DEVELOPING WETLAND DISTRIBUTION AND TRANSFER FUNCTIONS FROM LAND TYPE DATA AS A BASIS FOR THE CRITICAL EVALUATION OF WETLAND DELINEATION GUIDELINES BY INCLUSION OF SOIL WATER FLOW DYNAMICS IN CATCHMENT AREAS

VOLUME 1:

Improving the Management of Wetlands by Including Hydropedology and Land Type Data at Catchment Level

Report to the
Water Research Commission

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The publication of this report emanates from a project entitled "*Developing wetland distribution and transfer functions from land type data as a basis for the critical evaluation of wetland delineation guidelines by inclusion of soil water flow dynamics in catchment areas*" (WRC Project No. K5/2461)

This report forms part of a series of three reports. The other reports are:
- *Preliminary guidelines to apply hydropedology in support of wetland assessment and reserve determination* (WRC Report No. 2461/2/18), and
- *Framework for the regional wetland soil contextualization* (WRC Report No. 2461/3/18).

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EXECUTIVE SUMMARY

Wetlands are key elements of the catchment landscape and can be considered a signature of the hydrological dynamics of the surrounding catchment. They occur at positions in the landscape where climate, lithology, topography and biology create hydrologic conditions suitable for their development. Euliss *et al*. (2008) reflect that management is frequently directed towards wetlands as isolated habitats, rather than as ecosystems nested within larger, and often highly modified, landscapes. Although the hydrological link to the terrestrial component of the wetland catchment is often poorly understood, wetlands are dependent on rainfall infiltrating the upslope soil, being partitioned by the subsoil and fractured rock, and flowing down slope to return to the soil surface and wetland. This has implications when considering the impact of land use for guiding wetland management and reserve determination, and expanding upon buffers for wetland protection.

The Land Type Information System of the Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW) is available on request from ARC-ISCW for the full catchment landscape throughout South Africa and therefore has potential to support landscape interpretation. The overall aim of the project was to explore the potential of the Land Type information to support wetland identification and delineation (as specified in the project proposal) through the development of a computer programme and hydropedology database, compilation of national wetland distribution and erosion sensitive wetland zones, development of a framework for wetland identification guidelines and application of Land Type information to characterise the soils, hillslopes and Land Types which "feed" water to wetlands. The potential of the Land Type information to support landscape interpretation was recognised and the scope of the work related to application of Land Type information to characterise the soils, hillslopes and Land Types which "feed" water to wetlands was focussed towards wetland assessment rather than wetland identification, specifically catchment and wetland hydrological characterisation and wetland hydrological condition assessment. If the location of important wetland water source and water delivery zones within a wetland catchment could be identified, the premise was that detrimental land uses in these areas could be limited. This adjustment in focus was presented and accepted at the second, third and fourth Reference Committee meetings.

The expanded focus of the project beyond wetland identification led to an expanded project scope, as evidenced in the broad span of collated topics within Volume 1, and a doubling in output of guidelines in the form of Volumes 2 and 3. The PhD thesis in support of this project is currently at the midway point and, as such, several concepts and case studies are still in development. However, this project encapsulates the important coming together of two disciplines (soil science and wetland ecology) which had been in tension over the topic of wetland delineation in preceding years, challenged by differences in terminology and emphasis, despite the overlap in subject matter. For all the above reasons, this project can be considered a critically important preliminary foundation and stepping stone for future expansion and refinement. It has faced these significant challenges and has broken important ground, sufficiently collating and presenting key concepts to instigate further research and application to build on these first steps.

The project has grouped the final project deliverables into three volumes. **Volume 1** (this report) considers the whole project and summarises the results of the project deliverables. **Volume 2** presents a methodology for characterising the hydrological hillslopes which make up the wetland catchment, using both Land Type data and field-collected data, in order to support wetland assessment and the avoidance or minimisation of disturbance impact affecting the hydrological condition of wetlands. **Volume 3** comprises guidelines for regional wetland soil contextualisation in support of wetland delineation as a series of discussion documents which draw on the Land Type information to present the case for regional differences in wetland soils and wetland soil indicators.

The project draws from the 2015 WRC Report 2021/1/15 *Hydrology of South African soils and hillslopes (HOSASH)*. This project revealed the role of soil morphology as an established indicator of flowpaths and storage mechanisms of water in hillslopes. The HOSASH study made a valuable contribution to hydrological parameterisation of soil horizons, soil types and soil distribution patterns. During the HOSASH study, hydrological soil property data for a variety of soil horizons and soil types were digested and a partial selection of these have been used to populate the national soil database (Land Type database) in the current project. The current project also builds upon the HOSASH investigation with a focus on how this information can be used to unpack the drivers of wetland hydrology and support wetland assessment. At a local catchment scale, the concept of hydrological hillslopes was applied to investigate the role of hillslopes contributing to and driving wetland hydrology.

At the broad scale, the Land Type Information System of ARC-ISCW was applied in a series of national scale investigations to compile estimated wetland distribution maps. ARC-ISCW used the Natural Resource Zone (NRZ) computer program to group Land Types according to the dominant underlying geology formation and Land Type Broad Soil Pattern. The rationale behind this approach is that the underlying geology rock type, and hence geological formation, is strongly associated with soil type, and could be used as guideline to contribute to the understanding of the dominant controls of flowpaths in hillslopes, The hypothesis stated that Land Type Broad Soil Pattern would provide a natural resource basis to spatially understand and represent differences in wetland distribution at a national scale. Similarly, the approach was expected to represent differences in erosion susceptibility, also at a national scale. Soil forms and soil series of the South African Binomial Soil Classification System were assigned to classes expected to represent differences in soil hydrology. These hydrological classes were chosen to illustrate broad differences in degrees of expected water saturation.

The class W1 represented soil forms exhibiting the longest duration of water saturation. Classes W2, W3 and W4 represented soils with varying degrees of subsurface wetness or in lowland terrain positions. Class W2 represented Kroonstad soils with an eluvial horizon (interflow hydrology dominant), and gley horizon (extended periods of water saturation). Class W4 represented swell/shrink, black clay soils with only subsurface wetness. Clarity in the hydrology of these black clay soils is required, although they are listed in former wetland guideline documents as having special wetland significance. Similarly, Classes W3 and W5 represented soils with alluvial and podzol horizons respectively. Class W3 included podzol soils with a limited spatial distribution in the southern and Western Cape. A detailed understanding of the hydrology of the soils of classes W3 and W5 has not received extensive research, such that placement in a separate class was considered relevant. Greater confidence regarding the expected hydrology for the soils of class W6 was expected. Class W6 soils have an eluvial horizon, where water saturation in the surface and subsurface horizons is expected for short to intermediate durations. Differences in their duration of water saturation will be dependent on the prevailing climate, soil properties and local terrain position. These soils represent the largest contributions to zones where interflow hydrology is dominant in the landscape.

The NRZ program extracted and summed the proportion of soils to each of the permanent and temporary wetland classes. This was summed for each of the 7077 Land Types, and for geology formations representing major differences in rock type. The graphical distribution of Discharge Soils (W1) and Interflow Soils (W2 to W6) was evaluated using GIS quartile technology and presented in figures quoted in the report of Deliverable 4 (Turner *et al.,* 2015b). In these maps the area covered by Discharge Soils (W1) was low (for visual approximation refer to the original maps). In the map of Discharge Soils the class with the largest distribution of Discharge Soils ranged from 2.1 to 8.5%. The second largest class had an equally low percentage distribution of Discharge Soils covering only 0.8 to 2.1%. This result was surprising and would indicate that at national scale, Land Type assessment for Discharge Soils (using this single soil assessment approach) was unable to accurately estimate the proportions of hydromorphic soils considered to represent Permanent Wetlands. These higher proportions of Discharge Soils are present in the Apedal Soils of Basic and Intermediate Igneous Rocks, certain Sedimentary and Metamorphic Rocks and Quaternary Sand. The reason for this limitation can be ascribed to the limited technology available during the 1970s and early 1980s in estimating the areal extent of footslope and bottomland terrain positions at generalised scales. However, the Land Type information source does give a reasonable statement of the types of soils expected in bottomland terrain positions using the 1977 classification criteria.

The areal representation of Interflow Soils (W2 to W6), also using a GIS quartile assessment, gave much more realistic results (refer to the figures for Interflow Soils in Deliverable 4 – Turner *et al.,* 2015b). The graphical distribution of Interflow soils was summed for all five Interflow Soil classes (W2 to W6) since it was important to have a national perspective of surface water delivery from Interflow Soils. The total proportions of Interflow Soils are considerably higher than those of Discharge Soils with quantile classes of the highest map class set between 14.3 and 77.0%. The intermediate map class had between 7.9 and 14.3%. The highest proportions of Interflow Soils are distributed on the Maputaland Coastal Plain of KwaZulu-Natal, the granites of southern Mpumalanga, the sandstones of the KwaZulu-Natal Tugela Basin, the Gauteng Highveld, the sandstones and mudstones of the eastern and western Free State, and the coast and coastal hinterland of the southern and Western Cape. Intermediate proportions cover the most of the Eastern Cape (rainfall greater than 500 mm p.a.) and the interior coastal hinterland of the southern and Western Cape.

Testing wetland distribution using geology formations as a collective mapping tool had both advantages and disadvantages. Geology formation stratification demonstrated differences in wetland distribution and erosion susceptibility. However, the relatively complex geology stratifications at a generalised national scale made representative grouping on a geology formation difficult to interpret. The method applied to the initial hypothesis for a grouping of geology formations did not deliver the expected result. While geology formation strongly correlates with soil properties, a grouping of geology formations did not adequately reflect distributions of hydromorphic soils. It is, however, expected that differences in geology formations, when analysed at local scales, will yield differences in soil physical properties, and hence differences in soil hydrological properties.

Two honours student studies took place within the project. The objective of the first study was to devise a revised wetland classification system to produce a wetland distribution map grouped at soil form level, with the knowledge that certain soil forms express signs of wetness and are associated with permanent or seasonal/temporary wetlands. Soil forms were classified based on the 28 Land Type Broad Soil Patterns of South Africa. A wetland distribution map showing the wetland percentage surface area for each of the 7077 Land Types was produced. The second approach considered evaluation of the permanent and temporary wetlands per Land Type inventory with a conservative and liberal approach. It was found that the conservative approach may underestimate the frequency of wetland occurrence. However, the liberal approach overestimated the occurrence of wetlands. A third distribution map was prepared which falls somewhere in between the two. Findings include the fact that that there is a strong correlation between the percentage wetland distribution per Land Type and the mean annual precipitation, with wetlands more prevalent in higher rainfall climates. This contradicts tacit knowledge indicating drier yet larger areas of wetlands in drier areas. The Broad Soil Patterns provide considerable information on the geological, topographical and climatic factors that influence wetland formation and distribution, if interpreted correctly and integrated with knowledge of soil forming factors from other sources such as the soil classification "blue book" (Soil Classification: a Taxonomic System for South Africa). For the revised classification, the standard deviation is relatively high (>20) for the following broad Land Types; Ca, Db, Ga, Gb, Hb and Ia, which may indicate large variability within them. This variability may have a negative impact on the accuracy of the refined wetland distribution map. A revision of the criteria should include the following:

- Wetland expression dominated by E horizons.
- Correlate soil forms in specific Land Types and geological zones with redox morphology expression as a function of pH and Eh.
- Assess family level occurrence of signs of wetness in a geological, climatic and topographic context to remove an overexpression of wetlands as an artefact in the dataset.

The catchment-scale investigations of hydrological hillslope linkages to wetland were supported by a separate project funded by the City of Johannesburg. Although stream flow, (above and below the soil surface) and groundwater do at times contribute to wetlands across the country, the soil characteristics in this case study indicated that hillslope water dominates the contribution. The premise is that this is the case for many wetlands across South Africa, particularly those in zero and first order catchments. Wetlands are encapsulated within each hillslope, but the wetland, when considered as a functional unit, is the sum of multiple hillslopes. In this way, the wetland is an expression of its entire catchment. Certain areas of the wetland catchment, defined as hillslopes, may contribute more water, for longer periods. Hydropedological soil surveys and the role of soil morphology as an established indicator of flowpaths and storage mechanisms of hillslope water, were applied to identify the most important hydrological hillslopes contributing water to the wetlands, as well as to estimate timing and duration of the delivered water.

Overall, the project makes the following set of recommendations:

a) The work of this study is a preliminary bridging of soil science and applied wetland ecology concepts. Not all issues that came to light were resolved during the course of this project. Nevertheless, it lays a useful foundation for work going forward.

b) The hydropedology database was created in MS Access and populated with a limited dataset using the HOSASH data to test methodology. It needs a better operational Web-based platform in order to be generally accessible. Additional work, funding and collaboration will be required to establish a more improved database with proper data integrity to be used by various organisations. The importance of a regional guideline approach emerged as the most important point from the Land Type evaluation. This was discussed in the light of a concluding figure derived from the figure illustrating the distribution of Interflow Soils. It is important to note that the soil horizon is linked to an item in the database. From the information in the database, one can expect a certain response. This can contribute to hydrological modelling. An equation can also be used.

c) Land Type data offers several advantages including the catenal distribution of the soils and area covered by hydrological soil types. The generalised map that shows the zones with significant distribution of interflow gave the best outcome from the hypothesis and presented a natural resource perspective to link with legislation. Geology, in the way it was used in the method, did not correlate well. However, this does not imply that geology does not play a significant role. In future it might be valuable to overlay groundwater and other resource layers to this generalised interflow soils map to define strategic water resource areas and support decision-making.

d) However, the original Land Type Survey soil observations were limited to 1.2 m maximum depth for classification and thus missed recording some of the deep interflow soils. This is a gap in the Land Type data which restricts the evaluation of soils and fractured rock systems as a source of wetland water and limits its applicability for the aims of this project.

e) Wetland ecosystems do not solely occur in valley-bottom positions in the landscape. In South Africa and internationally, they also commonly occur on various higher slope positions. This is well described in wetland scientific literature and incorporated into best practice wetland assessment manuals (Mitsch and Gosselink, 2000; Brinson, 1993; MacFarlane *et al.*, 2009; Ollis *et al*., 2013). In all of the study sites for this project, wetlands were present on slope positions and were not adequately catered for by the Land Type Survey, where they are traditionally assigned to valley-bottom positions.

f) Following on from this, some soil forms are neither exclusively wetland soils or not. This results in the situation that some of the soil forms assigned to the interflow hydropedological group, typically seen as terrestrial soils by soil scientists, are wetland soils. An expanded understanding of the process hydrology in the hillslopes of the wetland catchment, and the hydroperiod of both wetland soils and deeper flowpaths, will contribute to distinguishing between wetland and terrestrial soils, and will aid in understanding their role in ecosystems and landscapes. Further investigation and classification of some of the interflow soils (which are not described in the South African soil classification system) is warranted, to harmonise soil surveys with wetland characterisation and delineation.

g) At the time of the original surveys, limited attention was paid to characterisation and classification of wetland soils. Wetland soil diagnostic criteria are not the same as that for currently described soil forms or families, and wetlands should be identified based strictly on defined morphology, not on soil form. The South African soil classification system does not yet take this into account. It, therefore, does not adequately distinguish wetland soils, giving rise at times to situations where an interflow soil form polygon may be found to be partly wetland and partly non-wetland, following a wetland delineation according to best practice methodology. This is a limitation for the application of Land Type information (which is based on the use of soil forms) to predict the presence of wetlands, and it is likely that a large proportion of wetlands will be unable to be detected. It is recommended that the South African soil classification system should give attention to wetland soils, and specifically distinguish wetland soils from other soils. This must be supported by hydrological measurements. Until such time as South African wetland soil classification is further developed, soil forms as a diagnostic criterion should be removed from wetland boundary delineation methodology in South Africa, as previously recommended by Kotze *et al*. (1996) and WRC report K8/718 (Job, 2008). This does not mean that soil form should not be used as an extremely useful informant in providing supporting information about the wetland, as shown by the deliverables for this project.

h) A wetland functional unit is very often a combination of hydrological regimes: in some cases temporary, seasonal and permanent zones may all be present within a single wetland. Limitations made it impossible to predict such fine-scale detail from the Land Type information in the study areas for this project. In certain landscapes, such as in the Hogsback study site, wetland functional units even cross multiple Land Type units. In examples such as Agulhas, the Land Type boundary divides some wetlands in two or even three different sections.

i) In some areas, a Land Type does not cover a full catena, but covers only part of the catena and needs to be combined for improved hydrological understanding.

j) It is considered possible to broadly predict which hillslopes within the wetland catchment are likely to provide dominant hydrological contribution to the wetland. However, this application of Land Type information is only useful where the scale of hydrological controls (hillslopes, geological structure and lithology, etc.) is in harmony with the scale of Land Type information, and where the hydropedology aspects were recorded successfully in the soil forms.

k) Recommended steps for using the Land Type information for broad predictions of hillslope-wetland interactions include the following: i) identifying the broad climate and geology region within which the wetland occurs using the Land Type information; ii) mapping the wetland boundary and wetland catchment boundary; iii) dividing the wetland catchment into hillslopes based on as detailed terrain mapping or contour information as possible; iv) dividing each hillslope into terrain morphological units based on as detailed terrain mapping or contour information as possible; v) disaggregating the Land Type data (using the soils listed for each terrain morphological unit and assign to the terrain morphological units within each hillslope); vi) developing a conceptual hydrological response model for each hillslope with expert interpretation of different soil/hillslope characteristics; and vii) estimating the proportional contribution of each hillslope to the wetland functional unit as a whole.

l) Volume 3 consists of several chapters to communicate a proposed framework for future guidelines for regional wetland soil contextualisation and should be seen as a discussion document rather than a specific research study.

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GLOSSARY

Aquiclude: solid, virtually impermeable area underlying or overlying an aquifer.

Aquifer: a geologic formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to yield substantial quantities of water.

Aquitard: a geologic formation or stratum with reduced permeability that lies adjacent to an aquifer and that allows only a small amount of liquid to pass.

Baseflow: the contribution to runoff from previous rainfall events where rainfall percolates through the soil horizons into the vadose and groundwater zones and then contributes a very slow delayed flow to streams whose channels are "connected" to the groundwater. These constitute the 'dry weather' flows which are significant in sustaining flows in non-rainy seasons (Schulze, 1985).

Catchment: area that drains to a tributary junction.

Catena: a series of soils linked by their topographic relationship (typically from crest to valley floor).

Confining layer: A body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers that restricts the movement of water into or out of those aquifers.

Critical zone: the thin outer layer of the earth's surface, extending from the top of the vegetation canopy to the bottom of the groundwater extent (NRC, 2001).

Evapotranspiration: the sum of water lost from a given land area during any specified time by transpiration from vegetation, by evaporation from water surfaces, moist soil and snow, and by interception (rainfall that never reaches the ground but evaporates from surfaces of plants and trees).

Flowpath: zones where water flows in the unsaturated zone, between the soil surface and the groundwater table.

Groundwater: water below the land surface in the saturated zone.

Groundwater level/groundwater table: the surface of the saturated zone at which the liquid pressure in the pores of soil or rock is equal to atmospheric pressure.

Hydrograph: the ratio of volume of water flow over time, presented in a graph.

Hydrological hillslope: areas that have distinct hydrological regimes which are both cause and consequence of a particular combination of plant cover, soil, slope characteristics (e.g. gradient, curvature and aspect) and slope position.

Hydrology: The study of the occurrence, distribution and movement of water.

Hydromorphy: Soil morphology related to reduction due to water saturation or near saturation.

Hydropedology: study of the hydrological interaction of water with soil and the fractured rock zone.

Hydroperiod: degree, duration, frequency and seasonality of inundation or saturation. The seasonal pattern of the water level in a wetland.

Interflow: lateral movement of water through the unsaturated zone.

Overland flow: water flowing on the soil surface.

Oxidised morphology: soil, saprolite or fractured rock with no signs of reduction.

Pedon: the smallest three-dimensional portion of the soil mantle needed to describe and sample soil in order to represent the nature and arrangement of its horizons.

Permanent saturation or inundation *(of wetland)****:*** wetland area characterised by saturation within 50 cm of the soil surface for most of the year, for most years (DWAF, 2005; Ollis *et al.,* 2013).

Polypedon: a group of adjoining pedons.

Recharge: filling up zones that can be replenished including soil horizons, saprolite, fractured rock or groundwater with water.

Redox: reactions involving the transfer of electrons from donor to acceptor, i.e. reduction-oxidation reactions.

Residence time: *(hillslope)* the time water spends in the hillslope from time of recharge entering the soil to the time it surface in wetlands or rivers; *(wetland)* the time necessary for the total volume of water in a wetland to be completely replaced by incoming water.

Response: flow rate, volume, and timing of hillslope water or wetland hydropattern, e.g. after a rainfall event. Often presented in a hydrograph.

Return flow: rainwater infiltrating the earth through soil, saprolite, fractured rock, hard rock, moving with gradient down slope and returning to the soil surface at a lower point the landscape.

Runoff: water leaving the catchment, not to be confused with overland flow.

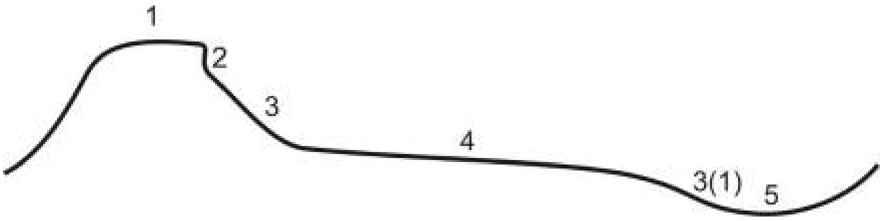
Saturated: all voids filled with water. This is seldom reached in natural conditions. Related to exclusion of air to the point where soil has anaerobic conditions.

Saturated zone: groundwater.

Seasonal saturation or inundation *(of wetland)****:*** wetland area characterised by saturation within 50 cm of the soil surface for 3 to 9 months of the year, usually during the wet season (Ollis *et al.,* 2013).

Temporary saturation or inundation *(of wetland)****:*** wetland area characterised by saturation within 50 cm of the soil surface for less than 3 months of the year (DWAF, 2005).

Terrain morphological unit (TMU): TMU 1 represents crest, 2 scarp, 3 midslope, 3(1) secondary midslope, 4 footslope and 5 valley floor **(**Land Type Survey Staff, 2004).



Unsaturated zone: includes soil horizons, saprolite and fractured rock above the surface of the regional groundwater table.

Water budget: an accounting of the inflow to, outflow from, and storage within a wetland or catchment.

1. INTRODUCTION

In a water-scarce country such as South Africa, water can be wasted through unwise development by industries, cities and towns before it reaches the point of ecological support (i.e. aquatic ecosystems). Urbanisation contributes to reduced infiltration of water to the soils, transforming what would be recharge of hillslopes and groundwater into a peak flow runoff response. Water in an urban setting may also be re-routed directly into streams, resulting in increased stream flows, erosion and flooding. As a result, water storage in hillslopes is reduced, and the slow release of the water from upland recharge soils to wetlands is reduced. The consequence for wetlands is progressive drying and diminished wetland function. Eco-hydrology is growing in importance in urban environments and in mining development because of the potential of these environments to dramatically alter water flows and, subsequently, to severely impact wetland functions and services. Eco-hydrology also has significance in agricultural environments, since it will contribute to the understanding of water flows to wetlands and rivers and, hence, to water management and policy development.

Three distinctly different spheres contribute to the hydrology of aquatic ecosystems in South Africa, namely rainfall, surface hydrology and groundwater hydrology. Two of the three, surface hydrology and groundwater hydrology, are confined to specific parts of the critical zone. The critical zone is defined as the thin outer layer of the earth's surface, extending from the top of the vegetation canopy to the bottom of the groundwater extent (NRC, 2001).

Hydropedology focusses on the third, hidden part of the hydrological cycle, the ***vadose zone***, which is wedged in between the land surface and the groundwater, and is the focus of this WRC report.

Soil water content and the duration of saturation, the heartbeat of wetland soils, are well correlated with soil morphology, as used in soil classification (Van Huyssteen *et al*., 2004), making it possible to define hydrological transfers through interpreting soil horizons and soil types. This was used to group soil types to their hydrological response (Van Tol *et al*., 2010a). This resulted in 6 hydrological hillslope classes, each with a characteristic predicted response to rain events (Van Tol *et al*., 2013a). The control of hillslope water contributing to the release of water to wetlands correlates well with the distribution of soils in the hillslope classes (Van Tol *et al.*, 2010a*,* 2011a; Kuenene *et al*., 2011, 2013).

1.1. Problem Statement / Rationale

The ARC-ISCW Land Type Information System (Land Type Survey Staff, 2004) covers the whole of South Africa and is based on extensive field observation and soil analyses. It is thus an untapped source of relevant information that can contribute to wetland distribution patterns. The geographic extent of wetlands derived from Land Type information may be of use in initial evaluation of wetland issues, policy development and subsequent decision-making actions in land use planning.

Field morphological observations and analyses beyond the wetland boundary can contribute to an improved understanding of wetland hydrological functioning. Since this information is linked to hillslope characteristics, and hydrological hillslope transfer functions can be defined for Land Types, a hydrological response for Land Types can be inferred at a desktop level.

A better understanding of water sources for wetlands and the delivery pathways of water to wetlands can contribute to improved assessment of land use impacts on wetlands. In the case of urban hydrology, the impact of urbanisation on wetland functioning can be better managed through the availability of this type of information. This will lead to improved recommendations in response to urban development actions, strengthened legislation and optimal use of wetland landscapes during the urbanisation process. Wetland and conceptual hydrological hillslope response models can contribute to benefit both the ecosystem and urban engineering.

1.2. National Scale Assessments

Assessments have been made using the national coverage of the Land Type Information System to evaluate broad impacts on the hydropedology and wetland distributions. This has been achieved through:

- The assessment of the distribution at general scales of soil hydromorphy derived from Land Type Information.
- An assessment of soils sensitive to erosion (Capacity Building Project).
- An overall assessment of the general Land Type properties (LT Broad Soil Patterns) in relation to a general assessment of hydrological regime (Appendix 6).
- The construction of a hydrological component to the ARC-ISCW Soil Information System, linkages of this new component to the original soil information sources and the (thus far) limited population of the database with soil hydrological information as examples of the soil hydropedological Information derived by the wider scientific community.

1.3. Regional Scale Assessments

The assessment for Regional Scale impacts on wetlands have been achieved through:

- Guidelines for regional wetland soil contextualisation (**Volume 3**).

1.4. Catchment Scale Assessments

These sections explore terrestrial-wetland interactions where hydropedological survey is used to explain:

- Soils, hillslopes and Land Types feeding wetlands.
- Preliminary guidelines to apply hydropedology in support of wetland assessment and reserve determination (**Volume 2**).

The “Preliminary guidelines to apply hydropedology in support of wetland assessment and reserve determination” aim to create awareness of the hydrological relationship between wetlands and the terrestrial part of hillslopes. Objectives include the desire to inform practitioners in all fields about the hidden half of the hydrological cycle and how it influences wetland expression in the landscape, and to apply hydropedology to the full landscape at different scales. This follows the subsurface hydrological cycle, stretching from the hillslope crest (typically recharge land) through the hillslope via interflow to the point of accumulation or expression at the surface, as wetlands and rivers. The second aim is to deliver guidance in support of avoiding or minimising the impact of disturbance affecting the hydrological condition of wetlands. Volume 3 presents a workflow methodology, characterising the set of hillslopes (including terrestrial and wetland controls) which make up the wetland catchment. This is developed into step-by-step procedures and products to support wetland assessment. Workflow must be designed according to the intensity and scale of the targeted area.

1.5. Report Structure

The final report comprises three volumes (Table 1.1), focussing on different scales. **Volume 1** captures the whole project and pulls together all the project deliverables. **Volume 2** is a stand-alone document which explains the different levels of survey intensity and describes wetland behaviour. The final document (**Volume 3**) is a series of concept articles that can provide some background guidance and contextualisation. However, Volume 3 should be not be seen as a definitive scientific document, but rather a series of ideas that can be expanded and updated.

Table 1.1: *Report structure in three volumes*

Volume 1 (this document)	**Volume 2**	**Volume 3**
Improving the management of wetlands by including hydropedology and Land Type data at catchment level	**Preliminary guidelines to apply hydropedology in support of wetland assessment and reserve determination**	**Guidelines for regional wetland soil contextualisation**
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2. KNOWLEDGE REVIEW

2.1. Land Type Information

2.1.1. Soil Hydropedology

Detailed literature reviews on the role of soils, and in particular soil properties and their spatial distribution, soil classification and soil mapping approaches, have been provided in earlier research projects of the Water Research Commission (WRC). Van Huyssteen *et al.* (2005) showed that the relationship between soil profile morphology and soil hydrology will contribute towards understanding hillslope hydrological processes and facilitate technology transfer between catchments. They researched the expression of soil redox morphology in relation to the duration of water saturation in soil profiles and determined the average durations for a range of soil diagnostic horizons within the Weatherley catchment in the Eastern Cape. The research showed that the diagnostic horizons and the soil form and family classes as defined in the Taxonomic System of the South African Soil Classification System strongly reflected differences in the duration of water saturation. This laid the foundation to use the soil classification concepts in a wider context in soil hydrological studies. It gave confidence to expand these soil classification classes into the widely accepted soil survey techniques and expand these concepts into soil mapping applications beyond those of the intensively researched catchments.

Studies in additional catchments enabled the soils to be grouped into hydrological response classes, described generally as recharge, interflow and responsive units (Le Roux *et al.,* 2011). The conceptual flowpaths through soils in hillslopes formed an important departure point in the initial phases of this project. The flowpaths were directly associated with soil classification classes that led to the initial hypothesis that soil information expressed at national and regional scales could provide information of the general hydropedology at these generalised scales. The HOSASH Project, sponsored by the WRC (Le Roux *et al*., 2015), integrated a spectrum of soil and hillslope research findings, including the use of both ancient and recent soil morphological and chemical properties, advanced soil survey techniques and conceptual hydrological response models for hillslopes as important processes towards the quantification of the hydrological processes. The report concluded (p. 335) that soil horizons, soil types and soil distribution patterns of Land Types could make local and small-scale extrapolation possible. This is in contrast to the thinking in hydropedological research that has, of necessity, always focussed on detailed studies. Extrapolation to scales of lesser detail, as in an assessment of Land Type Information, will necessarily imply lesser degrees of accuracy.

However, the initial hypothesis seemed a reasonable one to investigate generalised information sources. This hypothesis formed the initial phases of this report.

2.1.2. Introduction to the Soil Classification Systems

There have been two versions of South African Soil Classification System to date. The Binomial System (MacVicar *et al*., 1977), the older of the two versions, has been used in this study. The Land Type Survey information (discussed below) uses the Binomial System to provide, at a national scale, complete coverage in map and text data formats. Reference to the Taxonomic System (Soil Classification Working Group, 1991) is also made in this report. Both systems have very similar structure and information content with respect to soil hydromorphy. Initially, they were developed to promote information transfer of soils for agricultural purposes. Recently, the classification has been increasingly applied to evaluate the distribution of expected soil hydromorphy. In an ancillary capacity building study, it has also been applied in the assessment of erosion sensitivity, with initial emphasis on water erosion sensitivity (Mqina, 2015).

Both systems have a strong theoretical basis, with emphasis placed on visible morphological properties, and are supported by measurable soil chemical and physical properties. Interpretation of soil properties can be directly linked to soil wetness regimes. In general, soils with an organic, melanic or orthic horizon directly overlying a G (gley subsoil horizon), and the sandy (Fernwood) soils of depression topography (typically in KwaZulu-Natal), were considered as representing 'Permanent Wetness'; soils with an E horizon as representing 'Seasonal Wetness'; and soils with freely drained apedal horizons, duplex soils, black clay soils and shallow soils as representing 'Terrestrial Land'. The initial placement of soil classes into Recharge (Deep and Shallow), Interflow (A/B and Soil/Bedrock) and Responsive (Shallow/low infiltration and Saturated) (Van Tol *et al*., 2010b, 2013a) was applied (Appendix 1) and used to estimate broad wetland classes at a national scale.

2.1.3. Application of Land Type Information in assessments of the distribution of soils exhibiting Soil Hydromorphy

The initial hypothesis proposed that, at a national scale, soil and Land Type information could be used to estimate the extent and distribution of soil hydromorphy. Soil descriptive information, expressed via soil classification classes, and broad geological groups, could be used to estimate the extent of soil hydromorphy, and hence an estimate of the spatial extent of wetland and terrestrial distribution. This could be achieved via:

(i) A grouping approach of Land Types and broad geological information. Soils were first grouped in hydrological classes and a summation assessment of their distribution prepared. The advantage of this approach is that the assessment could be directly linked to the spatial distribution of Land Types and illustrated in distribution maps.

(ii) An individual Land Type assessment approach could be applied. The approach was considered preferable for a student honours project permitting training in the hydrological assessment of individual Land Types. (A subsequent development arising from this approach has potential in illustrating the range of possible interpretations that may be assigned to soil properties and to soil hydromorphy in wetland assessment.)

(iii) A similar approach could be followed to assess erosion sensitivity. Whereas in the previous approaches, soils were assessed for their hydromorphic properties, in this approach they were assessed for their sensitivity to erosion. The similarity in approaches also assisted in honours student training.

Approaches (ii) and (iii) were to be as capacity building projects for BSc (Honours) students from the University of Pretoria who were interested in wetland and wetland/erosion sensitivity studies. The approaches were achieved using the coverage of soil information from the Land Type Survey and using Binomial Soil Classification System. Soil classes were assigned into hydropedological classes (Recharge, Interflow and Responsive) (Van Tol *et al*., 2010b). Computer database query technology and GIS Mapping technology were used to spatially represent the resultant information. Groups of Land Types and Broad Geology Groups, and individual Land Types respectively were assigned to the respective hydropedological classes. A similar approach was used to assess erosion sensitivity.

2.1.4. Construction of a prototype Hydropedological Database as a component to the ARC-ISCW Soil Information System

Important hydropedological data has been reported in a number of research reports. ARC-ISCW has had experience in assembling a large collection of soil chemical and physical information in addition to the collection of soil map information. This Soil Information System has now found many applications in a diverse range of scientific disciplines. However, the important hydropedological information is distributed throughout an equally diverse range of sources. Collation into a central repository would appear to be beneficial to the science. This could facilitate its use in future to wider applications and extrapolation to catchments where data is limited.

With the establishment of an archiving repository for hydropedological data, the construction of a prototype Soil Hydropedology component to the ARC-ISCW Soil Information System seemed to have value to the scientific development of the discipline. Soil profile descriptions, soil chemical and physical analyses form part of the data collection processes in hydropedology. These components are already well established in the ARC-ISCW Soil Information System. The initial hypothesis was to add a hydropedological component to the existing system. The methods of construction for this deliverable are reported in Section 3 and the result in terms of construction and populating the database is shown in Section 4 of this report.

2.2. Wetland Delineation

Local, regional and national regulatory bodies in South Africa, including the Department of Water and Sanitation (DWS), have adopted legislation, policies and guidelines that regulate the use of wetland ecosystems to protect and maintain the benefits and services they provide to society and the natural environment.

It is acknowledged that a wetland boundary delineation on its own does not provide sufficient information about the hydrological or other drivers of wetland presence, and it does not provide information on the ecological state of the wetland, ecosystem services it may provide, wetland importance, or how land use within the wetland or its hydrological catchment may alter the biophysical characteristics of the system (South African Wetland Society, 2014). For this reason, DWS requires that both a wetland boundary delineation and a wetland assessment (including condition, ecological importance and sensitivity) be submitted as part of the Water Use Licence application process.

Methodology to identify wetlands needs to be rigorous, while not placing an unnecessary financial burden on the public such that compliance with the law is avoided and could actually lead to sustained wetland ecosystem destruction. Although hydrology is considered to be the primary biophysical driver behind the origin and maintenance of wetlands, it is considered the least economically feasible diagnostic feature of a wetland ecosystem to measure, due to its dynamic nature, which varies daily, seasonally and yearly (Ingram, 1983). Hillslope delivery of water to wetlands also varies spatially, and as the process is hidden (at times flowpaths may occur more than 2 m underground), it is very difficult to observe.

For both wetland boundary delineation and the assessment of hillslope water sources and flowpaths, it is, however, possible to make use of more rapid and consistently detectable diagnostic features ("indicators") which act as surrogates to indicate the presence of wetland hydrology, or hillslope flowpaths. For both hillslopes and wetlands, and for both hydropedology practitioners and wetland delineation practitioners, soil morphology has been adopted as a useful indicator. For terrestrial hillslopes, the indicators occur at multiple depths, sometimes to 2 m or more. Water flow in the vadose zone and the rate of flow controls the interaction with the soil, the biologically active upper vadose zone and biologically inactive fractured rock (Le Roux *et al.*, 2015). Flow rate and position in the landscape impact on the redox state and evaporation rate of the water. Variation in these processes controls oxidation, reduction, alternating oxidation-reduction processes, and the morphological indicators of these processes. In dry areas, evaporation dominates, and leaves signatures of precipitates (Van Tol *et al*., 2013b). These morphological properties can occur at any depth, indicating the depth of a flow path. In the case of wetlands, the soil morphology indicators must occur within the near-surface zone, such that they influence the roots of wetland plants, the hatching cycles of invertebrates or the biogeochemistry of the ecosystem, and the presence of hydrophytic vegetation is used as further indicator (DWAF, 2005). Soil morphology indicators can also serve to group wetlands into broad hydrological groups, namely, permanent and seasonally saturated. Soil morphology indicators are expected to be commonly present in wetlands, "except where specific physicochemical, biotic, or anthropogenic factors have removed them or prevented their development" (NRC, 1995). These are considered to be "special cases" and are not uncommon in South Africa or internationally. They have been introduced in the 2005 DWS wetland delineation manual (DWAF, 2005; Job, 2008), but there is scope for improved description of these cases.

The premise that nearly all wetland soils exhibit characteristic morphologies that result from repeated periods of saturation and/or inundation for more than a few days, has been confirmed in the literature and underpins both disciplines (wetland delineation and hydropedology). The anaerobiosis, supported by microbial activity in the soil, promotes biogeochemical processes, such as the accumulation of organic matter and the reduction, translocation, and/or accumulation of iron and other reducible elements (USACOE, 2006, p. 35). Soil morphology indicators relevant to wetland boundary delineation include: organic carbon (OC) accumulation; peat layers; grey matrix colours (chroma <2); high chroma mottles in grey matrix; low chroma mottles (>10%) in high chroma matrix; and presence of oxidised root channels (Gambrell and Patrick, 1978; Faulkner and Richardson, 1989; Mitsch and Gosselink 2000; Vepraskas, 1995; Vepraskas and Faulkner, 2001). South African research which has confirmed the international scientific literature and contributed knowledge about the South

African context includes that of Van Rooyen (1971), Van Huyssteen *et al.* (2005), Jennings (2007), Le Roux *et al.* (2011), Smith and Van Huyssteen (2011), Mapeshoane (2013), Kuenene *et al*. (2013), Van Tol *et al*. (2010a), Bouwer *et al*. (2015), Tinnefeld (2016), Johnson (2016) and Pretorius *et al*. (2017).

A wetland-focussed research project that jointly considers hydropedology and wetland ecology is timeous in South Africa, to contribute to proposed improvements in methodology. Both disciplines have in common a focus on the interpretation of characteristic redoximorphic and reduced soil morphologies that result from repeated periods of saturation and/or inundation for more than a few days. Terminology differences between disciplines, inadequately trained practitioners, misinterpretation and gaps in the way the subject matter is presented in the current delineation manual have been a source of confusion and controversy. Once it is agreed that both disciplines make use of the same principles of soil morphology interpretation, it becomes possible to focus on strengthening interpretations, and to specifically identify the remaining challenging issues, so that further research and discussion can be focussed. The guideline documents of Volumes 2 and 3 for this project, make a start on this.

Over the course of recent years, multiple cross-disciplinary meetings have been held to discuss gaps in the way the subject matter is presented.

In the case of wetland delineation, it is proposed to keep the internationally applied three indicator groups most commonly used, namely hydrology, soil morphology and vegetation, i.e. a multiple indicator approach. “Although vegetation is often the most readily observed parameter, sole reliance on vegetation or either of the other parameters as the determinant of wetlands can sometimes be misleading. Many plant species can grow successfully in both wetlands and non-wetlands, and hydrophytic vegetation and hydric soils may persist for decades following alteration of hydrology that will render an area non-wetland. The presence of hydric soils and wetland hydrology indicators in addition to vegetation indicators provide a logical, easily defensible, and technical basis for the presence of wetlands. The combined use of indicators for all three parameters enhance the technical accuracy, consistency, and credibility of wetland determinations” (USACOE, 1987).

With respect to soil morphology, it is suggested that the focus should be on expanded description and interpretation of soil morphology present on site, and that soil form would not be used as an indicator, not least because certain soil forms under the current classification system can at times be present in both wetland or non-wetland situations. Clearly, soil form can be derived from the expanded description and morphology interpretation; however, it is the detail of the morphology, and the measurements of the depth at which changes in morphology are observed, that are critical in a site-specific wetland delineation where a boundary line must be identified. In addition, the landscape position indicator would no longer be an indicator but would be amended into contextual supporting information to be gathered during the delineation (according to a datasheet which should be included into an update of the manual).

Basic plant and soil morphology indicators, as applied worldwide, appear to be sufficient to support wetland delineation in most cases. Past investigations by Swanepoel *et al*. (2008) and Job (2008) found that common soil morphology indicators (presence of gleyed soils or redoximorphic features within 50 cm of the soil surface) were sufficient in more than 80% of cases and that wetland and soil science practitioners were invariably in agreement on site in the field (Swanepoel *et al*., 2008). It is acknowledged (South African Wetland Society, 2014) that the description of the basic principles in the current manual could be more clearly stated and strengthened. Following this, the exceptions can be more clearly identified and described. Commonly anticipated “special cases” with respect to soil morphology indicators include soil parent material lacking in iron and manganese, soils with high pH, soils with red parent materials, and certain sandy soils (USACOE, 1987; USDA-NRCS, 2010). This project has also identified potential new special cases (Volume 3).

Currently, the 2005 DWS delineation manual only identifies special cases (“Specific Cases”) with respect to soils that are difficult to delineate. However, in many cases, there are factors other than the soil which make a site difficult to delineate. Importantly, on many “difficult sites”, soil can successfully be relied upon to indicate wetland conditions. In USA wetland delineation practice it is required to assess whether wetland conditions can be described as "normal circumstances". This acknowledges that there are instances in which the vegetation in a wetland has been inadvertently or purposely removed or altered as a result of recent natural events or human activities. Draining, ditching, berms, deposition of fill, irrigation and impoundments (dams) are further instances where normal circumstances have been altered by human activity. When such activities occur, an area may fail to meet the diagnostic criteria for a wetland. In such cases, an alternative method must be employed in making wetland determinations. The extent and relative permanence of the physical alteration of wetland hydrology and hydrophytic vegetation, and the purpose and cause of the physical alterations should be considered (USACOE, 1987). Natural events may also result in sufficient modification of an area that one or more wetland indicator parameters are absent. For example, changes in a river course may significantly alter hydrology (USACOE, 1987). A further challenge includes unvegetated wetlands, e.g. mudflats lacking macrophytic vegetation or unvegetated depression wetlands. These and other wetland types may be dry for extended periods of time and may not develop the most commonly applied soil morphology indicators. Specific guidance may be necessary to support wetland delineation in these areas, and this is explored in Volumes 2 and 3.

International delineation practice also cautions against the misinterpretation of “relict” soil morphology indicators (USACOE, 1987) which persist, even though an area has not been a wetland for a significant length of time. This requires distinguishing between recent (poorly-buffered) and ancient (well-buffered) indicators, and was not discussed within the 2005 DWS manual. Vegetation can change in a short time and qualify as an indicator of recent conditions. Related distribution pattern of biopore redox morphology is also a poor buffer and used to infer recent changes in hydrology (Omar *et al*., 2014). Soil morphology in general is well buffered.

2.3. Wetland Assessment

Since 2009 in South Africa, two units of assessment, namely the wetland and the wetland catchment, were formalised as being essential components of a thorough assessment of the condition of a wetland and, in particular, an understanding of impacts on the wetland. This assessment methodology was outlined in the WET-Health wetland assessment manual (MacFarlane *et al.,* 2009), and has been widely applied by wetland practitioners across South Africa.

A question fundamental to the hydrology component of the WET-Health wetland assessment is how the wetland hydroperiod is sustained, and what would be the reference or natural state of water delivery to a given wetland. Following on from this, impacts on the delivery of water to the wetland are assessed. To this end, the WET-Health methodology directs the practitioner through an assessment of the wetland catchment (Figure 2.1) (MacFarlane *et al.,* 2009), and Section 4.2 of this report examines in more detail the hillslope wetland water source and water delivery pathways through the hillslope to the wetland.

