Towards hydrological and geochemical understanding of an ephemeral palustrine perched water table “wetland” (Lanseria Gneiss, Midrand, South Africa)

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Abstract. Wetland delineation is commonly based on terrain unit, soil form, soil wetness and vegetation indicators. These and the shallow groundwater or proximate surface water are often absent in many ephemeral inland South African areas due to, for instance, prolonged dry periods (seasons to years) which mask these indicators, as well as disruption of surface materials due to construction, agricultural activities and field fires. Furthermore, many “wetlands” in South Africa comply with the four indicators, but the notable absent requirement for wetlands are missing, namely the shallow groundwater table, as many of these systems form in hillslope seeps, catenas or from perched water tables. A 200 m long excavation through one such a system is being studied in Midrand (Gauteng, South Africa). The site is underlain by Lanseria Gneiss and is waterlogged after long and intense periods of intense rainfall. Frequent downslope soil profiling, horizon-specific laboratory analyses for grading and Atterberg Limits, X-Ray Diffraction and X-Ray Fluorescensce Spectroscopy data are interpreted together with soil percolation tests to generate a conceptual model of the system. The results are discussed in terms of the need to consider these temporary systems that do not have a shallow groundwater table and that are not in direct contact with surface drainage features as a possible special type of wetlands, notably in arid regions where they play a very important role in biodiversity and should, therefore, be protected.

Keywords: wetland; catena; perched water table; palustrine wetland; ephemeral wetland; ferricrete.

1. Introduction

As most other arid to semi-arid countries, South Africa is characterised by low rainfall, limited surface drainage features and fairly deep groundwater tables. Subsequently, formal wetlands complying with the identifiers of soil wetness, soil form, land form and vegetation, together with the required shallow water table, may be limited due to the depth of the groundwater and the absence of distinct drainage features. A number of "wetlands" do, however, form following prolonged and intense rainfall events and are possibly associated with seep faces, catenas and temporary perched water tables.

The main objectives of this paper are to address the driving hydrological processes in the formation of these systems through the application of field and laboratory data, as well as to highlight the need for refined methodology to identify such temporary "wetland" systems that may very easily be overlooked during single investigations based on the landform, soil form, soil wetness and vegetation alone. Finally, recommendations are made regarding the possible inclusion of these systems as a special type of wetland, regardless of the absence of a shallow groundwater table, to ensure protection of these sensitive systems that are playing a vital part in biodiversity and water quality. Whether they are termed *temporary hillslope wetlands*, *perched water table wetlands*, *wet grasslands*, a type of *isolated* or *ephemeral wetlands* or *paluslopes* are not clearly defined in the wetland terminology, but the need for protection requires their formalised inclusion in the literature to ensure early identification.

2. Background

2.1. Defining wetlands

Wetlands are complex natural systems, which are commonly identified by biota and visible soil saturation. A detailed study by Day et al. (2010) on the assessment of temporary wetlands during dry conditions focuses on the wetland indicators and their applicability. In South Africa, the definition stipulated by the National Water Act (DWAF 1998) apply, viz. "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil."

Identification of the vegetation might seem readily achievable, but in South Africa these species are often absent during the dryer months or are removed for a variety of reasons.

The Ramsar Convention (2006) defines wetlands as areas where "…water is the primary factor controlling the environment and the associated plant and animal life" and occurring where the water table is at or near the land surface of the land or where the land is covered by shallow water. The formal definition of a wetland in the Ramsar Convention states that wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" and "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands". Excluding man-made wetlands, five types of wetlands are recognized, including marine, estuarine, lacustrine, riverine and palustrine, the latter referring to marshes, swamps and bogs.

Classification of wetlands is generally based on a variety of criteria, including vegetation, soil wetness and landform. For inland wetlands, Semeniuk and Semeniuk (1995) recommend thirteen such types of wetlands based on the landform and wetness criteria (Table 1). In terms of the wetness criterion, inundated implies free-standing water, whereas waterlogged refers to saturated soils without free-standing water. Paluslopes, as the most relevant possible class to the case study presented hereafter, are seasonally waterlogged either by seepage from waterlogged soils or due to direct precipitation and are non-emergent, resulting in wetland conditions on a slope.

2.2. Identification and classification of wetlands

Table 1. Classification of inland wetlands (after Semeniuk and Semeniuk 1995).

Land Form	**Permanently inundated**	**Seasonally inundated**	**Intermittently inundated**	**Seasonally waterlogged**
Basin	Lake	Sumpland	Playa	Dampland
Stream	River	Creek	Wadi	Trough
Flat	—	Floodplain	Barlkarra	Palusplain
Slope	—	—	—	Paluslope
Highland	—	—	—	Palusmont

A number of authors have recently considered inter-disciplinary influences on the occurrence of wetlands and, notably, referring to inland, isolated and/ or ephemeral wetlands. Siegel (1988) evaluates the influence of disturbance on a number of bogs, fens and mires, with precipitation being the main water contribution to these systems with possible influence of groundwater in fens. Although generally occurring in flatter areas, the concluding remarks accentuate the lack of hydrological understanding of the functioning of these wetlands. Richardson (2003) considered the classification of pocosins (swamps on hills), concluding that they may not be completely isolated, but it fact contribute to adjacent ecosystems. Zedler (2003) focussed specifically around vernal pools, which form in basins or flatter areas, but are also considered isolated from the regional hydrological system and are ephemeral. Gasca and Ross (2006), for instance, include proper regional hydrogeology to better understand the wetland system and the implications of groundwater abstractions thereon, whereas Steube et al. (2008) focus around the importance of collaboration between ecologists, hydrogeologists and geochemists. Lane et al. (2012) address the loss of wetlands due to agriculture and development, notably with respect to isolated wetlands. What are notable are the issues of lost wetlands and the need for incorporation of proper understanding of the subsurface hydrology.

