusting potential was lower for conservation tillage treatments, suggesting that current soil health measurements did not effectively capture important surface properties that influence yield. Conservation tillage will help to mitigate future water stress associated with changes in climate by increasing soil water in comparison to conventional tillage.

## Novel methods to detect non-rainfall water inputs in desert soils

Dilia Kool & Nurit Agam

In desert soils, diurnal changes in water content occur as dew forms and evaporates and water vapor is adsorbed and released from soil particles. As rainfall is limited, these non-rainfall water inputs (NRWIs) significantly contribute to hydrological and biogeochemical dynamics. The soil water content under these conditions typically ranges between 0.5% and 5%, which is a challenging range to measure. To date, attempts to quantify NRWI amounts and duration have been limited to short time periods at point or local scales. Determining the true importance of NRWIs in arid and extremely arid environments, which comprise 20% of the terrestrial surface, requires approaches to increase both the temporal and spatial extent of water content measurements in the 0.5-5% range.

Using weighing lysimeters as a reference, we assessed two approaches to detect diurnal changes in water content as a result of NRWIs. First, we tested of-the-shelf temperature and relative humidity sensors to assess changes in water content with high temporal resolution over longer periods of time. The sensors were used in both sand and loess soils in Israel as well as in sand in the Namib sand sea, Namibia. Results showed diurnal patterns in water content consistent with lysimeter measurements and additionally gave insight into the depth to which adsorption occurred. Second, we explored soil surface emissivity (ε) as an indicator that can be remotely sensed, allowing for measurements at larger spatial scales. Using a multispectral longwave radiometer, we related temporal changes in ε to NRWI accumulation over both sand and loess soils in the Negev desert, Israel. Results indicated that ε for the 8.3 µm wavelength was highly correlated to changes in lysimeter water content. The results show the potential to quantify NRWIs over longer periods of time and at larger spatial scales, and provide an initial indication of the magnitude of NRWIs in arid environments across the globe.

**Water Resources (Ecohydrology)**: Application of Soil Physics in:

- ***Quantifying Hydropedological Responses***
- Hydrological Processes and Modelling
- Treating Preferential and Fracture Flow

# Hydropedology as an important tool to characterize ecosystem services in line with the land-related UN-Sustainable Development Goals (SDG).

Johan Bouma

Em.prof soil science, Wageningen University, the Netherlands.

**Abstract**

Sustainable development is by now an important concept in the international policy agenda and provides an attractive focus for the science arena . The acceptance of the UN Sustainable Development Goals (SDGs) in 2015 by 193 countries has specified 17 goals. Some are particularly land-related covering major concerns about producing healthy food to combat hunger ( SDG2&3), protect the quality of ground and surface water, also considering waste disposal (SDG6), reducing emission of greenhouse gasses and stimulating carbon capture by soils as means for climate mitigation ( SDG13) and preserving biodiversity and combatting land degradation (SDG 15). Of course, sustainable development has not only an environmental character but economic and social aspects are important as well. Environmental studies *contribute*, therefore, to the overall SDG debate and a focus on ecosystem services,to be provided by farms, nature areas, city greens or entire regions, is therefore needed.Soil moisture regimes and water movement within landscapes have a dominant effect on ecosystem services in line with the land-related SDGs. Water acts like blood in man. Without it, soils and landscapes will be dead.

The hydropedology concept is based on the conviction that the effectivity of process-based soil physical and hydrological studies can be improved when pedological soil expertise is included in the analysis.This is based on at least four considerations to be discussed in this contribution: (i) soil structures in natural soils are not isotropic and homogeneous and this has a major effect on flow processes in soils to be expressed by redefined boundary conditions of the flow system based on soil morphological studies ; (ii) occurrence of characteristic subsurface soil horizons, formed by pedogenesis, can laterally re-direct flow processes that need to be recognized in modeling flow patterns on a regional scale; (iii) widely available soil maps allow extrapolation of measured point data to unmeasured locations elsewhere with similar soils. This, however, requires a functional soil analysis combining soil types that may be different pedologically but that act identical from a soil physical point of view. (iv) widely available soil databases allow derivation of pedotransferfunctions relating basic soil parameters ( e.g texture, %C, bulk density) to physical characteristics needed for modeling soil moisture regimes ( moisture retention, hydraulic conductivity). Limitations of the approach will be discussed.

The relevance of a hydropedological approach when studying soil moisture regimes and regional flow patterns of water can be most convincingly demonstrated to the policy and citizen arena when focused on contributions to ecosystem services in line with the SDGs.

# Using hydropedological characteristics to improve modelling accuracy in Afromontane catchments

Rowena Harrison[a], Johan van Tol[ab]
[a]Soil and Crop- and Climate Sciences, University of the Free State, Bloemfontein
[b]Afromontane Research Unit, University of the Free State, QwaQwa

## Abstract - Water Resources (Ecohydrology)

Mountain catchments provide several ecohydrological services to downstream locations. These include the ecological and physical processes that control the partitioning and routing of precipitation into evaporation, infiltration, transpiration, recharge, and runoff. The characteristics of the soils of these catchments form the basis of these services. This is because soil and water are the fundamental elements in understanding the hydrological response of the catchments within these mountains. By gaining insight into the hydropedological behaviour of these catchments, the unique lateral flow dynamics of a landscape and how these strongly alter the flow patterns of water, can be recognised. This study took place in the Cathedral Peak experimental research site, located within the uKhahlamba-Drakensberg escarpment, KwaZulu-Natal, South Africa. Digital soil maps of the hydropedological character of three of these Afromontane catchments were created. These were used along with climatic data, streamflow data, landcover data, a digital elevation model, and detailed properties of the soils of these catchments as inputs into SWAT+ models for each catchment. The default lateral time was used in the first set up of the model and the results compared against measured streamflow. The models were then set-up again but with the input of the detailed hydraulic properties, which were coupled with the location of the hydrological response units within the hydropedological soil group maps created for each catchment. These details were utilised as specific lateral time inputs into the models for each catchment. The specific lateral time inputs improved modelling accuracy in all statistical parameters used; R2, percent bias (PBIAS), Nash-Suttclife Efficiency (NSE), Kling–Gupta Efficiency (KGE), and standard deviation (ST DEV). Flow duration diagrams as well as graphical representations of the model performance furthermore showed the improvement in modelling accuracy as a result of the deeper understanding of the internal catchment processes. This study has highlighted that relevant information, based on reliable data, is essential to assess not only the current condition of water resources in a given catchment but also past trends and future possibilities and enhance the understanding of the ecohydrological processes of these areas.

## Pedological and Practical Impacts of Water Movement in Sandy Soils

M. Laker

Sandy soils have very high hydraulic conductivities, both vertical and lateral. The combination of high vertical and lateral hydraulic conductivities leads to massive lateral water movement in the lowest sandy part of a soil above a limiting layer. It plays a major role in the development of a toposequence which is in South Africa known as the plinthic catena. It was illustrated by an actual case. The sandy soil sequence is deep red->fairly deep yellow-brown over soft plinthite->albic over soft plinthite->albic over clayey G horizon. The soft plinthic horizon in South African soil classification has abundant high chroma red and yellow mottles in a matrix with some light grey in it, indicating a seasonal fluctuating water table. While digging a profile pit in soil with an albic horizon over soft plinthite, water seeped in from the upslope wall of the pit, indicating major lateral subsurface water movement in the soil seven months after the last major rain. In this case such toposequence is not only at the “front” of the hill, but also around the sides, in a horseshoe type pattern. The laterally subsurface moving water feeds the upland wetland forming the sponge area of the Elands river, stimulating further debate of where the boundary of a protected wetland should be. Four days after the profile pit had been dug it was found that the clear water which seeped into the pit had a reddish brown layer on top, indicating that iron was transported in the water, and oxidized where the water came in contact with oxygen in the atmosphere. This supports the conclusion that red and yellow mottles in a soft plinthic layer are formed when iron is oxidized with aeration when the water table drops below it. In granitic areas in the South African Lowveld a general soil pattern is deep red sand->deep yellow-brown sand->albic sand->prismatic clay subsoil overlain by shallow sandy soil. Bases are leached laterally from the sandy soils, causing the soils to be strongly acidic. Dispersed clay is leached in suspension laterally, like through a sieve. The clay and bases accumulate in the foot slope. This causes a major problem in tourism game parks/reserves. Unpalatable sour gras with very low nutritional value grow on the acidic sandy soils. These are not readily consumed by game. On the prismatic (solonetz) soil with high base content highly nutritional palatable gras grow. Game concentrate here and overgrazing results, leading to severe erosion of these vulnerable soils. Because fences are not aesthetically acceptable in a tourist area, vulnerable areas cannot be protected by fencing them off, as can be done on livestock farms. Where subsurface laterally moving water reaches dense clay soil a characteristic seepage line develops where water pops up to the soil surface. This type of situation can cause serious conditions where pollution hazards exist. This was demonstrated in a case study where toxic heavy metal concentrations arose from an abandoned gold mine tailings paddock. These leached laterally subsurface through sandy soil with a soft plinthic subsoil to where it reached a clay soil, where it popped out on the surface close to a stream. Pollution through lateral subsurface leaching occurred in two cases where winery effluent was disposed by means of irrigating pasture on deep sandy albic soil. This was illustrated by soluble organic compounds in the effluent undergoing anaerobic decomposition, forming black material which leached into streams.

## Application of hydropedological interpretations in hydrological modelling

Johan van Tol, Katrin Bieger, Stefan Julich, Pieter Le Roux, Simon Lorentz, Darren Bouwer

Capturing internal catchment hydrological processes in hydrological models is important for accurate predictions of the impact of climate and land-use change on water resources. Characterising and quantifying these processes are however difficult and expensive due to their dynamic nature and spatio-temporal variability. Hydropedological interpretations of soils and soil distribution patterns can be used to characterise key hydrological processes, especially in areas with no or limited hydrometric measurements. Here we applied a hydropedological approach to reflect flowpaths through detailed routing in SWAT+ for a 157 ha catchment (Weatherley) in South Africa. The hydropedological approach and a standard (no routing) approach were compared against measured streamflow (two weirs) and soil water contents (13 locations). The models were not calibrated against hydrometric measurements to establish the direct contribution of hydropedological interpretations on modelling efficiency. Streamflow was predicted well (NSE > 0.8; $R^2$ >0.82) for both approaches at both weirs. The standard approach yielded slightly better streamflow predictions. The hydropedological approach resulted in considerable improvements in the simulation of soil water contents ($R^2$ increased from 0.40 to 0.49 and PBIAS decreased from 40 to 20%). The routing capacity of SWAT+ as employed in the hydropedological approach reduced the underestimation of wetland water regimes drastically and resulted in a more accurate representation of the dominant hydrological processes in this catchment. We concluded that hydropedology can be a valuable source of 'soft data' to reflect internal catchment processes and, potentially, for realistic calibrations in other studies, especially those conducted in areas with limited hydrometric measurements.

