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 3:

Framework for the regional wetland soil contextualization

DISCUSSION DOCUMENT

Report to the

Water Research Commission

compiled by

JH van der Waals[1]

editing by

AT Grundling[2] and DG Paterson[2]

[1] *Terra Soil Science*

[2]*Agricultural Research Council – Institute for Soil, Climate and Water*

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Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

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:

- *Improving the management of wetlands by including hydropedology and land type data at catchment level* (WRC Report No. 2461/1/18), and
- *Preliminary guidelines to apply hydropedology in support of wetland assessment and reserve determination* (WRC Report No. 2461/2/18).

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PREAMBLE

This report is Volume 3 of the reports. ***Volume 1*** discussed various aspects of hydropedological concepts, as well as various scales of investigation of wetland assessment. It addressed the benefits and limitations of these various scales, with special emphasis on the nationally available 1:250 000 scale land type information. ***Volume 2*** looked at preliminary guidelines and sets of instructions to apply the information contained in Volume 1, as well as information on the various pathways of water flow, impacts and eventual effects on wetlands.

This volume, however, is presented as a discussion document, in order to supply additional information and concepts that may be of use to wetland practitioners, planners and other environmental researchers who are active in the field of wetland delineation. It was not one of the originally envisaged deliverables, but as the as the project developed, it was felt beneficial to provide the information that is presented here. A series of seven chapters address a range of topics and issues concerning the statutory and legal situation, challenges and the broader hydrological context, soils and land type information.

It should be clearly stated that, while the data and information in this volume is of a high standard, reflecting current concepts and experience of the author, it still forms a basis for discussion and should be seen as a starting point for further study and research into wetland delineation.

Report Structure

1. Introduction
2. Statutory context of wetland delineation and assessment
3. Challenges to the current wetland delineation and assessment approaches
4. Hydrological context and application of soil and landscape parameters
5. Introduction to the soils and land types of South Africa – understanding the broader soil context
6. Unpacking the land type data for wetland expression and the identification of wetland soils
7. The hydropedology context of redox morphology expression

Disclaimer

This document is intended as a discussion document. As such it is a work in progress and relies heavily on positive (and even negative) feedback. The document is therefore not in a final state and no such claims are made in the text. It is envisaged that the document will be expanded and edited/amended as more input is obtained from a range of other workers in the field.

Certain sections of this document have been used as a standard description in many Terra Soil Science reports to describe the challenges regarding wetland delineation in various environments (urban, mining, specific geological settings). This implies that certain sections are verbatim the same as in other reports provided to clients and the authorities.

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Mr B Madikizela	Water Research Commission (Chair)
Dr W Roets	Department of Water and Sanitation
Dr P Gama	Nelson Mandela Metropolitan University
Ms N Mbona	South African National Biodiversity Institute

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ABBREVIATIONS

ARC-ISCW	Agricultural Research Council Institute for Soil, Climate and Water
NFEPA	National Freshwater Ecosystem Priority Areas
SANBI	South African National Biodiversity Institute
WRC	Water Research Commission

CHAPTER 1 – INTRODUCTION

During the course of a number of years of work in the wetland delineation and wetland impact assessment environment a number of aspects have been identified that pose challenges to the effective assessment of wetland boundaries and hydrological functioning as well as the assessment of human impacts on these wetlands. In some severe cases it was found that standard delineation outcomes have led to significant degradation of the wetlands as the authorities omitted stipulating any storm water management measures outside of the wetland and buffer area.

1.1 Wetland Assessment and Delineation Background

1.1.1 Wetland Context

At the outset it has to be emphasized that this document will adhere to the philosophy that: "Every wetland has a context." Soil morphology (in the form of hydromorphism – morphological signs of wetness) is the tool for the elucidation of soil hydrology. This field of science is known as hydropedology. Together with proper geological and topographical contextualisation it makes for a landscape to be read like a book in terms of hydrological processes.

1.1.2 Legislative and Administrative Context

Wetlands have grown in stature regarding public awareness over the past two decades. Formal wetland delineation and assessment exercises are conducted within a specific administrative legal context with a number of acts that apply and with the National Water Act (Act no 36 of 1998) (NWA) and the National Environmental Management Act (Act No. 107 of 1998) (NEMA) being the central ones. The regulations of the acts guide the implementation / execution, and in turn stipulate the use, of applicable guidelines for specialists and environmental assessment practitioners (EAP). Both these acts accommodate administrative compliance and criminal prosecution aspects. It therefore follows that a wetland delineation exercise intended for the guiding of an administrative action can become the central basis for an argument in a criminal prosecution process.

The three main role players in the legal processes are 1) the competent authority that administers the acts and authorisation process, 2) the applicant that applies for specific authorisations and 3) the EAP or specialist that informs the administrative process based on scientific input. The specialist is required to be registered with the South African Council for

Natural and Applied Scientific Professions (SACNASP) under the Natural Scientific Professions Act (Act No. 27 of 2003) (NSPA). In the event of a criminal prosecution process the specialist could also become a specialist witness for the court. In this regard it is important to note that in South African law the reverse onus principle applies in criminal law. This leads to a threefold burden namely 1) emphasis on procedural and technical law aspects, 2) the competence and qualifications of the specialist and 3) the rigorous interrogation of the science upon which the process is based.

In 2005 the Department of Water Affairs and Forestry published the wetland delineation guidelines (DWAF, 2005) to serve as a tool for the delineation of the outer boundaries of wetlands. Although the intention is clearly stated, namely the delineation of the outer boundary of wetlands, these guidelines have formed the foundation for various competent authorities (in terms of environmental applications and authorisations) to guide the spatial planning processes during developments that include urban developments, physical mine boundary determinations and rehabilitation and conservation planning as well as rural land use changes.

1.1.3 Application Challenges of Delineation Outcomes

Within the context of the importance assigned to a delineation outcome in the spatial planning and authorisation processes there is a distinct lacuna (gap) that emerges when the process is disaggregated and analysed. This critique / evaluation aims to address the lacuna within a scientific context through the detailed disaggregation of the soil science components that the wetland delineation process and decision-making are based upon.

The regulator / competent authority uses the delineation outcome to determine the regulated zone. Depending on the competencies and process rigour of the competent authority (and its personnel) varying levels of input is provided regarding the results of the assessment. Due to 1) a lack of emphasis on the hydrological drivers of wetland expression and 2) a general poor understanding of all the effects of driver changes in hydrologically altered environments the general trend by the regulator is to enforce or enlarge hands-off buffer areas on wetlands. This approach provides a false sense of security to the regulator as the focus is invariably on the identification of habitat and biota parameters of the water expression in the landscape. However, when the drivers are considered it becomes evident that the intensified buffer approach is counter-productive.

1.1.4 Technical Delineation and Assessment Context Addressed in This Document

Wetland delineation is the process of establishing the boundary of the wetland / watercourse zone as regulated in the relevant legislation. **Wetland assessment** is the characterisation of the wetland properties, expression and function. It has as a fundamental component the description and elucidation of the hydrological drivers. Both of these aspects will be addressed in detail in this document in the context of the soil setting.

1.2 Wetland Drivers and Ecological Responses

The identification and assessment of wetlands rest on the elucidation and description of wetland habitat and wetland biota. These parameters have value in terms of their expression of ecosystem health and biodiversity characteristics of specific landscapes as they constitute the responses to a range of drivers centred around water (**Figure 1.1**). The response is specifically related to the physical / hydrological parameters of water summarised in the concept of “flow regime” and in the chemical / biological parameters summarised in the concept of “water quality” and is referred to in general as the ecosystem services associated with the responses (**Figure 1.1**). The flow regime, water quality and geomorphology characteristics (drivers) of a landscape determine the types and characteristics of the response expressed as habitat and biota. It therefore follows that in the event that the drivers are altered the responses, and therefore ecosystem services, will be altered as well. This concept is central to the understanding and elucidation of wetland (habitat and biota) impacts and is currently emphasised by the Department of Water and Sanitation (DWS) when considering water use licence application processes.

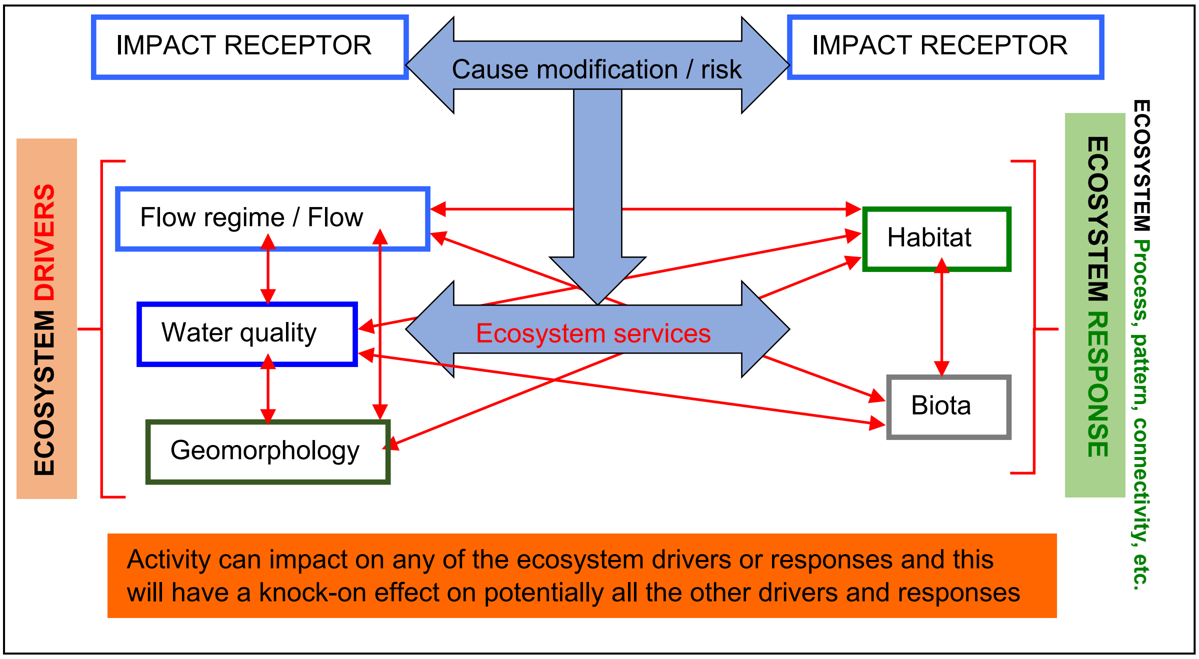

Figure 1.1 Ecosystem services drivers and responses (sourced from DWS)

The ecosystem drivers are contextualised in the geological, topographical and climatic setting. Together with biota and the relative age of the landscape these parameters constitute five soil forming factors that determine the specific soil profiles and characteristics encountered in a landscape. It is therefore no coincidence that two of the four wetland indicators relate to soil namely soil form (formal classification: SA Taxonomic System – Soil Classification Working Group, 1991) and soil wetness (redox morphology indictors of long-term water regime in the form of soil material colours and mottles as a function of iron chemistry and mineralogy) (DWAF, 2005). The remaining two are landscape position (geomorphology – ecosystem driver) and vegetation (biota – ecosystem response).

The assessment of wetlands is usually based on the measurement of ecological properties of the specific wetland or landscape. These relate to a host of living organisms that indicate the status and quality of the wetland with values assigned by specialists to these indicators. The wetland specialist therefore provides a snapshot of the condition of the wetland and this snapshot indicates the characteristics or “value” that will be lost once the wetland is impacted.

However, the ecological response is entirely dependent on the hydrological drivers of the wetland system. The drivers are numerous and include the following:

1. Surface hydrology of the landscape: This parameter determines flow dynamics of water with subsequent accumulation zones that correspond to depressions and low points. This driver is accounted for in the terrain unit indicator (wetland delineation guidelines) on a landscape scale but is often overlooked on a much

more localised scale in furrows, erosion features and micromorphological features encountered in many landscapes. The typical responses to these features relate to the well-established knowledge on wetland ecology in that wetter zones will indicate ecological signatures associated with the degree and duration of wetness. It therefore follows that surface runoff characteristics of a landscape, when altered, will alter the responses accordingly. Examples include road, paving or roof surfaces that seal the soil or complete alteration of landscape surfaces through cut and fill operations. The typical response to these operations are reflected in storm water signatures related to wetland vegetation establishment in culverts / channels, erosion of unstable soils and materials, and/or rapid filling of depressions with water following rainfall events.

2. Interflow or hillslope hydrology: This parameter is described in much more detail below and is a function of a number of soil, geology and landscape characteristics. The essence is that interflow or hillslope water can manifest in any position in the landscape and surface or near surface water will elicit an ecological response that can be measured and assessed. If however the soil, geological or landscape characteristics are altered the seepage pathways will also be altered and the wet ecological response may vary from disappearing in the areas that have become drier or being amplified in areas that have become wetter. Alteration of the surface, as discussed above, may also impede or increase infiltration with a subsequent increase in interflow and wet ecological response.
3. Groundwater hydrology: This parameter is influenced by both of the parameters described above and constitutes the water resource that is often accessed through boreholes or deep wells. Groundwater can in some cases intercept the land surface and in such conditions it will elicit a wet ecological response. If the water level changes the response will change accordingly.
4. Water quality: This parameter is a significant driver of the specific wet ecological response in that different organisms will provide distinct perspectives on the chemical signature of the water that manifests near or on land surfaces. However, this parameter can also be altered to varying degrees by the above parameters and their alteration and it therefore also constitutes a response to the above three.

It is critically important to note here that the natural landscape condition, with its equilibrium in terms of surface, hillslope, groundwater and water quality characteristics, forms the reference state for the assessment of ecological and hydrological parameters. Any alteration in these parameters would elicit altered responses that may be desirable or not. This also forms the philosophical and practical basis for integrated storm water management, wetland rehabilitation and artificial wetland design and construction.

1.3 Soil as a Tool for Wetland Driver and Context Description

The relevance of soils as tools for the elucidation and description of landscape context and hydrological drivers is discussed in detail below. It is however important to emphasize the differences that are evident in South African soils when these are compared to the soils of countries where wetland assessment processes based on the identification of hydric soil indicators are used in administrative and legal compliance processes. One such example is the large body of knowledge underpinning the identification, assessment, management and protection of wetlands in the USA that served as a motivation for the processes followed in South Africa.

Laker (2003) describes three main soil regions in the world namely 1) soils of the high latitudes and continental land masses in the northern hemisphere, 2) the soils of the humid and sub-humid tropics around the equator and 3) the soils of the southern hemisphere lying between 20 and 35 degrees south. The first regions is characterised by cooler to cold climates and have experienced relatively recent glaciation. The soils are therefore indicative of the cold weather in that they contain significant organic carbon and the soils also exhibit signs of youthful age when compared to older tropical soils. The second region is characterised by older and very pronounced pedogenesis. Both the aforementioned groups have been studied extensively and are adequately accommodated in several local and international soil classification systems. The third region is characterised by hard geology, old age and moderate to low rainfall leading to the development of very distinct soils that are not always comfortably accommodated in international classification systems. The South African Taxonomic System therefore accommodates the soils in a structure that is somewhat different to the well-known international systems (USDA Soil Taxonomy and WRB).

The benefit of the above third soil region is that the soils are found on predominantly stable and old land surfaces with the consequence that the soil morphology clearly indicates the hydrological functioning in the expression of redox morphology. This aspect therefore leads to a very distinct redox morphology foundation for wetland delineation. The extension of this argument is that the soil morphology, described within a distinct geological, topographical and climate context provides an excellent tool for the elucidation of landscape hydrological process. The hydrological drivers of wetland conditions can therefore be elucidated through a dedicated assessment of the soils and the weathered zone of the land surface. This argument forms the basis for the discussion to follow as well as the foundation for the determination of the “reference state” as required for ecological assessment techniques.

1.4 Aim of This Document

This document aims to provide a perspective and context of the South African land types and soils in order to guide wetland delineators and wetland assessors to understand soil processes that determine wetland boundaries and functioning. The document aims to provide the information in a digestible format and to function as a teaching and information source. The delineation and assessment process cannot be "mechanised" as it requires very dedicated field work as well as wetland and soil contextualisation. It is therefore hoped that this document could serve as a foundation for the continual equipping of wetland specialists to unearth and discover more soil knowledge as they grow as specialists.

1.5 Structure of This Document

This proposed framework document is structured as follows

1. Introduction
2. Statutory context of wetland delineation and assessment
3. Challenges to the current wetland delineation and assessment approaches
4. Hydrological context and application of soil and landscape parameters
5. Introduction to the soils and land types of South Africa – understanding the broader soil context
6. Unpacking the land type data for wetland expression and the identification of wetland soils
7. The hydropedology context of redox morphology expression

References

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

Laker, M.C. (2003) Advances in the South African Soil Classification System. *In* (Eds.) Eswaran, H., Rice, T., Ahrens, R., Stewart, B.A. Soil Classification: A Global Desk Reference. CRC Press, Boca Raton, pp.199-218.

CHAPTER 2 – STATUTORY CONTEXT

The statutory and regulatory context of wetland delineation and assessment determines largely the technical parameters used and rigour applied. It is critical to start the wetland delineation and assessment guideline contextualisation of soil parameters with the legal foundation. The discussions that pertain to wetland expression and the formal delineation of such expression in later chapters all refer back to the statutory and regulatory context elucidated in this chapter.

2.1 The National Water Act (NWA)

2.1.1 Purpose of the National Water Act

Wetlands are defined in the National Water Act (Act no 36 of 1998) (NWA) and their status in the Act has to be weighed against the act's purpose, namely:

"The purpose of the National Water Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all." (Department of Water Affairs, undated publication) http://www.dwaf.gov.za/Documents/Publications/NWAguide/part1.pdf
(Accessed: 07/03/2013 @ 12:01)

2.1.2 Wetland Definition

Wetlands are defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

"Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."

2.1.3 Watercourse Definition

"Catchment" is defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

"…, in relation to a watercourse or watercourses or part of a watercourse, means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points;"

“Watercourse” is defined, in terms of the National Water Act (Act no 36 of 1998) (NWA), as:

> “*(a)* a river or spring;
> *(b)* a natural channel in which water flows regularly or intermittently;
> *(c)* a wetland, lake or dam into which, or from which, water flows; and
> *(d)* any collection of water which the Minister may, by notice in the *Gazette*, declare to be a water course,
> and a reference to a watercourse includes, where relevant, its bed and banks;”

2.1.4 The Resource Directed Measures for Protection of Water Resources.

The following are specific quotes from the different sections of the “Resource Directed Measures for Protection of Water Resources” as published by DWAF (1999). All the components of the RDM document have bearing on this document and these will be discussed in more detail throughout the document.

2.1.4.1 The Resource Directed Measures for Protection of Water Resources: Volume 4: Wetland Ecosystems.

From the Introduction:

“This set of documents on Resource Directed Measures (RDM) for protection of water resources, issued in September 1999 in Version 1.0, presents the procedures to be followed in undertaking **preliminary determinations of the class, Reserve and resource quality objectives for water resources**, as specified in sections 14 and 17 of the South African National Water Act (Act 36 of 1998).

The development of procedures to determine RDM was initiated by the Department of Water Affairs and Forestry in July 1997. Phase 3 of this project will end in March 2000. Additional refinement and development of the procedures, and development of the full water resource classification system, will continue in Phase 4, until such time as the detailed procedures and full classification system are ready for publication in the Government Gazette.

It should be noted that until the final RDM procedures are published in the Gazette, and prescribed according to section 12 of the National Water Act, all determinations of RDM, whether at the rapid, the intermediate or the comprehensive level, will be considered to be preliminary determinations.”

2.1.4.2 The Resource Directed Measures for Protection of Water Resources: Generic Section "A" for Specialist Manuals – Water Resource Protection Policy Implementation Process

"Step 3: Determine the reference conditions of each resource unit"

"What are reference conditions?"

"The determination of reference conditions is a very important aspect of the overall Reserve determination methodology. Reference conditions describe the natural non-impacted characteristics of a water resource. Reference conditions quantitatively describe the eco-regional type, specific to a particular water resource."

2.1.4.3 The Resource Directed Measures for Protection of Water Resources: Appendix W1 (Eco-regional Typing for Wetland Ecosystems)

Pan systems are explained:

"6. Endorheic System

Definition

The Endorheic System comprises wetlands that would otherwise be classified as Palustrine or Lacustrine, but which possess **all** of the following additional characteristics:

1. circular to oval in shape, sometimes kidney-shaped or lobed;
2. flat basin floor;
3. less than 3 m deep when fully inundated; and
4. closed drainage (lacking any outlet).

Description

Wetlands of the Endorheic System are commonly referred to as pans in South Africa, and as small closed basins or playas in geomorphological literature. The majority of pans in the country occur in the area with a mean annual rainfall of less than 500 mm and an average net evaporation loss greater than 1000 mm per annum (Shaw 1988). Being located largely in dry regions, pans display characteristic patterns of ephemeral and irregular inundation. Pans in the arid western regions of South Africa may remain dry for years between temporary flooding, while those in the higher rainfall regions display seasonal inundation regimes, and may remain flooded over a number of seasons. Some of the larger pans on the Mpumalanga Highveld are permanently inundated, large, deep and have rooted vegetation (Allan *et al.,* 1995). As such, these pans would be classified as Lacustrine if their water depth exceeds 3 m.

Being endorheic, pans lose water largely by evaporation, which also contributes to the high salinity observed in many of these systems."

Artificial modifiers are explained namely:

"In order to fully describe wetland habitats it is necessary to apply certain Modifiers in the classification hierarchy. There are three groups: Water Regime, Water Chemistry and Artificial Modifiers.

Water Regime Modifiers

These require detailed knowledge of the duration and timing of inundation, both yearly and long term. Tidal Modifiers are determined largely by oceanic tides and are divided into Subtidal, Irregularly Exposed, Regularly Flooded and Irregularly Flooded. Non-tidal Modifiers include Permanently Flooded, Semi-permanently Flooded, Seasonally Flooded, Temporarily Flooded, Intermittently Flooded and Saturated. Habitats may also be Artificially Flooded.

For the Estuarine System, two additional modifiers have been defined: Permanently Open and Temporarily Open/Closed. As the permanence of the connection between the Estuarine System and ocean will significantly influence the ecology of the estuary, these modifiers were considered important (R. Taylor, KZNNCS, Pers. comm.).

Water Chemistry Modifiers

The accurate characterization of water chemistry in wetlands is difficult because of problems in measurement and fluctuation of the parameters according to season, time of day, or other factors. Despite these problems, the description of water chemistry is important, as it determines species composition of habitats and has implications for utilization and management of wetlands. The term "haline" is used to describe ocean-derived (NaCl-dominated) salinity, while "saline" is used for inland waters. Both of these terms are then used in combination with the prefixes Oligo-, Meso-, Poly-, Mixo- (Brackish), Eu- or Hyper- to describe salinity. The Cowardin system extends water chemistry to pH, using Acid, Circumneutral and Alkaline Modifiers.

Artificial Modifiers

"Many wetlands are man-made, while others have been modified from a natural state to some degree by the activities of humans. Since the nature of these alterations often greatly influences the character of such habitats, the inclusion of modifying terms to accommodate human influence is important. In addition, many human modifications, such as dam walls and drainage ditches, are visible in aerial photographs and can be easily mapped. The following Artificial Modifiers are defined and can be used singly or in combination wherever they apply to wetlands:

Farmed: the soil surface has been physically altered for crop production, but hydrophytes will become re-established if farming is discontinued

Artificial: substrates placed by humans, using either natural materials such as dredge spoils or synthetic materials such as concrete. Jetties and breakwaters are examples of Non-vegetated Artificial habitats

Excavated: habitat lies within an excavated basin or channel

Diked/Impounded: created or modified by an artificial barrier which obstructs the inflow or outflow of water

Partially Drained: the water level has been artificially lowered, usually by means of ditches, but the area is still classified as wetland because soil moisture is sufficient to support hydrophytes".

2.1.4.4 The Resource Directed Measures for Protection of Water Resources: Appendix W4 IER (Floodplain Wetlands) Present Ecological Status (PES) Method

In Appendix W4 the methodology is provided for the determination of the present ecological status (PES) of a palustrine wetland. The summarised tasks in the PES methodology are (for detailed descriptions refer to the relevant documentation):

1. Conduct a literature review (review of available literature and maps) on the following:
    a. Determine types of development and land use (in the catchment in question).
    b. Gather hydrological data to determine the degree to which the flow regime has been modified (with the "virgin flow regime" as baseline). The emphasis is predominantly on surface hydrology and hydrology of surface water features as well as the land uses, such as agriculture and forestry, which lead to flow modifications.
    c. Assessment of the water quality as is documented in catchment study reports and water quality databases.
    d. Investigate erosion and sedimentation parameters that address aspects such as bank erosion and bed modification.
    e. Description of exotic species (flora and fauna) in the specific catchment in question.
2. Conduct and aerial photographic assessment in terms of the parameters listed above.
3. Conduct a site visit and make use of local knowledge.
4. Assess the criteria and generate preliminary PES scores.

5. Generation of report.

Table 2.1 presents the score sheet with criteria for the assessment of habitat integrity of palustrine wetlands (as provided in the RDM documentation).

Table 2.1 "Table W4-1: Score sheet with criteria for assessing Habitat Integrity of Palustrine Wetlands (adapted from Kleynhans 1996)"

Criteria and attributes	Relevance	Score	Confidence
Hydrologic			
Flow modification	Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland.		
Permanent Inundation	Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota.		
Water Quality			
Water Quality Modification	From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland		
Sediment load modification	Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats.		
Hydraulic/ Geomorphic			
Canalisation	Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage.		
Topographic Alteration	Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railway lines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns.		
Biota			
Terrestrial Encroachment	Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions.		
Indigenous Vegetation Removal	Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion.		
Invasive plant encroachment	Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading).		
Alien fauna	Presence of alien fauna affecting faunal community structure.		
Over-utilisation of biota	Overgrazing, Over-fishing, etc.		
TOTAL MEAN			

Criteria

Hydrological Criteria

- "Flow modification: Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland."
- "Permanent inundation: Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota."

Water Quality Criteria

- "Water quality modification: From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland."
- "Sediment load modification: Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats."

Hydraulic / Geomorphic Criteria

- "Canalisation: Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage."
- "Topographic Alteration: Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railway lines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns."

Biological Criteria

- "Terrestrial encroachment: Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions."
- "Indigenous vegetation removal: Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion."
- "Invasive plant encroachment: Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading)."
- "Alien fauna: Presence of alien fauna affecting faunal community structure."
- "Over-utilisation of biota: Overgrazing, Over-fishing, etc."

Scoring Guidelines
Scoring guidelines per attribute:
Natural, unmodified = 5
Largely natural = 4
Moderately modified = 3
Largely modified = 2
Seriously modified = 1
Critically modified = 0

Relative confidence of score:
Very high confidence = 4
High confidence = 3
Moderate confidence = 2
Marginal/low confidence = 1

2.1.4.5 The Resource Directed Measures for Protection of Water Resources: Appendix W5 IER (Floodplain Wetlands) Determining the Ecological Importance and Sensitivity (EIS) and the Ecological Management Class (EMC)

In Appendix W5 the methodology is provided for the determination of the ecological importance and sensitivity (EIS) and ecological management class (EMC) of floodplain wetlands.

"Ecological importance" of a water resource is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales. "Ecological sensitivity" refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred. The Ecological Importance and Sensitivity (EIS) provides a guideline for determination of the Ecological Management Class (EMC)." Please refer to the specific document for more detailed information.

The following primary determinants are listed as determining the EIS:

1. Rare and endangered species
2. Populations of unique species
3. Species / taxon richness
4. Diversity of habitat types or features
5. Migration route / breeding and feeding site for wetland species
6. Sensitivity to changes in the natural hydrological regime
7. Sensitivity to water quality changes
8. Flood storage, energy dissipation and particulate / element removal

The following modifying determinants are listed as determining the EIS:

1. Protected status
2. Ecological integrity

2.1.4.6 Appendix W6: Guidelines for Delineation of Wetland Boundary and Wetland Zones

In Appendix W6 the methodology is provided for the delineation of wetland boundaries and zones. The emphasis in this document is on the interpretation of soil characteristics for the identification of the wetland boundaries. This document was the precursor of the wetland delineation guidelines as published by DWAF (2005).

2.2 <u>The Natural Scientific Professions Act of 2003</u>

According to the Natural Scientific Professions Act of 2003 it is illegal to conduct consulting work in the natural science field without an adequate and relevant registration. In this sense, the fact that two of the main wetland criteria relate to soil form and wetness it follows that only a registered soil scientist may conduct work where these criteria are used. The assessment of the wetland soil conditions on the site therefore also fall within the field of a registered soil scientist only.

In terms of the formal description of fields of competency on the SACNASP website the only field of practice that includes “wetland delineation” is that of a “pedologist”. Although this is considered to be a flaw the essence is that only a pedologist may formally pronounce on aspects pertaining to soil form classification and description of morphological signs of wetness (mottles, grey colours, etc.) in soils. From extensive experience in wetland delineation problems it is quite clear that there are many factors influencing the expression of signs of wetness in soils. These factors include predominantly the differences in chemistry of soils (as derived from different geologies) and the dominant influence of redox chemistry levels and buffers (poising of redox) in differing pH soil environments.

2.3 <u>Application of Wetland Delineation/Assessment Outcomes by the Regulator</u>

From several projects of which the outcomes and decisions by the regulator have been reviewed, it is with a feeling of unease that it is concluded that wetland assessments and delineation results are often used to guide authorised land use changes. In the absence of a dedicated link to hydrological parameters this author does not understand how such decisions can be made.

Example 1: Decision by the regulator on a mining boundary where a wetland boundary and buffer has been determined but where no reference is made to any measure to be taken by the mine to ensure the hydrological functioning of the new landscape (post mining) linking up to existing wetland.
Example 2: Decision by the regulator on the mining of a wetland that was dependent on whether the PES was a C or a D (with C the mining would not be authorised and with a D the mining was to be authorised). In these circumstances it was very easy to show that the hydropedology of the site did not differ significantly between a C and D. The larger omission was the fact that apart from the PES assessment there was no other indication by the regulator regarding rehabilitation measures for the mined site and the linking with the adjacent undisturbed hydrological zones.
Example 3: City of Joburg (CoJ) bylaws allowing the release of storm water into the lowest part of a landscape without giving due consideration to the altered hydrograph for a delineated wetland. Due to the altered hydrograph the wetland has been completely eroded away in the past 5 years. Therefore, a wetland was delineated and protected by the regulator regarding specific on site activities but the regulator did not apply its mind to other possible off-site impacts – in this case a perfectly legal activity by road planners.

