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Technical note

# Hydropedology of South African soil forms and families

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Hydropedology is an interdisciplinary field that studies the interactions between soil and water, recognizing that soils influence hydrological processes through their hydraulic properties, and serve as indicators of hydrological behaviour through their morphological properties that are shaped by water regimes. Given the practical implications of hydropedology and its integration into South Africa's latest soil classification system, an updated categorization of soil forms and 1 657 (1 629 + 28) families was necessary, organizing them into three overarching response groups based on their predominant hydrological responses: recharge, interflow, and responsive. Within these groups, recharge soils are further classified into deep, shallow, and slow subgroups, interflow soils encompass soil/bedrock, shallow, and slow categories, while responsive soils are subdivided into responsive shallow and responsive wet. This paper aims to enhance the reader's comprehension of hydrological responses and simplify the intricacies integrated into South Africa's official soil classification system.

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## INTRODUCTION

Hydropedology is an interdisciplinary field that focuses on the interactive relationship between soil and water. This field recognizes that soils not only control hydrological processes through their hydraulic properties but also serve as indicators of hydrological behaviour through the interpretation of morphological properties that have largely formed through water regimes. Significant progress has been made in South Africa over the past two decades in understanding, conceptualizing and quantifying hydropedological processes. The primary focus has been on interpreting soil morphology and its relationship to hydropedological behaviour at various scales, including soil horizons (e.g., Van Huyssteen et al., 2005), profiles (e.g., Van Tol et al., 2013a; Le Roux et al., 2015), hillslopes (e.g., Kuenene et al., 2011; Van der Waals, 2013; Van Tol et al., 2013b), and catchments (e.g., Van Zijl et al., 2016; Van Tol & Lorentz, 2018; van Tol et al., 2021). These hydropedological interpretations have been widely adopted by researchers, environmental consultants, and decision-makers. Hydropedological studies have contributed to configuring and parameterizing hydrological models, identifying pollution migration pathways, determining wetland sources, and selecting appropriate wetland restoration mechanisms. For a comprehensive review on recent hydropedological developments in South Africa see Van Tol, (2020). A hydropedological report has become a prerequisite for obtaining a water use license (WUL) in open-cast mining or in cases of significant land-use change.

A key aspect of most hydropedological studies is the interpretation of soil information embedded in a soil classification. This information is derived from in-situ descriptions of soil morphology and supported by measurements of hydraulic properties (e.g., particle size distribution, hydraulic conductivity, and porosity). The soil information is typically organized into different tiers of soil classification, such as diagnostic horizons, soil forms, or soil families. Establishing hydropedological behaviour, therefore, relies on linking soil classification principles and conventions to hydrological response and water regimes. In a previous effort, Van Tol and Le Roux (2019) grouped the 73 soil forms from South Africa's previous soil classification system, 'Soil Classification: A taxonomic system for South Africa', also known as the 'Blue Book' (Soil Classification Working Group, 1991), into 7 hydropedological groups. Since then, a new version of the soil classification system, titled 'Soil Classification: a natural and anthropogenic system for South Africa,' has been published (Soil Classification Working Group, 2018). As with the previous system, the classification of natural soils makes use of two main categories: soil forms ($n$ = 135), which can be further divided into soil families ($n$ = 1 629). For the first time, anthropogenic materials and human-impacted soils are included in the classification. Here, 6 different classes with 28 families are recognized and described.

The contribution of hydropedological research is evident in shaping the format and structure of the 2018 soil classification system. For instance, hydropedological interpretations influenced the inclusion of descriptions of soils to the bedrock interface (i.e., no depth limit criteria for classification), differentiation between fractured and solid rock and the recognition of different types of saprolitic weathering at the family level. Additionally, the differentiation between gley and gleyic horizons was also based on improved hydropedological understanding of soil formation and hydrological regimes. For detailed descriptions of the changes between the 1991 and 2018 soil classification systems, see Van Zijl et al. (2020).

With the publication of the new classification system and its strong hydrological emphasis, along with the inclusion of anthropogenic material, it is timely to revisit the hydropedological grouping proposed by Van Tol and Le Roux (2019). In this context, we propose new hydropedological types and aim to group the soil forms and 1 657 (1 629 + 28) families based on their dominant hydrological response. For each hydropedological type, this technical note begins with a brief theoretical description followed by tables (Tables 1 – 10) that categorize soil forms and families into various hydropedological groups.

## RECHARGE SOILS

### Processes, indicators and implications of recharge soils

**Process**: Hydrological recharge involves the replenishment of water and, from a hydropedological perspective, recharge soils facilitate the filling of underlying entities such as groundwater aquifers or downslope wetlands. Infiltration and hydraulic conductivity generally surpass rainfall intensity. Recharge soils are characterized as 'freely-drained' soils, indicating the absence of hindrances or layers impeding vertical water movement. However, this doesn't imply that most of the water will readily exit the profile. In arid and semi-arid regions, a significant portion of infiltrated water is extracted through evapotranspiration (ET). To achieve substantial recharge, the downward water flux in and out of the profile must surpass the upward extraction by evapotranspiration. Hydropedological recharge, therefore, encompasses not only water reaching groundwater aquifers but also includes recharge of wetlands, fractured bedrock flowpaths, and cases where infiltration and ET reach equilibrium.

**Indicators**: Recharge soil horizons are recognised by their lack of redox or reduction morphology in any part of the profile.