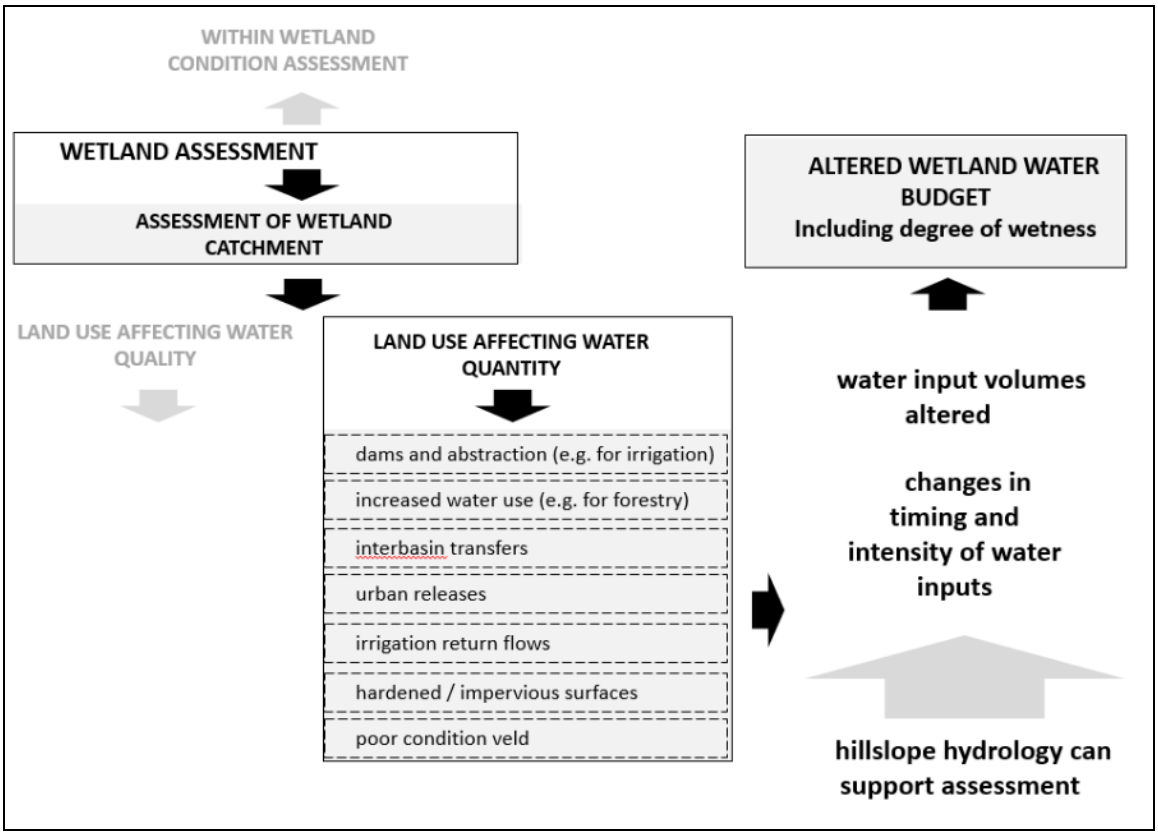


Figure 2.1: *Components of the hydrological assessment of a wetland catchment (adapted from MacFarlane et al., 2009).*

To adequately assess the potential impacts of land use change on wetland hydrology, therefore, requires looking beyond the boundary of the wetland into the nature of the water source in the catchment of the wetland. This requires an accurate estimate of what constitutes the water source(s) to the wetland, as well as an understanding of what controls the maintenance, frequency, timing and duration of the water within the wetland. This is critical information for an accurate assessment of the potential impacts a proposed change in land use may have on a wetland.

The wetlands of the catchment reflect the amount of water available from the wetland catchment over long time frames. The sub-surface flowpaths within the catchment hillslopes are critical components of the delivery of this water to the wetlands. The identification of water source areas, as well as an understanding of water delivery to the wetland, is critical for accurate assessment of the potential impacts a proposed change in land use may have on the hydrological regime of a wetland. Change in the hydrological condition of wetlands can be linked to changes in hillslope water storage and in the surface and subsurface delivery of water to the wetland. Thus, the protection of the source areas which capture much of the water ultimately delivered to the wetland, is critical. It is also critical to minimise alteration of the flowpaths which deliver the water between the source and the wetland.

The WET-Health methodology is well-developed with respect to assessing surface water delivery to wetlands. It does briefly refer to sub-surface water inputs, but this component could be further strengthened.

Finally, while the retention of a narrow buffer of natural vegetation around the wetland may protect a wetland from immediately adjacent water quality impacts, and may also be critical for biodiversity support, a buffer will have little to no impact on sustaining the hydrology of the wetland, without which the wetland would not exist. A hydropedological assessment of the wetland catchment can contribute to identification of the key water source areas and flowpaths driving wetland function and hydrological characteristics. Based on a hydropedological assessment of the wetland catchment:

- the location, timing, and quantity of non-riverine, overland and sub-surface water delivery to the wetland can be described in more detail, and
- key impacting land uses can be identified with higher confidence.

3. METHODS

3.1. National Scale

Three similar approaches to evaluate the distribution of soils with hydromorphy (and hence wetlands) and of erosion sensitivity are discussed. In all three approaches, the Land Type Information System of the ARC-ISCW was used as the primary information source (Land Type Survey Staff, 2004). In the first two approaches, soil morphology as expressed in the soil form was used as the indicator of the expected duration of saturation with water. The hypothesis was held during the initial stages of this project that individual soil forms alone represented either single recharge, interflow or responsive hydropedological class. Hence, it is necessary to report on research activities in this simplified context in the final project report.

The first wetland approach was performed by ARC-ISCW. A grouping of Land Types, together with a grouping of geology formations with similar lithology, was used to estimate the extent and distribution of hydromorphic soils. A computer program was adapted and developed for general analysis of the Land Type information source. This program estimated, for each group of Land Types, the Permanent Wetland, Seasonal/Temporary Wetland and Terrestrial Soils. Distribution mapping was done with GIS technology.

The second approach was performed as a University of Pretoria capacity building project (Fourie, 2015). Wetland distribution was assessed using individual Land Types as a primary assessment tool. A conservative, liberal and subsequently a revised assessment approach was used in the wetland distribution assessment.

The third approach, also performed as a University of Pretoria capacity building project, assigned in this case an assessment of erosion sensitivity to both soil form and series classes (Mqina, 2015). Database queries and GIS technology provided the erosion sensitivity distribution map.

The methods and results of the second and third approaches are fully documented in the two Honours degree theses (Fourie, 2015; Mqina, 2015). The electronic code (MS Access) for the computer program is installed on the computer system of ARC-ISCW, while a manual for the program is filed in the ARC-ISCW archive.

3.1.1 ARC-ISCW Soil Information System (computer program and database)

The NRZ computer program (Engelbrecht, 2007) grouped Land Type Soil Pattern and dominant underlying geology formation to estimate wetland distribution. The Soil Pattern is the main mapping unit of the Land Type Survey and displays major differences in soil distribution. Mapping of the hydrological properties (Recharge, Interflow and Responsive Zones) was done for individual Land Types. Maps reflect the distribution of hydrological units based on estimate soil distributions. The initial hypothesis considered that Land Type Broad Soil Patterns and a grouping of geology formation based on underlying rock types would contribute at national scale to the distribution of hydrological properties. It was expected to show major differences in soil hydromorphy and wetland distribution and that these major differences may have relevance at national scale to wetland guideline frameworks. The collective Land Type Broad Soil Patterns and the geology groups are reported in Tables 3.1 and Table 3.2 respectively.

Table 3.1: *Collective Land Type Broad Soil Pattern symbols and generalised description as used in this WRC project report*

Land Type Symbols from published sources	Collective Land Type Broad Soil Pattern Symbol	Description of Collective Broad Soil Pattern as used in WRC Report
Aa, Ab, Ac, Ad	AA	Apedal Dystrophic and Mesotrophic Soils (AA)
Ae	AE	Apedal Eutrophic Soils (AE)
Af	AF	Apedal Eutrophic Soils with Dunes (AF)
Ag, Ah, Ai	AG	Apedal Eutrophic Sands (AG)
Ba, Bb, Bc, Bd	BA	Plinthic Soils (BA)
Ca, Da, Db, Dc	CA	Plinthic and Duplex Soils (CA)
Ea	EA	Black and Red Clay Soils (EA)
Fa,Fb,	FA	Shallow Soils Lime Rare (FA)
Fc	FC	Shallow Soils Lime Abundant (FC)
Ga, Gb	GA	Podzolic Soils (GA)
Ha, Hb	HA	Deep Grey Sands (HA)
Ia	IA	Alluvial Soils (IA)
Ib, Ic	IB	Rockland (IB)

Geology formations (Geological Survey, 1984) are associated with soil properties and were similarly expected to show major differences in wetland distribution (Table 3.2). Soil forms (and in some cases soil series) (MacVicar *et al*., 1977) were assigned to a Hydrological Class (Van Tol *et al.,* 2010b), namely Recharge, Interflow or Responsive Classes. The computer program assigned each soil entry in each Land Type inventory to one of the hydrological classes. The first input file prepared summary information of Hydrological Classes (W1 to W6) for each Land Type Broad Soil Pattern (Table 3.1) and broad geology group (Table 3.2). A series of tables were prepared for each Hydrological Class expressing the relationship between Land Type Broad Soil Pattern and geology group (Deliverable 3 – Turner *et al.,* 2015a). Extracts of these tables are presented in this report (Tables 3.1, 3.2, 3.3). The result is expressed in tabular form and processed using a GIS technology applying a quantile analysis and map production processes with six map classes. Maps were prepared for each of 'Permanent Wetland', 'Seasonal/Temporary Wetland' and 'Terrestrial Land' classes.

Table 3.2: *Geology rock type groups used for association of wetland discharge and interflow soils derived from the 1:1 million geology map of South Africa (Geological Survey, 1984)*

Geology Group in WRC Report		**Map Symbol derived from 1:1 Million Geology Map of South Africa**
Symbol	**General Rock Type**	**(Reference Stratigraphic Group, Subgroup or Formation Map Symbol**
IA	Igneous Rocks – Acidic	Jj, Mbi, Mee, Mle, Mse, Nng, Nr, Ra, Rc, Rga, Rha, Rsk, R-Vm, R-Vma, R-Vmh, R-Vms,R-Vt,VA, VB, Vc, Vdm, Vdr, Vkw, Vme, Vro, Vse, Vsh, ZA, ZB, Zka, Zne, Vhh, Z-Rg, Zg, Nmp, Znm, VC
II	Igneous Rocks – Intermediate	Jb, Mj, Mvi, Mtu, Rd, Rk, Rro, R-Vz, Val, Vh, Vhd, Vo, Vri, Vve, Vvl, Zns, Zo
IB	Igneous Rocks – Basic	Jd, Jdr, Jl, Jdb, Ms, Mt, Vdi, Vdu, Na
IU	Igneous Rocks – Ultrabasic	Zgi, Zl, Zmu, Zp
SS	Sandstones – Siliceous	Kma, Ks, Ma, Mc, Mkf, Msm, Msw, Mwy, Ope, O-S, Sn, TRc, TRmc, Vma, Zm, Osn
SF	Sandstones – Feldspathic	Mv, Mwi, Pv,R-Vso,
SM	Sandstones – Micaceous	Ru, O-Sn
SC	Sedimentary Rocks – Conglomerate	Vlo, Vsi
SH	Shales	C-P, Db, Dbi, Dc, Dl, Dt, Np, Npo, Nt, Pe, Pf, Pk, Pp, Ppr, Ppw, Pt, P-TR, Pvo, Pw, Rj, Vp, Vrt, Vry, Vt, Vvs, Vw, Zf
SHM	Shales and Mudstones	Mam, Nk, Pm, P-TRsk, Rh, TRm, TRt, Pes
SHS	Shales and Sandstones	Pa, Pc, Pko, Pr, Ps, TRb
MUD	Mudstones	J-K, Kz, P-Tri, TRny, Vd, Vk, Vm, Pem
LIM	Limestone and Dolomite	Nh, Nmz, Nmu, Nsc, T-Qb, Vas, Vgh, Vl, Vle
QZ	Quartzite	Dw, Je, Mge, Mkh, Mm, Mr, Mu, Nf, Nfi, Nfl, Nka, Nku, Ns, Op, Rg, Rka, Rm, Rmp, Rmz, Rt, Tg,Vbr, Vby, Vlm, Vmg, Vst, Vsu, Zmo, Zw
M	Metamorphic Rocks – General	Vbi, Vds
MG	Metamorphic Rocks – Gneiss	MB, Mga, Mgl, Mgo, Mho,Mli, Mto, Nmp, Vmgr, Vpy, Vra, Vrs, Vvi, Z, ZC, ZD, Zgo, Zgu, Zhh, Zma, Rma
MS	Metamorphic Rocks – Schist	Jp, Me, Mfr, Mg, Nbe, Nbi, Nbr, Ng, Ngi, Nm, Nmf, Nmo, No, Npr, Rha, Vbi, Vdg
QSA	Quaternary Sand	Q, Qb, Qm, Qs, T-Qk, T-Qn, Qbsa, K-Ts, K-Mz, Km

The hydrological classes were designed to separate soils associated with Permanent Wetland and Seasonal Wetlands from Terrestrial Land classes. Soils with organic, melanic and orthic surface horizons **and** a gley subsurface horizon were assigned to class W1. In addition to the subsurface gleying where extended durations of wetness are expected, the surface organic and orthic horizons also have extended durations of water saturation, so the Permanent Wetland classification seems appropriate.

Several categories labelled as W2 to W6 were associated with Seasonal/Temporary Wetlands and represented expected differences in the extent of soil wetness. Class W2 comprises Kroonstad soils with a bleached orthic surface horizon and an E (eluvial) subsurface horizon where lateral water flows and longer durations of water saturation could be expected. However, these horizons are not expected to be fully saturated throughout the year. The subsurface gley horizon is expected to remain at near saturation, although water permeability is expected to be low, so that extensive discharge of water from deeper horizons may be limited. This class has important implications for water flows when studied at detailed scales. It emerged, however, that these soils had limited spatial extent as the dominant soil at national scale.

Class W3 comprised Dundee soils with an alluvial horizon located in bottomland positions. These soils are extensively used for agricultural production and are subjected to periodic flooding. The extent of their saturation with water is strongly dependent on local conditions. Nationally, this class occupies the lowland positions of numerous coastal and inland river systems. However, classification as a Temporary Wetland at national scale is somewhat tenuous. The class was evaluated separately as Temporary Wetlands.

Class W4 comprised Rensburg soils with a black clay surface horizons with shrink/swell properties and subsurface gleyed material. Rensburg soils were formerly considered to be in the Permanent Wetland class (DWAF, 2005). The presence of large cracks in the dry state (a diagnostic criterion for Rensburg soils) questions whether these soils have extended surface soil saturation. Although the soils cover large areas at a national scale, they were inserted here as Temporary Wetlands and evaluated separately.

Class W5 represented podzol soils with bleached E horizon soils and a subsoil accumulation of organic acids. Their location is limited to the narrow coastal plain of the southern Cape. Despite having bleached soil horizons, there is limited published information on the duration of water saturation for these soils.

Class W6 comprised a broad range of soils with a bleached surface horizon, an E (eluvial) subsurface horizon and a deeper horizon that is slowly permeable to water. Varying degrees of water saturation can be expected of these soils. During periods of limited rainfall or intense evaporation, the surface soils may be generally dry. However, after heavy rainfall, and where inflows of hillslope water can be expected, periodic to extended periods of saturation with water are encountered. Lateral water flows are expected. These soils have very important implications with regard to soil water storage and water flows. The extent and depth of saturation with water may be below that considered for recognition as wetlands. They have, however, been described in this report as Temporary Wetlands. This class has the largest areal extent in the interior of South Africa.

Terrestrial soils listed as Classes W7, W8, W9 and W10, together with Bottomland Land Classes (W11) and Upland Land Classes (W12), completed the assessment (Deliverable 3 – Turner *et al.,* 2015a).

Figures for discharge, and interflow soils are also presented in this summary report together with selected Land Type and geology group tables.

3.1.1.1 Testing wetland distribution using a single Land Type evaluation approach

As part of the University of Pretoria capacity building project (Fourie, 2015), soil forms classified by the Binomial Soil Classification System (MacVicar *et al*., 1977) were assigned to one of three wetland classes (Rountree *et al*., 2008). These classes were based on those of the DWS classification to describe (i) terrestrial non-wetland soil, (ii) temporary or seasonal wetland soil, and (iii) permanent wetland soil. Each of the 41 soil forms (Binomial Classification) were classified using two opposite approaches: a conservative and a liberal classification. For the conservative classification, soil forms that express signs of wetness in the subsoil horizon directly underlying the topsoil horizon were given a seasonal/temporary wetland status, whereas soils that do not express signs of wetness in the subsoil horizon directly underlying the topsoil horizon were given terrestrial status. For the liberal classification, soil forms that express signs of wetness in the subsoil horizon directly underlying the topsoil horizon were given a permanent wetland status whereas soils that do not express signs of wetness in the subsoil horizon directly underlying the topsoil horizon were given a seasonal/temporary status. Later, a revised classification approach was used (Appendix 2) in which the soil forms Avalon, Dundee, Glencoe, Glenrosa and Pinedene all contain horizons at some position in the soil profile that have signs of wetness and have therefore been given wetland status for either the liberal classification or for both the liberal and conservative classifications. However, these forms commonly fail to produce signs of wetness within 50 cm of the soil surface (Rountree *et al.,* 2008) and have therefore been given terrestrial status for the revised classification.

The reasoning behind the two approaches lies in the fact that soils with E (eluvial) horizons are commonly located on midslope positions and may express greater or lesser durations of water saturation. These soil properties are equally reflected in grey soil colours, but may not give a full representation of the extent of the duration of water saturation or of gley (wet) soil morphology. In general, soil forms with a gley horizon were assigned to class iii, and considered to exhibit permanent wetness, soils with an E horizon to class ii, exhibiting varying degrees of seasonal water saturation, and soils freely drained soils with red, yellow or brown colouration to class i, exhibiting only limited degrees of water saturation.

Using these two different classifications (and later a third revised classification), a query was conducted in the Microsoft Access database to determine the relative wetland soil distribution as percentage surface area for each Land Type polygon. The query assessed each Land Type evaluating the proportion of the three classes. The result was graphically expressed as maps showing the proportional distribution of the three wetland classes. These three maps were presented in the report of Deliverable 3 in October 2015 (Turner *et al.,* 2015a).

As a capacity building training exercise, a single Land Type was selected from each of the 28 Land Type Broad Soil Patterns. Using satellite images and GIS technology, wetland extent was graphically mapped. This exercise served as training in evaluating wetland distribution with limited field study.

3.1.1.2 Erosion sensitive areas derived from ARC-ISCW Land Type information

The project was designed as a capacity building project with the view to study both erosion sensitivity and its importance in soil wetland preservation. It used methodology similar to that for the distribution of hydromorphic soils, which enabled student interaction to take place. Collective Land Type Soil Patterns and collective broad geology groups were used to evaluate erosion sensitivity at a national scale. Land Type Soil Patterns provide a natural resource basis to spatially evaluate differences in the sensitivity of soils to water erosion. The hypothesis was that geology formation (South Africa Committee for Stratigraphy, 1980) as derived from the published 1:1 million geology map of South Africa (Geological Survey, 1984) would also contribute to an assessment of erosion sensitivity. As with Land Types, geology formations were grouped according to underlying lithology into 12 groups and assessed simultaneously with the Land Type groups. Soil forms and soil series of the Binomial Soil

Classification System (MacVicar *et al*., 1977) were assigned to high erosion sensitivity (labelled E1), moderate erosion sensitivity (E2) and limited erosion sensitivity classes (E3) based on knowledge of the performance to erosion of soil forms and the textural and base status properties of soil series. A simplified grouping of 18 rock types considered igneous rocks (4 classes), sedimentary rocks (8 classes), metamorphic rocks (3 classes) and limestone and dolomite, quartzite and Quaternary sand materials. The rationale behind this approach is that Land Type Soil Pattern and geology formation grouping would provide a natural resource basis to represent sensitivity of soils to water erosion. Erosion sensitivity was then assessed, tabulated and mapped in the same manner as for soil hydromorphy.

Figures and tables illustrating the percentage distribution of High (E1), Moderate (E2) and Limited (E3) erosion sensitivity classes at a national scale are presented in the report of Deliverable 5 (Turner *et al.,* 2015c). The figures, using a quartile analysis process, illustrate five erosion sensitivity classes, while tables present a comparison between Land Type Soil Patterns and broad geology classes for each of High, Moderate and Limited erosion sensitivity.

Figures for discharge, and interflow soils are also presented in this summary report together with selected Land Type and geology group tables.

Assumptions in the assessment of hydromorphic and erosion sensitive soils include the following:

- The assessments made in this section at a national scale derive the information coverage from national scale soil surveys contained in the ARC-ISCW Land Type Information System. These assessments must necessarily differ from those where information is derived from observations at much higher densities per unit land area. Persons familiar only with detailed assessment procedures commonly fail to understand evaluation systems at national scale and commonly discount their value to broader landscape units.
- The proportion of soils per inventory is an estimate, although it is widely accepted to have credibility at national scale. This could be achieved because soil inventories are based on extensive soil observation, careful terrain analysis, numerous soil laboratory analyses and standardised field and GIS procedures.
- The Land Type Survey re-evaluated morphological soil properties via an extensive network of soil observations. These were supported by profile description and soil analysis of standard soil chemical and physical properties. All the information is published in memoir books and recorded in electronic media. The survey did not record dynamic water saturation properties. This must be deduced from soil morphological

properties, expressed in its simplest manner from the soil form information. Evaluation of a Soil Hydrological Class can be assessed at a generalised statement from the soil form (and where necessary from additional soil property information). Generalised statements that a soil performs a dominantly recharge, interflow or discharge function can be made. However, even though a soil may behave in a dominant hydrological capacity (e.g. an interflow capacity), elements of other flow regimes will inevitably be present. Statements that a soil behaves in a specific hydrological capacity (e.g. a recharge soil), although held to be accepted at the commencement of the project, are now misleading.

- Assigning of soil dominant hydrological classes to a wetland type as Permanent, Temporary or Seasonal Wetlands and as Terrestrial Land have always been problematic. Soil classification relies largely on static soil properties as they can generally be classified to a specific soil category. However, the extent of saturation of soils with water has a dynamic nature. This is strongly reflected in wetland identification. Although at the inception of the project there was reservation that soil classification information could loosely be associated with wetland types, greater emphasis must be directed to their description within a soil hydrological class.
- Assigning the respective soil forms or series to a single hydropedological or erosion sensitivity class provided a first estimate assessment. This approach is somewhat simplistic but was held to be valid at the inception of the project. Results now indicate that additional procedures could have produced improved accuracy.
- Graphical representation necessarily requires that classes be established to present the analysis in picture formats. Individual polygon units contain more detailed information than can be presented in standard graphical formats. These graphical formats were designed to present information suitable for national or regional wetland assessment requirements.

3.1.2 ARC-ISCW Hydrology Database

Development of the ARC-ISCW Soil Information System commenced in the early 1980s when soil profile descriptions were first electronically captured, enabling printout pages to be made without manual resetting of the typeface. The system has since developed to include the capture, archiving and manipulation of soil chemical, physical, mineralogical and micronutrient analyses and a direct facility linking sample registration with the soil laboratory analysis results. The system has minimum essential location and site requirements to link individual chemical and physical components to a unique national soil profile number. The system catered for data capture methods and standards widely applied in general chemical soil research. The systems also now contain extensive digitised soil maps and images, including full coverage of South Africa for Land Type information. Each of these components would be of value to archiving of soil hydropedology information. Soil hydrology information is not currently included in the information content. The initial vision for the hydrology database was that soil hydraulic conductivity, soil water retention at various pressures (tensions or negative pressures) and soil bulk density will complement the chemical and physical data. These data could be of value in hydrological assessments. Later, additional fields could be added, while linkages to ARC-Peatland and other similar databases could be considered.

The initial assumption was that soil bulk density, hydraulic conductivity and soil water retention properties could simply be added to the existing components of the system. Soil bulk density is important in evaluating volumetric water contents that are usually measured gravimetrically, but has not traditionally been measured in many soil investigations. Hydraulic conductivity and soil water retention properties are essential for the estimation of soil water flows. There is now increasing research directed at soil water flow and catchment water contents and soil water residence times. These research results are reported in soil hydropedology and related publications, but are seldom linked to other branches of soil research. Linking these data to the Soil Information System could have considerable advantage in soil water research, and particularly its extrapolation via soil mapping studies to ungauged basins in a regional and national context. The construction of a prototype Soil Hydrology component in this report serves to assess the feasibility and establish early hydropedology data sources. The construction of the database envisaged the capture of only a limited number of hydropedology research profiles or sites to establish validity and methods during the testing phase. Once established, the content of the database could be expanded in future soil water research.

The first step was to collect a range of soil hydropedology research data for hydraulic conductivity. The available data soon indicated that although hydraulic conductivity and associated water retention values were measured, soil chemical data (exchangeable cations and organic matter) and soil physical data (particle size distribution of sand, silt and clay) were seldom at standard threshold values as applied in other soil research reporting. In addition, sample depths reported in soil profile descriptions were seldom the same as their accompanying important hydraulic conductivity measurements. This implied that with the time and resources available in this project, simple linking of hydropedological data to existing data fields could not be achieved without incorrectly forcing data into the existing computer data fields. The implication was that a new Soil Hydropedology database, linked to the Soil Information System, had to be constructed. This process is reported below.

Extensive soil hydrological data for ten sites was reported in the appendices of the HOSASH Water Research Commission Project (Le Roux *et al*., 2015: WRC Project No. 2021/1/15). Summary data was also reported elsewhere (Le Roux *et al*., 2011). Only soil hydrological data for a site at Twin Streams (8 profiles) is incorporated into this prototype database. However, studies at Ingula (3 profiles), Pan African Parliament Site (5 profiles), Irene (1 profile), Kruger National Park (8 profiles), Stellenbosch-Papegaaiberg (5 profiles), Riebeeck-Wes (3 profiles), Krugersdrift Dam (5 profiles), Taylors Halt (3 profiles) and Hopetown (13 profiles) are also contained in the HOSASH report (Le Roux *et al*., 2015) and are ideally suited to incorporation into the database. Numerous other research reports would have been published where infiltration rates, hydraulic conductivity, water retention values and bulk densities have been measured. For example, Turner (1976) measured infiltration rates and water retention at 23 sites in KwaZulu-Natal.

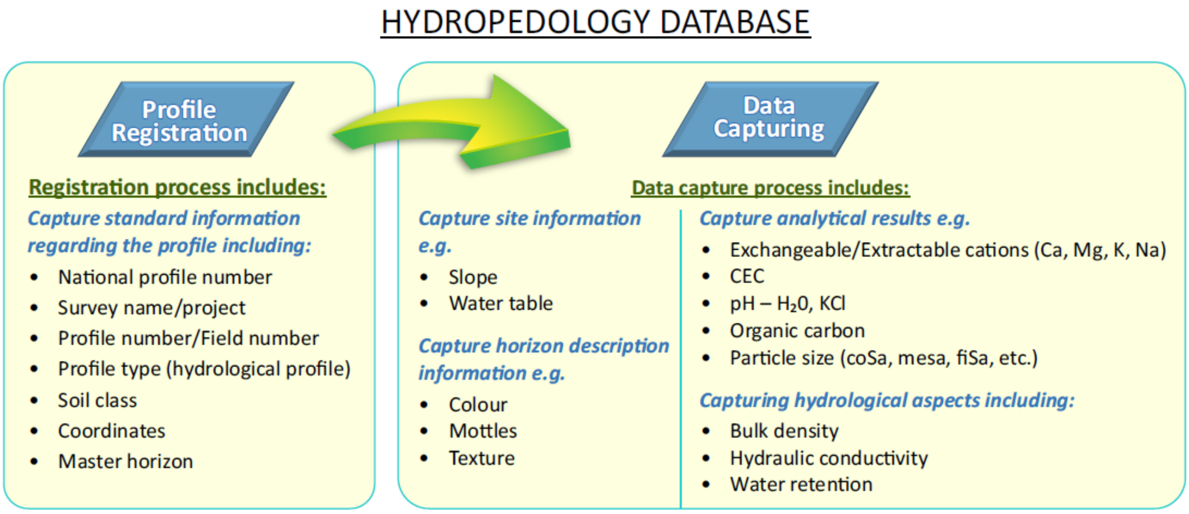


Figure 3.1: *A diagrammatic illustration of the structure and content of the Soil Hydropedology database.*

The database contains the essential module for site registration with location information used for linkage to other modules and to the linkage other components of the ARC-ISCW Soil Information System. Modules for profile description, chemical and physical data and soil hydrological data allow for manual or electronic data capture over a range of soil depths. Within a single soil depth, provision is made for soil hydraulic conductivity and soil water retention values at eight soil water tension values. The database structure is illustrated in Figure 3.1. A manual describing methods for data capture and extraction is presented as Appendix 5.

3.1.2.1 Assumptions and limitations in the use and future expansion of the database

The database is currently hosted and maintained by ARC-ISCW and uses a MS Access platform. Currently the database has limitations in that it is a single user application on a single computer. Future development could consider developing the database to allow the database to be used on multiple computers that will archive data at a central storage facility. Web-based applications, using more advanced operating systems than permitted by the MS Access, would also be advantageous. There were only limited records inserted during this testing phase. The vision for the database would be to have an active development and data capturing program to realize its full potential towards soil water research applications, especially applications concerned with the spatial distribution of soil water storage and flows. However, these limitations should be overcome as future developments take place.

Additional concerns relating to database methodology will require attention. Important in these are the linking of data from one source to other sources. While research results may be relevant to a particular research project, their incorporation into electronic structures requires additional thought and standardisation of units, thresholds and reporting methodology. These limitations can be overcome, but will usually require additional programming constraints, and an acceptance of standardisation by soil water researchers. Attention must be directed towards the unique computer linking fields (in this instance National Profile Number and site location), thickness and depth of soil horizons between descriptive, chemical and soil hydropedological data. Similarly, differing units and threshold values have limited their simple and direct incorporation into the database.

Several important future considerations towards the use of the database include developing it on a suitable advanced (and web-based) computer platform; standardization of data elements, units, methodology and naming conventions; and a facility to capture and validate data from external institutions. Finally, protocols for the financing and release of data to users should be established.

3.2. Catchment Scale – Case Studies

3.2.1 Weatherley Catchment

Weatherley is one of the few locations in South Africa with long-term hydrological information. The Weatherley study site captures approximately 15 years of hydrological monitoring data, along with intensive soil investigations and multiple investigations into hillslope hydrological processes. The catchment of approximately 250 ha was selected in 1995 for a long-term study aimed at comparing catchment hydrological conditions under natural grassland with those after afforestation. The study was initiated and executed by the School of Bioresources Engineering and Environmental Hydrology (SBEEH) of the University of KwaZulu-Natal in cooperation with North East Cape Forests (NECF) and Mondi Forests. The site is currently managed by PG Bison.

The Weatherley catchment is a headwater catchment located approximately 6 km south of the town of Maclear in the Eastern Cape (Figure 3.2). It is part of the Mooi River primary catchment. Land use is a mix of grassland and managed plantation. Vegetation type for the area is recorded as “Sub-escarpment grassland” (Mucina and Rutherford, 2006). The catchment is underlain by sediments and igneous rocks of the Stormberg Formations of the Karoo Supergroup. The Stormberg Group includes (in order of decreasing age) the Molteno, Elliott and Clarens Formations. Both Molteno and Elliott Formations are present in the Weatherley catchment (Lourens, 2013). The older Molteno Formation is dominated by sandstones formed from medium to coarse-grained river sands deposited in braided streams, and is overlain by the Elliott Formation, which is dominated by finer-grained red floodplain mudstones “with subordinate channel and crevasse splay deposits” (Visser and Botha, 1980). The red mudstone of the Elliot Formation is said to act mostly as an aquitard, and is “usually dry when drilled, with water typically encountered at the contact between the Elliot Formation and the underlying Molteno Formation” (Lourens, 2013). Shale units are noted to act as an aquitard when vertical and support an aquifer when horizontal (Lourens, 2013). In the context of the Weatherley catchment, it is anticipated that the sedimentary layers of both Elliot and Molteno Formations are predominantly horizontal and thus the Molteno Formation, predominant in the catchment, is also anticipated to act as a very slowly permeable aquitard.

A large seep wetland covers approximately 25% of the catchment. A stream initiates from the upper section of the wetland. The stream drains the catchment in a north-westerly direction.

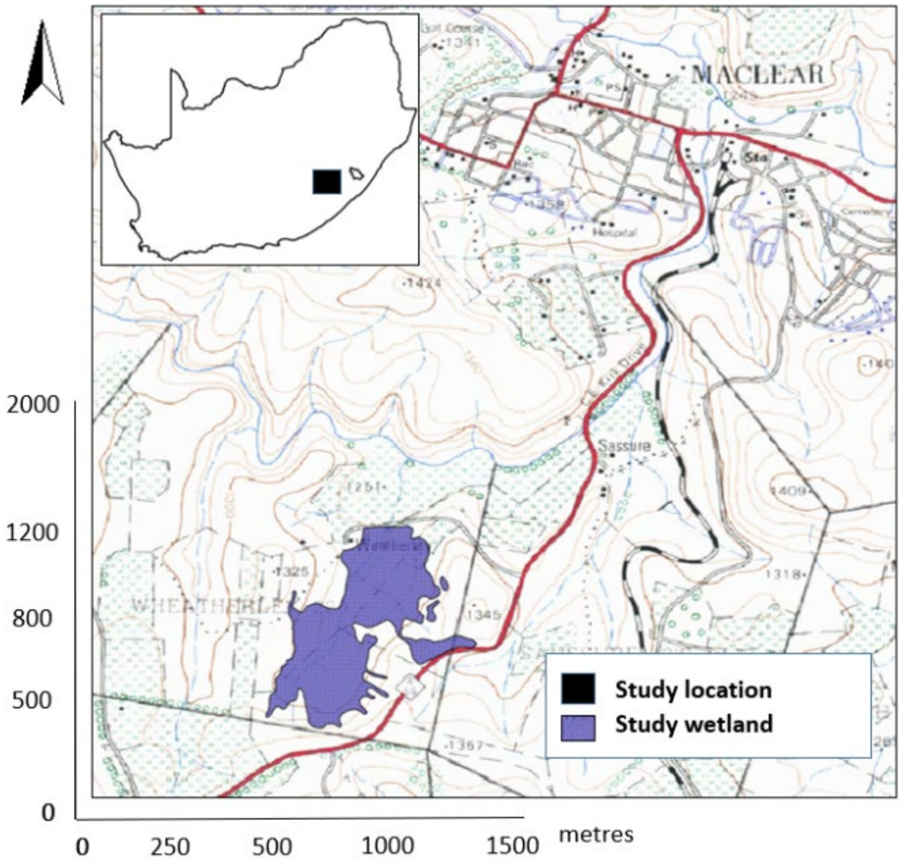


Figure 3.2: *Weatherley study site location.*

3.2.2 City of Johannesburg Midrand Catchment

This case study offered an opportunity to develop an approach for merging hydropedological studies into wetland assessment, and to benefit from data collected for a detailed assessment undertaken in the same study area. The assessment, commissioned by the City of Johannesburg, generated a soil map and set of hydrological response models through intensive soil data collection, followed by extrapolation through digital soil mapping (Tinnefeld *et al.,* 2017).

The City of Johannesburg study catchment is a headwater catchment located in the Kyalami agricultural holdings area of northern Johannesburg (Figure 3.3). It is part of the Upper Crocodile River primary catchment. The catchment is underlain by Archaean Lanseria Gneiss of the Johannesburg Dome or Halfway House granites (Geological Survey, 1986). Granitic and gneissic rocks at least 2 400 million years old are exposed in the area. The Archaean granites and gneisses can be classified as an inter-granular and fractured aquifer system (Lourens, 2013). These aquifer systems are said to be generally semi-confined or confined in nature, with fractures characterised by high permeability and low storage, while the rock matrix has low permeability and large storage capacity (Du Toit, 2001). The residual granite underlying hard plinthite serves as a local aquitard, with a reported porosity of 0.22 (Dippenaar *et al*., 2014). Fractures within the less weathered granite may serve as flowpaths, but in the completely weathered granite they appear to be more clogged with goethite and kaolinite and may play a role in the formation of the perched water table (Dippenaar *et al*., 2014). The regional water table occurs from depths up to 12 m (Dippenaar *et al*., 2014).

The study area is characterised by rocky, strongly undulating plains comprising crests, slopes and valley-bottoms (Munnik *et al*., 1992). The area lies between 1 400 and 1 550 m above sea level. Average slope varies from 2.1° to 4.2° and local relief is 200 m (Munnik *et al*., 1992). Streams flowing through this landscape are believed to be associated with the linear structures and granite-gneiss contact zones where fracturing and jointing occurs (Lourens, 2013). The permeable sand overlying these high density joints creates favourable recharge conditions if no clay layers are present (Du Toit, 2001). The granites of the study area landscape are intensively weathered with deep drainage lines resulting in a gently rolling topography. The African Erosion Surface is preserved on the crests, especially towards the south-eastern parts of the study area, and subsequent dissection, mainly during the Post African I erosion cycle, was responsible for the general lowering and undulating nature of the landscape, with the present convex-concave morphology due to processes of midslope shortening and retreat (Munnik *et al*., 1992). An east-west trending ridge forms a watershed within the study area, with the northern streams draining in a north-westerly direction towards the Rietspruit and Hennops Rivers and the southern streams flowing along a number of small streams before they eventually flow into the Jukskei River. The flow directions are consistent with the local geological structural trends in the area (Vermaak, 2008).

A large seep wetland covers 16% of the catchment and contributes to a stream which initiates from the wetland. The stream drains the catchment in a south-westerly direction.

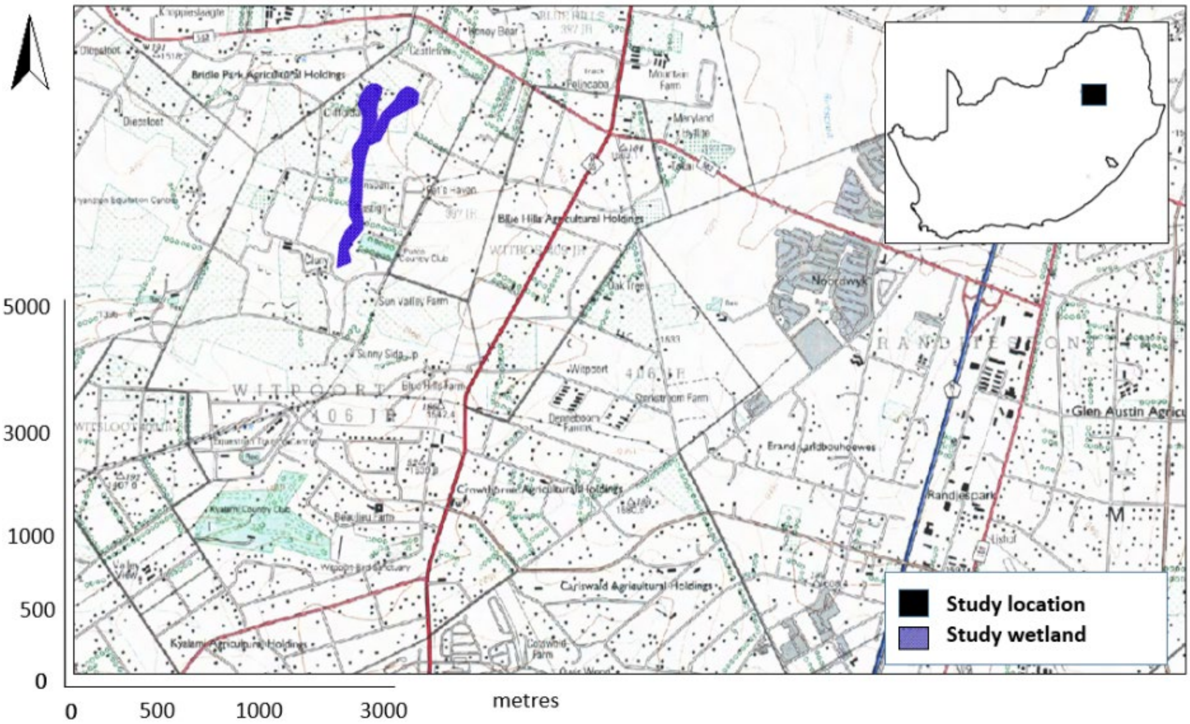


Figure 3.3: *City of Johannesburg study site location and overview.*

3.2.3 All Sites

Catchments in five areas of the country were chosen for a broad level review against Land Type data (Figure 3.4). No budget was allocated in this project for collection of new primary data, so the sites were primarily chosen based on existing availability of soil and hydrology data, as well as relatively comprehensive wetland mapping. Some new data was introduced through co-funding from the City of Johannesburg, which is the only urban site for the project. Three additional sites, including two escarpment sites, one in the Northern Cape (Nieuwoudtville), the other a Grassland site in the Eastern Cape (Hogsback), as well as a coastal site in the Western Cape (Agulhas), were included to widen the climatic and geographic range and number of Land Types for testing. Both Nieuwoudtville and Agulhas fall within the Fynbos Biome. The catchments vary in size, as well as in the area of wetland they support (Table 3.3).

Existing mapping of wetland boundaries was available for all of the chosen catchments, being one of the primary reasons for selecting those particular catchments. However, it was necessary for additional wetland areas to be mapped at all of the chosen sites, to ensure a moderate to high confidence and comprehensive mapping of the wetland extent for each area. A further focus in the choice of sites was to select areas high in seep wetland types, due to the anticipated strong connection of this hydrogeomorphic (HGM) type to hillslope hydrology, but all other wetland HGM types were also included in the assessment, whenever they occurred within the selected study catchments.

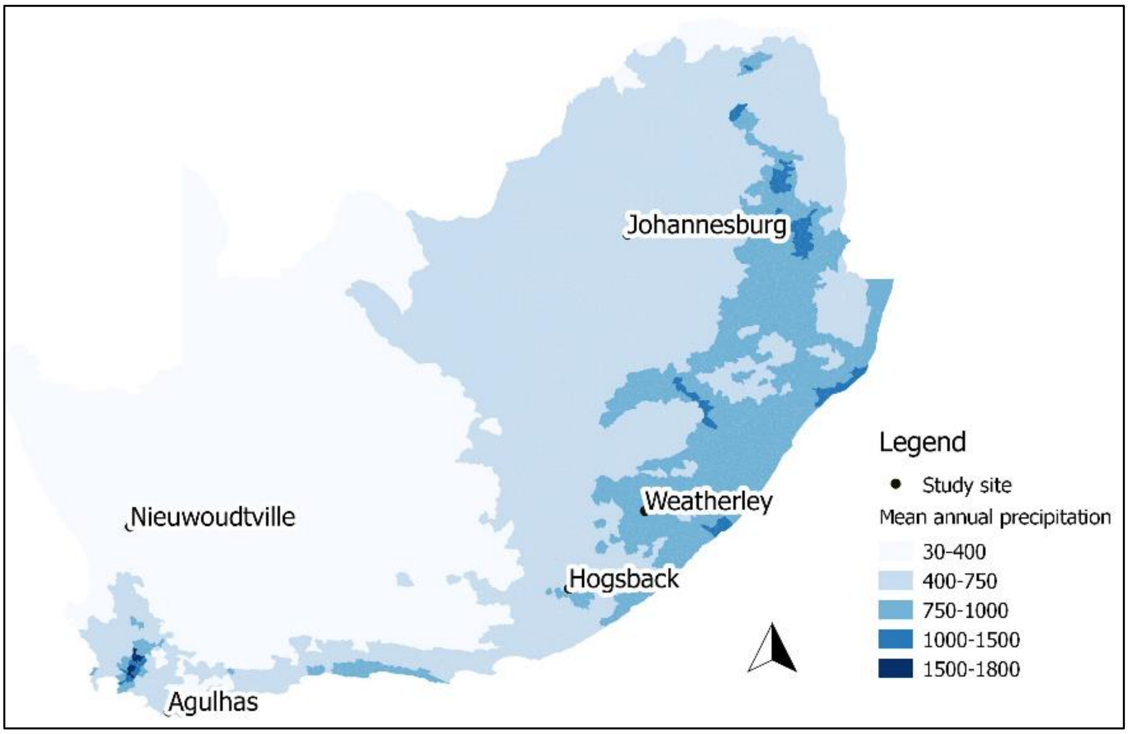


Figure 3.4: *Study catchment locations (showing mean annual precipitation per Quaternary catchment, based on Schulze, 1985).*

The Weatherley catchment supports the smallest area of wetland (83 ha), but the wetland covers the largest proportion of the study catchment (32%). The remaining sites were similar in cover of wetland area, which ranged between 16-20% of the catchment. While the Agulhas Plain and Johannesburg areas were very large (17 000 to 20 000 ha), the Niewoudtville and Hogsback catchments were moderate in size (1 700 to 3 100 ha), while the Weatherley catchment was very small in comparison, at just under 258 ha.

Table 3.3: *Overview of study catchments*

Study area	Weatherley	Johannesburg	Nieuwoudtville*	Agulhas Plain	Hogsback
Province	EC	Gauteng	NC	WC	EC
Study area, ha	258	20 000	1 752 & 2 962	17 068	3 195
Wetland ha (% catchment)	83 (32%)	3 200 (16%)	359 (20%) & 338 (11%)	2 587 (17%)	604 (19%)
Quaternary catchment	T35C	A21B, A21C	E32E & E40C	G50C	S32D
Quinary catchment(s)	5874	1135, 7086, 7127, 7143	6238, 6365	9428	7439

*Two adjoining catchments

A diverse set of regions across the country are represented, spanning a wide climatic gradient (Table 3.4). The Nieuwoudtville site falls firmly within the winter rainfall region, with most rain falling in August to October and when temperatures are cooler. The Agulhas Plain also falls within the winter rainfall region. The other three sites fall within the summer rainfall region, with most rain falling within the summer months of November to January.