# History of Vadose Zone Research in the savannas of the Kruger National Park

Riddell., ES., Lorentz, SA., Strydom T., Jumbi, F., Hachmann, J

The 'Kruger' is one of Africa's most long-established National Parks and its conservation management is guided by systemic scientific understanding of the parks biotic and abiotic fluxes. Given the semi-arid, water limited nature of the parks savanna's a concerted focus of this scientific endeavour has examined water as a driver of ecosystem dynamics of both terrestrial and aquatic biodiversity in the diverse landscapes of the park.

In this synthesis we present the outcomes of three studies conducted on long term monitoring sites, where soil water fluxes were observed along several catenas, these are: the Nkhuhlu long-term fire and herbivory exclosures along the perennial Sabie River; the Stevenson-Hamilton Supersite established as a long term observatory; and, the Experimental Burn Plots one of the world's longest running fire research experiments.

In summary the following were observed: during the 10 years of the exclosure experiment it was probably too early to determine the effects of mega-herbivore exclusion on soil water processes, nevertheless, where mega-herbivores had been excluded the transects exhibited better infiltration and retention characteristics than at sites where mega-herbivores had been partially excluded, especially within the riparian zone;  where groundwater-surface water interactions were observed through ephemeral drainages at the supersites soil hydrometry combined with groundwater and streamflow observations were able to highlight that the crest (coarser soils) were not the primary conduit for groundwater recharge as expected but rather through riparian zone infiltration; and, in the case of variable fire treatments (frequency and intensity) there was a discernible effect of fire effects on soil hydrophobicity in time following the treatment rather than as a direct result of fire intensity itself.

Examples of these results will be discussed and how the findings are used for savanna ecosystem management. *These three sites will also be visited during the Kirkham Conference field excursion.*

## The Effect of Soil Physical Properties on Bush Encroachment in the North West Province

W. Cloete

Bush encroachment (BE) is a serious form of land degradation and South Africa alone has lost an estimated 8 million hectares (ha) of grazing or cultivation land due to BE. This consequently leads to decreased food security. To prevent BE, one needs to understand the drivers and mechanisms that control the process and to advise when and where certain management actions should be implemented. The focus of this study was to understand the effect of soil type and certain soil physical properties on BE in the North West Province (NWP). Three study sites were selected by the Department of Environment, Forestry and Fisheries (DFFE). At each site, vegetation surveys were carried using the belt-transect method to determine the composition, density, and structure (height classes) of the woody component (tree- and shrub species). Soil profiles were described per soil horizon, soil samples were taken within each transect, which were analysed at the laboratory to determine the soil particle distribution (soil texture), pH, electrical conductivity (EC), and water retention of the soil. From the vegetation surveys, *Dichrostachys cinerea* and *Diospyros lycioides* were found to be the main woody encroacher species at all study sites with *D. lycioides* mainly occurring at the third (Kgomo-Kgomo) study site. The other recognized woody encroacher species included *Grewia flava*, *Grewia flavescens*, *Senegalia mellifera*, *Vachellia karroo*, *Vachellia tortillis*, and *Ziziphus mucronata*. Soil types and physical properties did not have a significant influence on all the woody species identified at each study site, but rather on specific encroacher species causing BE in the NWP. The results indicated that *D. cinerea* mostly occurred on soils with low clay content, while *G. flava* favoured soils with higher clay content. The highest extent of BE occurred at the second (Legkraal) and third (Kgomo-Kgomo) study sites, where the soil was characterised as deep soils with sandy loam texture. Species such as *Combretum apiculatum*, *Combretum inberbe*, and *Combretum hereroense*, occurred on shallow soils, while *Vachellia tortillis* preferred deep soil types. The encroacher species, *D. lycioides*, occurred on the subsoil with an alkaline pH, while both *D. lycioides* and *D. cinerea* preferred soils with EC higher than 25 mS/m. *D. lycioides* and *G. flava* both occurred in soils with high dry bulk densities (Pbs), especially at the third (Kgomo-Kgomo) study site. It therefore seems that soil types with specific soil properties, influence the occurrence of specific woody species causing BE in the NWP.

# The Virtual Irrigation Academy: from Soil Physics to Social Learning

Richard Stirzaker

CSIRO, Australia

Census data from irrigators in Australia and the USA show that the adoption of soil water monitoring tools remains low. The technological optimism that water management was essentially a ‘data problem’ that would be solved by a measuring device, has not materialised. This raises questions around how science-based solutions can help smallholder irrigators in low-income countries to improve their water productivity. The Virtual Irrigation Academy (VIA) puts forward an approach that combines farmer learning with simple monitoring tools that give farmers feedback on their management decisions, such as how deep the irrigation water penetrated into the root zone, whether the soil is wet, moist or dry and the change in nitrate and salt levels. The VIA has developed a suite of soil water and solute monitoring tools that give output as colours, which are thresholds for action. The Chameleon sensor gives output as blue (wet soil), green (moist soil) or red (dry soil). Since it measures soil tension rather than soil water content, no calibration is needed for different soil types. The Wetting Front Detector captures a soil water sample from infiltrating water, which is used for nitrate and salt monitoring. Data is presented as colour patterns on the VIA platform at https://via.farm/. Colour is a universal language that connects the knowledge domains of scientists and farmers into a unified learning system. Tens of thousands of VIA sensors are now used across 15 countries.

Based on surveys covering over 1000 crops in Malawi and Tanzania, nearly 70% of smallholder farmers said their yields had increased after using the equipment over a few seasons, despite problems of pests and diseases and low use of purchased inputs that characterise these schemes. Three quarters of irrigators reported saving water. However, benefits went beyond individual farmers and their irrigation decisions. As more farmers participated in monitoring, social learning around how water was managed at scheme scale opened up new opportunities for water governance. These included cleaning out canals so water moved faster, improved decisions around water delivery to different parts of a scheme to ensure equity and using saved water to irrigate larger areas.

**Does Conservation agriculture enhance soil hydraulic properties regardless of the farming system and agro-ecological zone?**

Eyob H Tesfamariam[1], Pacsu L Simwaka[1, 2], Amos R Ngwira[3], Paxie W Chirwa[1]

[1]University of Pretoria, Dept. of Plant and Soil Sciences, Corner of Lynwood Rd & Roper St, Hatfield 0002, South Africa

[2]Bvumbwe Agricultural Research Station, P.O Box 5748, Limbe, Malawi

[3]ICRISAT-Malawi, Chitedze Agricultural Research Station, P.O. Box 1096, Lilongwe, Malawi

Conservation agriculture (CA) is increasingly promoted among smallholder farms of sub Saharan Africa in a quest to improve food security while sustaining the natural resource base of the agro-ecosystems where agriculture is based. The aim of this study was to investigate the effects of CA and conventional tillage (CT) on selected hydraulic properties in two contrasting agro-ecological zones of Malawi. The on-farm trials were located in Chipeni, Chinguluwe, Lemu, and Zidyana. The study was conducted on farmers' fields which have been implemented for the past 10 years, with each farmer having the following treatments: CA with continuous sole maize (CA-SM), CA with maize-legume intercrops (CA-ML), and conventional tillage continuous sole maize (CT-SM)). Triplicate undisturbed soil cores were randomly collected per plot per replicate to a depth of 20 cm with a 4.5 cm diameter core sampler of 5 cm height that were used to determine bulk density, soil water characteristics and pore size distribution. Conservation agriculture improved soil porosity, pore size distribution, and soil plant available water by increasing the total porosity and the proportion of meso and micro pores compared with conventional tillage. It can be concluded that changing management practices from CT-SM to CA has the potential to improve the soil hydraulic properties across agro-ecological zones in Malawi which is important for the sustainability of Malawi's agriculture. Farmers should be encouraged to minimize tillage, retain residues as mulch on the soil surface and practice crop rotation and/or associations.

**Key words:** Conservation agriculture; traditional tillage; hydraulic characteristics; agro-ecologies; smallholder farmers

# Irrigation with reverse osmosis concentrate and brackish groundwater effects soil microbial composition and soil health

Manoj Shukla, Sarah Cerra, Akram Benali

New Mexico State University, USA

Continued drought is severely constraining availability of fresh surface water for irrigation and brackish groundwater is increasingly used to supplement the shortfalls in southern New Mexico. We are presenting results from two separate studies conducted to investigate effects of brackish water irrigation on soil microbial community. The objectives of the two studies were to evaluate impacts on soil microbial composition in plant rhizospheres. Three treatments of RO concentrate (EC = 8.0 dS/m), brackish groundwater (EC = 4.0 dS/m), and city of Las Cruces water (EC = 0.8 dS/m) as control were used to irrigate pecan trees. PLFA biomarkers for the microbial community were determined. For two seasons, gram-positive bacteria were found to be dominant while gram-negative bacteria disappeared in the second season. PLFAs biomarkers of fungi were found with all three treatments in the first season; however, they appeared only with BGW in the second season. Actinomycetes were recorded in the first season while they were not seen in the second season. Irrigating with RO and BGW shifted the soil microbial composition. Second study showed a slight changes in phylum composition of the microbial community. The number of 16S rRNA hits showed a similar pattern of decreasing from baseline to the end of year 1 and then increasing to near baseline numbers by the end of year 3. Irrigation also showed a significant effect on the total number of species. The greatest predictor of alpha diversity for each sample was pH. Long term continuous application of brackish water is not recommended for Pecans, however, Atriplex species, which require much smaller irrigation volumes can be irrigated for a longer period without reductions in biomass production.

# Selected Properties, Genesis, Classification and Conservative Approaches of Soils Derived from Imo Shale Geological Formation in Anambra State, Southeastern Nigeria

**Chukwuebuka Edwin Awaogu**[1], **Nancy Ekene Ebido**[1], **David Chukwuebuka Enemo**[1], **Charles Livinus Anija Asadu**[1], **Isong Abraham Isong**[2] **and Sunday Ewelem Obalum**[1]

[1]Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka.