**Impacts**: Extensive areas of recharge soils enhance the potential water intake by wetlands from their catchments. Diminished infiltration into recharge soils, often coupled with increased overland flow, curtails the hydroperiod (duration of saturation) of wetlands, subsequently reducing stream baseflow. Instances of reduced infiltration involve surface sealing due to structures (primarily roofs) and roads. Alteration in vegetation affects transpiration rates and volumes. Afforestation with deep-rooted trees diminishes the water draining through soils into fractured rock, thus lowering recharge of bedrock, wetlands and groundwater. Evaluating terrestrial hillslope area and storage volume necessitates considering the vegetation as a factor. Changes in infiltration rate between natural veld and cultivated fields may also influence recharge rates.

### Recharge soil groups

#### *Recharge (deep)*

These are deep, freely drained soils without any indication of saturation overlying fractured rock or deeply weathered saprolite (Table 1; Fig. 1a). In drier areas, the underlying bedrock might not be permeable, and the absence of hydromorphic properties is due to insufficient rainfall to cause saturation for significant periods. 'Recharge (deep)' soils contribute significantly to transpiration, but downward ET excess flow is the dominant flowpath.

#### *Recharge (shallow)*

These are freely drained topsoil horizons overlying fractured rock or saprolite (Table 2; Fig. 1b). The contribution of these soils to transpiration is lower than that of 'recharge (deep)' soils. Due to the relatively short residence time in the biological zone (solum), water exiting 'recharge (shallow)' soils has a lower reduction potential (oxygenized).

#### *Recharge (slow)*

In this group, slow vertical movement is the dominant flowpath (Table 3). 'Recharge (slow)' soils typically have clay-rich (luviated) subsoil horizons which act as a store, rather than a conduit, of water (Fig. 1c). ET excess water seldom reaches the bottom of the soil profile and the contribution to transpiration (upward flux) is generally the dominant flowpath. 'Recharge (slow)' also includes profiles with ineffective leaching and hence the accumulation and precipitation of bases in the form of lime and gypsum (Fig. 1d). Hydromorphic properties are absent from these profiles.

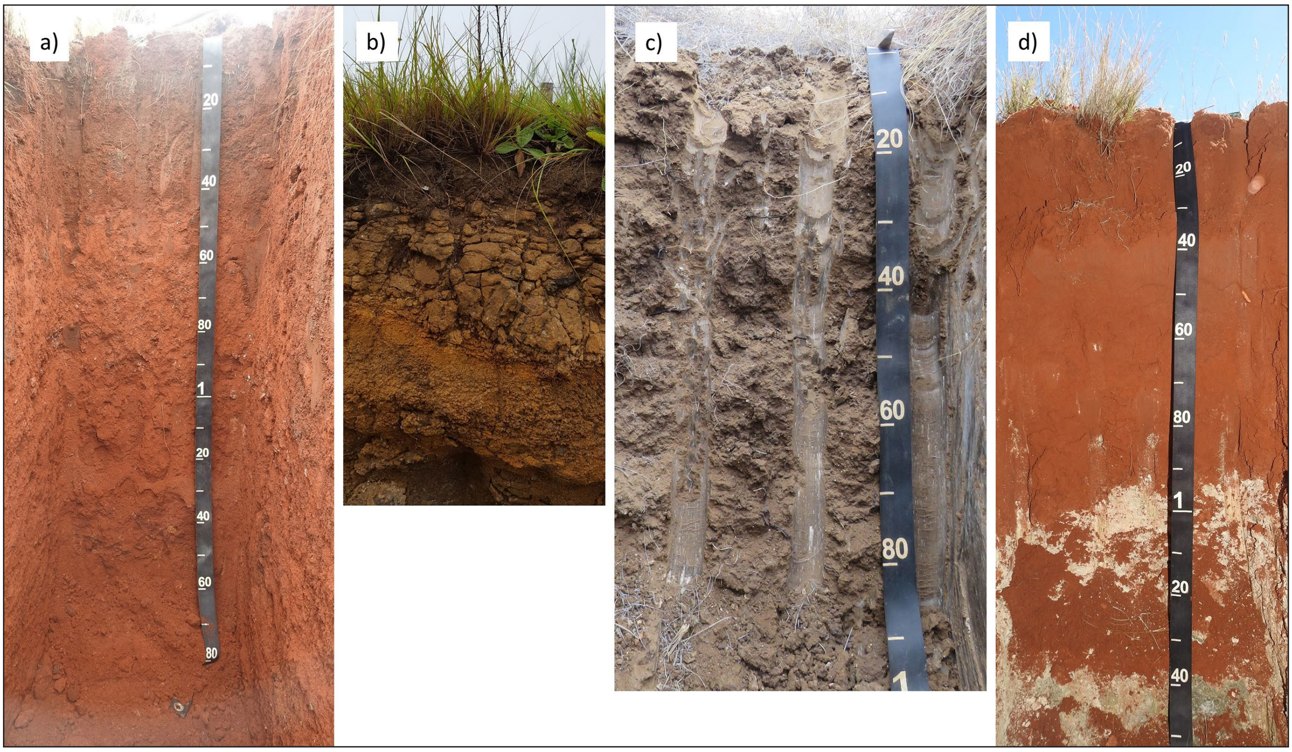


**Figure 1**. Examples of recharge soils: (a) recharge (deep), (b) recharge (shallow), (c) recharge (slow) – high clay contents limit fast vertical drainage, and (d) recharge (slow) – lime accumulations indicate insufficient leaching