Table 3.4: *Overview table of case study catchment regional climate characteristics*

Study area	Weatherley	Johannesburg	Nieuwoudtville	Agulhas Plain	Hogsback
MAP (Schulze, 1985)	908	694	194;285	544	704
MAT (ARC, 2016)	15/16	16/18	18	16	15
PE p/a (Schulze, 1985)	1 615	2 170	2 566; 2 419	671	1 662
MAR (Schulze, 1985)	168	41	0;26.9	100	105
Rainfall intensity (mm/hr) (ARC, 2016)	56.4	52.7	33.3	37.6	58.8

***MAP** = mean annual precipitation (mm); **MAT** = mean annual transpiration (mm); **PE** = potential evaporation (mm)); **MAR** = mean annual runoff (mm)*

3.3. Soils Feeding Wetlands

The formation of wetland soils and source of the water that forms these soils and maintains wetland hydrology, and the depth, duration and direction of movement of water in a wetland are directly related. The focus for this part of the study was to link soil data interpretations and wetland hydrologic functions, and to develop an understanding of how wetland soils and water react on a specific site, namely the Weatherley catchment in the Eastern Cape. The aim was to describe the relationship between a) wetland catchment soils and wetland hydrology, and b) wetland soils and wetland hydrology.

The overall objectives for this part of the study were:

- To consolidate existing meteorological and hydrological data to characterise the wetland catchment;
- To consolidate existing information and further investigate the hydroperiod timing, duration and depth range for the onsite wetland; and
- To consolidate existing information and further investigate wetland and wetland catchment hydropedological properties linked to wetland hydroperiod and hydrodynamics.

The wetland catchment boundary, which is the study site boundary, was confirmed against topographic data on GIS (Figure 3.5).

The wetland and wetland catchment at Weatherley in the Eastern Cape were investigated by means of mining of the extensive hydrological and soil-related datasets. No budget was allocated for new field work so the project relied heavily on the review and interpretation of historical data. Nevertheless, a rapid visit to the site was undertaken in July 2016. Data was collated against three representative transects leading from crest to wetland (Figure 3.5), through a consolidation of previous hydrological and pedological investigations (Roberts *et al*., 1996; Lorentz, 2001; Le Roux *et al*., 2015; Van Tol *et al*., 2010a; Van Huyssteen *et al.,* 2005).

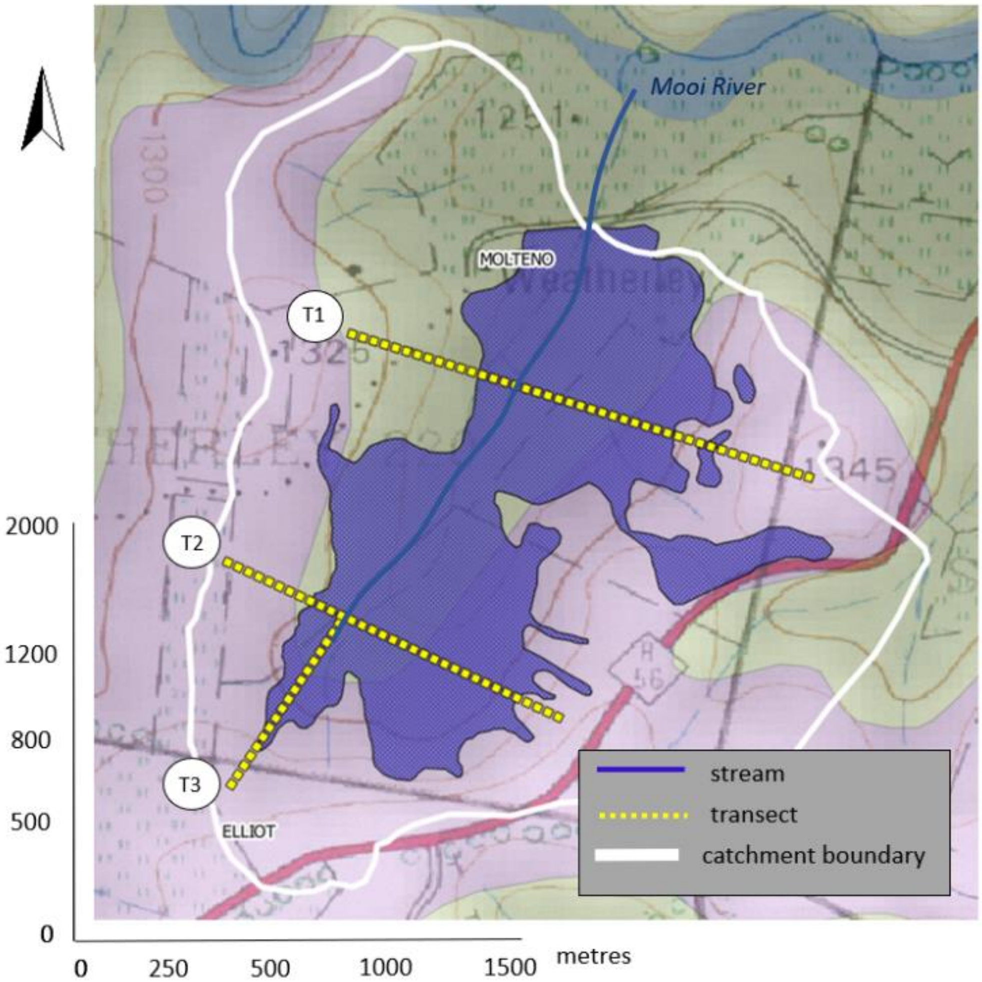


Figure 3.5: *Three transects were investigated across the wetland and wetland catchment.*

Soil data that was historically collected to recreate these transects include the soil survey of Roberts *et al.* (1996) and profile descriptions of Van Huyssteen *et al.* (2005). These were supported by additional auger observations in July 2016.

Hydrological monitoring at the Weatherley catchment was undertaken through the installation of a wide range of instruments situated throughout the catchment. Hydrology data was selected to support the transect interpretations (Lorentz, 2001; Freese, 2013; Van Huyssteen *et al*., 2005; Van Tol *et al*., 2010a).

Stream hydrograph data was also available from two weirs, one within the upper section of wetland and one close to the wetland outlet. State, date, range of stream and rainfall data applied to this study.

The wetland ecosystem boundary was delineated based on image interpretation of existing soil mapping (Roberts *et al.*, 1996) and interpretation of soil morphology reported from soil profile descriptions (Roberts *et al.*, 1996; Van Huyssteen *et al.*, 2005). The first approximate wetland boundary for the Weatherley site resulted from the soil mapping of the full catchment by Roberts *et al.* (1996). They distinguished between "marsh", for which no profiles were described, and the remainder of the site, for which soil profile descriptions were recorded. The extent of wetland mapped by Roberts *et al.* (1996) was expanded to include addition soils designated by them to be "hydromorphic". The data plots of Van Huyssteen *et al*. (2005) contributed to developing the approximate wetland boundary. All plots that were saturated within the top 50 cm for one month or longer were included within the wetland boundary.

The wetland was split into functional units according to hydrogeomorphic (HGM) type, according to the wetland classification system for South Africa (Ollis *et al*., 2013) (Table 3.5).

Table 3.5: *Hydrogeomorphic (HGM) wetland types for South Africa (Ollis et al., 2013)*

HGM Wetland Types
Floodplain
Channelled valley-bottom
Unchannelled valley-bottom
Depression
Flat
Seep

Soil water content is influenced by soil and terrain factors, but the predictive value of diagnostic horizon type for the degree and duration of wetness can also be exploited (Weber, 2011; Van Huyssteen *et al*., 2005; Van Tol *et al*., 2010a). Drawing on the soil morphology descriptions and daily soil water content, soil morphology indicators of hydrology were consolidated for each transect. These were reviewed against U.S.D.A. field indicators for wetlands (USDA-NRCS, 2010) and for evidence of flowpaths outside of wetlands.

The indicators include presence or absence of redox-morphology (Fe, Mn), the extent and intensity of gleying, and the differences in standard chemical determinations. These indicators were correlated on the Weatherley site against annual duration of water saturation above 0.7 of porosity (*ADs*>0.7) (Van Huyssteen *et al*., 2005). Van Huyssteen *et al*. (2005) reported *ADs*>0.7 on between 239 and 357 days per year for the soft plinthic B, unspecified material with signs of wetness, E and G diagnostic horizons.

Wetland hydroperiod categories (Table 3.6) for the Weatherley wetland were chosen from those presented in Table 3.7, based on consolidation of hydrology data and interpretation of soil profile morphology available for the site. The hydroperiod categories follow those developed for the South African wetland classification system by Ollis *et al*. (2013). The onsite wetlands are not considered to have an inundation class although there are occasional small scattered patches of surface ponding in places.

Table 3.6: *Hydroperiod classes related to wetland saturation*

Class	Description
Permanently saturated	All the spaces between the soil particles filled with water through the year in most years. This equates to the permanent (but not always 'inner') zone of a wetland according to terminology used in the DWAF (2005) wetland delineation manual.
Seasonally saturated	All the spaces between the soil particles filled with water for extended periods (generally 3 to 9 months duration), usually during the wet season but dry for the rest of the year. This equates to the seasonal zone of a wetland according to terminology used in the DWAF (2005) wetland delineation manual.
Intermittently saturated	All the spaces between the soil particles filled with water for irregular periods of less than one season (i.e. less than approximately 3 months). This corresponds to the temporary (but not always 'outer') zone of a wetland according to terminology used in the DWAF (2005) wetland delineation manual.

Table 3.7: *Values used for grouping wetlands according to saturation duration and frequency*

Saturation frequency	Saturation duration
None: <1 time in 100 years	Very brief: <2 days
Rare: 1 to 5 times in 100 years	Brief: 2 to <7 days
Occasional: >5 to 50 times in 100 years	Long: 7 to <30 days
Frequent: >50 times in 100 years	Very long: >=30 days

The description of soil morphology, depth to limiting layers, slope and hydrology measurements along the transect also supports interpretation of the wetland hydrodynamics. The term "hydrodynamics" includes the source and direction of water movement, namely, "horizontal" or "vertical" and "unidirectional" or "bidirectional". Cross-sectional and longitudinal profiles were developed to investigate the relative role of each transect in contributing to the overall hydrology of the wetland "functional unit". Wetland cross-section and longitudinal gradient was calculated from orthophotography and existing 1:50 000 topographic maps with some field verification in combination with onscreen digitising using QGIS. The above data was interpreted in order to develop a description of the hillslope and wetland hydroperiod controls on extent, frequency, duration and water movement into, through and out of the hillslope and wetland.

Historical research in the Weatherley catchment (Lorentz, 2001; Le Roux *et al*., 2015; Van Tol *et al*., 2011b) described five hillslope classes, each functioning in a similar way hydrologically. The interpreted data from the study site transects were reviewed against these and an overall conceptual hydrological response model was developed for the full wetland, including linking the event frequency of the final catchment hillslope classes to their relative influence on the wetland.

3.4. Hillslopes Feeding Wetlands

Soils, hillslopes and catchments differ in the way they respond to rain events and seasons. The contributions to wetland hydroperiod, therefore, differ. It is expensive and sometimes not possible to measure hydrology in the "invisible" zone. The previous section, however, illustrated the potential of "indicators", commonly used for wetland delineation and soil classification, to also be used to extrapolate flowpaths and water source areas, especially in combination with topography. The focus for this part of the study is to link hillslopes and hillslope hydrological class to wetland hydrodynamics.

Wetlands are part of each hillslope, while the wetland functional unit is commonly the sum of multiple hillslopes. In addition, while the wetland may be an expression of its entire catchment and the hillslopes that make up the catchment, certain areas of the catchment (i.e. certain hillslopes) may play a more dominant role.

Figure 3.6 illustrates this spatially, beginning with the division of the entire wetland catchment into units (hydrological soil classes grouped into hillslopes) which behave in a similar way, hydrologically. This implies that water is delivered to the wetland via two broadly different flow path and storage combinations. It also implies that a given land use may have a different impact on the wetland hydrology depending on where it is located within these hydrological hillslopes. Study units, therefore, include wetland catchment boundary, divided into hydrological hillslopes, each hillslope further divided into hydrological units, one of which represents the wetland functional unit.

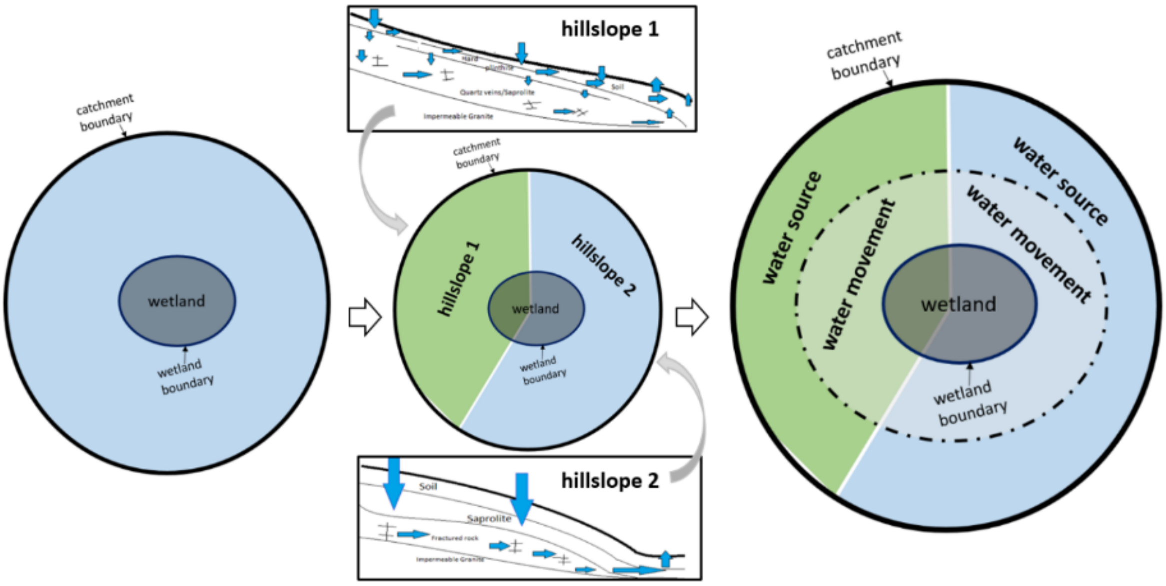


Figure 3.6: *A stylised wetland catchment divided into two different hillslope hydropedological classes.*

One catchment within Kyalami agricultural holdings to the north-west of the City of Johannesburg was chosen for detailed analysis for this case study. The wetland catchment boundary, which is the study site boundary, was confirmed against topographic data on GIS (Figure 3.7).

The sub-catchment supports a seep wetland within the headwaters of the catchment, leading into a channelled valley-bottom wetland. The wetland boundary was mapped based on existing wetland spatial data prepared by Strategic Environmental Focus (2008) and Wetland Consulting Services (2009), and adjusted based on further image interpretation on desktop. Field indicators of wetland hydrology were later reviewed against the wetland boundary and the boundary was further adjusted.

The site was visited in the field over five days in April 2016. Eight representative hillslope and wetland transects were undertaken (Figure 3.7), extending from the catchment crest through the wetland and up to the opposite crest or, at the very least, past the centre of the wetland. A hand auger was used to investigate soils, along the transects, to a depth of 1.2 m (depth of auger without extensions) or refusal, if a restricting layer such as rock or hard plinthite was encountered. In several cases, an auger extension was used and deeper investigations were undertaken. The soils were classified (Soil Classification Working Group, 1991) and described in the field in terms of Munsell soil colour, presence of mottles and other indicators of wetness, presence of free water, horizon depth and texture. Samples from each visually differing horizon were submitted for laboratory analysis of texture, pH and carbon content. Onsite redox measurements were taken where free water was encountered within the auger plot, using a hand-held redox meter.

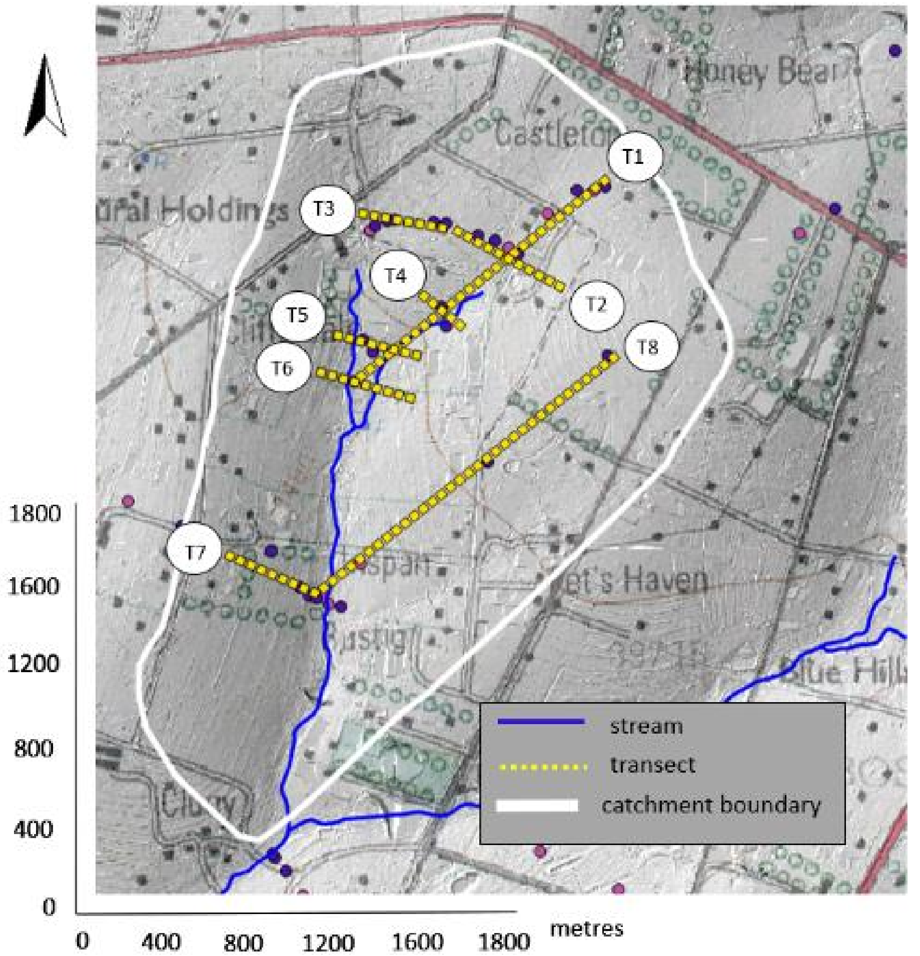


Figure 3.7: *Eight transects were investigated across the wetland and wetland catchment.*

No hydrology measurements were available, but soil morphology indicators of hydrology were consolidated for each transect. These were reviewed against U.S.D.A. field indicators to identify the wetland (USDA-NRCS, 2010), and for evidence of flowpaths outside of wetlands.

Cross-sectional and longitudinal profiles were developed to investigate the relative role of each transect in contributing to the overall hydrology of the wetland “functional unit”. Wetland cross-section and longitudinal gradient was calculated from orthophotography and existing 1:50 000 topographic maps with some field verification in combination with onscreen digitising using QGIS. The above data was interpreted in order to develop a description of the hillslope and wetland hydroperiod controls on extent, frequency, duration and water movement into, through and out of the hillslope and wetland.

To apply the outputs of a hydropedology investigation to wetland management and land use decision-making, a wetland catchment can be grouped into hillslope hydropedological response classes. Soils encountered along the transects can be grouped into hydrological soil types. In order to identify sets of similarly functioning hillslopes, the data collected in the field was presented along the cross-section, highlighting position in the landscape, depth to potentially limiting horizons, and descriptions of soil morphology. In some plots, multiple depths are noted, reflecting the potential for multiple, shallow and deep flowpaths.

3.5. Land Types Feeding Wetlands

3.5.1 Rapid review of Land Type against total wetland area

To investigate the extent to which Land Types can contribute to prediction of wetland occurrence, 35 Land Types were identified which coincide with the selected study area sites. A rapid comparison was then undertaken of responsive soils predicted in Land Type information against wetland area mapped on the ground. Total predicted wetland area was calculated for each Land Type polygon by summing the percentage extent of all soil forms qualifying as responsive soils according to Table 3.8 (Hydrological classification of South African soil forms). Total mapped wetland area was calculated for the full area of each Land Type polygon. For each Land Type extent, existing wetland mapping data was identified and, where necessary, improved using QGIS, Google Earth and SPOT imagery. The percentage wetland was calculated and compared to the percentage wetland predicted in the Land Type inventory.

3.5.2 Desktop disaggregation of Land Types, supported with terrain analysis

A desktop numerical disaggregation of Land Type data with additional terrain analysis was conducted for the urban site within the City of Johannesburg, located on the Halfway House Granite Formation. Two Land Types coincide with the granite dome extent, namely Bb1 and Bb2. The desktop disaggregation was then reviewed against field data.

The Land Types and study area shape files were imported into QGIS. Using the study area boundaries, the Land Types were ‘cut’ and the area falling only within the study area was determined. Together, the two Land Types cover a total area of approximately 110 000 ha, of which 70 000 ha fall within the boundary of the City of Johannesburg, and approximately

20 000 ha within the study area for this project. The study area thus represents just under one fifth or 20% of the total area of Halfway House Granites and of the Land Types Bb1 and Bb2. The latter have an identical soil pattern but a slight difference in climatic parameters.

The soils contributing to Land Types Bb1 and Bb2 and their estimated percentage extent within each Land Type were listed. The Land Type inventory also estimates the percentage allocation of each of the above soil forms per terrain unit or position in the landscape, from the landscape crest to the valley floor. This can be applied to any study area, Quaternary or Quinary catchment boundary by dividing the hydrological category total within the Land Type by the Land Type total, then multiplying that by the Land Type percentage in the study area (Van Zijl *et al.*, 2013).

Drawing on evidence of soil morphology, soil chemistry and terrain evaluation properties, soil types may be grouped according to their hydrological response (Van Tol *et al*., 2011b, 2013b), and into hydrological hillslope sequences or catenas resulting in hydrological hillslope classes (Le Roux *et al*., 2015). A list of soil forms allocated to a hydrological class, originally sourced from Van Tol *et al*. (2013b), is given in Table 3.8. Importantly, terrain components, such as slope and terrain morphological unit, were collectively interpreted. This can be a significant factor affecting the hydrology of an area, and may lead to adjustments of where certain soil forms are allocated in Table 3.8.

Each hydrological category from Table 3.8 may be assigned to the Land Type inventory list of soil forms and added together to yield a final percentage for the specific category, offering a potential insight into the hydrological landscape of an area. Land Types Bb1 and Bb2 appear to be dominated by interflow soils, followed by responsive shallow, recharge, and responsive wetland hydrological soil types.

Although the Land Type inventory includes information of soil distribution on terrain morphological units across landscape position, as noted above, it is challenging to incorporate this successfully into broad-scale interpretations. Besides a larger scale, one that can incorporate a more accurate depiction of the range of terrain present in an area, inclusion of curvature is helpful. The most commonly applied terrain analysis tool is the topographic position index (TPI) developed by Jenness *et al*. (2013) and updated in 2016. This tool has been adapted for use in the open source (QGIS and SAGA) software used in this study.

Table 3.8: *Hydrological classification of South African soil forms (adapted from Van Tol et al., 2013b)*

Recharge		Interflow		Responsive	
Deep	**Shallow**	**A, E and/or B horizon**	**In deep subsoil, saprolite or fractured rock***	**Shallow or slow infiltration**	**Saturated**
Arcadia Milkwood Mispah Kranskop Magwa Inanda Lusiki Kinkelbos Sweetwater Bonheim Inhoek Tsitsikama Concordia Houwhoek Griffin Molopo Clovelly Kimberley Constantia Hutton Shortlands Brandvlei Jonkersberg Pinegrove Groenkop Valsrivier Swartland Etosha Gamoep Oakleaf Trawal Augrabies Dundee Namib	Mayo Knersvlakte Glenrosa Witbank Garies	Kroonstad Longlands Estcourt Klapmuts Westleigh Dresden Nomanci (on solid rock)* Cartref Wasbank Coega Oudtshoorn	Steendal Immerpan Lamotte Westleigh Dresden Witfontein Avalon Glencoe Pinedene Vilafontes Bainsvlei Fernwood Bloemdal Sepane Tukulu Montagu Askam Plooysburg Prieska Addo	Orthic A/solid rock* Melanic/solid rock* Humic/solid rock* Arcadia (disturbed)	Champagne Rensburg Willowbrook Katspruit

**Hard rock is fractured and it is anticipated to have a relatively high flow through. Solid rock is impermeable to water.*

In QGIS and SAGA, the study area was divided into three topographic or terrain morphological units (TMU) to match those of the Land Type inventory for the study area.

The study area was divided into 270 hillslopes using open source software QGIS and GRASS, and the nationally available 30 m digital elevation model (DEM). To best support wetland assessment, the hillslopes were kept distinct, but grouped into wetland catchments. Van Zijl *et al*. (2013) developed an approach for spatial disaggregation of Land Types and for incorporating terrain information in support of digital soil mapping to yield conceptual hydrological response models. The slope of each hillslope is calculated in GIS, and the final hillslope shapefile, together with the DEM layer, is transferred to SAGA GIS. Within SAGA, these hillslope shapefiles and DEM are used in terrain analysis. The slope (%), planform and profile curvature were the main variables generated. Grid values are assigned to the hillslope shapefile and exported as a 'XYZ' file which can be opened in MS Excel. Within Excel the information generated by the terrain analysis is used for further statistics.

The slope range defining the different terrain units in the study area included valleys, slopes and ridges/crests. A range in values was identified for each of these, based on where the histogram changes from concave to convex. Based on this, parameters were determined, according to the mean, minimum, maximum and standard deviation of the main variables, to create clusters into which the hillslopes can be grouped (Van Zijl *et al.*, 2013). Each cluster has a unique combination of topography, lithology and soil distribution patterns. The soil association assigned to each terrain unit and hillslope was confirmed using expert knowledge obtained from studying the Land Type and knowledge of soil-forming processes.

Terrain morphometry data generated for the overall study included elevation above stream channel, aspect, slope length, plan and profile curvature and landscape topographic position. This was generated using the nationally available 30 m DEM. Wetland catchment area was developed on SAGA GIS v2.1.2, with manual visual correction in places, as part of generating the study area hillslopes. Terrain morphometry data generated for each wetland included wetland and wetland catchment size, wetland width and length and longitudinal gradient, and mean catchment gradient. Catchment gradient and valley longitudinal gradient was calculated in QGIS v2.10.1 from 25 m contours. Wetland size was calculated in QGIS, with manual wetland boundary adjustments made in limited areas based on field visits and more recent orthophoto interpretation of wetland boundary. For each of the areas, median annual simulated runoff, mean annual precipitation and potential evaporation were obtained from Schulze (1985). Mean annual catchment runoff or discharge was calculated from median annual runoff data supplied by Schulze (1985) and calculated catchment area. Mean catchment steepness was determined using the 30 m resolution DEM of southern Africa supplied by NASA's Shuttle Radar Topography Mission in 2000. The geological character of bedrock underlying the wetland was also noted, as was the presence of faults.

4. RESULTS

4.1. National Scale

4.1.1. ARC-ISCW Soil Information System (computer program and database)

A computer program for the estimation of wetland distribution derived from ARC-ISCW Land Type Information and erosion sensitive soils.

<u>**Hydromorphic Soils**</u>

Responsive (discharge) soils:

The estimation of extent of hydromorphy from Land Types is strongly dependent on how each soil form is assigned to either recharge, interflow or responsive soil hydrological classes for each Land Type. These results for responsive (discharge) soils (Figure 4.1) indicate the highest responsive class (2.11-8.50%, dark blue shading) located along the coastal belt of the southern and Western Cape, the escarpment zones of the Drakensberg extending from the central Eastern Cape, through KwaZulu-Natal and into the southern Mpumalanga highlands. There is a further major zone in the sandy northern KwaZulu-Natal coastal plain and smaller, isolated zones located in the coastal and central highveld provinces. The estimated extent for the distribution of hydromorphic soils (and hence wetlands) is relatively low throughout South Africa. Adjacent to the high responsive (discharge) class is the intermediate responsive class (discharge class 0.81-2.10%, light blue) (Figure 4.1) extending inland of the Cape coastal belt, eastward and northward of the Drakensberg escarpment and westward of the Vaal River catchment. There is a further extensive zone in the Kalahari area of the Northern Cape bordering on Botswana and Namibia. All wetlands are important in their own right in conservation of natural resources. However, these important wetland distribution zones where wetlands have the highest spatial distributions should receive special attention in the formulating of wetland guidelines.

Analysis of the extent of hydromorphic soils is determined for each Land Type and can be viewed in the detail of the data analysis. This data can be presented at scales that show the distribution at individual Land Types by electronically enlarging the national scale to an individual polygon scale. Percentages of wetland classes (Responsive and Interflow Classes, W1 to W6) can similarly be presented for individual Land Types and then used to implement guidelines or regulations at detailed to regional scales.

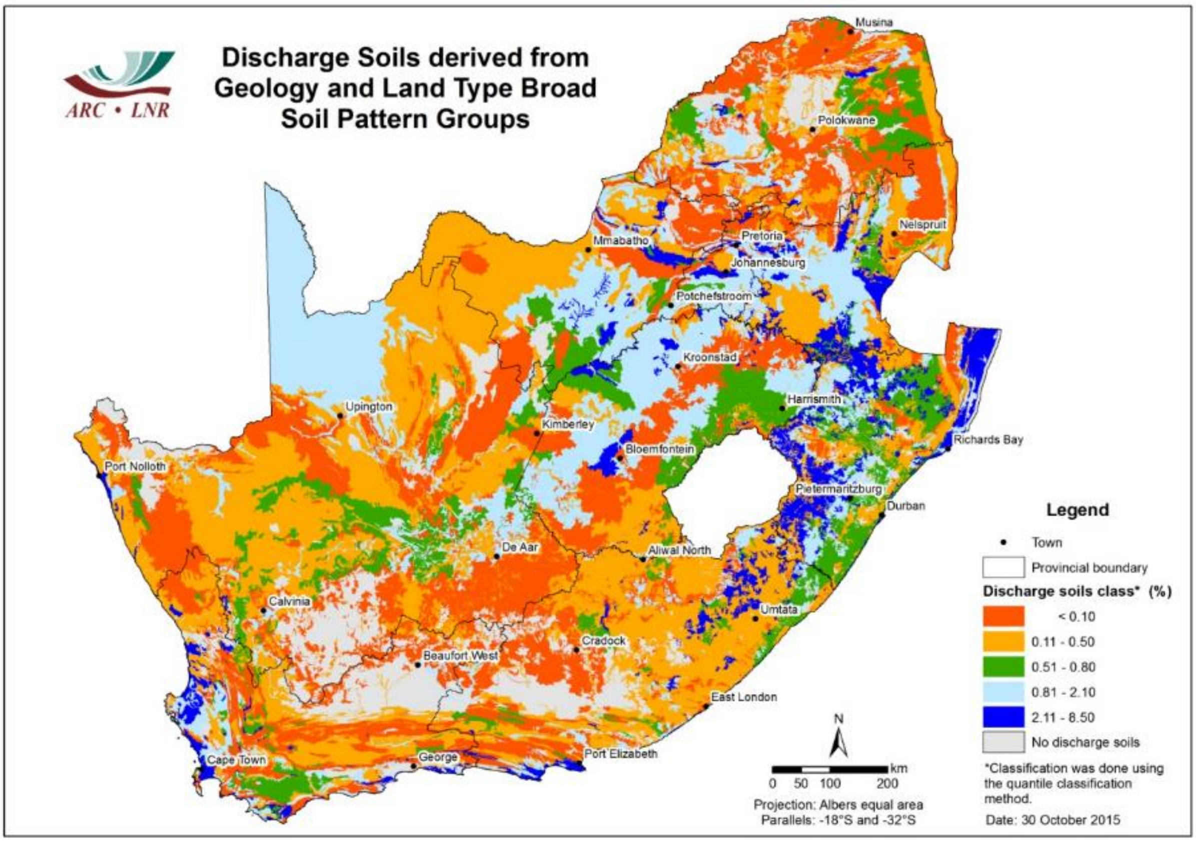


Figure 4.1: *Responsive (discharge) soils derived from geology and Land Type Broad Soil Pattern groups.*

The initial hypothesis considered that trends in hydromorphic soil may become apparent when similar geology lithological rock types were considered. To facilitate the analysis, similar lithologies were grouped according to geology formation (South African Committee for Stratigraphy, 1980). However, trends were not apparent (Table 4.1). Further reporting is limited to the trends only within Land Type Soil Patterns.

The highest distributions of responsive (discharge) soils belonging to the Champagne, Katspruit, Fernwood and Willowbrook soil forms are located in the ***Apedal*** (each of the dystrophic, mesotrophic and eutrophic base status soil classes), in the ***Plinthic*** and in the ***Deep Grey Sand*** Land Type classes (Table 4.1). Colouring of the blocks (Table 4.1) has the same significance as those of Figure 4.1. Dark and light blue blocks again represent the highest soil responsive (discharge) classes. These Land Type classes should play important roles in wetland conservation and in water delivery (Table 4.1).

Table 4.1: *Responsive (discharge) W1 soils (Champagne, Katspruit, Fernwood and Willowbrook)*

W1 - Discharge Soils (Ch,Ka,Fw(depression topography),Wo)													
Geology Group	Land Type Broad Soil Pattern Groups												
	Apedal Dys-Mesotrophic (AA)	Apedal Eutrophic (AE)	Apedal Eutrophic Dunes (AF)	Apedal Eutrophic Sands (AG)	Plinthic Soils (BA)	Polinthic & Duplex Soils (CA)	Black Red Clay Soils (EA)	Shalllow Soils Lime Rare (FA)	Shallow Soils Lime abundent (FC)	Podsolic Soils (GB)	Deep Grey Sands (HA)	Alluvial Soils (IA)	Rockland (IB)
Acid Igneous Rocks (IA)	0.50	0.10		0.10	0.50		0.10	0.10	1.30	0.00	2.00		0.10
Intermediate Igneous Rocks (II)	2.30	0.70			0.90	0.70	4.70	0.50				8.50	
Basic Igneous Rocks (IB)	2.40	0.00			1.40	0.20	0.20	0.40	0.00			0.50	0.00
Ultrabasic Igneous Rocks (IU)													2.50
Sandstone Siliceous(SS)	0.40				2.10	2.20	0.10	0.50	0.10	1.00	6.20		0.10
Sandstone Felspathic (SF)	2.20			5.00	2.10	2.20	3.10	0.80	0.20				0.10
Sandstone Micaceous(SM)	0.40												
Sedimentary Rocks Conglomerate (SC)	1.90				1.20			0.20					0.10
Shale (SH)	2.00	1.90		0.60	2.20	1.70	0.30	0.60	0.40		8.40	0.50	0.10
Shale and Mudstone Rocks (SHM)	2.50	0.20	0.60		0.80	0.30		0.50				3.30	0.10
Shale and Sandstone (SHS)	2.50	0.10	0.10		1.60	0.10	0.10	0.30			1.00	0.30	0.00
Mudstone (MUD)	1.60	0.00	0.30	1.20		1.00	0.40	0.10				0.50	0.00
Limestone and Dolomite (LIM)	6.50					2.80			0.10		1.40		
Quartzite (QZ)	2.20	0.00	0.20		2.80			0.20	0.10		0.40	0.90	0.10
Metamorphic Rocks General (M)													
Metamorphic Rocks-Gneiss (MG)	2.10	0.00		0.00	0.30	0.30	0.10	0.80			4.70		0.00
Metamorphic Rocks Schist(MS)	0.20			0.10		1.10		0.40				0.30	
Quaternary Sand (QSA)	0.70	0.50	1.10	0.20	1.40	1.30	1.40	0.00	0.10	2.70	6.40	1.30	0.00

Interflow Soils:

Interflow soils contribute significantly to surface water delivery. Their duration of saturation is expected to be dependent on soil properties and seasonal climate variability. Water drains laterally from these soils when they receive water from hillslopes of higher topographical locations and after rainfall events. They are only partly saturated during periods of low water additions from hillslopes and have very low water saturation during periods of low rainfall.

The graphical distribution of Interflow soils (Figure 4.2) is summed for all five Interflow soil classes (W2 to W6) since it is important to have a national perspective of their surface water delivery. The total proportions of Interflow soils are considerably higher than those of responsive (discharge) soils with quantile classes of three higher classes set at 2.6-7.9% (green), 7.9-14.3% (light blue) and 14.3-77.0% (dark blue), respectively (Figure 4.2). The highest proportions of Interflow soils are distributed on the Maputaland Coastal Plain of

KwaZulu-Natal, the granites of southern Mpumalanga, the sandstones of the KwaZulu-Natal Tugela Basin, the Gauteng Highveld, the sandstones and mudstones of the eastern and western Free State and the coastal belt and hinterland of the southern and Western Cape. Intermediate proportions cover most of the Eastern Cape (rainfall greater than 500 mm p.a.) and the coastal hinterland of the southern and Western Cape (Figure 4.2).

The semi-permanent wet Interflow soils of the Kroonstad form W2 (Figure 4.2, Table 4.2) and the temporarily wet E horizon Interflow soils W6 of ***Plinthic***, ***Plinthic and Duplex Soils*** and ***Deep Grey Sands*** (Figure 4.2, Table 4.2) provide the highest contribution to interflow water delivery across most geology groups.

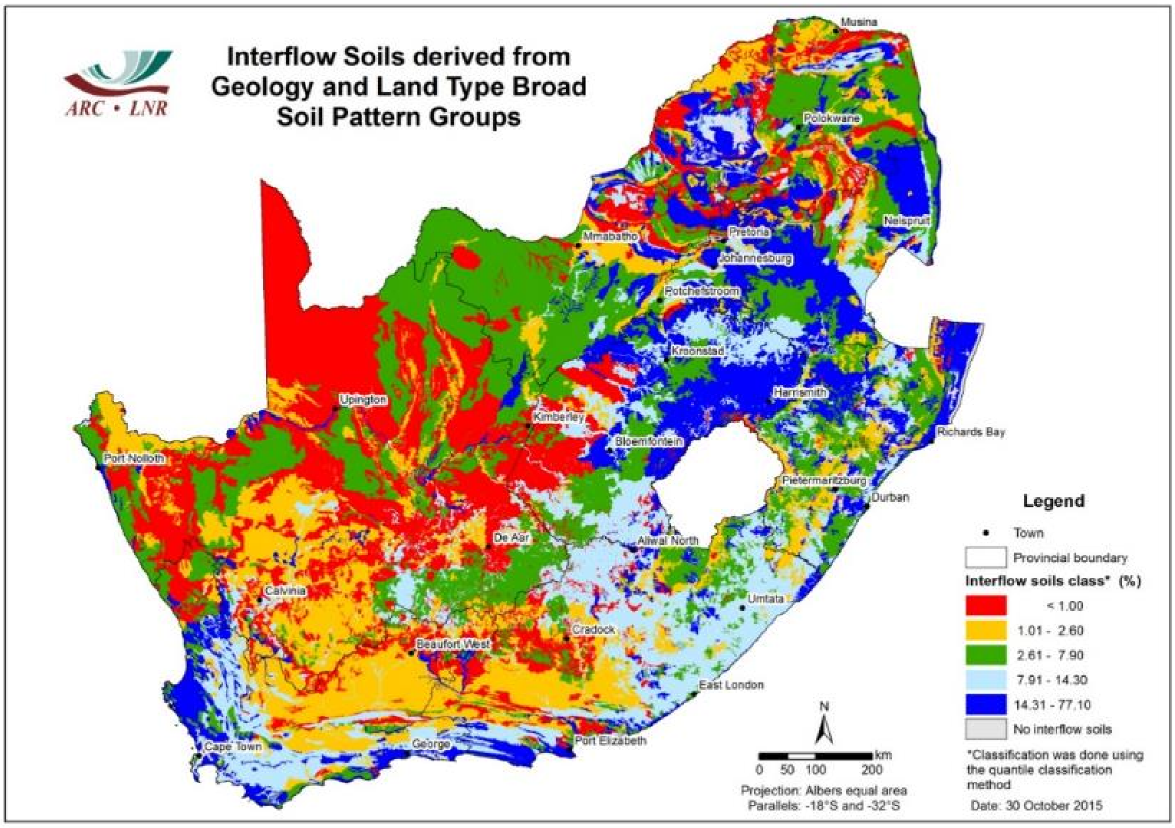


Figure 4.2: *Interflow soils derived from geology and Land Type Broad Soil Pattern groups.*

The Kroonstad (Kd) soils (W2) are generally deep (>1 m) grey sands over wet slowly permeable clay subsoils. In addition to overland flows during intense rain events, vertical infiltration and near surface lateral flows of the surface horizon can be expected. Horizontal and lateral water movement through the E horizon of these soils is expected, while the slowly permeable subsurface is expected to have only slow water discharge to stream systems. The Kroonstad soil form is generally considered to have higher water saturation values than other

E horizon soils and has thus been evaluated separately (W2) (Table 4.2). Kroonstad soil form is represented in the ***Plinthic, Plinthic and Duplex*** and ***Deep Grey Sand*** Broad Soil Patterns (Table 4.2). Since soil formation requires a sandy E horizon, it is dominantly associated with Acid and Intermediate Igneous Rocks, Sandstone, Shale, Mudstone, Limestone and Dolomite, Quartzite, Metamorphic Gneiss and Schist and Quaternary geology groups.

Table 4.2: *W2 Semi-permanent wet Interflow soils; Kroonstad (Kd) soil form*

W2 - Semi Permanent Wet Interflow Soils (Kroonstad (Kd) Soil Form													
Geology Group	Land Type Broad Soil Pattern Groups												
	Apedal Dys-Mesotrophic (AA)	Apedal Eutrophic (AE)	Apedal Eutrophic Dunes (AF)	Apedal Eutrophic Sands (AG)	Plinthic Soils (BA)	Polinthic & Duplex Soils (CA)	Black Red Clay Soils (EA)	Shallow Soils Lime Rare (FA)	Shallow Soils Lime abundent (FC)	Podsolic Soils (GB)	Deep Grey Sands (HA)	Alluvial Soils (IA)	Rockland (IB)
Acid Igneous Rocks (IA)	0.50	0.60		0.60	0.80	5.90		0.60	9.30		0.20		
Intermediate Igneous Rocks (II)						16.70	0.10	0.00					
Basic Igneous Rocks (IB)	0.20				0.00	0.10	0.20	0.20					
Ultrabasic Igneous Rocks (IU)													
Sandstone Siliceous(SS)	1.50	0.10		2.40	3.60	25.80	0.10	2.20	0.20	0.90	6.70	0.40	1.30
Sandstone Felspathic (SF)	0.30				2.30	3.10	0.00	0.60					
Sandstone Micaceous(SM)	1.50					42.20							
Sedimentary Rocks Conglomerate (SC)					0.40								
Shale (SH)	0.20	0.00			5.70	1.60	1.40	1.10	0.00		18.00	0.20	0.00
Shale and Mudstone Rocks (SHM)	2.1	0.80			4.00	1.10	1.30	1.50		13.30		2.00	
Shale and Sandstone (SHS)	0.6				4.50	0.60	0.50	1.50	0.00		1.80	0.40	0.00
Mudstone (MUD)	1.50				0.90	4.20	0.10	0.10				1.30	
Limestone and Dolomite (LIM)	1.60					9.20		0.10	0.20		2.60		
Quartzite (QZ)	1.10	0.30		0.00	1.20	13.80		1.80	1.20		3.20	1.40	0.20
Metamorphic Rocks General (M)													
Metamorphic Rocks-Gneiss (MG)	0.60	0.20		0.00	0.90	4.10		0.50					
Metamorphic Rocks Schist(MS)	1.50	0.60			3.10	13.70		1.20	6.70		13.20	0.50	
Quaternary Sand (QSA)	0.80	0.10		0.10	5.10	18.70		0.50	0.10	9.30	3.70	0.40	

The Dundee (Du) soils (W3) are stratified intermediate to deep (>600 mm to 1 m), alluvial sands to sandy loams, located in bottomland terrain positions. The stratified texture of these soils can imply that they are both saturated with water and moderately to freely drained. Their hydrological response should best be evaluated at detailed information scales.

The Rensburg (Rg) soils (W4) are dark brown to black swelling clays with a wet, gleyed subsoil horizon. The DWS wetland guidelines record these soils in a permanent wetland class (DWAF, 2005). Despite the presence of a subsurface gleyed horizon, the shrink/swell properties, large surface cracks in the dry state and the self-mulching properties indicate that Rensburg soils may not be correctly recognised as extended surface (and indeed subsurface) water saturation. A rainfall event on dry Rensburg soils will result in rapid water infiltration into surface cracks, swelling of surface soils and eventually ponding of surface water. Hydraulic conductivity of the surface vertic clay and subsurface gleyed clay is generally slow. The soils are formed from basic igneous rocks on generally flat terrain. Surface ponding of excess water is expected and surface flow to low positions that may include pans or stream or river systems. Notwithstanding these limitations, these soils were considered as Temporary Wetlands for this report.