[2]Department of Soil Science, Faculty of Agriculture, Forestry and Wildlife Resource Management, University of Calabar, Calabar

Soil properties reflects the differentiation in materials from which solum was formed. In essence they depict anisotropic nature, thus calls for the study of associations of soil and zonal landscape for efficient nutrient management. This was achieved through the use of soil profile. The investigations on the soils overlying the Imo shale formation was done genetically and the inferences obtained were used to appraise their agricultural potentials. With the aid of a geological map that was obtained from the Department of Geology, University of Nigeria, Nsukka, Imo shale geological formation as well as other geological formations in Anambra State was obtained. The geological map facilitated the identification of the areas underlain by the Imo shale formation. A reconnaissance visit was carried out with the aid of google imageries to these areas underlain by the Imo shale geological formation. A general view of these areas was established and it led to identifying two distinct physiographic units; upland and wetland soils. Each of the physiographic unit was mapped into two units as IMO U1, IMO U2, IMO W1 and IMO W2 with a soil pit sunk, described and sampled in each of them. These four pits depicted differentiation in their morpho-physicochemical properties as well as their mineralogical properties. The soil classification was carried out according to the USDA Soil Taxonomy and FAO/UNESCO WRB guided by their characteristics. Ultisols and Inceptisols in the USDA (United States Department of Agriculture) System correlated with Acrisols, Leptosols and CAmbisols in WRB (World Reference Base) for Soil Resources System. Quartz dominated the entire soils in the mineral phase and was also higher in the wetland soils, while kaolinite was higher in the upland soils. Cronstedtite and anatase occurred in trace amounts in upland and wetland soils, respectively. Furthermore, the soil reaction (pH) was strongly to moderately acidic in the entire soils; the organic carbon level was low to high in upland soils and low to moderate in the wetland soils. C/N, Ca/Mg ratios, available phosphorus as well as basic cations except $Mg^{2+}$ were low in the soils. The study sites were within the humid tropical zone, hence the impact of the humid tropical climate constituted the obvious loss in the soils' cation reserve; particularly the dominating high mineralization rate, leaching, eluviation-illuviation in the soils. Comparatively, the weathering intensity was at an advanced stage in the upland soils than the wetland soils with the dominance of kaolinite.

**Key words**: Soil properties, geological formation, classification, physiographic units, conservative approaches, soil profile.

# Modelling Water Flow in Directly Seeded Paddy Soils Under Alternate Wetting and Drying Irrigation Practice Using HYDRUS-1D

Denis Bwire*[1], Hirotaka Saito[2] and Kenichi Tatsumi[2]

Drought is becoming a serious global challenge contributing to a decrease in the available water resources for irrigation agriculture in recent decades, triggering developments in water saving methods. Pot experiments were conducted under greenhouse conditions to compare the soil water flow between the custom continuous flooding (CF) and alternate wetting and drying (AWD) irrigation practice during the rice growing seasons in 2021 and 2022. Four irrigation treatments, including continuous flooding (CF) as control and three AWD treatments were considered. Each treatment was replicated three times. Irrigation applications under AWD treatments were based on 5, 10 and 15 cm deep water levels (referred to as AWD5, AWD10, and AWD15, respectively) throughout the rice cultivation period with ponding depth of 2-5 cm in both CF and AWD conditions. In this study, soil water matric potential, soil water content, and weather conditions during directly seeded rice cultivation at Tokyo University of Agriculture and Technology, Japan were observed. Since water management in CF and AWD conditions differed, soil water flow was simulated using the HYDRUS-1D model for one cultivation season, from June to September 2021, based on the measured matric potential and soil water content distribution in soil profiles. We compared HYDRUS-1D simulations with the CF and AWD practice's experimental data and optimized the operational parameters. In addition, System-dependent boundary conditions, which initiate irrigation whenever the water level drops below the pre-determined depths, were considered.

The results show that the HYDRUS -1D model can predict matric heads and soil moisture conditions in paddy soils compared with experimental data. The AWD practice throughout the whole rice cultivation efficiently used irrigation water with a slight difference in yield as compared to CF.

**Key Words:** Paddy Soils, AWD Practice, Irrigation Water Management, HYDRUS-1D

# Water use of agricultural and bioenergy crops in the Piedmont and Coastal Plain Regions of North Carolina

Henrique Carvalho and Josh Heitman (North Carolina State University, Department of Crop and Soil Sciences, Raleigh, NC, USA)

Bioenergy crops are being promoted as an alternative option to reduce dependence on finite fossil fuel reserves and mitigate greenhouse gas emissions. Current research shows that bioenergy grasses and woody species can yield substantial amounts of biomass with relatively low inputs of water and fertilizer, making them potential candidates for land areas considered marginal. However, relatively little is known about the water and energy use of bioenergy species for the conditions of North Carolina. Results from studies conducted in 2021 that were designed to evaluate water and energy balances of corn, miscanthus, and sycamore fields on the Piedmont and Coastal plain regions of North Carolina will be presented in this talk. Bowen ratio energy balance systems were employed to measure energy fluxes from these crops in soils considered marginal. Preliminary results will be discussed in the context of the soil physical properties at each site and precipitation available during the growing season.

## Zonal calibration of SWAT+ models using soft data in R

Katrin Bieger, Christoph Schürz, Eugenio Molina Navarro, Alejandro Sánchez Gómez, Johan van Tol, and Jeffrey G. Arnold

In recent years, watershed modelers have put increasing emphasis on simulating hydrological processes within watersheds as realistically as possible, which is essential for providing stakeholders, watershed managers, and policy makers with accurate predictions of the environmental impacts of future land use and climate. Depending on their characteristics, different parts of the landscape differ in how they receive, store, and deliver water during and in between precipitation events. Compared to previous versions of the Soil and Water Assessment Tool (SWAT), its most recent version, SWAT+, has enhanced capabilities to represent this variability of hydrological processes within the watershed. To take full advantage of these new capabilities, it is important to also improve the consideration of process representation in calibration and validation procedures.

We developed a semi-automated calibration procedure in R that allows us to calibrate different, user-defined zones within a watershed separately. While the parameter sampling and simulation runs are performed automatically, the definition of parameter ranges for the zones and the selection of acceptable model runs are done manually based on available soft data and expert knowledge. This presentation will provide an overview of the calibration procedure and demonstrate its applicability using three examples, (1) the calibration of upland areas and floodplains in the Little River Experimental Watershed in Georgia, USA, (2) the calibration of geological zones in the Tagus River Basin in Spain, and (3) the calibration of hydropedological soil types in the Weatherley Catchment in South Africa. In all three study areas, the simulation of water budgets and hydrological processes was improved by applying the new calibration procedure.

# Development of a South African national input database to run the SWAT model in a GIS

Jay le Roux

UNIVERSITY OF THE FREE STATE
DEPARTMENT OF GEOGRAPHY
BLOEMFONTEIN
E-mail: lerouxjj@ufs.ac.za

and

Ndifelani Mararakanye, Leushantha Mudaly, Harold Weepener, Michael van der Laan

A major limitation to model application in South Africa (SA) is the lack of standardized geospatial and "open-source" datasets. This study collates multiple geo-spatial datasets at a national scale and interpret/format the data for use as baseline input to run the Soil and Water Assessment Tool (SWAT) in any catchment in SA. The national input database to run the SWAT model in SA is stored in the Water Research Observatory (WRO) data portal: https://www.waterresearchobservatory.org/data-and-resources/hydrological-data-and-modelling. The portal provides geo-spatial input datasets including the following:

- SWAT catchment outline data (tertiary and quaternary) including the hydrologically corrected SRTM DEM of SA at 90 m resolution;
- South African National Land Cover (2014; 2018; 2020) linked to SWAT land cover codes;
- Soil map with SWAT attribute data for each Land Type of SA;
- Weather statistics (WGN) files required as input by the model.

Performance of the national baseline data was determined by comparing streamflow and sediment outputs with previous modelled catchment data models, as well as comparison of the hydrological accuracy against measured streamflow data. Although the catchment data models were slightly superior compared to the national data models, the national data is capable of modelling streamflow and sediment dynamics at a catchment scale. This national input database will assist researchers to set up and run the SWAT model anywhere in SA. Modellers will be able to use the input data 'as is', or alternatively supplement and/or improve and/or replace the input data with their own recent/sophisticated data. Such an input dataset is an important step forward in the application of hydrological models to assist agricultural water management in SA.

# Streamflow prediction with deep learning: a South African semi-arid catchment case study

C. E. Schutte[a], M. van der Laan[a,b], B. van der Merwe[c]

[a] Department of Plant and Soil Sciences, Faculty of Natural and Agricultural Science, University of Pretoria, Pretoria 0002, South Africa.

[b] Agricultural Research Council, Pretoria 0002, South Africa.

[c] Department of Geography, Geoinformatics and Meteorology, Faculty of Natural and Agricultural Science, University of Pretoria, Pretoria 0002, South Africa.

Hydrological data, including streamflow, are fundamental to properly manage South Africa's scarce water resources, prepare effective flood and drought mitigation measures and to develop informed climate change adaptation strategies. However, the national streamflow monitoring network is declining. This is a cause for concern as it presents a long-term threat to South Africa's water security. This study investigated the use of deep learning to generate reliable streamflow estimates. Thirty years of freely available weather data from the Climate Forecast System Reanalysis was used as input into Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) network models for streamflow prediction in a South African semi-arid catchment. The weather data variables selected were maximum and minimum temperature, precipitation, relative humidity, wind speed and solar radiation. Five years of daily streamflow values not used in model training were then compared to simulated streamflow. The root mean squared error (RMSE) and the coefficient of determination ($R^2$) were used to assess model performance, with lower RMSE and higher $R^2$ values indicating better performance. The lowest RMSE value obtained for both the LSTM and GRU models, which performed similarly, was 2.9 $m^3 s^{-1}$ and is considered low (for reference, the mean streamflow is 2.2 $m^3 s^{-1}$ and the standard deviation is 3.3 $m^3 s^{-1}$). The highest $R^2$ value obtained was 0.42, however, so the models were considered only moderately accurate. Actual weather station data were then run to test the impact on model performance, and results showed a considerable increase in accuracy, with RMSE and $R^2$ values of 2.5 $m^3 s^{-1}$ and 0.69, respectively. Both deep learning models captured the general seasonal trends, such as high flows during wet seasons and low flows during dry seasons. The models failed, however, to accurately predict peak flows, apart from a few instances where the actual weather station data-driven models showed increased accuracy. This study illustrates that LSTM and GRU network models can be used to generate accurate streamflow data, but also highlights the importance of using actual weather station data. Future work will test other sources of freely available weather data, as well as static catchment attributes (such as soil characteristics) and will aim to improve peak flow predictions.