**Table 1.** Recharge (deep) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Stanger (Sg) | All families | |
| Abbotspoort (Ab) | All families | |
| Inhoek (Ik) | 1100; 2100 | Families without alluvial wetness |
| Kranskop (Kp) | All families | |
| Longtom (Lg) | 1110; 1120; 1210; 1220; 2110; 2120; 2210; 2220 | Families without gleylithic |
| Magwa (Ma) | All families | |
| Gangala (Ga) | 1110; 1120; 1210; 1220; 2110; 2120; 2210; 2220 | Families without gleylithic |
| Inanda | All families | |
| Henley (He) | 1110; 1120; 1210; 1220; 2110; 2120; 2210; 2220 | Families without gleylithic |
| Sweetwater | All families | |
| Constantia (Ct) | All families | Albic horizons on freely drained horizon will predominantly recharge |
| Shepstone (Sp) | All families | |
| Villafontes (Vf) | 1110; 1210; 2110; 2210 | Aluvic neocutanic |
| Tsitsikamma (Ts) | 1110; 1210; 2110; 2210 | Gleying absent below podzol |
| Houwhoek (Hh) | 1111; 1112; 1211; 1212; 1221; 2111; 2112; 2121; 2211; 2212 | Families without Ortstein hardening and gleylithic |
| Concordia (Cc) | 1111; 1112; 1211; 1212; 2111; 2112; 2211; 2212 | Families without Ortstein hardening |
| Kinkelbos (Kk) | 1111; 1121; 1211; 1221; 2111; 2121; 2211; 2221 | Aluvic neocarbonate |
| Fernwood (Fw) | All families | Check carefully for gleying as described under sandy gley, if gleyed rather *Interflow (soil/bedrock)* |
| Griffin (Gf) | All families | |
| Palmiet (Pm) | All families | |
| Glencoe (Gc) | All families | Considerable lateral flow below hard plinthic possible - verify if not *Interflow (soil/bedrock)* |
| Clovelly (Cv) | 1111; 1121; 1211; 1221; 1311; 1321; 2111; 2121; 2211; 2221; 2311; 2321; 3111; 3121; 3211; 3221; 3311; 3321; 1112; 1122; 1212; 1222; 1312; 1322; 2112; 2122; 2212; 2222; 2312; 2322; 3112; 3122; 3212; 3222; 3312; 3322 | All families without gleylithic |
| Carolina (Ca) | All families | |
| Ermelo (Er) | All families | |
| Tongwane (Tg) | All families | |
| Lichtenburg (Lc) | All families | Considerable lateral flow below hard plinthic possible - verify if not *Interflow (soil/bedrock)* |
| Nkonkoni (Nk) | 1111; 1121; 1211; 1221; 1311; 1321; 2111; 2121; 2211; 2221; 2311; 2321; 3111; 3121; 3211; 3221; 3311; 3321; 1112; 1122; 1212; 1222; 1312; 1322; 2112; 2122; 2212; 2222; 2312; 2322; 3112; 3122; 3212; 3222; 3312; 3322 | All families without gleylithic |
| Vaalbos (Vb) | All families | |
| Hutton (Hu) | All families | |
| Magudu (Md) | All families | |
| Nshawu (Ns) | All families | |
| Shortlands (Sd) | All families | |
| Jonkersberg (Jb) | 1100; 2100 | Gleying absent below podzol |
| Groenkop (Gk) | 1110; 1120; 2110; 2120 | Families without Ortstein hardening and gleylithic |
| Pinegrove (Pg) | 1110;1120;2110; 2120 | Families without Ortstein hardening |
| Quaggafontein (Qf) | 1111; 1211; 2111; 2211; 3111; 3211 | Aluvic neocutanic with dry alluvial |
| Tubatse (Tb) | 1111; 1211; 2111; 2211; 3111; 3211; 1112; 1212; 2112; 2212; 3112; 3212 | Aluvic neocutanic with dry lithic |
| Bethasda (Be) | 1111; 1112; 1211; 1212; 2111; 2112; 2211; 2212; 3111; 3112; 3211; 3212 | Aluvic neocutanic |
| Oakleaf (Oa) | 1110; 1210; 2110; 2210; 3110; 3210 | Aluvic neocutanic |
| Dundee (Du) | 1111; 1121; 1211; 1221; 2111; 2121; 2211; 2221; 3111; 3121; 3211; 3221 | Alluvial wetness absent |
| Namib | All families | |

**Table 2.** Recharge (shallow) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Mayo (My) | 1100; 1200; 2100; 2200 | Families without gleylithic |
| Milkwood (Mw) | 1100; 2100 | Fractured hard rock |
| Nomanci (No) | 1100; 1200; 2100; 2200 | Families without gleylithic |
| Graskop (Gp) | 1100; 2100 | Fractured hard rock |
| Dresden | 1000; 2000 | Chromic and dark topsoil indicates hard plinthic is permeable |
| Glenrosa (Gs) | 1110; 1210; 2110; 2210; 3110; 3210; 1120; 1220; 2120; 2220; 3120; 3220 | Saprolithic and geolithic support recharge |
| Mispah (Ms) | 1110; 1210; 2110; 2210; 3110; 3210 | Fractured hard rock |