Podzol soils (W5) are characterised by grey and occasionally yellow-brown sandy (<15% clay) soils with a subsoil accumulation of humified material with iron and aluminium, commonly under 'fynbos' vegetation. The Podzolic soils are restricted in their distribution to the coastal areas of the southern and Western Cape of sandstone, shale and Quaternary sand geology groups.

Soils of the Cartref (Cf), Longlands (Lo), Wasbank (Wa), Vilafontes (Vf) Shepstone (Sp), Constantia (Ct) Estcourt (Es) and Fernwood (Fw of normal topography) forms (W6) all have grey, sandy to sandy loam E horizons over varying diagnostic subsoil horizons of potentially differing water permeability. All these soils commonly have bleached surface horizons, with limited textural difference between the surface and E horizon. In the dry state, surface infiltration is expected to be moderate to rapid. During rain events, saturation of the surface and E horizon is expected. Near-surface and overland flows could be expected that may be controlled by slope angle, small textural difference between surface horizons and small organic matter accumulations that may result in greater macro-porosity of the surface horizon. Lateral water flows through the E (eluvial) horizon during periods of water saturation are expected. The flow rates will be dependent on the grade of sand in the E horizon, with loose coarse sands expected to have greater flow rates than compact fine sands. These soils could be expected to be located from the lower footslope to upper midslope terrain positions. The extent of the E horizon along the length of the slope is a function of slope angle, soil texture (a geology related function) and prevailing climate. For example, Longlands soils may extend over the greater portion of moderate slopes on the medium grained sandstone geology of the Vryheid Formation in the KwaZulu-Natal Interior Basins, while Cartref soils may extend to the crests of fine grained Beaufort mudstones of the Eastern Cape. However, where free drainage conditions prevail, the E horizons may be restricted only to lower slope positions. These E horizon soils are commonly associated with erodible duplex soils present in the bottomlands. In the eastern provinces, many of these bottomlands have experienced severe gully erosion. In these regions, lateral water flows are expected to be the dominant flow mechanism. However, where this gully erosion has occurred, overland flows and concentration of channelled water to produce the gullies has in all probability disrupted the natural flow dynamics. Altered durations of water will require additional research information between well-conserved and eroded catchments.

In the Cartref soil, this subsoil horizon is partly weathered rock. In addition to the expected rapid response to near-surface lateral water flows, limited saturated flow to the rock horizons is expected. In the Longlands soil, it is a soft plinthic horizon that invariably overlies gleyed material with deeper fluctuations of water saturation capable of producing reducing conditions that have given rise to the plinthic horizon. In the Wasbank soil, the extent of induration of the plinthic gives rise to a range soil morphology that reflects both moist to drier subsurface conditions.

The Vilafontes, Shepstone and Constantia soils have moderately permeable brown, red and yellowish subsurface sandy material, so that dominantly freely-drained conditions are expected. Fernwood soils have deep grey sand subsurface horizons on flat terrain. In the high rainfall eastern coastal regions, partial saturation of water in the subsoil is expected, while a deep subsoil may have geological layers of limiting permeability with various levels of water saturation and deep subsurface flows.

The Estcourt soil has an E horizon overlying a slowly permeable, dense prismatic subsurface clay. A range of deeper subsurface materials, comprising variously alluvial materials through to hard rock are commonly encountered. Slow vertical water flows and limited water storage on subsurface horizons and deep subsurface materials is expected.

Despite limitations discussed in this report, each of these soils was evaluated in the Interflow hydrological class and in keeping with the initial hypothesis, described as Temporary Wetland soils.

These soils are dominantly present in the Broad Soil Patterns for ***Plinthic***, ***Plinthic and Duplex***, ***Shallow Soils with lime rare to abundant***, and ***Deep Grey Sands***. They will occur on a wide variety of geology groups comprising generally sand bearing materials including acid to intermediate igneous rocks, sandstones, shales, mudstones, limestone and dolomite, quartzite, metamorphic gneiss and schist and Quaternary sand.

Table 4.3: *W6 Interflow soils (Cartref (Cf), Longlands (Lo), Wasbank (Wa), Vilafontes (Vf) Shepstone (Sp), Constantia (Ct) Estcourt (Es) and Fernwood (Fw of normal topography) forms*

W6 - Temporaraly Wet E Horizon Interflow Soils (Cf,Lo,Wa,Vf,Sp,Ct,Es,Fw(Normal topogtaphy))													
Geology Group	Land Type Broad Soil Pattern Groups												
	Apedal Dys-Mesotrophic (AA)	Apedal Eutrophic (AE)	Apedal Eutrophic Dunes (AF)	Apedal Eutrophic Sands (AG)	Plinthic Soils (BA)	Polinthic & Duplex Soils (CA)	Black Red Clay Soils (EA)	Shalllow Soils Lime Rare (FA)	Shallow Soils Lime abundent (FC)	Podsolic Soils (GB)	Deep Grey Sands (HA)	Alluvial Soils (IA)	Rockland (IB)
Acid Igneous Rocks (IA)	3.70	5.00		3.00	13.10	37.60	0.10	14.50	20.20		54.00		0.70
Intermediate Igneous Rocks (II)	1.10				0.20	9.90	0.10	0.70				4.30	
Basic Igneous Rocks (IB)	1.40	0.10			3.20	0.30	0.80	2.10				0.10	0.00
Ultrabasic Igneous Rocks (IU)		1.30											
Sandstone Siliceous(SS)	8.30	2.00		12.70	23.60	30.50		16.50	0.70	30.70	39.40	2.10	7.60
Sandstone Felspathic (SF)	1.80	0.20		11.20	12.30	9.70	1.60	4.30	2.20				3.60
Sandstone Micaceous(SM)													
Sedimentary Rocks Conglomerate (SC)	2.90				4.60		0.20	0.70					1.40
Shale (SH)	1.20	0.30	1.50	0.20	8.90	2.30	4.40	6.70	0.20	17.00	43.70	0.70	0.20
Shale and Mudstone Rocks (SHM)	5.20	3.00		0.60	19.70	7.60	3.40	10.40	1.60		30.20	3.10	0.40
Shale and Sandstone (SHS)	2.20				10.20	1.60	2.70	12.50	0.20		43.30	0.50	0.00
Mudstone (MUD)	2.10	0.20		1.10	10.10	12.70	0.90	1.50				0.90	0.20
Limestone and Dolomite (LIM)	6.10					28.70		2.20	2.60		62.70		0.40
Quartzite (QZ)	9.30	2.00		0.60	9.30	16.00	0.40	9.40	3.00		51.10	5.30	1.10
Metamorphic Rocks General (M)													
Metamorphic Rocks-Gneiss (MG)	2.20	0.50		0.00	18.50	11.50		6.30	0.10		59.60		0.10
Metamorphic Rocks Schist(MS)	7.90	1.80			1.40	10.20		3.30	2.40		56.30	0.00	0.50
Quaternary Sand (QSA)	5.80	0.10	0.70	3.90	13.80	12.60	0.10	1.30	0.10	32.50	72.50	1.20	0.50

The assessment provides a robust overview of the distribution of Responsive (discharge) and Interflow soils. It assumes that each soil form will demonstrate a dominant soil hydromorphic character. The assumption only allows for simple overview assessment and has applications limited to this perspective. It was, however, the viewpoint held during the initial phases of the project. Table 4.4 illustrates some of the limitations in this early assessment.

Table 4.4: *Limitations in assigning a soil form to a single soil hydrological class*

Wetland Category	Soil Form	Discussion
Permanent Wetlands (W1)	Champagne (Ch)	Wet surface horizons and saturated subsurface horizons necessary for accumulation of high level of organic matter. Responsive soil.
	Katspruit (Ka)	Generally moist surface horizon and wet subsurface horizon. Responsive soil.
	Willowbrook (Wo)	Surface horizon generally dry with wet subsurface horizon. Generally Responsive soil.
	Fernwood (depression topography) (Fw)	Generally wet subsurface horizon necessary to accumulate elevated levels of organic matter. Responsive soil.
Hydrological Class '*Temporary Wetlands'* (W2)	Kroonstad (Kd)	Wet clay subsurface soil, with generally wet E horizon and lateral water flow and moist to wet surface horizon. Responsive soil.
Hydrological Class '*Temporary Wetlands'* (W3)	Dundee (Du)	Stratified alluvium of irregular textures and structures. A bottomland soil with considerable variation of hydraulic properties.
Hydrological Class '*Temporary Wetlands'* (W4)	Rensburg (Rg)	Generally, recharge surface soils and wet to saturated subsurface soils. Responsive soil but susceptible to erosion that will alter water delivery properties. Formerly written in guidelines as Responsive soil.
Hydrological Class '*Temporary Wetlands'* (W5)Temporary Wetlands (W3) Podzolic soils	Houwhoek (Hh) Lamotte (Lt)	Sandy soils generally with extensive bleached horizons indicative of podzolic removal of organic matter and iron. Research on water flow and duration of saturation limited. Expected to exhibit seasonal water saturation.
Interflow Hydrological Class *'Temporary Wetlands'* (W6) Soils with an E horizon	Cartref (Cf) Longlands (Lo) Wasbank (Wa) Vilafontes (Vf) Shepstone (Sp) Constantia (Ct) Estcourt (Es) Fernwood (normal topography) (Fw)	All soils expected to have bleached surface horizons that may be indicative of near-surface flows following intense rain events. Lateral water flow expected in all soils after intense rain events Cf, Orthic/E horizons over lithic material. Limited subsurface water saturation expected. Lo Orthic/E over soft plinthic. Fluctuating water saturation below plinthic horizon and limited discharge expected. Wa Orthic/E over hard plinthic. Variable deep subsurface materials with limited to moderate water discharge. Sp, Ct, Vf, Fw Orthic//E over sandy materials. Deep drainage expected.

Result of testing wetland distribution using a single Land Type evaluation approach. University of Pretoria capacity building project (Fourie, 2015):

The wetland distribution map for the revised classification (Figure 4.3) illustrates the location of wetlands as derived from an estimation of the hydromorphic properties of soil forms. The largest percentage distribution (dark blue colouration) is present in northern KwaZulu-Natal and the coastal areas of the Western Cape. Intermediate distributions are located in the interior of KwaZulu-Natal and the eastern Free State. Wetlands are further distributed in moderate proportion throughout the Mpumalanga Highveld, Gauteng, Limpopo, North West and Free State provinces and the southern coastal belt of the Western Cape. The importance of the map serves mainly to highlight the distribution of wetlands that could promote improved focus on wetland conservation at regional scale.

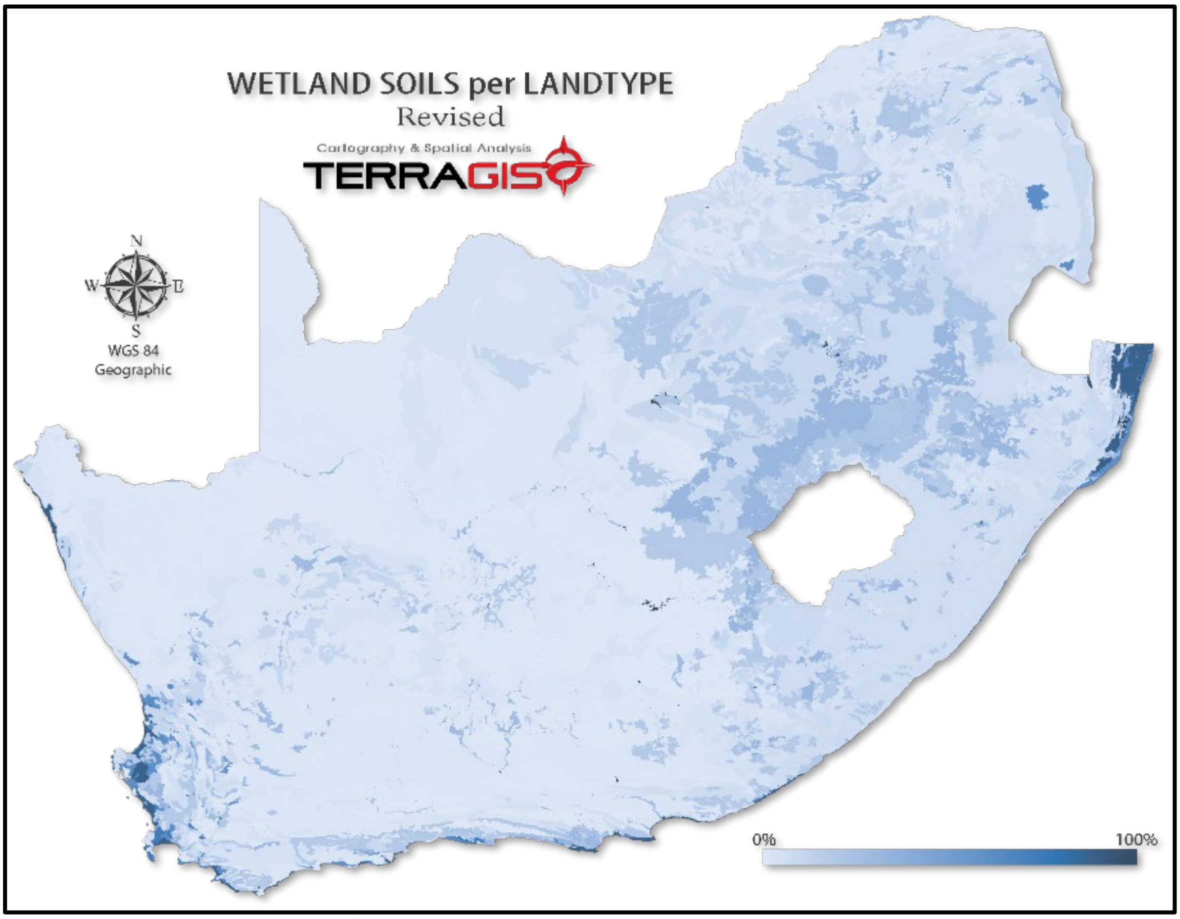


Figure 4.3: *Assessment of the approach in testing wetland distribution using a single Land Type evaluation.*

The conservative and liberal assessments under- and over-estimated wetland extent which negated their further usefulness. Regrettably, the initial hypothesis that Land Type information would provide information of regional wetland distribution has delivered only very limited benefit to the wetland knowledge base. The study did, however, provide a good training opportunity for human capacity development in young soil and wetland scientists.

Erosion Sensitive Areas

Estimation of erosion sensitive zones derived from ARC-ISCW Land Type information: The map distribution of Highly Erodible Soils is presented graphically in Figure 4.4 with the distribution per geology group and Land Type Broad Soil Pattern expressed in Table 4.5.

Duplex Soils (CA) are known to have generally higher proportions of sodium (Na) on the cation exchange complex and are thus highly dispersive, leading to erosion. Rockland (Ib) occurs on steep slopes and hence is prone to erosion. Similarly, the Shallow Soils Groups (Fa-Fc) also generally occur on steep slopes and higher erosion levels could be expected. Black clay soils (Ea) often occur in bottomland terrain positions, where water concentration is present, and may contain elevated levels of sodium. Each of these factors contributes to erosion.

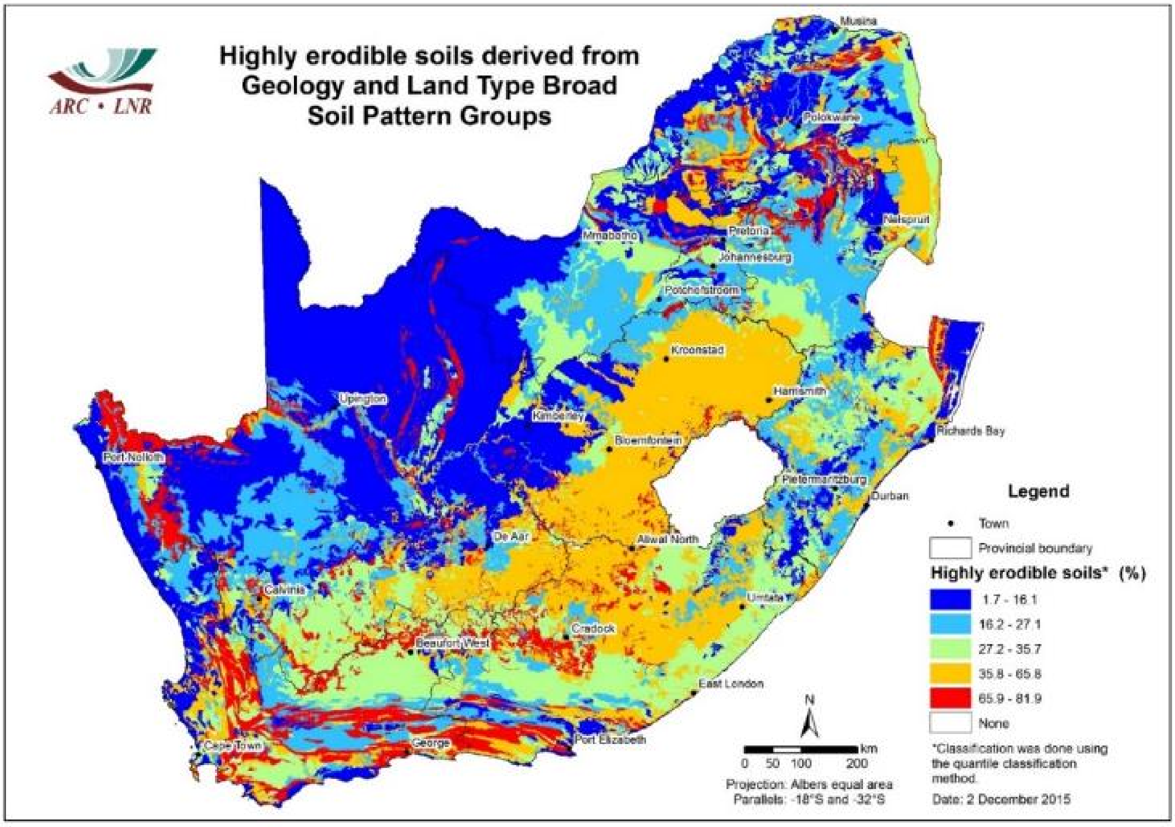


Figure 4.4: *Highly erodible soils derived from geology and Land Type Soil Pattern groups.*

However, certain black clay soils do occur on gentle slopes so that their presence in generally erosion prone terrain is not constant, as reflected in summary Table 4.5. These soils are located in the eastern Free State, north-western Eastern Cape and the eastern part of the Western Cape, together with occurrences distributed throughout all provinces The intermediate proportions (green blocks) are probably represented by steeper land situations (Figure 4.4, Table 4.5).

High proportions of Erosion Sensitive Soils are represented on all geology formations for the Rockland Class (Ib) and Plinthic and Duplex Class (Ca) over most geology formations. This may indicate that geology grouping is not as sensitive an indicator of erosion sensitivity as proposed in the initial hypothesis. However, individual geology formations at specific sites may contribute to erosion sensitivity.

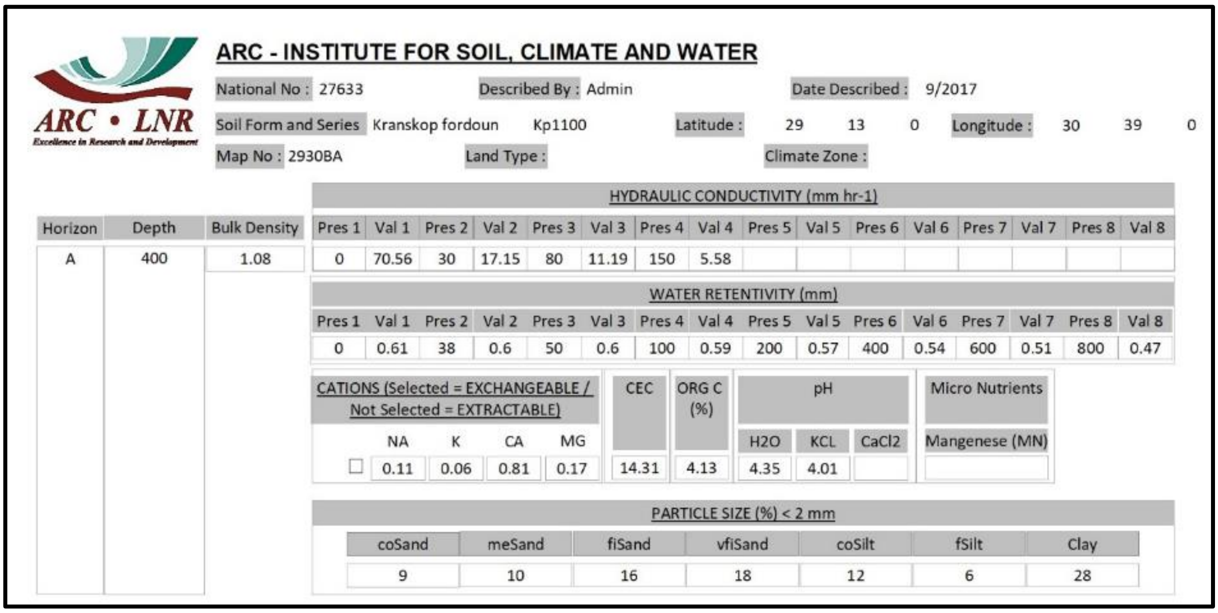
The soils developed from the red mudstones of the Molteno and Elliot Geology Formations are known to be particularly sensitive to erosion. Figure 4.4 also illustrates other areas (red and yellow colour) where the underlying geology formations may give rise to particularly erosion sensitive soils. This should be investigated through GIS technology on a case by case basis.

Table 4.5: *Highly erodible soil group*

E1 Highly Erodible Soil Group													
	Land Type Broad Soil Groups												
Geology Group	Apedal Dys-Mesotrophic (AA)	Apedal Eutrophic (AE)	Apedal Eutrophic Dunes (AF)	Apedal Eutrophic Sands (AG)	Plinthic Soils (BA)	Plinthic & Duplex Soils (CA)	Black Red Clay Soils (EA)	Shallow Soils Lime Rare (FA)	Shallow Soils Lime Abundent (FC)	Podsolic Soils (GB)	Deep Grey Sands (HA)	Alluvial Soils (IA)	Rockland (IB)
	Percentage Soil Occupancy												
Acid Igneous Rocks (IA)	11.70	12.10	4.90	27.20	26.10	66.00	43.40	35.80	46.30		25.80	17.90	68.10
Intermediate Igneous Rocks (II)	16.40	28.10		25.40	27.10	54.40	42.40	23.20	23.60			72.30	75.80
Basis Igneous Rocks (IB)	16.10	14.50	11.00		26.90	62.60	27.40	34.00	46.30			31.30	73.10
Ultra-Basic Igneous Rocks (IU)		16.20						12.40	23.40				66.50
Sandstone Siliceous (SS)	16.50	9.70		12.90	36.80	77.60	7.10	43.10	29.50	45.70	28.50	37.70	81.90
Sandstone Feldspathic (SF)	16.40	9.70		16.00	26.20	65.80	45.90	30.60	32.10				70.50
Sandstone Micaceous (SM)	10.60					81.60							77.50
Sedimentary Rocks Conglomerate (SC)	16.30	6.40			21.90		9.90	18.90					64.80
Shale (SH)	12.80	11.60	2.60	12.70	33.60	57.40	37.00	31.10	25.80	38.70	36.70	22.20	69.60
Shale and Mudstone (SHM)	19.70	11.30		17.50	44.80	64.60	15.20	40.60	42.10		44.80	52.20	70.60
Shale and Sandstone(SHS)	18.40	25.60		20.30	45.70	53.20	41.40	35.70	33.00		50.70	34.20	73.90
Mudstone (MUD)	14.40	10.70	1.80	8.20	20.80	67.40	37.50	30.20	37.40			47.80	68.00
Limestone and Dolomite (LIM)	26.90	1.90		12.00		81.60		39.90	6.90		10.90	56.60	78.60
Quartzite (QZ)	24.80	17.90		23.90	23.40	74.90		40.90	33.20		29.80	38.60	78.00
Metamorphic Rocks General (M)	9.00	6.10				67.80	22.80	28.30				17.00	69.40
Metamorphic Rocks Gneiss (MG)	14.50	11.60	1.90	17.00	33.80	47.00	14.80	25.80	30.90		62.40	19.90	70.80
Metamorphic Rocks Schist (MS)	21.80	22.30		17.30	13.00	55.50		27.40	35.00		38.30	25.50	80.90
Quaternary Sand (QSA)	6.60	6.60	1.70	4.70	35.20	58.50	27.60	11.40	10.10	32.30	9.20	37.50	69.40

Operational result for the construction of a prototype Soil Hydropedology database:

Confirmation for the operation of a Soil Hydropedology database has been demonstrated. The programming in MS Access has been completed and installed on a single computer of ARC-ISCW. Each component of the program has been tested by the capture of records by mechanical and electronic means. Eight soil profile records from the Twin Streams Research Site in KwaZulu-Natal (Le Roux *et al.,* 2015) have been inserted and printout pages prepared (Figures 4.5 to 4.7).



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National No : 27633 | Described By : Admin | Date Described : 9/2017

Soil Form and Series : Kranskop fordoun Kp1100 | Latitude : 29 13 0 | Longitude : 30 39 0

Map No : 2930BA | Land Type : | Climate Zone :

Horizon	Depth	Bulk Density
A	400	1.08

HYDRAULIC CONDUCTIVITY (mm hr-1)

Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	70.56	30	17.15	80	11.19	150	5.58								

WATER RETENTIVITY (mm)

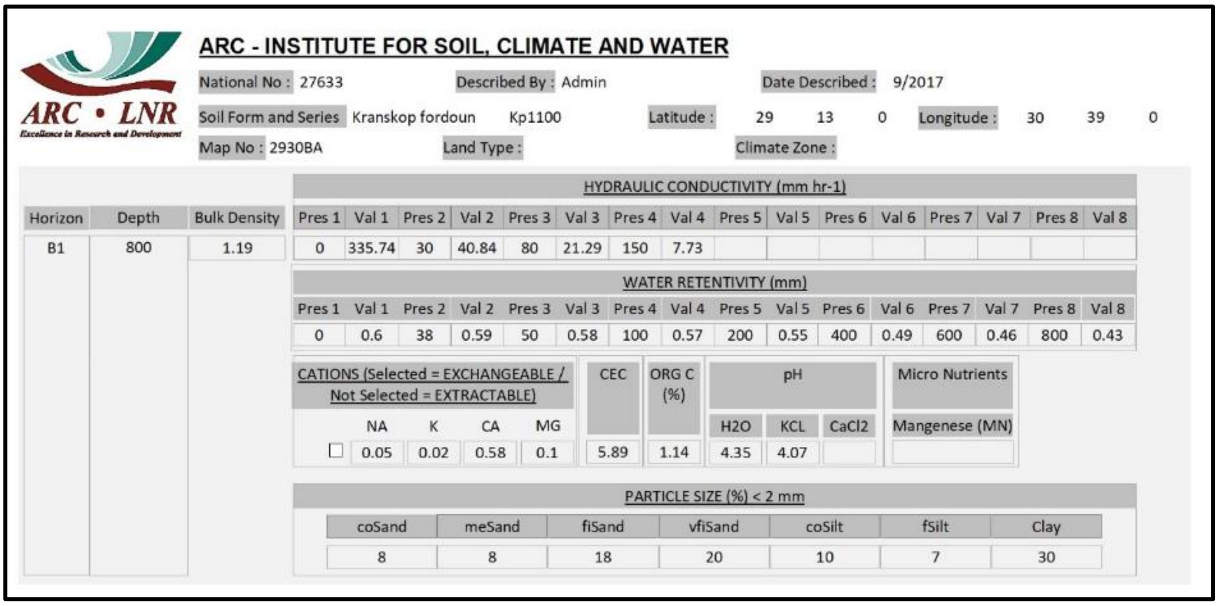
Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	0.61	38	0.6	50	0.6	100	0.59	200	0.57	400	0.54	600	0.51	800	0.47

CATIONS (Selected = EXCHANGEABLE / Not Selected = EXTRACTABLE)					CEC	ORG C (%)	pH			Micro Nutrients
	NA	K	CA	MG			H2O	KCL	CaCl2	Mangenese (MN)
☐	0.11	0.06	0.81	0.17	14.31	4.13	4.35	4.01		

PARTICLE SIZE (%) < 2 mm

coSand	meSand	fiSand	vfiSand	coSilt	fSilt	Clay
9	10	16	18	12	6	28

Figure 4.5: *Printout of the topsoil horizon from the Twin Streams research site. Four hydraulic conductivity and four water retentivity values are illustrated with their accompanying soil pressure potentials.*



ARC - INSTITUTE FOR SOIL, CLIMATE AND WATER

National No : 27633 | Described By : Admin | Date Described : 9/2017

Soil Form and Series : Kranskop fordoun Kp1100 | Latitude : 29 13 0 | Longitude : 30 39 0

Map No : 2930BA | Land Type : | Climate Zone :

Horizon	Depth	Bulk Density
B1	800	1.19

HYDRAULIC CONDUCTIVITY (mm hr-1)

Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	335.74	30	40.84	80	21.29	150	7.73								

WATER RETENTIVITY (mm)

Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	0.6	38	0.59	50	0.58	100	0.57	200	0.55	400	0.49	600	0.46	800	0.43

CATIONS (Selected = EXCHANGEABLE / Not Selected = EXTRACTABLE)					CEC	ORG C (%)	pH			Micro Nutrients
	NA	K	CA	MG			H2O	KCL	CaCl2	Mangenese (MN)
☐	0.05	0.02	0.58	0.1	5.89	1.14	4.35	4.07		

PARTICLE SIZE (%) < 2 mm

coSand	meSand	fiSand	vfiSand	coSilt	fSilt	Clay
8	8	18	20	10	7	30

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ARC - INSTITUTE FOR SOIL, CLIMATE AND WATER

National No : 27633 | Described By : Admin | Date Described : 9/2017

Soil Form and Series: Kranskop fordoun Kp1100 | Latitude : 29 13 0 | Longitude : 30 39 0

Map No : 2930BA | Land Type : | Climate Zone :

Horizon	Depth	Bulk Density
B2	2000	1.24

HYDRAULIC CONDUCTIVITY (mm hr-1)

Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	372.43	30	41.6	80	17.42	150	3.6								

WATER RETENTIVITY (mm)

Pres 1	Val 1	Pres 2	Val 2	Pres 3	Val 3	Pres 4	Val 4	Pres 5	Val 5	Pres 6	Val 6	Pres 7	Val 7	Pres 8	Val 8
0	0.54	38	0.53	50	0.52	100	0.5	200	0.46	400	0.42	600	0.39	800	0.36

CATIONS (Selected = EXCHANGEABLE / Not Selected = EXTRACTABLE)					CEC	ORG C (%)	pH			Micro Nutrients
	NA	K	CA	MG			H2O	KCL	CaCl2	Mangenese (MN)
☐	0.09	0.06	0.92	0.97	4.08	0.66	4.35	4.06		

PARTICLE SIZE (%) < 2 mm

coSand	meSand	fiSand	vfiSand	coSilt	fSilt	Clay
6	12	16.5	15.5	9	8.5	33

Figure 4.6: *Printouts of the two subsoil horizons from the Twin Streams research site. Four hydraulic conductivity and four water retentivity values are illustrated with their accompanying soil pressure potentials.*

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SOIL PROFILE DESCRIPTION

NATIONAL SOIL PROFILE NO : 27633

Map/photo : 2930BA Greytown

Latitude + Longitude: 29° 13' 0" / 30° 39' 0"

Land Type No :

Climate Zone :

Altitude : 11100 m

Terrain Unit: Lower Midslope

Slope: 9 %

Slope Shape :

Aspect : North

Microrelief : None

Parent Material Solum : Origin single, unknown

Underlying Material : Sandstone (unspecified)

Soil form and family Kranskop fordoun

Surface rockiness : None

Surface stoniness : None

Occurence of flooding : None

Wind erosion : None

Water Erosion : None

Vegetation / Land use : Plantation (Forestry)

Water table : None

Described by : Adminastrator

Date Described : 9/2017

Weathering of underlying material: Strong physical, strong chemical

Alteration of underlying material : Normal weathering

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0 - 400	Moist; horizon undisturbed; dark brown 7.5YR3/2(dry); brown 7.5YR5/2(moist); fine sandy clay loam; weak coarse subangular blocky; friable; few normal matrix pores; water absorption: 1 second(s); common roots; clear smooth transition.	Humic
B1	400 - 800	Moist; horizon undisturbed; strong brown 7.5YR4/6(dry); strong brown 7.5YR4/6(moist); fine sandy clay loam; structureless; friable; few normal matrix pores, medium cracks; water absorption: 1 second(s); common roots; clear smooth transition.	Yellow-brown apedal
B2	800 - 2000	Moist; horizon undisturbed; red 2.5YR4/8(dry); dark red 2.5YR3/6(moist); fine sandy clay loam; structureless; friable; medium cracks; water absorption: 1 second(s); common roots.	Red apedal

Figure 4.7: *Printout of a profile description of a Kranskop soil form soil from the Twin Streams research site.*

4.2. Catchment Scale – Case Studies

4.2.1 Soils feeding wetlands (Weatherley case study)

Wetlands are recognised as important for biodiversity support and for the delivery of ecosystem services to people. In order to regulate the use of these systems so that their natural functions may be preserved, wetlands need to be able to be identified and their outer boundaries delineated.

A *Wetland delineation manual* was published for this purpose by the U.S. Army Corps of Engineers in 1987, providing guidance on field wetland delineation methods, data sheets, how to approach problem sites, as well as extensive references to literature supporting the scientific principles underlying the delineation method (USACOE, 1987). During the 1990s, a wetland working group spanning multiple disciplines and areas of expertise contributed to the initiation of similar wetland delineation guidance in South Africa. These specialists reviewed the international literature, including the U.S. Army Corps of Engineers methodology, and worked with the Rennies Wetland Project (later the Mondi Wetlands Programme) to provide a set of guidelines which could be used nationally for the delineation of wetlands. This guidance was not developed specifically for the forestry industry (South African Wetland Society, 2014). *Guidelines for delineation of wetland boundaries and wetland zones (*Kotze and Marneweck, 1999*)* was developed as part of a series of Resource Directed Measures for Wetland Ecosystems, and implemented by the Department of Water Affairs and Forestry (now DWS) for infrastructure-related projects. This was followed by the manual *A practical field procedure for identification and delineation of wetlands and riparian areas* (DWAF, 2005).

South Africa does not yet have an official list of hydric soils, i.e. soils that always support wetlands. The 2005 DWS document lists four soil forms that would be the equivalent of the USA “hydric soils” as they are described in the 2005 manual to always indicate the presence of wetlands. Historical reference to these soils can be found in Kotze *et al*. (1996). They attribute the selection of the soils to Scotney and Wilby (1983), who published a list of the four soil forms which they reported to be most common in South African wetlands, as well an expanded list of soil forms which they encountered in “temporary wetlands”. An update to the current South Africa delineation manual was prepared by Rountree *et al.* (2008) but it remains in draft form. The 2005 guidelines were adopted and approved by DWS management (at Director-General level) and are referred to in the *General Authorisation 1199* (published in 2009) as the method to be used. At such time as the method and guidelines are amended in the future, then approval from DWS management (DG) must again be obtained to ensure a standardised approach within the department and by all practitioners.

The list of wetland soils remains unchanged in the 2008 draft document (Table 4.6) but a notable change in wording appears, from "the permanent zone will always have" and the expanded list of soil forms "will occur" within wetlands in the 2005 version, to "wetlands may" be present in the 2008 version. Also in the 2008 document, the authors highlight that the listed soil forms "are not diagnostic indicators of wetlands. The presence of these soil forms only indicate a possible presence of wetlands, since in some instances the wet conditions may be deeper in the soil profile and thus neither result in wetland soils within 50 cm of the surface nor in the occurrence of wetland vegetation on the surface" (Rountree *et al.*, 2008, p. 24).

Table 4.6: *Extract from the unpublished draft update to the DWS wetland delineation manual (Rountree et al., 2008)*

The following soil forms are diagnostic of wetlands and are associated with **permanently or seasonally saturated** wetlands:	Champagne, Katspruit, Willowbrook, Rensburg
However, wetlands may also be present in areas characterised by the following soil forms, where signs of wetness are incorporated at the **form level**:	Kroonstad, Longlands, Wasbank, Lamotte, Estcourt, Klapmuts, Vilafontes, Kinkelbos, Cartref, Fernwood, Westleigh, Dresden, Avalon, Glencoe, Pinedene, Bainsvlei, Bloemdal, Witfontein, Sepane, Tukulu, Montagu
And wetlands may also be present in areas characterised by the following soil forms, where signs of wetness are incorporated at the **family level**:	Inhoek, Tsitsikamma, Houwhoek, Molopo, Kimberley, Jonkersberg, Groenkop, Etosha, Addo, Brandvlei, Glenrosa, Dundee

The problematic inclusion of the Rensburg soil form as diagnostic of the presence of permanent or seasonal wetland has already been discussed in Section 4.1.1, and has resulted in such soils being placed as indicators of Temporary wetlands in Table 4.7. In this project for the national scale application of Land Type data to predict wetland occurrence, a similar exercise was undertaken, where wetland wetness classes were assigned to soil forms and soil series based on an intuitive estimate of soil wetness.

Table 4.7 introduces two additional soil forms, not listed in the DWS wetland delineation guidance tables, namely Shepstone and Constantia. Twelve soils that were listed in the DWS wetland delineation guidance tables but omitted from Table 4.7 are Klapmuts, Kinkelbos (discussed earlier), Dresden, Avalon, Glencoe, Pinedene, Bainsvlei, Bloemdal, Witfontein, Sepane, Tukulu and Montagu.

Table 4.7: *Identification of soil forms per wetland category*

Wetland Category	Soil Form		Sub-category
	Name	**Symbol**	**Soil Series Code**
Permanent Wetlands (W1)	Champagne	Ch	All
	Katspruit	Ka	All
	Willowbrook	Wo	All
	Fernwood (depression topography)	Fw	30,31,32,40,41,42
Temporary Wetlands (W2, W4, W3)	Kroonstad	Kd	All
	Rensburg	Rg	All
	Dundee	Du	All
Temporary Wetlands (W5) Podzolic soils	Houwhoek	Hh	All
	Lamotte	Lt	
Temporary Wetlands (W6) Soils with an E horizon	Cartref	Cf	
	Longlands	Lo	
	Wasbank	Wa	
	Vilafontes	Vf	
	Shepstone	Sp	
	Constantia	Ct	
	Estcourt	Es	
	Fernwood (normal topography)	Fw	10,11,12,20,21,22

In light of the above differences, two further datasets are reviewed below where the presence of a wetland has been confirmed either by detailed plant assessment or detailed hydrological monitoring. In the case of Collins (2010), an investigation of 354 wetland plots, including 25 soil forms across the Free State Province, found several of the above-mentioned soil forms to be present in wetlands (Table 4.8). A further seven soil forms are listed in Table 4.8 (column 3) that do not appear on any of the above tables. It is likely that several of these occurred towards the drier wetland margins or atypical wetland situations.

At the Weatherley site, the presence of wetlands was substantiated with detailed hydrological data. Five soil forms across 28 profiles met the hydrology criteria for the presence of wetlands (Table 4.9), namely saturation within 50 cm of the soil surface for more than 14 consecutive days (NTCHS, 1991), as well as the degree of saturation at which Van Huyssteen *et al*. (2005) noted the onset of reducing conditions (annual duration of saturation is greater than 70%).

Table 4.8: *Selected wetland sites in the Free State Province (Collins, 2010)*

Soils	DWS 2005 and 2008	Table 4.7	Not listed
Addo n=2	x		
Arcadia n=2			x
Augrabies n=22			x
Bloemdal n=1	x		
Bonheim n=1			x
Brandvlei n=1	x		
Champagne n=15	x	x	
Clovelly n=10			x
Coega n=2			x
Constantia n=2			x
Dundee n=7	x	x	
Glencoe n=1	x		
Glenrosa n=4	x		
Hutton n=2			x
Inhoek n=1	x		
Katspruit n=207	x	x	
Kroonstad n=22	x	x	
Mispah n=5			x
Montagu n=6	x		
Pinedene n=18	x		
Prieska n=4			x
Rensburg n=2	x	x	
Swartland n=1			x
Westleigh n=1	x		
Willowbrook n=10	x	x	

Table 4.9: *Selected wetland soil profiles across the Weatherley site (Van Huyssteen et al., 2005)*

Soils	DWS 2005 and 2008	Table 4.7
Katspruit n=7	x	x
Kroonstad n=5	x	x
Longlands n=2	x	x
Tukulu n=1	x	
Westleigh n=2	x	

Two soils occur within the wetland at the Weatherley site that are not included in Table 4.7, but their presence within wetland and substantiated hydrology data (Figure 4.6) suggests that they should be considered for inclusion at least within the temporary wetland category. Furthermore, the data shows that, even within the site, for example, one location of Tukulu soil is not wetland and one location is. This suggests that multiple soil forms may potentially support wetlands, depending on local or regional context. The same soil forms may be wetter in some parts of the country than others, depending on hillslope hydrology driven by local climate, lithology and topography. This appears to be the case even across one site in Figure 4.8, noting the wide variation of saturation evident across different profiles of the same soil form. The topographic position of each of the profiles, their configuration and relationship to each other across the site, as well as other factors that may drive or control the duration of saturation in each profile, are discussed further below.

The annual duration of saturation in each of the 28 profiles from the Weatherley site is represented in a series of graphs prepared by Van Huyssteen *et al*. (2005) and reproduced in Figure 4.8, with the top 50 cm of soil illustrated. All but three profiles would be included as wetland soils. For the three non-wetland profiles (Bloemdal profile 210, Tukulu profile 212 and Pinedene profile 202) the upper 50 cm of the profile is never saturated to 70% or greater. At other profiles (Bloemdal profile 220, Tukulu profile 203 and Pinedene profile 233), saturation to 70% or greater in the upper 50 cm of the profile was recorded.

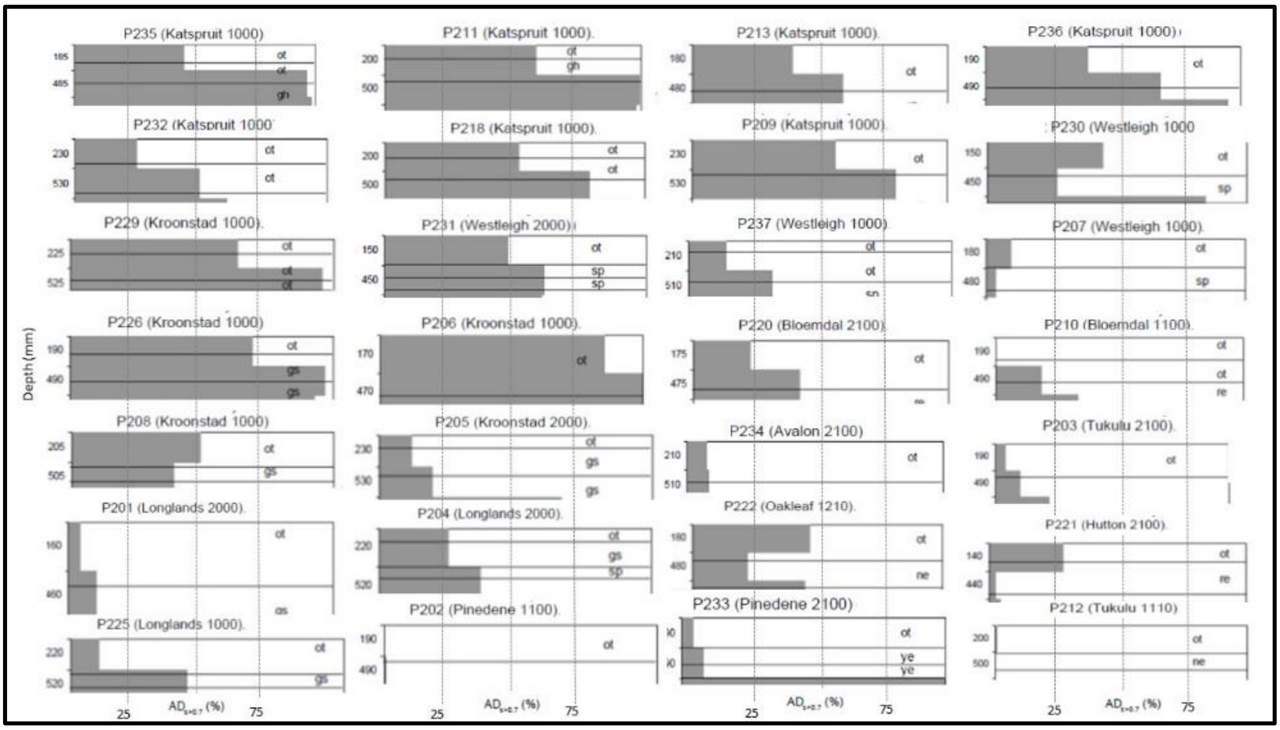


Figure 4.8: *Soil profiles from the Weatherley site where annual duration of saturation is >70% within the top 50 cm (Van Huyssteen et al., 2005).*

South African soils are mature, especially the soils on which water has had an influence. Maturity implies well expressed morphology in distinct horizons. The findings of Van Tol *et al*. (2013b), where links were drawn between observable soil and landscape properties such as slope length, slope angle, and increase and decrease in colour and clay content of A/E horizons, can contribute as significantly to the understanding of wetland hydrodynamics as they have to overall hillslope hydrology. Van Tol *et al.* (2011b) focussed on E horizons, which are formed by redox and eluviation, and found, for example, that soils with clear transitions between A/E horizons and abrupt transitions between E/B horizons tended to generate sub-surface lateral flows, as did E horizons with many, medium or larger mottles present. The soil horizon formation and redox morphology provides an indication of the direction of movement and length of time of the translocation of clays (e.g. vertically downward or upward).