**Key words**: Streamflow prediction, artificial intelligence, Long Short-Term Memory network, Gated Recurrent Unit network.

# Accurate seasonal streamflow forecasts developed for rainfall-dominated watersheds using remote sensing soil moisture and groundwater data

Briana M. Wyatt, Mingxiu Wang, Tyson E. Ochnser

Surface water resources are increasingly vulnerable due to changes in rainfall patterns and atmospheric water demand caused by climate change. Surface water managers in the Great Plains of the US face major challenges due to the region's drought-prone climate and large inter-annual variability in rainfall and streamflow. A lack of access to seasonal streamflow forecasts like those widely used in the snow-dominated watersheds of the western US further increases the vulnerability of surface water resources in the region. Recently completed work by the PIs shows that in-situ soil moisture measurements can be used in a statistical forecasting model to produce accurate streamflow forecasts in rainfall-dominated regions and are able to provide >50% improvement over streamflow forecasts based on antecedent precipitation alone. However, the use of this method is currently restricted to watersheds where data from in-situ soil moisture monitoring stations are readily available. The current research expands upon this work to determine whether utilizing remotely-sensed soil moisture data will allow the creation of similarly effective seasonal streamflow forecasts in five watersheds lacking in-situ soil moisture monitoring networks. Our results demonstrate that forecasts incorporating remote sensing-based soil moisture and groundwater level information explain 79-93% of observed variability in streamflow, have RMSE values nearly 60% lower than precipitation-only forecasts, and are comparable in accuracy to operational forecasts used in the snow-dominated western US. Because of the ubiquity of remote sensing data, this method has strong potential for expansion to other rainfall-dominated regions, both in the US and globally.

# Importance of Understanding Soil-Water Relationships in Marginal Rainfed Cropping Areas

Michiel Laker and Gerhardus Nortjé

Areas with marginal rainfall for rainfed cropping are important for production of staple grains towards achieving food security in countries in the hot, dry mid-latitudes. In South Africa 75% of its white maize, the main staple grain, is produced in such areas. The latter are characterised by mean annual rainfall of 500 mm and less, which is also unreliable, and mean annual PET of 2200-2800 mm. Successful rainfed grain production in such areas demands a combination of highly effective rain water infiltration and storage of adequate quantities of this water in plant-available forms in the soil. In South Africa's marginal maize production areas these two conditions are met in the red and yellow-brown fine sandy soils which are dominant in these areas. They have high infiltration capacities and high plant-available water capacities and are generally fairly deep to deep. Fine sandy soils with 8-10% clay were found to have a plant-available water capacity of about 100 mm per metre soil depth. The high plant-available water capacity of the soils is related to the fact that the upper limit of plant-available water in them is at a soil water potential of -5 kPa, which is much higher than the former generally accepted -33 kPa, and that a large proportion of the plant-available water is retained at high soil water potentials. The dense root systems of grain crops like maize and wheat penetrate to more than 2 metres depth where the effective rooting depth of the soil is adequate and extract water to considerable depths. Yields are more stable on soils with extra water storage in the lower subsoil, which supplies water into the root zone. Most important is the presence of a horizon with a seasonal fluctuating water table, as indicated by what in the South African soil classification is termed a soft plinthic horizon, i.e. a horizon with high chroma red and yellow mottles in a matrix with at least some light grey in it. This horizon must be at adequate depth. Towards lower rainfall regimes, lower subsoil horizons with more permanent wetness also become important. In drier areas where brittle lime pans, soft carbonate horizons in the South African soil classification and hyper calcic horizons in WRB, occur in the lower subsoil these were found to perform the same role of providing additional water storage. The latter was found to not only stabilise yields compared with deep well-drained soils in such areas, but to actually give higher average yields. Efficient soil water management is paramount in these areas. To minimize occurrences of poor yields and crop failures, it is important to have a certain minimum amount of plant-available water in the soil before planting. It was found that this is best achieved by means of a so-called long fallow system. It has a 10 month fallow period, which in the summer rainfall area includes at least one full summer rain season. It was found that maize crop models like *Ceres-maize* and some South African models fail in sub-optimal and marginal areas, especially where the presence of horizons like soft plinthic horizons have significant impacts. In contrast the CYSLAMB maize model, developed in marginal rainfall areas in neighbouring Botswana, gave good results.

**How fast the earth surface breathe? Gas transport in high permeability soils and earth surface discontinuities**

**Noam Weisbrod[1], Maria Dragila[2], Elad Levintal[1,3]**

1. **ZIWR, BIDR, BGU**
2. **OSU**
3. **ZIWR, BIDR, BGU (Currently at UC Davis)**

Gas movement within the earth's subsurface and its exchange with the atmosphere are some of the principal processes in soil, ecosystem, and atmospheric environments. For a decade, our group has explored the roles played by atmospheric conditions and matrix properties in gas transport at the earth-atmosphere interface, where surface discontinuities, such as fractures, boreholes and aggregated soils, exist and may affect the process.

The gas transport mechanisms, resulting from the development of a thermal gradient and surface wind, were analyzed both independently and in combination. Two types of experiments were carried out: (1) under field conditions and (2) under highly controlled laboratory conditions. During all studies, temperature and wind conditions across the media and at the media-atmosphere interface were monitored. Results show that the magnitudes of thermal- and wind-induced convection were directly related to the media permeability, given favorable ambient conditions at the media-atmosphere interface. Such ambient conditions included high diurnal temperature amplitude (~± 10 °C) or high surface wind (~2 m/s measured 10 m above ground). In addition, specific results from the field experiment were used to establish an empirical model that predicts gas transport magnitude as a function of wind speed and media permeability.

With respect to other discontinuities, such as boreholes and fractures, the effect of atmospheric conditions was investigated, namely atmospheric pressure and temperature, on air, $CO_2$, and radon transport. Using high-resolution spatiotemporal measurements, it was concluded that diurnal atmospheric pressure oscillations (barometric pumping) and borehole-atmospheric temperature differences (thermal-induced convection) controlled the air transport within the boreholes. For one of the boreholes monitored, the air velocities and $CO_2$ emissions to the atmosphere were quantified (up to ~6 m/min and ~5 g-$CO_2$/min, respectively). This reveals the role of boreholes as a source of greenhouse gas emissions.

The results and conclusions derived from our studies are expected to improve our understanding of the governing mechanisms controlling gas movement in porous media, fractures, and boreholes, and their functions in gas exchange across the earth-atmosphere interface.

# Creating pedotransfer functions to determine important soil hydraulic properties.

A. Kock

Soil and water parameters are important for hydrological modelling of watersheds using the Soil and Water Assessment Tool (SWAT), SWAT is a continuous-time, semi-distributed and process-based model. Measured soil properties data vary from dataset to dataset and the amount of data as well as the type of data may differ due to the needs, aim and cost constraints of a respective study. Certain commonly used soil properties are almost always measured for soil samples for example soil texture, pH, cation exchange capacity (CEC) etc. Other soil hydraulic properties are more time consuming and more expensive to measure for example, Saturated hydraulic conductivity (Ks), soil water content at field capacity ($\theta_{33}$) and soil water content at wilting point ($\theta_{1500}$) are not readily measured and included into soil datasets. A soil dataset from Van Tol (2022) with 221 soil samples was used to create the PTFs. For Ks, five multiple regressions models, three for bulk density (BD), two for $\theta_{33}$ or drained upper limit (DUL) and three for $\theta_{1500}$ or lower limit (LL) were created using different combinations of available soil property data in the Van Tol (2022) dataset, respectively. One Cubist model was also created for Ks with all soil properties to evaluate the performance of machine learning algorithms compared to standard multiple linear regression models. Pedotransfer functions for Ks created using Cubist and all available soil properties as predictors had the best overall performance (ME = -1,78, RMSE = 152,1, R2 = 0,6, RPD = 1,6 and CV = 100.6). The Ks-A PTF with multiple linear regression follows in performance (ME = -2.54, RMSE = 161.16, R2 = 0,59, RPD = 1,58 and CV = 105.77) with relatively low RMSE, high R2 and RPD. Two of the BD PTFs had the best performance with BD-P created using Cubist having the best performance (ME = -0.01, RMSE = 0.08, R2 = 0.92, RPD = 3.7 and CV = 5.88). Pedotransfer functions for Ks using multiple linear regression are suboptimal for practical use while, the Ks PTF developed with Cubist showed more potential as being useful as a PTF in predicting Ks from BD, Organic carbon, CEC, sand, silt and clay. This however is only true if enough soil data is available to develop the PTF. Bulk density PTFs were the best performing PTFs from all the soil properties chosen in this study and produced PTFs that are accurate and reliable enough to be practically used. Pedotransfer functions for DUL and LL we're not as successful and PTFs for these soil properties are not usable for any predictions.

# Coupling of Surface Soil moisture and Evapotranspiration from Field to Remote Sensing Footprint Scale

Deanroy Mbabazi, Vinit Sehgal, and Binayak P. Mohanty*

Texas A&M University

bmohanty@tamu.edu

Evapotranspiration (ET) and soil moisture (SM) are critical processes that control land-atmosphere interactions. ET and SM determine carbon, water, and energy cycles. Coupling of ET and SM define water-limited regimes for dry surfaces, and energy limited regimes for wet surfaces. The ET-SM coupling relationships are commonly studied using the evaporative fraction-soil moisture relationship (EF-based frameworks) and pathways of soil moisture dry downs. Pathways of soil moisture dry downs (SM loss-based frameworks) have recently been applied to Soil Moisture Active Passive (SMAP) satellite-based SM to parameterize ET-SM coupling relationships at the global scale. In this study, we investigated and parameterized the evolution of ET-SM coupling from the field to satellite footprint scale using the EF-based framework. Field scale ET and SM were obtained from 163 eddy covariance and soil moisture sensors installed at Texas Water Observatory, Ameriflux, and FLUXNET sites around the globe. Satellite scale ET and SM were estimated from MODIS (and LANDSAT) and SMAP satellites, respectively. We obtained effective EF-based hydrological regimes and their parameters globally. The results indicate variability in ET-SM coupling strength across field to satellite scale and between the EF-based and SM-loss based frameworks. Hydrological regime parameters varied with climate, ecosystem, and soil texture for both the EF and SM-loss based frameworks. Hydrological regimes and parameters showed strong interseasonal variability due to vegetation dynamics and seasonal climate. These hydrological regimes and parameters can be incorporated in land surface models and hydrological modeling frameworks.