2.4 Lack of Clarity on Reference State and Man-Made Wetlands

Thompson (2006) provides and extensive discussion on the juristic and practical nature of wetlands and watercourses. Storm water effects in man-made structures and impoundments that do not form part of natural drainage features are excluded from the definition and description of wetlands and watercourses.

The current legislation and guidelines are not clear on the differentiation between natural wetlands and man-made wetlands and how to deal with these differences in an urban development context where hydrological drivers are altered extensively on a catchment and local scale. This lack of clarity often translates into decisions being made by the regulator (metropolitan authority, provincial authority or national authority) that may vary significantly between different levels of decision making and that may often be perceived as either an "erring on the side of caution" approach or a complete abdication and releasing of wetlands / watercourses for alteration or destruction. A specific case is where the provincial competent authority, upon being informed that a wetland / watercourse area at the N1/N4 interchange in Tshwane showed signs of extensive human impact, released the area for development, contrary to the recommendations in the specialist report, without any dedicated hydrological management measures. This author is of the conviction that even highly impacted wetlands and watercourses should be managed hydrologically and that the competent authorities should emphasize this need even though the ecological characteristics of a wetland /

watercourse area has been degraded significantly. This is especially relevant in urban areas where urban hydrological signatures abound and where wetlands / watercourses / storm water flows have led to a gradual change in the original reference state conditions. However, as this aspect is difficult to conceptualise in the current legislation and authorisation processes it is recommended that specific and focussed guidelines and procedures be generated to deal with the urban hydrological and ecological challenges.

2.5 <u>Summary and Implications</u>

The legal context, and specifically the legal technical description of a wetland and a watercourse, is the starting point of all wetland investigations. The fact that wetland investigations yield areas of land that require protection and that sterilise specific land uses for various users means that the outcomes of these investigations are open to rational challenge. It is therefore imperative that the unpacking of wetland soil parameters always refer back to the legal and statutory foundation as contained in the various acts.

The chapters that follow on this one will unpack the empirical underpinning of the legal context as well as provide context to the understanding of the highly variable environment in which the empirical processes have to be applied.

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CHAPTER 3 – CHALLENGES REGARDING THE EXISTING WETLAND ASSESSMENT TOOLS

3.1 Introduction

The assessment of wetlands implies that there are specific sets of tools with which to conduct the assessment. With a rapidly developing field of practice significant pressure exists for the establishment of tools that are readily available and that have been scrutinised thoroughly. However, the rapid nature of the developing field has inevitably led to the adoption of tools that have not been refined through proper assessment of adequacy nor rigorous peer review. This chapter addresses some of the limitations of and errors in the current approach and assessment tools.

3.2. Philosophical and Practical Challenges Regarding the Foundation of Wetland Assessment

There are several challenges regarding the assessment and delineation of wetlands. Most of these challenges are grounded in the philosophy underpinning wetland science and assessment. The essence of the problem includes:

1. The main philosophy underlying wetland assessment and delineation is that the wetland is an ecological response to the presence of water. The emphasis in the measurement of this response is therefore placed on ecological parameters.
2. Wetlands are often viewed as discrete entities with measurable properties and boundaries. Most wetlands, however, are in essence entities that are visible reflections/expressions of water in a landscape. It is the hidden component of wetlands, the water feeding mechanisms and processes in the larger landscape, which are often overlooked or merely addressed superficially. This implies that for a thorough wetland assessment all hydrological parameters have to be elucidated in as much detail (at least conceptual) as is practically achievable.
3. Wetland assessments and regulation are often biased towards ecological parameters. Although this is understood and supported to a degree the main relevance of wetland assessment stems from the inclusion of the definition in the National Water Act as well as its link with water courses. The fact that wetlands are protected in the National Water Act therefore implies a bias towards the water resource with the ecological parameters being dependent on the water – and not the other way round.
4. Due to the linked nature of wetlands and their supporting landscape it is evident that development or land use impacts that do not alter the landscape's hydrology have very little impact on the hydrological functioning of the wetland. The opposite is true

for impacts that alter the landscape's hydrology in such a way that surface, subsurface and groundwater flow paths of water are severed or severely modified (examples include opencast mining operations and urban developments with extensive excavated foundations). It follows therefore that the delineation, ecological assessment and superficial hydrological assessment of a wetland cannot provide meaningful answers regarding the maintenance (through mitigation and adequate intervention) of water flow regimes – regimes that are responsible for the presence and functioning of the wetland in the first place.

It is in this context that the existing tools and guidelines regarding wetland assessment are considered to be problematic as they do not address any of the requirements for detailed wetland rehabilitation planning in especially opencast mining and urban environments.

3.3. Detailed Disaggregation and Interpretation of the Definition of a Wetland

Wetlands are defined in the NWA as:

> *"Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."*

In order to address wetland identification, delineation and assessment it is necessary to disaggregate the definition. The discussion below emanates from the author's experience in a number of administrative and criminal compliance cases that he has been involved in, both in advising the site and the client separately. From the lengthy and detailed interrogation of the definition of a wetland and what is meant or implied by the law the following unpacking is provided:

1. "*Land which is transitional between terrestrial and aquatic systems* …": This implies areas with variable hydrological and ecological characteristics of which the variation can be described as the linear (assumed) transition from one pole (terrestrial/dry) to another (aquatic/wet).
2. "… *where the water is usually at or near the surface* …": Although the regular condition is implied there is no reference to any empirical interpretation. This aspect therefore introduces uncertainty and the potential for significantly variable interpretation.
3. "… *or the land is periodically covered with shallow water* …": This statement introduces and alternative to the above statement but, again there is no reference to any empirical interpretation and it therefore introduces uncertainty and the potential for significantly variable interpretation

4. "… *and which land in normal circumstances* …": Normal circumstances are not defined with a subsequent introduction of uncertainty and variability in interpretation. According to Mernewecke and Kotze (as cited in DWAF, 1999) "normal circumstances" in the definition refers to "without human modifications".
5. "… *supports or would support vegetation typically adapted* …": Vegetation species and communities can be described and named and can provide distinctly measurable indicators of wetland conditions. This is therefore a clear indicator if the requisite scientific knowledge is available.
6. "… *to life in saturated soil*.": Soil saturation (degree, intensity and duration) can be measured empirically (although at significant financial and time cost) or deduced from the soil morphology to varying degrees of certainty (Lin, 2012; Van Tol, et al, 2010b). The soil morphological indictors (all functions of soil forming factors and processes) have been studied and described extensively in the soil science literature.

An evaluation of the disaggregation above yields that the only certain descriptors, from a scientific, practical and legal perspective, are vegetation and soil indicators. It is also clear that the emphasis is on "saturated soil" and the plants that are adapted to grow under such conditions. Later in this document the concept of "saturation", and the requirements for its empirical elucidation, will be discussed in more detail.

Additionally, from the definition and the purpose of the water act it can be assumed that wetlands are merely the expression of wetness in landscapes and that the water resource can occur in landscapes in many other forms. One form that is not explicitly mentioned is seasonally perched water tables and their associated vadose zones that are instrumental in the "feeding" of wetlands through lateral flow mechanisms in the landscape. From the purpose of the NWA it is assumed that these water resources are included explicitly in the Act. This aspect has a significant bearing on the contents of rehabilitation plans and reports.

3.4. <u>The Wetland Delineation Guidelines</u>

In 2005 the Department of Water Affairs and Forestry published a manual entitled "A practical field procedure for identification and delineation of wetland and riparian areas" (DWAF, 2005).

3.4.1 Origin of the Wetland Delineation Guidelines

The wetland delineation guidelines have their origin in the "Resource Directed Measures for Protection of Water Resources. Volume 4: Wetland Ecosystems" as published by DWAF (1999) and then specifically in "Appendix W6: Guidelines for delineation of wetland boundary and wetland zones".

Although a major step forward in the approach to wetlands, these guidelines were published in 1999 and it was without considering detailed soil morphological and chemical parameters that influence the expression of wetness in soil nor the hydrological linkages in landscapes where the wetlands occur. As the science has developed and expanded it has become apparent that the original approach is limited and scientifically flawed in some instances. This aspect has major ramifications in the event that administrative compliance and criminal prosecutions are based on such information.

3.4.2 Thrust of the Wetland Delineation Guidelines

The "…manual describes field indicators and methods for determining whether an area is a wetland or riparian area, and for finding its boundaries." The definition of a wetland in the guidelines is that of the NWA and it states that wetlands must have one or more of the following attributes:

- "**Wetland (hydromorphic) soils** that display characteristics resulting from prolonged saturation"
- "The presence, at least occasionally, of **water loving plants (hydrophytes)**"
- "A **high water table** that results in saturation at or near the surface, leading to anaerobic conditions developing in the top 50 cm of the soil."

The guidelines further list four indicators to be used for the finding of the outer edge of a wetland. These are:

- Terrain Unit Indicator. The terrain unit indicator does not only identify valley bottom wetlands but also wetlands on steep and mild slopes in crest, midslope and footslope positions.
- Soil Form Indicator. A number of soil forms (as defined by the Soil Classification Working Group, 1991) are listed as indicative of permanent, seasonal and temporary wetland zones.
- Soil Wetness Indicator. Low chroma soil colours and high chroma mottles are indicated as colours of wet soils. The guidelines stipulate that this is the primary indicator for wetland soils. In essence, the reduction and removal of Fe in the form of "bleaching" and the accumulation of Fe in the form of mottles are the two main criteria for the identification of soils that are periodically or permanently wet.
- Vegetation Indicator. This is a key component of the definition of a wetland in the NWA. It often happens though that vegetation is disturbed and the guidelines therefore place greater emphasis on the soil form and soil wetness indicators as these are more

permanent whereas vegetation communities are dynamic and react rapidly to external factors such as climate changes and human activities.

The main emphasis of the guidelines is therefore the use soils (soil form and wetness) as the criteria for the delineation of wetlands.

3.4.3 Auditable Process

The wetland delineation guideline manual aims to provide a "… scientifically robust, simple to apply and … standardised, affordable and auditable method of spatially defining …" hydrologically sensitive areas (DWAF, 2005).

The guidelines refer to the prescribed delineation procedure as being "auditable". Several challenges exist with the concept of an auditable interpretation of soil indicators (soil form as well as signs of wetness). The following comments are made regarding the "auditable" nature of the procedure:

1. The fixed nature of the interpretation is based on depth of mottles in the soil and that being 50 cm as the cut-off. Anecdotal evidence suggests that this figure is based on the assumed rooting depth of wetland plants meaning that a water table below 50 cm will not be expressed through the presence of wetland plants due to their roots growing only to 50 cm. This assumption is based on the inference that all wetlands are fed by regional water tables where the water level fluctuates (as fed from below) and then fluctuation is predominantly vertical (up and down). Even though a 50 cm criterion is distinctly auditable the assumption is highly erroneous and limited in that plants exhibit much wider variation in terms of rooting depth and that most seasonal and temporary wetlands are fed through interflow and surface water ingress processes – therefore implying a horizontal fluctuation of water dependent on topographic characteristics.
2. An "auditable" process does not make allowance for variable interpretation or environmental variability induced by geology, topography and climate. These parameters induce very distinct variation in the morphological expression of wetness in soil – variation that is at best interpreted with varying opinions by pedologists.
3. No allowance is made for return flow processes that may produce daylighting of water in soils or on rock outcrops. These processes are hillslope driven and the guidelines do not even allude to such.
4. Auditing of vegetation is problematic due to its dynamic nature (regional, edaphic, climatic variation) as well as due to human influences.

3.4.4 *Gaps in the Existing Assessment Tools*

The existing tools for the assessment and characterisation of wetlands are predominantly restricted to the:

1. Delineation of the outer boundary of a wetland;
2. Assessment of the ecological status of a wetland; and
3. Assessment of the related services that wetlands perform.

None of these tools address in adequate detail the hydrological functioning of the landscapes in which the wetlands occur. As wetlands are inherently and explicitly dependent on water, the omission of adequate hydrological parameters from wetland assessment processes is considered a critical flaw. The discussion below is restricted to a brief description of the specific tools as well as their shortcomings. A detailed discussion will follow at a later stage as I am, with several other colleagues, in the process of consultation and advising to DWA on the matter. This consultation and advisory process will continue for a significant period of time as the development of adequate tools is a protracted process.

3.4.5 *Empirical Limitations of Wetland Indicators*

The wetland indicators discussed above are limited to a certain degree in the following manner:

<u>Topographic Indicator</u>

The topographic indicator is limited to wetlands that are associated with surface topographical variation and it is therefore limited to specific landscape positions. The topographic indicator does not make allowance for variation in physical properties below the soil surface. In this sense, aspects such as return-flow zones and interflow zones (that often occur in midslope or footslope positions) are not accommodated. In practice these areas prove the most problematic in terms of interpretation and delineation.

Van Tol *et al.* (2013a) classified several hillslopes on the basis of hydrological functioning and identified six dominant hydrological hillslope classes. These main classes can be tied in with land type data (as generated by the Land Type Survey Staff, 1972-2006) at a high level to start the detailed disaggregation of hillslopes and wetland functioning "provinces" in SA. Van Tol (2010a) also indicates that a conceptual soil morphology based model provided acceptable indications of hillslope hydrology of a selected hillslope in the Weatherly catchment. Data generated in-field through hydrological sampling supported the conceptual model findings and this provided a possible foundation for high-level assumptions based on land type data interpretation.

Vegetation Indicator

The vegetation indicator is limited predominantly by regional and local variation in edaphic and climatic conditions. The regionalization of vegetation guidelines should address this aspect satisfactorily.

Soil Form Indicator

The soil form indicator suffers from a number of limitations namely:

1. Soil forms present in an area do not necessarily indicate wetlands and they have to be viewed in a wider context as their classification is also not an auditable process (due to variable interpretation). The presence of a specific soil form may indicate the presence of a wetland though but this aspect will have to be confirmed on the site through additional indicators.

2. Certain soil forms are erroneously assigned to specific wetland conditions viz. the Rensburg and Willowbrook forms that are assigned to permanent wetland areas. Although it is accepted that these can occur in permanent wetland zones their formation is dependent on distinct cycling between wet and dry seasons (Driessen & Dudal, 1991). The development of 2:1 clay minerals found in these soils depends on the accumulation of weathering products and clays in lower lying landscape positions and/or from basic materials *in situ*. These clays are, depending on a range of factors, either swelling or non-swelling and their formation requires a distinct time (seasonally) where evaporation exceeds precipitation, with consequent drying of the soil, to lead to a concentration of bases (Ca and Mg). Clay minerals such as smectite are often expressed in the form of distinct cracks in vertic soils. From this discussion it follows that the Rensburg and Willowbrook soils could only have formed in conditions that resemble a **seasonal wetland**. Drainage lines on the site can, if dominated by Rensburg or Willowbrook soils, therefore not be classified as permanent wetlands unless there are other characteristics indicating conditions of permanent saturation.

3. Improved elucidation of the presence of soil forms in landscapes is required through adequate contextualisation of the various soil forming factors and processes. This is especially relevant as the roles of the soils in wetlands and wetland functioning is often poorly understood. Recent improvements regarding these processes and context have been reported on by Van Tol *et al.,* (2010); Van Tol *et al.,* (2013a); Van Tol *et al.,* (2010a) Van Tol *et al.,* (2015) and Van Zijl and le Roux (2014).

Soil Wetness Indicator

The soil wetness indicator is in all probability the most problematic as there are numerous physical and chemical determinants. The main indicator of reduction is the very handy redox morphological variation of Fe – and this is the assumption that most wetland delineation exercises are based upon. There is a distinct variability in expression of the quantity / intensity parameters of mottles in different soil environments. This variation is in most cases linear for simple parameters but soils always exhibit combinations of variable parameters that make linear interpretation highly suspect and problematic. A brief elucidation of the problem components include:

1. The Fe content and reserve of soils and parent material vary significantly and impart varying expression of Fe redox morphology with consequent challenges in interpretation. This is especially valid for comparisons between quartz dominated sandy soils and soils derived from basic igneous materials with high clay contents. This aspect induces variation between landscapes with homogenous parent materials (within the specific landscape) or within landscapes where variation in parent materials is found within the landscape.

Investigations by Van Huyssteen *et al.,* (1997) indicated a large degree of correlation between the colour of soil horizons and the degree of wetness of the soil horizons. In later investigations in a different geographical environment Van Huyssteen *et al.,* (2007) described the duration of saturation in soils in a hydrological sequence (dryer to wetter) namely Hutton, Westleigh and Katspruit. The morphological properties of the soils corresponded well with the measurement of degree of saturation and the conclusion was that “soil classification, supported by soil mapping and interpretation” provides value through its application in the modelling of hydrological processes. Furthermore Van Huyssteen *et al.,* (2009) indicate that there is a distinct correlation between orthic A horizons and underlying subsoil horizons and proceeds to propose a refinement of interpretation of Orthic A horizons to aid in the interpretation for hydrological purposes. The comparison of colour expression linked to hydrological properties between different clay content and Fe reserve soils still remains elusive due to the complexity of the variation in nature. The redox and mineralogical contextualisation of the soil colours remains important as Van der Waals (2013) indicated a disaggregation between the colours of a sequence of orthic A horizons with respect to the underlying subsoil B or E horizon sequence colours.

2. The Mn content of soils influences redox poise processes that in turn influence the expression of Fe redox morphology. This aspect ties in with the point discussed above but with the added variable that the Mn poise effect introduces. In recent investigations (Mudaly, 2015) it was been found that the Mn content of soils vary significantly and that the Mn content determines the extent of the redox poise, therefore inhibiting Fe reduction in high Mn content

soils. This aspect has an overbearing influence on the expression of wetness differences, even when vegetation parameters indicate similarities, between two geological zones in the Gauteng Province namely the Halfway House Granite Dome (low Mn content soils) and the Chuniespoort Group dolomites (high Mn content soils).

3. Textural differences in soils lead to differential expression of redox morphology with sandy soils often exhibiting a complete lack of mottling, even under conditions of a fluctuating water table, below certain clay content thresholds. (Ellis, personal communication).

4. Variation in pH gradients linked to electron activity (Eh) influences redox morphology changes linearly with the expression of high chroma Fe minerals decreasing in intensity at higher pH levels. This aspect therefore introduces distinct pH dependence with respect to the intensity of colour expression and therefore removes a "level playing" field completely regarding the interpretation of redox morphology linked to hydrological regime. A distinct example illustrating the challenge is the fact that in oxidised conditions at pH levels below 7 the dominant Fe minerals are oxides and hydroxides with high chroma values and at pH levels above 7 the dominant Fe minerals are carbonates (siderite) that are white in colour. It therefore follows that in high pH environments the presence of Fe minerals is often masked by the presence of lime (Ca and Mg carbonates). In order to address this challenge for the delineator it is important to provide adequate context regarding the variable soil parameters such as pH, EC, water potential, etc. This challenge is particularly relevant in the case where delineation exercises are conducted in arid environments where the presence of lime or above neutral pH conditions often determine soil morphology parameters.

5. Climatic / rainfall gradients often lead to differences in the chemistry of soils as expressed in lime content, electrical conductivity and pH – all of which play a role in the redox reaction intensity. Le Roux and du Preez (2008) confirmed mottle formation in arid environments and concluded it to be low intensity even though it was not possible from the data to indicate intensity of formation. When compared to the intensity of processes under very wet conditions this aspect poses further research questions regarding the mechanisms of mottle formation from a thermodynamic perspective.

Le Roux and du Preez (2006) make an argument that the uncertainty of whether plinthite formation is active (and in phase with current climatic conditions) limits the correct interpretation of the characteristics of plinthic soils and that this limitation spills over into agricultural evaluation of plinthic soils as a source of water for crops. The argument can be extended to the limitations placed on the interpretation of wetland conditions as stated in the DWAF (2005) delineation guidelines with a consequent unknown level of error in interpreting degree and duration of saturation. Le Roux and Du Preez (2006) found, however, that the occurrence and expression of plinthic character are in harmony with current environmental conditions in the soils that were investigated. The findings are focused on soil that qualify as diagnostic plinthic horizons and there is still a dearth of information on the dynamics of mottles in soils that do not qualify as plinthic horizons but where the mottles are used as indicators of wetland conditions. This aspect and the uncertainty linked to the interpretation of current vs relict properties in essence renders the interpretation of plinthic character / properties as a basis for wetland identification moot.

Bouwer *et al.* (2015) found that chemical indicators of recent flow regime, flow path and storage mechanisms are related to ancient soil water regime morphological indicators as well as the current measured hydrological properties. In their study it was concluded that soil chemical properties aid in the validation of conceptual hydropedological response models and aids in the characterisation of flow paths, flow direction and storage mechanisms.

6. With the advancement of science new concepts and knowledge is introduced. A distinct example of this is references to “blue green colouration” in soils classification texts (Soil Classification Working Group, 1991) that indicate conditions of distinct saturation (and gleying) in those texts. The mineral responsible for the green colouration has been identified as “Fougerite” with the name formally approved in 2004 (Trolard, 2006). It is suggested that fougerite may be an important precursor to many ferric oxides in soil environments and the mineral has been reported to be stable at Eh conditions of -0.5 to 0.5 V (moderate conditions of reduction) and pH conditions of 6 to 11 (Ruby *et al*., 2010; Génin, 2004). This finding somewhat contradicts the assumption that the horizons in which these minerals occur are saturated and highly anaerobic. In this case the emerging scientific information guides the more correct interpretation of high clay content G horizons as being dominated by unsaturated flow conditions rather than mass flow conditions as experienced regularly in E horizons. These interpretations are confirmed by established soil physics knowledge.

7. Even though often interpreted as such by wetland delineators bleached colours, as defined for the E horizon, do not necessarily indicate prolonged wetness. This is especially relevant in quartz rich environments such as sand dunes and deep sand deposits, quartz rich parent materials with a very low Fe reserve, landscapes where podzolization processes drive E horizon formation and the bleaching of topsoil horizons due to more intense conditions of Fe reduction than in associated subsoil horizons in the profile. The distinction between the above-mentioned environments is aided through the provision of context (landscape, geology, climate, etc.). E horizons are correctly associated with distinct subsurface lateral flow in many landscapes but the soils characteristics are by no means homogenous (and therefore open to excessive extrapolation). In this regard Van Tol *et al.,* (2013b) found that subsurface lateral flow in E horizons (considered the main formation driver the horizon) is

easily correlated with readily observable soil and landscape properties. They further discuss the importance of the transition from E to subsoil horizons in that more abrupt transitions indicate a more pronounced subsurface lateral flow with chemical properties of the soils sampled confirming the trends. This aspect could be used to readily distinguish between subsurface lateral flow dominated and formed E horizons (in that their subsoils have lower hydraulic conductivities) compared to E horizons formed through podzolization where there often is negligible difference between textural properties of E vs Podzol subsoil horizons. The latter is a problem in wetland delineation circles as the podzol derived E horizons are typically not primarily formed through hydrological and redox related processes in the classical hillslope hydrology context. Additional contextualisation is often required as Van der Waals (2013) reported on a distinct degree of bleaching occurring in orthic A horizons overlying high chroma yellow-brown apedal B horizons in the plinthic catena. From this investigation it was concluded that the bleaching was a function of more intensive redox processes in the A horizon when compared to be B horizon due to more intensive and regular fluctuations of water (through rainfall) in the presence of a higher organic matter content in the root zone of the plants (predominantly A horizon). In agreement in principle with Van Tol *et al.,* (2013b) it was postulated that the bleached A horizons may experience more intensive lateral flow of water albeit with frequent fluctuation.

Compound Challenge

A compound challenge is the fact that in practice it is often found that delineators auger to 50cm only to identify soil wetness parameters (mottles). In order for a soil to be classified according to the Taxonomic System (Soil Classification Working Group, 1991) the auger should reach 150 cm (or refusal). It therefore follows that the emphasis of depth and presence of mottles often scuppers the complete investigation and classification of the soils leading to an incomplete identification of indicators.

Data Availability Challenge

Often the largest limiting factor in the generation of a scientifically sound wetland assessment is adequate data and information in terms of availability and access. The data requirements of such exercises are significant and cost and budget constraints often limit the scope of work. Van Tol et al., (2010b) provides an example of how soil indicators were successfully and efficiently used to describe hillslope hydrology. The "pedosequence (soil distribution pattern) reveals how the hillslope responds hydrologically." The interpretations of soil properties as indicators of hillslope hydrology play an important role in the understanding of hydrological functioning of gauged catchments, but probably more so in ungauged catchments due to the dearth of other data. The other data alluded to refer to soil maps and the associated information. In this regard Van Zijl *et al.,* (2013) found that "digital soil mapping methods combined with expert knowledge and soil observations can be used to disaggregate land types into accurate soil association maps" with more information leading to higher map accuracy. They also concluded that the land type survey data (Land Type Survey Staff, 1972-2006) constitutes a good basis for such exercises. This even though the investigation covered only two (Ea34 and Ca11) of the 7000+ land types of SA. This author, however, supports the above conclusion based on survey exercises that have been conducted in a large number of land types. A similar methodology and approach was used to create conceptual hydrological soil response map in the Kruger National Park (van Zijl and le Roux, 2014). The suitability of the approach was confirmed through the successful application of hydropedological insights in hydrological modelling based on the more detailed soil information generated above by van Zijl and le Roux (2014) (Van Tol *et al.,* 2015).

3.4.6 Practical Legal Limitations of Wetland Indicators

The wetland indicators require very specific contextualisation in specific climatic areas and geological zones that influence the expression of redox morphology. Due to altering rainfall conditions and the fact that soil morphological properties take longer to adapt to rainfall variation than vegetation it is clear that correlation is important in determining legal liability. In this sense a proper elucidation of the context and the science that underpins the understanding of the redox morphology drivers is critical. It therefore also follows that there has to be an amendment to the general indicators used currently through the expansion of the knowledge of the variability within the South African landscape context.

3.4.7 Proposed Improvements

Having indicated that there are numerous limitations to the current wetland delineation approach it is important to focus on dedicated improvements that can be implemented/incorporated easily. These improvements include:

1. Expansion of the landscape indicator to include concepts of hillslope hydrology and flow paths for the elucidation of connectivity in a landscape.
2. Improvement and correction of the soil form indicator description through a dedicated contextualisation of the range of soil forms that occur in a specific landscape. The contextualisation of the soil forms can be conducted readily through the interpretation of land type soil data using the principle of "driest soils on crests and wettest soils in depressions". The land type data includes as part of the identification per land type a rather homogenous set of topographic, geological and climatological parameters and therefore yields a very useful first level interpretation of soil variation on a 1:250 000 scale for South Africa. This concept is illustrated in **Figure 3.1** and assumes that redox morphology expression and soil form occurrence is a function of a number of soil forming factors but predominantly determined by the water regime of the landscape.

3. Contextualisation of the soil wetness indicator description to reflect differing pH/Eh/parent material environments. Again this parameter can be elucidated through the use of the principle illustrated in point 2 above with **Figure 3.1** providing the rationale for the variation. In this case the assumption is that the realistic range of redox morphology expression observed in a specific landscape will be captured by the "driest" and "wettest" position boundaries.
4. Systematic generation of regional or land type distribution based wetland delineation and assessment guidelines through the integration of available information sourced from specialist and workers or through dedicated and focussed research.

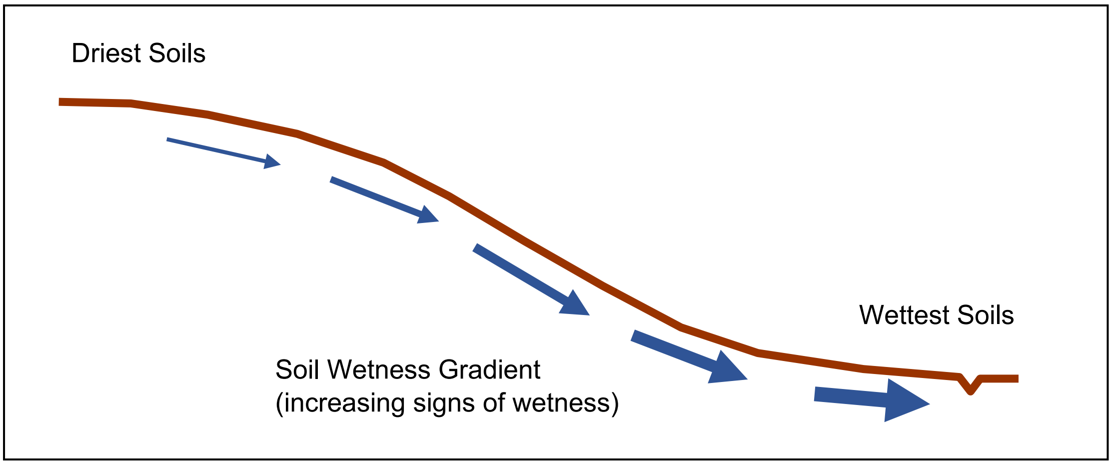

Figure 3.1 Conceptual indication of increased soil wetness along a hillslope

Having indicated that there are numerous limitations to the current wetland delineation approach it is important to focus on dedicated improvements that can be implemented/incorporated easily. These improvements include:

1. Updating of the current delineation guidelines (including the draft version from 2008) to serve as a national standard document indicating variability in SA (broadly) through:
    a. Improvement of the landscape indicator to include seepage (including interflow, seepage and return-flow wetlands)
    b. Improvement and correction of the soil form indicator description. Introduction of the concept of "driest soils on crests and wettest soils in depressions" as a method of determining the range of soil variation in specific landscapes.
    c. Improvement and correction of the soil wetness indicator description to reflect differing pH/Eh/parent material environments. Linking of soil wetness indicators to the concept of "driest soils on crests and wettest soils in depressions" as a method of determining range of soil variation in different landscapes.
    d. Introduction of measuring and inference tools for generation of empirical data on wetness.

e. Introduction of regional and/or land type based detailed guidelines that will include:
    i. Localized topographic indicators and pointers / aids;
    ii. Localized soil form sequences (catena) and soil form variability. (Utilize method of soil form variation range in land type); and
    iii. Localized variation in terms of soil wetness indicators. (Utilize method of soil form variation range in land type).
2. Correction of scientific inaccuracies and inconsistencies in the current documents and improvement of the principles and guidelines to a proper standard through focused research, peer review and formal publication.