The South African soil classification system does not distinguish between redox E horizons and podzol E horizons. The latter can be included in seasonal and temporary zones. However, soils with E horizons on apedal horizons without any reduction or redox morphology nor horizon limiting water flow (e.g. Vilafontes) should be excluded. Indications are that these E horizons rather relate to several days of rain creating temporary near-saturation conditions, along with high biological activity in the lower orthic A horizon.

As revealed above, soils from most forms may potentially support wetlands, but it is not appropriate to call all of these soil forms "hydric" (wetland) soil forms. It is accepted that variation in oxidation-reduction processes in response to soil saturation commonly results in morphological indicators of these processes. These morphological properties should occur within 50 cm from the surface in order for the soils to classify as wetland soils. Thus, it is anticipated that across any given soil form, certain profiles may be found to exhibit morphological evidence of saturation for sufficient duration to support wetland soils, while others may not. The discussions would suggest that the process of wetland delineation would be best placed to use soil morphological parameters characteristically serving as indicators, rather than soil forms. Many indicators were developed specifically for the purposes of wetland delineation. Hydromorphic soil properties relevant to wetland identification include the following: organic carbon (OC) accumulation; peat layers; gley colours (gley Munsell pages); grey matrix colours (chroma <2); high chroma mottles in grey matrix; low chroma mottles (>10%) in high chroma matrix; and presence of oxidised root channels (Mitsch and Gosselink, 2000; Vepraskas, 1995). In South Africa, Kotze *et al.* (1996) found that "a review of soil morphology/water-regime studies revealed that along the continuum from temporarily wet to permanently wet areas: matrix chroma decreases; the most intensively mottled zone becomes progressively shallower; mottle abundance increases then decreases; and soil organic matter increases" (Table 4.10).

Currently, the most comprehensive compilation of the best available research on this topic is the U.S.D.A. list of "*Field indicators of hydric soils in the United States"*, first compiled in 1998 and updated in 2010. Recorded morphology and soil colours of those soils verified to be wetland soils based on interpretation of the hydrological measurements of Van Huyssteen *et al*. (2005), were reviewed against the U.S.D.A. indicators (Table 4.11). Colours were recorded for soils in the moist state. The Weatherley soils, encompassing 6 soil forms and 12 profiles, were found to correspond to two USDA-NRCS (2010) indicators, namely depleted matrix (F3) and redox dark surface (F6).

Table 4.10: *Soil morphology/water-regime relationships proposed by Kotze et al. (1996)*

Soil depth (mm)	Degree of wetness		
	Temporary	**Seasonal**	**Permanent**
0-100	Matrix chroma: 0-3 Mottles: Few/Nil Organic carbon: Low/ intermediate	Matrix chroma: 0-2 Mottles: Common Organic carbon: Intermediate	Matrix chroma: 0-1 Mottles: Few/Nil Organic carbon: High
300-400	Matrix chroma: 0-2 Mottles: Few	Matrix chroma: 0-1 Mottles: Common/many	Matrix chroma: 0-1 Mottles: Few/Nil

Table 4.11: *Review of wetland soils for Weatherley against USDA-NRCS (2010) field indicators*

Indicator	Indicator name	Weatherley soil form	Weatherley soil colours
F3	Depleted matrix	Katspruit (n=5) Westleigh (n=1)	Matrix colours (moist) of 10YR4/6, 10YR5/6, 7.YR4/2
F6	Redox dark surface	Katspruit (n=2) Kroonstad (n=3) Longlands (n=1) Tukulu (n=1)	Matrix colours (moist) of 10YR3/1, 10YR2/1 to depths ranging between 30 and 74 cm from the surface Mottles present in all examples.

Characteristics of Indicator F3 (USDA-NRCS, 2010) – A **depleted matrix** requires 60% or more of the soil mass to have a value of 4 or more and a chroma of 2 or less. Redox concentrations are required in soils with matrix colours of 4/1, 4/2 or 5/2 (Figure 4.9).

Characteristics of Indicator F6 (USDA-NRCS, 2010) – A **redox dark surface** occurs within the top 30 cm of the soil profile and requires a matrix value of 3 or less and a chroma of 1 or less and the presence of 10% or more redox depletions OR a matrix value of 3 or less and a chroma of 2 or less and the presence of 20% or more redox depletions.

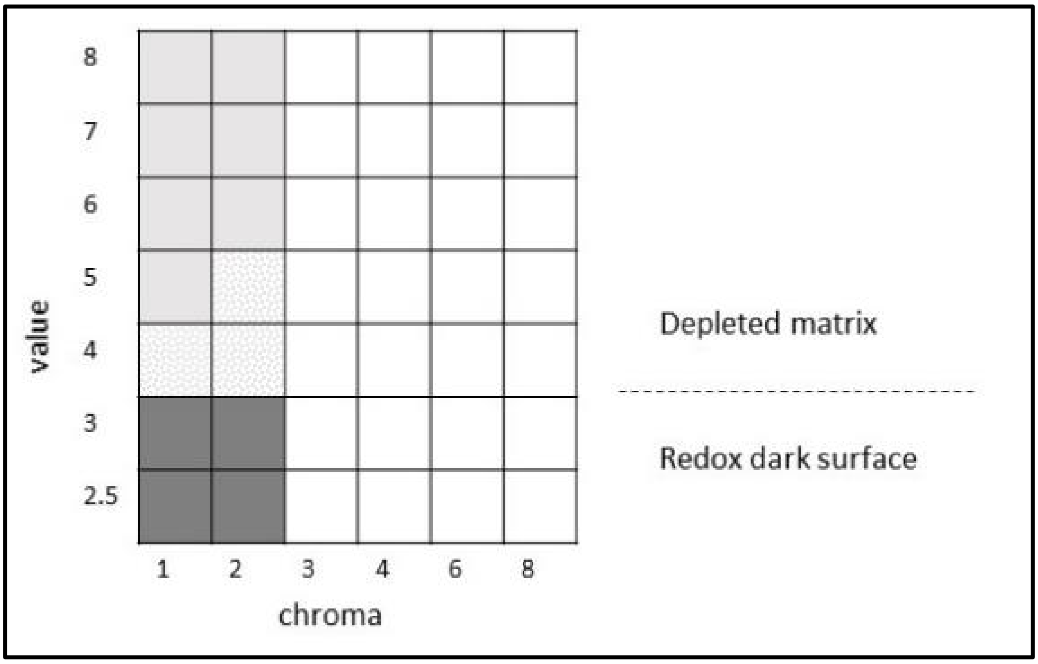


Figure 4.9: *An illustrated summary of Munsell chart values and chroma for USDA-NRCS (2010) indicators F3 and F6. The three very light grey blocks (4//1, 4/2 and 5/2) indicate that mottles need to be present for the profile to qualify as a wetland soil.*

Interestingly, none of the profiles met the criteria for Loamy Gleyed Matrix (F2), despite the documented presence of a G horizon in a large number of the soil profiles (Table 4.11). This may be attributed to a difference in interpretation of the diagnostic criteria required to identify a gleyed (G) horizon. Both USDA-NRCS (2010) and the Soil Classification Working Group (1991) consider soils with a gleyed horizon to reflect "intense reduction as a result of prolonged saturation with water" and that "grey, blue and green colours predominate due to the absence of iron compounds [grey colours] or the presence of ferrous compounds [blue and green colours]" (Soil Classification Working Group, 1991, p. 225). However, within the guidance of the USDA-NRCS (2010) as well as the associated wetland delineation guidance manuals (USACOE, 1987, 2006), a gleyed matrix must correspond with the colours on the two Munsell chart gley colour pages with values of 4 or more (USDA-NRCS, 2010). There is no record of gleyed soil colours in the results of the Weatherley soil profiles and for this review none could therefore be allocated to any of the U.S.D.A. "gleyed matrix" indicators. This has implications when interpreting the hydrodynamics of the soils, and will be discussed further in the case study section of this report, where clay content and other soil characteristics may be brought to bear. Rather, according to their recorded colours within the top 50 cm of the soil, Weatherley soils documented as having a G horizon were grouped together with E horizon soils under the concept of the presence of a depleted matrix (Table 4.11). Although this is acknowledged to be a very cursory introduction, it is hoped that several of these indicators can be explored in more detail in future, so as to develop a similar list for application in South Africa.

4.2.2 *Hillslopes feeding wetlands (City of Johannesburg case study)*

A wetland complex, comprising of a headwater seep transitioning into a valley-bottom HGM wetland type, was selected from the wetland GIS dataset provided by the City of Johannesburg CGI department. Once the study area wetland was chosen, the associated wetland catchment was mapped on GIS to define the study area (Figure 3.3). The mapped catchment and study area is approximately 170 ha. Within this wetland catchment, the headwater seep initiates as two “arms” within the concave sections of the upper slope and transitions into the valley-bottom wetland in the lower third of the catchment. A narrow band of side seepage occurs down the length of the valley-bottom wetland.

4.2.2.1 Transects

The wetland and wetland catchment are characterised by eight transects (Figure 4.10). Transect 1 is a longitudinal transect, extending from the crest of the side arm of the seep, down through the confluence with the main arm of the seep, and broadly continuing down the centreline of the wetland until the catchment outlet. Transect 1 shares soil investigation plots in common with Transects 2, 4, 5, 6 and 7 where they intersect (Figure 4.10). These shared plots are not repeated in Table 4.12, which characterises Transect 1. Instead, they are referred to briefly, but the full descriptions of these plots appear in the tables representing the cross-section transects.

The remaining seven transects are cross-sectional transects. In the case of Transects 7 and 8 they extend from the crest of the wetland catchment down slope to the wetland centreline. The remaining Transects 2, 3, 4, 5 and 6 extend through the wetland and up the hillslope to either side of the wetland (Figure 4.10).

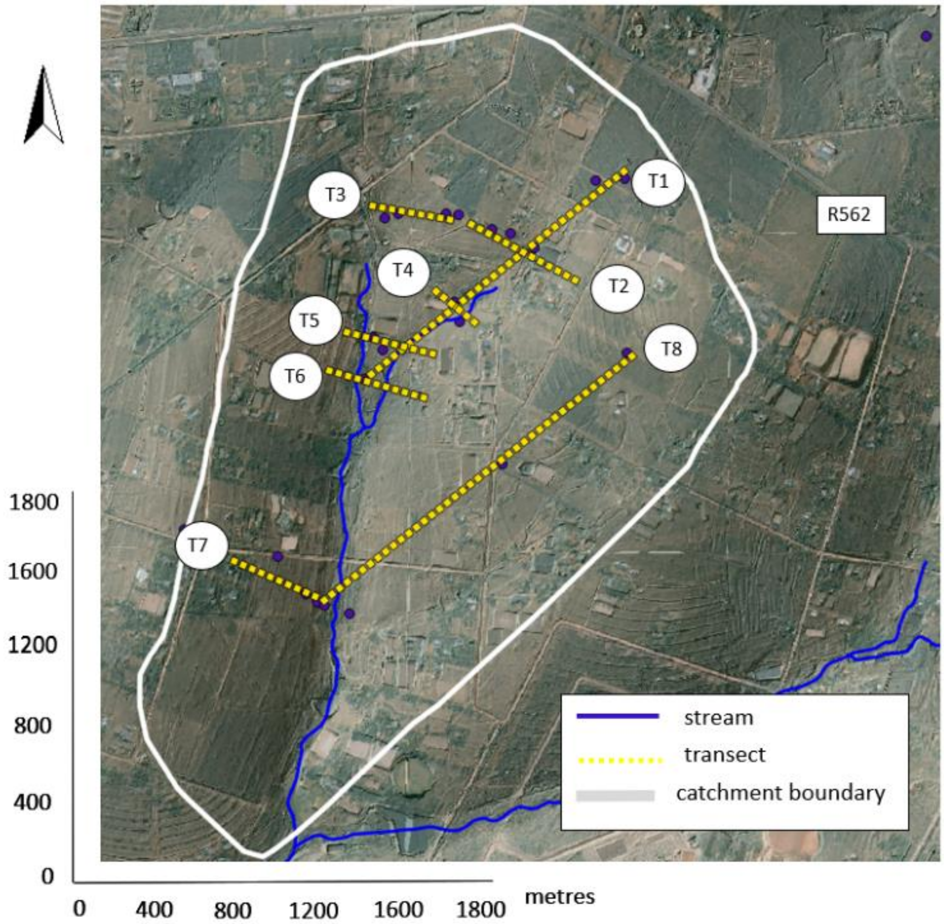


Figure 4.10: *Wetland catchment and transect locations (City of Johannesburg site).*

Transect 1 is a longitudinal transect, extending from the crest of the catchment at 1 550 m.a.s.l. down a side arm into the midpoint of the seep wetland at 1 495 m.a.s.l. (Figures 4.11 and 4.12, Table 4.12). Where this transect crosses through the upper seep wetland, it includes soil plots 11, 15, 16 and 21 which are described in the cross-sectional transects (Tables 4.12, 4.13 and 4.14). They are included in both, so that both the longitudinal and cross-sectional characteristics of the catchment can be described.

The overall wetland catchment elevation ranges from 1 580 m.a.s.l. in the upper catchment to 1 450 m.a.s.l. at the catchment outlet (Figure 4.11), representing a decrease in elevation of approximately 130 m over a 2 km distance. The average slope is 6% but it is evident that the slope flattens out for approximately 200 m, representing the crest of the catchment hillslope, and also approximately two-thirds of the way down the catchment. In this flattening area the average slope is 1% and it is surmised that there is an underlying stratigraphy control, either a shelf of hard plinthite or rock. The seep wetland transitions to valley-bottom wetland HGM type at this location. The average slope of the seep wetland in the upper two thirds is 6%, while the average slope of the valley-bottom as it continues to the catchment outlet is 3%.

Table 4.12: *Transect 1 soil morphology characteristics*

Horizon [a]	Depth	Colour (Munsell)		Redox features [b]
		Dry	Wet	
Pedon 1 crest, Clovelly				
ot	150	5YR5/3	10YR4/3	fe, y, fi, ft, sc, rc
yb	350	5YR5/2	5YR4/4	fe, o/y, fi, ds, sc, rc
sp1	900	5YR6/3	5YR6/6	my, o/y/g, me, ds, sc, rc
sp2	1400	5YR8/3	5YR6/8	fi, lg, ds, sc, rc
so	2200	5YR8/2	5YR6/6	
r	-	-	-	
Pedon 2 midslope, Constantia				
ot	100	5YR6/3	5YR4/3	-
gs	500	7.5YR7/3	7.5YR6/4	-
yb	1100	5YR7/4	5YR6/8	fe, y, fi, ds, sc, rc
so	1600	5YR7/8	5YR5/6	me, ds, sc, rc
r	-	-	-	
Pedon 3, Avalon – see Table 4.13, Transect 2				
Pedon 10, Griffin – see Table 4.14, Transect 4				
Pedon 16, Fernwood – see Table 4.14, Transect 5				
Pedon 17, Kroonstad – see Table 4.15, Transect 6				
Pedon 21, Kroonstad – see Table 4.15, Transect 7				

[a] *ot=orthic A horizon; gs=E horizon; gc=G horizon; yb=yellow brown apedal B horizon; sp=soft plinthic B horizon; hp=hard plinthic B horizon; so=saprolite; r=rock (granite); ob=overburden.*

[b] *Redoximorphic features: mottle abundance fe=few; co=common; my=many; mottle size fi=fine; me=medium; lg=large; mottle colour b=black; o=orange; r=red; y=yellow; g=grey; mottle contrast ft=faint; ds=distinct; pr=prominent mottle pattern sc=stagnic; gc=gleyic; mottle distribution ra=random; rc=root channels; ps=ped skins; mottle transition ab=abrupt; cl=clear; gr=gradual; df=diffuse.*

Note: *Water table within 50 cm of soil surface and/or indicators of conditions of the presence of saturation for long enough to develop anaerobic conditions within 50 cm of soil surface (Vepraskas and Sprecher, 1997; DWAF, 2005; USDA-NRCS, 2010).*

Soil plots described in Table 4.12 are plotted against a longitudinal slope in Figure 4.11. Depth to rock at soil investigations in the vicinity ranged between 1.6 and 2 m deep.

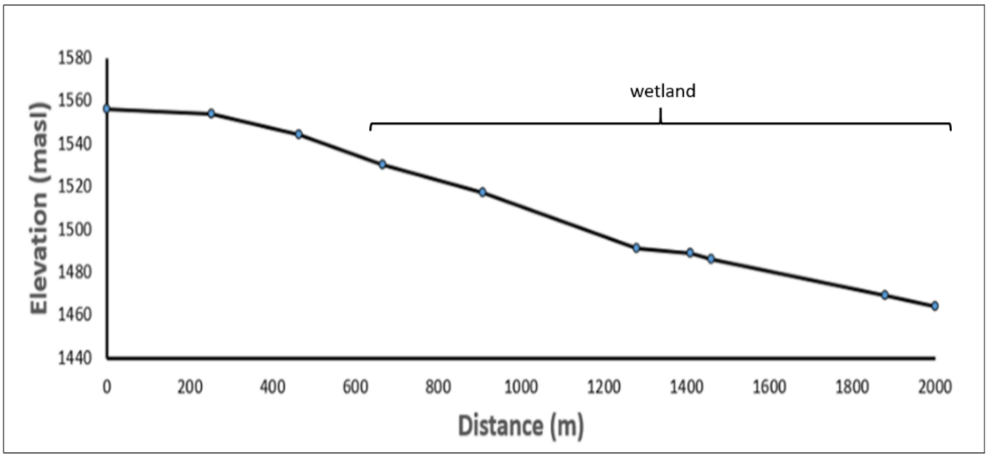


Figure 4.11: *Longitudinal section of Transect 1.*

Table 4.13: *Transects 2 and 3 soil morphology characteristics*

Horizon [a]	Depth	Colour (Munsell)		Redox features [b]
		Dry	Wet	
Transect 2				
Pedon 3 upper slope, Avalon				
ot	100	10YR4/3	10YR3/3	-
yb1	300	10YR6/4	10YR4/4	-
yb2	1100	10YR6/6	10YR5/4	my, b/r/o/y, me, ds, sc, rc
r	-	-	-	
Pedon 4 midslope, Longlands				
ot	50	7.5YR5/6	7.5YR5/4	fe, o/y, fi, ds, cs, rc
sp	600	7.5YR6/6	7.5YR7/8	fe, b/o, fi, ds, sc, rc
so	1500	7.5YR7/6	7.5YR5/8	fi/lg, ft/ds/sc/gc/rc
r	-	-	-	
Pedon 5 lower slope, Westleigh				
ot	100	10YR5/4	10YR4/4	-
sp	900	10YR6/6	10YR5/8	my, b/o/y/g, me, ds, sc, rc
r	-	-	-	my, b/r/o/y, me, ds, sc, rc
Transect 3				
*Pedon 6 valley floor [*5 upper]*, Westleigh*				
ot	100	7.5YR6/3	7.5YR5/3	vfe, o, fi, ds, sc, rc
sp	1100	7.5YR6/8	7.5YR6/6	my, b/r/o/y, me, ds, sc, rc
so	1300	7.5YR7/4	7.5YR6/8	
r	-	-	-	
Pedon 7 valley floor [5 mid], Westleigh				
ot	200	10YR6/3	10YR5/3	-
sp	700	10YR6/4	10YR5/7	my, o/y/g ,fi, ds, sc, rc
so/yb	1500	10YR6/6	10YR5/8	
r	-	-	-	
Pedon 8 valley floor, Avalon				
ot	60	7.5YR4/4	7.5YR4/4	vfe, o, fi, pr, sc, rc
yb	750	7.5YR5/4	7.5YR4/4	fe, o/y ,fi, ds, sc, rc
sp	900	7.5YR5/4	7.5YR4/3	
hp	-	-	-	
Pedon 9 valley floor, Westleigh				
ot	150	7.5YR5/4	7.5YR4/4	fe, b/r/o, fi, pr, sc, rc
sp1	800	7.5YR6/4	7.5YR5/3	co, b/r/o/y, fi/me, ds, sc, rc
sp2	1000	7.5YR6/6	7.5YR5/6	
r	-	-	-	

[a] *ot=orthic A horizon; gs=E horizon; gc=G horizon; yb=yellow brown apedal B horizon; sp=soft plinthic B horizon; hp=hard plinthic B horizon; so=saprolite; r=rock (granite); ob=overburden.*

[b] *Redoximorphic features: mottle abundance fe=few; co=common; my=many; mottle size fi=fine; me=medium; lg=large; mottle colour b=black; o=orange; r=red; y=yellow; g=grey; mottle contrast ft=faint; ds=distinct; pr=prominent mottle pattern sc=stagnic; gc=gleyic; mottle distribution ra=random; rc=root channels; ps=ped skins; mottle transition ab=abrupt; cl=clear; gr=gradual; df=diffuse.*

Note: *Water table within 50 cm of soil surface and/or indicators of conditions of the presence of saturation for long enough to develop anaerobic conditions within 50 cm of soil surface (Vepraskas and Sprecher, 1997; DWAF, 2005; USDA-NRCS, 2010).*

The second transect was conducted across the head of the wetland and characterises the transition from non-wetland, where the flowpaths and saturated soils are still relatively deep as they transition down slope to a point where the water and flowpaths surface (Table 4.13). This transect has been divided into Transect 3 which crosses the main head of the wetland, and Transect 2 which crosses the head of a side arm of the wetland. In both cross-sectional transects, soil colours are predominantly yellow or bleached (Figure 4.13). Transect 3 (the upper section of the main wetland) was not further characterised as it is largely within a private property that was not accessed, while the side arm was the focus of the characterisation.

Figure 4.12: *A view down slope (left) and habitat view from the crest (right) of the hillslope within Transect 1.*

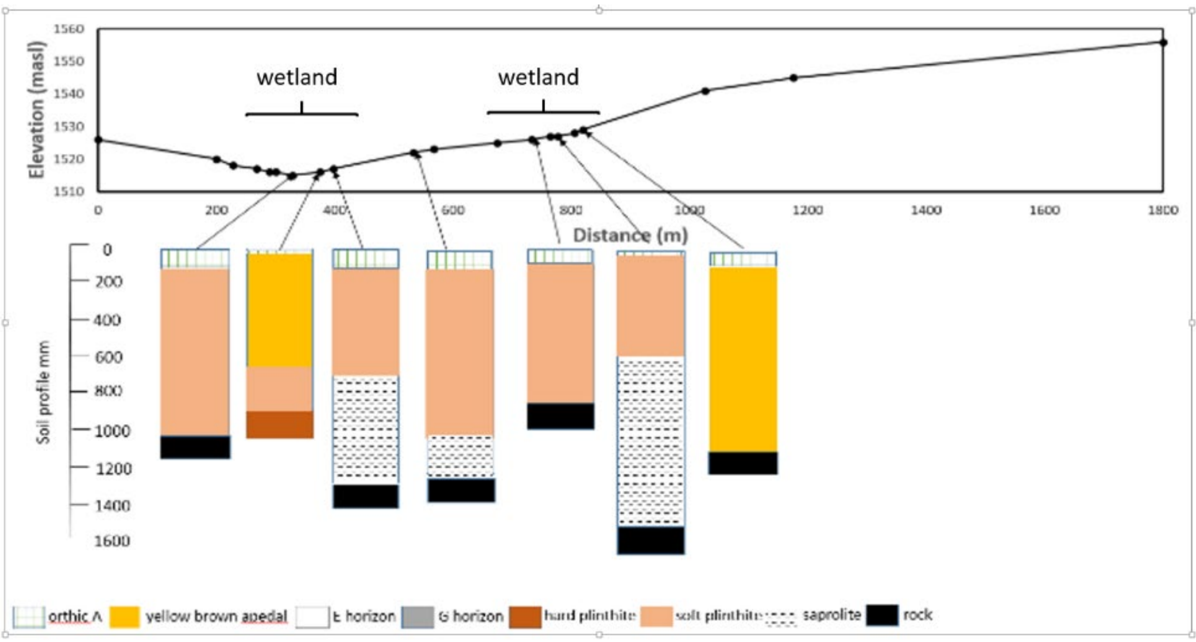


Figure 4.13: *Cross-section and soil profiles representative of Transects 2 and 3.*

Transect 4 plots are characterised as a combination of non-wetland and seasonal wetland, with anticipated short duration of saturation (Table 4.14, Figure 4.14). Wetland soils are shallow, typically only 500-700 mm above prevalent hard plinthite (although the underlying material was not observed, granite protruded and was visible within the immediate vicinity, as shown in Figure 4.15). Being so shallow, the soils are subject to high evapotranspiration. As with Transect 1, soil colours are commonly yellow or bleached.

Table 4.14: *Transect 4 soil morphology characteristics*

Horizon [a]	Depth	Colour (Munsell)		*(redox features not available)*
		Dry	Wet	
Pedon 10 upper slope, Griffin				
ot	100	7.5YR4/4	7.5YR3/3	
yb	400	5YR5/3	5YR3/3	
hp	-	-	-	
Pedon 11 footslope, Wasbank				
ot	100	7.5YR4/3	7.5YR3/3	
gs	700	5YR6/3	5YR4/3	
hp	-	-	-	
Pedon 12 footslope, Wasbank				
ot	150	10YR4/4	10YR3/4	
gs	300	10YR4/3	10YR3/4	
hp	-	-	-	
Pedon 13 valley floor, Clovelly				
ot	100			
yb	600	7,5YR5/3	7,5YR4/4	
so	1300	5YR5/8	5YR4/6	
hp	-	-	-	
Pedon 14 footslope, Hutton				
ot	100	5YR4/3	5YR2/3	
re/lc	750	5YR5/8	5YR4/4	
so	1300	5YR5/6	5YR4/6	
r	-	-	-	

[a] *ot=orthic A horizon; gs=E horizon; gc=G horizon; yb=yellow brown apedal B horizon; sp=soft plinthic B horizon; hp=hard plinthic B horizon; so=saprolite; r=rock (granite); ob=overburden.*
Note: *Water table within 50 cm of soil surface and/or indicators of conditions of the presence of saturation for long enough to develop anaerobic conditions within 50 cm of soil surface (Vepraskas and Sprecher, 1997; DWAF, 2005; USDA-NRCS, 2010).*

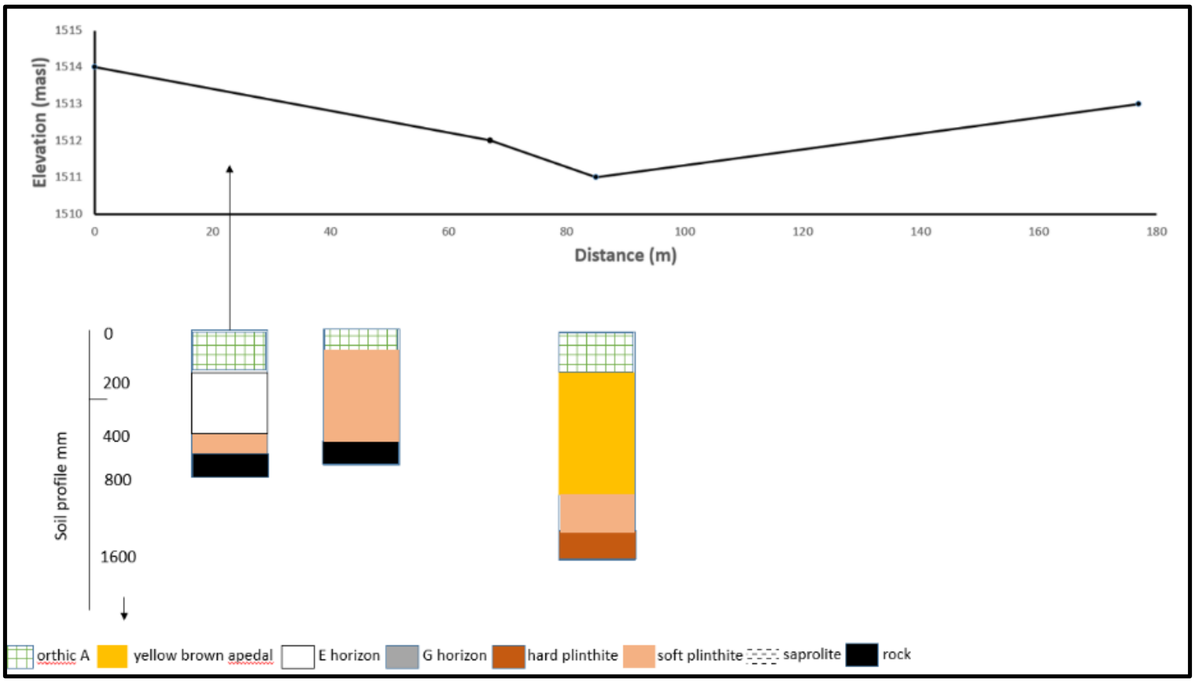


Figure 4.14: *Cross-section and soil profiles representative of Transect 4.*

Figure 4.15: *Evidence of hard plinthite at the surface within a wetland plot in Transect 4.*

In Plot 15 of Transect 5, the E horizon occurs 120 mm below the soil surface, with rock at 900 mm depth. Hard plinthite was observed at the surface immediately adjacent to the wetland. In Plot 16, the G horizon is 200 mm below the soil surface, with rock at 1 600 mm depth, located in the centre of the wetland, and away from the centre, saprolite was observed at 800 mm depth underlying the G horizon (Table 4.15, Figure 4.15).

Table 4.15: *Transect 5 soil morphology characteristics*

Horizon [a]	Depth	Colour (Munsell)		Redox features [b]
		Dry	Wet	
Pedon 15 footslope, Katspruit				
ot	200	10YR5/2	10YR3/2	fe, y, fi, ft, sc, rc
gc	875	10YR6/2	10YR6/6	fe, y/g, me, pr, gc, rc/ps
r	-	-	-	
Pedon 16 valley floor, Longlands				
ot	120	7.5YR8/1	7.5YR7/4	fe, o, fi, ft, sc, rc
gs	800	7,5YR7/3	7,5YR6/4	fe, y/g, fi, pr, gc, rc
so/sp	1600	7,5YR7/6	7,5YR5/8	
r	-	-	-	

[a] *ot=orthic A horizon; gs=E horizon; gc=G horizon; yb=yellow brown apedal B horizon; sp=soft plinthic B horizon; hp=hard plinthic B horizon; so=saprolite; r=rock (granite); ob=overburden.*

[b] *Redoximorphic features: mottle abundance fe=few; co=common; my=many; mottle size fi=fine; me=medium; lg=large; mottle colour b=black; o=orange; r=red; y=yellow; g=grey; mottle contrast ft=faint; ds=distinct; pr=prominent mottle pattern sc=stagnic; gc=gleyic; mottle distribution ra=random; rc=root channels; ps=ped skins; mottle transition ab=abrupt; cl=clear; gr=gradual; df=diffuse.*

***Note:** Water table within 50 cm of soil surface and/or indicators of conditions of the presence of saturation for long enough to develop anaerobic conditions within 50 cm of soil surface (Vepraskas and Sprecher, 1997; DWAF, 2005; USDA-NRCS, 2010).*

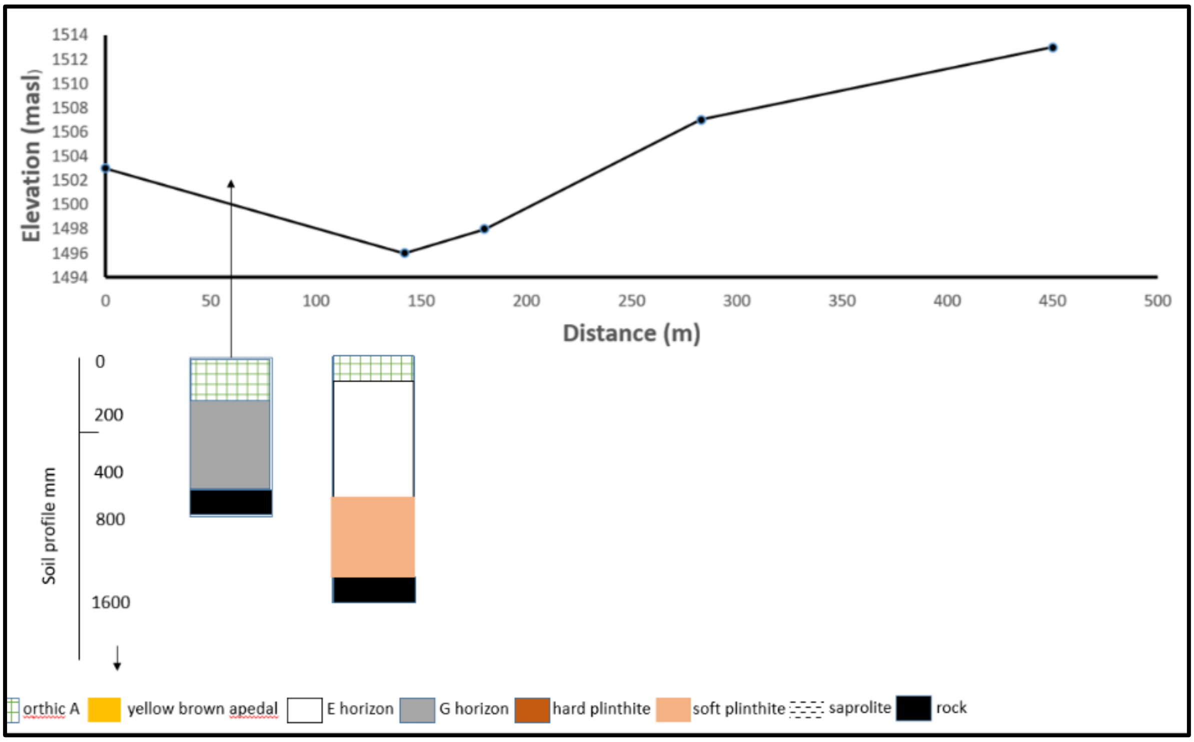


Figure 4.16: *Cross-section and soil profiles representative of Transect 5.*

In Transect 6, the centre of the wetland has gleyed soil present from 100 mm below the surface, soft plinthite/saprolite at 1 300 mm and rock at 2 300 mm. A second plot closer to the wetland edge is gleyed from 200 mm below the surface, and rock was met at 1 500 mm (Table 4.16, Figures 4.17 and 4.18).

Table 4.16: *Transect 6 soil morphology characteristics*

Horizon [a]	Depth	Colour (Munsell)		*(redox features not available)*
		Dry	Wet	
Pedon 17 valley floor, Kroonstad				
ot	200	10YR5/4	10YR4/3	
gs	800	10YR5/4	10YR7/2	
gc1	1500	10YR6/1	10YR6/2	
r	-	-	-	
Pedon 18 valley floor, Kroonstad				
ot	100	10YR4/2	10YR2/3	
gs	600	10YR6/2	10YR6/3	
gc1	1300	10YR6/3	10YR5/2	
so/sp	2100	10YR7/6	10YR6/8	
so/yb	2300	10YR7/4	10YR5/6	
r	-	-	-	

[a] ot=orthic A horizon; gs=E horizon; gc=G horizon; yb=yellow brown apedal B horizon; sp=soft plinthic B horizon; hp=hard plinthic B horizon; so=saprolite; r=rock (granite); ob=overburden.
***Note:** Water table within 50 cm of soil surface and/or indicators of conditions of the presence of saturation for long enough to develop anaerobic conditions within 50 cm of soil surface (Vepraskas and Sprecher, 1997; DWAF, 2005; USDA-NRCS, 2010).*

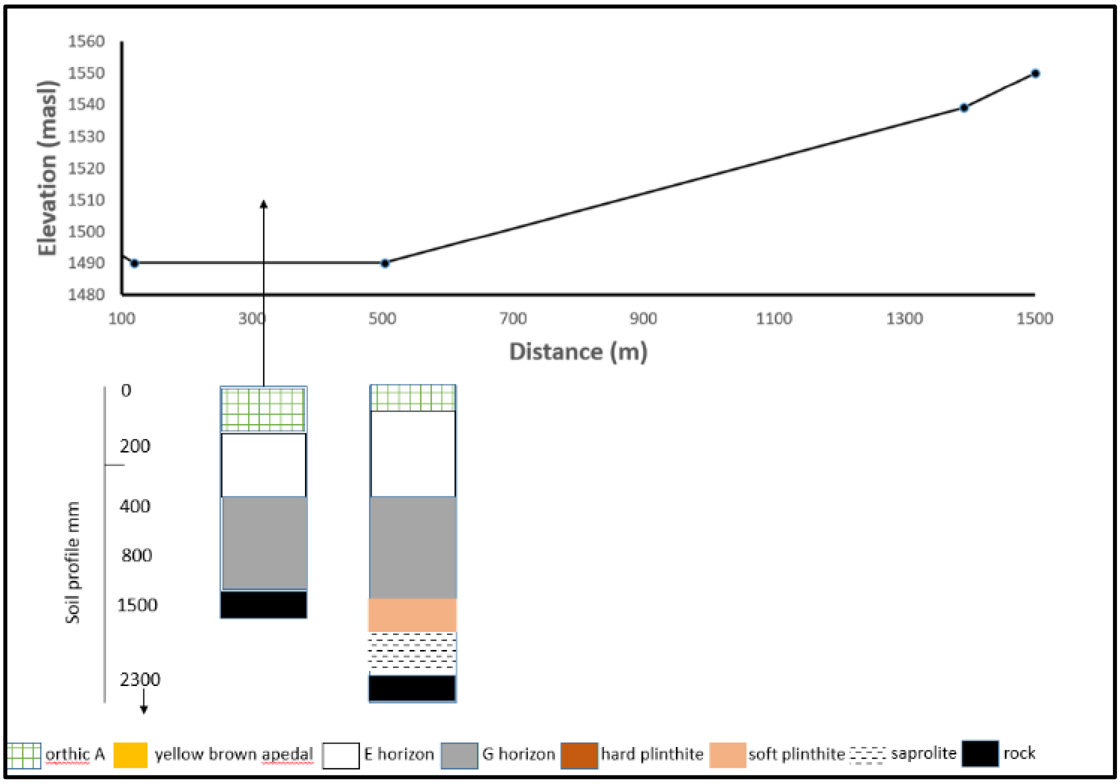


Figure 4.17: *Cross-section and soil profiles representative of Transect 6.*

Figure 4.18: *Redoximorphic features (left) and grey soils (right) in Transect 6.*

Within the scope of the hillslope hydropedological response classes described earlier in this report, the responsive hydrological soil class reflects the presence of wetland. However, wetlands are also present where soil forms with an interflow hydropedological response are wet to the surface for long enough, meeting the National Water Act (1998) definition. For legislation purposes, wetland is distinguished from non-wetland and the boundary of the ecosystem established primarily by examining the morphology of the top 50 cm of soil for indicators of reducing conditions, supported with wetland vegetation and actual hydrology observations.

4.2.2.2 Hillslopes

Elevation for the wetland catchment has a range of approximately 110 m, from 1 440 m.a.s.l. at the catchment outlet to 1 550 m.a.s.l. at the highest crest. Terrain analysis was undertaken in QGIS and SAGA to establish landscape morphometrics, in order to systematically distinguish between crest, slope and valley floor for the wetland catchment. The slope range defining the valley floors and crests ranged between 0 and 3%, while slopes ranged between 3 and 20%. The crest position is not well developed, achieving 200 m width at most, and supporting a slope of 1-3%. The valley floor position is also limited within this wetland catchment, achieving a 1% slope in places, but mostly steeper than this. The majority of the area is occupied by slopes. Overall, catchment gradients ranged from 0-20%, with an average of 6%. An initial morphometric analysis divided the wetland catchment into 10 sub-catchments or hillslopes. However, the amplitude in morphological averages for this wetland catchment is small. For this reason, the sub-catchments were simplified into two broadly similar groups, with length of slope being the strongest determinant. Hillslope 1 (Figure 4.19) has an average slope length of 530 m, 7% slope, and covers 31% of the catchment. Hillslope 2 (Figure 4.19) has an average slope length of 1 km, a 6% slope, and covers 69% of the catchment. They can both be divided into approximately 13% recharge area (covering approximately 22 ha of hillslope 1 and 53 ha of hillslope 2) and 53% interflow (covering approximately 80 ha of hillslope 1 and 140 ha of hillslope 2) hydrological soil classes or hydropedological response units (Table 4.17). This is typical of much of the study area, where interflow regions dominate the landscape.

A review of catchment aspect (Figure 4.19 (left)) helped to accentuate the differences in planform and profile curvature during the process of grouping the catchment into topographically and morphologically similar hillslopes (Figure 4.19 (right)).

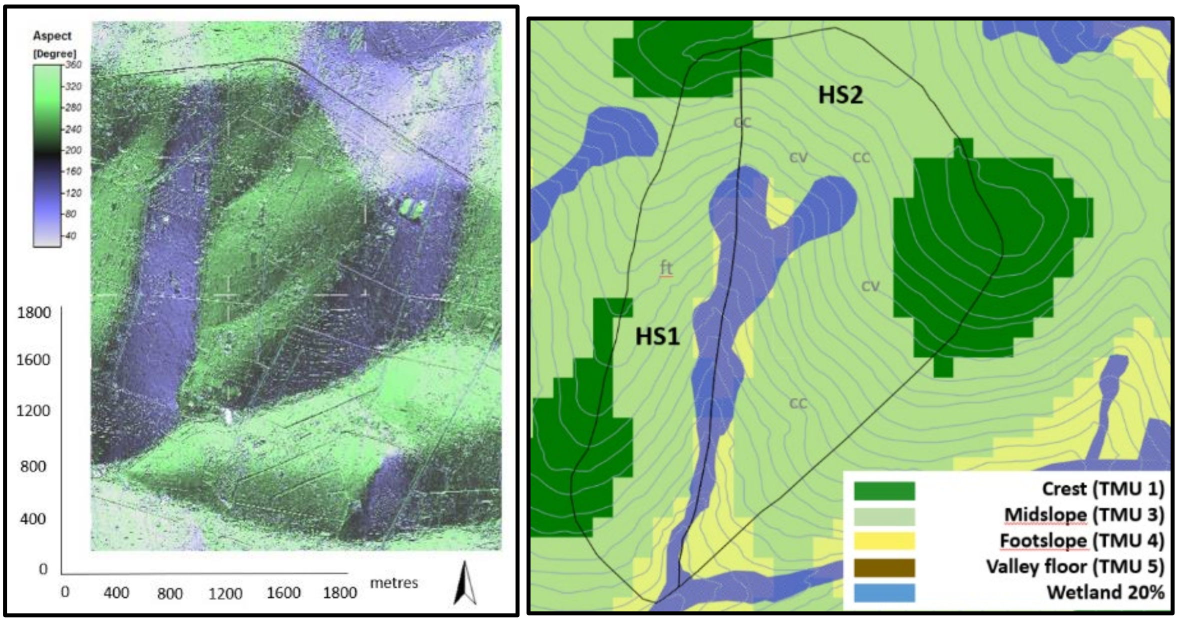


Figure 4.19: *Overview of catchment aspect (left) which also accentuates landscape planform and profile curvature morphometery, and the two broadly similar hillslopes, HS1 and HS2, into which the catchment was grouped (right).*

The crests of both hillslopes support a small area of Hutton soils, which function as deep recharge soils. The infiltration rate of these soils exceeds rainfall intensity, and any overland flow, under natural conditions, is expected to infiltrate within metres of where it reaches the ground. Water not taken up by evapotranspiration (ET excess water) infiltrates the recharge soils and percolates down to the saprolite horizon, slowly infiltrating the saprolite to reach the underlying weathered rock, which is typically, in this catchment, within 2 m of the soil surface. With a successive decrease in vertical infiltration rates as the distance from soil surface to impermeable layer becomes smaller down slope, interflow is initiated, as water ponds at the various and successively slower transitions of vertical drainage. Both hillslopes are dominated by interflow soils, covering more than 50% of their area.

Water that ultimately reaches the wetland via the hillslope soil response to rainfall, predominantly within the interflow zone, can be characterised into two broad groups. ***Event-driven interflow*** implies that the process is only active during and immediately after a rain event or a series of rain events. It is common in topsoils. Event-driven slow interflow is associated with an E or bleached A horizon and related to high-lying positions. ***Post-event-driven interflow*** occurs in topsoils only in midslope and footslope. It is more typical down slope in second and third horizons. Where flow from subsoil horizons builds up to saturate topsoils, two flowpaths may be established, a shallow flowpath that can be event to permanently saturated, and a deep flow path that can be seasonally to permanently saturated.

The soil morphology indicates that these horizons are better developed in the transition to the temporary wetland. Table 4.17 characterises this for the study site.