# Fire effects on soil properties in a large African conservation area

Tercia Strydom [1,2] *, Izak Smit [1,3] and Johan van Tol [2]

[1] *Scientific Services, South African National Parks, Skukuza, South Africa;*
[2] *Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, 9300, South Africa*
[3] *School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Braamfontein, 2001, South Africa*

E-mail: tercia.strydom@sanparks.org (* Corresponding Author)

Fires have been an important ecosystem driver in the Earth system for millions of years. It drives ecosystem composition, diversity and structure, rendering numerous terrestrial ecosystems dependent on fires for maintaining their health and functioning. In Kruger National Park, South Africa, fires have been used as a management tool to maintain biodiversity for decades. Whilst many studies have focused on the effect of fire on vegetation and herbivores, little is known about how fires impact soil properties in this fire-prone savanna ecosystem. Other studies conducted in other fire-prone landscapes around the world have found significant effects on soil physical, chemical and biological properties.

Kruger National Park has long-term experimental infrastructure which has allowed a unique opportunity to investigate the effect of varying fire treatments on soils. These include the long-term experimental burn plots (~ 70 years) and an herbivore exclusion site with and without fire treatments (~20 years). As of 2022, roughly 15 studies investigating fire effects on soil properties have been published. Majority of these studies were focused on fire impacts on soil carbon and nitrogen, with very few focusing on the physical and biological properties of the soil.

We will provide an overview of the fire and soil related research which has been conducted in the park, some of the key findings as well as what main research gaps remain.

# Mechanistically upscaling of root water uptake: from the single root segment to the ecosystem.

Jan vanderborght[1], Valentin Couvreur[2], Felicien Meunier[3], Andrea Schnepf[1], Martin Bouda[4], Daniel Leitner[5],and Mathieu Javaux[1,2]

[1] Agrosphere Institute, IBG-3, Forschungszentrum Jülich GmbH, Germany
[2] Earth and Life Institute, UC Louvain, Belgium
[3] Computational and Applied Vegetation Ecology lab, Ghent University, Belgium
[4] Institute of Botany of the Czech Academy of Sciences, Pruhonice, Czechia
[5] Simwerk, Leonding, Austria

Transpiration by vegetation is an important component of the terrestrial water cycle. Since water and $CO_2$, respectively, leave and enter the canopy through the same 'gates', transpiration, $CO_2$ assimilation, and vegetation (crop) growth are closely linked. How much water plants can supply for transpiration depends on how much soil water their root system can extract how much water they can transport to the canopy. When this supply becomes smaller than the rate of transpiration through open stomata, plants close stomata and reduce transpiration, and consequently also assimilation. The water supply depends on plant hydraulic properties, the root system architecture, the soil hydraulic properties and the forces that bind water in the soil, which are expressed in terms of the soil water potential. In this contribution, we discuss how the supply function can be derived mechanistically from the hydraulic properties of roots, the root system architecture, the distribution of the water potentials in the root zone and the soil hydraulic properties. We start from a fully 3D model that couples flow in the soil and the 3D root system, that considers the hydraulic properties of individual root segments, and that resolves the water potential gradients in the rhizosphere between the bulk soil and the soil-root interface. Then we develop an upscaled model that considers uniform bulk soil water potentials in larger soil volumes based on an analysis of the flow equations in the detailed 3D root architecture and using semi-analytical solutions of Richards equation in the rhizosphere. The upscaled models are parameterized using, in principle, directly observable soil and root properties. We discuss how different root water uptake models that are commonly used in 1D soil water flow models can be related to the obtained upscaled model and on which assumptions they rely. We demonstrate how the parameters of these commonly used root water uptake models are related to both soil and root properties but also on environmental conditions like the transpiration demand. By injecting more mechanistic understanding in the parameterization of commonly used root water uptake models, it becomes possible to include root system traits into soil water balance models and improve the prediction of how different root systems will function, with respect to water supply, under different climates and soil types. This is a crucial step to identify root 'ideotypes' for water uptake. Finally, we extent the model to include different plant species

that extract water from a shared soil volume. We discuss how such a system can be upscaled and how competition and synergies between species can be evaluated based on their root hydraulic traits. This is an important step towards the functional evaluation of mixed ecosystems.

## Root activity for water uptake: a hydraulic approach

Ali Mehmandoostkotlar
Instituut voor Landbouw en Visserijonderzoek ILVO, Melle, Belgium
Mathieu Javaux
Université Catholique de Louvain, Louvain la Neuve, Belgium

Despite most macroscopic models for root water uptake considering root length density (RLD) to describe root water uptake (RWU) distribution, there are numerous studies demonstrating inconsistencies between soil water content profile and RLD that can be attributed to the inability of some roots to extract water. In fact, the physical relationship between RWU and the root system ignores the hydraulic characteristics of the root. To cope with this rigid assumption, the activity of a root system can be defined as the portion of the root system extracting majority of soil water. Root water uptake activity depends on the hydraulic head gradient between root-soil interface and xylem and on root segment conductance, which are terms not considered in macroscopic models. Therefore, both soil and root hydraulic properties are critical in determining RWU activity. Yet, in real root systems, active root fraction is continuously changing due to root development, root adaptation and soil moisture heterogeneity, which are not possible to be assessed considering the currently available experimental facilities. Therefore, our aim in this study is threefold: (1) establish a theoretical framework to investigate root water uptake activity; (2) Investigate with 0D hydraulic architecture model and 3D architectural soil-root water flow model to estimate the active root fraction and to find the effective parameters on active root fraction and finally (3) demonstrate and provide orders of magnitude of active root fraction for real situations. The initial results showed that RWU activity for a single segment depends on radial hydraulic conductivity distribution if xylem conductance is not limiting. The active fraction of the root for fibrous and taproot systems at different ages with their realistic root hydraulic properties was investigated under equilibrium and realistic soil water potential and compared with some existing values in literature. The simulated active root fraction and obtained ones from the previous studies rarely exceed 30% of the whole root system. The active root fraction is therefore an important factor to know and characterize to properly estimate soil resistance and stress onset.

# Predicting soil water retention curves from soil physical properties of old store-and-release covers in Mpumalanga Highveld, South Africa

Roeline van Schalkwyk[1], Albert J. van Zyl[2], Eduard J. Hoffman[3], and Johan L. van Zyl[4]

[1]Research assistant, Dept. of Soil Science, Stellenbosch University, South Africa. Email: roelinevs@gmail.com

[2]Environmental Soil Scientist, Terrasim CC, Pretoria, South Africa

[3]Department Chairperson, Dept. of Soil Science, Stellenbosch University, South Africa

[4] Extraordinary professor, Dept. of Soil Science, Stellenbosch University, South Africa

A study was conducted at the Mpumalanga Highveld, South Africa, to predict the soil water retention curves (SWRCs) of old (> 20 years) store-and-release covers (SRCs). Furthermore, data sets of well- and poorly constructed covers, and the availability of data on appropriate input parameters for predicting long-term performance of such covers are limited. This includes SWRCs and SWRCs are time consuming, labour intensive and costly, where the accuracy of SWRCs is important for long-term cover performance modelling. In this study, multiple linear regression models of SCRs were developed from particle-size distribution, soil organic matter (SOM) and soil bulk density. Soil water retention curves of 14 matric potentials were established using the pressure plate apparatus. The SRCs data-set was split into training and testing sets to validate the SWRC model. The statistical analysis of the *best-fit* SWRC model of 14 matric potentials had an adjusted $R^2$ = 0.827 from three fractions of sand-, two fractions of silt-, clay content, SOM, and bulk density. The SWRC model performed fairly well and the validation versus the field measured data was satisfactory.

# Autocorrelation in Soil Moisture Sensor Measurement Errors: A Mechanistic Error Modelling Approach

[1]*Hendrickx, M., [1,2]Vanderborght, J., [1]Diels, J., [3,4]Janssens, P.

*marit.hendrickx@kuleuven.be

[1] Department of Earth and Environmental Sciences, KU Leuven, Belgium

[2] Agrosphere Institute (IBG-3), Forschungszentrum Jülich GmbH, Germany

[3] Soil Service of Belgium, Belgium

[4] Department of Biosystems, KU Leuven, Belgium

Real-time sensor data on the soil moisture status of the root zone have come to play an important role in irrigation scheduling. The use of this information, however, remains a challenge mainly due to measurement errors. When measuring soil moisture with sensors at fixed positions, a deviation from the mean soil moisture in the root zone may persist over time resulting in autocorrelated measurement errors which must not be interpreted as independent errors. The uncertainty of time series of autocorrelated measurements may be underestimated when these measurements are assumed to be uncorrelated.

In order to evaluate the uncertainty of repeated soil moisture measurements, a model of their autocorrelation is required. Temporal autocorrelation models can be derived from time series of measurements but their assumptions about the origin of the error, i.e., a Markovian and stationary random error process, might not apply to soil moisture measurements in a field plot. As an alternative, we propose a mechanistic error model that is based on the spatial variability of the soil water retention curve, and assumes a uniform soil water potential in the field. We tested whether soil moisture variability and autocorrelation could be predicted 1) based on mean soil moisture contents, 2) using the variability of the soil water retention curves, and 3) using information on the variability and covariance of the van Genuchten parameters based on a first-order expansion of the retention curve (Qu et al., 2015). This model was tested in two steps. First, a theoretical approach was used to assess the proposed error models using a virtual dataset of soil moisture measurements derived from water flow simulations in a heterogeneous field with variability in soil hydraulic properties and root water uptake. The advantage of this approach is that the soil variability is known, so that we can verify our assumptions. Second, a case study approach was adopted to evaluate the model in a practical setting. For this approach, in situ soil moisture sensor measurements (TEROS10, Meter Group) as well as soil water retention curves were obtained at different locations in a field plot.

The results show that, in a virtual soil, water retention variability can be used to predict both soil moisture variability and measurement error autocorrelation, under the assumption of a uniform soil water potential throughout the field. Moreover, we found that the error model is applicable in practice, but we have to keep in mind practical limitations and implications such as soil compaction and hysteresis. Measuring soil heterogeneity and quantifying its

*Keywords: Dependent measurement errors, Error modelling, Autocorrelation, Soil moisture sensing, TEROS10, van Genuchten parameter uncertainty, Soil moisture variability, Soil water retention curve variability*

impact on measurement errors and their autocorrelation is vital to interpret soil moisture sensor measurements, which is required when measurement data are used for agricultural water management. An error model such as presented in this study can be used in applications such as inverse modelling, where a soil water balance model is calibrated with soil moisture sensor measurements. Further research is required to assess the impact of the error model on the parameterization of a soil water balance model. The error model should give more insight in prediction uncertainties of the soil water balance model.