**Table 3.** Recharge (slow) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Darnall (Da) | 1110; 1120; 1210; 1220; 2110; 2120; 2210; 2220 | Families without gleylithic |
| Bonheim (Bo) | All families | |
| Steendal (Sn) | All families | |
| Immerpan (Im) | All families | |
| Molopo (Mp) | All families | |
| Akham (Ak) | All families | |
| Kimberley (Ky) | All families | |
| Plooysburg | All families | |
| Garies (Gr) | All families | |
| Heilbron (Hb) | All families | |
| Utrecht (Ut) | 1111;1211; 1311; 1411; 1121; 1221; 1321; 1421; 2111; 2211; 2311; 2411; 2121; 2221; 2321; 2421 | All families without alluvial wetness |
| Sandile (Sa) | 1111;1211; 1311; 1411; 1121; 1221; 1321; 1421; 2111; 2211; 2311; 2411; 2121; 2221; 2321; 2421; 1112;1212; 1312; 1412; 1122; 1222; 1322; 1422; 2112; 2212; 2312; 2412; 2122; 2222; 2322; 2422 | All families without gleylithic |
| Cookhouse (Ck) | All families | |
| Sterkspruit (Ss) | All families | |
| Queenstown (Qt) | 1111;1211; 1311; 1411; 1121; 1221; 1321; 1421; 2111; 2211; 2311; 2411; 2121; 2221; 2321; 2421 | All families without alluvial wetness |
| Swartland (Sw) | 1111;1211; 1311; 1411; 1121; 1221; 1321; 1421; 2111; 2211; 2311; 2411; 2121; 2221; 2321; 2421; 1112;1212; 1312; 1412; 1122; 1222; 1322; 1422; 2112; 2212; 2312; 2412; 2122; 2222; 2322; 2422 | All families without gleylithic |
| Spioenberg (Sb) | All families | |
| Valsrivier (Va) | All families | |
| Erin (En) | All families | |
| Makgoba (Mb) | All families | |
| Etosha (Et) | All families | |
| Gamoep (Gm) | All families | |
| Soutvloer (Sv) | All families | |
| Oudtshoorn (Ou) | All families | |
| Quaggafontein (Qf) | 1121; 1221; 2121; 2221; 3121; 3221 | Luvic neocutanic with dry alluvial |
| Tubatse (Tb) | 1121; 1221; 2121; 2221; 3121; 3221; 1122; 1222; 2122; 2222; 3122; 3222 | Luvic neocutanic with dry lithic |
| Bethasda (Be) | 1121; 1122; 1221; 1222; 2121; 2122; 2221; 2222; 3121; 3122; 3221; 3222 | Luvic neocutanic |
| Oakleaf (Oa) | 1120; 1220; 2120; 2220; 3120; 3220 | Luvic neocutanic |
| Palala (Pl) | All families | |
| Addo (Ad) | All families | |
| Prieska (Pr) | All families | |
| Sendelingsdrif (Sf) | All families | |
| Trawal (Tr) | All families | |
| Motsane (Mt) | 1111; 1121; 1211; 1221; 2111; 2121; 2211; 2221; 3111; 3121; 3211; 3221 | Alluvial wetness absent |
| Burgersfort (Bg) | 1111; 1121; 1211; 1221; 2111; 2121; 2211; 2221; 3111; 3121; 3211; 3221; 1112; 1122; 1212; 1222; 2112; 2122; 2212; 2222; 3112; 3122; 3212; 3222 | Dry lithic |
| Hofmeyer (Hf) | All families | |
| Augrabies | All families | |
| Kolke (Ko) | All families | |
| Olienhout (Oh) | All families | |
| Koiingnaas (Ks) | All families | |
| Brandvlei (Br) | All families | |
| Rooiberg (Ro) | All families | |

## INTERFLOW SOILS

### Processes, indicators, and implications of interflow soils

**Process**: Interflow in soils arises from two primary processes. The first process is attributed to anisotropy in hydraulic conductivity. This occurs when a permeable horizon overlays less permeable (restrictive) horizons or material, causing vertical draining water to accumulate atop the restricting horizon and subsequently drain laterally downslope. The restrictive horizon can be situated at various depths, such as the topsoil/subsoil interface or the soil/bedrock interface. The second process involves the return of bedrock flowpaths into the soil, saturating the lower part of the profile. These horizons rely on recharge return flows from upslope lands (recharge zones) and, if permeable, could also receive water from overlying horizons. Therefore, it is crucial to analyse the morphology of profiles both higher up the hillslope and downslope from an observation point. The interflow area exhibits variations in slope gradient and fracture systems, and the water content of interflow horizons and soils ranges from periodic to permanent saturation. Flow rates are primarily influenced by slope angle and interflow horizon conductivity (Van Tol et al., 2013). In interflow soils, the duration of saturation increases vertically in the soil profile and downslope in the hillslope (Van Huyssteen et al., 2005). Sudden increases in deep subsoil moisture content on midslope and lower slopes indicate the return flow from fractured rock to soil saprolite and deep subsoil. This bedrock flowpath can sustain interflow long after the rainy season ends (Le Roux et al., 2010).

Interflow pathways can be categorized as shallow and deep. Shallow flowpaths occur at the topsoil/subsoil interface and generally within 500 mm from the surface. Deep interflows manifest at the soil bedrock interface, occurring at depths greater than 500 mm from the surface. These pathways typically intersect within wetlands. Shallow interflow is usually event-driven, with flow corresponding to specific rainfall events or a series thereof. Deep interflow hinges on recharge and bedrock flow, exhibiting a seasonal pattern.

**Indicators**: Shallow and deep interflow soils exhibit morphological evidence of reduction and redox processes in the second and third horizons (evident through grey colours and mottles). When observed in a second horizon, an albic horizon is typically present above the restricting layer.

**Impacts**: Regardless of whether it occurs in soils or fractured rock, interflow is often within the depth range affected by land-use change activities. The interception of lateral flowpaths due to foundations, pipelines, and open-cast mining can diminish the contribution of these soils to wetland and streamflow water regimes. Surface sealing (such as roofs and pavements) increases overland and peak flow, thereby reducing recharge and negatively affecting the sustained supply of water to wetlands and streams. The hydrological zone sensitive to land-use change extends beyond the typical wetland buffer zone. This extension is determined by the depth of critical flowpaths identified as substantial contributors to wetland hydrology and the potential negative impact of the proposed land-use change.

### Interflow soil groups

#### *Interflow (soil/bedrock)*

In this group lateral flow is generated, either due to low permeability of the bedrock which restricts vertical drainage or due to return flow from the bedrock flowpath to the soils (Table 4; Fig. 2a). The flowrate via this pathway is determined by the slope and conductivity of the interflow horizon. Flow is normally maintained on a seasonal basis, but it depends on the length and recharge area of the bedrock-return flowpath.