Table 4.17: *Catenal hydropedological (soil-water relationship) characteristics*

Hillslope 1					
Auger plot	**Soil form**	**TMU**	**Soil horizons**	**Hydropedological class**	**Interpreted rainfall response**
1	Hutton	1	A / red apedal B / saprolite / fractured rock	Deep recharge	Vertical downward flow. Feeds interflow.
2	Avalon	3	A / yellow-brown apedal B / soft plinthic B / saprolite / fractured rock	Soil/bedrock interflow	Event and post-event driven; periodic in season.
3	Longlands	3	A / E / soft plinthic B / saprolite / fractured rock	A/B interflow	Post-event to seasonal. Shallow and deep interflow.
4	Kroonstad	4	A / E / G / hard or solid rock	A/B interflow and soil/rock interflow	Seasonal, post-seasonal to permanent in the subsoil. Event to post-event flow in topsoil.
5	Fernwood	4	A / E / solid rock	Soil/rock interflow	Post-event driven. Shallow and deep interflow.
6	Kroonstad	4	A / E / saprolite G	A/B interflow	Seasonal, post-seasonal to permanent in the subsoil. Event to post-event flow in topsoil.
7	Kroonstad	4	A / E / G / saprolite / hard or solid rock	A/B interflow	Seasonal, post-seasonal to permanent in the subsoil. Event to post-event flow in topsoil.
8	Katspruit	5	A / G / solid rock	Responsive	Seasonal, post-seasonal to permanent in the subsoil. Event to post-event flow in topsoil.
Hillslope 2					
Auger plot	**Soil form**	**TMU**	**Soil horizons**	**Hydropedological class**	**Interpreted response and contribution to wetland**
1	Hutton	1	A / red apedal B / saprolite / fractured rock	Deep recharge	Vertical downward flow. Feeds interflow.
2	Pinedene	3	A / yellow-brown apedal B / E / saprolite / fractured rock	Soil/bedrock interflow	Event and post-event driven; permanent in season.
3	Avalon	3	A / yellow-brown apedal B apedal B / soft plinthic B / plinthic saprolite / fractured rock	Soil/bedrock interflow	Event and post-event driven; periodic in season.
4	Glencoe	3	A / yellow-brown apedal B / hard plinthite / plinthic saprolite / hard rock	Soil/bedrock interflow	Event and post-event driven; periodic in season and extreme in wetter rainfall season.

Generally, to distinguish which interflow (shallow, multiple, deep) hydropedological soil classes might impact on the wetland hydrology that is vital for its sustainability, can be summarised as follows: Shallow interflow (from the soil surface to 50 cm) is (rainfall) event-driven, if present on the crest and upper midslope. However, at the lower midslope position, this class tends to respond post-event, where soils develop morphology that may qualify as wetland. Deep interflow within the hillslope is the source that sustains the dominant and long-term inflow of water to saturate the wetland, and is of extreme importance to sustain wetland hydroperiod.

Based on Table 4.17, Hillslope 1 can be interpreted as follows:
Fractures in the underlying hard rock occur repeatedly down slope in the granites, serving as flowpaths for water and dominating pedogenesis. In the upper and middle midslope, relatively shallow depth to bedrock impedes recharge and supports lateral flow, becoming return flow to the saprolite, subsoil and even to the soil surface, visible as redox morphology in bleached topsoils and even local patches of Fe and Mn accumulation as hard plinthite. Bleached topsoils on saprolite or solid rock on the crest are interpreted as event-driven saturation on an impermeable layer of solid rock underneath the saprolite or soil. This shallow interflow in the topsoil horizon at the A/R soil interface supports wetness lower down the slope. Hard plinthite accumulation is an indication that significant amounts of water drain laterally in the soil and return to the soil surface to oxidise and precipitate the Fe/Mn. This process is more active in high rainfall years and post-seasonal. The rock fracture controls are visible as repeated steps down slope. Occurrence of hard plinthite increases and becomes more pronounced down slope as the soil/rock flow path lengthens. The permeability and resistance to vertical flow through the hard plinthite varies. Where it is impermeable, it serves as an aquiclude, separating interflow into shallow and deep flowpaths. In the lower midslope, the deep yellow-brown apedal Avalon subsoil implies that the duration of flow increases.

Based on Table 4.17, Hillslope 2 can be interpreted as follows:
In the upper slope an E horizon is present directly above the saprolite, indicating dominant lateral interflow and leaching under reduced conditions. As bio-activity is low in the subsoil, bleaching requires (and thus is evidence of) post-event-driven saturation. This means that, over the long term, the interflow component is expected to be significant within this slope. Overlying the E horizon is a yellow-brown apedal B horizon, indicating short periods of saturation of the whole profile after large rain events or the mid rainy season of high rainfall years. Lower down the slope, the soft plinthite replaces the E horizon and is an indication of increased saturation time in the underlying saprolite, indicating addition of water from rock to soil return flow. The deeper interflow flowpaths are less prone to root extraction and associated

transpiration, and are longer and slower. They contribute to the tail end of flow and support longer, wetter conditions evident in the wetland at the toe of this hillslope, with wetter conditions also extending further into the wetland, i.e. approximately two-thirds of the wetland width, in comparison to the wetland at the toe of hillslope 1.

Interflow wetlands occur from midslope and lower positions, where fractured rock/soil return flow wets the soil for longer periods. An example is the Longlands soil form in the case study, where the yellow-brown apedal B subsoil is replaced by a bleached to a grey-coloured E horizon overlying soft plinthic B, indicating that waterlogging is post-event to seasonally driven. These wetlands are typically seasonally saturated. Responsive wetland soils occur further down slope in the form of Kroonstad and Katspruit soils with a shallow interflow in the A and E horizons, and fractured rock/soil return flow in the G horizon, where it is vertically upwards. The response of the subsoil G horizon is indicative of a large source and stable supply of water. These requirements are met by a combination of a long slope, large hill storage and deep interflow, creating slow flowpaths and seasonal to post-seasonal event-driven saturation. Depending on the length of slope and storage capacity within the hillslope, these wetlands are a combination of permanent and seasonally saturated, with wide seasonal fluctuations as water is also delivered via shallow flowpaths with event- and post-event-driven response.

Based on the understanding developed in the wider report, it is expected that much of the water that infiltrates into the deep flowpaths of the saprolite and fractured rocks within the hillslope over months and years, ultimately seeps out in the lower slope and the wetlands, maintaining long-term saturation in these ecosystems. The deep flowpaths are responsible, in particular, for the permanently saturated wetlands. Multiple shallow flowpaths are also present within the hillslope as E and plinthic horizons. These respond quickly to rain events and are responsible for a variation in seasonally fluctuating water tables of the wetlands.

The wetlands of the catchment reflect the amount of water available from the wetland catchment over long time frames. The below-surface connections are critical components of the delivery of this water to the wetlands. The principal reasons for change in the present ecological state (condition) of the wetlands, with respect to the hydrological component, can be linked to changes in storage and in the surface and subsurface delivery of water to the wetland. Thus, the protection of the source areas which capture much of the water that is ultimately delivered to the wetland, is critical. It is also critical to minimise alteration of the flowpaths which deliver the water between the source and the wetland.

4.2.3 Land Types feeding wetlands

Two approaches were investigated to review Land Type prediction of wetland extent at the local catchment scale.

The first approach selected catchments across five regions of South Africa which contained extensive wetland mapping, and reviewed them against the percentage wetland per catchment. Overall, as already reported in Section 4.1.1, it was found that the Land Type information from this approach under-predicted wetland occurrence. For the Weatherley catchment, which is approximately 258 ha, expert mapping determined wetland coverage at approximately 32% of the study catchment, compared to a predicted occurrence of between 2.5 and 25.5% for responsive (wetland) soils. For the Niewoudtville catchment, which accommodates two adjoining catchments of approximately 1 752 and 2 962 ha, a desktop mapping study mapped wetland coverage at approximately 20% and 11% of the study catchments, respectively. This compares to a predicted occurrence of approximately 1% for responsive (wetland) soils. For the Agulhas catchment, which is approximately 17 068 ha, desktop mapping estimated wetland coverage at approximately 19% of the study catchment, compared to a predicted occurrence of 2 to 4% for responsive (wetland) soils. For the Hogsback catchment, which is approximately 3 195 ha, a desktop study mapped wetland coverage at approximately 19% of the study catchment, compared to a predicted occurrence of 3 to 22% for responsive (wetland) soils. For the City of Johannesburg, which is approximately 20 000 ha, a desktop study by Wetland Consulting Services (2009) mapped wetland coverage at approximately 16% of the study catchment, compared to a predicted occurrence of between 0.4 and 1.1% for responsive (wetland) soils. The responsive soil test results are based on the prediction for permanently wet wetlands. For the temporary wetland class, this Land Type, along with other granite geologies and sandstone and shale geologies, predicted an intermediate occurrence ranging from 8.8 to 19.0%.

A second exercise was undertaken to investigate the extent to which Land Types contribute to prediction of wetland occurrence. Thirty-five (35) Land Types were identified to coincide with four selected study area sites. Total predicted wetland area was calculated for the full area of each Land Type polygon based on a sum of the percentage cover of soils that fit within the “responsive soil class” (Table 3.8). The predicted wetland extend based on Land Cover disaggregation and selection of the responsive percentage soil cover is shown in blue in Figure 4.20.

Table 4.18 identifies which of the 36 Land Types occur on which study area sites across the country, and associated Broad Soil Patterns (see also Appendix 6).

Table 4.18: *Selected Land Types and Broad Soil Patterns per case study catchment area*

Study area	Province	Land Type and Broad Soil Patterns								
		Red Yellow	Plinthic	Plinthic	Pedocutanic/ Prismacutanic	Vertic / Melanic / Red	Shallow	Ferrihumic horizon	Regic sand	Rocky/ Floodplain
Weatherley	EC	Ac492								
Johannesburg	Gauteng		Bb1 Bb2							
Hogsback	EC				Db175		Fa426			Ib337 Ib339
Agulhas Plain	WC				Db109		Fa749	Gb17	Hb37 Ha17	
Nieuwoudtville	NC			Ca135			Fb961		Hb105	Ib479

This was then reviewed against desktop mapping of wetlands, where wetland extent was identified during the course of this project by interpretation of aerial imagery based on "heads-up" mapping by an experienced wetland mapper, including a relatively high level of field verification. The mapped wetland extent based on moderate to high confidence wetland mapping is shown in orange in Figure 4.20.

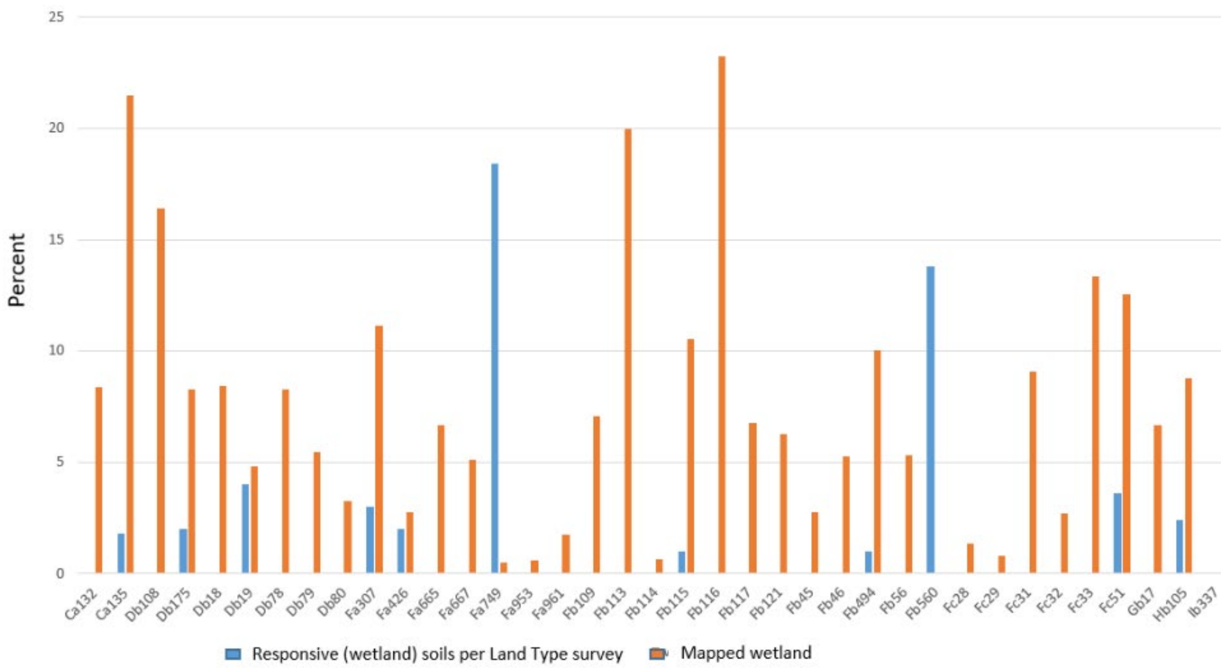


Figure 4.20: *Review of mapped wetland area against estimated extent of wetlands within Land Type data.*

In 33 of the cases, the Land Type inventory under-predicted the presence of wetlands. In two cases, Fa749 and Fb560, the Land Type inventory over-predicted the presence of wetlands (Figure 4.20). In the four units having the greatest extent of directly mapped wetland, three of these have no wetland mapped based on Land Type data and in the fourth unit the extent of wetland is about ten times less than the directly mapped extent. Thus, for the units included in this test, the Land Type information performs poorly in terms of identifying wetland-rich units, which is somewhat unexpected. However, closer study of the Land Type methodology and purpose will confirm that wetland identification was not the main purpose of the survey, especially given the scale of investigation.

5. LAND TYPE INFORMATION CONCLUDING STATEMENTS

5.1. General Summary with regard to Land Type Information

5.1.1 Consideration of scale

- Maps and evaluations in this report are presented at a national scale and depict, for brevity in the report, A4 size images. In this format, the maps serve to give an overview perspective.
- Evaluations throughout the analysis phase of the report were carried out at an individual Land Type scale that accurately depicts mapping boundaries and can be projected to large readable scales where individual Land Types can be easily studied and greater levels of detail can be examined without difficulty. Study of individual Land Types with respect to Responsive (discharge) or Interflow zones can assist in formulating detailed scale guidelines.

5.1.2 Responsive (discharge) soil zones

- Responsive (discharge) soil zones cover a relatively small percentage of South Africa.
- They are regionalised in the Cape and Drakensberg mountain systems, and in southern Mpumalanga, western Free State and North West Province.
- Each of these systems feeds water into the densely populated metropolitan areas and the Vaal and subsequently the Orange River drainage systems. (An exception, the coastal plain of Maputaland in KwaZulu-Natal, is not densely populated, although it contains dominantly discharge soils and remains an ecologically sensitive wetland zone, worthy of conservation status.)
- Responsive (discharge) soil zones are closely associated with sandy soil zones in the coastal plain of Maputaland, the sandy southern and Western Cape coastal areas, and the mountainous zones stretching from the northern interior of the Eastern Cape, the Drakensberg escarpment and the mountainous zone of southern and eastern Mpumalanga. There is a smaller zone associated with the dolomite geology of Gauteng and North West Province.

5.1.3 Interflow soil zones

- Interflow soil zones cover large areas and are located in eight provinces: Limpopo, Mpumalanga, Gauteng, Free State, North West, KwaZulu-Natal, Eastern Cape and Western Cape.

- They are strongly associated with Land Type Soil Groups (Land Type Survey Staff, 2004) of deep sands (Ha, Hb) sands to sandy loam plinthic soils (Ba, Bb, Bc, Bd), apedal soils (Ab, Ac, Ad, Ae), shallow soil groups (Fa, Fb) and with rock land (Ib).
- Interflow soil zones are strongly associated with Quaternary sand geology, and sandstone and associated rock type geologies of the Soutpansberg, Waterberg, Ecca and Beaufort Groups (Geological Survey, 1984).

5.2. General Summary with regard to Land Type Information as evaluated in the Original Project Conceptualisation

The initial hypothesis at the commencement of the project was that Land Type information could contribute to the schematic distribution of generalised zones of soil hydromorphy, and hence to wetland soil classes. The Land Type database was interrogated and soil form (and in some cases soil series) assigned to hydromorphic soil classes. Each of these classes was subsequently taken to represent Responsive (discharge), Interflow and Terrestrial Land classes.

5.2.1 Responsive (discharge) class

Figure 5.1 (dark blue) illustrates the general distribution at a national scale over South Africa. The highest responsive classes are in the sandy soil zones located in Maputaland, KwaZulu-Natal, the southern and Western Cape coastal areas, and the mountainous zones stretching from the northern interior of the Eastern Cape, the Drakensberg escarpment and the mountainous zone of southern and eastern Mpumalanga. There is a smaller zone associated with the dolomite geology of Gauteng and North West Province.

Lower proportions of responsive (discharge) soils are located on the fringes of the Cape and Drakensberg systems. A further very important zone lies in southern Mpumalanga, western Free State and North West Province, feeding the Vaal and subsequently the Orange River Drainage Systems (Figure 5.1, light blue). Each of the Cape, Drakensberg and southern Mpumalanga systems feed water into the densely populated metropolitan areas. This generalised analysis confirms well established factual information in water use policy.

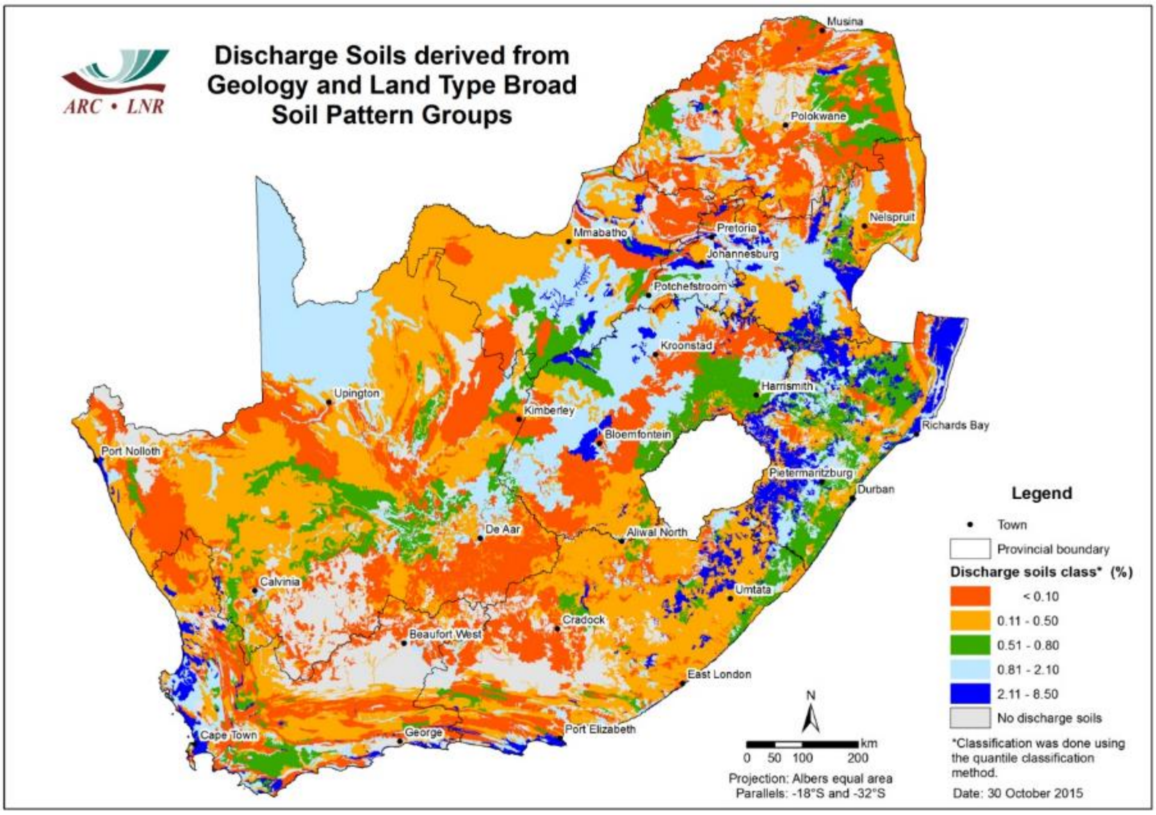


Figure 5.1: *Responsive (discharge) soils derived from geology and Land Type soil groups.*

The Responsive (discharge) zone in the western Free State and North West Province lies in the grain producing areas, while irrigation along the westward-flowing rivers of the western Free State and the Orange River is vital to sustaining national food security. Their protection via regional considerations requires attention within a framework of wetland guidelines.

5.2.2 Interflow class

Limpopo: The Interflow class covers large areas of the north-western and central interior, the eastern seaboard and southern and western coastal areas (Figure 5.2, dark and light blue). In north-eastern Limpopo, the interflow zone comprises plinthic and apedal soils (Land Type Patterns Ba, Bb, Ab, Ac symbols) (Land Type Survey Staff, 2004) that are derived from sandstones of the Soutpansberg Geology Formation (Geological Survey, 1984). This formation appears to distinctly form the natural boundary to this dominantly interflow zone. Similarly, in north-western Limpopo the interflow zone again comprises plinthic and sandy and clay apedal soils, with rock land (Land Type Patterns Ba, Bb, Bc, Bd, Ac, Ea and Ib symbols) (Land Type Survey Staff, 2004) that are again clearly distributed together with the sandstones of the Waterberg Geology Group (Kransberg Subgroup) (Geological Survey, 1984).

Eastern Mpumalanga: Interflow zones (Figure 5.2) cover coarse sand lithosolic soils (Land Type Patterns Fa, Fb, Hb symbols) (Land Type Survey Staff, 2004) that are derived from various potassic granites (ZB symbol) (Geological Survey, 1984).

Southern Mpumalanga, Gauteng and Free State: Interflow zones cover large areas of the central and eastern highveld (Figure 5.2) comprising sandy and sandy loam plinthic and apedal soils (Land Type Patterns Ba, Bb, Bc, Bd, Ac, Fa symbols) (Land Type Survey Staff, 2004). These interflow zones feed the Vaal River and its tributaries in Mpumalanga and Gauteng, supplying water to the densely populated metropolitan areas of Gauteng. In the Free State, the large interflow areas cover virtually the whole of the province with waters feeding the Vaal River and its tributaries to the west and the Orange River and its tributaries to the south.

KwaZulu-Natal (Tugela Basin, Maputaland, northern and southern coastal belt): Interflow zones cover large areas of the central Tugela Basin (Figure 5.2) comprising sandy and sandy loam plinthic and apedal soils (Land Type Patterns Bb, Bd, Ac, Fa symbols) (Land Type Survey Staff, 2004) distributed with the Ecca and Beaufort Geology Formations (Geological Survey, 1984). Interflow and discharge soils of Maputaland and the northern coastal belt comprise deep grey and occasionally red Quaternary sands (Land Type Patterns Ha, Hb symbols) (Land Type Survey Staff, 2004). The interflow zones of the southern coastal belt comprise grey Quaternary sand, and as with eastern Mpumalanga, steeper granitic geology also gives rise to high proportions of interflow soils.

Eastern Cape: In the eastern coastal areas, interflow zones (Figure 5.2) comprise generally shallow soils on incised land of the Ecca and Beaufort Group geology (Adelaide and Tarkastad Formations) (Geological Survey, 1984). In the north-west of the province, highly erodible duplex soils (Land Type Survey Staff, 2004) form the interflow class, derived from Molteno and Elliot Geology Formations (Geological Survey, 1984). This result was not expected and the erodibility of these zones gives reason for some concern as a source of water delivery. The interflow feature arises from sub-dominant proportions of shallow E horizons on lithic material that are located in the crests of the duplex soil zones.

Southern and Western Cape coastal areas: High interflow zones occur in association with deep Quaternary sands (as in KwaZulu-Natal) (Geological Survey, 1984). The quartzitic sandstones of the Cape Fold Mountains (Table Mountain Geology Group) (Geological Survey, 1984) also have high interflow water delivery (Figure 5.2).

Notable features in the distribution of interflow soils

In seeking to understand the distribution of interflow soils across South Africa, their distribution in the Waterberg and Vhembe Districts of Limpopo Province immediately stands apart in their uniqueness and boundary conditions (Figure 5.2). Should Regional Wetland Guidelines, or more aptly in this case, Regional Soil Hydromorphy Guidelines, be constructed for this province, then these districts must clearly receive special consideration. Their special consideration seems important in any formulation of guideline regulations. Their distribution is driven and bounded by soil and geology information, and they represent a significant proportion of the province.

Similarly, the dominantly interflow soils in the northern districts of the Eastern Cape Province are important within the context of the water resources of the province (Figure 5.2).

Having considered these districts, what guideline considerations should also be assigned to similar interflow districts in other provinces? Clearly, they too must receive special consideration when preparing framework guidelines for hydromorphic soils or any subsequent wetland formulations.

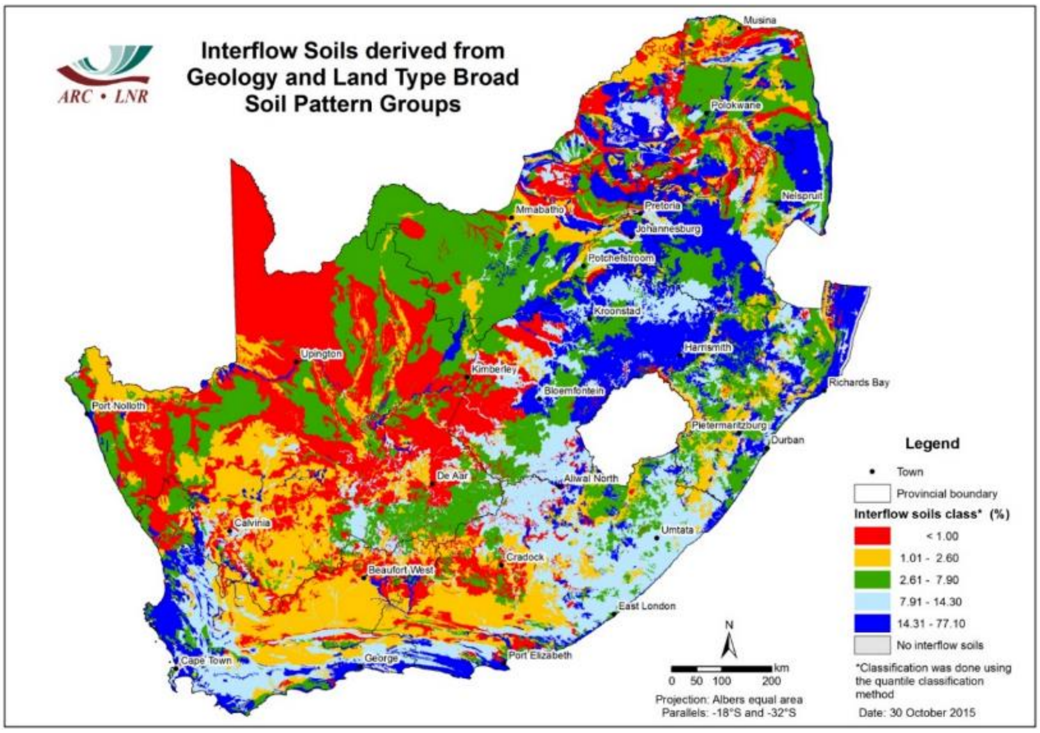


Figure 5.2: *Interflow soils derived from geology and Land Type Soil Pattern groups.*

In assessing the interflow soils, a simplified map depicting their distribution was prepared (Figure 5.3). This map follows the initial concept as applied in this report. While this approach may have limitations, not anticipated at the initiation of the project, it does confirm a regionalised location of interflow soils. The extensive location in a regional perspective and their dominance on certain Land Type Soil Patterns is of significance. An approach to consider the soil properties of these dominant Soil Patterns would now appear to be of greater importance and significance in a regional approach regarding the use of regional soil properties in any guideline framework. It is also noteworthy that other natural resource information, when used in conjunction with soil information, could pave the way for future improved guideline frameworks.

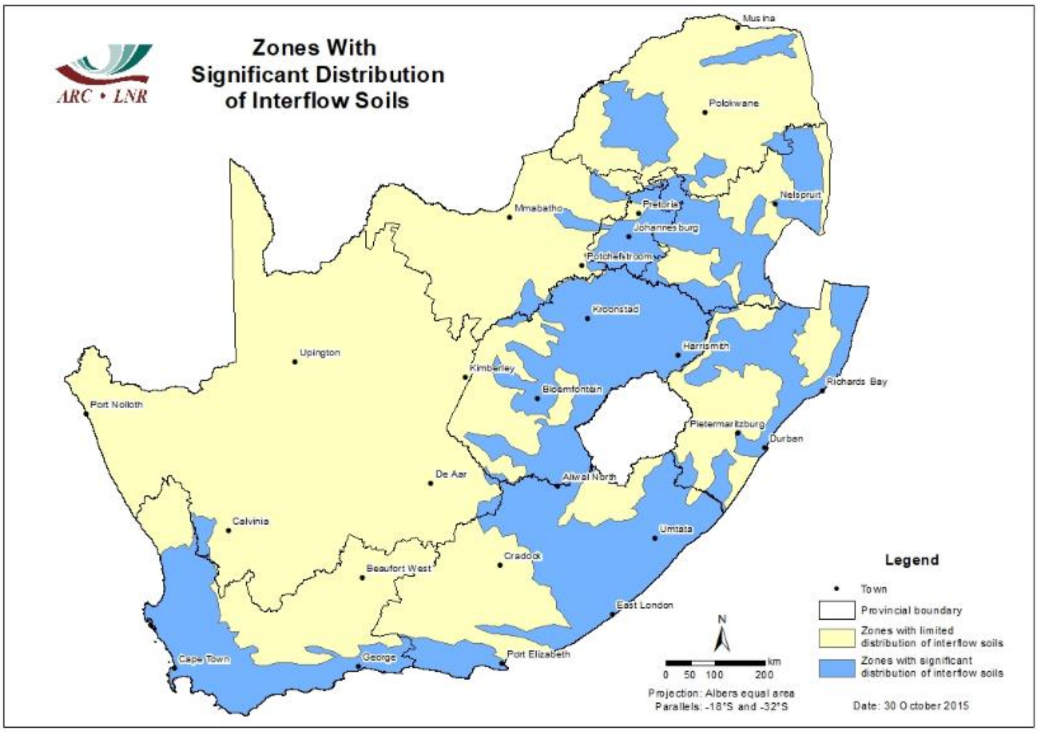


Figure 5.3: *Interflow soils derived from geology and Land Type Broad Soil Pattern groups*.

5.3. Recommendations

5.3.1 Regional approach to formulating Wetland Guidelines

Guidelines for wetland identification have in the past been formulated only from criteria evaluated by site specific examination. A Regional Framework for wetland guidelines seems not to have been formulated to facilitate administrative functioning of wetland matters. A Framework for Wetland Guidelines comprising a small number of regional units and extending over a province would seem to have merit in applying differences in detailed guidelines unique to the natural resources and cultural conditions of that provincial region. It would appear that only limited consideration has been given to structuring a framework of guidelines based on well researched, published natural resources information. Such information must have a sound scientific basis, have easily recognised criteria to natural boundaries, and enjoy widespread public acceptance. It was the departure point of this project that soil property information, and more specifically soil spatial information, could form a basis for such guidelines. Detailed soil information (soil profile morphology and analytical data) can play important roles in site-specific wetland identification. Such soil information should be used together with and to complement other site-specific vegetation, terrain and climate information. However, collective soil information, and equally important, collective vegetation and climate information, should provide insightful perspectives into the general natural resource features necessary in identifying and administering wetland function.

The Land Type Information System (Land Type Survey Staff, 2004) could conceivably provide a basis to collectively understand and subsequently identify those soil properties necessary to evaluate wetlands at detailed scales of investigation. These properties will no doubt differ from region to region, and soil zones strongly dominated by soils such as swelling black clays, or plinthic soil zones with both freely-drained and lateral interflow soils, or zones dominated by deep, freely-drained apedal soils might all require separate treatment within future guidelines. Their documentation in soil classification criteria and their distribution in mapped soil pattern boundaries could contribute to a scientific basis in changing aspects of wetland identification and administration.

To this end, soil science is certainly not a static scientific subject and new initiatives and greater detail of investigation must contribute to the structuring and interpretations given to the importance of soil information. An example is the recent publication of a revised soil classification system, *Soil Classification: A Natural and Anthropogenic System for South Africa* (Soil Classification Working Group, 2018), where improved identification of soils with soil wetness properties places greater emphasis on soil water in the landscape.

The vegetation map for South Africa (Mucina and Rutherford, 2006) might also have potential significance in wetland identification. Some vegetation boundaries show similarities to those of Land Types. Indeed, the criteria that drive soil formation could well reflect in plant response. The use of these two natural resource information systems, providing a detailed yet regional scale overview, could, when used in combination, provide a useful information system in support of natural resource conservation. The vegetation map has already been an integral component of the National Wetland Map since 2013, when it was incorporated as part of the National Freshwater Ecosystem Priority Areas (NFEPA) project, as a surrogate for wetland regionalisation. However, soil information could provide further underlying support for wetland characterisation.

The review of the potential application of the Land Type Survey to predict wetland occurrence and to improve wetland boundary delineation practice in South Africa, resulted in the following set of recommendations:

- Land Type data offer several advantages of which the catenal distribution of the soils and area covered by hydrological soil types are the most important. However, at the time of undertaking the Land Type Survey, little or no attention was paid to classification of wetland soils and no attention was given to terrestrial soils as a source of the wetland water. Survey observations were limited to 1.2 m depth, often excluding the material serving as flowpaths for wetlands. These are gaps in the Land Type data that limits its applicability for the aims of this project.
- Wetland soil diagnostic criteria, when applied in a field delineation, are not the same as those for currently described soil forms or families, and wetlands should be identified based strictly on defined morphology, not on soil form. The South African soil classification system classifies soils according to morphology and excludes depth other than the 1.2 m limitation and mottled morphology according to distribution pattern and quantity. It does not, therefore, adequately distinguish wetland soils, giving rise, in one commonly occurring example, to a situation where a soil form polygon may be found to be partly wetland and partly non-wetland, when wetland delineation according to best practice methodology is undertaken. This is a limitation for the application of Land Type information (based on soil forms) to predict the presence of wetlands, and it is likely that a large proportion of wetlands will be unable to be detected. Two recommendations arise from this:
    - The South African soil classification system should give attention to characterisation of wetland soils, and specifically distinguish wetland soils from other soils. This must be supported by at least a year of hydrological measurements.
    - Soil forms as a diagnostic criterion should be removed from wetland boundary delineation methodology in South Africa, as previously recommended by Kotze *et al*. (1996) and WRC report K8/718 (Job, 2008). However, this does not mean that soil form should not be used as an extremely useful informant in providing supporting information about the wetland, as shown by this WRC project.

- Wetland ecosystems do not solely occur in valley-bottom positions in the landscape. In South Africa, and internationally, they also commonly occur on various higher slope positions. This is well described in wetland scientific literature and incorporated into best practice wetland assessment manuals (Mitsch and Gosselink, 2000; Brinson, 1993; MacFarlane *et al.*, 2009; Ollis *et al.*, 2013). In all of the study sites for this project, seep wetland types were present on slope positions and were not adequately catered for by the Land Type Survey, where wetlands are traditionally assigned to valley-bottom positions.
- Following on from this, some soil forms are neither exclusively wetland soils nor non-wetland soils. This results in the situation that some of the soil forms assigned to the interflow hydropedological group, typically seen as terrestrial soils by soil scientists, are wetland soils. An expanded understanding of the process hydrology in the hillslopes of the wetland catchment, and the hydroperiod of both wetland soils and deeper flowpaths, will contribute to distinguishing between wetland and terrestrial soils, and will aid in understanding their role in ecosystems and landscapes. Further investigation and classification of some of the interflow soils (which are also currently excluded in naming of soil forms in the South African soil classification system) is warranted, to harmonise soil surveys with wetland characterisation and delineation.
- Importantly, the Land Type Survey was limited to 1.2 m maximum depth for classification and thus missed recording some of the deep interflow soils.
- A wetland functional unit is very often a combination of hydrological regimes: in many cases temporary, seasonal and permanent zones may all be present within a wetland. Scale limitations made it impossible to predict such a level of detail from the Land Type information in the study areas for this project.
- It is considered possible to broadly predict which hillslopes within the wetland catchment are likely to provide dominant hydrological support to the wetland. However, this application of Land Type information is only useful where the scale of hydrological controls (hillslopes, geological structure and lithology, etc.) is in harmony with the scale of Land Type information, and where the hydropedology aspects were recorded successfully in the soil forms.
- Recommended steps for using the Land Type information for broad predictions of hillslope-wetland interactions include: a) identifying the broad climate and geology region within which the wetland occurs using the Land Type information; b) mapping the wetland boundary and wetland catchment boundary; c) dividing the wetland catchment into hillslopes based on as detailed terrain mapping or contour information as possible; d) dividing each hillslope into terrain morphological units based on as

detailed terrain mapping or contour information as possible; e) disaggregating the Land Type data (using the soils listed for each terrain morphological unit and assigning to the terrain morphological units within each hillslope); f) developing a conceptual hydrological response model for each hillslope with expert interpretation of different soil/hillslope characteristics; and g) estimating the proportional contribution of each hillslope to the wetland functional unit as a whole (see also Volume 3 guidelines).

- A hydropedological assessment can contribute to identification of key water source areas driving wetland function and hydrological characteristics and assessment of alteration from natural conditions of water inputs to the wetland in terms of volume, timing and intensity.
- Based on a hydropedological assessment of the wetland catchment:
  - the location, timing and quantity of non-riverine, overland and sub-surface water delivery to the wetland can be described in more detail, and
  - the key impacting land uses can be identified with greater confidence.
- As the water supply of hillslopes to wetlands is seasonally, post-seasonally and event-driven, the factors controlling wetland hydroperiod can be equated as:
  - **Wetland hydroperiod = Nett Precipitation** (Precipitation - Evaporation) **+ Recharge ability** (fracture rock qualities, transpiration, soil depth, evaporative demand, vegetation, etc.) **+ Storage capacity of the hillslope** (hill volume, fracture system) **+ Release controlling factors** (dykes, rock layers, biological).
- Wetland soil indicators must be split into ***ancient*** (soil morphology and mineralogy), ***recent*** (organic carbon content and chemistry) and ***current*** (water level, pH, redox) indicators. A supporting wetland soil indicator is organic carbon content, and organic C content profiles should be investigated along with current indicators of pH and redox.
- Although soil is generally an ancient, yet relevant, indicator of abiotic hydrology, it is also a reliable indicator of the soil ecosystem, a biotic system driven mainly by hydrology. To distinguish between these systems, soil hydrology with or without a strong biological factor is the core of wetland classification.

5.4. Data Archiving

Archiving and maintenance of all Land Type information is regularly performed by staff of the ARC-ISCW. A procedure needs to be developed to use and maintain the hydropedology database created in this project.

6. REFERENCES

Bouwer, D., le Roux, P.A.L., van Tol, J.J. and van Huyssteen, C.W. (2015) Using ancient and recent soil properties to design a conceptual hydrological response model. *Geoderma* 241-242: 1-11.

Brinson, M.M. (1993) A hydrogeomorphic classification for wetlands. *Wetland Research Programme Technical Report WRP-DE-4*. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. Washington, DC.

Collins, N. (2010) Phytosociology and ecology of selected depression (pan) and valley-bottom wetlands of the Free State Province. Unpublished PhD thesis. University of Free State, Bloemfontein.

Department of Water Affairs and Forestry (DWAF). (2005) A practical field procedure for identification and delineation of wetland and riparian areas. Department of Water Affairs and Forestry, Pretoria.

Dippenaar, J.L., van Rooy, J.L., Breedt, N., Huiseman, S.E., Muravha, S., and Mulders, J. (2014) Vadose Zone Hydrology: concepts and techniques. WRC Report No. TT584/13. Water Research Commission, Pretoria.

Du Toit, W.H. (2001) An investigation into the occurrence of groundwater in the contact aureole of large granite intrusions (batholiths) located west and northwest of Pietersburg. Department of Water Affairs, Pretoria.

Engelbrecht, H.F. (2007) Natural Resource Zone Creation Application – Implementation Manual. Version 1.0. ARC-ISCW Report No. GW/A/2007/63. ARC-Institute for Soil, Climate and Water, Pretoria.

Euliss, N.H. Jr., Smith, L.M., Wilcox, D.A. and Browne, B.A. (2008) Linking ecosystem processes with wetland management goals: charting a course for a sustainable future. *Wetlands*, Vol. 28, No. 3, September 2008, pp. 553-562 AND *USGS Northern Prairie Wildlife Research Centre.* Paper 272. http://digitalcommons.unl.edu/usgsnpwrc/272

Faulkner, S.P. and Richardson, C.J. (1989) Physical and chemical characteristics of freshwater wetland soils. In: D.A. Hammer (ed), Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, MI.

Fourie, B. (2015) Refining wetland classification for South Africa. Unpublished BSc (Hons) thesis. Department of Plant and Soil Sciences, University of Pretoria, Pretoria.

Freese, C. (2013) A description, quantification and characterization of hillslope hydrological processes in the Weatherley catchment, Eastern Cape Province, South Africa. Unpublished MSc thesis. University of KwaZulu-Natal, Durban.

Gambrell, R.P. and Patrick, W.H. (1978) Chemical and microbiological properties of anaerobic soils and sediments. In: D.D. Hook and R.M. Crawford (eds), Plant Life in Anaerobic Environments. Ann Arbor Science, Ann Arbor.

Geological Survey. (1984) Geological map of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland. (1: 1 000 000). Geological Survey of South Africa, Pretoria.

Geological Survey. (1986) 1:250 000 Geological Series 2626 West Rand and 2628 East Rand. Geological Survey of South Africa, Pretoria.

Ingram, H.A.P. (1983) Hydrology. In: A.P. Gore (ed), Ecosystems of the World: 4a. Mires, swamp, bog, fen and moor. Regional Studies. Elsevier. Oxford.

Jenness, J., Brost, B. and Beier, P. (2013) Land Facet Corridor Designer: Extension for ArcGIS. Jenness Enterprises. Available at: http://www.jennessent.com/arcgis/land_facets.htm

Jennings, K. (2007) Effect of varying degrees of water saturation on redox conditions in a yellow brown apedal B soil horizon. Unpublished MSc thesis. University of Free State, Bloemfontein.

Job, N.M. (2008) Report on the application of the Department of Water Affairs and Forestry wetland delineation method to wetlands of the Western Cape. WRC Report No. K8-718. Water Research Commission, Pretoria.

Johnson, T.L. (2016) Evaluation of iron-coated tubes to detect reduction in soils for wetland identification in the Kruger National Park. Unpublished MSc thesis. University of Free State, Bloemfontein.

Kotze, D.C. and Marneweck, G. (1999) Guidelines for delineation of wetland boundaries and wetland zones In: DWAF, Resource Directed Measures for Wetland Ecosystems.

Kotze, D.C., Klug, J.R., Hughes, J.C. and Breen, C.M. (1996) Improved criteria for classifying hydric soils in South Africa, *South African Journal of Plant and Soil* 13(3): 67-73, DOI: 10.1080/02571862.1996.10634378.

Kuenene, B.T., van Huyssteen, C.W. and le Roux, P.A.L. (2013) Selected soil properties as indicators of soil water regime in the Cathedral Peak VI catchment of KwaZulu-Natal, South Africa. *South African Journal of Plant and Soil* 30(1): 1-6.

Kuenene, B.T., van Huyssteen, C.W., le Roux, P.A.L., Hensley, M. and Everson, C.S. (2011) Facilitating interpretation of Cathedral Peak VI catchment hydrograph using soil drainage curves. *South African Journal of Geology* 114: 525-534.

Land Type Survey Staff. (2004) ARC-ISCW Land Type Information System: Electronic Format. ARC-Institute for Soil, Climate and Water, Pretoria.

Le Roux, P.A.L., Hensley, M., Lorentz, S., van Tol J.J., van Zijl, G.M., Kuenene, B.T., Bouwer, D., Freese, C.S., Tinnefeld, M. and Jacobs, C.C. (2015) HOSASH: Hydrology of South African Soils and Hillslopes. WRC Report No. 2021/1/15. Water Research Commission, Pretoria.

Le Roux, P.A.L., van Tol, J.J., Kuenene, B.T., Hensley, M., Lorentz, S., Everson, C.S., van Huyssteen, C.W., Kapangaziwiri, E. and Riddell, E. (2011) Hydropedological interpretations of the soils of selected catchments with the aim of improving the efficiency of hydrological models. WRC Report No. 1748/1/10, Water Research Commission, Pretoria.

Lorentz, S.A. (2001) Hydrological systems modelling research programme: hydrological processes. WRC Report No. 637/1/01. Water Research Commission, Pretoria.

Lourens, P. (2013) The relation between South African geology and geohydrology. Unpublished MSc thesis. Institute for Groundwater Studies, University of the Free State, Bloemfontein.

MacFarlane, D.M., Kotze, D.C., Ellery, W.N., Walters, D., Koopman, V., Goodman, P. and Goge, C. (2009) WET-Health: A technique for rapidly assessing wetland health. WRC Report No. TT 340/08. Water Research Commission, Pretoria.

MacVicar, C.N., de Villiers, J.M., Loxton, R.F., Verster, E., Lambrechts, J.J.N., Merryweather, F.R., le Roux, J., van Rooyen, T.H. and Harmse, H.J. Von M. (1977) Soil Classification: A Binomial System for South Africa. Department of Agricultural Technical Services, Pretoria.

Mapeshoane, B. (2013) Soil hydrology and hydric soil indicators of the Bokong wetlands in Lesotho. Unpublished MSc thesis. University of Free State, Bloemfontein.

Mitsch, W.J. and Gosselink, J.G. (2000) Wetlands. 3rd Ed. John Wiley and Sons, Inc., USA.

Mqina, S. (2015) The influence of land types on water infiltration and soil erosion. Unpublished BSc (Hons) thesis. Department of Plant and Soil Sciences, University of Pretoria, Pretoria.