All the above recommendations can be accommodated in the assessment of a landscape's hydropedology. A dedicated discussion of this concept follows later in the document.

3.5. <u>PES and EIS</u>

3.5.1 Limitations

The present ecological state (PES) and ecological importance and sensitivity (EIS) parameters prescribed for wetland investigations are provided for in "Appendix W4: IER (Floodplain wetlands) Present ecological status (PES) method" and "Appendix W5: (IER) (Floodplain wetlands) Determining the ecological importance and sensitivity (EIS) and ecological management class (EMC)" of the RDM.

It is very important to note that the PES is an ecological assessment at an "intermediate" level of detail that includes surface hydrological parameters of a wetland and catchment. As these assessments are performed by ecologists it must be assumed that the hydrological information is not of a detailed nature. A detailed assessment would have to be conducted by a suitably registered hydrologist to have relevance in court. The PES ranks a wetland from A to F depending on the degree of alteration. It must be assumed that all the wetlands that have been impacted hydrologically in a significant manner constitute wetlands with an F rating. Wetlands that have been mined out completely do not exist anymore and cannot be rated. The guidelines do not indicate how to handle wetlands that have sections that are without impact and sections that have been mined out completely.

The EIS is based primarily on ecological parameters and it becomes irrelevant in a mined-out or urban environment.

The PES methodology already forms an adaptation from the methodology to assess palustrine wetlands. Hillslope seepage wetlands and pan systems have a range of different drivers and as such some modification of the criteria has been made by this author to accommodate the specific hydropedology drivers of hillslope seepage wetlands and pans.

The criteria as described in Appendix 4 is provided below with the relevant modification or comment provided as well.

1. Conduct a literature review (review of available literature and maps) on the following:
    a. Determine types of development and land use (in the catchment in question).
    b. Gather hydrological data to determine the degree to which the flow regime has been modified (with the "virgin flow regime" as baseline). The emphasis is predominantly on surface hydrology and hydrology of surface water features as well as the land uses, such as agriculture and forestry, which lead to flow modifications. <u>Important Note</u>: The hydropedology of landscapes is not explicitly mentioned in the RDM documentation and this author will make a case for its consideration as probably the most important component of investigating headwater systems and seepage wetlands and areas.
    c. Assessment of the water quality as is documented in catchment study reports and water quality databases.
    d. Investigate erosion and sedimentation parameters that address aspects such as bank erosion and bed modification. <u>Important Note</u>: The emphasis in the RDM documentation is again on river and stream systems with little mention of erosion of headwater and seepage zone systems. Again a case will be made for the emphasis of such information generation.
    e. Description of exotic species (flora and fauna) in the specific catchment in question.
2. Conduct and aerial photographic assessment in terms of the parameters listed above.
3. Conduct a site visit and make use of local knowledge.
4. Assess the criteria and generate preliminary PES scores.
5. Generation of report.

The score sheet and criteria for the assessment of habitat integrity of palustrine wetlands (as provided in the RDM documentation) is provided in Table 2.1 and the subsequent text in Chapter 2. The discussion below repeats the text of the "criteria" provided in Chapter 2 with added comments by the author.

Important Note on Pan and Hillslope Seepage Wetland Systems: The present ecological state (PES) determination is, as discussed earlier in the report, based on criteria originally generated for palustrine and floodplain wetlands. Pan (or endorheic) wetlands in dry environments and seepage wetlands in all areas very rarely have the same degree of saturation or free water and consequently often do not have permanent wetland zones associated with them. These wetlands are therefore often characterised at best by seasonal or temporary waterlogging properties or high salt content soils and crusts. As such a standard PES approach is flawed as it rests on a range of ecological parameters that do not apply to predominantly dry pan systems or the more fluctuating type wetlands associated with seeps. The existing criteria is provided below as is a comment on the applicability as well as proposed improvements.

Criteria

Hydrological Criteria

- "Flow modification: Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland." Comment: Although the description is wide it is very evident that it does not cater adequately for dry pan environments or for hillslope seepage wetlands that do not undergo inundation. The main criterion should therefore be the surface and subsurface hydrological linkages expressed as a degree of alteration in terms of the surface, hydropedology and groundwater hydrology.
- "Permanent inundation: Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota." Comment: Mostly not applicable to dry pan or seepage wetlands.

Water Quality Criteria

- "Water quality modification: From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland." Comment: Water quality in this context applies generally but cognisance should be taken of very high salt content of the ephemeral water in the pan and/or seepage water quality that can be natural but significantly different to exposed water bodies. The pan system and function generally renders the water unsuitable for human or animal consumption due to very high salt loads. In seepage wetlands the water quality parameters are of a highly complex nature due to many redox processes within the hillslope.

- "Sediment load modification: Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats." Comment: This is a very relevant concept but on very large pan systems become almost irrelevant due to scale. In many dry pan systems the process of sedimentation and addition of salts is a natural and continuous process. On hillslopes this parameter should be linked to erosivity of the soils as well as the specific land use influences.

Hydraulic / Geomorphic Criteria

- "Canalisation: Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage." Comment: Again this is a very relevant concept but in large dry pan systems the impacts are often dwarfed or negated by constant variation in rainfall over the area. On hillslopes this parameter should be linked to erosivity of the soils as well as the specific land use influences. This concept does however not address the influences on the hydropedology of the hillslope and these aspects should be elucidated and contextualised.
- "Topographic Alteration: Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railway lines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns." Comment: Again this is a very relevant concept but in large dry pan systems the impacts are often dwarfed or negated by constant variation in rainfall over the area. On hillslope seeps this is a very relevant aspect but it is never brought into the context of the hydropedology of the hillslope. These aspects should be elucidated and contextualised.

Biological Criteria

- "Terrestrial encroachment: Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions." Comment: Again this is a very relevant concept but in large dry pan systems the impacts are not distinguishable from naturally prolonged dry cycles. On hillslopes seeps these aspects should be linked to erosivity of the soils as well as the specific land use influences. This concept does however not address the influences on the hydropedology of the hillslope. These aspects should be elucidated and contextualised.
- "Indigenous vegetation removal: Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation

functions, organic matter inputs and increases potential for erosion." Comment: See comment above.

- "Invasive plant encroachment: Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading)." Comment: See comment above. "Alien fauna: Presence of alien fauna affecting faunal community structure." Comment: See comment above.
- "Over-utilisation of biota: Overgrazing, Over-fishing, etc." Comment: This aspect is almost irrelevant in dry pan systems as the biota is very sparse or even absent within the pan during dry years. In wet years the variable occurrence of biota influences short bursts of activity as in the form of migrating birds feeding on short life-span invertebrates.

3.5.2 Proposed Improvements

It is proposed that an additional parameter, the hydropedology status (HPS) be included to complement the PES parameter. The mechanism in which this parameter could function is discussed later in the report.

3.6 Summarising Conclusion

During wetland assessments and delineations it is important to provide a perspective on assessment tools, the original or reference state of the wetland, the assessment process and outcome as well as the intended or possible state of the wetland and site post development or impact. Urban and mining developments are good examples of cases where surrounding developments and land use changes have significant effects on wetland integrity and water quality emanating from the site.

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CHAPTER 4 – HYDROLOGY CONTEXT OF WETLAND ASSESSMENT AND DELINEATION

The biophysical context of a wetland is largely that of the soils of the landscape with the associated vegetation. The soil component includes the hydrology of the soils as well as the associated landscape hydrology. In order to place all these aspects in perspective it is necessary to provide adequate context and elucidation. The section below provides a condensed explanation of the relevant parameters.

4.1 Water Movement in the Soil Profile

In a specific soil profile, water can move upwards (through capillary movement), horizontally (owing to matric suction) and downwards under the influence of gravity.

The following needs to be highlighted in order to discuss water movement in soil:

- Capillary rise refers to the process were water rises from a deeper lying section of the soil profile to the soil surface or to a section closer to the soil surface. Soil pores can be regarded as miniature tubes. Water rises into these tubes owing to the adhesion (adsorption) of water molecules onto solid mineral surfaces and the surface tension of water.

  The height of the rise is inversely proportional to the radius of the soil pore and the density of the liquid (water). It is also directly proportional to the liquid's surface tension and the degree of its adhesive attraction. In a soil-water system the following simplified equation can be used to calculate this rise:

  $$\text{Height} = 0.15/\text{radius}$$

  Usually the eventual height of rise is greater in fine textured soil, but the rate of flow may be slower (Brady and Weil, 1999; Hillel, 1983).

- Matric potential or suction refers to the attraction of water to solid surfaces. Matric potential is operational in unsaturated soil above the water table while pressure potential refers to water in saturated soil or below the water table. Matric potential is always expressed as a negative value and pressure potential as a positive value.

  Matric potential influences soil moisture retention and soil water movement. Differences in the matric potential of adjoining zones of a soil results in the movement of water from the moist zone (high state of energy) to the dry zone (low state of energy) or from large pores to small pores.

The maximum amount of water that a soil profile can hold before leaching occurs is called the field capacity of the soil. At a point of water saturation, a soil exhibits an energy state of 0 J kg^{-1}. Field capacity usually falls within a range of -15 to -30 J.kg^{-1} with fine textured soils storing larger amounts of water (Brady and Weil, 1999; Hillel, 1983).

- Gravity acts on water in the soil profile in the same way as it acts on any other body; it attracts towards earth's centre. The gravitational potential of soil water can be expressed as:

  Gravitational potential = Gravity x Height

  Following heavy rainfall, gravity plays an important part in the removal of excess water from the upper horizons of the soil profile and recharging groundwater sources below.

  Excess water, or water subject to leaching, is the amount of water that falls between soil saturation (0 J.kg^{-1}) or oversaturation (> 0 J kg^{-1}), in the case of heavy rainfall resulting in a pressure potential, and field capacity (-15 to -30 J kg^{-1}). This amount of water differs according to soil type, structure and texture (Brady and Weil, 1999; Hillel, 1983).

- Under some conditions, at least part of the soil profile may be saturated with water, resulting in so-called saturated flow of water. The lower portions of poorly drained soils are often saturated, as are well-drained soils above stratified (layers differing in soil texture) or impermeable layers after rainfall.

  The quantity of water that flows through a saturated column of soil can be calculated using Darcy's law:

  $$Q = Ksat.A.\Delta P/L$$

  Where Q represents the quantity of water per unit time, Ksat is the saturated hydraulic conductivity, A is the cross sectional area of the column through which the water flows, ΔP is the hydrostatic pressure difference from the top to the bottom of the column, and L is the length of the column.

Saturated flow of water does not only occur downwards, but also horizontally and upwards. Horizontal and upward flows are not quite as rapid as downward flow. The latter is aided by gravity (Brady and Weil, 1999; Hillel, 1983).

- Mostly, water movement in soil is ascribed to the unsaturated flow of water. This is a much more complex scenario than water flow under saturated conditions. Under unsaturated conditions only the fine micropores are filled with water whereas the macropores are filled with air. The water content, and the force with which water molecules are held by soil surfaces, can also vary considerably. The latter makes it difficult to assess the rate and direction of water flow. The driving force behind unsaturated water flow is matric potential. Water movement will be from a moist to a drier zone (Brady and Weil, 1999; Hillel, 1983).

The following processes influence the amount of water to be leached from a soil profile:

- Infiltration is the process by which water enters the soil pores and becomes soil water. The rate at which water can enter the soil is termed infiltration tempo and is calculated as follows:

$$I = Q/At$$

  Where I represents infiltration tempo (m s^{-1}), Q is the volume quantity of infiltrating water (m^3), A is the area of the soil surface exposed to infiltration (m^2) and t is time (s).

  If the soil is quite dry when exposed to water, the macropores will be open to conduct water into the soil profile. Soils that exhibit a high 2:1 clay content (swelling-shrinking clays) will exhibit a high rate of infiltration initially. However, as infiltration proceeds, the macropores will become saturated and cracks, caused by dried out 2:1 clay, will swell and close, thus leading to a decline in infiltration (Brady and Weil, 1999; Hillel, 1983).

- Percolation is the process by which water moves downward in the soil profile. Saturated and unsaturated water flow is involved in the process of percolation, while the rate of percolation is determined by the hydraulic conductivity of the soil.

  During a rain storm, especially the down pouring of heavy rain, water movement near the soil surface mainly occurs in the form of saturated flow in response to gravity. A sharp boundary, referred to as the wetting front, usually appears between the wet soil and the underlying dry soil. At the wetting front, water is moving into the underlying soil in response to both matric and gravitational potential. During light rain, water movement at the soil surface may be ascribed to unsaturated flow (Brady and Weil, 1999; Hillel, 1983).

The fact that water percolates through the soil profile by unsaturated flow has certain ramifications when an abrupt change in soil texture occurs (Brady and Weil, 1999; Hillel, 1983). A layer of course sand, underlying a fine textured soil, will impede downward movement of water. The macropores of the coarse textured sand offer less attraction to the water molecules than the macropores of the fine textured soil. When the unsaturated wetting front reaches the coarse sand, the matric potential is lower in the sand than in the overlying material. Water always moves from a higher to a lower state of energy. The water can, therefore, not move into the coarse textured sand. Eventually, the downward moving water will accumulate above the sand layer and nearly saturate the fine textured soil. Once this occurs, the water will be held so loosely that gravitational forces will be able to drag the water into the sand layer (Brady and Weil, 1999; Hillel, 1983).

A coarse layer of sand in an otherwise fine textured soil profile will also inhibit the rise of water by capillary movement (Brady and Weil, 1999; Hillel, 1983).

Field observations and laboratory based analysis can aid in assessing the soil-water relations of an area. The South African soil classification system (Soil Classification Working Group, 1991.) comments on certain field observable characteristics that shed light on water movement in soil. The more important of these are:

- Soil horizons that show clear signs of leaching such as the E-horizon – an horizon where predominantly lateral water movement has led to the mobilisation and transport of sesquioxide minerals and the removal of clay material;
- Soil horizons that show clear signs of a fluctuating water table where Fe and Mn mottles, amongst other characteristics, indicate alternating conditions of reduction and oxidation (soft plinthic B-horizon);
- Soil horizons where grey colouration (Fe reduction and redox depletion), in an otherwise yellowish or reddish matrix, indicate saturated (or close to saturated) water flow for at least three months of the year (Unconsolidated/Unspecified material with signs of wetness);
- Soil horizons that are uniform in colouration and indicative of well-drained and aerated (oxidising) conditions (e.g. yellow brown apedal B-horizon).

4.2 Water Movement in the Landscape

Water movement in a landscape is a combination of the different flow paths in the soils and geological materials. The movement of water in these materials is dominantly subject to gravity and as such it will follow the path of least resistance towards the lowest point. In the landscape there are a number of factors determining the paths along which this water moves. **Figure 4.1** provides a simplified schematic representation of an idealised landscape (in "profile curvature". The total precipitation (rainfall) on the landscape from the crest to the lowest part or valley bottom is taken as 100 %. Most geohydrologists agree that total recharge (the water that seeps into the underlying geological strata), is less than 4% of total precipitation for most geological settings. Surface runoff varies considerably according to rainfall intensity and distribution, plant cover and soil characteristics but is taken as a realistic 6% of total precipitation for our idealised landscape. The total for surface runoff and recharge is therefore calculated as 10% of total precipitation. If evapotranspiration (from plants as well as the soil surface) is taken as a very high 30% of total precipitation it leaves 60% of the total that has to move through the soil and/or geological strata from higher lying to lower lying areas. In the event of an average rainfall of 750 mm per year it results in 450 mm per year having to move laterally through the soil and geological strata. In a landscape there is an accumulation of water down the slope as water from higher lying areas flow to lower lying areas.

To illustrate: If the assumption is made that the area of interest is 100 m wide it follows that the first 100 m from the crest downwards has 4 500 m^3 (or 4 500 000 litres) of water moving laterally through the soil (100 m x 100 m x 0.45 m) per rain season. The next section of 100 m down the slope has its own 4 500 m^3 of water as well as the added 4 500 m^3 from the upslope section to contend with, therefore 9 000 m^3. The next section has 13 500 m^3 to contend with and the following one 18 000 m^3. It is therefore clear that, the longer the slope, the larger the volume of water that will move laterally through the soil profile to accumulate in lower lying positions.

Amongst other factors, the thickness of the soil profile at a specific point will influence the intensity of the physical and chemical reactions taking place in that soil. **Figure 4.2** illustrates the difference between a dominantly thick and a dominantly thin soil profile. If all factors are kept the same except for the soil profile thickness it can be assumed with confidence that the chemical and physical reactions associated with water in the landscape will be much more intense for the thin soil profile than for the thick soil profile. Stated differently: The volume of water moving through the soil per surface area of an imaginary plane perpendicular to the direction of water flow is much higher for the thin soil profile than for the thick soil profile. This aspect has a significant influence on the expression of redox morphology in different landscapes of varying soil/geology/climate composition.

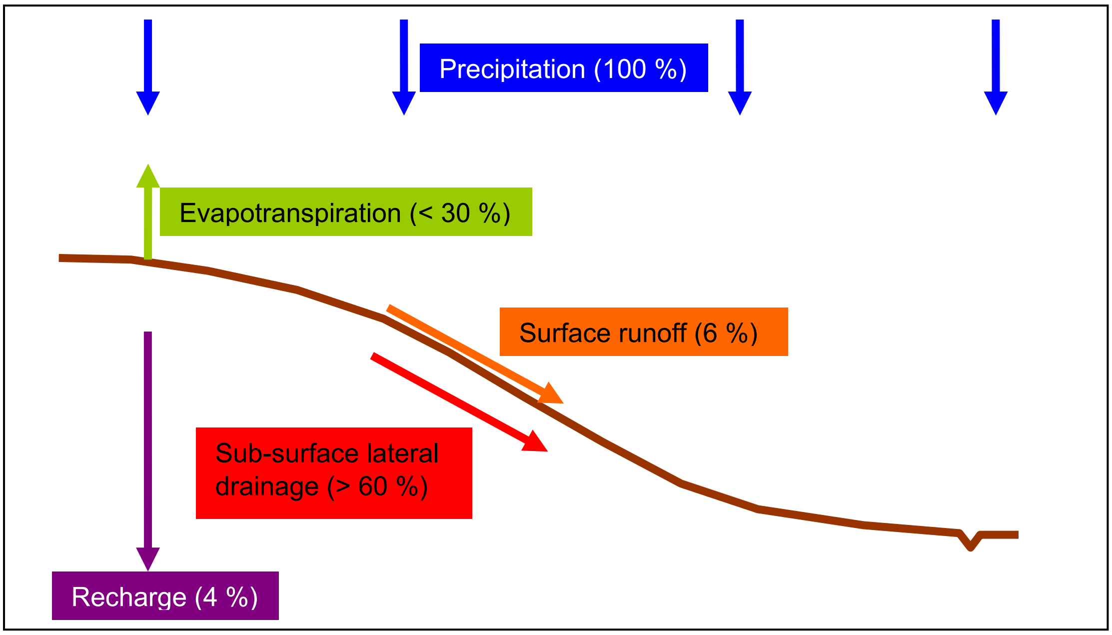

Figure 4.1 Idealised landscape with assumed quantities of water moving through the landscape expressed as a percentage of total precipitation (100%)

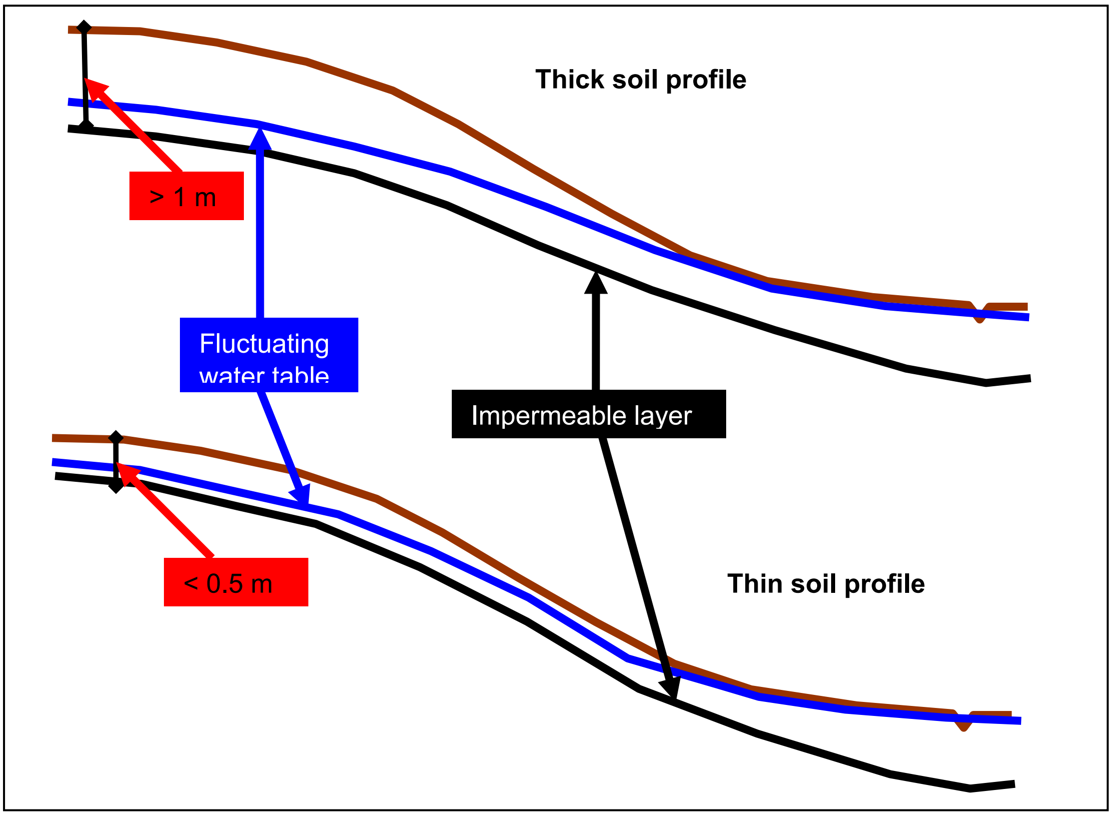

Figure 4.2 The difference in water flow between a dominantly thick and dominantly thin soil profile

Flow paths through soil and geological strata, referred to as “interflow” or “hillslope water”, are very varied and often complex due to difficulty in measurement and identification. The difficulty in identification stems more from the challenges related to the physical determination of these in soil profile pits, soil auger samples and core drilling samples for geological strata. The identification of the morphological signs of water movement in permeable materials or along planes of weakness (cracks and seams) is a well-established science and the expression is mostly referred to as “redox morphology”. In terms of the flow paths of water large variation exists but these can be grouped into a few simple categories. **Figure 4.3** provides a schematic representation of the different flow regimes that are usually encountered.

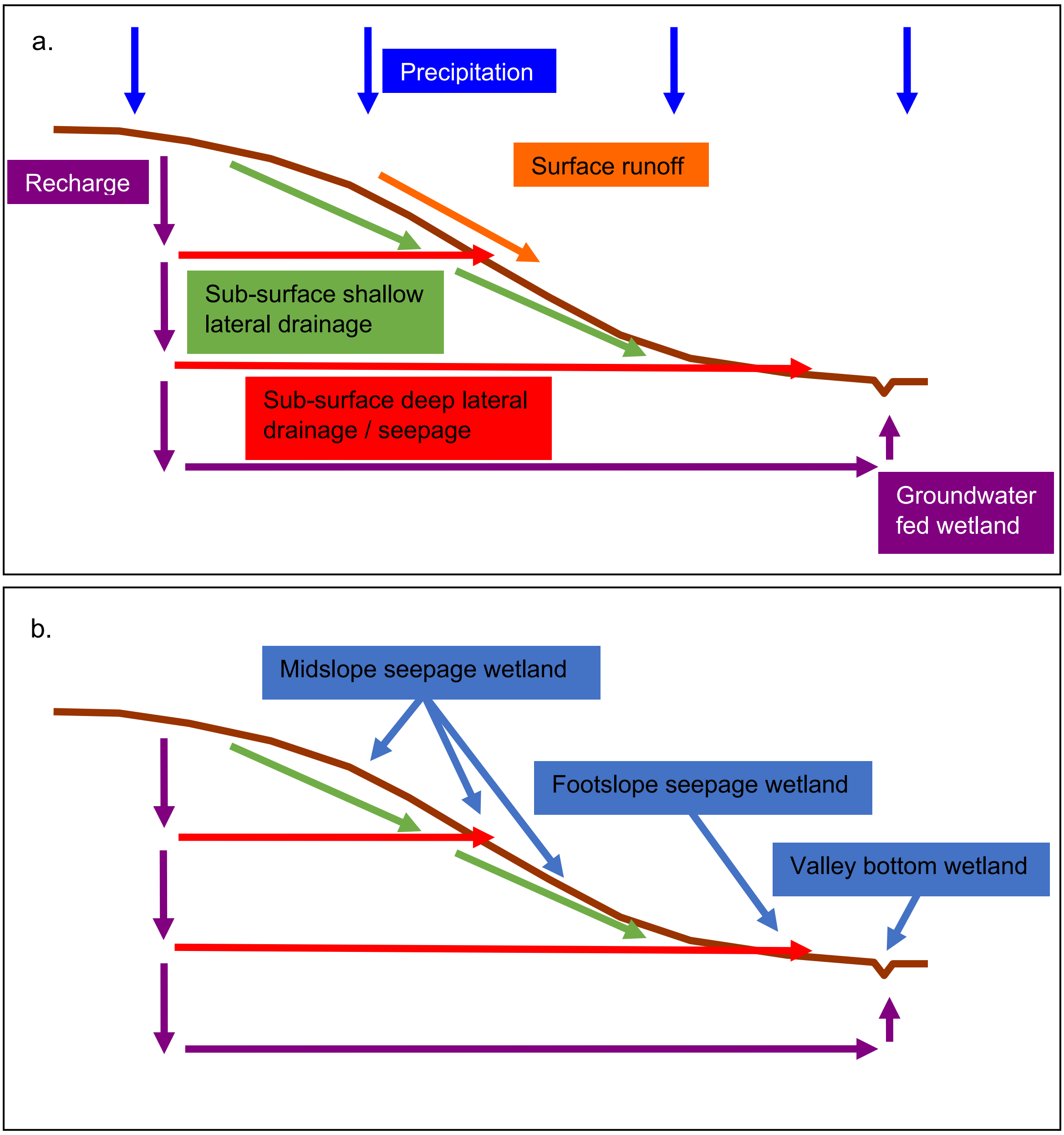

Figure 4.3 Different flow paths of water through a landscape (a) and typical wetland types associated with the water regime (b)

The main types of water flow can be grouped as 1) recharge (vertically downwards) of groundwater; 2) lateral flow of water through the landscape along the hillslope (interflow or hillslope water); 3) return flow water that intercepts the soil/landscape surface; and 4) surface runoff. Significant variation exists with these flow paths and numerous combinations are often found. The main wetland types associated with the flow paths are: a) valley bottom wetlands (fed by groundwater, hillslope processes, surface runoff, and/or in-stream water); b) hillslope seepage wetlands (fed by interflow water and/or return flow water); and wetlands associated with surface runoff, ponding and surface ingress of water anywhere in the landscape.

4.3 Free Draining versus Inward Flowing Systems

Free draining systems in this case refer to typical hillslopes where water drains towards the lowest point in the landscape and the flows out in a drainage feature or watercourse. Inward draining systems have no outflow (such as pans) and the dominant water removal is therefore through evaporation losses. The dominant hydrological functioning of inward draining landscapes can be assumed to be very similar if only the side slopes are considered. **Figure 4.4** provides an indication of the hydrological processes experienced in such landscapes. The hydrological difference between the two systems is seen in the fact that the free draining systems reaches a maximum water content soon and releases water downstream in drainage features. The inwardly draining system accumulates water and theoretically can do such until it overflows or the water seeps away through more porous soils.

4.4 Implications for Wetland Conservation in Urban Environments

Whether an area is designated a wetland or not loses some of its relevance once drastic influences on landscape hydrology are considered. If wetlands are merely the expression of water in a landscape due to proximity to the land surface (viz. the 50 cm mottle criterion in the delineation guidelines) it follows that potentially large proportions of the water moving in the landscape could fall outside of this sphere – as discussed in detail above. **Figures 4.5** and **4.6** provide schematic representations (as contrasted with **Figure 4.3**) of water dynamics in urban environments with distinct excavations and surface sealing activities respectively.