*Keywords: Dependent measurement errors, Error modelling, Autocorrelation, Soil moisture sensing, TEROS10, van Genuchten parameter uncertainty, Soil moisture variability, Soil water retention curve variability*

## Non-invasive monitoring of nanoparticle transport and fate in the soil - a spectral induced polarization study

Shany Ben Moshe and Alex Furman

Metallic nanoparticle (NP) transport and their fate in the natural environment have been of major interest over the last decade due to the increasing use of NPs in many industries and their subsequent accumulation in the environment. However, the study of NP fate and transport in soils traditionally relies on intensive sample collection and chemical analysis. In this work we use spectral induced polarization (SIP) to monitor the transport of metallic NPs in soils. In SIP, an alternating current in wide range of frequencies is injected, and the phase and amplitude difference between the injected and induced potential are measured. Our experimental setup involves flow-through columns packed with different types of soil, through which a suspension of NPs with different ionic compositions is passed. Electrical potentials are recorded at three locations along the column. The analyzed SIP measurements allow not only non-invasive, non-destructive monitoring of the NP's progression through the soil but also deduction of the NPs' fate through combination with elemental analysis and size distribution measurements. The sensitivity of SIP to the presence of the NPs is high and captures their progression patterns in the soil even in low and environmentally relevant NP concentrations. Our results indicate that SIP is a promising method for the monitoring of NPs in the soil and with further research may serve as an easy and efficient alternative to the standard methods that involve extensive water and soil sampling.

# Investigating the accuracy of various calibration equations of the EnviroScan sensor in soil water content estimations in Hungary.

D.M.K. Kibirige

Precise soil water content monitoring has been important for various environmental and hydrological applications. Commercial sensors have been commonly used to detect soil water content (SWC). Sentek soil sensors are among the most commonly used downhole sensors. The EnviroScan sensor is a stand-alone continuous soil water monitoring system due to its ability to monitor fluctuations in SWC levels in real-time, demonstrating the crop's complex water usage in response to changing environmental conditions and irrigation management strategies. The major challenge with any soil sensor is its calibration. Much research on calibration equations for soil sensors has been conducted. Most authors suggest that the default calibration equations of a sensor must be calibrated to specific soil textures to estimate (SWC) accurately. The suggested EnviroScan/Diviner 2000 manufacturer calibration procedure is not as easy as the calibration manual presents. This study aimed to choose the calibration equation with the best accuracy to improve SWC estimates. The difference between this study and other studies was calibrating the sensor without disturbing the site – mainly off-site sampling for calibration - and comparing the approach using the same soil material with all known calibration techniques described in the literature. The study area was located in the northeastern part of Hungary and comprised three regions – the University of Miskolc (clay sample), Tiszavásvari (loam sample), and Görömböly (sand sample). The general framework of the calibration procedure comprised of two phases; the first phase involved a field experiment, where three regions with different textures were selected, gravimetric soil samples were collected, and Sentek calibration measurements were recorded between March and June 2020. The second phase was conducted in October 2020 because the field exercise did not provide wide enough coverage of the potential SWC ranges. Therefore, complementary measurements were performed in the field by wetting the sandy soil with a known volume of water due to its faster infiltration. Due to their slower infiltration rates, loam and clay were artificially wetted in the laboratory. The results showed that the Sentek default calibration equations in all three classes had relatively low performances; however, significant refinement was achieved by selecting Sentek soil-specific equations from the manufacturer's libraries. The Sentek soil-specific equations often yielded satisfactory results with improved $R^2$ values and lowered RMSEs ranging between 2% and 4%. The study derived three new EnviroScan soil texture-specific calibration equations. These newly derived equations proved to be better than the Sentek default equations & Sentek soil-specific equations in estimating SWC. Also, the study proved that a small sample size of EnviroScan sensors could estimate SWC with an accuracy of $R^2$ greater than 0.6 at a small scale. In conclusion, a thorough calibration exercise achieved a very good fit between observed and estimated SWC values, improving the estimation accuracy. A wider application of these new calibration equations can be tested and applied in similar regions under similar field and laboratory conditions and assumptions to further investigate their applicability.

## Soil water sampler concentrations are influenced by the source and history of solute addition

Michael van der Laan and Richard J. Stirzaker

Agricultural Research Council-Natural Resources and Engineering, Private Bag X79 Pretoria, 0001, South Africa

Department of Plant and Soil Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

CSIRO Land and Water, P.O. Box 1666, ACT 2601, Australia

Measuring soil water solute concentrations can be useful for informing fertiliser and salinity management and calculating leaching losses. But interpretation of the concentrations in water from samplers can be complex. Movement of a conservative tracer (chloride, $Cl^-$) added to the soil surface with the irrigation water and a non-conservative tracer (nitrate, $NO_3^-$) originating from soil organic matter mineralisation was studied in a large weighing lysimeter. Soil water samples were collected using active (suction cup) and passive (wetting front detector) samplers placed at different depths. The Hydrus 1-D model was used to simulate the system, due to its ability to represent more mobile and less mobile regions of water and solute mixing across the pore spectrum based on several different theories, which is widely accepted as being important in modelling leaching. Concentrations of $Cl^-$ were more similar in samples from active and passive samplers than was the case for $NO_3^-$. Despite trying different non-equilibrium flow and transport processes (the Hydrus 1-D options: Mobile Immobile Water Model, Dual-Porosity Model, Dual-Permeability Model, and the Dual-Permeability Model with Immobile Water), $Cl^-$ concentrations measured from the samplers could generally not be accurately modelled after a certain point. These results together indicate that the slow diffusion of ions in and out of smaller pores over a period of days to weeks is a very important process, and that the history and source of solute additions can significantly influence the soil water sample measured concentrations. The lateral transport into smaller pores by diffusion and wetting and drying cycles may therefore be as important a process to consider as the vertical transport by advection in interpreting measured concentrations from samplers. Solutes in the small pores can therefore remain ‘unseen’ by commonly used active samplers; and it would require soil water extraction at much higher pressures in the laboratory to measure these concentrations in the micro-pores.

# Soil aquifer treatment: Process optimization and alternative approaches

Alex Furman

Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa, Israel

Sustainable irrigation with treated wastewater (TWW) is a well-established solution for water scarcity in arid and semi-arid regions. Soil aquifer treatment (SAT) provides a solution for both the need for tertiary treatment and the seasonal storage of wastewater. However, stresses over land use and the need to control the obtained water quality make the optimization of SAT of great importance. This presentation will focus on process optimization, conducted using a combination of laboratory experiments and a numerical model. In addition, we will explore two studies that look at different approaches to enhance the efficiency and capacity of SAT facilities.

This study investigates the influence of SAT systems' operational dynamics (i.e., flooding and drying periods) and the ultimate outflow quality. A series of four long-column experiments were conducted, and flooding periods (FP) were kept constant at 60 minutes for all experiments, while drying periods (DP) were 2.5 and 4 times the duration of the flooding periods. A numerical model was developed and calibrated. The model includes both descriptions of the water flow in the system and reactive solute transport, considering the main dominant biogeochemical reactions in SAT. A simple optimization process was performed based on simulation results, and the local optimum for the experimental SAT system was found at a DP duration of ~ 2.8 times the FPs. The optimal operation also matched well with experimental results. The results suggest that SAT should be treated as a pseudo-reactor that, to a great extent, could be manipulated hydraulically to achieve the desired water quality while increasing the recharge volumes.

We also look at two SAT alternatives. In the first, we explore the concept of Ag-SAT, namely using agricultural plots as a temporal alternative to the SAT-dedicated infiltration basin. A preliminary study suggests that AG-SAT can generate water similar to conventional SAT in terms of quality, with no apparent impact on citrus trees for up to 72 hours of winter floods. The second study looks at active air injection to the subsurface to increase infiltration time. A laboratory-scale study suggests about double the infiltration volumes with similar or better water qualities and the advantage of short and frequent air injection over long and sparse ones.

# Estimation of surface water flux from near-surface soil moisture measurements through PDE-constrained optimization

Toshiyuki Bandai, Teamrat A. Ghezzehei, Noemi Petra

Surface water flux is a vital variable for various applications in soil physics, such as soil water balance. However, measuring surface water flux is difficult unless we build costly lysimeters. In this work, we seek to use near-surface soil moisture measurements to estimate surface water flux through PDE-constrained optimization. Here, soil water dynamics is described by the Richardson-Richards equation (RRE), and the surface water flux is the top boundary condition. Thus, estimating surface water flux can be framed as an inverse problem governed by the RRE given near-surface soil moisture measurements. This inverse problem is challenging due to inherent measurement and model errors as well as the dimension of the target parameters (i.e., surface water flux at each time step). To quantify the uncertainty of the estimate caused by the measurement and model errors, we formulate a Bayesian inverse problem, where we seek the posterior probability density of the surface water flux. In this work, we assume Gaussian noise and prior probability densities, and approximate the posterior density with a Gaussian characterized by its mean and covariance. The mean of the posterior is obtained by the solution of a deterministic optimization problem, where we use Newton's method to minimize the objective function using the first and second-order adjoint-based derivative information. The covariance is given by the inverse of the second derivative (Hessian) of the negative log-likelihood. The eigenvalue spectrum of the Hessian informs the ill-posedness of the inverse problem. We demonstrate how soil types affect the uncertainty of the surface water flux estimation.

# Effects of N-fertilizer rates on $CO_2$ emission and yield of maize under different tillage system

D. Arije

Agriculture in Nigeria has been faced with two major problems over the years; enhancing food production and promoting environmental sustainability. To address this problem, an experiment was conducted at the Department of Crop, Soil, and Pest Management of the Federal University of Technology, Akure (7□16□N, 5□12□E) located in the rainforest vegetation zone of Nigeria to examine the impact of N-fertilizer types on $CO_2$ production and emission, yield in the 2021 growing season (wet and dry season). The experiment was laid out in a factorial design having a split-plot arrangement with tillage methods in the main plots and N-fertilizer rates in sub-plots with three replicates. Three tillage methods were used; zero-tillage, conventional (plough + harrow + ridge), and reduced tillage (plough + ridge). Urea fertilizer was applied at the rate of 100 kg/ha, 300 kg/ha, and 600 kg/ha, as well as a control plot where no fertilizer was applied. Crop parameters such as number of leaf, leaf area, plant height, and yield parameters were collected. Initial soil physical and chemical properties were determined as well as the weekly $CO_2$ emission from each experiment plot was determined. Results obtained from this study show the importance of fertilizer in enhancing maize yield as the maize yield from the fertilized plot was significantly higher than the control plots. $CO_2$ gas emitted was high in the first week of the experiment (immediately after tillage), but dropped in subsequent weeks until an inconsistent trend or pattern was observed. Result confirms the roles of high precipitation and soil moisture in $CO_2$ emission as the emission was high during the wet season than in the dry season. It was concluded that zero tillage can reduce $CO_2$ emission, enhance yield and provide environmentally friendly conditions.