Wetlands are indicated based on the presence of one or more of the following indicators (DWAF 2005): (1) terrain unit indicators to outline portions of the landscape likely for the occurrence of wetlands; (2) soil form indicators to identify soils subjected to prolonged and frequent saturation; (3) soil wetness indicators relating to the morphological evidence of prolonged and frequent saturation; and (4) vegetation indicators identifying hydrophilic vegetation. Additional to this, wetlands should contain at least hydromorphic soils, occasional presence of water-loving plants (hydrophytes) and/ or a high water table resulting in anaerobic conditions in the upper 0.50 m of the soil.

Day et al. (2010) additionally suggest abiotic indicators (to be used together with a variety of biotic determinants) which include shallow clay or an impervious layer within 0.5 m of the surface, deep cracking on thick clayey substrata, organic fines on surface, mulch layers, sediment deposits on plants and rock, biotic crusts, algal marker, water marks on rocks and structures and shells or exoskeletons of aquatic vertebrates.

The possible absence of distinct vegetation and disruption of natural surface soils are significant omissions in classical wetland delineation. With regards to what is termed *temporary perched water hillslope wetlands* in this paper, these indicators are rarely all simultaneously present and are often absent altogether for prolonged periods. These wetlands form typically due to perched water tables occurring annually or less frequently, notably dependent on prolonged high intensity precipitation events in these upper hillslopes. Wetland biota resurface directly following waterlogging.

Attempts at characterising temporary wetlands are limited. Wise et al. (2000) considered the importance of quantifying the interaction between isolated wetlands and the deeper aquifers (which – although not necessarily temporary systems – addresses the importance of deeper investigation). Warwick and Brock (2003) evaluated duration and season of flooding with respect to germination, establishment of wetland plants and completion of life cycles. Espinar and Clemente (2007) related seasonal cracks and dispersion of topsoil during dry periods to different diaspores at different depths in Mediterranean temporary wetlands in Spain. Herrero and Castañeda (2009) evaluated the importance of wetlands in arid areas with specific reference to the variability from perennial to temporary, fresh water to hypersaline and in size from less than 1 km^2 to more than 9 000 km^2. Additionally, they specifically mention the highly variable interannual and seasonal rainfall patterns and biota adapted to extreme environments. Roshier and Rumbachs (2004) applied AVHRR satellite data to map temporary wetlands in the arid regions of Australia. Bagella et al. (2010) evaluated plant assemblages within nine temporary wetlands in the Mediterranean biogeographical region, which are dependent on the groundwater depth and the period of flooding. Although most of these studies consider temporary wetlands related to distinct drainage features, isolated wetlands, or the biotic markers of temporary wetlands, it relates to these poorly studied yet extremely important components of the hydrological cycle.

3. Materials and Methods

3.1. Study site

The site is situated in the Midrand area (Johannesburg) of Gauteng Province at the junction of the N1 motorway and Olifantsfontein Road between Pretoria and the Johannesburg, South Africa (Fig. 1(a) and Fig. 1(b)). The topography ranges between 1 561 mamsl in the northeastern corner of the site to 1 493 mamsl where the drainage features exits the site at the western boundary, amounting to an average gradient of 3°

(from Google Earth © imagery). The study site is underlain by Archaean Lanseria Gneiss of the Johannesburg Dome Granite (Fig. 1(b)), comprising essentially tonalite, granodiorite and trondjemite (Robb et al. 2009).