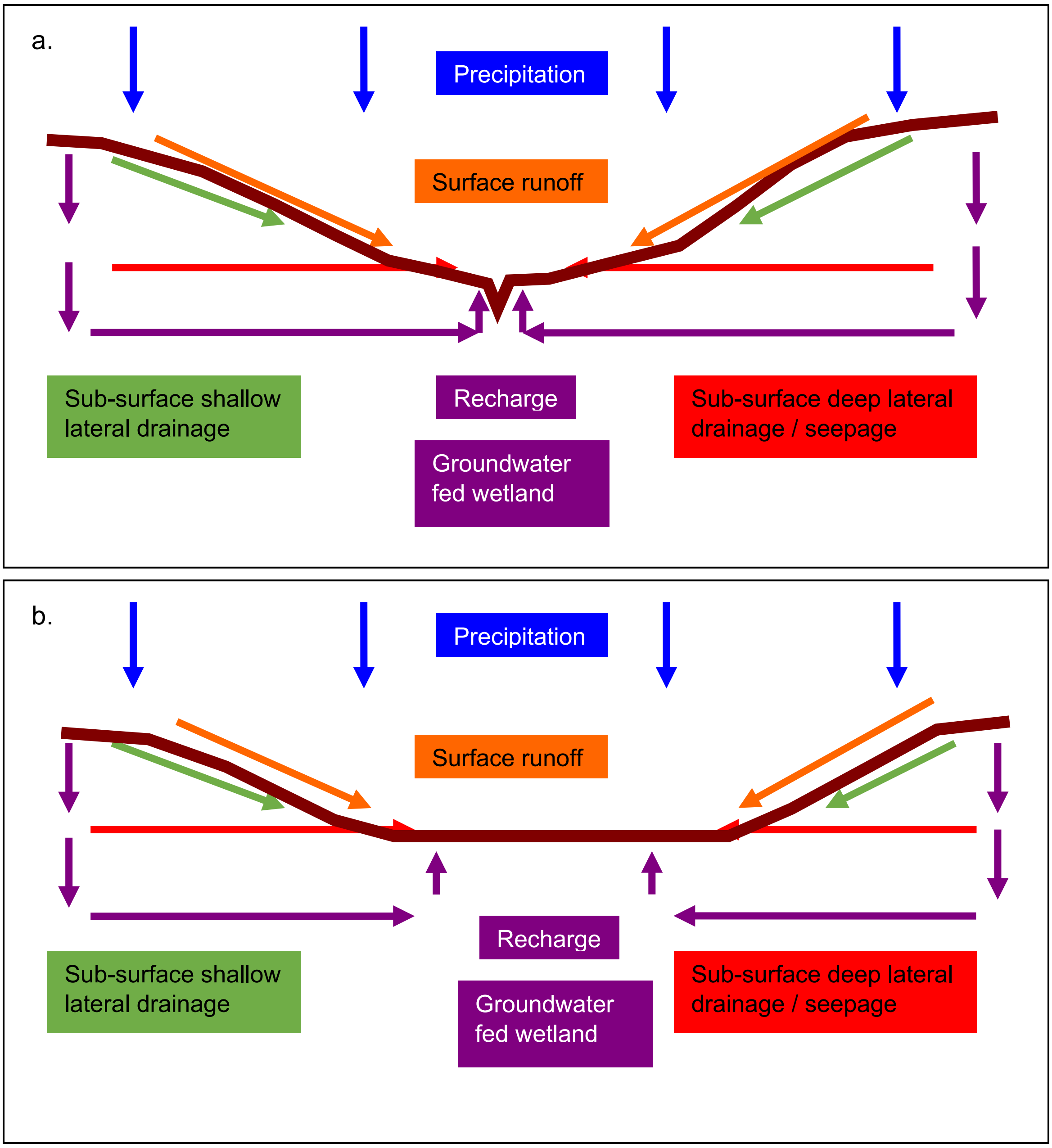

Figure 4.4 Similarity in flow paths for free draining (a) and inward draining (b) systems

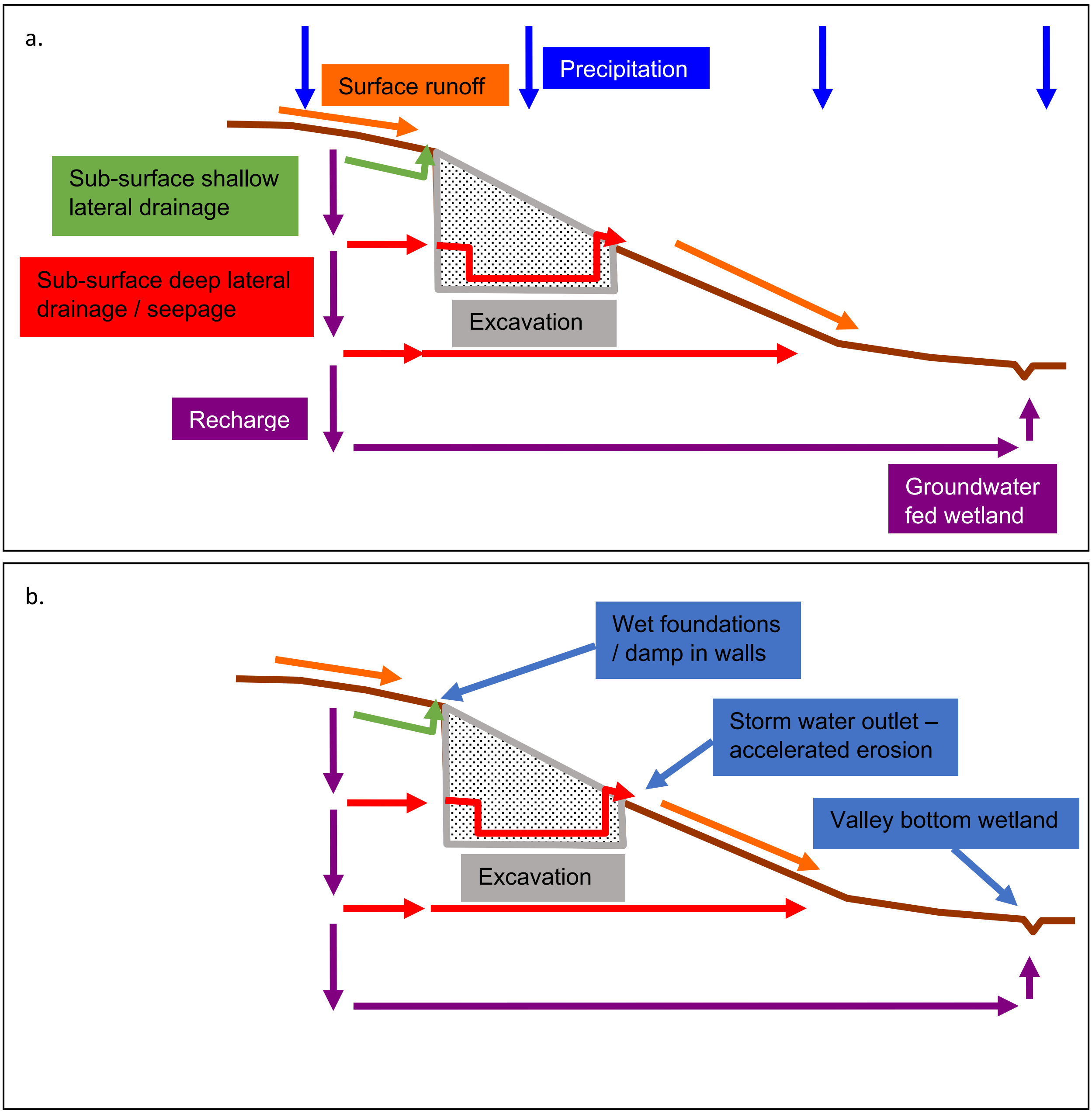

Figure 4.5 Different flow paths of water through a landscape with an excavated foundation (a) and typical wetland types associated with the altered water regime (b)

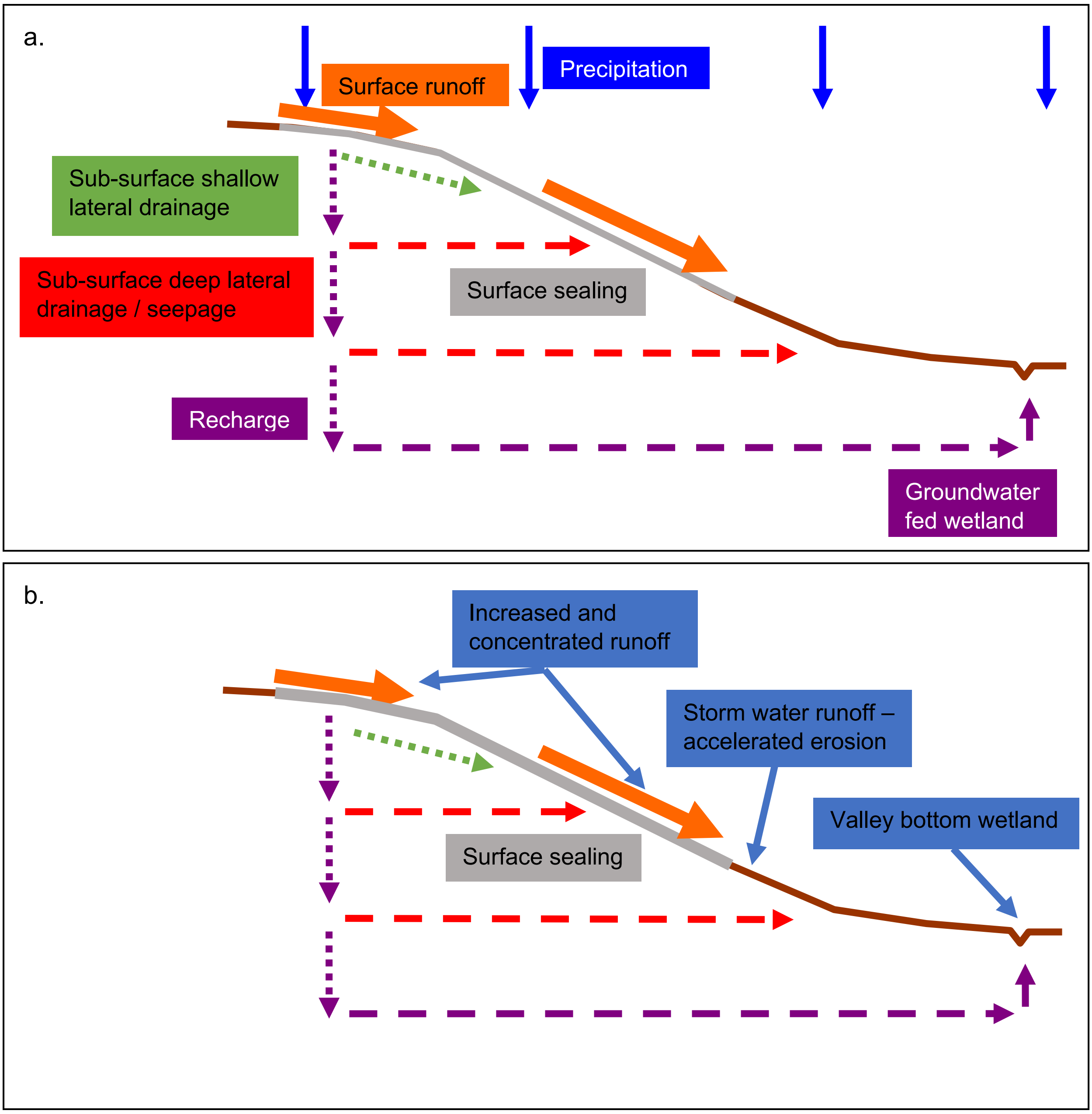

Figure 4.6 Different flow paths of water through a landscape with surface sealing (buildings and paving) (a) and typical wetland types associated with the altered water regime (b)

Through the excavation of pits (**Figure 4.5**) for the construction of foundations for infrastructure or basements for buildings the shallow lateral flow paths in the landscape are severed. As discussed above these flow paths can account for up to 60% of the volume of water entering the landscape in the form of precipitation. These severed flow paths often lead to the ponding of water upslope from the structure with a subsequent damp problem developing in buildings. Euphemistically we have coined the term “wet basement syndrome” (WBS) to describe the type of problem experienced extensively on the Halfway House Granite Dome (HHGD). A different impact is experienced once the surface of the land is sealed through paving (roads and parking areas) and the construction of buildings (in this case the roof provides the seal) (**Figure 4.6**). In this case the recharge of water into the soil and weathered rock experienced naturally is altered to an accumulation and concentration of water on the surface with a subsequent rapid flowing downslope. The current approach is to channel this water into storm water structures and to release it in the nearest low lying position in the landscape. These positions invariable correlate with drainage features and the result is accelerated erosion of such features due to a drastically altered peak flow regime.

The result of the above changes in landscape hydrology is the drastic alteration of flow dynamics and water volume spikes through wetlands. This leads to wetlands that become wetter and that experience vastly increased erosion pressures. Later in the document a perspective is provided on the erodibility of the soils of the HHGD. It is important to note the correlation between increasing wetness, perching of water and erodibility.

4.5 Implications for Wetland Conservation in Opencast Mining Environments

Figure 4.7 provides a schematic representation (as contrasted with **Figure 4.3**) of water dynamics in an opencast mining environment.

With the typical opencast mining the "topsoil" and overburden rock is stripped to access coal seams at depth. The "topsoil" often includes the entire weathered zone (entire soil profile) without consideration of specific soil layers or horizons. As indicated earlier, it is within these soil layers that a large proportion of water in landscape flows. Although advised by myself and others in many EIA reports the approach of stripping soil horizons separately is almost always ignored by mine planners and mining companies due to the high cost associated with it. The stripping of overburden rock destroys further flow paths. Once the void is "rehabilitated" it is filled with loose and unconsolidated material with vastly different physical properties (porous and unconsolidated versus solid or sparingly permeable bedrock). Due to the drastic change in physical properties the filled-in mine void area becomes an area of drastically increased recharge. Some workers in the field indicate a 10- to 20-fold increase in recharge. The recharge into the filled-in material implies that water will percolate down to the original mine floor with a subsequent filling of the void until it decants at the lowest point. Due to the pyrite content of many associated rock layers (that have now been broken up with a drastically increased surface area) these voids start generating sulphates and acid. The mine drainage water exiting the mine area at the decant point then leads to the establishment of an acid and/or sulphate-rich seep. These have many wetland characteristics but with the difference that they are highly altered chemically and biologically.

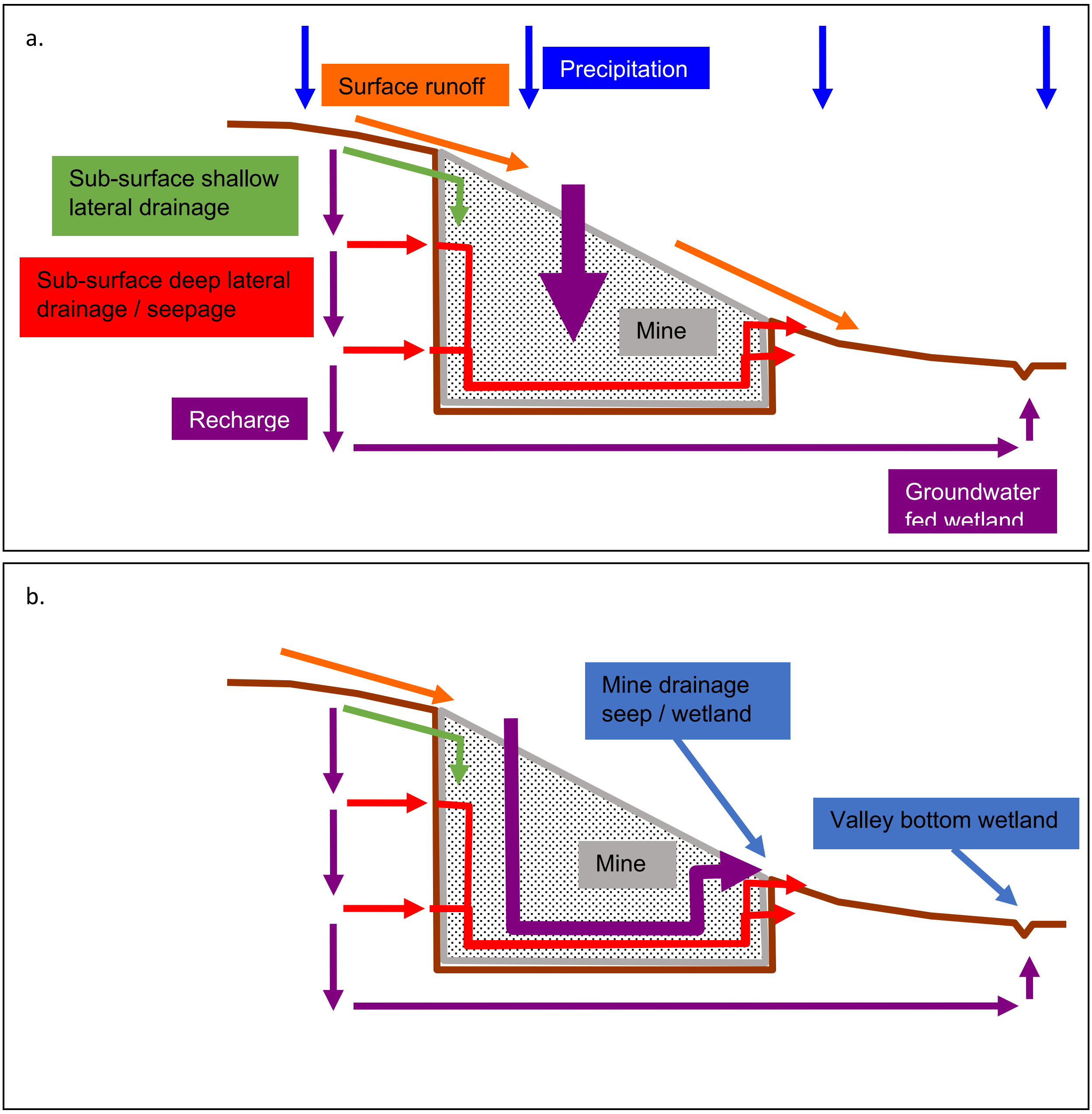

Figure 4.7 Different flow paths of water through a landscape with an opencast mine (a) and typical wetland types associated with the water regime (b)

4.6 Implications for Wetland Conservation in Underground Mining Environments

Figure 4.8 provides a schematic representation (as contrasted with **Figure 4.3**) of water dynamics in an underground mining environment. In underground mining environments very few, if any, of the near surface flow paths of water are impacted or severed. In some cases the mine acts as a sink for groundwater and then leads to concentrated outflows at access points. These outflows depend on the dip of the access point as well as the time and level of accumulation in the underground areas. In coal and gold mine environments the water flowing out of the access point (or occasionally boreholes) could be highly acid with an acid plume in the wetlands (natural or mine induced) that occur in such areas.

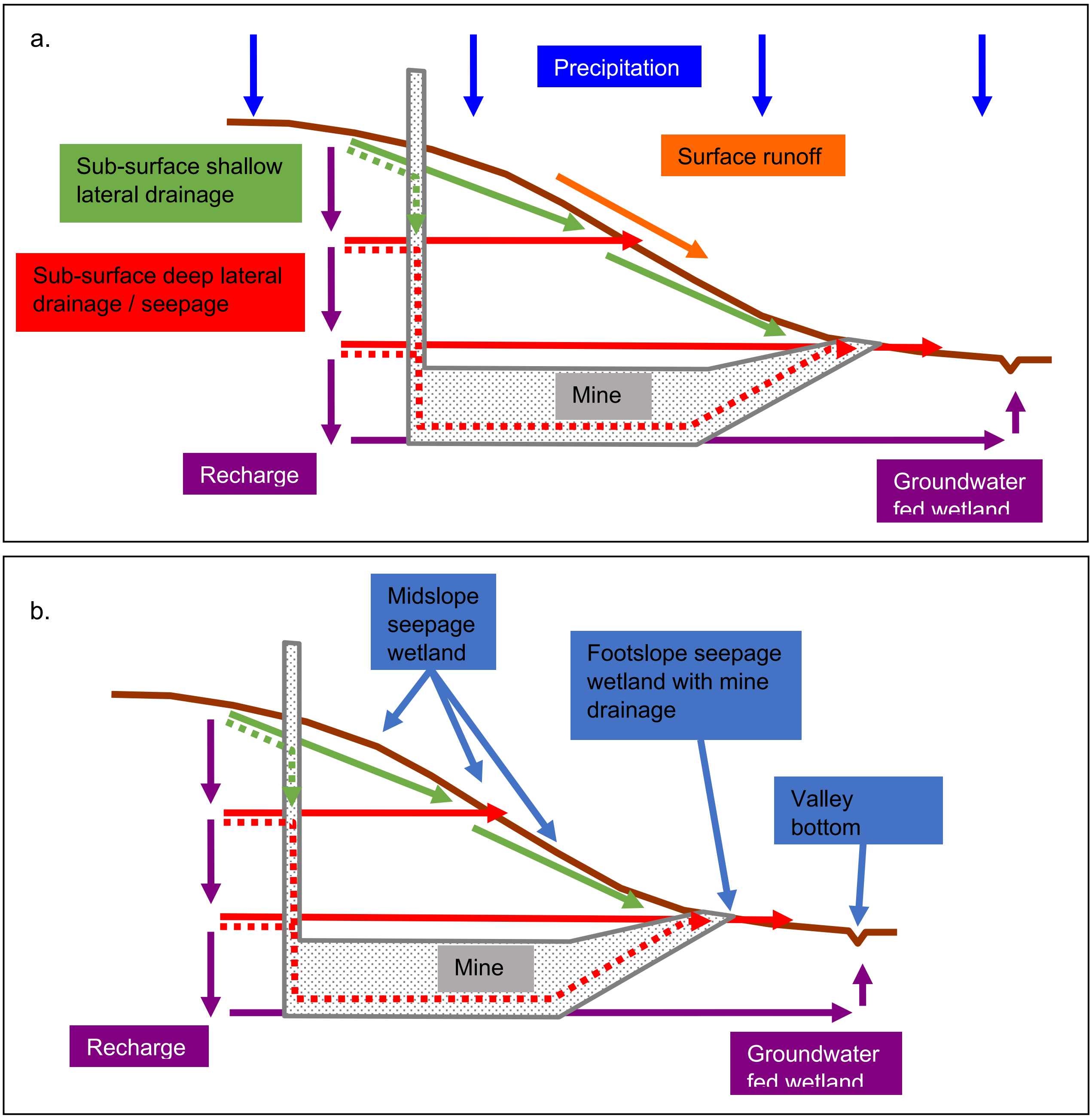

Figure 4.8 Different flow paths of water through a landscape with an underground (a) and typical wetland types associated with the water regime (b)

4.7 Implications for Wetland Conservation in Agricultural Environments

Figure 4.9 provides a schematic representation (as contrasted with **Figure 4.3**) of water dynamics in an agricultural environment. In these environments the hydrology of the landscape is not severely altered and most, if not all, of the hydrological processes remain largely intact. The one alteration that can be experience is the increase removal of water from the landscape due to the water demand of the plants. Due to seasonality and aspects such a crop growth period and irrigation the specifics can be very variable.

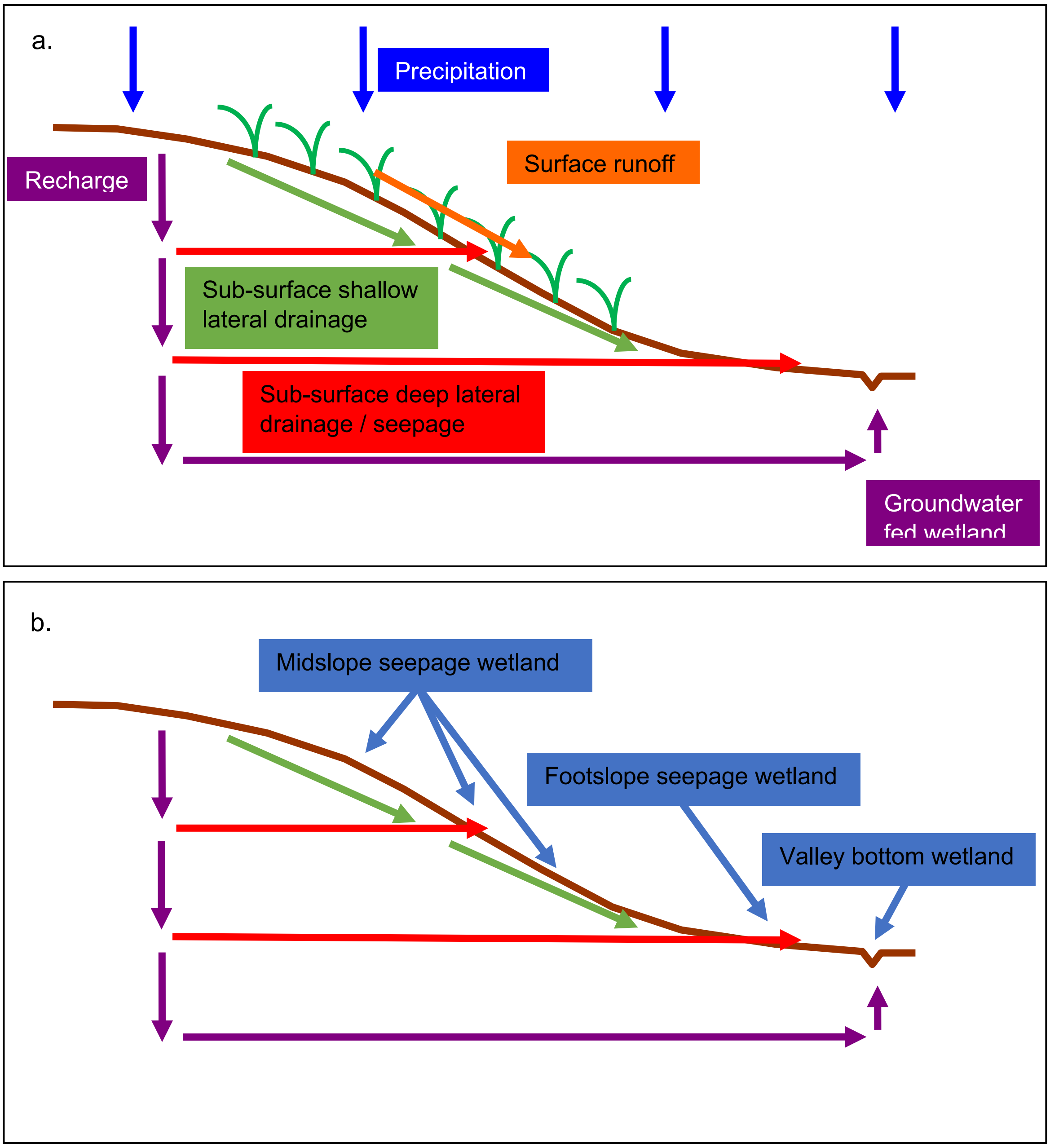

Figure 4.9 Different flow paths of water through an agricultural landscape (a) and typical wetland types associated with the water regime (b)

4.8 Implications for Wetland Conservation in Forestry Environments

Figure 4.10 provides a schematic representation (as contrasted with **Figure 4.3**) of water dynamics in a forestry environment. As is the case with agricultural environments the hydrology of the landscape is not severely altered and most, if not all, of the hydrological processes remain largely intact. The main alteration is water demand by the trees that could remove significant amounts of water from the landscape – water that would have fed wetlands. The outcome is a landscape where wetlands, even if delineated, are dryer than they would have been under natural veld.

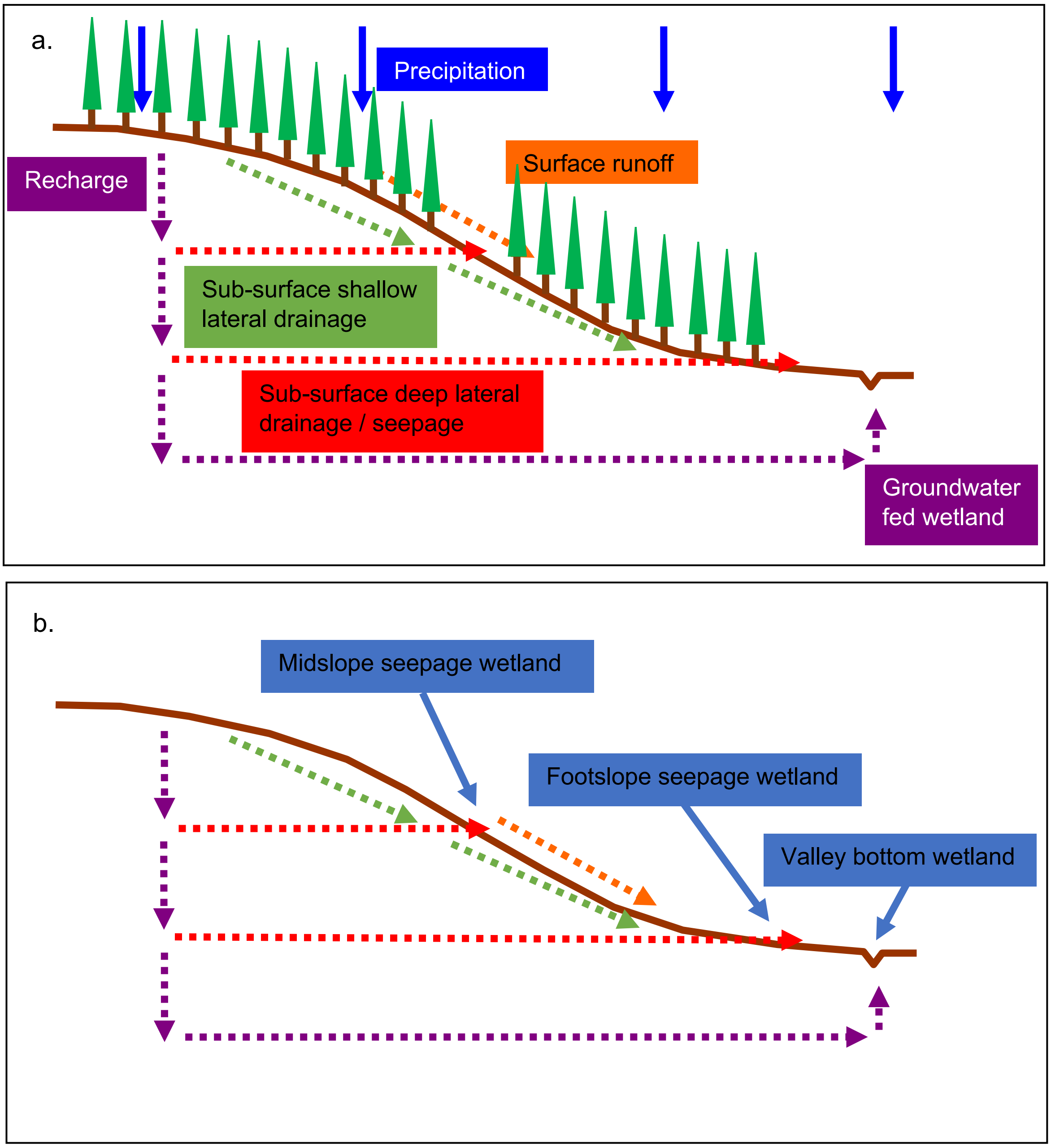

Figure 4.10 Different flow paths of water through a forestry landscape (a) and typical wetland types associated with the water regime (b)

4.9 Summary and Application

The movement of water in a landscape is a function of several factors in soil and in the underlying materials. Variations in these properties lead to the expression of wetlands in any of a range of possible positions where the water approaches the soils surface (as per the technical inference of the definition of a wetland in the NWA). The implications are that 1) presence of wetlands and expression of water are not observable on the land surface alone and these have links to multiple subsurface mechanisms in an integrated system, 2) human activities that impact on the integrate flow mechanisms and quantities will influence the expression of wetlands in a landscape, and 3) wetland assessment requires a solid understanding and elucidation of the flow mechanisms (water regime drivers) and water quality drivers in order to adequately plan for the mitigation and management of impacts that in turn will influence hydrological responses.