Mucina, L. and Rutherford, M.C. (2006) The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19. South African National Biodiversity Institute, Pretoria.

Munnik, M.C., Verster, E. and van Rooyen, T.H. (1992) Spatial pattern and variability of soil and hillslope properties in a granitic landscape, Pretoria-Johannesburg area. *South African Journal of Plant and Soil* 9(2): 43-51.

National Research Council (NRC). (1995) *Wetlands: Characteristics and boundaries*. Washington, DC: National Academy Press, 2101 Constitution Avenue NW, Washington, DC 20418; (800) 624-6242.

National Research Council (NRC). (2001) Basic research opportunities in Earth Science. Washington, DC: National Academy Press.

National Technical Committee for Hydric Soils (NTCHS). (1991) Hydric soils of the United States. United States Department of Agriculture, Soil Conservation Service, USDA-SCS Misc. Publ. 1491, Washington, DC.

National Water Act. (1998) South African National Water Act, Act 36 of 1998.

Ollis, D.J., Snaddon, C.D., Job, N.M. and Mbona, N. (2013) Classification system for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

Omar, M.Y, le Roux, P.A.L. and van Tol, J.J. (2014) Interactions between stream channel incision, soil water levels and soil morphology in a wetland in the Hogsback area, South Africa. *South African Journal of Plant and Soil* DOI: 10.1080/02571862.2014.944593.

Pretorius, M.L., van Huyssteen, C.W. and Brown, L.R. (2017) Soil colour indicates carbon and wetlands: developing a colour proxy for soil organic carbon and wetland boundary on sandy coastal plains in South Africa. *Journal of Environmental Monitoring and Assessment* 189: 556.

Roberts, V.G., Hensley, M., Smith-Baillie, A.L. and Paterson, D.G. (1996) Detailed soil survey of the Weatherley catchment. ARC-ISCW Report No. GW/A/96/33. ARC-Institute for Soil, Climate and Water, Pretoria.

Rountree, M., Batchelor, L., MacKenzie, J. and Hoare, D. (2008) Updated manual for the identification and delineation of wetlands and riparian areas. Department of Water Affairs and Forestry, Pretoria.

Schulze, R. (1985) Hydrological characteristics and properties of Southern Africa 1: Runoff response. *Water SA* 11(3): 121-128.

Scotney, D.M. and Wilby, A.F. (1983) Wetlands and agriculture. *Limnological Society of South Africa.* 9, 134-140.

Smith, K. and van Huyssteen, C.W. (2011) The effect of degree and duration of water saturation on selected redox indicator: pe, Fe^{2+} and Mn^{2+}. *South African Journal of Plant and Soil* 28: 119-126.

Soil Classification Working Group. (1991) Soil Classification: A Taxonomic System for South Africa. ARC-Institute for Soil, Climate and Water, Pretoria.

Soil Classification Working Group. (2018) Soil Classification: A Natural and Anthropogenic System for South Africa. ARC-Institute for Soil, Climate and Water, Pretoria.

South African Committee for Stratigraphy. (1980) Stratigraphy of South Africa. Part 1. (Comp. L.E. Kent), Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda: Handbook Geological Survey of South Africa 8. Council for Geosciences of South Africa, Pretoria.

South African Wetland Society. (2014) Wetland delineation working group position paper on wetland delineation. Cape Town.

Strategic Environmental Focus. (2008) Wetland Audit for the City of Johannesburg. Strategic Environmental Focus (Pty) Ltd.

Swanepoel, C.M., Morgenthal, T.L., Prinsloo, H.P. and Schoeman, J.L. (2008) Final report on wetland delineation. Report to the Department of Agriculture. ARC-ISCW Report No: GW/A/2008/22. ARC-Institute for Soil, Climate and Water, Pretoria.

Tinnefeld, M. (2016) Conceptual hydrological response models of selected arid soilscapes in the Douglas area, South Africa. Unpublished MSc thesis. University of Free State, Bloemfontein.

Tinnefeld, M., le Roux, P.A.L., Job, N.M., van Zijl, G.M., van Tol, J.J. and Lorentz, S.A. (2017) Research report on the hydropedology of part of the Halfway House Granite Dome. For the Department of Infrastructure and Environment, City of Johannesburg Metropolitan Council, Johannesburg. Institute of Groundwater Studies, University of the Free State, Bloemfontein.

Turner, D.P. (1976) A study into water infiltration. Unpublished MSc (Agric.) thesis. University of Natal, Pietermaritzburg.

Turner, D.P., Grundling, A.T., van der Walt, M., van der Waals, J.H. and Fourie, B. (2015a) Estimation of wetland distribution and erosion sensitive zones derived from ARC-ISCW Land Type Information using a grouping approach (Part 1) and a single Land Type evaluation approach (Part 2). ARC-ISCW Report No. GW/A/2015/32. ARC-Institute for Soil, Climate and Water, Pretoria.

Turner, D.P., Grundling, A.T. and van der Walt, M. (2015b) Compile estimated wetland distribution map and associated database. ARC-ISCW Report No. GW/A/2015/31. ARC-Institute for Soil, Climate and Water, Pretoria.

Turner, D.P., Grundling, A.T. and van der Walt, M. (2015c) Erosion-sensitive zones from land type information (Part 1 and Part 2). ARC-ISCW Report No. GW/A/2015/43. ARC-Institute for Soil, Climate and Water, Pretoria.

U.S. Army Corps of Engineers (USACOE). (1987) Corps of Engineers Wetland Delineation Manual by Environmental Laboratory. Available from: U.S. Army Waterways Expt. Station, ER-W, Vicksburg, MS.

U.S. Army Corps of Engineers (USACOE). (2006) Interim regional supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region. J.S. Wakeley, R.W. Lichvar and C.V. Noble (eds). ERDC/EL TR-06-16. Vicksburg, MS: U.S. Army Engineer Research and Development Centre.

U.S.D.A. Natural Resources Conservation Service (USDA-NRCS). (2010) Field Indicators of Hydric Soils in the United States. G.W. Hurt (ed). Wetland Science Institute and Soils Division. NRCS Wetland Science Institute, Louisiana.

Van Huyssteen, C.W., Hensley, M., le Roux, P.A.L., Zere, T.B. and du Preez, C.C. (2005) The relationship between soil water regime and soil profile morphology in the Weatherley Catchment, an afforestation area in the Eastern Cape. WRC Report No. 1317/1/05. Water Research Commission, Pretoria.

Van Huyssteen, C.W., le Roux, P.A.L., Hensley, M. and Zere, T.B. (2004) Duration of soil saturation in selected soils of Weatherley, South Africa. *South African Journal of Plant and Soil* 23(1): 14-20.

Van Rooyen, T.H (1971) Soils of the central Orange River basin. Unpublished PhD thesis. University of the Free State, Bloemfontein.

Van Tol, J.J., Hensley, M. and le Roux, P.A.L. (2010b) Literature review on hydrology of soil types (HOST). Deliverable 2. WRC Report No. K5-2021. Water Research Commission, Pretoria.

Van Tol, J.J., Hensley, M. and le Roux, P.A.L. (2013b) Pedological criteria for estimating the importance of subsurface lateral flow in E horizons in South African soils. *Water SA* 39: 47-56.

Van Tol, J.J., le Roux, P.A.L. and Hensley, M. (2011b) Soil indicators of hillslope hydrology. In: B.O. Gungor (ed), Principles-Application and Assessments in Soil Science. Intech, Turkey.

Van Tol, J.J., le Roux, P.A.L., Hensley, M. and Lorentz, S.A. (2010a) Soil as indicator of hillslope hydrological behaviour in the Weatherley Catchment, Eastern Cape, South Africa. *Water SA* 36: 513-520.

Van Tol, J.J., le Roux, P.A.L., Hensley, M. and Lorentz, S.A. (2011a) Soil Indicators of hillslope hydrology in Bedford catchment. *South African Journal of Plant and Soil* 27(3): 242-251.

Van Tol, J.J., le Roux, P.A.L., Lorentz, S.A. and Hensley, M. (2013a) Hydropedological classification of South African hillslopes. *Vadose Zone Journal* 12(4), doi:10.2136/vzj2013.01.0007, 10 pp.

Van Zijl, G.M., le Roux, P.A.L. and Turner, D.P. (2013) Disaggregation of land types using terrain analysis, expert knowledge and GIS methods. *South African Journal of Plant and Soil* 30(3): 123-129.

Vepraskas, M.J. (1995) Redoximorphic features for identifying Aquic conditions. NC Agr. Res. Service, NC State University, Raleigh, NC. Technical Bulletin 301. Available from: Department of Agricultural Communications, Box 7603, North Carolina State University, Raleigh, NC 27695-7603; (919) 515-3173.

Vepraskas, M.J. and Sprecher, S.W. (eds) (1997) Aquic conditions and hydric soils: the problem soils. Soil Science Society of America. Madison, Wisconsin.

Vepraskas, M.J. and Faulkner, S.P. (2001) Redox chemistry of hydric soils. In: J.L. Richardson and M.J. Vepraskas (eds), Wetland Soils: Genesis, Hydrology, Landscapes and Classification. Boca Raton: Lewis Publishers.

Vermaak, J.J.G. (2008) Geotechnical and hydrogeological characterisation of residual soils in the vadose zone. Unpublished MSc thesis. University of Pretoria, Pretoria.

Visser, J.N.J. and Botha, B.J.V. (1980) Meander channel, point bar, crevasse splay and aeolian deposits from the Elliot Formation in Barkly Pass, North-eastern Cape. *Transactions of the Geological Society of South Africa* 83: 55-62.

Weber, R. (2011) Soil Hydrodynamic Interpretations for Wetlands. Technical Note. U.S.D.A. Natural Resources Conservation Service. Central National Technical Service Centre (CNTSC), Fort Worth, Texas.

Wetland Consulting Services. (2009) Wetland and riparian protection and management plan for the City of Johannesburg. Wetland Consulting Services (Pty) Ltd.

APPENDICES

Appendix 1. Hydrological Classification of South African Soil Forms (Van Tol *et al*., 2010b).

Recharge			Interflow		Responsive	
Deep		Shallow	A/B horizon	Soil/Bedrock	Shallow/low infiltration	Saturated
Kranskop	Hutton	Nomanci	Kroonstad	Lamotte	Arcadia	Champagne
Magwa	Shortlands	Steendal	Longlands	Westleigh	Milkwood	Rensburg
Inanda	Jonkersberg	Immerpan	Wasbank	Dresden	Mispah	Willowbrook
Lusiki	Pinegrove	Mayo	Constantia	Witfontein		Katspruit
Sweetwater	Groenkop	Brandvlei	Estcourt	Avalon		
Bonheim	Valsrivier	Coega	Klapmuts	Glencoe		
Inhoek	Swartland	Knersvlakte	Vilafontes	Pinedene		
Tsitsikama	Etosha	Glenrosa	Kinkelbos	Bainsvlei		
Concordia	Gamoep	Witbank	Cartref	Bloemdal		
Houwhoek	Oudtshoorn		Fernwood	Sepane		
Griffin	Oakleaf			Tukulu		
Molopo	Addo			Montagu		
Askham	Prieska					
Clovelly	Trawal					
Kimberley	Augrabies					
Plooysburg	Dundee					
Garies	Namib					

Appendix 2. Statistical analysis of conservative, liberal and revised classifications; indicating the average surface area percentage for each Land Type as well as standard deviation and coefficient of variation (after Fourie, 2015).

Land type	Conservative			Liberal			Revised		
	Average	Stdev	CV	Average	Stdev	CV	Average	Stdev	CV
Aa	4.9	3.2	0.7	21.3	11.4	0.5	5.1	3.4	0.7
Ab	6.1	6.0	1.0	24.4	12.0	0.5	6.5	6.4	1.0
Ac	7.1	6.2	0.9	26.8	10.4	0.4	7.2	6.3	0.9
Ad	7.2	8.5	1.2	29.6	12.3	0.4	8.5	9.0	1.1
Ae	2.6	4.0	1.5	12.2	11.1	0.9	2.9	4.7	1.6
Af	0.4	0.9	2.1	5.4	6.5	1.2	1.3	3.2	2.5
Ag	1.8	2.8	1.5	19.4	11.2	0.6	1.9	2.9	1.5
Ah	2.1	3.1	1.5	17.6	11.3	0.6	4.2	5.8	1.4
Ai	2.2	3.6	1.7	27.7	15.9	0.6	11.9	14.2	1.2
Ba	11.0	8.5	0.8	40.6	12.8	0.3	11.6	9.3	0.8
Bb	22.2	14.6	0.7	60.8	17.0	0.3	23.7	15.6	0.7
Bc	7.5	8.0	1.1	33.4	12.5	0.4	7.8	8.1	1.0
Bd	19.8	15.8	0.8	58.9	16.6	0.3	21.2	15.9	0.8
Ca	30.3	21.2	0.7	55.7	20.1	0.4	32.4	22.9	0.7
Da	1.7	2.4	1.4	17.5	8.1	0.5	1.7	2.4	1.4
Db	17.7	18.1	1.0	34.3	19.5	0.6	19.2	20.3	1.1
Dc	10.6	11.4	1.1	20.8	11.8	0.6	10.9	11.5	1.1
Ea	9.2	14.3	1.6	21.9	15.8	0.7	9.2	14.4	1.6
Fa	7.4	7.9	1.1	47.6	15.8	0.3	8.0	8.6	1.1
Fb	4.5	6.0	1.3	47.2	15.4	0.3	4.8	6.5	1.4
Fc	2.3	4.8	2.1	47.4	17.0	0.4	2.8	6.0	2.1
Ga	54.0	20.1	0.4	80.2	18.2	0.2	74.4	22.5	0.3
Gb	26.2	7.7	0.3	53.0	16.1	0.3	23.3	21.3	0.9
Ha	4.9	7.4	1.5	90.7	10.8	0.1	88.0	10.7	0.1
Hb	16.0	17.3	1.1	72.6	19.6	0.3	61.9	22.5	0.4
Ia	27.5	26.6	1.0	33.2	27.5	0.8	28.9	28.3	1.0
Ib	1.7	2.8	1.6	20.1	7.5	0.4	1.8	2.8	1.5
Ic	1.1	1.6	1.4	11.0	4.0	0.4	1.2	1.7	1.4

Appendix 3. Title page of the thesis report as submitted by Mr B Fourie for the degree BSc (Hons) to the University of Pretoria, November 2015.

Refining Wetland Classification for South Africa

By

Brendon Fourie

(Student Number 11210509)

Submitted in partial fulfilment of the requirements for the degree BSc (Hons) Environmental Soil Science

(GDK 775)

Project leader: Dr David P Turner (ARC-ISCW)

Participants:

Mr Chris de Jager (UP)

Dr Johan van der Waals (Terra Soil Science)

October 2015

Appendix 4. Title page of the thesis report as submitted by Mr S Mqina for the degree BSc (Hons) to the University of Pretoria, November 2015.

THE INFLUENCE OF LAND TYPES ON WATER INFILTRATION AND SOIL EROSION

by

SIYABONGA MQINA

A dissertation submitted in partial fulfilment of the requirements for the degree of Honours of Science in Agriculture (Environmental Soil Science) In the Department of Plant Production and Soil Science University of Pretoria

Supervisor Mr. C. De Jager
Co-Supervisor: Dr Van Der Waals

May 2015

SOIL
HYDROPEDOLOGY DATABASE
USER MANUAL

ARC • LNR

Gert De Nysschen

November 2017

INTRODUCTION

This system was developed to store soil profile information as well as hydro-pedology, chemical and physical information per horizon.

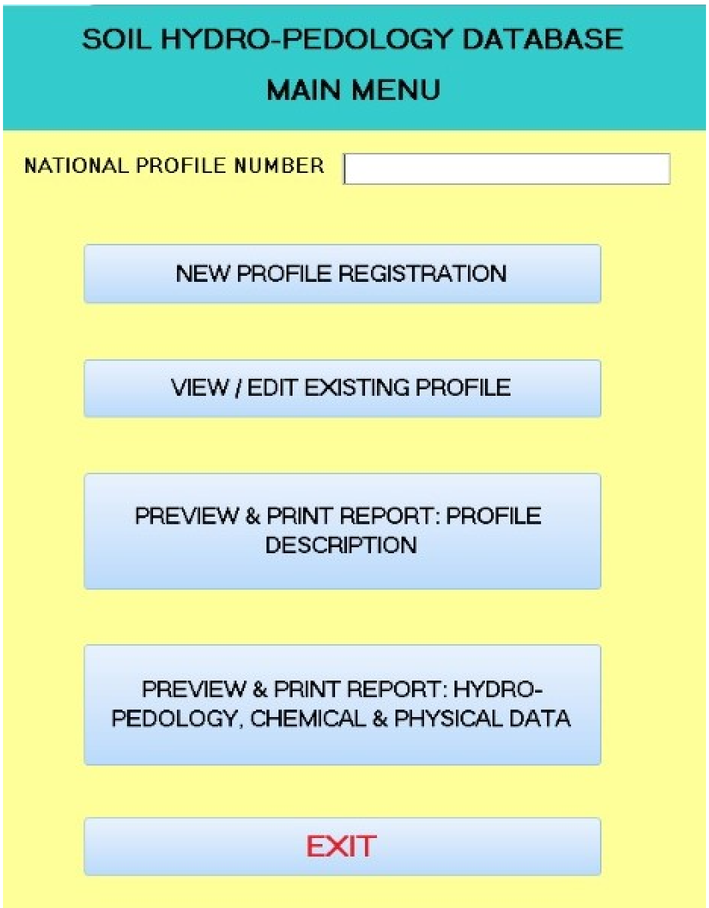
This includes:

- Profile header information
- Site information
- Information for each horizon:
    - Descriptive information
    - Soil hydro-pedology information
    - Soil chemical information
    - Soil physical information

USING THE DATABASE SYSTEM

The system is currently a stand-alone database system to be used by one user at any given time. The database can be accessed by starting MS-Access 2013 or later and then opening the database, named: *Soil_Hydro_Pedology_DB.accdb*.

After launching the database the Main Menu of the system will open:



NATIONAL PROFILE NUMBER: If a new profile is to be registered, leave the text box blank and click on **NEW PROFILE REGSTRATION**.

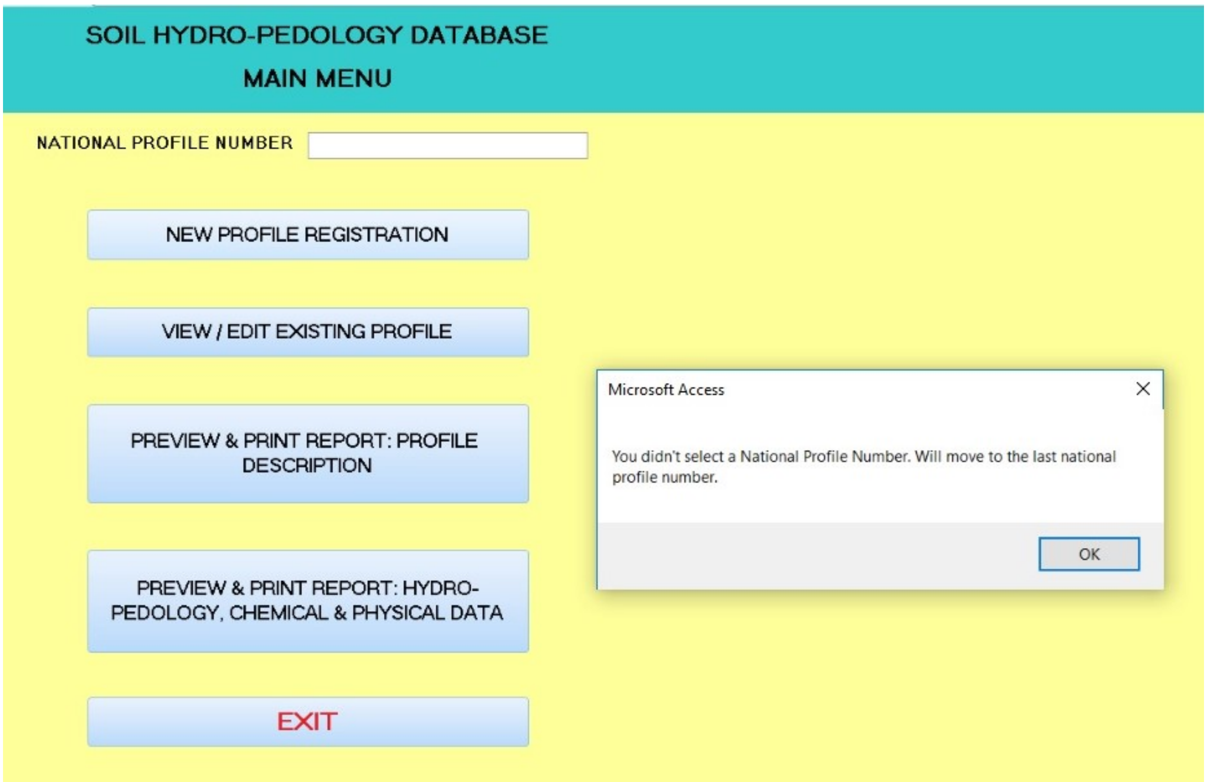
To view or edit an existing National Profile, supply a valid National Profile Number and click on **VIEW EXISTING PROFILE**.

From the **MAIN MENU** Form, the user can:

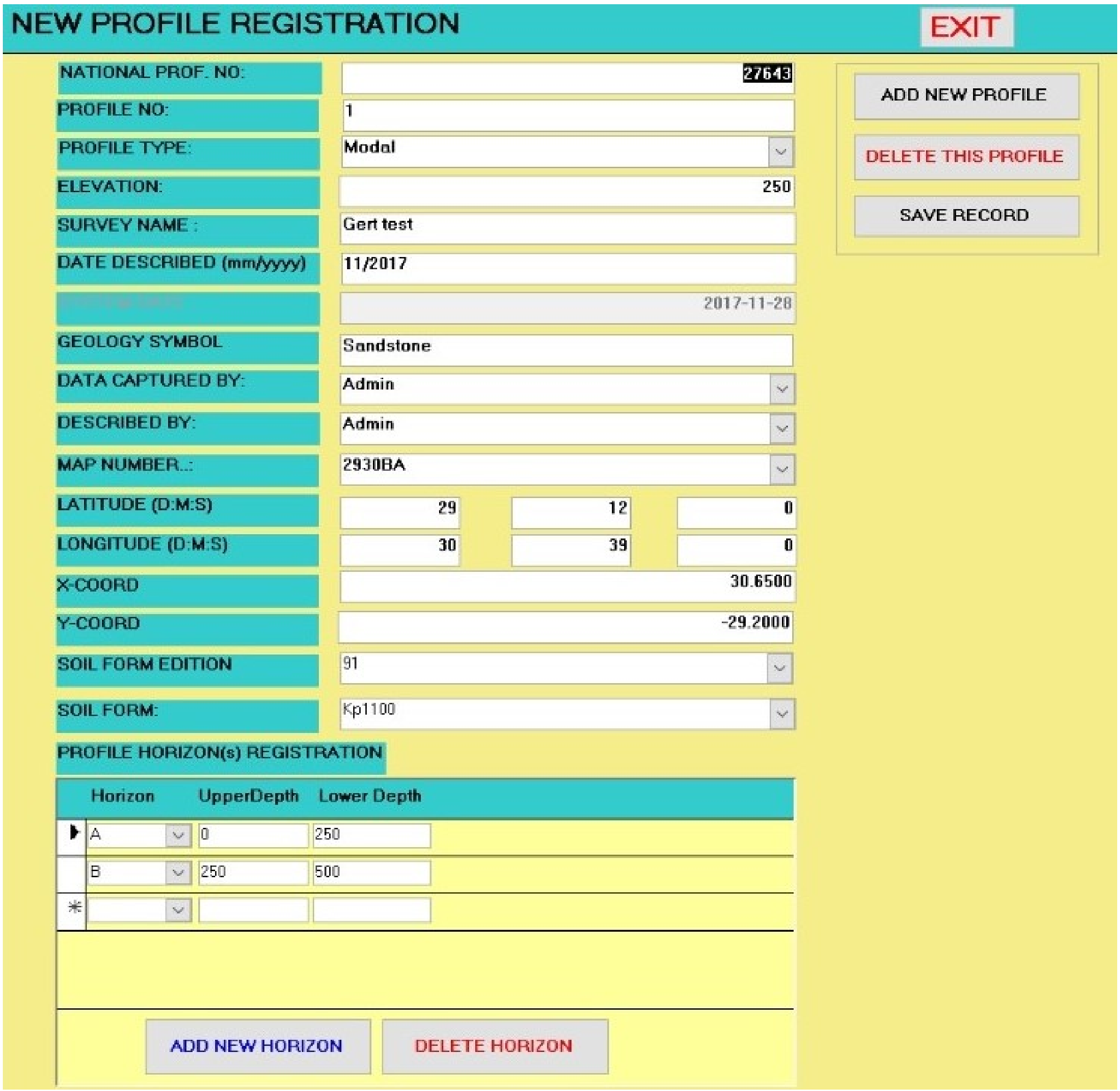
- **NEW PROFILE REGISTRATION**: Registers a new profile
- **VIEW / EDIT EXISTING PROFILE**: Allows viewing and editing of an existing profile
- **PREVIEW & PRINT REPORT: PROFILE DESCRIPTION**: Previews and prints a profile description report.
- **PREVIEW & PRINT REPORT: HYDROPEDOLOGY, CHEMICAL & PHYSICAL DATA**: Previews and prints the hydropedology, chemical and physical data for a selected profile.
- **EXIT**: Exits the program.

NEW PROFILE REGISTRATION

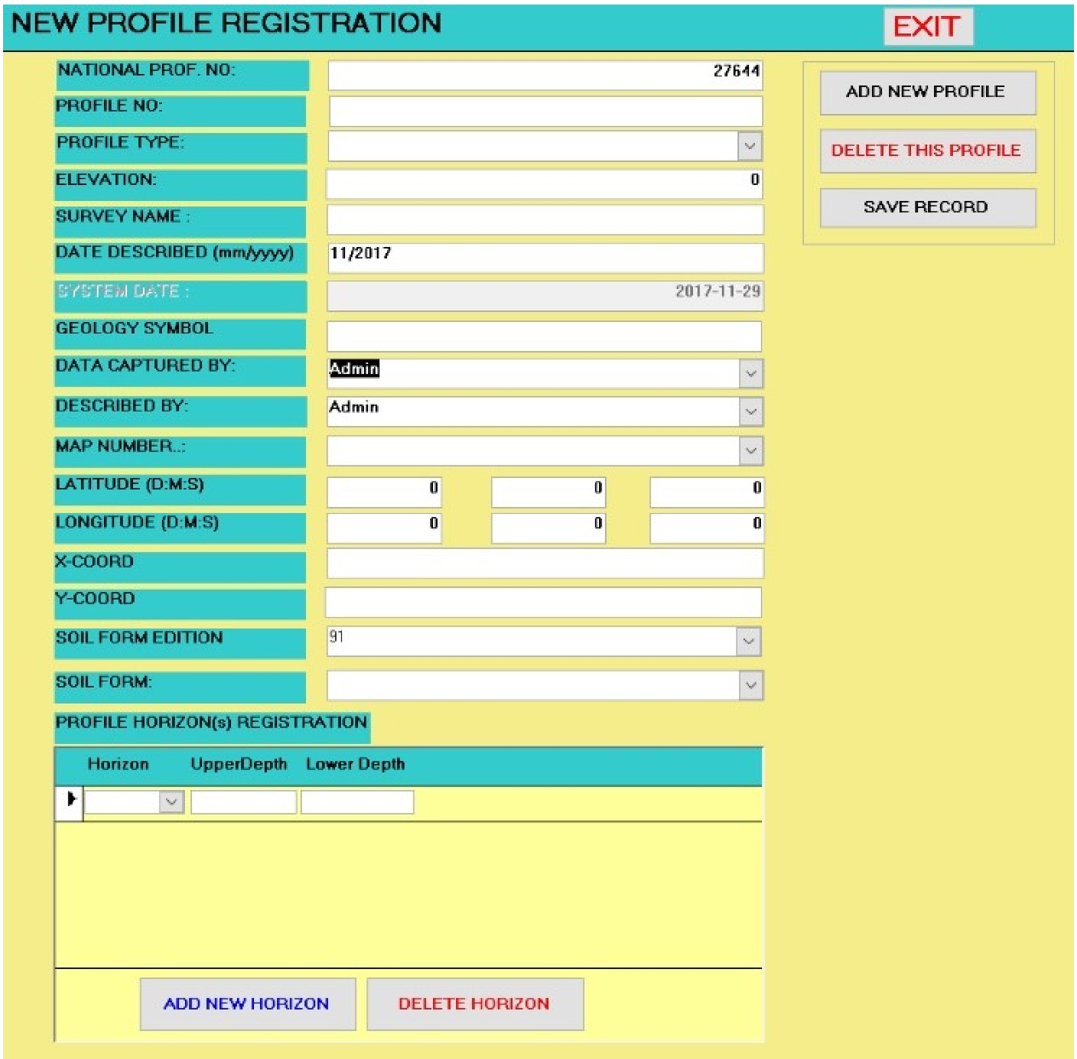
By leaving the **National Profile Number** text box empty and clicking the **NEW PROFILE REGISTRATION** option, a message informing the user that the system will move to the last National Profile Number will be displayed.



Click **OK** and the New Profile Registration form will open, displaying information of the last national profile.



Click **ADD NEW PROFILE** to add / register a new profile. A blank registration form, as below, will be displayed:



This will allow the user to supply all the relevant information to register a new profile. The next available National Profile Number will be assigned automatically. The user should supply all other relevant information including the registration of the different profile horizons.

EXIT: Back to previous form

ADD NEW PROFILE: Adds a new blank profile with the next available National Profile Number.

DELETE THIS PROFILE: Deletes all the data for the current profile.

SAVE RECORD: Saves the current profile to the database.

For **HORIZON** Registration:

ADD NEW HORIZON: Adds empty record to add horizon information

DELETE HORIZON: Deletes the selected horizon information

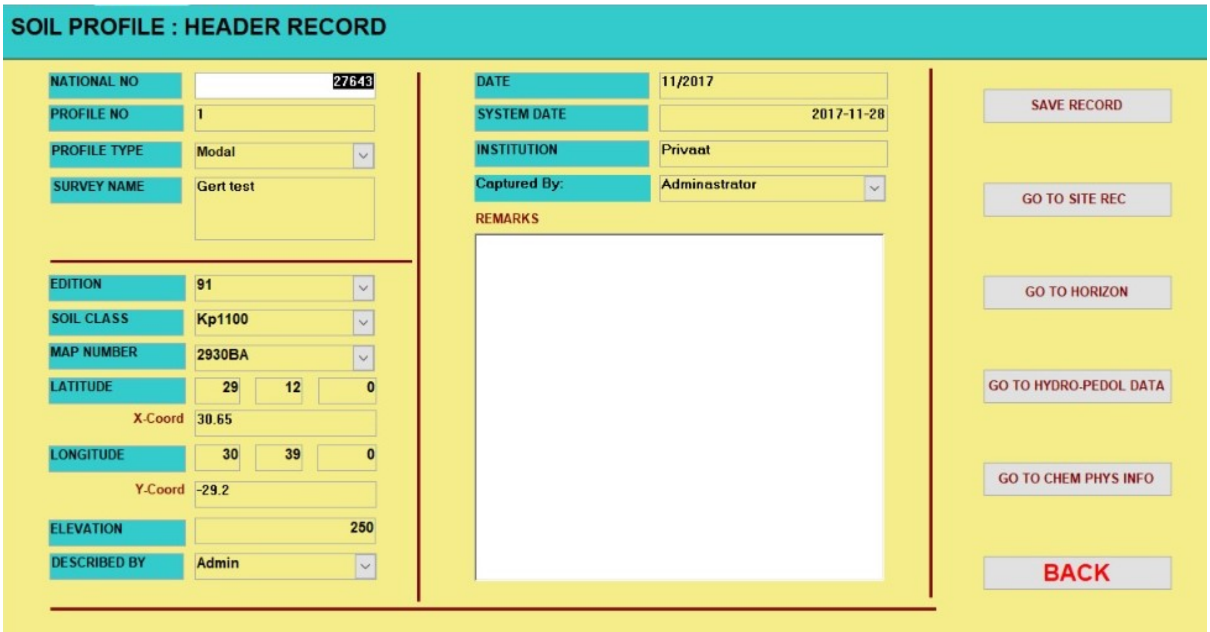
The following fields are of importance and must be completed as minimum requirements:

- Profile Number (Supplied by the system)
- Profile Type
- Survey Name
- Data Captured By
- Described By
- Latitude
- Longitude

Click **SAVE RECORD** when done to save the data to the database.

VIEW / EDIT EXISTING PROFILE

To view and / or edit an existing profile, supply a valid National Profile Number on the **MAIN MENU** form and then click **VIEW / EDIT EXISTING PROFILE**. The following form will open:



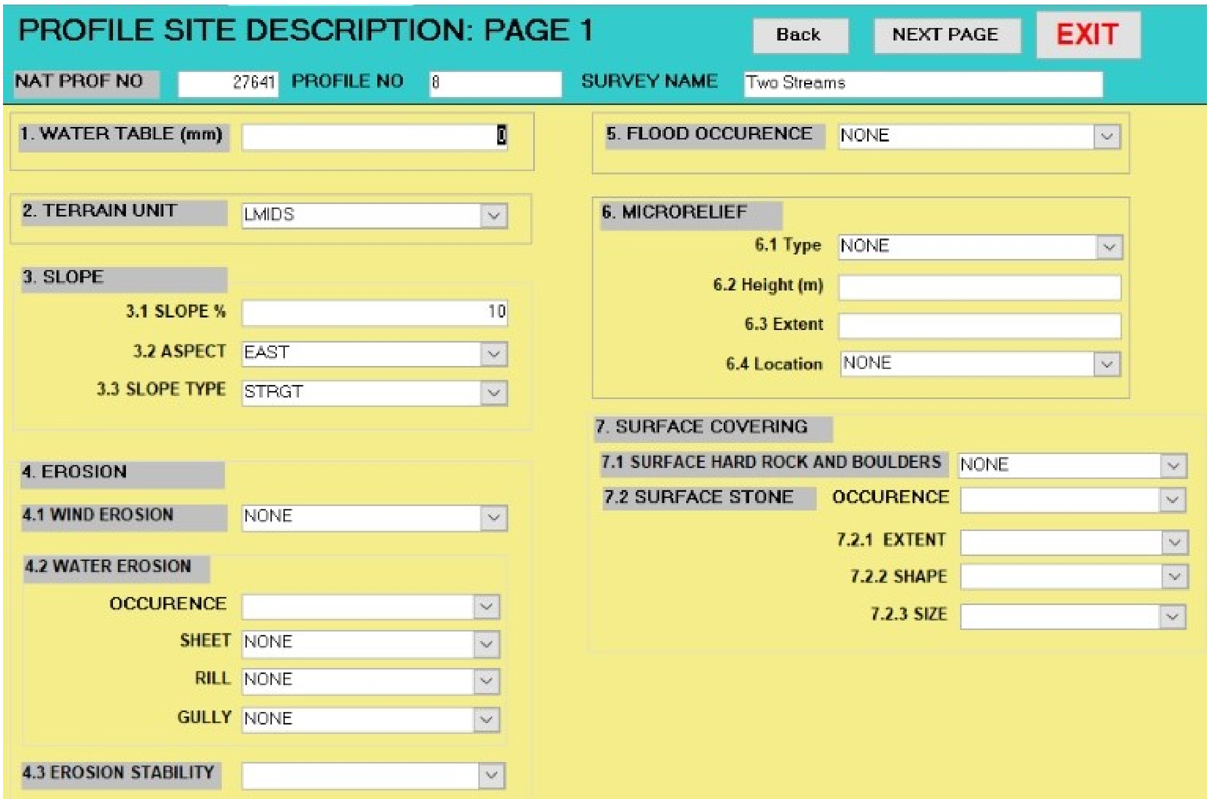
This form, known as the Profile Header Record, provides a summary of the information already captured when the profile was registered. This information can be edited if needed.

Also from this page, the user can access the following:

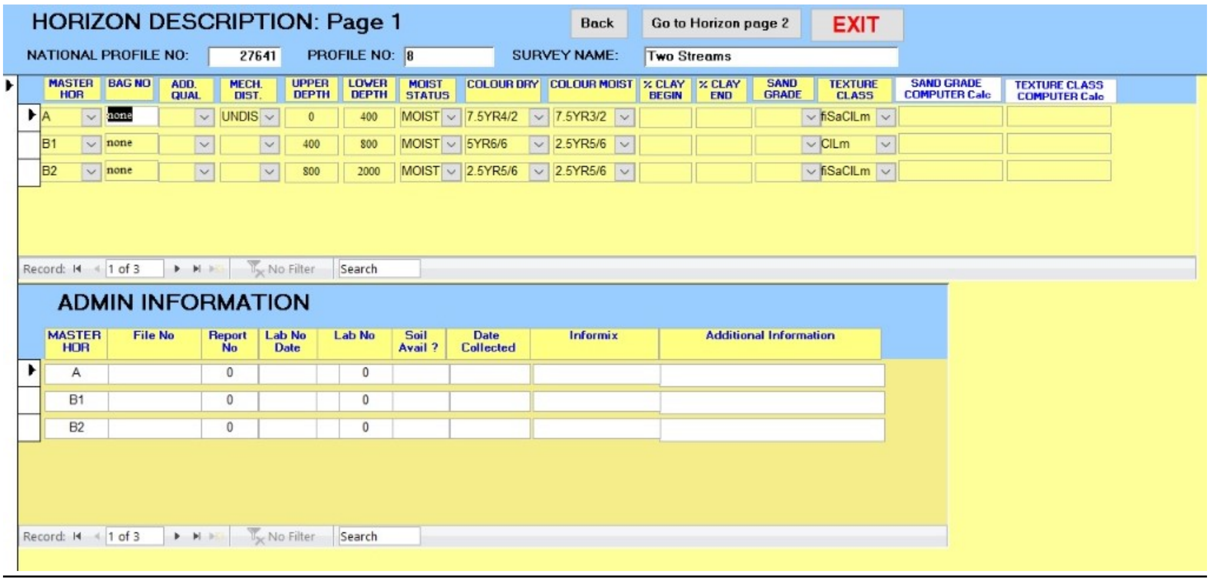
- **SAVE RECORD**: Saves the current record.
- **SITE INFORMATION**: Allows capturing or editing of site information.
- **HORIZON INFORMATION**: Allows capturing or editing of horizon information.
- **HYDRO-PEDOLOGY DATA**: Allows capturing or editing of hydro-pedology data.
- **CHEMICAL AND PHYSICAL INFORMATION**: Allows capturing or editing of chemical and physical information.

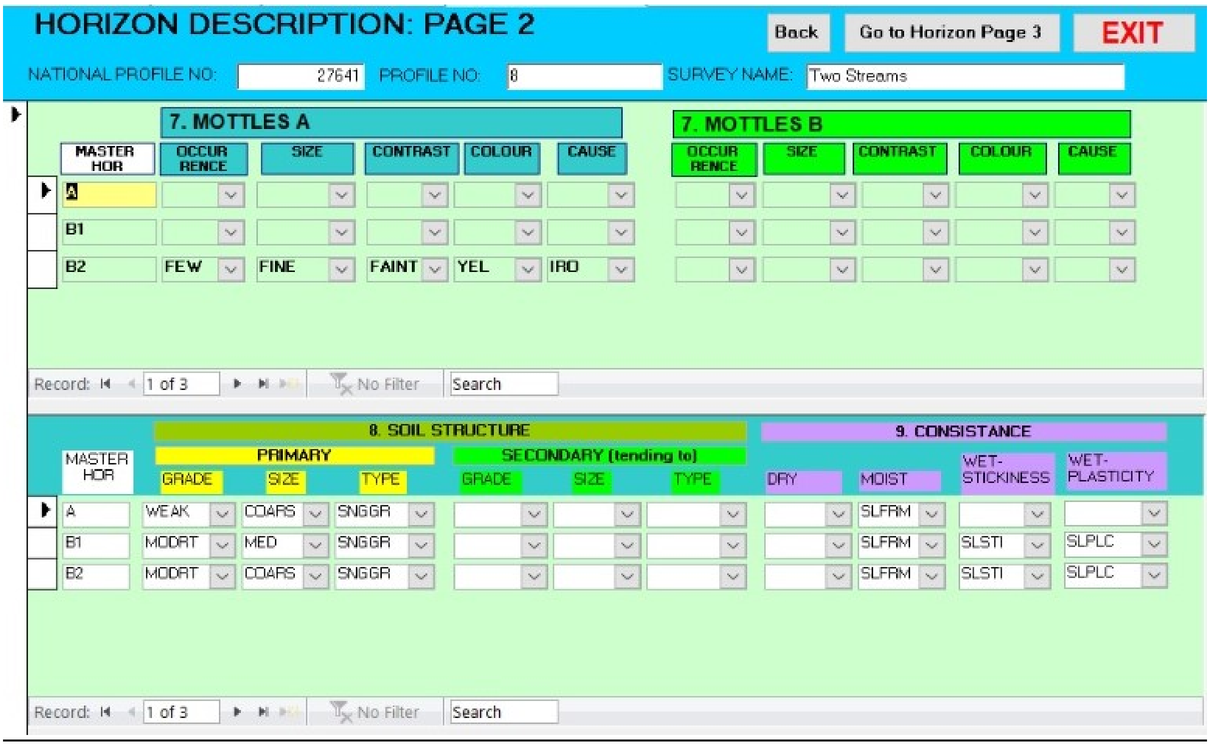
Following pages are examples of the PROFILE SITE INFORMATION, HORIZON INFORMATION, HYDRO-PEDOLOGY INFORMATION and CHEMICAL and PHYSICAL INFORMATION.

<u>PROFILE SITE REC</u>



PROFILE HORIZON DESCRIPTION INFORMATION





Various other information pertaining to the horizon of each profile is also captured in the database but not shown here. These include:

- Matrix Pores
- Macro Pores
- Cracks
- Cementation of Horizon

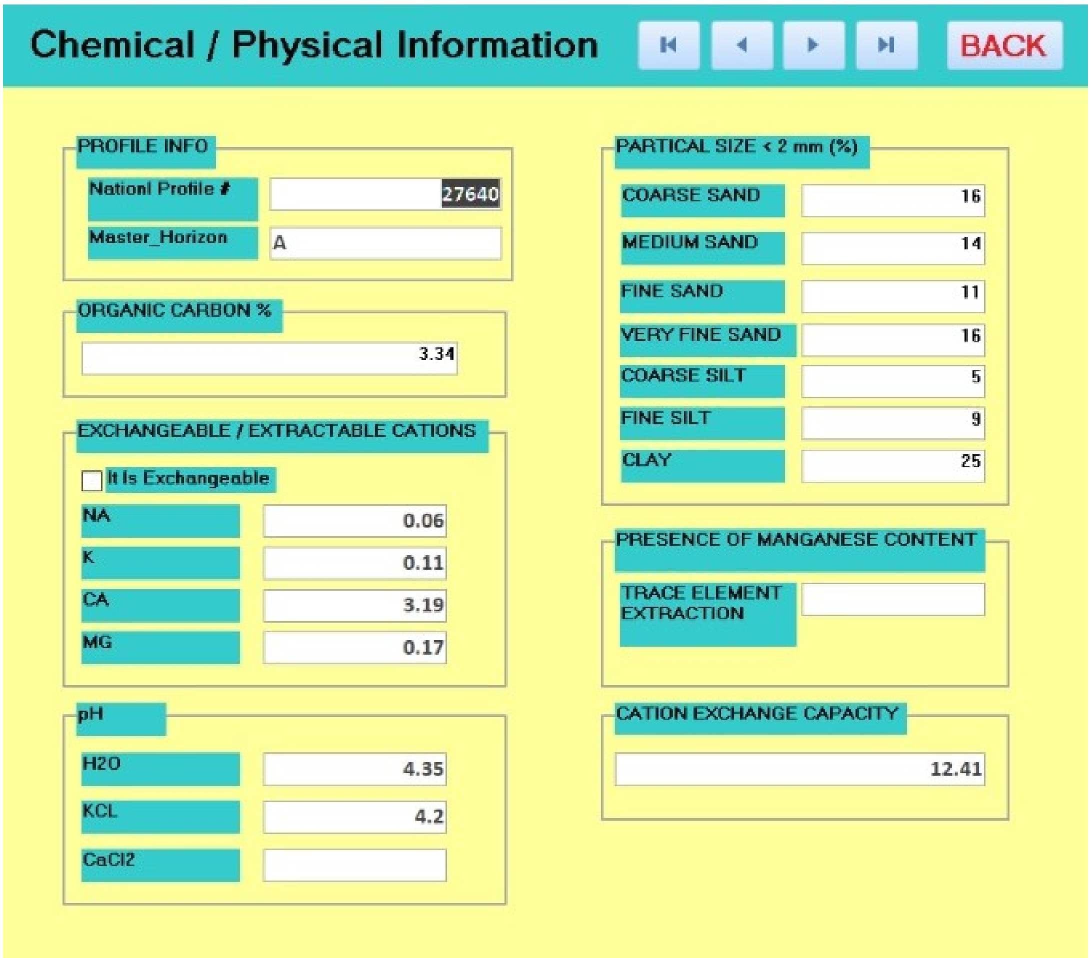
- Free lime – non-hardened
- Slickensides
- Cutans
- Coarse Fragments (Gravel / Stones / Boulders)
- Surface and subsurface features
- Depositional Stratification
- Water absorption
- Roots
- Transition
- Diagnostic horizons and material

HYDRO-PEDOLOGY DATA


Hydro-Pedology Data BACK

National Profile No	27640	Master Horizon	A	Site	Two Streams		
Lat (Degrees)	29	Lat (Minutes)	12	Lat (Seconds)	27		
Long (Degrees)	30	Long (Minutes)	38	Long (Seconds)	52		
X Coordinate	30.6477777776619	Y Coordinate	-29.2074999998324				
Soil	Gf1100	Lower Depth	400	Bulk Density	1.16		
HYDRAULIC	CONDUCTIVITY (mm hr-1)			WATER	RETENTION (mm)		
Pressure 1	0	HC Value 1	88.8	Pressure 1	0	W Reten Value 1	0.58
Pressure 2	30	HC Value 2	6.9	Pressure 2	38	W Reten Value 2	0.57
Pressure 3	80	HC Value 3	3.6	Pressure 3	50	W Reten Value 3	0.56
Pressure 4	150	HC Value 4	1.6	Pressure 4	100	W Reten Value 4	0.55
Pressure 5		HC Value 5		Pressure 5	200	W Reten Value 5	0.51
Pressure 6		HC Value 6		Pressure 6	400	W Reten Value 6	0.44
Pressure 7		HC Value 7		Pressure 7	600	W Reten Value 7	0.38
Pressure 8		HC Value 8		Pressure 8	800	W Reten Value 8	0.32

CHEMICAL AND PHYSICAL INFORMATION



Appendix 6. Land Type Broad Soil Patterns by Dr DP Turner (26 January 2017).