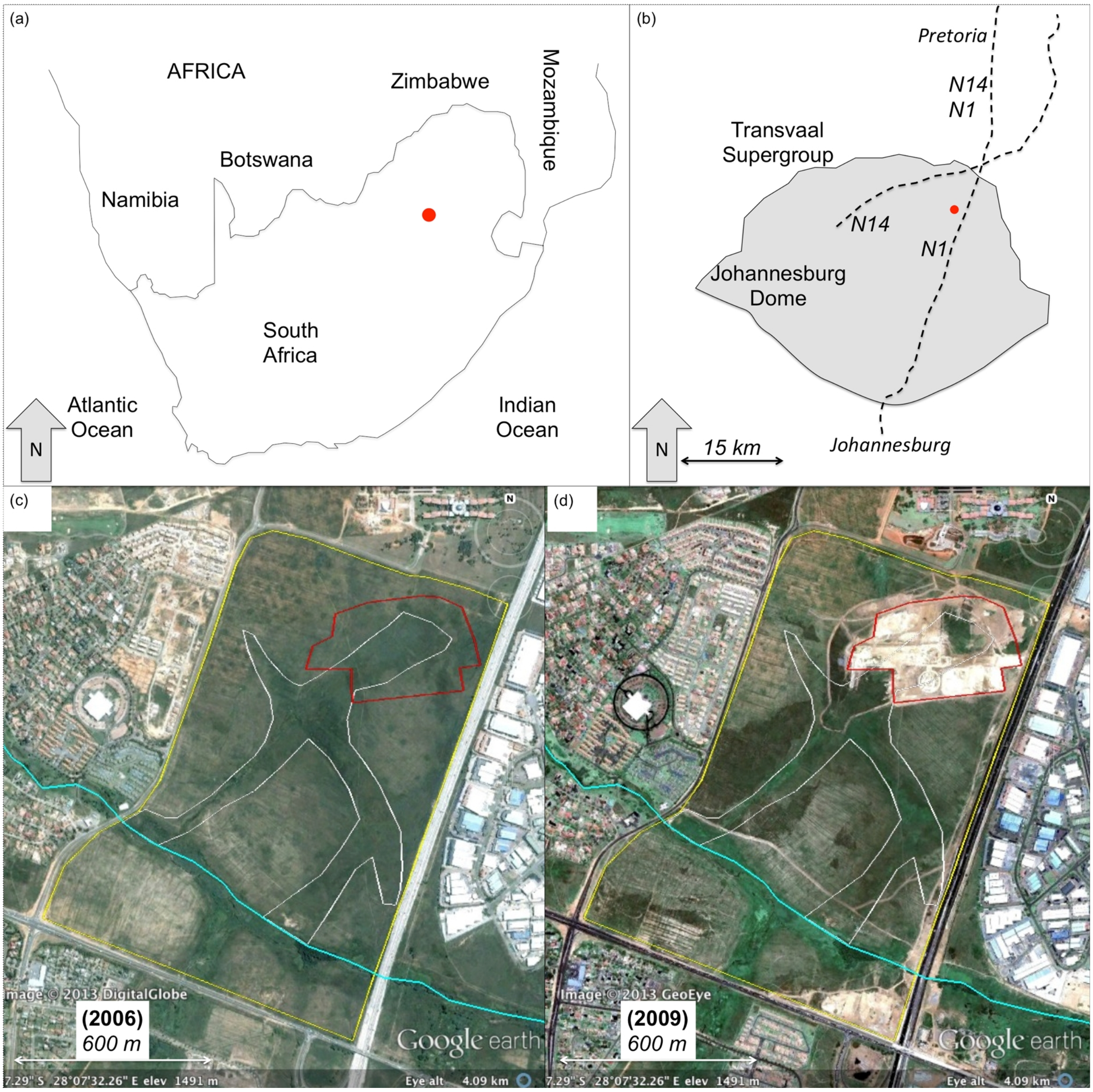

Figure 1. (a) Locality, (b) regional geology with Johannesburg Granite Dome indicated, and (c) and (d) satellite imagery before and after excavation indicating the boundaries of the site, the nearest surface drainage feature and extent of the wetness (© Digital Globe/ Google Earth 2013).

The upper reaches of the site were excavated for development in 2008. Fig. 1(c) depicts the site prior to excavation in 2006 and Fig 1(d) directly following excavation in 2009. Note the extent of the wet conditions as visible from the satellite imagery and the nearest drainage feature approximately 800 m downslope of the excavation (© Google Earth 2013). Distinct biota were absent during the dryer winter months when the environmental investigations were being conducted, which was followed by a field fire destroying whatever vegetation remained. Subsequently, construction commenced and a 200 m long profile is now exposed from the upper slope to the lower slope, giving valuable insight into the anatomy of the hydrological system.

3.2. Water levels

Three piezometers were installed following excavation with depths varying between 3 m and 6 m. Seepage water appears between surface and approximately 2 m below surface following intense periods of rainfall and is practically absent in the dryer months and years. The regional groundwater is expected to occur within fractured granite and the depth has not been confirmed on the site, although it is assumed to be deeper than 6 m (the depth of the deepest piezometer which is occasionally dry).

The perched water table occurs shallower than 1 m below surface (when present) and is expected to be connected to the stream forming the southern perimeter of the site.

3.3. Profile Description and Sampling

Sixteen soil profiles were described according to the draft South African National Standard on soil profiling for engineering purposes (SABS 2009), of which seven have been extensively sampled and included in this study. Standard parameters are moisture, colour, consistency, soil structure, soil type (texture) and origin with other noteworthy observations added where relevant.

The seven profiles were sampled in each visually differing horizon (based on origin, viz. colluvium, ferricrete in pebble marker and residual granite, residual granite, completely weathered granite and highly weathered granite bedrock). 39 samples in total were submitted for X-Ray Diffraction (XRD), X-Ray Fluorescence Spectroscopy (XRF), soil grading and hydrometer, and Atterberg limits determination. The latter were used to determine porosity based on density relationships. The bulk dry density (ρ_B) was determined in the laboratory from lumps of undisturbed sample to preserve the natural soil structure. The solid fraction density (ρ_S) was determined according to Eq. 1 as the sum of the percentage of minerals present (f_i based on the XRD results) and published typical specific gravities of these minerals (converted to mineral density $\rho_{mineral}$ as per Table 2).

$$\eta = 1 - (\rho_B / \rho_S) \text{ where } \rho_S = \Sigma (f_{mineral} \cdot \rho_{mineral}) \quad (1)$$

Table 2. Mineral densities used in the calculation of porosity (specific gravity ranges after Deer et al. 1996).