#### *Interflow (shallow)*

These soils are marked by vertical anisotropy in hydraulic conductivity where a permeable topsoil overlies a restricting subsoil layer (Table 5; Fig. 2b). These soils are also termed 'interflow (A/B)'. Lateral flow is generated by specific rain events and the duration of lateral flow in 'interflow (shallow)' soils is relatively short.

#### *Interflow (slow)*

This hydropedological group comprises soils with high clay contents at the soil/bedrock interface (Table 6; Fig. 2c). Although they could be saturated for long periods, their contribution to streamflow is relatively small because of the low hydraulic conductivity. In some cases, they act primarily as a store of water and not a conduit.

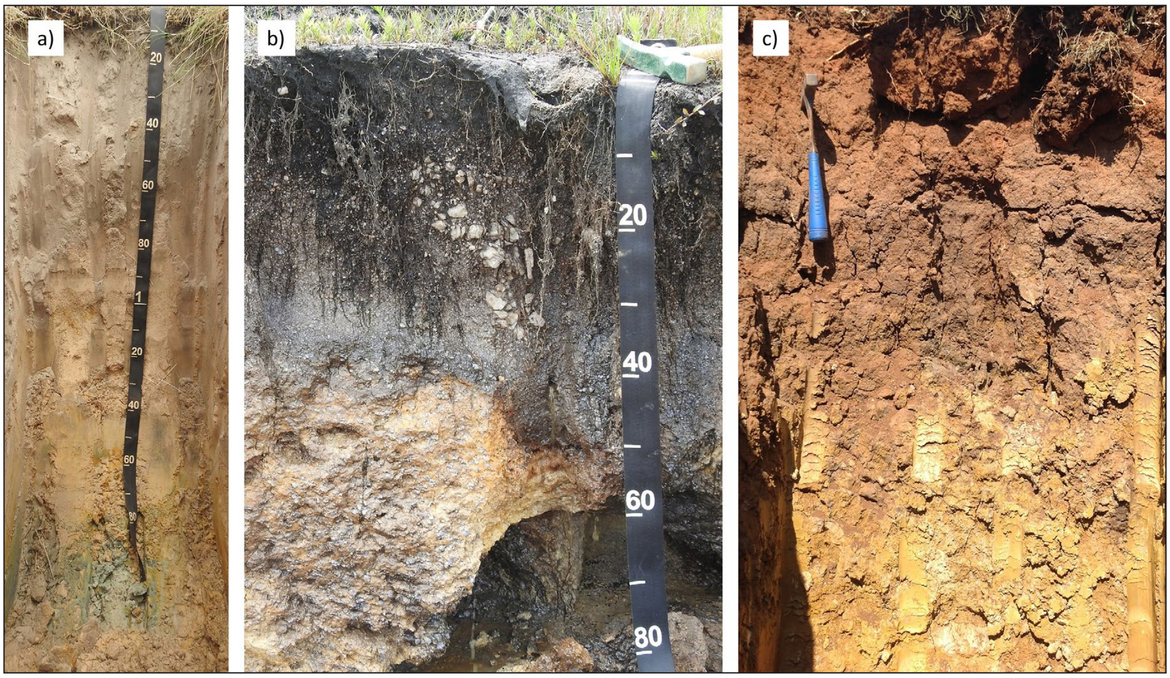


**Figure 2.** Examples of interflow soils: (a) interflow (soil/bedrock) – notice grey colours at bottom of profile, (b) interflow (shallow) – water exiting in grey albic between 300 and 500 mm and (c) interflow (slow) – morphological properties of saturation present but high clay contents limit lateral flow

**Table 4.** Interflow (soil/bedrock) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Stanger (Sg) | 1300; 2300 | Lateral flow implied by gleylithic |
| Inhoek (Ik) | 1200; 2200 | Lateral flow implied by alluvial wetness |
| Eland (El) | All families | |
| Longtom (Lg) | 1130; 1230; 2130; 2230 | Lateral flow implied by gleylithic |
| Netherley (Ne) | All families | |
| Gangala (Ga) | 1130; 1230; 2130; 2230 | Lateral flow implied by gleylithic |
| Umvoti (Um) | All families | |
| Henley (He) | 1130; 1230; 2130; 2230 | Lateral flow implied by gleylithic |
| Mkuze (Mk) | 1200; 2200 | Aluvial wetness specified at family level |
| Tsitsikamma (Ts) | 1120; 1220; 2120; 2220 | Gleying present below podzol |
| Lamotte (Lt) | All families | |
| Houwhoek (Hh) | 1113; 1123; 1213; 1223; 2113; 2123; 2213; 2223; | All families with gleylithic |
| Kransfontein (Kf) | All families | |
| Avalon (Av) | All families | |
| Clovelly (Cv) | 1113; 1123; 1213; 1223; 1313; 1323; 2113; 2123; 2213; 2223; 2313; 2323; 3113; 3123; 3213; 3223; 3313; 3323 | All families with gleylithic |
| Bainsvlei (Bv) | All families | |
| Nkonkoni (Nk) | 1113; 1123; 1213; 1223; 1313; 1323; 2113; 2123; 2213; 2223; 2313; 2323; 3113; 3123; 3213; 3223; 3313; 3323 | All families with gleylithic |
| Jonkersberg (Jb) | 1200; 2200 | Gleying present below podzol |
| Witfontein (Wf) | All families | |
| Groenkop (Gk) | 1130; 1230; 2130; 2230 | All families with gleylithic |
| Tshiombo (To) | 1110; 1210; 2110; 2210; 3110; 3210 | Aluvic neocutanic |
| Quaggafontein (Qf) | 1112; 1212; 2112; 2212; 3112; 3212 | Aluvic neocutanic with alluvial wetness |
| Tukulu (Tu) | 1110; 1210; 2110; 2210; 3110; 3210 | Aluvic neocutanic |
| Tubatse (Tb) | 1113; 1213; 2113; 2213; 3113; 3213 | Aluvic neocutanic with Gleylithic |
| Montagu (Mu) | 1110; 1210; 2110; 2210; 3110; 3210 | Aluvic neocarbonate |
| Dundee (Du) | 1112; 1122; 1212; 1222; 2112; 2122; 2212; 2222; 3112; 3122; 3212; 3222 | Alluvial wetness present |
| Lepellane (Lp) | 1100; 1200; 2100; 2200 | Dark or chromic topsoils |