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CHAPTER 5 – CONTEXTUALISATION OF SOUTH AFRICAN SOILS: BROAD LAND TYPES

5.1 Introduction

The generation of a wetland guideline document for South Africa requires the contextualisation of the soil landscape. The most detailed soil information data set for SA is the land type database of the Agricultural Research Council (ARC). This chapter provides a high-level introduction and contextualisation of the soils of SA based on the broad land types as contained in the land type database. The aim of this chapter is to provide a reference point for the understanding of the soil properties evident in SA as a function of climatic, geological and topographical factors. This discussion serves as a starting point for the more detailed regional / geology based wetland delineation and assessment guidelines that follow in later chapters.

5.2. Background to the Land Type Inventory for South Africa

The Institute for Soil Climate and Water (ISCW) of the Agricultural Research Council (ARC) and its predecessors collected soil in a structured manner to generate "land types" for South Africa (Land Type Survey Staff, 1972-2006). The land type data is presented at a scale of 1:250 000 and entails the division of land into land types, typical terrain cross sections for the land type and the presentation of dominant soil types for each of the identified terrain units (in the cross section). The soil data is classified according to the Binomial System (MacVicar *et al.,* 1977) but has to be interpreted and re-classified according to the Taxonomic System (Soil Classification Working Group, 1991) for present day use.

The following, where indicated in inverted commas, is a verbatim description ("Legend to the Land Type Maps") of the land types and their soils as provided in the land type memoirs (Land Type Survey Staff, 1972-2006).

"Broad soil patterns *(vide infra)* were chosen at the start of the survey for the purpose of constructing a common legend for the land type maps. These broad soil patterns and their associated colours have a restricted function, namely to

- improve the readability of the maps and
- to give the reader an indication of the soils of the area."

"It was also considered convenient to number the land types according to these broad soil patterns. Each land type was allocated a number by placing it in the broad soil pattern (defined in the paragraphs that follow) that accommodated it and then giving it the next available number in the soil pattern. Thus land type number Ea39 was given to the thirty-ninth land type that qualified for inclusion on broad soil pattern (or map unit) Ea. Often, land belonging to the same land type occurs as islands separated by other land types. Each such separate occurrence is identified using the system Ea39a, Ea39b, etc. A single occurrence of a land type may occur on two map sheets; the same system of postscripts is used to indicate the two portions of the land type. Since these postscripts indicate different occurrences of the same land type, they are not part of the land type number. There follows a list of the soil patterns and a description of the soils to which each refers. Technical terms are explained in the book "Soil Classification: A Binomial System for South Africa" (MacVicar *et al*., 1977)."

5.3. The Land Type Inventory – Main Land Type Groups

The land type inventory will be focused on as this represents the most detailed assessment of the soil resources of South Africa at a national scale. Other information/data may exist in areas but these are restricted to localised areas such as the KwaZulu-Natal Province. Due to very wide variation it is a challenge presenting the soils of South Africa on a map! One way is to use the land types contained in the land type database. The country is divided into nine broad land types (with subdivisions) namely:

A Red and yellow structureless soils without water tables within the observable soil profile
B Plinthic landscapes with almost no upland duplex* and margalitic# soils
C Plinthic landscapes with commonly occurring upland duplex* and margalitic# soils
D Duplex* soils dominant
E Dark and red coloured structured and high base status
F Pedologically young and shallow/rocky soils
G Podzolic soils
H Bleached sandy (quartz dominated) soils
I Miscellaneous young land classes that include alluvial depressions and rock dominated landscapes

*relatively permeable topsoil overlying a slowly permeable subsoil
#structured, dark-coloured high base status

Note: These land type categories have been accepted for South Africa and form part of the national resource inventory. One area that is not covered is Marion Island where the soils follow patterns not described in the categories of the land type data. Also, the SA Binomial and Taxonomic Systems are often used by South Africans conducting soil surveys in other parts of Africa. Even though the basic soil patters are similar it needs to be noted that the land type data is limited to South Africa.

5.4. The Land Type Inventory – Broad Land Types Distribution and Soils

Below follows a discussion of the broad land types in terms of central concept, geographic distribution, signature soils and horizons (with a discussion on the changes from the Binomial System to the Taxonomic System), main redox morphology and wetland context parameters and land capability and agricultural potential. The main driver of wetland expression, apart from the geological and topographical determinants, is the climate and rainfall of South Africa (**Figure 5.1**). It is important to consider the dominant influence of precipitation on the soil type and distribution in terms of wetland and water regime contexts.

Note: The following sections can be printed or saved in an electronic format to use as a quick reference guide to the soil distribution and characteristics in South Africa.

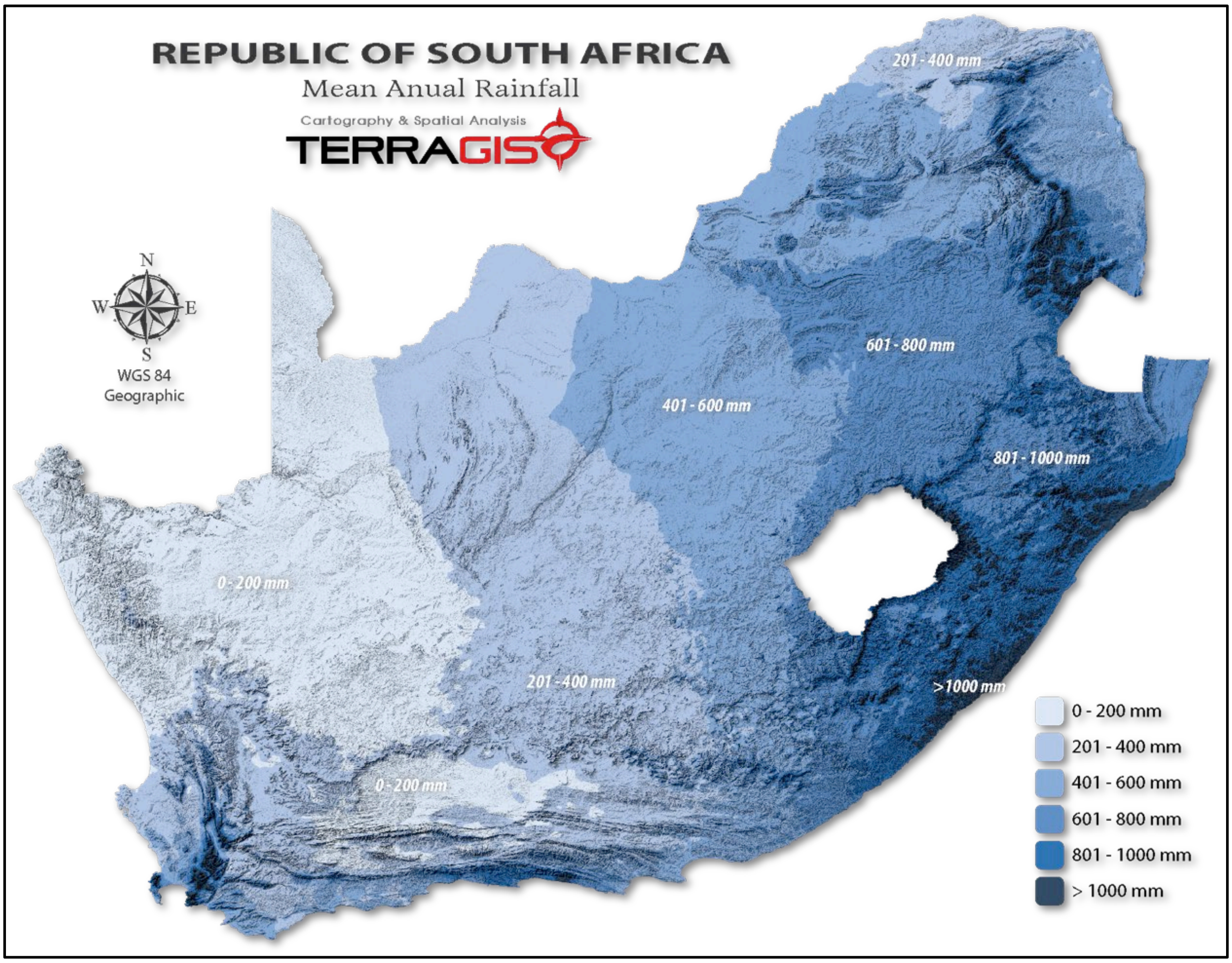


Figure 5.1 Rainfall average distribution of South Africa

5.4.1 Red and yellow structureless soils without water tables within the observable soil profile

Central Concept

The central concept of this land type category is the dominance of freely drained soils in the bulk of the landscape with a lack of redox morphology that would indicate perched water tables. The soils range from high rainfall and mistbelt areas with high organic C topsoils through the central parts of the country to the western and northern parts with low rainfall. The rainfall and temperature gradients contribute to variable leaching status with high rainfall landscape soils being highly leached with a low base status (dystrophic). The intermediate rainfall areas are characterised by moderate to less pronounced leaching in the form of intermediate (mesotrophic) and higher (eutrophic) base status. The more arid areas are characterised by soils with base saturation levels exceeding 100 % and then often with lime occurrence within the profiles. The concept, although limited to soils without water tables, is quite wide as it includes well-developed profiles in old landscapes and higher rainfall ranging to soils that include arid profiles and permanent red and yellow dunes in the western part of the country.

Geographic Distribution

Freely drained soils occur in South Africa from the very low rainfall areas in the west (Northern Cape Province) to very high rainfall areas in the east (KwaZulu-Natal Province). The soil properties associated with the rainfall gradient is accommodated in the different A land type categories with humic A horizon dominated and highly leached (dystrophic) forms in the east to poorly leached (eutrophic and lime and arid mineral dominated) forms in the west (**Figure 5.2**).

Signature Horizons and Forms

Binomial System: In this system the signature soils for these land types are the Inanda, Magwa, Kranskop, Hutton and Clovelly forms (**Table 5.1**). At series level these soils forms further categorises in terms of clay content, leaching status (usually dystrophic and no lime for the humic forms) and presence of lime (for the Hutton and Clovelly forms).

Taxonomic System: Humic horizon soil forms remain the same in the TS. Lime containing versions of the Hutton and Clovelly forms are accommodated in the Taxonomic System with the addition of specific lime containing diagnostic horizons separate from the **red apedal** and **yellow-brown apedal** horizons. The new horizons (with associated new forms – **Table 5.1**) are **neocarbonate**, that typically has the colour of a red or yellow-brown apedal but tests positive with HCl, and **soft carbonate** in which the morphology of the lime (powdery accumulations, nodules or concretions, honeycomb or boulder form) dominate the morphology. At family level the clay content categories have been consolidated to luvic and non-luvic with the leaching categories remaining the same as in the BS.

Dominant Soil Moisture Regime and Wetland Context

The dominant soil moisture regime in these soils is one of free drainage and leaching from the profiles. In the more arid areas the leaching of salts is hindered by low precipitation (and subsequent evaporation of water from the profile) rather than poor drainage. The consequence is that these soils invariably don't exhibit mottling or redox morphology that would result from perched and/or fluctuating water tables. Wetland soils do occur in these landscapes but are generally limited to the immediate watercourse areas in depressions.

Land Capability and Agricultural Potential

The land capability of these soils is determined by a combination of soil depth and climatic constraints. Even though most of these soils are physically suited to crop production and agricultural uses rainfall is the dominant determining factor influencing crop choice, growth period and crop water supply.

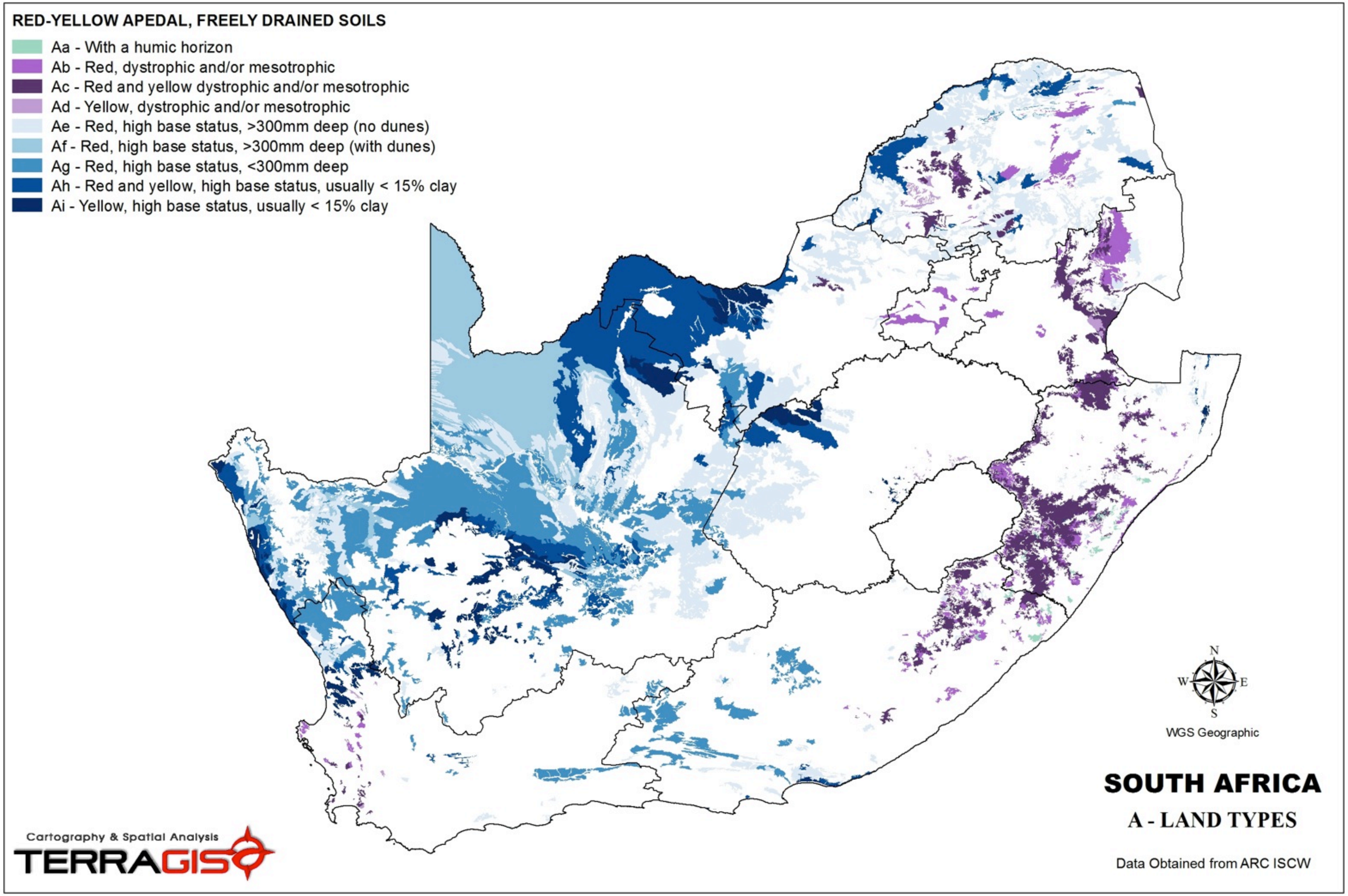


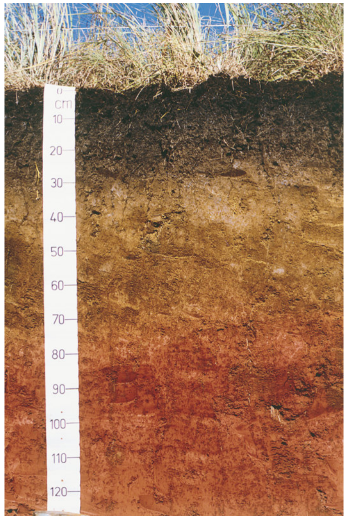
Figure 5.2 Distribution of the A land types

Table 5.1 A land type signature horizons and soil forms

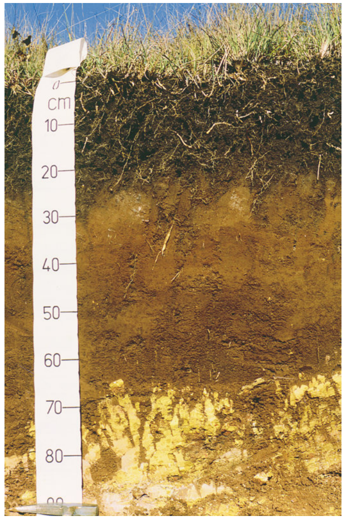
Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Humic / red apedal	Inanda	Humic / red apedal	Inanda
Humic / yellow-brown apedal	Magwa	Humic / yellow-brown apedal	Magwa
Humic / yellow-brown apedal / red apedal	Kranskop	Humic / yellow-brown apedal / red apedal	Kranskop
Orthic / red apedal B	Hutton	Orthic / red apedal / unspecified	Hutton
		Orthic / red apedal / soft carbonate	Kimberley
		Orthic / red apedal / hardpan carbonate	Plooysburg
		Orthic / red apedal / dorbank	Garies
Orthic / yellow-brown apedal	Clovelly	Orthic / yellow-brown apedal / unspecified	Clovelly
		Orthic / yellow-brown apedal / soft carbonate	Molopo
		Orthic / yellow-brown apedal / hardpan carbonate	Askham
Lime containing versions of the Hutton and Clovelly with addition of neocarbonate horizons		Orthic / neocarbonate / soft carbonate	Addo
		Orthic / neocarbonate / hardpan carbonate	Prieska
		Orthic / neocarbonate / dorbank	Trawal
		Orthic / neocarbonate / unspecified	Augrabies

Signature soil form profile photos (courtesy: ARC-ISCW)

Kranskop

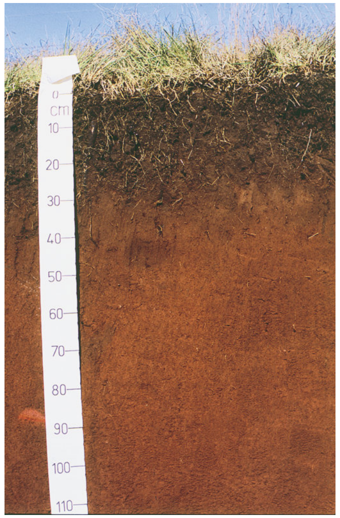


Kranskop



Magwa

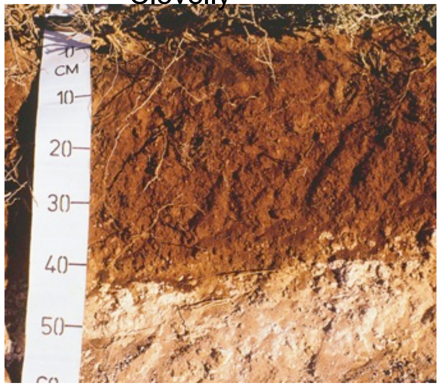
Inanda



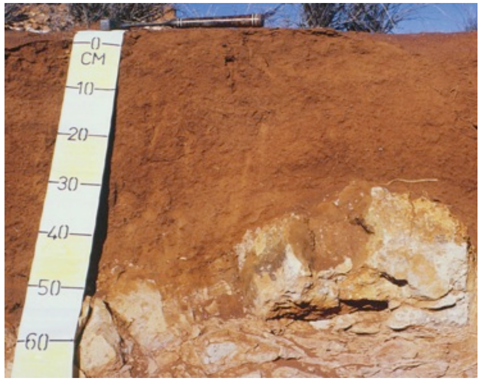
Inanda

Clovelly

Hutton

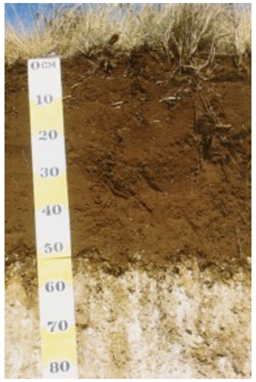


Kimberley



Plooysburg

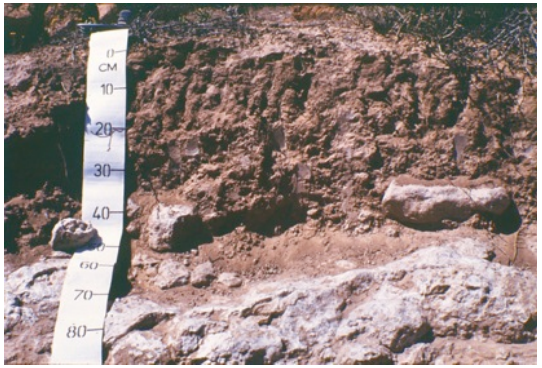
Garies



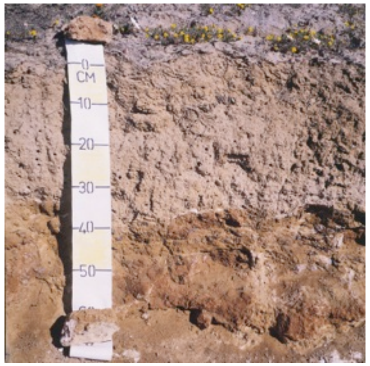
Molopo

Askham

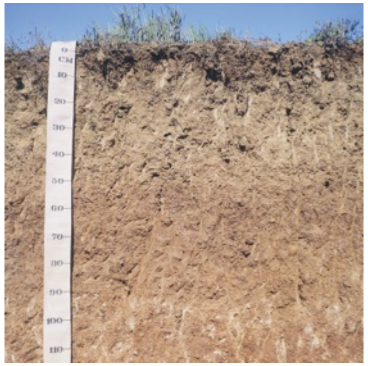
Addo



Prieska



Trawal



Augrabies

5.4.2 Plinthic landscapes with almost no upland duplex and margalitic soils

Central Concept
The central concept of this land type category is the presence of subsoil geological layers (typically sedimentary rock such as sandstone and shale) having led to the formation of perched and fluctuating water tables that are expressed in a specific redox morphology. This redox morphology is in the form of plinthic character (more than 10 % of the land type) as well as distinct gleying in lower lying landscape positions and lower parts of soil profiles. The horizons overlying the plinthic or gleyed horizons exhibit distinct affinities with the predominantly non-lime containing structureless soils discussed for the A land types (section 5.4.1).

Geographic Distribution
These soils occur most frequently in quartz dominated parent materials such as quartzite, sandstone and old aeolian deposits in the higher rainfall areas of SA (**Figure 5.3**). A rainfall associated leaching gradient is evident in the dominance of dystrophic and mesotrophic soils in the south and east and eutrophic soils in the north and west.

Signature Horizons and Forms
<u>Binomial and Taxonomic System</u>: The soils forms that contain plinthic subsoils in the BS are similar to the ones contained in the TS with the addition of the Lichtenburg form in the latter (subsequent to the publishing of the 1991 version). The soil forms and their diagnostic horizons are provided in **Table 5.2**. The signature horizons are the **red apedal** and **yellow-brown apedal** with subsoil **soft plinth**ic and **hard plinthic** horizons. An addition here is the E horizon that indicates a distinct lateral water movement and leaching in these landscapes. The categorisation below soil form level for the red and yellow-brown apedal horizons is similar between the two systems in that at family level (TS) the clay content categories have been consolidated to luvic and non-luvic with the leaching categories remaining the same as in the BS. In the case of the E horizon the series dominated sand grade categories in the BS have been changed to dry and moist colour differences in the TS. The latter is considered important as an indication of the Fe content in the soils with the more bleached versions (in the moist state) indicating lower Fe contents in the form pf sand grain Fe coatings.

Dominant Soil Moisture Regime and Wetland Context
The moisture regime in these soils is often dominated by the presence of restricting rock and soil layers at depth that lead to the perching of water in localised water tables and lateral seepage zones. The soils are therefore characterised by distinct zones of water fluctuation, zones of prolonged saturation with clearly expressed redox morphology features and zones where water manifests close or at the surface through return flow. The redox morphology indicative of the presence of the water is what is often used as the textbook description of mottling and grey colour as indicative of wetland conditions. It therefore follows that landscapes with plinthic soils have a large proportion of the soil covered surface that qualifies as wetland with distinct permanent, extensive seasonal / seepage and temporary wetland zones. Due to the generally accepted notion that the degree and duration of saturation is expressed increasingly through grey and bleached soil colours it follows that the red soil dominated plinthic landscapes (viz. Ba and Bc land types) tend to exhibit smaller wetland soil distributions than yellow and bleached soil dominated plinthic landscapes (viz. Bb and Bd land types)

The Ba land type soil distribution can be considered the “modal” example of colour juxtaposition that is used for the identification of terrestrial and wetland zones in a landscape.

Land Capability and Agricultural Potential
The land capability of plinthic landscapes is very strongly linked to 1) the depth of the soil profiles and 2) the extent and degree of lateral seepage and water feeding mechanisms at depth. Euphemistically these soils are often referred to as being characterised by “subsoil irrigation” processes. These processes lead to good crop yields in most years, average and dry years with high rainfall years proving problematic with inundation of fields and drowning of plants. The extensive temporary and seasonal seepage areas provide a degree of insurance to land users against crop failures in the variable rainfall environment of South Africa’s grain crops production areas.

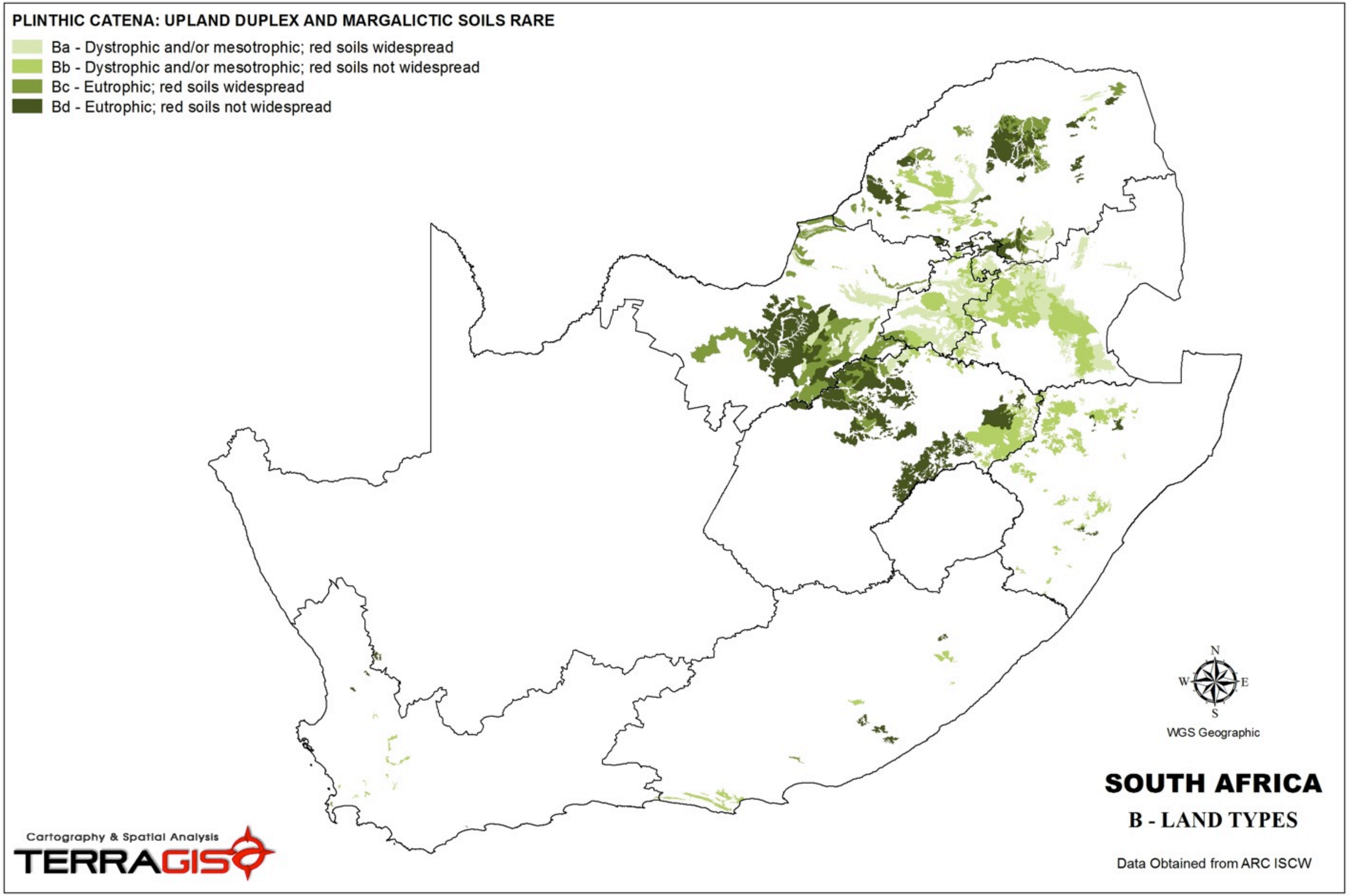


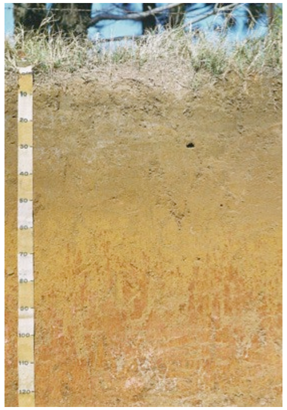
Figure 5.3 Distribution of the B land types

Table 5.2 B land type signature horizons and soil forms

Binomial System		Taxonomic System	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / red apedal / soft plinthic	Bainsvlei	Orthic / red apedal / soft plinthic	Bainsvlei
		Orthic / red apedal / hard plinthic	Lichtenburg
Orthic / yellow-brown apedal / soft plinthic	Avalon	Orthic / yellow-brown apedal / soft plinthic	Avalon
Orthic / yellow-brown apedal / hard plinthic	Glencoe	Orthic / yellow-brown apedal / hard plinthic	Glencoe
Orthic / yellow-brown apedal / gleycutanic B	Pinedene	Orthic / yellow-brown apedal / unspecified material with signs of wetness	Pinedene
		Orthic / red apedal / unspecified material with signs of wetness	Bloemdal
Orthic / E / soft plinthic	Longlands	Orthic / E / soft plinthic	Longlands
Orthic / E / hard plinthic	Wasbank	Orthic / E / hard plinthic	Wasbank
Orthic / soft plinthic	Westleigh	Orthic / soft plinthic	Westleigh
Orthic / hardpan ferricrete	Mispah	Orthic / hard plinthic	Dresden

Signature soil form profile photos (courtesy: ARC-ISCW)


Bainsvlei


Avalon


Glencoe


Longlands


Wasbank


Westleigh

Dresden

5.4.3 Plinthic landscapes with commonly occurring upland duplex and margalitic soils

Note: The central concept of this land type category is a combination of the plinthic catena with occurrence of duplex (D land types) and margalitic (E land types) soils in upland positions (**Figure 5.4**). The discussions of the B, D and E land applies for the purpose of this document.