Mineral	**Specific Gravity Range**	**Assumed Mineral Density $\rho_{mineral}$ (kg/m^3)**
Alkali Feldspar (K → Na)	2.55 - 2.63	2 560
Plagioclase (Na)	2.62	2 620
Plagioclase (Ca)	2.76	2 760
Quartz	2.65	2 650
Goethite	~ 4.3	4 300
Kaolinite	2.61 - 2.68	2 640

3.4. In-situ percolation testing

The percolation test is used for the field determination of a percolation rate, which is related to the saturated hydraulic conductivity. This method entails the excavation of a vertical test hole with 150 mm diameter and 400 mm depth. All sides of the excavation are to be scarified to ensure optimal infiltration and the test hole bottom is covered with pea-sized gravel. The test hole has to be pre-soaked and the water level is then allowed to drop to 180 mm and time measurements are taken for the drop to 130 mm. The hole is refilled to a water level of 180 mm and the measurements are repeated until the percolation rates do not vary by more than 10% between consecutive readings. The percolation rate (mm/h) is determined by dividing the last drop in water level (mm) by the time taken for this drop (hours) (SABS 1993). The field hydraulic conductivities were determined based on the assumptions that (a) the drop in head over the cross-sectional area per time represents vertical influx Q once constant flow rates are assumed; (b) the hydraulic gradient is unity and essentially vertical under these constant flow rate conditions where the material is assumed presoaked; and (c) all natural moisture content variations and lateral fluxes are minimized by allowing the test site to pre-soak.

4. Results

4.1. Material succession and soil profiles

Fig. 2 shows a panorama viewing southward to the east – west section in the excavation (profile VP01 was described at the left hand of the excavation and profile VP06 just outside of the photograph on the right hand side). Note the distinct seepage from the ferricrete and the apparent regeneration of the wetland conditions on the bedrock forming the excavation floor.

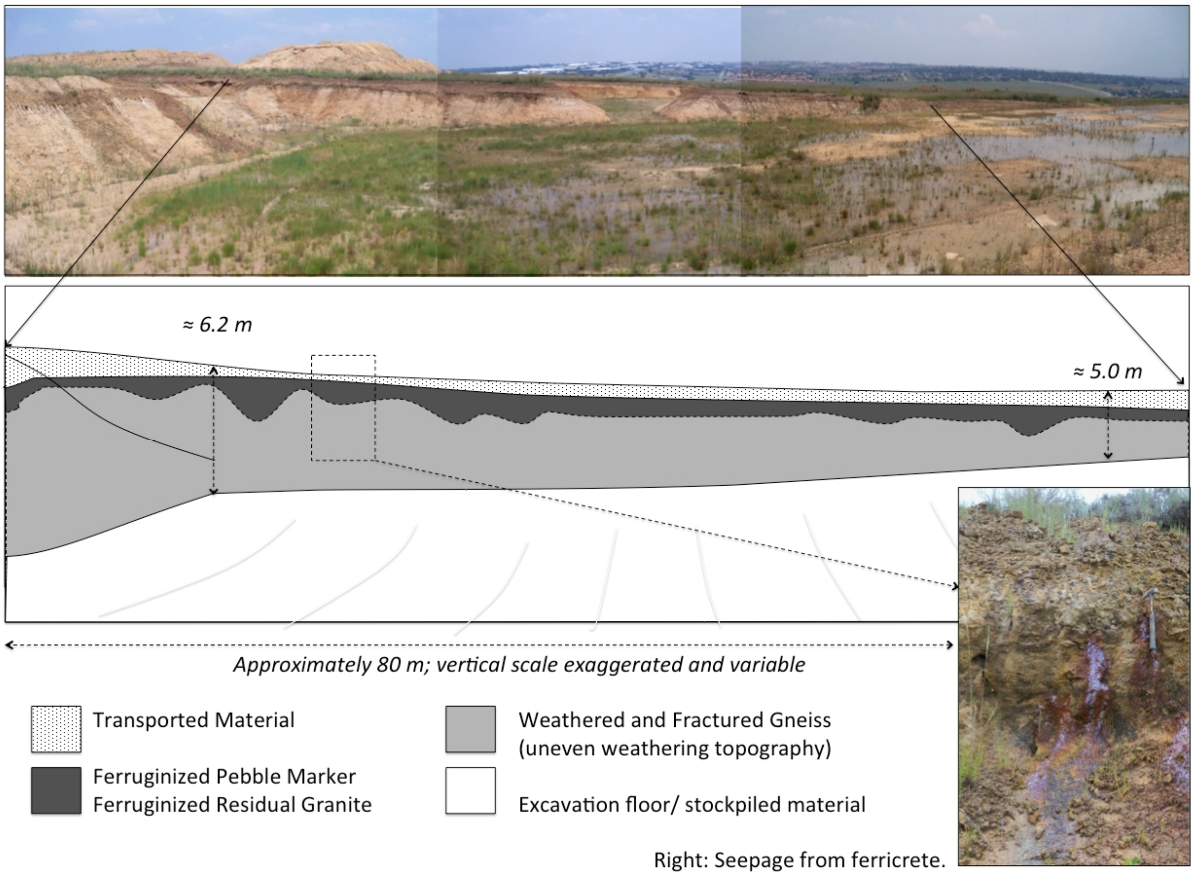

Figure 2. Existing excavation of the site under investigation.