**Table 5.** Interflow (shallow) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Mayo (My) | 1300; 2300 | Gleylithic indication of interflow/saturation in lithic |
| Nomanci (No) | 1300; 2300 | Lateral flow implied by alluvial wetness |
| Kroonstad (Kd) | 1110; 1120; 1210; 1220 | Families with dark/chromic topsoil |
| Villafontes (Vf) | 1120; 1220; 2120; 2220 | Luvic neocutanic |
| Longlands (Lo) | All families | |
| Wasbank (Wa) | All families | |
| Estcourt (Es) | All families | |
| Klapmuts (Km) | All families | |
| Kinkelbos (Kk) | 1112; 1122; 1212; 1222; 2112; 2122; 2212; 2222 | Luvic neocarbonate |
| Cartref (Cf) | All families | |
| Iswepe (Is) | All families | |
| Westleigh (We) | 1100; 1200; 2100; 2200 | Families with dark and chromic topsoils |
| Lepellane (Lp) | 3100; 3200 | Bleached topsoil |
| Concordia (Cc) | 1121; 1122; 1221; 1222; 2121; 2122; 2221; 2222 | Families with Ortstein hardening |
| Houwhoek (Hh) | 1121; 1122; 1222; 2122; 2221; 2222 | Families with Ortstein hardening without gleylithic |
| Wasbank (Wa) | All families | |
| Groenkop (Gk) | 1210; 1220; 2210; 2220 | Families with Ortstein hardening without gleylithic |
| Pinegrove (Pg) | 1210; 1220; 2210; 2220 | Families with Ortstein hardening |
| Glenrosa (Gs) | 1130; 1230; 2130; 2230; 3130; 3230 | Gleylithic indication of interflow/saturation in lithic |

**Table 6.** Interflow (slow) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Lauriston (Lr) | All families | |
| Potsdam (Pd) | 1120; 1220; 2120; 2220 | Slow conductivity of pedocutanic with wet alluvium |
| Darnall (Da) | 1130; 1230; 2130; 2230 | Slow conductivity through pedocutanic with gleylithic |
| Dartmoor (Dm) | All families | |
| Highmoor (Hm) | All families | |
| Pinedene (Pn) | All families | |
| Bloemfal (Bd) | All families | |
| Idutywa (Id) | All families | |
| Utrecht (Ut) | 1112;1212; 1312; 1412; 1122; 1222; 1322; 1422; 2112; 2212; 2312; 2412; 2122; 2222; 2322; 2422 | Families with alluvial wetness present |
| Sandile (Sa) | 1113;1213; 1313; 1413; 1123; 1223; 1323; 1423; 2113; 2213; 2313; 2413; 2123; 2223; 2323; 2423 | Interflow implied by gleylithic |
| Sepane (Se) | All families | |
| Queenstown (Qt) | 1112;1212; 1312; 1412; 1122; 1222; 1322; 1422; 2112; 2212; 2312; 2412; 2122; 2222; 2322; 2422 | Families with alluvial wetness present |
| Swartland (Sw) | 1113;1213; 1313; 1413; 1123; 1223; 1323; 1423; 2113; 2213; 2313; 2413; 2123; 2223; 2323; 2423 | All families with gleylithic |
| Tukulu (Tu) | 1120; 1220; 2120; 2220; 3120; 3220 | Luvic neocutanic |
| Tshiombo (To) | 1120; 1220; 2120; 2220; 3120; 3220 | Luvic neocutanic |
| Quaggafontein (Qf) | 1122; 1222; 2122; 2222; 3122; 3222 | Luvic neocutanic with alluvial wetness |
| Tubatse (Tb) | 1123; 1223; 2123; 2223; 3123; 3223 | Luvic neocutanic with gleylithic |
| Montagu (Mu) | 1120; 1220; 2120; 2220; 3120; 3220 | Luvic neocarbonate |
| Motsane (Mt) | 1112; 1122; 1212; 1222; 2112; 2122; 2212; 2222; 3112; 3122; 3212; 3222 | Alluvial wetness present |
| Burgersfort (Bg) | 1113; 1123; 1213; 1223; 2113; 2123; 2213; 2223; 3113; 3123; 3213; 3223 | All families with gleylithic |

## RESPONSIVE SOILS

### Processes, indicators, and implications of responsive soils

**Process**: Responsive soils are characterized by their swift reaction to precipitation events, resulting in the generation of overland flow. Overland flow originates from three main mechanisms:

- Shallow soils overlaying relatively impermeable bedrock lead to overland flow due to their limited storage capacity, which quickly becomes exceeded after typical rainfall events.
- Soils experiencing prolonged saturation generate overland flow due to saturation excess.
- Soils with low surface infiltration rates trigger overland flow through infiltration excess (Hortonian flow). This phenomenon is evident in soils with high 2:1 clay content, as well as soils that have undergone physical (compaction or crust formation) or chemical (sodicification) degradation.