**Keywords:** Fertilizer, Maize, yield, tillage, $CO_2$ emissions

## Contributions to Vadose Zone Research by the University of Pretoria

Matthys A Dippenaar
University of Pretoria

The Department of Geology of the University of Pretoria (UP) has been involved in research on the complex highly variable vadose zone comprising manmade materials, transported soils to residual soils, completely weathered to fresh rocks, and enriched to hardpan pedocretes. Our research explains the spatial flow mechanisms and regimes of natural material successions and supersede anthropogenic materials such as cemeteries, permeable pavement, and artificial ground above it. The talk summarises R 5.6 million worth of Water Research Commission in 12 years during which UP provided worldwide new science and >20 peer-reviewed paper, three completed and four current PhD students. We contributed to complex flow systems and how moisture moves within unsaturated double porosity systems subjected to spatial, anthropogenic and temporal changes.

# Rainfall Induced Transient Pressure Wave Mechanisms in Tailings Dams

Charné Theron[1], Simon A. Lorentz[2]

[1]Department of Spatial Planning, Rijks University of Groningen (RUG), Netherlands, c.theron@rug.nl ORCID 0000-0002- 2900-5513

[2]SRK Consulting, South Africa, ORCID 0000-0003- 3058-6789

Previous studies conducted on the causes of failure of Tailings Storage Facilities indicate rainfall-induced slope instability as the main trigger. However, the generation of certain physical/hydrological processes causing landslides, and the behaviour of soil hydraulic properties in the vadose zone when exposed to high intensity rainfall events, have only been considered on natural hillslopes. This paper aims to investigate whether the rapid mobilisation of pre-event water through two transient pressure waves, i.e. Groundwater Ridging and the Lisse Effect, contribute to slope instability through the propagation of pore air pressure. For this purpose, a 2.85 m high soil column (600 mm ID), containing tailings at *in-situ* dry bulk density, was used to investigate infiltration characteristics in the partially saturated porous medium. The column was fitted with seven data ports, each consisting of a time domain reflectometry probe, a mini tensiometer, and a pore air pressure probe. The experimental setup allowed for the application of artificial rainfall at different intensities and controlled boundary conditions, during which time, automatic logging of hydraulic state variables was continuously recorded. This study also briefly discusses the anticipated impact of climate change on rainfall parameters and quantifies the geotechnical characteristics of the tailing's porous media under variably saturated states. The results showed that after the application of water to the soil surface, pore air pressure ahead of the wetting front increased, causing air pressure wave propagation to mobilise pre-event water and reduce pore water suction. This led to the conclusion that high intensity rainfall events, combined with pre-event water, contribute to the generation of transient pressure waves in tailings porous media, thereby inducing the rapid transmission of pressure head to a potential failure plane and contributing to slope instability.

# Surface Boundary Conditions for Finite Element Simulation of Platinum Tailings in a Semi-Arid Environment

S. Lorentz[1,2] B. Gray[1] S. Imrie[1] and A. Clulow[2]

[1] SRK Consulting (South Africa)
[2] Dept. Ag. Meteorology, University of KwaZulu-Natal, South Africa

The fate of water in tailings impoundments needs to be properly understood and predicted in order to comply with the Global Industry Standard on Tailings Management (GISTM). Recently, finite element simulation of tailings pore water has been applied to estimate the saturation distribution; the position of phreatic surface and fluxes of pore water to drain systems. Paramount to the success of these simulations is a realistic representation of the tailings surface boundary conditions.

In the semi-arid areas of southern Africa, Annual Potential Evapotranspiration (PET), the atmospheric demand for water uptake, exceeds annual rainfall by more than threefold. Nevertheless, the intensity and volumes of daily rainfall result in water ingress into platinum tailings porous media and result in periodic recharge to a phreatic surface. In this semi-arid environment, evaporation losses from bare surfaces are primarily dependent on the hydraulics of the porous medium, which controls the fluxes of water and vapour to the surface, rather than the atmospheric demand. However, the fate of the deposited water is difficult to assess, particularly at high rates of rise, due to the partition of fluxes, comprising surface runoff to the pool, infiltration during rain and deposition, percolation from the deposited layer post deposition, entrainment of interstitial water and evaporation from wetted and drying surfaces. Practitioners have often resorted to empirical approaches to estimate evaporation losses and infiltration rates. This can result in significant error to the overall water budget, poor estimates of recharge to the phreatic surface and confounding conditions for water management.

In this study, a series of simultaneous observations of atmospheric driving forces, material characteristics and water dynamics were conducted in situ. The observations included full meteorological monitoring and characterisation of the tailings hydraulic properties. In-situ observations included automatic recording lysimeters in the tailings beach to measure evaporation rates and tailings pore water sensors in selected profiles on the beach to measure infiltration and percolation flux states. Finally, a Surface Renewal station was erected on the tailings beach prior to, during and post deposition to observe actual evaporation fluxes during these conditions. From these observations the rate of infiltration and evaporation losses were calculated and compared to finite element simulations. This paper describes the experimental set-up, the observed fluxes and the assessment against simulations. Guidelines are presented and compared with global standards and guidelines for future estimation of evaporation, infiltration and percolation fluxes during tailings dam operation.

*Keywords:* Evaporation, Infiltration, Surface Renewal.

**The stochastic interpretation of water balance components predicted by a hydrological model**

Quirijn de Jong van Lier – University of São Paulo, Brazil

Vadose zone hydrological models employing finite difference numerical solutions of the Richards equation allow simulating the movement and predicting the state of soil water and associated quantities in the vadose zone. Robust algorithms are available to perform such simulations and most numerical issues with these have been solved. Parameters describing the relation between hydraulic conductivity K, pressure head h, and water content θ determine the quality of model output. These parameters are commonly expressed as means, standard errors, and correlations between parameters. We developed a stochastic framework to evaluate the outputs of the SWAP hydrological model according to the uncertainty and correlations in the VGM parameters. Performing runs with $10^5$ stochastic realizations, we evaluated the predictions of evaporation, transpiration, bottom flux, and runoff and their frequency distribution for some scenarios of crops and soils. Results will be discussed and show that no general conclusion can be drawn about the frequency distributions of soil water balance components as a result of the uncertainty of and correlation between VGM parameters. Skewed or multimodal distributions of output parameters are common, and the most commonly performed prediction using the average VGM parameter values does not always agree to the mean or median of stochastic realizations. Users of hydrological models should be aware of this propagation of uncertainty and correlation into the model outputs. The investigation of the representativeness of average VGM parameters in specific scenarios adds to the interpretation of the predictive power of hydrological models.

# Evaluating the reliability of the South African National Land Type Map, iSDA, AfSIS, and SoilGrids-DSSAT-10km soil databases for small scale application in South Africa

Aimee Thomson

University of Pretoria

Obtaining accurate, reliable soil parameter information for model application is a global challenge. The temporal and monetary obstacles associated with in field soil data collection have been diminished through the creation of online estimated soil parameter databases. Database resources are plentiful and relatively accessible to the public, however, soil parameters obtained from these databases often do not represent the area under observation accurately and are prone to user misapplication. This study investigates the reliability of the databases AfSIS, SoilGrids-DSSAT-10km, iSDA, and the South African National Land Type Map for point scale application in South Africa. Measured data of three study sites occurring in different regions of South Africa were compared to the estimated parameters of the online databases, as well as data obtained from the National Land Type Survey of South Africa map. Profile parameters under observation included clay content, silt content, bulk density, soil organic carbon, pH and total nitrogen, and were compared at 0.05 m increments. Significant* discrepancies, demonstrated by the statistics, between the measured and estimated values were observed, with no database clearly outperforming another. This study highlights the necessity of creating a local, more accurate soil database for South Africa, especially in the face of climate change and food insecurity.

# The cosmic-ray neutron probe: a potential irrigation scheduling tool for centre-pivot irrigated potatoes?

JM Steyn, JG Annandale, CS Everson, M van der Laan, T Smit, R Kumasamba

Department of Plant and Soil Sciences, University of Pretoria, Private Bag X20, Pretoria, South Africa

Many of the most popular irrigation scheduling tools make point measurements of soil water content (SWC) which are prone to error due to vertical and horizontal spatial variability. The cosmic-ray probe (CRP) is a relatively newly developed instrument capable of making claimed area averaged estimates of soil water content to depths ranging from 0.1 to 0.7 m. The CRP potentially has the ability to measure the soil water content of an entire 30 ha centre-pivot irrigated field, but this has not been tested and reported on extensively. This study was undertaken to investigate the accuracy and usefulness of the CRP as an intermediate scale soil water sensor, and to ascertain if the measurements are of use for irrigation scheduling of a shallow rooted crop like potatoes. One dryland and three irrigated field trials were conducted across the north-eastern part of South Africa, in which the calibration, accuracy, effect of vegetation and usefulness of data for irrigation scheduling was assessed. CRP measurements generally reflected changes in soil water content over the growing season. However, the effective measurement depth under irrigation appears to be less than 0.2 m, and surface ponding contributed to high levels of variability in readings due to the neutron moderating effect of this surface water. Although the data presented in this study suggests some potential for CRP measurements for irrigation scheduling of shallow rooted crops, there remains uncertainty around the effect of water contained in biomass, and the shallow depth of measurement is likely to be the major limitation for its practical use.

## Digital Soil Mapping for Hydrological Modelling in the Goukou Catchment

Eddie Smit

Although soils form an integral part of landscape hydrological processes, the importance of soil information in hydrological modelling is often neglected. This study investigated the impact of soil information on streamflow modelling accuracy and hydrological process representation. Two different levels of soil information were compared to long-term streamflow in the upper Goukou catchment (230 $km^2$), South Africa, over a period of 23 years using the Soil Water Assessment Tool (SWAT+). The land type soil map (LTSM) dataset was less detailed and derived from the best, readily available soil dataset for South Africa currently. The hydrological soil map (HSM) dataset was more detailed and was created using infield hydropedological soil observations combined with digital soil mapping techniques. Monthly streamflow simulation was similar for both soil datasets, with Nash-Sutcliffe Efficiency and Kling-Gupta Efficiency values of 0.57 and 0.59 (HSM), and 0.56 and 0.60 (LTSM), respectively. It is however important to assess through which hydrological processes were these streamflow values generated as well as their spatial distribution within the catchment. Upon further assessment the representation of hydrological processes within the catchment differed greatly between the two datasets, with the HSM more accurately representing the internal hydrological processes as it was based on infield observations. It was concluded that hydropedological information could be of great value in effective catchment management strategies, since it improves representation of internal catchment processes.