Four typical soil profiles along the slope are shown in Fig. 3, representing the upper slope (VP07), upper-midslope (VP01), midslope (VP03) and mid-lower slope (VP06). Note the distinct absence of ferricrete in VP03 (although some discolouration is evident), as well as the pinholed structure in all the upper soil horizons. Bulk of the surface soils grade as silty sand with bedrock becoming progressively less weathered and less fractured with depth.

VP07

0.00 Slightly moist, light brown speckled light orange, medium dense, pinholed, silty SAND. Transported (Colluvium) with abundant roots.

0.85 Dry, light orange mottled and blotched black, very dense, honeycomb FERRICRETE in sandy gravel with abundant quartz pebbles. Residual Granite.

2.48 Dry, light brown mottled yellow and orange stained black along joints, dense, jointed, silty SAND. Completely Weathered Granite.

3.26

VP01

0.00 Dry, greyish brown, medium dense, slightly pinholed with open root channels, clayey silty SAND. Colluvium.

0.46 Dry, brownish orange mottled and blotched black speckled red, very dense, intact. Honeycomb Ferricrete formed in Pebble Marker (with scattered quartz gravel).

0.75 Dry, brownish orange blotched black speckled red, very dense, intact. Honeycomb Ferricrete formed in Residual Granite.

1.90 Dry, white to grey patched yellowish grey, medium dense, intact, silty sandy GRAVEL. Completely Weathered Granite.

3.20 Dry, dusky red speckled yellow and white stained black on joint surfaces, foliated with moderately spaced joints becoming widely spaced with depth, coarse-grained, highly weathered, soft-rock GRANITE.

6.20

VP03

0.00 Slightly moist, greyish brown with reddish orange speckled, medium dense, pinholed, silty clayey SAND. Transported (Colluvium) with abundant roots.

0.84 Slightly moist, orange brown speckled and blotched orange, medium dense, pinholed, silty clayey SAND. Transported (Colluvium).

1.27 Dry, dark yellowish grey blotched orange, dense, (intact), silty SAND. Residual Granite.

2.20 Dry, dark yellowish grey blotched orange, very dense, (intact), gravelly SAND with subangular quartz pebbles. Completely Weathered Granite.

3.40

VP06

0.00 Slightly moist, dark brown mottled reddish orange, medium dense, pinholed, silty SAND. Transported (Colluvium) with roots.

0.45 Slightly moist, light brown blotched reddish orange, loose, (intact), silty clayey SAND. Transported (Colluvium) with roots.

1.14 Slightly moist, light reddish orange mottled black and white, very dense, honeycomb FERRICRETE in sandy gravel. Residual Granite.

2.49 Slightly moist, light grey mottled black and red stained black on joints, dense, (jointed), silty SAND. Completely Weathered Granite.

3.83 Light orange brown stained black on joints, moderately jointed, highly weathered, soft-rock GRANITE.

4.97

Figure 3. Profiles logs on the upper slope (VP07), upper-midslope (VP01), mid slope (VP03) and mid-lower slope (VP06).

Figure 4 shows the soil mineralogy for different horizons in the seven sampled soil profiles. The absence of ferricrete is supported by the absence of goethite in VP07 on the upper reaches of the slope and VP03 in the central portions.