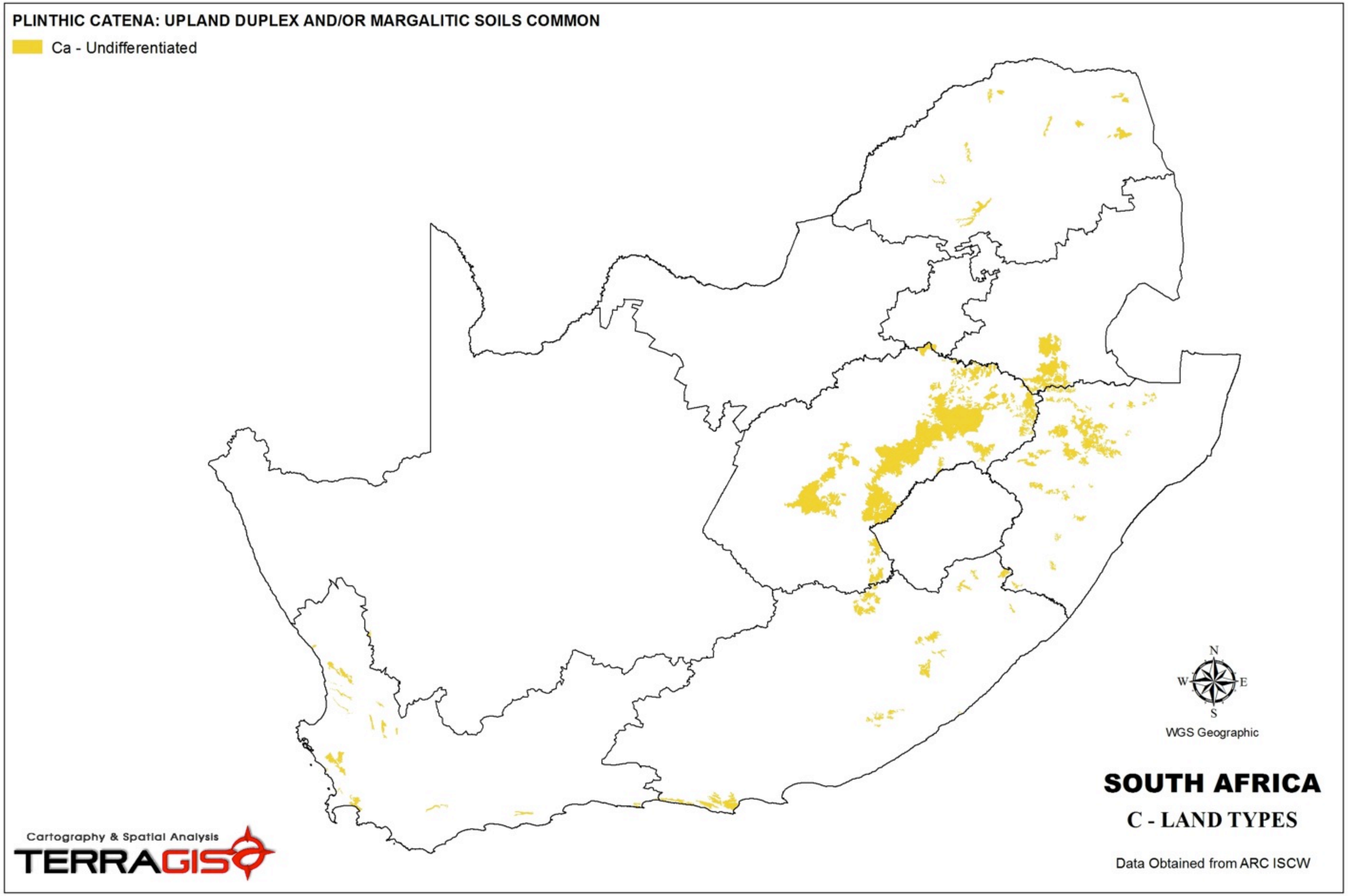


Figure 5.4 Distribution of the C land types

5.4.4 Duplex soils

Central Concept
The central concept of this land type category is the presence of soils with a distinct difference between coarser textured topsoil and finer textured and highly structured subsoil horizons. The origin of the textural and structural differences include 1) deposition of coarser textured geological material over in-situ parent materials with high clay forming potential to yield a “binary profile” or more dominantly 2) distinct clay migration from surface horizons to a subsoil horizon due to dispersive and unstable clay conditions induced by elevated Na (and often Mg) concentrations on clay surfaces. Invariably the clay depleted matrix will exhibit signs of clay removal under conditions of eluviation and the clay enriched horizon will exhibit clear clay illuviation and clay accumulation characteristics. These soils are often associated with specific parent materials that contain elevated concentrations of the dispersive cation Na (as well as Mg in many cases). Due to the poor inherent drainage of duplex soils they often exhibit lime accumulation in the subsoils in areas that would otherwise not have large occurrences of lime containing soils.

Geographic Distribution
Duplex soils occur throughout South Africa but dominate on Karroo geology characterised by shales and mudstones (**Figure 5.5**). In this regard the widest distribution is centred around a large area that stretches westward from (and including) Lesotho in the Free State, Eastern Cape and Northern Cape provinces. Significant occurrences are also found in the areas of the Western Cape and KwaZulu-Natal provinces associated with similar geology.

Signature Horizons and Forms
<u>Binomial and Taxonomic System</u>: Duplex soils in the BS are similar to the ones contained in the TS. The soil forms and their diagnostic horizons are provided in **Table 5.3**. The signature horizons are the prismacutanic and pedocutanic B horizons. The overlying horizons are dominantly coarser textured orthic A and/or E horizons. Distinct signs of gleying are excluded and are accommodated under the G horizon that is allowed to exhibit a wide range of structural properties.

<u>Taxonomic System</u>: The presence of an E horizon overlying a pedocutanic horizon and materials with distinct redox morphology below a pedocutanic horizon is accommodated in two additional soil forms respectively namely: Klapmuts and Sepane.

Dominant Soil Moisture Regime and Wetland Context
Duplex soils are characterised by a distinct difference in saturated and unsaturated hydraulic conductivity between the coarser overlying and higher clay content structured underlying horizons. In this regard the coarser materials can accommodate more distinct lateral flows of water with its associated redox morphology in the form of bleaching and removal of sesquioxides. The structured subsoil horizon may exhibit a certain degree of redox morphology expression (redox depletions and redox accumulations) that can, in its maximal expression< lead to the classification of a G horizon in the lower parts of the landscape. Wetlands are often identified in areas with E horizons and shallow lateral seepage due to the perching of the water on the structured subsoil.

Distinct water accumulation and lateral flows may also occur beneath the structured horizons in unconsolidated materials or fractured and weathering rock. In these cases the redox morphology is consistent with the criteria used for wetland identification except for the depth criteria that precludes it from formal wetland identification.

Land Capability and Agricultural Potential
Duplex soils are generally considered to be suitable for controlled grazing and to a limited extent for dryland cropping practices. However, these soils are inherently unstable and susceptible to erosion and as such any surface related disturbance in the form of vegetation removal or overgrazing will result in extensive erosion and degradation if preventative measures are not implemented. Due to the distinct clay rich and structured subsoils water supply to plants is generally low and these soils are characterised by sweeter grasses than areas in the same climate without such soils.

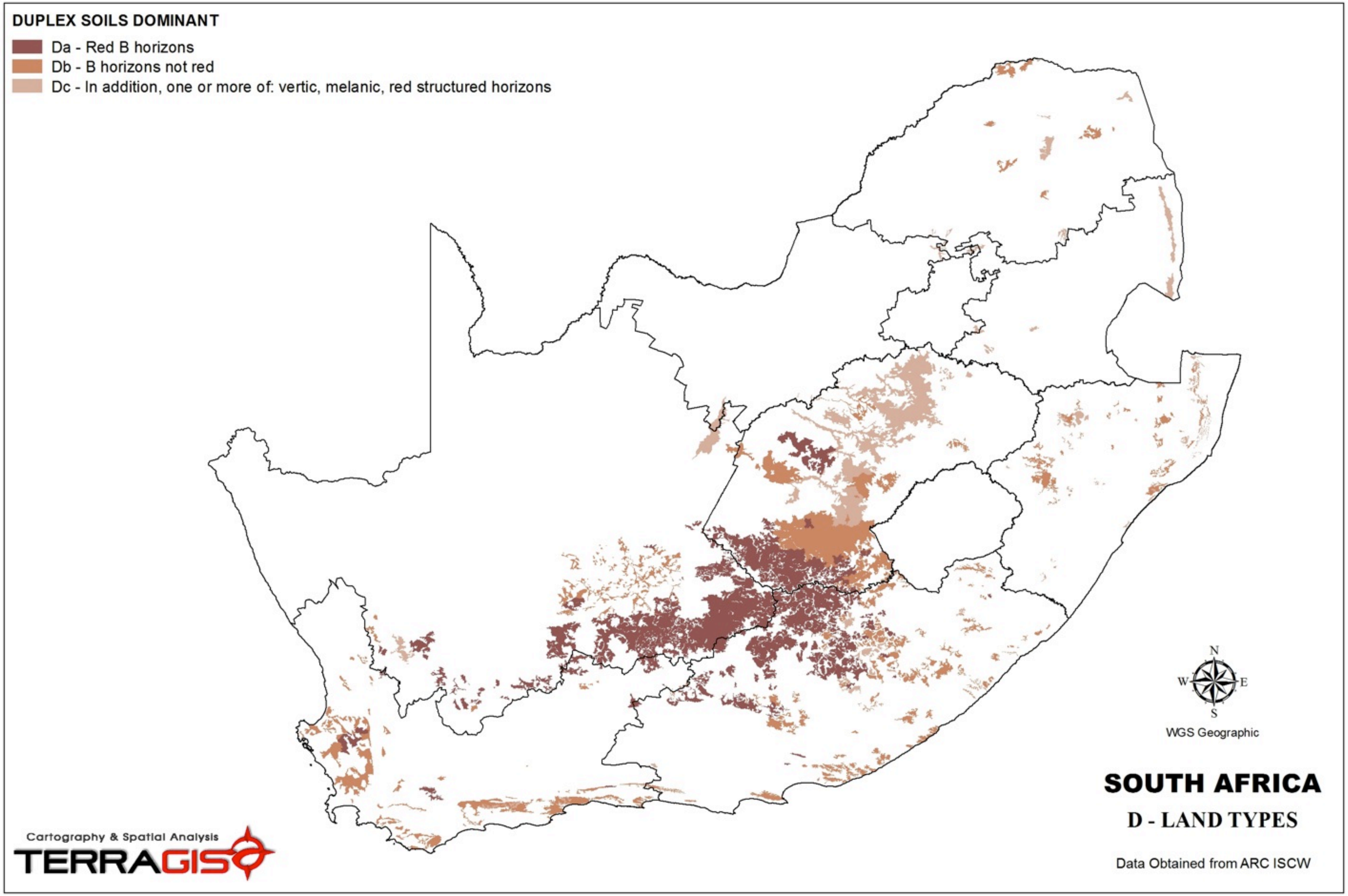
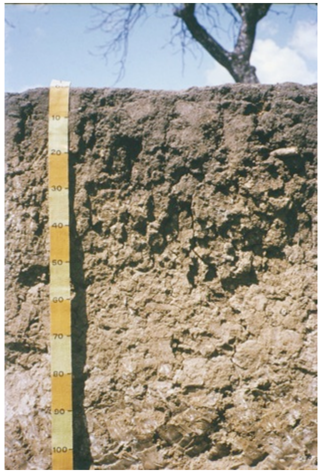


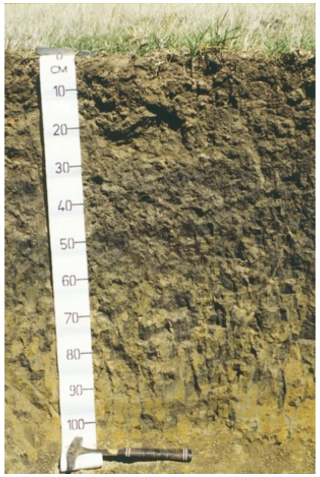
Figure 5.5 Distribution of the D land types

Table 5.3 D land types signature horizons and soil forms

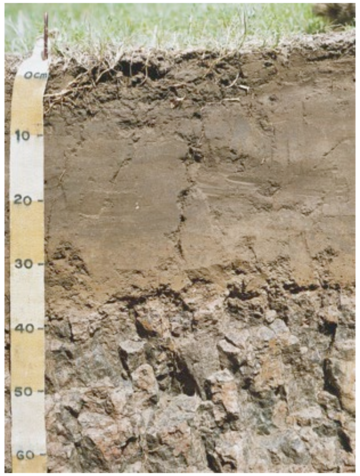
Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / pedocutanic	Valsrivier	Orthic / pedocutanic / unconsolidated material without wetness	Valsrivier
		Orthic / pedocutanic / unconsolidated material with wetness	Sepane
Orthic / pedocutanic / saprolite	Swartland	Orthic / pedocutanic / saprolite	Swartland
Orthic / prismacutanic	Sterkspruit	Orthic / prismacutanic	Sterkspruit
Orthic / E / Prismacutanic	Estcourt	Orthic / E / Prismacutanic	Estcourt
		Orthic / E / pedocutanic	Klapmuts

Signature soil form profile photos (courtesy: ARC-ISCW)

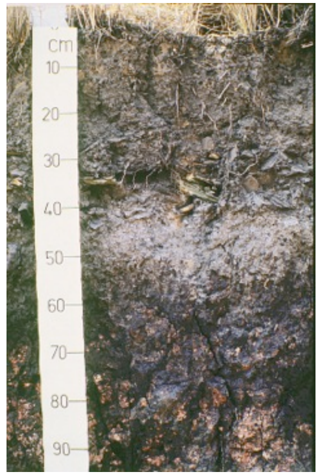

Valsrivier


Sepane


Swartland


Sterkspruit


Estcourt


Klapmuts

5.4.5 Dark and red coloured structured and high base status soils

Central Concept
The central concept of this land type category is dominance of 1) basic igneous geology and/or 2) soils in lower landscape positions that have developed in environments suited to the formation of 2:1 swelling and non-swelling clays. The formation and accumulation of such clays yield soil horizons, in more than half of the landscape, that are characterised by self-mulching and heaving conditions in the case of swelling clays and dark and/or red coloured stable structured soils in the case of non-swelling clays. These soils are inherently fertile and of a high base status due to the dominance of Ca and Mg in their formation.

Geographic Distribution
These soils occur in areas where basic igneous geology (in the form of dolerite, diabase, gabbro, andesite, basalt, etc.) form the dominant parent materials on generally level (**Figure 5.6**). Localised distributions of such soils, especially with darker soil horizons, occur in many other land types but then as a function of accumulation of the weathering products necessary for such soil development in lower landscape positions. Generally these soils require a distinct wet and hot season contrasted with a warm and dry season to form. Notable occurrences are southwest of Lesotho in the Eastern Cape, Eastern Free State and south-western Mpumalanga provinces, Northern KwaZulu-Natal province and the Lebombo Mountain range and the north-eastern sections of the Northwest Province.

Signature Horizons and Forms
Binomial and Taxonomic System: The signature diagnostic horizons are **vertic** and **melanic** A horizons and **red structured** B horizons (**Table 5.4**). Invariably vertic and melanic dominated soils have underlying soil horizons that also exhibit high base status and Ca and Mg dominance in the form of extensive lime accumulations. In rocky areas these soils are generally dominated by shallow profiles overlying rock that is rich in Ca and Mg.

Dominant Soil Moisture Regime and Wetland Context
The dominant soil moisture regime in these soils varies largely in line with the area of formation. In relatively flat landscapes on igneous geology the moisture regime is one of rapid infiltration of water following dry periods and the localised accumulation of water in subsoil horizons under high matrix suction forces due to the high clay content. In these cases the soils may exhibit distinct signs of poor internal drainage in the form of subsoil G horizons. In many cases the landscape exhibits “gilgai” microrelief and then the subsoil G horizons exhibit distinct bowl shapes with vertic soil material in the central part of the bowl. “Gilgai” microrelief may also be linear with the relevant linear orientation of the G horizon depressions. In the case of the formation of melanic horizons the “gilgai” microrelief does not occur by the poor internal drainage of the soils may still be expressed as distinct G horizon subsoils. The G horizons in this case do not indicate regional or localised water tables and therefore do not indicate extensive wetland areas. In the event of no internal drainage impediments these soils may allow percolation of water downward through the profile to weathering rock and lime rich subsoil horizons. Red structured B horizons develop in similar conditions but exhibit good drainage under all conditions – therefore characterising it as terrestrial soils only.

In the case of formation in low lying landscape positions capes the occurrence of vertic and melanic horizons indicate a hillslope and water related weathering product accumulation process. In this regard these soils are then often associated with watercourses and localised wetland conditions – conditions in which the presence of a G horizon at depth invariable indicates some connectivity to hillslope water accumulation processes and wetlands / watercourses.

Due to the high pH and base saturation of these soils Fe redox morphology is not readily expressed as the dominant Fe mineral is siderite ($FeCO_3$). Siderite is white in colour and is masked by the presence of lime nodules, that often occur in vertic and melanic soils, with the result that high chroma mottles cannot be used the identification of water fluctuation zones.

Land Capability and Agricultural Potential
The land capability of these soils is determined by predominantly by the rainfall as the soils are inherently fertile but difficult to till (vertic soils). Irrigation practices are limited due to the poor drainage characteristics in many areas.

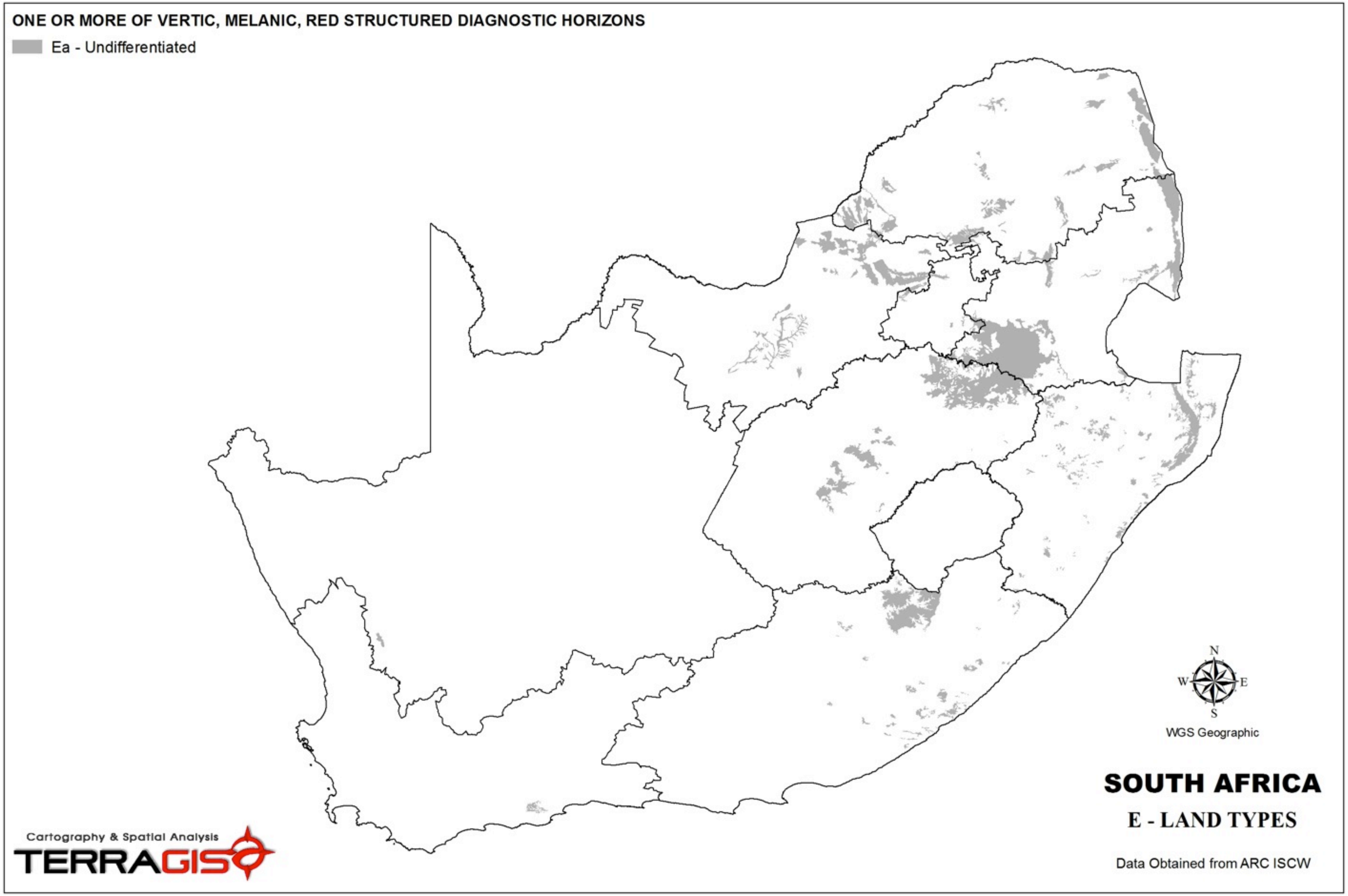


Figure 5.6 Distribution of the E land types

Table 5.4 E land types signature horizons and soil forms

Binomial System		Taxonomic System	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Vertic / not specified	Arcadia	Vertic / unspecified	Arcadia
Vertic / G	Rensburg	Vertic / G	Rensburg
Melanic / G	Willowbrook	Melanic / G	Willowbrook
Melanic / pedocutanic	Bonheim	Melanic / pedocutanic	Bonheim
Melanic / neocutanic or stratified alluvium	Inhoek	Melanic / unspecified	Inhoek
Melanic / lithocutanic	Mayo	Melanic / lithocutanic	Mayo
Melanic / hard rock	Milkwood	Melanic / hard rock	Milkwood
Melanic / hardpan carbonate	Milkwood	Melanic / hardpan carbonate	Immerpan
		Melanic / soft carbonate	Steendal
Orthic / red structured	Shortlands	Orthic / red structured	Shortlands

Signature soil form profile photos (courtesy: ARC-ISCW)

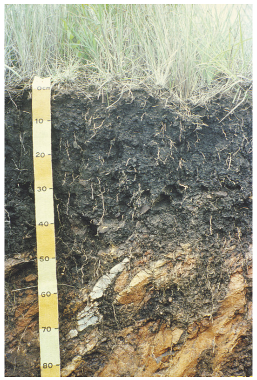

Arcadia


Rensburg

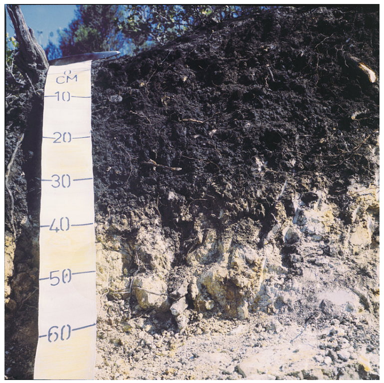

Willowbrook


Bonheim


Inhoek


Mayo


Milkwood


Immerpan


Steendal


Shortlands

5.4.6 *Pedologically young and shallow/rocky soils*

Central Concept

The central concept of this land type category is the dominance of shallow, rocky and often pedologically young soils dominating in landscapes that are invariably characterised by undulating to hilly and incised terrain (but excluding rock dominated landscapes). The soils develop on a wide range of lithologies and are shallow due to the constant weathering and downslope transportation of physical weathering products through water (alluvial) and slope (colluvial) processes. Due to the wide range of parent materials and occurrence throughout South Africa these land types don't have specific soil morphology characteristics save for the shallow nature of the profiles. The only distinction that is made is based upon the presence of lime and the position in the landscape where the lime accumulation has taken place – an indication of aridity as well as to a degree the type of parent material (basic materials rich in Ca and Mg or more acid and quartz dominated materials with low Ca and Mg levels).

Geographic Distribution

These land types occur throughout South Africa in landscapes with undulating to hilly and incised topography on hard geology (**Figure 5.7**). The broad land type is divided into three groups namely: 1) soils with no lime generally in the higher rainfall areas; 2) soils with lime in lower landscape positions generally in lower rainfall areas; and 3) soils with lime in all landscape positions in arid areas. The dominance of the lime rich soils is very prominent in the central-western basin of the country and the lime absent soils in the higher rainfall areas of the Eastern Cape and KwaZulu-Natal Provinces.

Signature Horizons and Forms

<u>Binomial and Taxonomic System</u>: The signature diagnostic horizons of soils in this land type are **lithocutanic** and **hard rock** horizons of varying lithology and physical and chemical character (**Table 5.5**). The presence or absence of lime is dealt with at family level in the Glenrosa and Mispah soil forms.

<u>Binomial System to Taxonomic System Changes</u>:

The Mispah soil form in the Binomial System contained all cemented and hard subsoil horizons including dorbank, hardpan carbonate, hard plinthite and hard rock. The soil form was split up for the TS to include only hard rock with the other horizons as the second horizon yielding different soil forms in the TS. Generally there is a large degree of correlation between the arid subsoils (hardpan carbonate and dorbank) with the landscapes containing lime throughout (Fc land types) and in this regard these land types and soils generally tie in with the Ae to Ai land types discussed earlier in terms of overall moisture regime and content.

Dominant Soil Moisture Regime and Wetland Context

The dominant soil moisture regime in these soils is one of free drainage and recharge of lower fractured rock layers. The degree of recharge depends on the extent and connectedness of fracturing in the underlying geology. Due to the dominance of rapid percolation through the fractured rock material signs of redox morphology are generally lacking except in cases where climate and the flow regime conspire to yield prolonged periods of wetness and saturation. Under such conditions the presence of redox morphology is accommodated at family level in the Glenrosa form. Therefore, these landscapes do not have clear expression of wetland conditions as a rule but specific cases may prove otherwise during detailed investigations. However, due to the "water capturing" function that rocky and shallow soils play they invariably contribute to the expression of wetness and wetlands further down the slope. In this regard in arid landscapes the accumulation of lime in lower lying landscape positions may indicate the preferential flow paths and hydrology even though these signatures do not qualify as wetlands per se.

Land Capability and Agricultural Potential

Due to the dominance of shallow and rocky soils these landscapes are generally left to extensive grazing and game farming or wilderness areas. However, under specific climatic conditions that favour specific crops these soils are successfully used for high value farming enterprises. An example is the production of grapes for consumption or wine production in Western and Northern Cape Provinces.

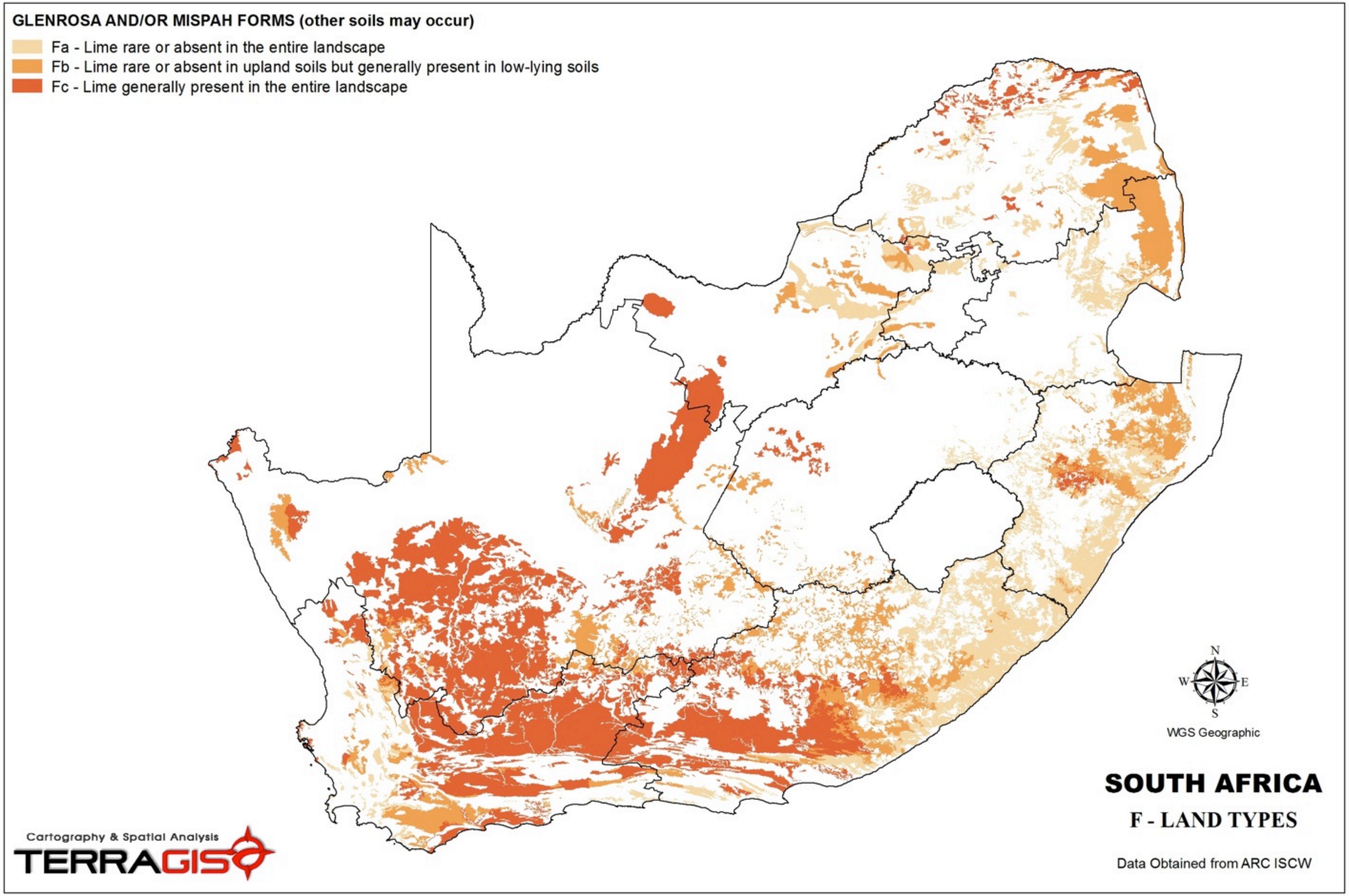
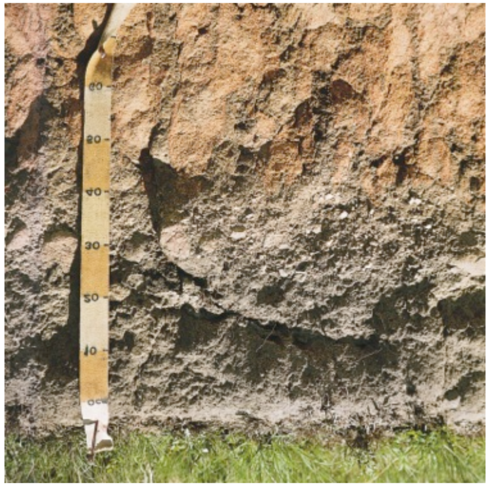


Figure 5.7 Distribution of the F land types

Table 5.5 F land types signature horizons and soil forms

Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / lithocutanic	Glenrosa	Orthic / lithocutanic	Glenrosa
Orthic / hard rock	Mispah	Orthic / hard rock	Mispah

Signature soil form profile photos (courtesy: ARC-ISCW)



Glenrosa

Glenrosa

Mispah

5.4.7 *Ferrihumic soils (Podzolic soils)*

Central Concept

The central concept of this land type category is the dominance of podzolic processes in the landscape and presence of soils with diagnostic podzol B horizons (more than 10 % of the landscape) in landscapes also characterised by some exposed rock (but not enough to qualify as Ib and Ic land types). Diagnostic podzol horizons occur in landscapes that are dominated by quartz and therefore sandy soils. The presence of fynbos vegetation in a winter rainfall environment on the sandy parent materials of the southern Cape (Western Cape and Eastern Cape Provinces) yields an incomplete oxidation of organic decay products yielding humic and fulvic acids in plant root zones. The soluble organic acids yield complexes of Fe, Al and Mn that leach out of the surface soil horizons and that precipitate and accumulate in lower horizons. The upper horizons have undergone removal of sesquioxides (and therefore are depleted of Fe and Mn related pigments) and the podzol horizon has experienced an accumulation of sesquioxides with associated increased pigmentation. The accumulated Fe and Al is in an amorphous form.