**Keywords:** hydrological processes; SWAT+ model; hydropedology; land type soil map; hydrological soil map

# Development and application of a micro-tensiometer

Prof SW Jacobsz

University of Pretoria, Department of Civil Engineering

sw.jacobsz@up.ac.za

South Africa is a water-scarce country, resulting in most soils being unsaturated. Soil suction is of great interest in various sub-disciplines in civil engineering, agriculture and other fields.

Tensiometers allow for the direct measurement of soil suctions. High capacity tensiometers, with capacities in excess of 100 kPa, are difficult to source and expensive. A low-cost (components approx. R500), high-capacity tensiometer was developed at UP, capable of routinely measuring suctions over 1 MPa.

A maximum suction of 1.7 MPa was measured by allowing evaporation from a saturated tensiometer's ceramic filter element. Suctions over 1 MPa are routinely measured.

# Emergent Properties of Soil Moisture Dynamics Beyond Darcy Scale and Their Applications in Hydrology

Vinit Sehgal and Binayak Mohanty
Texas A&M University, College Station, Texas, USA

Simultaneous and complex interactions between soil, vegetation, and climate govern the effective soil moisture (SM) dynamics beyond the Darcy scale. Latest advancements in SM remote sensing (RS) can facilitate a better understanding of largescale SM dynamics and their controls, inspiring novel applications in hydrology. Using global surface SM observations from NASA's SMAP satellite (36 KM), we parameterize the pathway of SM drydowns to quantify footprint scale land-atmospheric coupling strength and effective soil water retention properties. SM drydown parameters are used for near-real-time, global-scale, flash drought impact assessment, and to improve the understanding of the governing controls of SM dynamics at the RS-footprint scale. We identify the critical thresholds of footprint-scale soil-vegetation-climate interactions and SM preferential states, to quantify the crossing properties (intensity-frequency and duration) of the dynamic shift of SM between wet and dry hydrologic states. We demonstrate that at continental scales, crossing properties of SM explain the coexistence patterns of soil-vegetation and climate, thereby providing an important tool in quantifying the collective impacts of climate change on global ecosystems. At the watershed scale, crossing properties of SM can capture sub-watershed scale variability in soil hydraulic response to atmospheric forcings and facilitate a computationally efficient method of estimating effective parameters for large-scale Land-Surface and/or Earth System Models.

# Contradicting strategies: How deep roots help apple trees combat droughts under varying deep soil wetness.

Bing Cheng Si, Huijie Li, Department of Soil Science, University of Saskatchewan

Both field observation and numerical model have demonstrated that trees can extend their roots to deep soil (>1 m in depth). However, little work has been done to assess how deep roots impact trees' transpiration. This study hypothesized that when available water in deep soil is exhausted, roots in drying soil will inhibit forest transpiration. To test this hypothesis, two irrigation schemes—shallow soil irrigation (SI) and shallow soil plus deep soil irrigation (SDI)—were performed in September 2017 in a 23-year-old apple orchard. After irrigation (100 mm for SI and 500 mm for SDI), soil water within the top 3 m for SI and top 8 m for SDI were replenished to about field capacity. Measurements were conducted before irrigation in July, 2017 and after irrigation from April to July in 2018. The results showed that the two treatments had similar soil water status and sap flow density before irrigation ($P > 0.05$). Soil water storage from 1 to 18 m depth decreased more than 1200 mm after afforestation. However, after irrigation, sap flow density in the SI treatment was significantly smaller than that in the SDI treatment ($P < 0.05$). Sap flow density in the SI treatment only accounted for 60 ± 6% of that in the SDI treatment during the period with high water demand. Stomatal conductance in the SI plot was significantly smaller than that in the SDI treatment, while there was no difference in leaf area index between the two plots. These results demonstrated that deep roots have opposing roles: they promote transpiration when there is sufficient available water in deep soil, but inhibit transpiration via decreasing stomatal conductance when available water in deep soil is exhausted. These findings improve the understanding of how deep roots impact apple tree water use in water-limited environments.

**Nitrogen Fixation by Mungbean Genotypes in Different Soil Textures**

Ensuring food and nutritional security under high climate variability and a rapidly growing population remains a challenge. Mungbean [*Vigna radiata* (L.) Wilczek] is a short duration and drought-tolerant legume crop capable of symbiotic atmospheric nitrogen fixation, making it suitable to smallholder production systems. However, estimates of biological $N_2$ fixation by mungbean in different soils has not been extensively studied compared to other legume crops. We conducted this study to evaluate plant growth and symbiotic performance of five mungbean genotypes inoculated with *Bradyrhizobium* and grown in loamy sand and silt loam soils under glasshouse conditions. The percent of nitrogen derived from atmosphere (%Ndfa) using the $^{15}N$ natural abundance method was higher in the loamy sand soil (28%) than the silt loam soil (22%). Mungbean fixed more N when grown in the silt loam soil (67 mg $plant^{-1}$) than in loamy sand (16 mg $plant^{-1}$) and also took up more N from the silt loam soil (235 mg $plant^{-1}$) than loamy sand soil (40 mg $plant^{-1}$). Overall, mungbean relied more of soil mineral N than symbiotically fixed N for its N nutrition. Genotype IC 8972-1 produced significantly ($P$<0.05) more biomass (7.85 g $plant^{-1}$) and had higher shoot N content (200 mg $plant^{-1}$) and soil N uptake (155 mg $plant^{-1}$) but recorded the lowest %Ndfa values (23%) compared to other genotypes. The significant interaction ($P$<0.05) between soil texture and genotypes for dry matter root and %Ndfa indicates the role of legume roots in symbiotic $N_2$ fixation. Correlations between dry matter and N-fixed, soil N uptake and $\delta^{15}N$ (‰), and shoot N content were significant ($P$<0.05), suggesting genotypes together with soil properties could alter $N_2$ fixation in mungbean. Results from this study illustrate the need to consider soil physical and chemical properties and genotypes in order to maximize N contribution to agricultural production systems.

**Keywords**: Mungbean, Nitrogen fixation, $^{15}N$, %Ndfa, Soil texture

## Plant growth in soils with particulate plastics

MB Kirkham

Particulate plastics contaminate the terrestrial environment, yet no information exists concerning the water-relations of plants grown in soil with particulate plastics. Therefore, the first objective of this experiment was to determine the growth, stomatal resistance, and evapotranspiration rate of wheat when grown in soil with particulate plastics. Because particulate plastics can be a vector for toxic trace-element uptake, the second objective of this experiment was to determine the uptake of cadmium (Cd) to see if they enhanced its uptake. Wheat (*Triticum aestivum* L. 'Everest') was grown for 28 days under greenhouse conditions in pots with a commercial potting soil. The particulate plastic was polyethylene glycol with a molecular weight of 8000 (called PEG 8000). At the beginning of the experiment, pots were divided into three sets: pots with soil that received no PEG 8000 (called the no-PEG treatment); pots with soil into which dry PEG 8000 was mixed at a rate of 2% on a dry-weight basis (called the dry-PEG treatment); and pots with soil that received PEG 8000 via irrigation of a 2% solution of PEG 8000 (called the wet-PEG treatment). The three sets of pots were divided in half, and, during the experiment, half of the pots were irrigated with a 100 μg/mL Cd solution. The pots in the no-PEG treatment and the dry-PEG treatment were irrigated with tap water or the 100 μg/mL Cd solution. The pots in the wet-PEG treatment were irrigated with a solution containing 2% PEG and no Cd or 2% PEG and 100 μg/mL Cd. During the experiment, height was measured with a ruler, evapotranspiration rate was determined by weighing the pots, and stomatal resistance was measured using a porometer.

Both with and without Cd, 18 days after planting plants in the wet-PEG treatment were shorter than plants in the no-PEG treatment. Both with and without Cd, the evapotranspiration rate of plants in the wet-PEG treatment was reduced by 0.3 mm/day compared to plants in the no-PEG treatment. Without Cd, the stomatal resistances of plants grown in the wet-PEG treatment and in the no-PEG treatment were 295 s/m and 178 s/m, respectively; for plants grown with Cd, these values were 322 s/m and 231 s/m, respectively. Shoots of plants grown in the no-PEG treatment with Cd and in the dry-PEG treatment with Cd had similar Cd concentrations, and each had a concentration of about 130.0 mg/kg Cd. Plants grown in the wet-PEG treatment with Cd had a Cd concentration of 204.8 mg/kg. The presence of wet PEG in the soil increased the Cd in the plants by 1.5 times (204.8 vs 130.0 mg/kg). The results showed that PEG 8000 was a potent vector for the transport of Cd to wheat leaves.

# Soil structure revealed from covariation in thermal and electrical properties

Josh Heitman and Yongwei Fu, NC State University; and Robert Horton, Iowa State University

Soil structure is defined as the spatial arrangement of solids and a combination of different types of pores. Both soil thermal and electrical properties can provide insights about soil structure but when each is considered separately, the picture remains incomplete. As solid phase is dominant in heat transfer, soil thermal conductivity varies widely according to soil porosity, mineral composition, particle shape and orientation but is less sensitive to pore geometry controlled by connectivity and pore tortuosity. Alternately, soil electrical conductivity depends most on fluid phases and thus it varies widely according to pore geometry over the complete range of saturation but it is less sensitive to soil solids-related properties mentioned above. To-date, very few studies have attempted to characterize soil structure from electrical and thermal properties together. Because electrical and thermal properties each provide unique perspectives on soil structure, we hypothesize that thermal and electrical properties characterized together may offer a new opportunity to dynamically predict soil hydraulic properties of structured soils from in situ measurements. A general expression for soil unsaturated hydraulic conductivity can be developed as the product of a pore-geometry term, controlled by pore tortuosity and connectivity, and a pore-size distribution term. In our work the pore-geometry term was represented by the electrical conductivity, where electrical current and water flow were treated as analogous processes. The pore-size distribution term was developed in terms of thermal conductivity which was derived based on the similarity between soil water retention and thermal conductivity curves. Our work provides a theoretical basis to determine in-situ variations in field hydraulic properties and soil structure from co-located thermal and electrical property measurements.