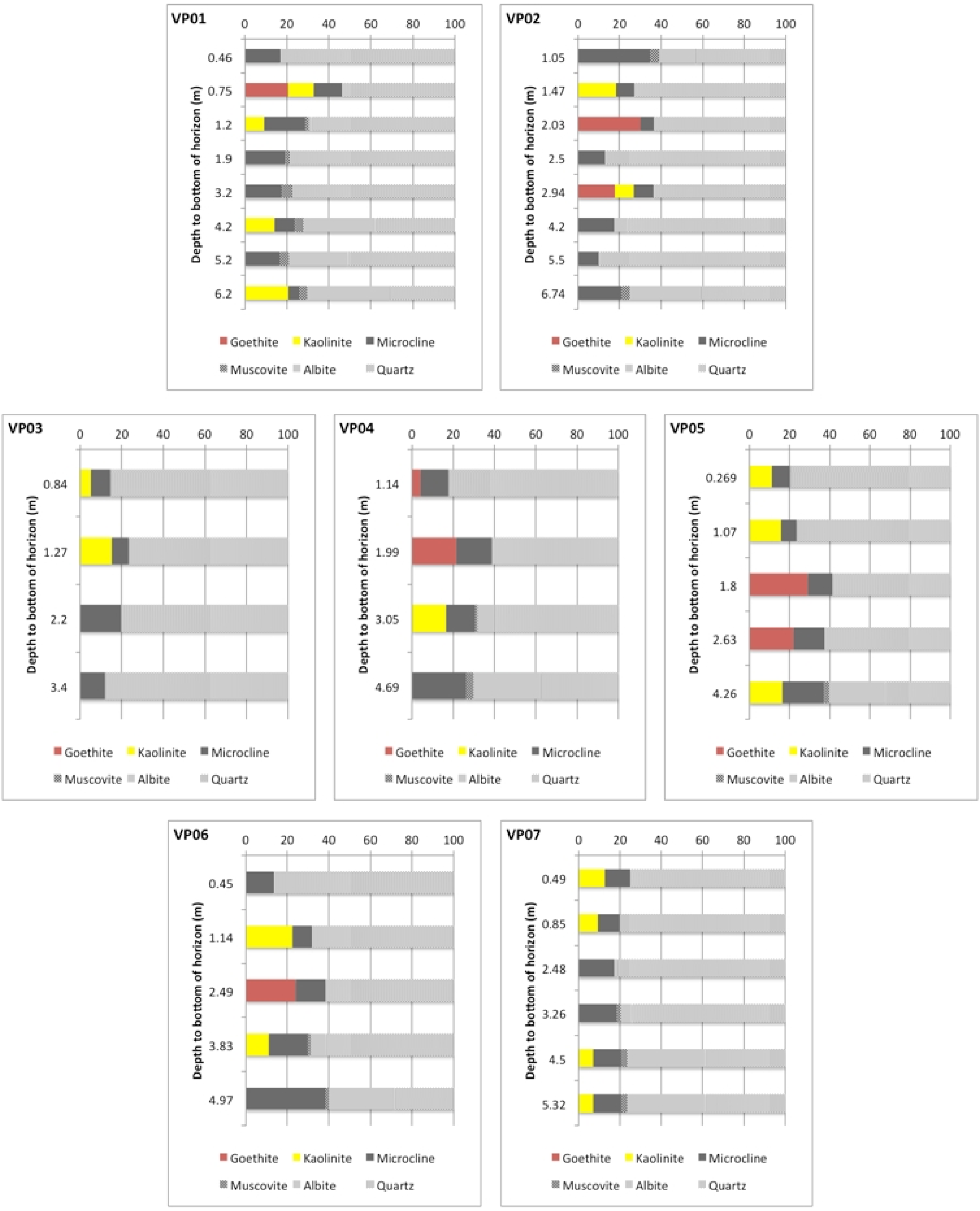

Figure 4. Mineralogy (quantitative XRD) by soil horizon for seven sampled soil profiles.

4.2. Porosity

The calculated porosities are shown in Table 3. The highest porosities were calculated for the open textured colluvium and residual granite. The ferruginized horizon exists in the pebble marker and/ or upper parts of the residual granite and shows lower porosity. However, this lower porosity is characterised by large voids with visible water seepage as opposed to the smaller pores in the other materials. The large pores in the ferruginized horizons allow entry of water from the shallower voided horizons. On entry, due to lower adhesion and apparent lateral interconnectivity, water is allowed to move down gradient in this ferruginized horizon as is evident in the excavation where water seeps out of ferricrete. Where ferricrete is absent, infiltrating or interflow water may be forced to percolate deeper under gravity and possibly result in groundwater recharge. The ferricrete is therefore not an aquiclude, but a conductive zone with large interconnected pores.

Table 3. Porosity values calculated for each soil horizon based on bulk densities and XRD results.

Horizon	**η (average)**	**Standard Deviation**	**Count**
Colluvium	0.22	0.04	3
Ferruginized Horizons	0.15	0.05	3
Residual Granite	0.23	0.08	8
Completely Weathered Granite	0.15	0.06	3
Fractured Granite	0.15	0.02	5

4.3. Hydraulic conductivity

Field percolation test results are shown in Table 4. Average saturated vertical hydraulic conductivity according to this method generally varies within one order of magnitude between roughly 5 x 10^{-5} m/s in the upper-midslope to 6 x 10^{-4} m/s in the mid-lower slope. In all instances, this represents surficial colluvium with ferricrete or residual granite near the base of the trial hole. As the surface materials are tested, the test constraint of determining a vertical conductivity is acceptable, as infiltrating water will probably move in this direction until the ferruginized horizons where interflow commences.

Table 4. Percolation test results.

Landform	**Test**	**K (m/s)**	**Mean**	**St. Dev**	**n**
Upper - Mid	Perc01	1.55E-05	6.94E-05	6.54E-05	8
	Perc07	2.13E-04			
	Perc09	3.07E-05			
	Perc10	6.21E-05			
	Perc11	9.52E-05			
	Perc12	8.77E-05			
	Perc13	1.96E-05			
	Perc14	3.15E-05			
Mid - Lower	Perc02	1.14E-04	1.81E-04	5.93E-05	6
	Perc03	1.96E-04			
	Perc04	2.38E-04			
	Perc05	1.25E-04			
	Perc06	2.56E-04			
	Perc08	1.54E-04			

4.4. Conceptual model

Fig. 5 depicts a conceptual cross-section incorporating soil type and mineralogy descriptions at four representative positions along the slope. Hydraulic conductivities derived from percolation testing under presoaked conditions are noted for three positions along the slope. Major anticipated infiltration, recharge and interflow directions are inferred based on visual evidence and interpretation of the data (profile descriptions, *K*-values, soil texture).