Geographic Distribution

Podzol dominated landscapes occur in the southern Cape (Western Cape and Eastern Cape Provinces) associated with quartz rich lithology and parent materials as well as fynbos vegetation characterised by winter rainfall (**Figure 5.8**). Although the distribution of podzol soils is not limited to the Western Cape Province the land types in which they dominate are. Podzols occur as associated soils in land types along the southern Cape where other soils dominate with a consequent different land type category discussed elsewhere in this document.

Signature Horizons and Forms

Binomial System: The podzol horizon soils forms in the Binomial System are limited to soils with E horizons but with varying subsoil horizons (**Table 5.6**)
Taxonomic System: The TS has seen an expansion of the soils forms with podzol horizons to include a distinction between E horizon and non-E horizon containing soils (**Table 5.6**). The list has further been expanded to accommodate a placic pan and a distinction between underlying unconsolidated materials with and without signs of wetness (redox morphology).

Dominant Soil Moisture Regime and Wetland Context

The dominant soil moisture regime in these soils is one of free drainage and leaching through the profiles to depth limiting layers that may include geological materials (such as underlying shales and transported finer textured materials) or perched water tables on top of impermeable materials. The formation of the podzol B horizon is usually associated with a slight change in the chemical equilibria in the soil profile. However, the formation of the E and podzol horizons is not primarily mediated by saturated conditions that usually lead to bleaching and sesquioxide depletion. In this regard the colours of the E and podzol B horizons cannot be used as indicators of profile redox morphology. It is therefore very challenging to identify redox morphology indicators as mottles are generally absent and colour variations associated with other chemical processes. In general redox morphology is readily observed in underlying finer texture layers in the form of redox depletions and accumulations (mottles). Another indicator is the organic C content of the A horizon as expressed in the colour. Generally it can be assumed that a darker A horizon colour indicates a potentially wetter profile due to the retardation of organic matter breakdown under wetter condition. This is a generalised assumption and the identification of wetland and wetland conditions remain very challenging in podzol dominated landscapes, especially if a 50 cm mottle criterion is used and if the natural vegetation has been replaced by pasture grasses – as is the case in large areas characterised by podzol soils.

Land Capability and Agricultural Potential

The land capability of these soils is determined predominantly by climatic conditions and rainfall. Large areas characterised by podzol soils on flat to undulating terrain have been transformed into improved pastures for milk production. In rocky areas podzol dominated landscapes may be used effectively for the production of apples and pears. The soils are generally suited to irrigation practices due to sandy and well-drained profiles.

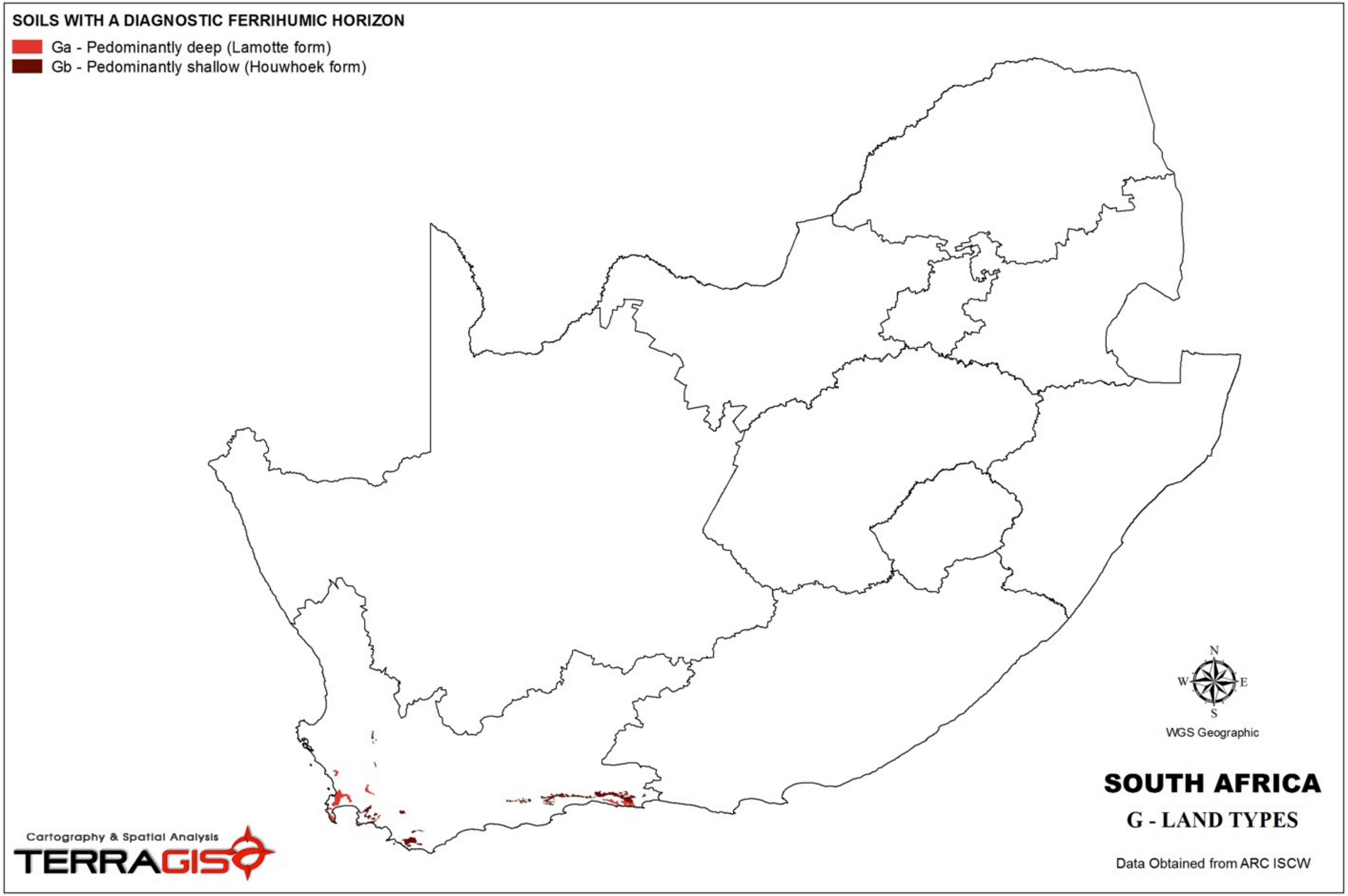
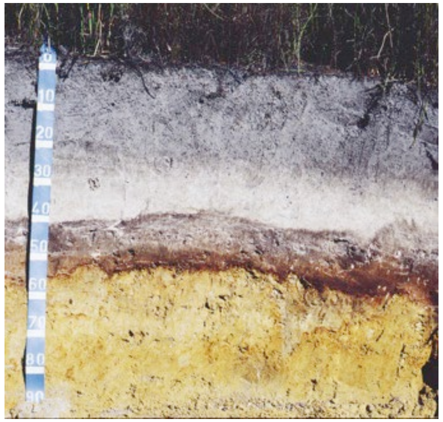


Figure 5.8 Distribution of the G land types

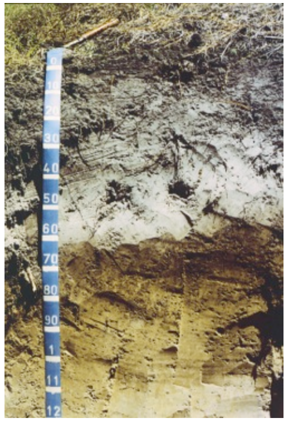
Table 5.6 G land types signature horizons and soil forms

Binomial System		Taxonomic System	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / E / ferrihumic / saprolite	Houwhoek	Orthic / E / podzol / saprolite	Houwhoek
Orthic / E / ferrihumic / unconsolidated material	Lamotte	Orthic / E / podzol / unconsolidated material with signs of wetness	Lamotte
		Orthic / E / podzol / unconsolidated material without signs of wetness	Concordia
		Orthic / E / podzol + placic pan	Tsitsikamma
		Orthic / podzol / saprolite	Groenkop
		Orthic / podzol / unconsolidated material with signs of wetness	Witfontein
		Orthic / podzol / unconsolidated material without signs of wetness	Pinegrove
		Orthic / podzol + placic pan	Jonkersberg

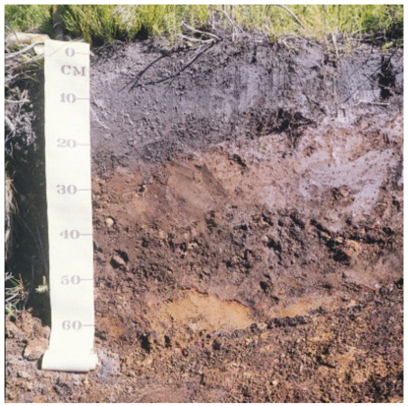
Signature soil form profile photos (courtesy: ARC-ISCW)

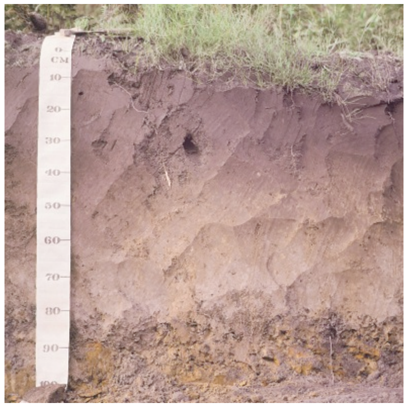

Tsitsikamma

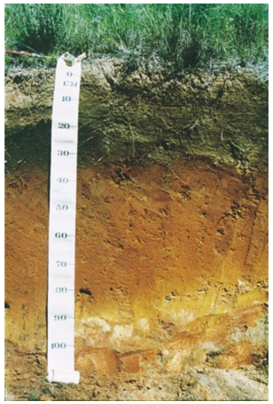

Lamotte


Concordia


Houwhoek


Jonkersberg


Witfontein


Pinegrove


Groenkop

5.4.8 *Bleached sandy (quartz-dominated) soils*

Central Concept

The central concept of this land type category is the dominance of quartz and sandy deep soil profiles with grey colours. These materials are inherited from coastal sand deposits (such as beach sands and dunes) and / or quartz dominated grey sandy soils derived from quartz rich granite geology with deeply weathered soil profiles. The soils are grey and light coloured due to the lack of Fe coatings on the sand grains. However, due to the light coloured quartz material in the parent materials the soils also exhibit such properties with the consequence that the light colours are not due to bleaching from redox processes.

Geographic Distribution

These soils occur most extensively in northern KwaZulu-Natal on the Maputaland Coastal Plain, the western shores of the Western Cape Province and limited sections of coast on the rest of the coastline of South Africa (**Figure 5.9**). A distinct occurrence of sandy soils associated with other soils is found on granite geology of the Mpumalanga Province.

Signature Horizons and Forms

Binomial System: In the BS the signature soil horizon for these land types is the **regic sand** horizon (**Table 5.7**). In the specific system it accommodated both deep sandy deposits from aeolian origin and granite weathering origin in one soil form namely Fernwood. In the land type description soils of the Constantia, Shepstone and Vilafontes forms were included in this unit.

Taxonomic System: In the TS the concept of a **regic sand** was condensed to only reflect coarse materials of aeolian origin that exhibit clear stratification and then assigned to the Namib soil form. The deep sandy soils that form on weathered granite geology (and acknowledged to occur on other quartz rich parent materials as well) have been allocated to the **E horizon** category in the Fernwood form (**Table 5.7**). In this regard the Fernwood form and E horizon description emphasises a larger contribution of redox process in the formation of these soils than was the case in the BS.

Dominant Soil Moisture Regime and Wetland Context

The original concept of this land type was one of light and grey coloured soils having formed from such coloured parent materials without distinct influences of redox processes. This implies that these soils have the colours of reduction related bleached soils but not the chemical formation processes – an aspect that causes significant confusion in terms of the interpretation of wetland characteristics. The split of the Fernwood soil form in the TS has clarified the dry vs wet light coloured soil form challenge somewhat through accommodating the former in the stratified regic sand and the latter in the new Fernwood concept However, this development does not solve the challenge of identifying redox morphology in deep sandy profiles. It is generally accepted that mottling does not occur (or is very poorly discernible) in sandy soils due to the association of high chroma Fe accumulations with finer textured material – that is absent in the sandy soils.

From the texture and porosity it is evident that these soils and landscapes exhibit rapid drainage and percolation of water and therefore qualify as terrestrial soils. However, the presence of regional water tables leads to stagnation and shallow water tables in these landscapes but then without the clear redox morphology observed in other landscapes. The essence is that these soils and land types are very challenging when trying to identify wetland features based on soil properties. The general assertion listed for the podzol soils, one of increasingly dark and elevated organic C levels with increasing wetness, also applies effectively in this land type but will require empirical observation, measurement and description.

Land Capability and Agricultural Potential

The H land types are dominated by deep bleached sandy soils and are therefore not suited to crop production unless irrigation is practiced with dedicated nutrient management. In most cases these soils occur as dunes and are therefore left under natural vegetation. The grazing potential of these soils is also very low – especially in cases where they occur in low rainfall areas.

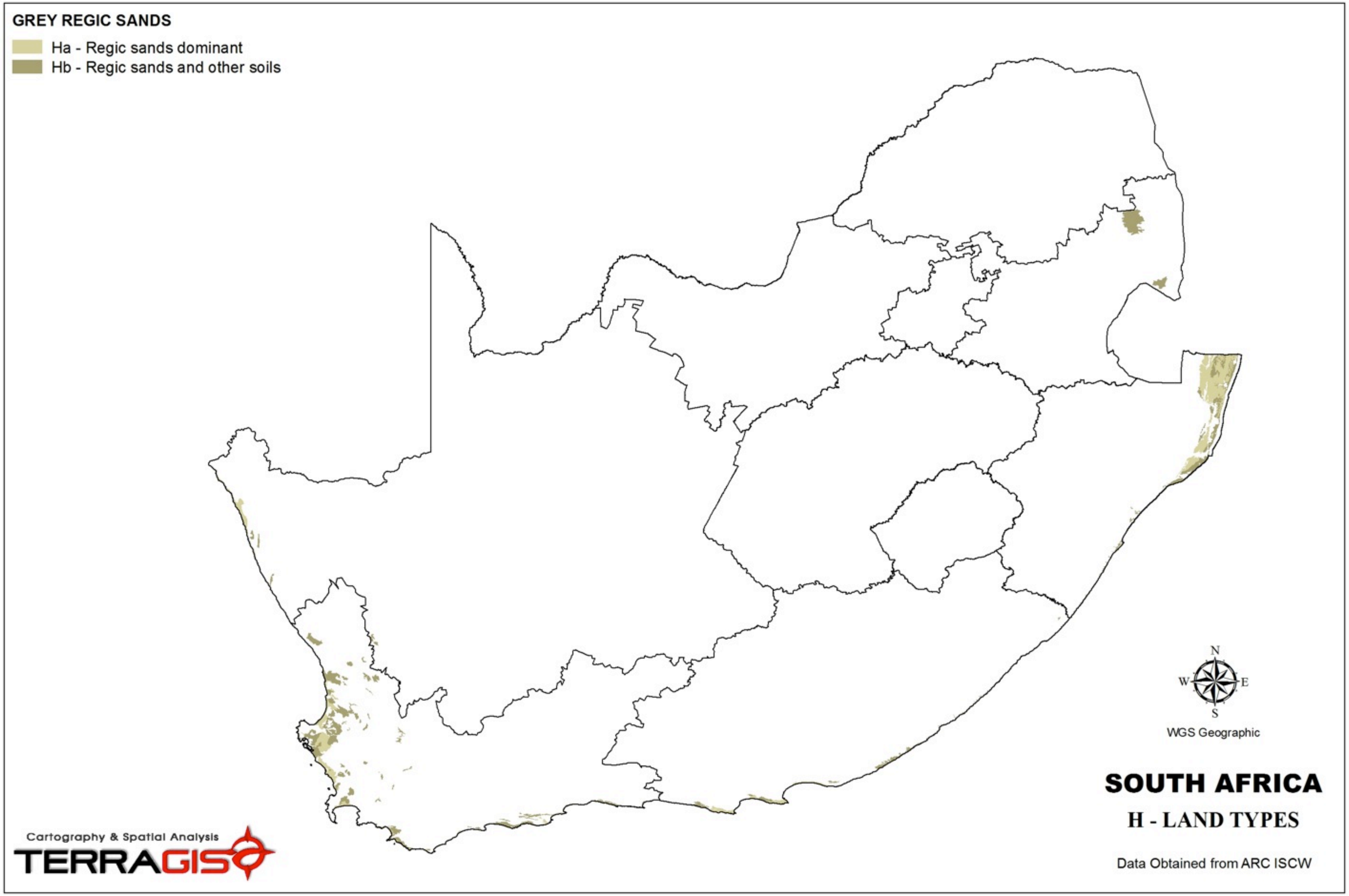


Figure 5.9 Distribution of the H land types

Table 5.7 H land types signature horizons and soil forms

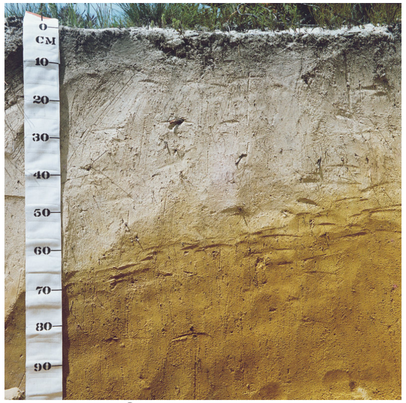
Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / regic sand	Fernwood	Orthic / regic sand	Namib
		Orthic / E	Fernwood
Orthic / E / lithocutanic	Cartref	Orthic / E / lithocutanic	Cartref
(Orthic / E / red apedal)	(Shepstone)	Discontinued	
(Orthic / E / yellow-brown apedal)	(Constantia)	(Orthic / E / yellow-brown apedal)	(Constantia)
(Orthic / E / neocutanic)	(Vilafontes)	(Orthic / E / neocutanic)	(Vilafontes)

Signature soil form profile photos (courtesy: ARC-ISCW)

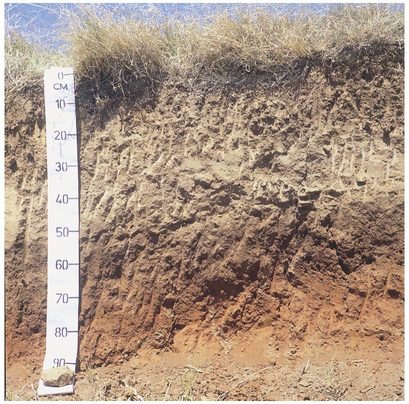
Fernwood

Cartref

Namib



Constantia



Vilafontes

Shepstone

5.4.9 *Miscellaneous young land classes that include alluvial depressions and rock dominated landscapes*

Central Concept

The central concept of this land type category is a rest group that contains soil patterns and types that are difficult to accommodate in the A to H land types. The remaining soil patterns and types include **Ia** land types with deep, pedologically young unconsolidated deposits that typically occur in large drainage depressions that occur in arid environments. The remaining land types (**Ib** and **Ic**) accommodate landscapes where exposed rock, stones and boulders constitute between 60-80 % and more than 80% of the land surface respectively. The soils underlying the rock on the surface would have qualified for inclusion in other land types were it not for the extensive rock occurrence on the surface.

Geographic Distribution

These land types occur throughout South Africa and the distribution depends mainly on topography, underlying geology and extensive flat drainage depression (**Figure 5.10**).

Signature Horizons and Forms

Binomial System: The soils that characterise the **Ia** land types predominantly have pedologically young materials (**stratified alluvium** and **neocutanic** horizons with and without lime) in the soil forms Dundee and Oakleaf (**Table 5.8**). The **Ib** and **Ic** land types are dominated by exposed rock and soils of the Glenrosa and Mispah forms (refer to discussion on the F land types).
Taxonomic System: In terms of the **Ia** land types the signature diagnostic horizons are similar with the addition of the neocarbonate horizon to accommodate all the lime containing materials with pedologically young and also well-developed red and yellow-brown apedal materials. In this regard a number of soil forms have been added in the TS.

Dominant Soil Moisture Regime and Wetland Context

In general the moisture regime of the Ia land types is dominated by surface flows of water with infiltration and subsequent lime and gypsum translocation. As these land types occur more readily in dry to arid environments the dominance of lime in the soil will mask most redox morphology features due to alkaline condition. These conditions lead to the potential development of redox depletions in the form of grey colours but will not readily yield high chroma redox accumulations (in the form of Fe oxides and hydroxides) due to the dominance of white $FeCO_3$ minerals (as the dominant Fe minerals in alkaline soil solution conditions). Additionally, the youthful nature of the soils lead to limited expression of mottling.
For the soil moisture regime and wetland context for the Ib and Ic land types refer to the discussion on the very similar F land types.

Land Capability and Agricultural Potential

These land types occur throughout the country and are, save for broad alluvial plains considered to be of very low agricultural potential. The alluvial plains are often used for subsistence and / or small-scale flood irrigation activities. Commercial scale flood irrigation activities are practiced in areas such as the Sak River in the Northern Cape Province. The rocky areas are typically utilized for extensive grazing of sheep and goats with many of these areas falling into large zones of game farming and wilderness land.

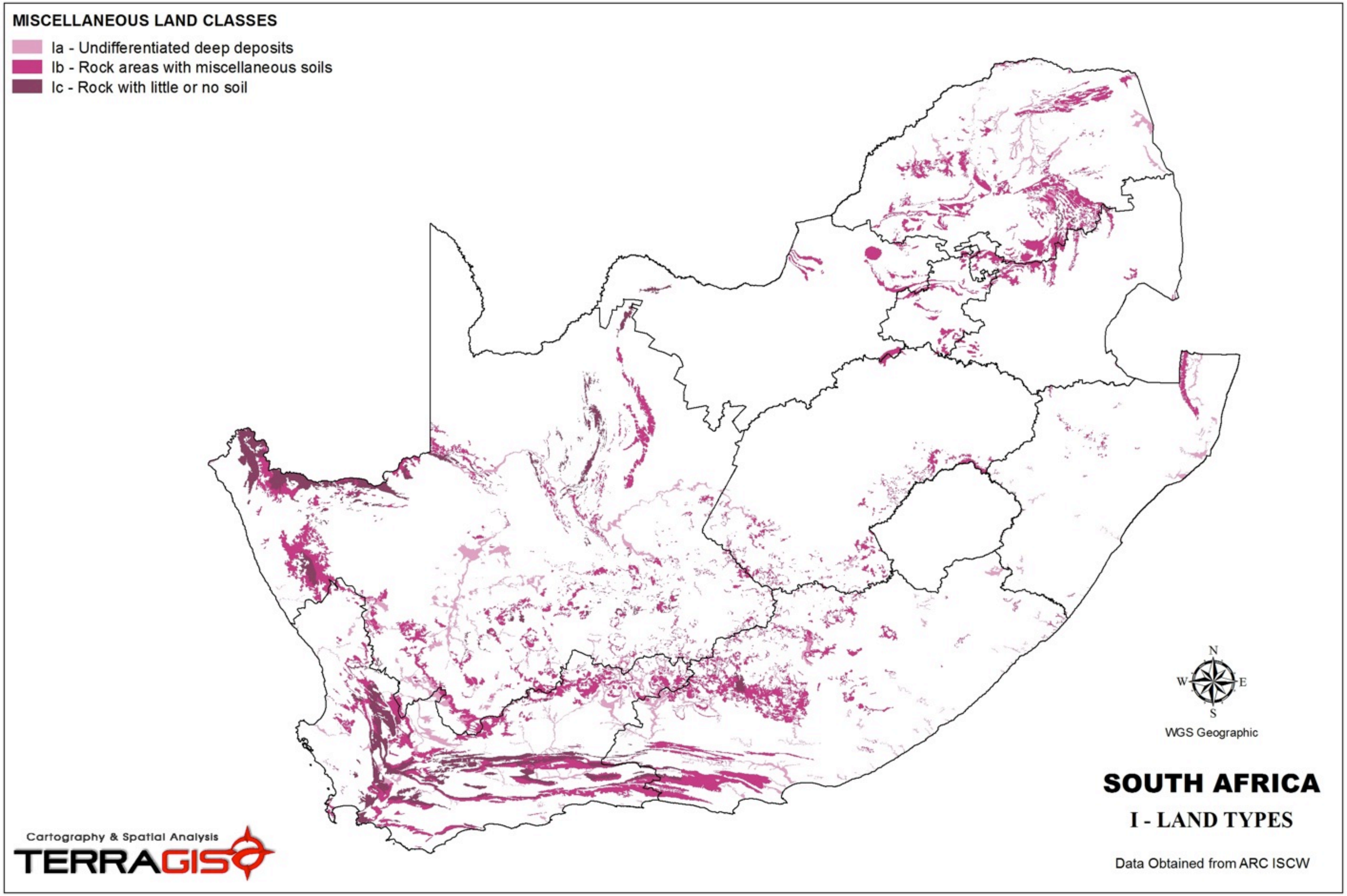
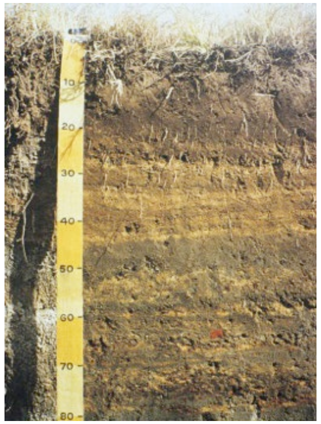


Figure 5.10 Distribution of the I land types

Table 5.8 I land types signature horizons and soil forms

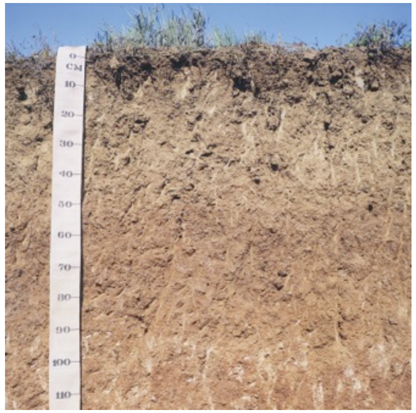
Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Orthic / stratified alluvium	Dundee	Orthic / stratified alluvium	Dundee
Orthic / neocutanic	Oakleaf	Orthic / neocutanic / unspecified	Oakleaf
		Orthic / neocutanic / unspecified material with signs of wetness	Tukulu
		Orthic / neocutanic / soft carbonate	Etosha
		Orthic / neocarbonate / unspecified	Augrabies
		Orthic / neocarbonate / unspecified material with signs of wetness	Montagu
		Orthic / neocarbonate / soft carbonate	Addo
Orthic / hard rock	Mispah	Orthic / hard rock	Mispah
Orthic / lithocutanic	Glenrosa	Orthic / lithocutanic	Glenrosa
Soil / rock complex		Soil / rock complex	

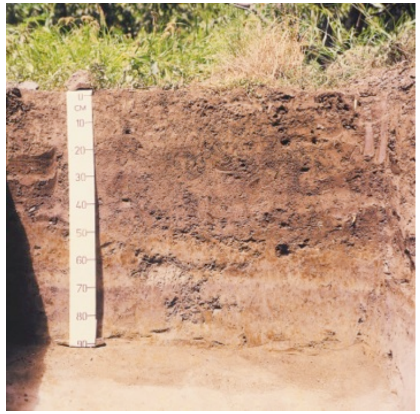
Signature soil form profile photos (courtesy: ARC-ISCW)


Dundee


Oakleaf


Tukulu


Augrabies


Montagu

5.4.10 Soils occurring in most land types as a function of low lying landscape position and specific hydrology

Central Concept
The central concept of these soils is that they constitute the soils that occur in low-lying positions in most land types. They are therefore limited in geographical extent in that they do not constitute entire land types, but rather, occur throughout most land types as soils in specific landscape positions.

Geographic Distribution
The geographic distribution of these soils is wide and they occur in all landscapes with enough rainfall and hydrological process driven accumulation of water to give expression of G horizons.

Signature Horizons and Forms
Binomial and Taxonomic System: The signature soil forms are all characterised by the presence of **G horizons** or organic C rich layers (**organic O horizon**) that indicate prolonged saturation (**Table 5.9**).