**Indicators**: Bleached topsoil horizons in shallow soils serve as reliable indicators of shallow responsive soils. The presence of hydromorphic properties near the surface and high organic carbon content (peat and organic horizons) suggests a saturation excess response. Topsoils exhibiting physical activity (vertic properties) expand during the wet season, causing a significant decrease in infiltration rates. Indicators of overland flow dominance and soil responsiveness include sodicity and degradation, such as sheet and rill erosion.

**Implications**: Overland flow contributes to the peak flow phase of the hydrograph. In areas dominated by responsive soils, a considerable portion of rainfall fails to infiltrate, and water isn't retained for plant uptake. The occurrence of overland flow can result in flooding and infrastructural damage. While overland flow might be prevalent in higher elevation regions within a landscape, this water could eventually re-infiltrate and contribute to lateral or recharge flowpaths. In exceptionally wet years, entire landscapes might become 'responsive,' although such occurrences are rare.

### Responsive soil groups

#### *Responsive (shallow)*

These are soils with limited depth and hence small storage capacity (Table 7). Underlying rocks are slowly permeable and rapid recharge of bedrock flowpaths is not likely. When significant rainfall is received, the storage capacity of the soil is exceeded, and overland flow is then generated. The soils 'respond' quickly to rain events.

#### *Responsive (wet)*

These are soils marked by saturation close to the surface layers for extended periods, especially during the wet season (Table 8). Additional precipitation will not infiltrate but overland flow will be generated. These soils respond quickly to rain events, resulting in high peak flows.

#### *Responsive (Hortonian)*

Soils with vertic horizons will swell and close during wet periods. The hydraulic conductivity/infiltration rate of these soils with high 2:1 clay content is less than the rainfall intensity and will therefore generate overland flow due to infiltration excess (Table 9). This is often referred to as Hortonian overland flow. Degraded soils with surface crusting or sodic soils will behave similarly.

**Table 7.** Responsive (shallow) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Milkwood (Mw) | 1200; 2200 | Solid rock |
| Graskop (Gp) | 1200; 2200 | Solid rock |
| Dresden | 3000 | Bleached topsoil indicates hard plinthic is slowly permeable |
| Coega (Cg) | All families | |
| Knersvlakte (Kn) | All families | |
| Mispah (Ms) | 1120; 1220; 2120; 2220; 3120; 3220 | Solid rock |

**Table 8.** Responsive (wet) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Mfabeni (Mf) | All families | Long periods of saturation implied by presence of peat horizon |
| Nhlangu (Nh) | All families | |
| Muzi (Mz) | All families | |
| Kromme (Kr) | All families | |
| Champagne (Ch) | All families | |
| Manguzi (Mg) | All families | |
| Makhasana (Mh) | All families | |
| Didema (Dd) | All families | |
| Rensburg (Rg) | All families | Vertic horizon would limit infiltration, still be responsive |
| Willowbrook (Wo) | All families | |
| Katspruit (Ka) | All families | |
| Kroonstad (Kd) | 2110; 2120; 2210; 2220 | Families with bleached topsoil indicate saturation close to surface |
| Westleigh (We) | 3100; 3200 | Families with bleached topsoil indicate saturation close to surface |

**Table 9.** Responsive (Hortonian) families of the South African Soil Classification

| Soil form | Families | Remarks |
|---|---|---|
| Glen (Gl) | All families | Vertic horizons will have low conductivity when saturated/swell |
| Zondereinde (Zo) | All families | |
| Dwaalboom (Dw) | All families | |
| Bakwena (Bk) | All families | |
| Waterval (Wv) | All families | |
| Mkuze (Mk) | 1100; 2100 | |
| Arcadia | All families | |
| Rustenburg | All families | |

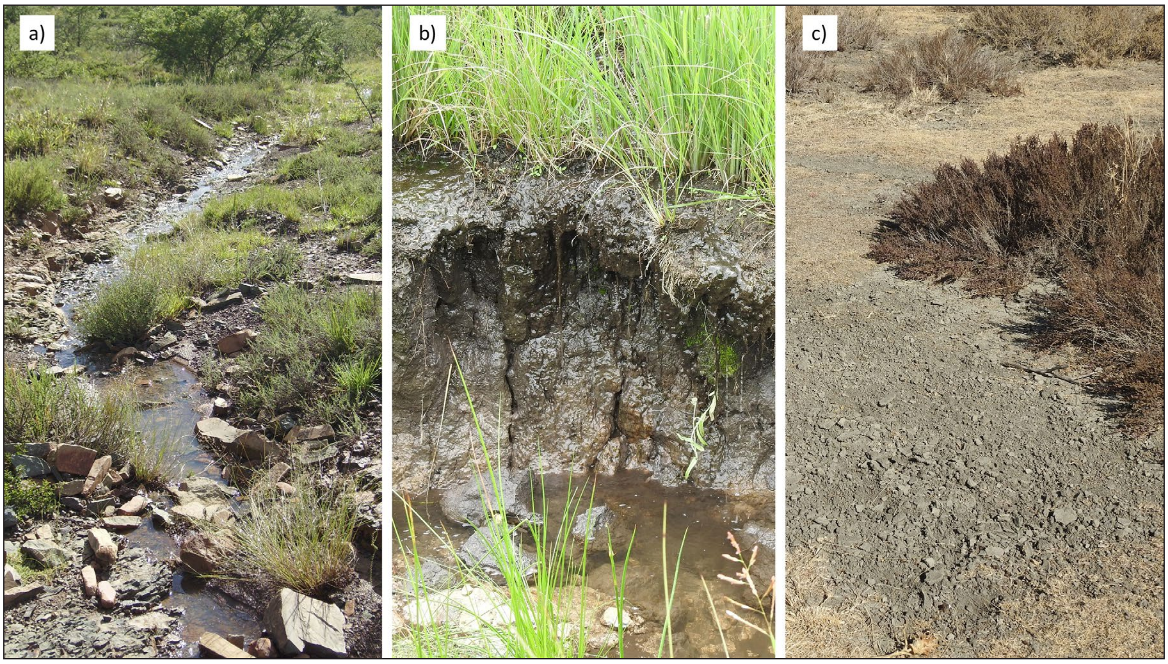


**Figure 3.** Examples of responsive soils: (a) responsive (shallow) – overland flow generated due to low storage capacity, (b) responsive (wet) – overland flow generated by saturation excess and (c) responsive (Hortonian) – overland flow will be generated by due to crusting and low infiltration rates