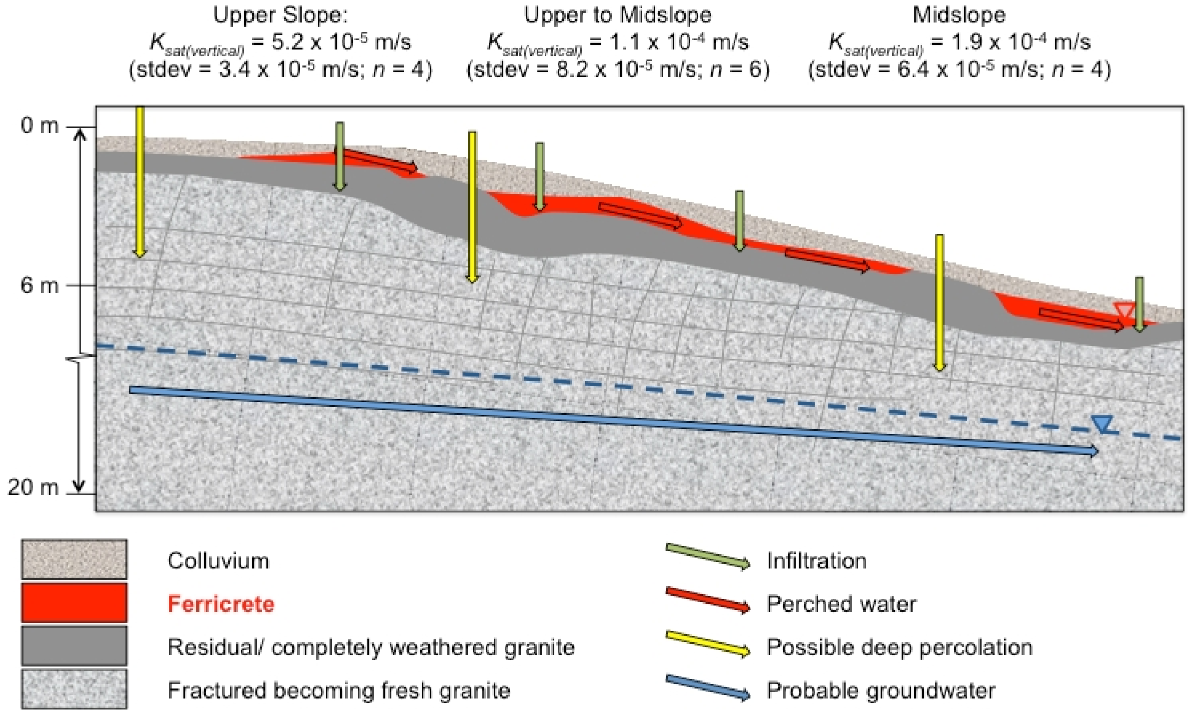

Figure 5. Simplified schematic section indicating the main horizons, hydraulic conductivities and conceptual flow.

High porosity together with small pore size and low connectivity in the upper transported soil horizons result in water retained by adhesion with excess water gradually draining under gravity. The underlying ferricrete is less porous but with larger pores and better connectivity, resulting in cohesion between water molecules and subsequently drainage under gravity. However, as the saprolite underlying the ferricrete is once again porous but with much smaller pores and more clogging due to clay minerals such as kaolinite and mica, adhesion retains moisture with interflow in the overlying ferricrete being easier than percolation into the saprolite. This results in surface infiltration, interflow in the perched water table in the ferricrete, and limited deeper percolation in ferruginized portions (Fig. 6).