GENERALIZED SOIL PROPERTIES AND EXPECTED HYDROLOGICAL RESPONSE FOR LAND TYPE BROAD SOIL PATTERNS

Introduction: The information quoted below in the titling of Land Type Map Descriptions and the Land Type General Identification quotes directly the content described in Land Memoir Number 1. It is referenced as: *(Land Type Survey Staff. 1984. Land Types of the maps 2522 Bray, 2622 Morokweng, 2524 Bray, 2624 Vryburg. Memoirs of the Agricultural Natural Resources of South Africa. No.1. Department of Agriculture (currently ARC-Institute for Soil, Climate and Water) Pretoria.* This memoir was published in book format in 1984 by the Department of Agriculture. All Land Type information is currently archived in electronic and hard copy formats by the Agricultural Research Council – Institute for Soil, Climate and Water and is available from this source.

Soil properties are taken from soil profile descriptions and soil analyses published in Land Type Memoirs and collected largely during Land Type Survey (1972 to 2004). They are archived by ARC-ISCW. Summary information and interpretation is generally that derived from the authors' tacit knowledge of soil properties and their distributions.

Aa – **LAND TYPE SYMBOL – RED AND YELLOW, FREELY-DRAINED SOILS WITH HUMIC HORIZONS**

Land Type General Identification: Red and yellow, freely-drained apedal soils with humic topsoils (Kranskop, Inanda and Magwa) occupying at least 40% of landscape.

Generalized Soil Properties

Forms and Series (1977 Edition): Kranskop, Inanda and Magwa humic soils together with Griffin, Hutton ad Clovelly soils, with Katspruit bottomland soils and streambeds.
Estimated Depth: Deep soils with thick humic A horizons and elevate levels of organic carbon.
Texture: Generally sandy clay to clay.
Base Status: Dystrophic, low exchangeable Ca, Mg, K, Na and elevated levels of exchangeable Al and H. Low CEC.
Organic Matter: Elevated levels extending to lower horizons.
Structure: Apedal structure.
Mineralogy: Kaolinitic with amorphous clay mineralogy, very low 2:1 minerals.
Water retention, degree of saturation and hydraulic conductivity: High, freely drained with high water infiltration and hydraulic conductivity.

Expected Hydrological Response

Deep recharge soils dominate landscape to low terrain positions.

Ab, Ac, Ad – LAND TYPE SYMBOLS – RED AND YELLOW, FREELY-DRAINED SOILS

Land Type General Identification: Red and yellow, freely-drained apedal soils with Hutton, Griffin and Clovelly soils occupying more than 40% of the landscape. ***Ab*** Land Types are dominated by red soils (yellow soils <10%), ***Ac*** Land Types are dominated by yellow soils (red soils < 10%), while ***Ad*** Land Types have neither red nor yellow soils as dominant.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, Griffin and Clovelly are dominant, together with Glenrosa, with moderately weathered to fractured rock soil/rock interface. Soil/Rock complexes with apedal soils may be present. Small proportions of thick Kranskop, Inanda and Magwa humic soils may be present. Plinthic soils and soils with neocutanic horizons are generally absent. Duplex soils and black clays are absent. Katspruit dominates bottomland soils and streambeds.
Estimated Depth: Generally deep soils with moderate levels of organic carbon.
Texture: Generally sandy clay loam to clay.
Base Status: Dystrophic, low exchangeable Ca, Mg, K, Na and elevated levels of exchangeable Al and H. Low CEC.
Organic Matter: Moderate to elevated levels of OC in A horizon with lower levels in subsoil horizons.
Structure: Apedal structure.
Mineralogy: Kaolinitic with amorphous clay mineralogy, very low 2:1 minerals.
Water retention, degree of saturation and hydraulic conductivity: High, freely drained with high expected water infiltration and hydraulic conductivity.

Expected Hydrological Response

Moderately deep to deep recharge soils dominate landscape to low terrain positions.

Ae – LAND TYPE SYMBOL – RED, FREELY-DRAINED SOILS WITH HIGH BASE STATUS (*No dunes*)

Land Type General Identification: Red and yellow, freely drained apedal soils of the Hutton, Griffin and Clovelly soils occupying more than 40% of the landscape. Deeper (> 300 mm, but generally 500 to 1 000 mm) red soils of the Hutton form are dominant. Mishap and Glenrosa soils usually occupy significant proportions of the landscape. Soils with neocutanic, plinthic, duplex horizons and shallow black clay soils may occupy small proportions of the landscape. Katspruit, duplex soils and black clay soils usually occupy bottomland terrain positions with streambeds and erosion.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, Griffin and Clovelly are dominant with Glenrosa with moderately weathered to fractured rock soil/rock interface. Soil/Rock complexes with apedal soils may be present. Plinthic soils and soils with neocutanic horizons, generally of a limited extent. Duplex soils and black clays are generally absent. Katspruit dominates bottomland soils and streambeds.
Estimated Depth: Generally moderately deep to deep soils with moderate levels of organic carbon.
Texture: Generally sandy loam to sandy clay loam.
Base Status: Eutrophic, base saturated with exchangeable Ca, Mg, K, Na, usually non-calcareous upland soils although lime may be present in bottomlands. CEC generally low to moderate, with neutral to slightly alkaline pH levels.
Organic Matter: Low organic carbon levels in topsoils, and very low levels in subsoil horizons.

Structure: Apedal structure. Bottomland soils generally exhibit moderate to strong block structure.
Mineralogy: Kaolinitic in Hutton soils, mixed 2:1 mineralogy in bottomland soils.
Water retention, degree of saturation and hydraulic conductivity: Low to moderate water retention and freely drained in Hutton soils with high water retention in bottomland soils. Degree of saturation is dependent on terrain position. Hydraulic conductivity of Hutton soils is high with high to low hydraulic conductivity on bottomland soils.

Expected Hydrological Response

Moderately deep recharge soil dominates upland landscape. Mispah and Glenrosa soils have recharge properties during dry rainfall periods and surface flow and interflow properties during intense rain events. Stable bottomland soils have discharge properties, while duplex and black clay soils may be associated with erosion land and are expected to exhibit a range of hydraulic properties.

Af – LAND TYPE SYMBOL – RED, HIGH BASE STATUS, FREELY-DRAINED SOILS *(Greater than 300 mm thick, with dunes)*

Land Type General Identification: Red, freely-drained apedal soils of the Hutton form, occupying more than 40% of the landscape, with dune terrain. Soils are generally deep (greater than 1 200 mm) and invariably sandy with a fine, or fine to medium grain texture. Yellow, freely-drained sandy soils (Clovelly form) and grey sands (Fernwood form *or Namib form 1991 classification*) are present at the base of dunes. Climate is arid to semi-arid with limited occurrences of surface water. Limited information is available on the soils of the inter-dune channel areas. These areas may exhibit variable (though currently poorly quantified) extent of water saturation in these arid climates.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, with generally limited proportions of Clovelly and Fernwood soils. Limited information on bottomland soils with possible streambeds or pans is available.
Estimated Depth: Generally deep sands, with very low levels of organic carbon.
Texture: Fine- or fine- to medium-grained sands.
Base Status: Eutrophic to calcareous base status (Ca, Mg, K, Na) with low CEC, and neutral to alkaline pH values.
Organic Matter: Very low organic carbon levels throughout soil profiles.
Structure: Loose, single-grain structure.
Mineralogy: Not well documented, expect mixed micaceous, 2:1 clay mineralogy with quarzitic and primary minerals in sand particles.
Water retention, degree of saturation and hydraulic conductivity: Low, low degree of saturation and high hydraulic conductivity properties. Hydraulic conductivity of bottomland sites is not well documented.

Expected Hydrological Response

Deep recharge soils are expected.

Ag – LAND TYPE SYMBOL – RED, HIGH BASE STATUS, FREELY-DRAINED SOILS (*Less than 300 mm thick*)

Land Type General Identification: Shallow (less than 300 mm thick), red, freely-drained apedal soils of the Hutton form, (>40% of landscape). Dominant proportions of shallow Hutton soils with limited extent of deeper (generally 400-600 mm) soils. Mispah soils (on hard and poorly fractured rock) and Glenrosa soils (on fractured to partly weathered rock) occupy a large extent of the remainder of the landscape. Bottomlands may contain alluvium (Dundee and Oakleaf) soils together with calcareous Katspruit, duplex (Valsrivier, Sterkspruit) and black clay (Bonheim) soils.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, with generally limited proportions of Clovelly and Fernwood soils. Mispah Glenrosa, and Rockland. Dundee, Oakleaf, calcareous Katspruit, Valsrivier, Sterkspruit and Bonheim.
Estimated Depth: Shallow soil depths in uplands, shallow to variable in bottomlands.
Texture: Fine or fine to medium grained sandy loam soils.
Base Status: Eutrophic to calcareous base status (Ca, Mg, K, Na) with low CEC, and neutral to alkaline pH values.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Single-grain structure, apedal and weak block structure in uplands, bottomlands may also contain blocky structured soils.
Mineralogy: Hutton soils contain kaolinitic and quarzitic mineralogy. Expect mixed micaceous, 2:1 clay mineralogy with quarzitic and primary minerals in bottomland soils.
Water retention, degree of saturation and hydraulic conductivity: Low, low degree of saturation and high hydraulic conductivity properties are expected. Hydraulic conductivity of bottomland sites is not well documented.

Expected Hydrological Response

Shallow recharge soils (Hutton) are expected during dry periods, while surface and interflow properties are expected during intense rain events. Short durations for bottomland discharge soils are expected.

Ah and Ai – LAND TYPE SYMBOL – RED AND YELLOW, HIGH BASE STATUS, FREELY-DRAINED SOILS *(Less than 15% clay)*

Land Type General Identification: Moderately deep to deep (400-1 200 mm), red and yellow, high base status, Hutton and Clovelly soils (***Ah***), or moderately deep to deep (400-1 200 mm), yellow, high base status, Clovelly soils (***Ai***). Hutton and Clovelly soils occupy more than 40 percent of the landscape. Mispah soils (on hard and poorly fractured rock) and Glenrosa soils (on fractured to partly weathered rock) occupy a large extent of the remainder of the landscape. Bottomlands may contain alluvium (Dundee and Oakleaf) soils together with calcareous Katspruit, duplex (Valsrivier, Sterkspruit) and black clay (Bonheim) soils.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, with generally limited proportions of Clovelly and Fernwood soils. Mispah Glenrosa, and Rockland. Dundee, Oakleaf, calcareous Katspruit, Valsrivier, Sterkspruit and Bonheim.
Estimated Depth: Shallow soil depths in uplands, shallow to variable in bottomlands.

Texture: Fine- or fine- to medium-grained sandy loam soils.
Base Status: Eutrophic to calcareous base status (Ca, Mg, K, Na) with low CEC, and neutral to alkaline pH values.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Single-grain structure, apedal and weak block structure in uplands, bottomlands may also contain blocky structured soils.
Mineralogy: Hutton soils contain kaolinitic and quarzitic mineralogy. Expect mixed micaceous, 2:1 clay mineralogy with quarzitic and primary minerals in bottomland soils.
Water retention, degree of saturation and hydraulic conductivity: Low, low degree of saturation and high hydraulic conductivity properties are expected. Hydraulic conductivity of bottomland sites is not well documented.

Expected Hydrological Response

Shallow recharge soils (Hutton) are expected during dry periods, while surface and interflow properties are expected during intense rain events. Short durations for bottomland discharge soils are expected.

Ba and Bb – LAND TYPE SYMBOL – PLINTHIC CATENA: UPLAND DUPLEX AND MARGALITIC SOILS RARE, DYSTROPHIC AND MESOTROPHIC SOILS. ***(Ba – Red soil widespread. Bb – Red soils not widespread)***

Land Type General Identification: A very large part of the South African interior is occupied by a catena in its perfect form represented by Hutton, Avalon, Bainsvlei, and Longlands soil forms. Glencoe, Wasbank, Westleigh and occasionally Tambankulu and Mispah (Hillside and Klipfontein series; *or Dresden 1991 classification*) plinthic soils are also present. Plinthic soils occupy at least 10% of the landscape. Where sedimentary rocks dominate the underlying geology, Pinedene and Kroonstad occupy lower slope positions, while Katspruit soil forms and streambeds are present in stable bottomland terrain positions. Duplex soils of the Valsrivier and Sterkspruit forms and alluvium (Dundee and Oakleaf forms) are dominant in many less stable bottomland sites. In addition, where basic igneous rocks are widespread, black clay soils of the Rensburg, Willowbrook and Bonheim soils also occupy bottomland positions. Mispah, Glenrosa and rock land are also common features of the landscape. Margalitic soils refers to black clays of the Rensburg, Arcadia, Willowbrook, Bonheim, Tambankulu, Mayo and Milkwood soil forms.

Ba represents Land Types where dystrophic red soils are widespread, while ***Bb*** represents Land Types where dystrophic yellow-brown and grey soils are widespread. ***Ba*** and ***Bb*** Land Types are generally located in the eastern and central interior basins.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, Avalon, Glencoe, Longlands, Wasbank and Westleigh on upland sites, together with Mispah, Glenrosa on shallow sites, and Clovelly and Swartland also present. There is also exposed rock land on sandstone or mudstone upland sites.
Kroonstad, Pinedene and Katspruit dominate where there are stable streambeds. Bottomland sites with Valsrivier, Sterkspruit, Bonheim, Rensburg and alluvium tend to occur where gully erosion is prominent.
Estimated Depth: Moderately deep (500 to 800 mm) to deep (>1 200 mm) soils are associated with moderate slopes in the eastern to central interior, while generally deep

(>1 200 mm) soils are associated with the flat terrain and wind-blown Quaternary geology of the western interior.
Texture: Fine-or fine-to medium-grained sandy loam soils.
Base Status: Dystrophic and mesotrophic base status (Ca, Mg, K, Na) with low CEC, and acid to neutral pH values.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Single-grain structure, apedal and weak block structure in uplands, bottomlands may also contain blocky structured soils.
Mineralogy: Kaolinitic and quarzitic mineralogy in upland and lower midslope soils. Smectite and micaceous mineralogy is expected in clay bottomland soils.
Water retention, degree of saturation and hydraulic conductivity: Low in surface horizons. Moderate water retention expected in plinthic and other subsurface horizons. Degree of water saturation is low in surface horizons, while E horizons generally have a high degree of water saturation for short durations following rain events. Water saturation is expected to be moderate to high for deeper subsurface horizons and may extend to longer durations following repeated rain events. Degree of water saturation is expected to be variable where erosion gullies dominate bottomland terrain positions.

Expected Hydrological Response

Hutton, Mispah and Glenrosa soils are expected to function as recharge soils in both surface and subsurface horizons, Avalon Glencoe, Bainsvlei and Pinedene soils have recharge function in surface soils and expected interflow function in deeper subsurface horizons. Longlands, Wasbank, Westleigh and Kroonstad soils have a dominant interflow function, with bottomland Kroonstad and Katspruit soils having a discharge function. Variable hydrological functions could be expected from other soils where erosion has dominated bottomland sites.

Bc and Bd – LAND TYPE SYMBOLS – PLINTHIC CATENA: UPLAND DUPLEX AND MARGALITIC SOILS RARE, EUTROPHIC SOILS. *(Bc – Red soils widespread. Bd – Red soils not widespread)*

Land Type General Identification: A very large part of the South African interior is occupied by a catena in its perfect form represented by Hutton, Avalon, Bainsvlei, and Longlands soil forms. Glencoe, Wasbank, Westleigh and occasionally Tambankulu and Mispah (Hillside and Klipfontein series; *or Dresden 1991 classification*) plinthic soils are also present. Plinthic soils occupy at least 10% of the landscape. Where sedimentary rocks dominate the underlying geology, Pinedene and Kroonstad occupy lower slope positions, while Katspruit soil forms and streambeds are present in stable bottomland terrain positions. Duplex soils of the Valsrivier and Sterkspruit forms and alluvium (Dundee and Oakleaf forms) are dominant in many bottomland sites. In addition, where basic igneous rocks are widespread, black clay soils of the Rensburg, Willowbrook and Bonheim soils also occupy bottomland positions. Mispah, Glenrosa and rock land are also common features of the landscape. Margalitic soils refers to black clays of the Rensburg, Arcadia, Willowbrook, Bonheim, Tambankulu, Mayo and Milkwood soil forms.

Bc represents Land Types where eutrophic red soils are widespread, while ***Bd*** represents Land Types where dystrophic yellow-brown and grey soils are widespread. ***Bc*** and ***Bd*** Land Types are generally located in the west and in the western areas where Quaternary wind-blown sands are present.

Generalized Soil Properties

Forms and Series (1977 Edition): Hutton, Avalon, Glencoe, Longlands, Wasbank and Westleigh on upland sites, together with Mispah, Glenrosa and Clovelly on shallow sites over hard rock geology, but tend to be absent in the areas of Quaternary sands. There is also exposed rock land on sandstone or mudstone upland sites.
Kroonstad, Pinedene and Katspruit dominate where there are stable streambeds. Bottomland sites with Valsrivier, Sterkspruit, Bonheim, Rensburg and alluvium tend to occur where gully erosion is prominent.
Estimated Depth: Moderately deep (500 to 800 mm) to deep (1 200 mm) soils are associated with moderate slopes in the central to western interior, while generally deep (>1 200 mm) soils are associated with the flat terrain and wind-blown Quaternary geology of the western interior.
Texture: Fine- or fine- to medium-grained sand to sandy loam soils.
Base Status: Eutrophic base status (Ca, Mg, K, Na) with low CEC, and neutral to alkaline pH values. Free lime is common in bottomland sites.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Single-grain structure, apedal and weak block structure in uplands, bottomlands may also contain blocky structured soils.
Mineralogy: Kaolinitic and quarzitic mineralogy in upland and lower midslope soils. Smectite and micaceous mineralogy is expected in clay bottomland soils.
Water retention, degree of saturation and hydraulic conductivity: Low in surface horizons. Moderate water retention expected in plinthic and other subsurface horizons. Degree of water saturation is low in surface horizons, while E-horizons generally have high degree of water saturation for short durations following rain events. Water saturation is expected to be moderate to high for deeper subsurface horizons and may extend to longer durations following repeated rain events. Degree of water saturation is expected to be variable where erosion gullies dominate bottomland terrain positions.

Expected Hydrological Response

Hutton, Mispah and Glenrosa soils are expected to function as recharge soils in both surface and subsurface horizons, Avalon Glencoe, Bainsvlei and Pinedene soils have recharge function in surface soils and expected interflow function in deeper subsurface horizons. Longlands, Wasbank, Westleigh, Kroonstad soils have a dominant interflow function, with bottomland Kroonstad and Katspruit soils have a discharge function. Variable hydrological functions could be expected from other soils where erosion has dominated bottomland sites.

Ca – LAND TYPE SYMBOL – PLINTHIC CATENA: UPLAND DUPLEX AND MARGALITIC SOILS COMMON

Land Type General Identification: ***Ca*** Land Types indicate land that qualifies for the plinthic catena (Avalon, Bainsvlei, Longlands, Glencoe, Wasbank, and Westleigh and occupy more than 10% of the land surface), but which has, in upland positions, margalitic soils (Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad) and occupy more than 10% of the land surface)

Generalized Soil Properties

The generalized soil properties will be those of the soils of the ***Bc*** and ***Bd*** Land Types for the plinthic soils, and the ***Db*** and ***Dc*** Land Types for the duplex soils.

Da – LAND TYPE SYMBOL – PRISMACUTANIC AND PEDOCUTANIC DIAGNOSTIC HORIZONS DOMINANT *(Da – red B horizons)*

Land Type General Identification: These Land Types accommodate duplex soils and gleycutanic soils, including Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad soil forms. After subtracting exposed rock land, these Land Types consist of land with more than 50% duplex soils. ***Da*** refers to land where red duplex soils are dominant. Red duplex soils are largely restricted to the mudstone and sandstone geology of the north-western regions of the Eastern Province and the north-eastern regions of the Northern Cape. Red duplex soils occupy very limited proportions in other regions of South Africa.

Generalized Soil Properties

Forms and Series (1977 Edition): Estcourt, Sterkspruit, Swartland, Valsrivier soil forms are dominant, with Glenrosa and Mispah soil forms and associated rock land. Bonheim, Mayo, and Milkwood occupy limited proportions of the Land Types. Alluvium may be present in bottomland sites.

Estimated Depth: Valsrivier and Bonheim soils are generally moderately deep to deep (800 to 1 200 mm), Estcourt and Sterkspruit soils may range from shallow (400 mm) in crest and upper midslope positions through moderately deep (500-800 mm) soils with commonly deep (>1 200 mm) subsurface alluvial horizons to hard bedrock. Swartland, Glenrosa and Mispah soils are shallow (100 to 400 mm thick) on fractured to hard rock.

Texture: Fine- or fine- to medium-grained sandy loam to sandy clay topsoils on sandy clay to clay subsoils.

Base Status: Eutrophic base status (Ca, Mg, K, Na) with low to moderate CEC and neutral pH values in surface horizons, with commonly eutrophic to calcareous subsurface horizons with moderate to high CEC and alkaline pH values.

Organic Matter: Low organic carbon levels throughout soil profiles.

Structure: Weak block structure in topsoils with strong prismatic to block structure on subsoil horizons.

Mineralogy: Variable quartzitic, micaceous and kaolinitic in surface horizons. Smectite, quartzite and micaceous mineralogy is expected in clay subsurface horizons.

Water retention, degree of saturation and hydraulic conductivity: Low water retention is expected in surface horizons, variable degrees of duration of water saturation, and low to moderate infiltration and hydraulic conductivity. Moderate water retention expected in prismacutanic and pedocutanic horizons, low to moderate degrees of duration of saturation and very low hydraulic conductivity values. Variable but generally low to moderate hydraulic conductivity may be expected in alluvial subsoil horizons. Deeper unconsolidated materials and soils with properties resembling deeper "bleached E horizons" may exhibit moderate hydraulic conductivity.

Expected Hydrological Response

Recharge and overland surface flows can be expected for the surface horizons of duplex soils in upland terrain positions. Recharge of subsurface horizons can be expected after prolonged rain events as hydraulic conductivity of these horizons is low. Limited lateral flow in deep subsurface horizons can be expected where evidence of deep subsurface gleying is present. This evidence is generally not documented in Land Type inventories, but may be interpreted from certain soil profile descriptions and analyses. Slow interflow is expected in midslope soils and slow discharge flow in bottomland soils. Many Da landscapes have extensive sheet and gully erosion that will alter expected soil property interpretations.

Db and Dc – LAND TYPE SYMBOLS – PRISMACUTANIC AND PEDOCUTANIC DIAGNOSTIC HORIZONS DOMINANT *(Db – not red; Dc – In addition, one or more of vertic, melanic and red structured horizons are present)*

Land Type General Identification: These Land Types accommodate duplex soils and gleycutanic soils, including Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad soil forms. After subtracting exposed rock land, these Land Types consist of land with more than 50% duplex soils. ***Db*** refers to land where brown duplex soils are dominant. ***Dc*** includes land where, in addition to the duplex soils, soils with vertic, melanic and red structured horizons comprise more than 10% of the land surface.

Generalized Soil Properties

Forms and Series (1977 Edition): Estcourt, Sterkspruit, Swartland, Valsrivier soil forms are dominant, with Kroonstad, Glenrosa and Mispah soil forms and associated rock land. Bonheim, Mayo, Milkwood, Arcadia and Rensburg soil forms occupy more than 10% of the land surface in ***Dc*** Land Types. Small proportions of Hutton soils and alluvium may be present.
Estimated Depth: Valsrivier and Bonheim soils are generally moderately deep to deep (800 to 1 200 mm), Estcourt and Sterkspruit soils may range from shallow (400 mm) in crest and upper midslope positions through moderately deep (500-800 mm) soils with commonly deep (>1 200 mm) subsurface alluvial horizons to hard bedrock. Swartland, Glenrosa and Mispah soils are shallow (100 to 400 mm thick) on fractured to hard rock.
Texture: Fine- or fine- to medium-grained sandy loam to sandy clay topsoils on sandy clay to clay subsoils.
Base Status: Eutrophic base status (Ca, Mg, K, Na) with low to moderate CEC and neutral pH values in surface horizons, with commonly eutrophic to calcareous subsurface horizons with moderate to high CEC and alkaline pH values.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Weak block structure in topsoils with strong prismatic to block structure on subsoil horizons.
Mineralogy: Variable quartzitic, micaceous and kaolinitic in surface horizons. Smectite, quartzite and micaceous mineralogy is expected in clay subsurface horizons.
Water retention, degree of saturation and hydraulic conductivity: Low water retention is expected in surface horizons, variable degrees of duration of water saturation, and low to moderate infiltration and hydraulic conductivity. Moderate water retention expected in prismacutanic and pedocutanic horizons, low to moderate degrees of duration of saturation and very low hydraulic conductivity values. Variable but generally low to moderate hydraulic conductivity may be expected in alluvial subsoil horizons. Deeper unconsolidated materials and soils with properties resembling deeper "bleached E horizons" may exhibit moderate hydraulic conductivity.

Expected Hydrological Response

Recharge and overland surface flows can be expected for the surface horizons of duplex soils in upland terrain positions. Recharge of subsurface horizons can be expected after prolonged rain events as hydraulic conductivity if these horizons is low. Limited lateral flow in deep subsurface horizons can be expected where evidence of deep subsurface gleying is present. This evidence is generally not documented in Land Type inventories, but may be interpreted from certain soil profile descriptions and analyses. Slow interflow is expected in midslope soils and slow discharge flow in bottomland soils. Many ***Db*** and ***Dc*** landscapes have extensive sheet and gully erosion that will alter expected soil property interpretations.

Ea – LAND TYPE SYMBOL – ONE OR MORE OF: VERTRIC, MELANIC, RED STRUCTURED DIAGNOSTIC HORIZONS

Land Type General Identification: These Land Types accommodate high base status, dark-coloured and/or red structured soils, usually of clay texture, associated with basis igneous rocks. More than half of the land surface is covered by vertic, melanic or red structured diagnostic horizons. Duplex soils or exposed rock may cover significant portions of the land surface, but vertic, melanic or red structured horizons are dominant.

Generalized Soil Properties

Forms and Series (1977 Edition): Vertic soils include Arcadia and Rensburg soil forms, melanic soils include Bonheim, Mayo, Milkwood, Inhoek, Tambankulu and Willowbrook soil forms. Shortlands soils have a red structured diagnostic horizon. Mispah and Glenrosa soils, duplex soils Sterkspruit, Valsrivier, Swartland and Estcourt soil forms may be present, with various proportions of rock land and are usually associated with sub-dominant sedimentary rock types.
Estimated Depth: Arcadia Rensburg and Bonheim soil are usually moderately deep (600 to 900 mm), Shortlands soils are usually shallow to moderately deep (400 to 800 mm) while Mayo, Milkwood Tambankulu and Willowbrook soils are usually shallow (200 to 500 mm).
Texture: Clay soils, while certain Mayo and Milkwood soils may have sandy clay textures.
Base Status: Eutrophic base status (Ca, Mg, K, Na) with high to moderately high CEC and neutral to slightly alkaline pH values. Lime concretions are common in all soil forms.
Organic Matter: Moderately high organic carbon levels are common in topsoils of all black clays.
Structure: Strong, fine, block structure is common in topsoils and moderate to strong, fine to coarse, block structure in subsoil horizons.
Mineralogy: Smectite is the dominant mineral in Rensburg and Arcadia soils, smectite and 2:1 mineralogy is commonly dominant in Bonheim, Mayo and Milkwood soils. Kaolinite and mica are dominant in Shortlands soils.
Water retention, degree of saturation and hydraulic conductivity: High water retention is present in all soil horizons. Variable degrees of duration of water saturation can be expected. Rensburg and Willowbrook soils have extended periods of water saturation in subsurface horizons. Brown coloured subsoils of Bonheim form may have limited periods of partial saturation. Mayo, Milkwood and Shortlands soils are freely-drained. Larger cracks are present on drying of vertic soils that high infiltration values are expected as water enters dry soil. Infiltration rates will decrease significantly on wetting and swelling of these soils. Bonheim, Mayo and Milkwood topsoils exhibit moderate to strong structure on drying and will have moderate infiltration rates for dry soils. Infiltration is expected to be moderate to low in moist topsoils. Rensburg, Arcadia and Bonheim soils have high swelling clays and low hydraulic conductivities. Shortlands, Mayo and Milkwood soils are expected to have moderate infiltration rates and moderate hydraulic conductivities.

Expected Hydrological Response

Shortlands, Mayo, Milkwood and Arcadia soils will behave as recharge soils at upland sites and recharge and interflow soils at midslope sites. Bonheim soils are expected to have recharge, interflow and discharge properties dependent on landscape position, while Rensburg and Willowbrook soils are expected to have discharge properties.

Fa and Fb- LAND TYPE SYMBOLS – GLENTROSA AND/OR MISPAH FORMS (OTHER SOILS MAY OCCUR) *(Fa – Lime rare or absent in the entire landscape. Fb – Lime rare or absent in upland soils but generally present in low-lying soils.)*

Land Type General Identification: These Land Types are intended to accommodate pedologically young landscapes that are not predominantly rock and not predominantly alluvial or Aeolian, and in which the dominant soil forming process has been rock weathering, the formation of orthic topsoil horizons, and commonly clay illuviation, giving rise to lithocutanic horizons. The soil forms which epitomize these processes are Glenrosa and Mispah. However, exposed rock and soils belonging to almost any other soil form may be found in these Land Types, provided they do not qualify the land for inclusion into another Land Type.

Fa refers to land in which lime is not encountered regularly in any part of the landscape. ***Fb*** indicates land in which lime occurs regularly (there need not be much lime) in one or more valley bottom sites.

Lime has been used as an indicator of the extent which these youthful landscapes have been leached.

Generalized Soil Properties

Forms and Series (1977 Edition): The Land Type is dominated by Glenrosa and Mispah soil forms. Glenrosa soils are identified by an orthic topsoil horizon directly overlying fractured rock or where tilting or weathering of the underlying rock has taken place, weathered to the extent that clay illuviation into this material has taken place. These partly weathered materials provide a medium for plant growth and facilitate water flows. Mispah soils are identified where the underlying rock is hard with limited fracture planes, that root penetration and growth of annual plants is restricted. Water flows will also be restricted. Soil depth is usually shallow.

Fa Land Types are characterized by greater weathering of underlying parent rock in climates with generally higher rainfall or a lower evapotranspiration demand. This may take the form of the underlying saprolite rock having a softer consistence with greater weathering, through to a range of soil forms with identifiable diagnostic horizons. In higher rainfall zones, Hutton, Clovelly, Oakleaf, Avalon and Longlands soil forms are also present as identifiable soil forms, or within soil/rock complexes. These soils may have a mesotrophic base status and an acid pH values. Slopes may be steeper, resulting in greater soil loss with limited soil depth. In lower rainfall zones with basic igneous rocks, Mayo, Milkwood and shallow or rocky Shortlands soils may be present.

Fb Land Types are characterized by less intense weathering of underlying parent rock in climates with generally higher evapotranspiration demand and seasonal dry periods. On sedimentary parent materials, Westleigh, Longlands, Swartland Sterkspruit and Valsrivier soils are expected. Mayo, Milkwood and Bonheim soil forms are expected where basic igneous rocks are the parent material. Soil/rock complexes commonly form part of the landscape. Lime concretions are present in bottomlands where slightly acid to slightly alkaline pH values are expected.

Estimated Depth: Soil depth is generally shallow (200 to 500 mm) for the Glenrosa and Mispah soil forms. Soil depth of other soil forms is usually also restricted, although small areas of deeper soil are to be expected.

Texture: Textures for the soils of ***Fa*** and ***Fb*** Land Types is strongly dependent on the clay forming potential of the underlying geological formations. Textures are variable, although sandy loam to sandy clay loam textures for the Glenrosa and Mispah soils can be expected. Similar topsoil textures for the Westleigh, Swartland and Sterkspruit are expected, with sandy

clay to clay textures for subsoils of duplex soils. Clay textures for Mayo, Milkwood and Bonheim soils may be expected.
Base Status: Base status (Ca, Mg, K, Na) is variable and dependent on rainfall. Mesotrophic to eutrophic base status may be expected for ***Fa*** Land Types, and eutrophic base status for ***Fb*** Land Types.
Organic Matter: Moderately to low levels of organic carbon levels are expected for ***Fa*** Land Types, and low levels for ***Fb*** Land Types.
Structure: Variable structure are to be expected.
Mineralogy: Kaolinite, quartz and micaceous mineralogy could be expected for topsoil horizons. Smectite and micaceous mineralogy is expected for the Mayo soils, and the subsoil horizons of the duplex soils.
Water retention, degree of saturation and hydraulic conductivity: Low water retention, degree of saturation and hydraulic conductivity is expected for the Glenrosa and Mispah soils.

Expected Hydrological Response

In the dry state, Glenrosa, Mispah (and Mayo, Milkwood) soils will function as recharge sites. However, limited soil depth will result in the soils rapidly being saturated with water. Overland flow and interflow on sloping land could be expected. Exposed rock land will result in rapid overland flow. The soil/rock complexes are expected to function as recharge or interflow soils depending on the dominant soil properties.

Fc – LAND TYPE SYMBOL – GLENTROSA AND/OR MISPAH FORMS (OTHER SOILS MAY OCCUR) ***(Fc – Lime generally present in the entire landscape)***

Land Type General Identification: These Land Types are intended to accommodate pedologically young landscapes that are not predominantly rock and not predominantly alluvial or Aeolian, and in which the dominant soil forming process has been rock weathering, the formation of orthic topsoil horizons, and commonly clay illuviation, giving rise to lithocutanic horizons. The soil forms which epitomize these processes are Glenrosa and Mispah. However, exposed rock and soils belonging to almost any other soil form may be found in these Land Types, provided they do not qualify the land for inclusion into another Land Type.

Fc indicates land in which lime occurs in the entire landscape.

Lime has been used as an indicator of the extent which these youthful landscapes have been leached.

Generalized Soil Properties

Forms and Series (1977 Edition): The Land Type is dominated by Glenrosa and Mispah soil forms. Glenrosa soils are identified by an orthic topsoil horizon directly overlying fractured rock or where tilting or weathering of the underlying rock has taken place with weathered to the extent that clay illuviation into this material has taken place. These partly weathered materials provide a medium for plant growth and facilitate water flows. Mispah soils are identified where the underlying rock is hard with limited fracture planes, that root penetration and growth of annual plants is restricted. Water flows will also be restricted. Soil depth is usually shallow.

Fc Land Types are characterized by limited weathering of underlying parent rock in arid climates with high evapotranspiration demand. Slopes may be steeper resulting in greater soil loss with limited soil depth. In lower rainfall zones with basic igneous rocks Mayo, Milkwood and shallow or rocky Shortlands soils may be present.

Estimated Depth: Soil depth is generally shallow (100 to 300 mm) for the Glenrosa and Mispah soil forms. Soil depth of other soil forms is usually also restricted, although small areas of deeper soil are to be expected.
Texture: Textures for the soils of ***Fc*** Land Types is strongly dependent on the clay forming potential of the underlying geological formations. Textures are variable, although sandy loam to sandy clay loam textures for the Glenrosa and Mispah soils can be expected.
Base Status: Base status (Ca, Mg, K, Na) is high.
Organic Matter: Low levels of organic carbon levels are expected for ***Fc*** Land Types.
Structure: Variable structure is to be expected.
Mineralogy: Kaolinite, quartz and micaceous mineralogy could be expected for topsoil horizons.
Water retention, degree of saturation and hydraulic conductivity: Low water retention, degree of saturations and hydraulic conductivity is expected for the Glenrosa and Mispah soils.

Expected Hydrological Response

In the dry state, Glenrosa, Mispah (and Mayo, Milkwood) soils will function as recharge sites. However, limited soil depth will result in the soils rapidly being saturated with water. Overland flow and interflow on sloping land could be expected. Exposed rock land will result in rapid overland flow. The soil/rock complexes are expected to function as discharge or interflow soils.

Ga and Gb – LAND TYPE SYMBOLS – SOILS WITH A DIAGNOSTIC FERRIHUMIC (PODZOL) HORIZON *(Ga – Predominantly deep Lamotte form, Gb – Predominantly shallow Houwhoek form)*

Land Type General Identification: These Land Types are intended to accommodate parts of South Africa where podzols occur. After subtracting exposed rock, the areas covered by Lamotte or Houwhoek soils exceeds 10% of the land surface, provided the areas covered by these soils exceeds that of Aa-Ai, Ba-Bd, Ca, Da-Dc, Ea, Ib or Ic Land Types. Land may qualify for inclusion in Ga or Gb Land Types even though the area covered by Lamotte and Houwhoek soils is less than the soils characteristic of the Fa-Fc, Ha, Hb and Ia Land Types. Ga and Gb Land Types are restricted to the Southern and Western Cape coastal areas.

Generalized Soil Properties

Forms and Series (1977 Edition): Ga Land Types consist of Lamotte (and Houwhoek) soil forms together with deep grey and red sands. Gb Land Type consists of Houwhoek (and Lamotte) soil forms with rock land and other soil and soil rock complexes.
Estimated Depth: Ga Land Types have generally deep sands (900 mm) and ***Gb*** Land Types shallow soils and rock land.
Texture: Sands
Base Status: Variable.
Organic Matter: Moderate organic carbon levels may be present for the Lamotte and Houwhoek topsoils. Low levels of organic carbon levels are expected for subsoil horizons.
Structure: Loose sandy soils.
Mineralogy: Quartz mineralogy.
Water retention, degree of saturation and hydraulic conductivity: Low water retention. Degree of water saturation and hydraulic conductivity are not well documented.

Expected Hydrological Response – Variable.

Ha and Hb – LAND TYPE SYMBOLS – GREY REGIC SANDS *(Ha – Regic sands dominant, Hb – Regic sands and other soils)*

Land Type General Identification: These Land Types accommodate land in which deep grey sands of the Fernwood are a prominent feature. Constantia and Shepstone and Vilafontes forms are also included. ***Ha*** indicates land where these soils occupy more than 80% of the area, while ***Hb*** indicates land where these soils occupy between 20 to 80% of the area. In the SA Binomial Classification System (1977), the Fernwood soil form was classified as an orthic topsoil over a regic sand subsoil horizon. The SA Taxonomic System (1991) classified these sandy subsoil horizons to an E horizon, better reflecting the presence of water saturation during wet seasons with frequent rainfall events. Fernwood soils in of the eastern coastal regions are expected to have periods of saturated or near saturated water contents, together with periods where water saturation is low (essentially dry soil water regime). The SA Taxonomic Classification System (1991) introduced the Namib Soil form with an orthic horizon over regic sand where cross-bedding planes are evident in the soil morphology. The Namib soil form is characteristic of arid (and to some extent semi-arid) landscapes. The Land Type information considers only the 1977 classification, that Fernwood soils have a deep grey sand morphology. Fernwood soils of the eastern coastal regions will have periods of both high water saturation and relative low water saturation values, while those of the western coastal regions are expected to have limited periods of water saturation.

Generalized Soil Properties

Forms and Series (1977 Edition): Ha. Dominantly Fernwood, with Shepstone and Constantia soils. ***Hb.*** Fernwood with greater proportions of sandy Hutton, Clovelly and Oakleaf soils. Other sandy soils may occur.
Estimated Depth: Deep (>1 200 mm).
Texture: Fine- or fine- to medium-grained sands.
Base Status: Low with low CEC values in eastern regions with acid soils. Western regions may contain shells and carbonates.
Organic Matter: Low organic carbon levels throughout soil profiles.
Structure: Loose, single-grain structure.
Mineralogy: Variable quarzitic and kaolinitic mineralogy in eastern regions.
Water retention, degree of saturation and hydraulic conductivity: Low water retention throughout all horizons. Degree of saturation is described above. High hydraulic conductivity properties are expected. (Sands located on the Cape Peninsula may exhibit hydrophobic hydraulic properties that are not well documented.)

Expected Hydrological Response

Recharge and interflow properties in upland sites and discharge properties in low terrain positions.

Ia – LAND TYPE SYMBOL – MISCELLANEOUS LAND CLASSES *(Ia – Recent Alluvium)*

Land Type General Identification: These Land Types accommodate land with pedologically youthful deep unconsolidated sediments. Common soils are Dundee and Oakleaf.

Generalized Soil Properties

Forms and Series (1977 Edition): Dundee and Oakleaf soils with variable proportions of other soils in a generally recent alluvial environment.
Estimated Depth: Variable, but commonly deep (>900 mm).
Texture: Variable, due to depositional nature.
Base Status: Variable.
Organic Matter: Generally low.
Structure: Variable, usually apedal to weak block structure.
Mineralogy: Variable.
Water retention, degree of saturation and hydraulic conductivity: Variable.

Expected Hydrological Response

Variable, but often occurring in lowland positions, so dominated by discharge functions.

Ib and Ic – LAND TYPE SYMBOLS – MISCELLANEOUS LAND CLASSES *(Ib – Rock areas with miscellaneous soils, Ic – Rock areas with little or no soil.)*

Land Type General Identification: These Land Types accommodate land with pedologically youthful deep unconsolidated sediments. Rock land and soil/rock complexes dominate.

Generalized Soil Properties

Forms and Series (1977 Edition): Ib indicates Land Types with exposed country rock, stones and boulders covering 60 to 80% of the area. ***Ic*** indicates Land Types with exposed country rock, stones and boulders covering more than 80% of the area
Estimated Depth: Very limited (often <100 mm).
Texture: Variable.
Base Status: Variable.
Organic Matter: Generally low.
Water retention, degree of saturation and hydraulic conductivity: Variable.

Expected Hydrological Response

Recharge and interflow properties in upland sites and discharge properties in low terrain positions.

Appendix 7. Capacity Building

A. Student Training

The following students have been officially added to the project via the FMS:

Student	Course	University	Student No.
Brendon Fourie	BSc (Hons)	UP	11210509
Siyabonga Mqina	BSc (Hons)	UP	15338470
Matimba Mathew Chauke	BSc (Hons)	UFS	2008047702
Nancy Job	PhD	UFS	2016036168

B. Technology Transfer

i. Thesis publications

- *Refining wetland classification for South Africa* by B Fourie, BSc (Hons) project. See Appendix 3 for title page (Fourie, 2015).
- *The influence of Land Types on water infiltration and soil erosion* by S Mqina, BSc (Hons) project. See Appendix 4 for title page (Mqina, 2015).

ii. The Water Wheel publications

- *The science of hydropedology – linking soil morphology with hydrological processes* by Johan van Tol, Pieter le Roux and Simon Lorentz. *The Water Wheel* May/June 2017, pp. 20-22. The article content focussed on the basics of hydropedology. This project focussed on applications of hydropedology. A follow-up article will focus on the results of this project.
- *The science of women in wetlands*. *The Water Wheel* July/August 2017, pp. 24-27. Nancy Job features in the article and reference is made to her work on hillslope hydrological processes on wetland form and function.

iii. Presentations

Annual Wetland Seminar (10 February 2017)

- Nancy Job presented at the ARC-IMCG Wetland seminar held at the DEA on 10 February 2017. The title of the presentation was: *Exploring landscape-wetland linkages*.

Pre-Indaba engagement (7 July 2017)

- Nancy Job presented a draft version of the guidelines to the KZN Wetland Forum on 7 July 2017. The presentation generated positive discussion and interest.

National Wetlands Indaba 2017 (16-19 October 2017)

- Oral presentation by Pieter le Roux. The title of the presentation was: *Wetlands: pinnacles of the hidden half of the hydrological cycle.*
- Poster presentation on the *Hydropedology database* (Turner, Paterson, Grundling, van der Walt and de Nysschen).

International Society of Wetland Scientists Annual Meeting (28 May-1 June 2018)

- Oral presentation by Nancy Job. The title of the presentation was: *Wetlands: pinnacles of the hidden half of the hydrological cycle.*