**Table 10.** Hydropedological grouping of anthrosols and technosols

| Soil form | Family | Description | Hydropedology group |
|---|---|---|---|
| Grabouw | 1000 | Some original horizons remain, but in a disturbed state | Check properties of original soil and group according natural soils |
| | 2000 | Original horizons overturned and irreversibly mixed (dorbank, hard plinthite, hard carbonate, lithic, prismacutanic, hard rock) for agricultural purposes | Recharge (shallow) |
| | 3000 | Physically degraded and disturbed due to water actions (water erosion caused by anthropogenic activities) | Responsive (Hortonian) |
| | 4000 | Physically disturbed due to aeolian actions (wind erosion instigated by anthropogenic activities) | Recharge (deep) |
| | 5000 | Natural soil horizons severely compacted without any removal or overturning of original horizon | Responsive (Hortonian) |
| Witbank | 1100 | Ex-natural Soils covering natural soils | Classify and group as natural soils |
| | 1200 | Ex-natural soils covering anthropogenic materials | Responsive (shallow) |
| | 1300 | Ex-natural soil cover as fill material in excavated areas | Responsive (shallow) |
| | 2100 | Anthropogenic materials covering undisturbed natural soils | Responsive (shallow) |
| | 2200 | Anthropogenic materials covering anthropogenic materials | Responsive (shallow) |
| | 2300 | Anthropogenic materials covering excavated areas | Responsive (shallow) |
| Industria | 1100 | Chemical pollution of natural soils | Classify and group as natural soils |
| | 1200 | Chemical pollution of anthropogenic materials | Classify and group as natural soils |
| | 2100 | Radioactive natural and anthropogenic materials | Classify and group as natural soils |
| Stilfontein | 1100 | Natural soils saturated by natural quality water | Responsive (wet) |
| | 1200 | Anthropogenic materials saturated by natural quality water | Responsive (wet) |
| | 2100 | Natural soils saturated by polluted water | Responsive (wet) |
| | 2200 | Anthropogenic materials saturated by polluted water | Responsive (wet) |
| | 3100 | Natural wetland soils drained and irreversibly altered by clearly identified human-induced action | Interflow (soil/bedrock) |
| | 3200 | Natural wetland soils drained and burnt | Interflow (soil/bedrock) |
| Cullinan | 1000 | Large, exposed excavations without backfilling | Responsive (Hortonian) |
| Maropeng | 1100 | Exposed archaeological material | Responsive (Hortonian) |
| | 1200 | Sub-surface archaeological material | Classify and group as natural soils |
| Johannesburg | 1100 | Uncovered urban waste | Responsive (Hortonian) |
| | 1200 | Urban waste covered with ex-natural topsoil | Responsive (shallow) |
| | 1300 | Urban waste covered with liners and topsoil | Responsive (Hortonian) |
| | 2100 | Cemeteries and grave sites | Classify and group as natural soils |
| | 2200 | Other urban uses | Describe according to use – typically Responsive (Hortonian) |

### Anthrosols and technosols

As per the defined criteria, anthrosols and technosols have undergone such extensive human-induced alterations that their physical, chemical, and hydrological functions have been transformed, rendering their original natural soil form indiscernible (Soil Classification Working Group, 2018). This classification system makes a distinction between materials that have undergone inadvertent modifications (anthrosols) and those that have been deliberately transported through human intervention (technosols). When observable impacts are present, a thorough depiction of the nature and extent of the disturbance is necessary. When evaluating these soils, it is very important to consider the new physical properties. Properties such as crusting on exposed subsurface horizons and compaction associated with rehabilitated soils need to be considered. In certain scenarios, identifying the impact might be unfeasible, as is the case with radioactive pollution. Table 10 offers guidance on the hydropedological categorization of anthrosol and technosol families/classes.

## CONCLUSIONS

In conclusion, this study has introduced a new hydropedological grouping for soils of South Africa as described under the new soil classification system (Soil Classification Working Group, 2018). This is an improvement and refinement on the previous hydropedological grouping (Van Tol and Le Roux, 2019). The result is an updated categorization of the 135 soil forms and 1 657 families of both natural and anthropogenic soils. The soil forms and families are organized into three overarching groups based on their predominant hydrological responses: recharge, interflow, and responsive. Within these groups, recharge soils are further classified into deep, shallow, and slow subgroups, interflow soils encompassed soil/bedrock, shallow, and slow categories, while responsive soils are subdivided into responsive shallow, responsive wet and responsive soils where infiltration excess flow dominates.

The new grouping provides a more realistic representation of flowrates in various soil profiles. It serves as a basic building block to characterise hillslope hydrological response. This is important in hydropedological studies which aim to understand, protect and manage water resources. The new grouping will also assist modellers to simplify soil inputs into models by focusing on the hydrological behaviour of the soils and not taxonomic differences which complicate model inputs.

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## AUTHOR CONTRIBUTIONS

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