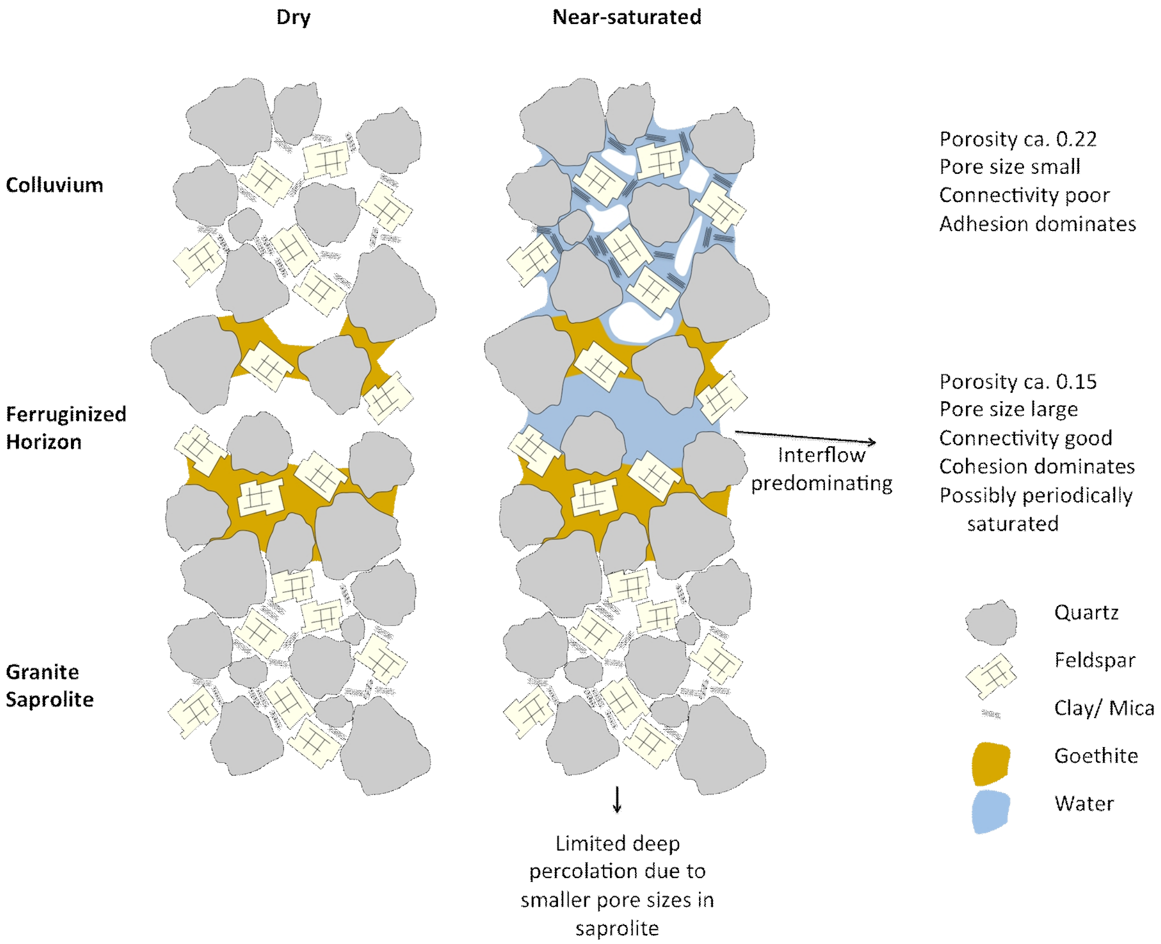

Figure 6. Inferred dry and near-saturated conditions for the typical ferruginized soil profile.

5. Conclusions and Findings

Transported soil horizons (notably upper colluvium) are pinholed with porosity in the order of 0.22. Ferricrete has larger pore sizes with average porosity in the order of 0.15 and is underlain by residual granite with porosity of 0.22. Vertical near-saturated hydraulic conductivities (which represent infiltrating water derived from precipitation on land surface) for these materials vary between 7 x 10^{-5} m/s on the upper to midslope to 1.8 x 10^{-4} on the midslope to lower slope.

Ferricrete underlies colluvium on the upper-midslope and the mid-lower slope and is distinctly absent just below the midslope and on the upper reaches of the slope. Yellow, orange and red discolouration of residual soil and weathered rock is much more pronounced than the discolouration in the colluvial materials, suggesting that leaching may occur in the upper horizons followed by precipitation in the deeper horizons. As visual evidence of seepage and distinct large connected pores are present in the ferricrete, it is expected that water infiltrating will enrich in mobile ions. Thereafter, enriched water will move as interflow within the ferricrete or alternatively may be sourced from interflow further upslope or from the bedrock below. The ferricrete is therefore expected to form upward, hence the distinct absence of some significant identifiers (such as soil mottling and wetness) in the upper horizons.

The residual granite underlying the ferricrete (or the colluvium, where absent) is once again more porous, stained with goethite and possibly resulted from the weathered bedrock (porosity 0.15 and lower) serving as a local aquitard. Fractures within the lesser weathered granite may serve as flow paths, although the same structures in the completely weathered granite appears to be more clogged with goethite and kaolinite.

Kaolinite forms from the weathering of the feldspars and may be sources from bedrock further upslope. This clay mineral, albeit not expansive, aids in clogging of porosity and may play an important role in the formation of the perched water table.

The flow in the ferricrete results as the larger pores promote cohesion between water molecules rather than adhesion to mineral surfaces. The direction and degree of interconnectivity govern the flow rate and direction. Vertical percolation will result where the ferricrete pinches out or where the void space is directly connected to that of the deeper horizons, although imbibition into smaller pores in the residuum may be less pronounced given the large void spaces within the ferricrete. The importance of pore size (scale of porosity) as opposed to volumetric porosity is accentuated in this process where the path of least resistance is the larger pores in the ferricrete, resulting in interflow rather than deeper percolation.

The weathered bedrock forms a fractured vadose zone. The ferricrete forms due to alternating reducing and oxidizing conditions, the latter supplying opportunity for precipitation of goethite. The system – which mimics a temporary wetland – is not related to the permanent groundwater table, therefore making classification of the site as a wetland (s.s.; sensu stricto or in the strict sense as defined in the National Water Act, DWA 1998) impossible. However, its behaviour as such in a region where groundwater is not shallow results in ecosystems flourishing in this area following long and intense rainfall events.

In areas where groundwater is generally deep and where rainfall is erratic, intense and concentrated within short periods, perched water tables form, which may result in waterlogged conditions supporting wetland vegetation. As the groundwater or surface water itself does not form the system, classification as a wetland is presently not possible and these sensitive systems are being zoned for development. This adversely impacts biodiversity, water quality and influences the development as water later affects foundations and underground services.

Importantly, the identification of these systems is limited and often contradicts wetland identification. Firstly, groundwater and surface water do not always directly influence these systems and they might appear isolated and are – as in the case of this study – supplied by precipitation or interflow only. Secondly, waterlogging occurs from depth or from upslope, often leaving soil wetness indicators in upslope or underlying soil horizons and not in the shallow soils where identification is evident. Thirdly, as these systems are highly ephemeral, the likelihood of identification during one field visit become limited as waterlogging and wetland vegetation occur only following long and intense rainfall, which might occur seasonally or less frequently.

Systems such as these should not be considered exceptions to the rule. As wetlands (s. s.) are not common in these terrains, the hydrological and ecological systems that depend on these temporary or perched systems are not presently protected. Whether these systems are *perched water table wetlands*, *temporary hillslope wetlands*, *intermittently waterlogged slopes*, *paluslopes* or *wet grasslands*, a need arises to classify them as a special type of wetland also requiring preservation and cognisance. This may require something as basic as awareness of these systems and the implications of development, to the level of incorporation as a distinct type of wetland to ensure future protection.

6. Acknowledgements

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