Dominant Soil Moisture Regime and Wetland Context
The dominant soil moisture regime in these soils is one of a hydrological response in the form of water at or near the soil surface as caused by hillslope processes or regional / local water tables. As such they are often found in the lowest parts of landscapes. These soils are invariably associated with seasonal / permanent wetland conditions and exhibit grey colours and other redox morphology indicators of prolonged saturation and wetness.

Land Capability and Agricultural Potential
The land capability of these soils is generally wetland and possible grazing. Due to the prolonged periods of saturation they are not cultivated on a commercial scale but subsistence farmers may plant crops in such soils behind receding floodlines or during dry periods.

Table 5.9 Low lying landscape position and specific hydrology signature horizons and soil forms

Binomial System		**Taxonomic System**	
Horizon sequence	**Soil form**	**Horizon sequence**	**Soil form**
Organic O / gleyed material	Champagne	Organic O / unspecified	Champagne
Vertic / G	Rensburg	Vertic / G	Rensburg
Melanic / G	Willowbrook	Melanic / G	Willowbrook
Orthic / G	Katspruit	Orthic / G	Katspruit
Orthic / E / gleycutanic B	Kroonstad	Orthic / E / G	Kroonstad

Signature soil form profile photos (courtesy: ARC-ISCW)

Champagne

Rensburg

Willowbrook

Katspruit

Kroonstad

References

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MacVicar, C.N. *et al.* 1977. Soil Classification. A binomial system for South Africa. Sci. Bull. 390. Dep. Agric. Tech. Serv., Repub. S. Afr., Pretoria.

Soil Classification Working Group. 1991. Soil Classification. A taxonomic system for South Africa. *Mem. Agric. Nat. Resour. S.Afr.* No.15. Pretoria.

CHAPTER 6 – UNPACKING THE LAND TYPE DATA: SOIL AND WETLAND PROPORTIONS

6.1 Introduction

The generation of a wetland guideline document for South Africa requires the contextualisation of the soil landscape. The most detailed soil information data set for SA is the land type database of the Agricultural Research Council (ARC). This chapter provides a high-level introduction and contextualisation of the soils of SA based on the broad land types as contained in the land type database. The aim of this chapter is to provide a reference point for the understanding of the soil properties evident in SA as a function of climatic, geological and topographical factors. This discussion serves as a starting point for the more detailed regional / geology based wetland delineation and assessment guidelines that follow in later chapters.

6.2 Soil Classification as a Requirement for Wetland Delineation

The delineation of wetlands is a process that is driven by the requirements for wetland conservation in various national acts (NWA, NEMA, CARA, MPRDA, etc.) and the spatial planning and conservation needs/policies of municipal, provincial and national regulation bodies/departments. A formal wetland delineation procedure and outcome is required for any land use change that may develop in urban and rural environments in South Africa. The diligence with which these exercises are conducted vary widely and depend on the specific competent authority.

In 2005 the then Department of Water Affairs and Forestry (DWAF) published a manual for the delineation of wetlands (hereinafter referred to as the "wetland delineation guidelines – DWAF, 2005". This document was updated in 2008 but the soil indicators were not significantly amended. The original document provides for the use of four wetland indicators that may be used namely:

1. Terrain Unit Indicator. Landscape position and general association with water courses and low-lying areas provide the main indications.
2. Soil Form Indicator. The soil forms defined by the Soil Classification Working Group (1991) are grouped according to their degree of wetness and position in either 1) a permanent or 2) seasonal / temporary wetland context.
3. Soil Wetness Indicator. The redox morphology of a soil is used as an indication of association with wetland conditions with emphasis placed on grey low chroma matrix colours and mottles.

4. Vegetation Indicator. Vegetation characteristics in the form of species occurrence and vegetation structure are used to identify different zones as well as terrestrial areas (outside of the wetland).

As part of a critical investigation into the suitability of the current wetland assessment tools that inform the use of the indicators it was proposed that available soil information be used to provide an indication of wetland distribution and extent in South Africa. The only soil data available at a national level is the land type inventory (Land Type Survey Staff, 1972-2006) as generated by the ARC-ISCW and its predecessors. The history of the process is described in detail by Laker (Laker, 2003). A limitation regarding the acceptance of the land type by a wider audience is the fact that the classification system that was used is the Binomial System for South Africa (MacVicar *et al.,* 1977). The current system in use is the Taxonomic System (Soil Classification Working Group, 1991) – a system that is based on the Binomial System but which has a number of additions and diverging approach at levels below soil form. A detailed comparison between the two systems as well as limitations and limited criticism is provided by Laker (Laker, 2003).

Therefore, in order to unpack the land type inventory data for useful wetland soil information extraction a correlation exercise has to be conducted between the two classification systems and this information has to be packaged in the context of the intentions of the wetland delineation guidelines (DWAF, 2005).

6.3 Classification System Changes Affecting Land Type Data Mining

The first step in the process was to correlate the soil forms in the Binomial System (BS) with the soil forms in the Taxonomic System (TS). For many of the BS soil forms the translation to the equivalent in the TS is direct correlation in that all the criteria (diagnostic horizon definitions and diagnostic horizon sequence) remain exactly the same. However, many soil forms were added to the BS (43 forms) to yield the TS (71 forms). Each of the added forms constitutes a new addition and in some cases were motivated through the addition of new diagnostic horizons (and criteria). In a limited number of cases diagnostic horizon criteria were amended and this yielded new soil forms or even the deletion of two BS forms. The comparison of the two systems is provided in **Tables 6.1** and **6.2** with a dedicated numeric note provided to discuss each change.

Table 6.1 Correlation matrix between the Binomial System and the Taxonomic System for specifically defined diagnostic topsoil horizons

Topsoil horizon	**Subsoil Horizons and Soil Form – Binomial System (1977)**			**Subsoil Horizons and Soil Form – Taxonomic System (1991)**		
	Second horizon/material	**Third horizon/material**	**Binomial system soil form**	**New second subsoil horizon**	**New third subsoil horizon**	**Taxonomic system soil form**
Organic	Gleyed material	-	**Champagne**	Unspecified	-	**Champagne[1]**
Humic	Yellow-brown apedal B	Red apedal B	**Kranskop**	Yellow-brown apedal B	Red apedal B	**Kranskop[2]**
	Yellow-brown apedal B	-	**Magwa**	Yellow-brown apedal B	Unspecified	**Magwa[2]**
	Red apedal B	-	**Inanda**	Red apedal B	Unspecified	**Inanda[2]**
	New in TS	-		Pedocutanic B	Unspecified	**Lusiki[2,3]**
				Neocutanic B	Unspecified	**Sweetwater[2,3]**
	Lithocutanic B	-	**Nomanci**	Lithocutanic B	-	**Nomanci[2]**
Vertic	G	-	**Rensburg**	G	-	**Rensburg[4]**
	Not specified	-	**Arcadia**	Unspecified	-	**Arcadia[4]**
Melanic	G	-	**Willowbrook**	G	-	**Willowbrook[5]**
	Pedocutanic B	Not specified	**Bonheim**	Pedocutanic B	Unspecified	**Bonheim[5]**
	Lithocutanic B	-	**Mayo**	Lithocutanic B	-	**Mayo[5]**
	Neoocutanic B	-	**Inhoek**	Unspecified	-	**Inhoek[6]**
	Stratified alluvium					
	Hard rock, hardpan ferricrete, hardpan calcrete, hardpan silcrete or dorbank	-	**Milkwood**	Hard rock	-	**Milkwood[7]**
				Soft carbonate B	-	**Steendal[7]**
				Hardpan carbonate	-	**Immerpan[7]**
	Soft plinthic B	-	**Tambankulu**	Soft plinthic B	-	**Discontinued[8]**

Soil Classification Correlation Notes:

1. The diagnostic horizon "gleyed material" in the BS was changed to an "unspecified" horizon in the TS with the definition in the TS having the added entry that the horizon "… is saturated for long periods …". The implication is that the "morphological" approach in the BS was substituted for an "empirical measurement" approach in the form of gauging the period of saturation. The BS approach is more in line with a morphological classification and the TS approach introduces an aspect that cannot be measured in the field. However, the central concept of the soil form is the same for the two versions. Differences in series (TS) and family (BS) criteria relate to clay content and pH (BS) and nature of the organic material and underlying materials (TS).
2. The concepts remain the same between the BS and TS with the exception that thin Humic A horizons were introduced at family level in the TS. This constitutes and addition to the TS.
3. The Lusiki and Sweetwater forms were added in the TS.

Table 6.2 Correlation matrix between the Binomial System and the Taxonomic System for soils with Orthic A topsoil horizons

Subsoil Horizons and Soil Form – Binomial System (1977)			Subsoil Horizons and Soil Form – Taxonomic System (1991)		
Second horizon/material	**Third horizon/material**	**Binomial system soil form**	**New second subsoil horizon**	**New third subsoil horizon**	**Taxonomic system soil form**
G	-	**Katspruit**	G	-	**Katspruit[5]**
E	G	**Kroonstad**	E	G	**Kroonstad[5]**
	Soft plinthic B	**Longlands**		Soft plinthic B	**Longlands[5]**
	Hard plinthic	**Wasbank**		Hard plinthic	**Wasbank[5]**
	Yellow-brown apedal B	**Constantia**		Yellow-brown apedal B	**Constantia[5]**
	Ferrihumic B / unconsolidated material	**Lamotte**		Podzol B with placic pan	**Tsitsikamma[9]**
				Podzol B / uncon. mat. with signs of wetness	**Lamotte[9]**
				Podzol B / uncon. mat. no signs of wetness	**Concordia[9]**
	Ferrihumic B / saprolite	**Houwhoek**		Podzol B / saprolite	**Houwhoek[5]**
	Prismacutanic B	**Estcourt**		Prismacutanic B	**Estcourt[5]**
	New in TS			Pedocutanic B	**Klapmuts[10]**
	Neocutanic B	**Vilafontes**		Neocutanic B	**Vilafontes[5]**
	-	**New**		Neocarbonate B	**Kinkelbos[10]**
	Lithocutanic B	**Cartref**		Lithocutanic B	**Cartref[5]**
Regic sand	-	**Fernwood**		Unspecified	**Fernwood[11]**
E	Red apedal	**Shepstone**		-	**Discontinued[8]**
Soft plinthic B	-	**Westleigh**	Soft plinthic B	-	**Westleigh[5]**
New in TS	-	**(Mispah)**	Hard plinthic	-	**Dresden[5]**
Yellow-brown apedal B	Soft plinthic B	**Avalon**	Yellow-brown apedal B	Soft plinthic B	**Avalon[5]**
	Hard plinthic	**Glencoe**		Hard plinthic	**Glencoe[5]**
	Gleycutanic B	**Pinedene**		Unspec. mat. with signs of wetness	**Pinedene[12]**
	Red Apedal B	**Griffin**		Red Apedal B	**Griffin[5]**
	Not specified	**Clovelly**	Yellow-brown apedal B	Soft carbonate B	**Molopo[13]**
				Hardpan carbonate	**Askham[13]**
				Unspecified	**Clovelly[5]**
			Neocarbonate B	Unspec. mat. with signs of wetness	**Montagu[13]**
				Soft carbonate B	**Addo[13]**
				Hardpan carbonate	**Prieska[13]**
				Dorbank	**Trawal[13]**
				Unspecified	**Augrabies[13]**
Red apedal B	Soft plinthic B	**Bainsvlei**	Red apedal B	Soft plinthic B	**Bainsvlei[5]**
	Not specified	**Hutton**	Red Apedal	Hard plinthic	**Lichtenburg[5]**
				Unspec. mat. with signs of wetness	**Bloemdal[12]**
				Soft carbonate B	**Kimberley[13]**
				Hardpan carbonate	**Plooysburg[13]**
				Dorbank	**Garies[13]**
				Unspecified	**Hutton[5]**
			Neocarbonate B	Unspec. mat. with signs of wetness	**Montagu[13]**
				Soft carbonate B	**Addo[13]**
				Hardpan carbonate	**Prieska[13]**

Subsoil Horizons and Soil Form – Binomial System (1977)			**Subsoil Horizons and Soil Form – Taxonomic System (1991)**		
Second horizon/material	**Third horizon/material**	**Binomial system soil form**	**New second subsoil horizon**	**New third subsoil horizon**	**Taxonomic system soil form**
				Dorbank	**Trawal**[13]
				Unspecified	**Augrabies**[13]
Red structured B	-	**Shortlands**	Red structured B	-	**Shortlands**[5]
New in TS	-	**-**	Podzol B with placic pan	-	**Jonkersberg**[14]
			Podzol B / uncon. mat. with signs of wetness	-	**Witfontein**[14]
			Podzol B / uncon. mat. no signs of wetness	-	**Pinegrove**[14]
			Podzol B / saprolite	-	**Groenkop**[14]
Prismacutanic B	-	**Sterkspruit**	Prismacutanic B	-	**Sterkspruit**[5]
Pedocutanic B	Unconsolidated material	**Valsrivier**	Pedocutanic B	Uncon. mat. with signs of wetness	**Sepane**[15]
				Uncon. mat. no signs of wetness	**Valsrivier**[5]
Pedocutanic B	Saprolite	**Swartland**	Pedocutanic B	Saprolite	**Swartland**[5]
Neocutanic B	-	**Oakleaf**	Neocutanic B	Unspec. mat. with signs of wetness	**Tukulu**[13]
				Soft carbonate B	**Etosha**[13]
				Hardpan carbonate	**Gamoep**[13]
				Dorbank	**Oudtshoorn**[13]
				Unspecified	**Oakleaf**[5]
			Neocarbonate B	Unspec. mat. with signs of wetness	**Montagu**[13]
				Soft carbonate B	**Addo**[13]
				Hardpan carbonate	**Prieska**[13]
				Dorbank	**Trawal**[13]
				Unspecified	**Augrabies**[13]
		(Clovelly, Hutton or Oakleaf)	Soft carbonate	-	**Brandvlei**[13]
Lithocutanic B	-	**Glenrosa**	Lithocutanic B	-	**Glenrosa**[5]
Hard rock, hardpan ferricrete, hardpan calcrete, hardpan silcrete or dorbank	-	**Mispah**	Hard rock	-	**Mispah**
			Hardpan carbonate	-	**Coega**[13]
			Dorbank	-	**Knersvlakte**[13]
Stratified alluvium	-	**Dundee**	Stratified alluvium	-	**Dundee**[5]
Regic sand	-	**(Fernwood)**	Regic sand	-	**Namib**[11]
New in TS	-	**-**	Man-made soil deposit	-	**Witbank**

SC = Same Concept (The BS and TS soil forms are essentially the same)

Note: Permanence/duration of saturation of is not defined

4. The Rensburg and Arcadia forms are essentially the same between the BS and TS with the difference that additional colour variation has been specified at family level in the TS
5. Similar between BS and TS

6. The Inhoek soil form accommodates both neocutanic and stratified alluvium underneath the melanic A horizon. The is the same for the BS and the TS
7. The Milkwood form in the BS yielded the Milkwood, Steendal and Immerpan forms in the TS as the agglomerated subsoil criteria in the BS was disaggregated for the TS.
8. This soil form was discontinued in the TS for reason that is not clear to this author. In an expanded classification system it would be proposed that this form be incorporated again.
9. The Lamotte form in the BS was expanded to accommodate a placic pan (Tsitsikamma), unconsolidated material with signs of wetness below the podzol B (Lamotte) and unconsolidated material without signs of wetness (Concordia) in the TS
10. The Klapmuts soil form was added to the TS
11. The Fernwood form in the BS was changed from a regic sand to a deep E horizon soil. The regic sand is now accommodated in the Namib form. The concept of a regic sand in the BS has therefore changed to accommodate thick eluvial horizons (E – Fernwood) and thick aeolian deposits (Namib)
12. The gleycutanic B horizon of the BS has been substituted with an unspecified material with signs of wetness in the TS.
13. Carbonate containing and dorbank horizons were added to the TS which has led to a proliferation of soil forms accommodating these diagnostic horizons. The carbonate or dorbank horizons do not have colour criteria and therefore are the same forms having evolved from both the red and yellow-brown apedal horizons.
14. Podzols were expanded in the TS to accommodate podzol B horizons underlying orthic A horizons (and not only E horizon) with the inclusion of placic pan (Jonkersberg), unconsolidated material with signs of wetness below the podzol B (Witfontein), unconsolidated material without signs of wetness (Pinegrove) and saprolite (Groenkop).
15. The Sepane form was added to the TS as a pedocutanic B horizon overlying unconsolidated material with signs of wetness with the aim of distinguishing it from dry profiles such as the Valsrivier.
16. The Mispah soil form accommodated all shallow soils with hard subsoil horizons in the BS. In the TS the Mispah only accommodates “hard rock” as subsoil material.

6.4 Recent Developments in Soil Hydrological Characterisation

Recently the soils of South Africa were classified and described in terms of their hydrological role and functioning (Van Tol *et al.,* 2013). The second step in the process of unpacking the existing soil information is the correlation of the Taxonomic System soil forms with the hydrological characteristics. **Table 6.3** provides a summary of the hydrological role of South African soils and their hydrological classification based on the work by Van Tol *et al.* (2013).

Table 6.3 Hydrology classification of diagnostic horizons and soil forms in the Taxonomic System (after van Tol *et al.,* 2013)

Horizons	General hydrology inferred from morphology / genesis	Soil forms
Recharge (Free draining)		
Humic A	Free draining and no redox morphology	Kranskop, Magwa, Inanda, Lusiki, Sweetwater, Nomanci
Vertic A	Free draining during dry state, impervious during saturated state. Saturation for prolonged periods accommodated in Rensburg form with vertic / G horizon	Arcadia
Melanic A	Free draining during dry state, impervious during saturated state. Saturation for prolonged periods accommodated in Willowbrook form with melanic / G horizon	Bonheim Steendal Immerpan Mayo Milkwood Inhoek
Orthic A	Refer subsoil horizons below	
Yellow-brown apedal B	Chromic horizon indicative of free-draining character, usually through matrix	Griffin Molopo Askham Clovelly
Red apedal B	Chromic horizon indicative of free-draining character, usually through matrix	Kimberley Plooysburg Garies Hutton
Red structured B	Chromic horizon indicative of free-draining character, usually along preferential flow paths along ped face surfaces	Shortlands
Prismacutanic B	Free draining through preferential flow paths along ped face surfaces	Sterkspruit
Pedocutanic B	Free draining through preferential flow paths along ped face surfaces	Valsrivier Swartland
Lithocutanic B	Free draining through preferential flow paths along ped face surfaces	Glenrosa
Neocutanic B	Chromic horizon indicative of free-draining character, usually through matrix	Etosha Gamoep Oudtshoorn Oakleaf
Neocarbonate B	Chromic horizon indicative of free-draining character, usually through matrix	Addo Prieska Trawal Augrabies
Podzol B	Chromic horizon indicative of free-draining character, usually through matrix. When associated with E horizon the formation of	Tsitsikamma Concordia

	the E horizon is dominantly through podzolosation processes and not through redox depletion	Houwhoek Jonkersberg Pinegrove Groenkop
Regic sand	Bleached horizon due to parent material influence and not redox depletion, indicative of free-draining character, usually through matrix	Namib
Stratified alluvium	Variable chromic or bleached horizon indicative of free-draining character, usually through matrix	Dundee
Dorbank	Chromic horizon indicative of free-draining character, usually along preferential flow paths along cracks	Knersvlakte
Saprolite	Variable weathering horizon indicative of free-draining character, usually through matrix	
Soft carbonate	Variable white/light horizon indicative of free-draining character, usually through matrix	Brandvlei
Hardpan carbonate	Variable horizon indicative of free-draining character, usually along preferential flow paths along cracks	Coega
Unconsolidated material without signs of wetness	Free draining through preferential flow paths along ped face surfaces	
Hard rock	Variable horizon indicative of free-draining character, usually along preferential flow paths along cracks	Mispah
Man-made soil deposit	Free draining through preferential flow paths along ped face surfaces or along cracks	Witbank
Interflow (lateral) A/B horizon		
E horizon (Soft plinthic) (Hard plinthic)	1. Above hard or clay enriched horizon indicates saturation and often lateral flow 2. E horizons on podzol B horizons are excluded unless the underlying horizon qualifies in terms of signs of wetness	Kroonstad Longlands Wasbank Constantia (Shepstone)
E horizon (duplex)	Above hard or clay enriched horizon indicates saturation and often lateral flow (in E)	Estcourt Klapmuts
E horizon (over accumulation horizon)	Above clay or lime enriched horizon indicates saturation and often lateral flow (in E)	Vilafontes Kinkelbos Cartref Fernwood
Interflow (lateral) Soil/Rock interface		
Soft plinthic (Hard plinthic)	Clay enriched (or sometimes hardened) subsoil horizon with redox morphology indicates saturation due to water flow through “return flow” from rock in hillslope processes	Westleigh Dresden Avalon Glencoe Bainsvlei (Lichtenburg)
Unconsolidated material with signs of wetness	Clay enriched (or sometimes clay depleted and bleached) subsoil horizon with redox morphology indicates saturation due to water flow through “return flow” from rock in hillslope processes	Lamotte Witfontein Sepane
Unspecified material with signs of wetness	Clay enriched (or sometimes clay depleted and bleached) subsoil horizon with redox morphology indicates saturation due to water flow through “return flow” from rock in hillslope processes	Pinedene Bloemdal Tukulu Montagu
Responsive (Saturated) **This horizon dominates the hydrology so any soil form with such horizon placed in this section**		
Organic	Formed under saturated conditions	Champagne
G horizon	1. Some overlap with plinthic (see classification criteria and splitting) 2. Occurs as non-diagnostic horizon under soft plinthic as per definition	Rensburg Willowbrook Katspruit

6.5 Correlation with Wetland Delineation Guideline Approach

The third step in the process is to correlate the previous categories with the approach in the wetland delineation guidelines (DWAF, 2005). These guidelines specifically state that the soils listed under the permanent and seasonal / temporary wetland zones could occur in such environments. At no point does the guideline document allude to the notion that the specific soils would indicate the specific wetlands zones under which the soils are listed. This discussion may appear pedantic but it has a distinct bearing on the way the guidelines are interpreted. This author interprets the guidelines as indicating the possible occurrence of such soils. However, the guidelines have been erroneously interpreted by many workers as to indicate that the specific soils imply the presence of the specific zones. As this approach is considered erroneous but still widely applied the correlation of the wetland zones with soil forms is provided in **Table 6.4** with an alphabetic letter note to discuss the technicalities of each case.

The emphasis here is therefore what the guidelines indicate rather than a critical assessment regarding its application and validity. These aspects will be discussed in the notes provided after the table.

Therefore, **Table 6.4** contains the following:

- Correlation between the Binomial System and Taxonomic system in terms of diagnostic soil horizons and soil forms.
- A classification of the soil forms in the Taxonomic System in terms of their implied status within the DWAF (2005) guidelines.
- A revised interpretation of the DWAF (2005) guideline soil form context taking into account a more conservative approach to the understanding of degree and period of saturation by pedologists. In addition, the term “seasonal” (S) is used as a synonym for “fluctuation zone” (F) as the soils that are periodically wet are more readily described by pedologists as experiencing “fluctuating water levels” rather than “seasonal wetness”. The implication is that any rainfall event or period may induce the fluctuation and that this is not necessarily season bound.
- An indication of the classification level at which wetness is identified namely form or family level.
- A hydrology based category for each soil form as provided in **Table 6.3**.

It is important to note that the classification / categorisation provided in **Tables 6.1** to **6.3** are generalisations that are useful at a high level of discussion. These categories have to be refined for site specific and soil specific conditions during soil surveys for wetland delineation purposes.

Table 6.4 Correlation of South African soil forms with various wetness categorisations

Binomial system soil form	Taxonomic system soil form	DWAF, 2005	Revised classification	Wetness at level	Hydrology
Champagne	Champagne[1]	Permanent	P[A]	Form	Responsive
Kranskop	Kranskop[2]	Terrestrial	T[B]	-	Recharge
Magwa	Magwa[2]	Terrestrial	T[B]	-	Recharge
Inanda	Inanda[2]	Terrestrial	T[B]	-	Recharge
New in TS	Lusiki[2,3]	Terrestrial	T[B]	-	Recharge
New in TS	Sweetwater[2,3]	Terrestrial	T[B]	-	Recharge
Nomanci	Nomanci[2]	Terrestrial	T[B]	-	Recharge
Rensburg	Rensburg[4]	Permanent	S/F[C]	Form	Responsive
Arcadia	Arcadia[4]	Terrestrial	T[B]	-	Recharge
Willowbrook	Willowbrook[5]	Permanent	S/F[D]	Form	Responsive
Bonheim	Bonheim[5]	Terrestrial	T[B]	-	Recharge
Mayo	Mayo[5]	Terrestrial	T[B]	-	Recharge
Inhoek (Neocutanic)	Inhoek[6]	Terrestrial	T[D]	-	Recharge
Inhoek (Stratified Alluvium)		Season/Temp	S/F[D]	Form	Recharge
Milkwood	Milkwood[7]	Terrestrial	T[B]	-	Recharge
New in TS	Steendal[7]	Terrestrial	T[E]	-	Recharge
New in TS	Immerpan[7]	Terrestrial	T[B]	-	Recharge
Tambankulu	Discontinued[8]	Season/Temp	S/F[F]	Form	Interflow soil/bedrock
Katspruit	Katspruit[5]	Permanent	P[G]	Form	Responsive
Kroonstad	Kroonstad[5]	Season/Temp	S/F[H]	Form	Interflow A/B
Longlands	Longlands[5]	Season/Temp	S/F[H]	Form	Interflow A/B
Wasbank	Wasbank[5]	Season/Temp	S/F[H]	Form	Interflow A/B
Constantia	Constantia[5]	Season/Temp	T[I]	Form	Interflow A/B
New in TS	Tsitsikamma[9]	Season/Temp	T[J]	Form	Recharge
Lamotte[9]	Lamotte[9]	Season/Temp	S/F[J]	Form	Interflow soil/bedrock
New in TS	Concordia[9]	T	T[J]	-	Recharge
Houwhoek	Houwhoek[5]	Season/Temp	S/F[J]	Form	Recharge
Estcourt	Estcourt[5]	Season/Temp	T[K]	Form	Interflow A/B
New in TS	Klapmuts[10]	Season/Temp	T[K]	Form	Interflow A/B
Vilafontes	Vilafontes[5]	Season/Temp	T[K]	Form	Interflow A/B
New in TS	Kinkelbos[10]	Season/Temp	T[K]	Family	Interflow A/B
Cartref	Cartref[5]	Season/Temp	T[K]	Family	Interflow A/B
Fernwood	Fernwood[11]	Terrestrial	S/F[L]	Form	Interflow A/B
Shepstone	Discontinued[8]	Season/Temp	T[I]	Form	Interflow A/B
Westleigh	Westleigh[5]	Season/Temp	S/F[F]	Form	Interflow soil/bedrock
(Mispah)	Dresden[5]	Season/Temp	S/F[F]	Form	Interflow soil/bedrock
Avalon	Avalon[5]	Season/Temp	S/F[N]	Form	Interflow soil/bedrock
Glencoe	Glencoe[5]	Season/Temp	S/F[M]	Form	Interflow soil/bedrock
Pinedene	Pinedene[12]	Season/Temp	S/F[N]	Form	Interflow soil/bedrock
Griffin	Griffin[5]	Terrestrial	T[B]	-	Recharge
New in TS	Molopo[13]	Season/Temp	S/F[O]	Family	Recharge
New in TS	Askham[13]	Terrestrial	T[B]	-	Recharge
New in TS	Clovelly[5]	Terrestrial	T[B]	-	Recharge
New in TS	Montagu[13]	Season/Temp	S/F[O]	Form	Interflow soil/bedrock
New in TS	Addo[13]	Season/Temp	S/F[O]	Family	Recharge
New in TS	Prieska[13]	Terrestrial	T[B]	-	Recharge

Binomial system soil form	Taxonomic system soil form	DWAF, 2005	Revised classification	Wetness at level	Hydrology
New in TS	Trawal[13]	Terrestrial	T[B]	-	Recharge
New in TS	Augrabies[13]	Terrestrial	T[B]	-	Recharge
Bainsvlei	Bainsvlei[5]	Terrestrial	T[N]	-	Interflow soil/bedrock
New in TS	Lichtenburg[5]	Terrestrial	T[M]	-	Recharge
New in TS	Bloemdal[12]	Terrestrial	T[N]	-	Interflow soil/bedrock
New in TS	Kimberley[13]	Family	T[O]	Family	Recharge
New in TS	Plooysburg[13]	Terrestrial	T[B]	-	Recharge
New in TS	Garies[13]	Terrestrial	T[B]	-	Recharge
Hutton[5]	Hutton[5]	Terrestrial	T[B]	-	Recharge
Shortlands	Shortlands[5]	Terrestrial	T[B]	-	Recharge
New in TS	Jonkersberg[14]	Season/Temp	S/F[J]	Form	Recharge
New in TS	Witfontein[14]	Season/Temp	S/F[J]	Form	Interflow soil/bedrock
New in TS	Pinegrove[14]	Terrestrial	T[J]	-	Recharge
New in TS	Groenkop[14]	Season/Temp	S/F[J]	Family	Recharge
Sterkspruit	Sterkspruit[5]	Terrestrial	T[B]	-	Recharge
New in TS	Sepane[15]	Season/Temp	S/F[N]	Form	Interflow soil/bedrock
Valsrivier[5]	Valsrivier[5]	Terrestrial	T[B]	-	Recharge
Swartland	Swartland[5]	Terrestrial	T[N]	-	Recharge
New in TS	Tukulu[13]	Season/Temp	S/F[N]	Form	Interflow soil/bedrock
New in TS	Etosha[13]	Season/Temp	S/F[N]	Family	Recharge
New in TS	Gamoep[13]	Terrestrial	T[B]	-	Recharge
New in TS	Oudtshoorn[13]	Terrestrial	T[B]	-	Recharge
Oakleaf[5]	Oakleaf[5]	Terrestrial	T[B]	-	Recharge
New in TS	Brandvlei[13]	Season/Temp	S/F[N]	Family	Recharge
Glenrosa	Glenrosa[5]	Season/Temp	S/F[N]	Family	Recharge
Mispah	Mispah	Terrestrial	T[B]	-	Recharge
New in TS	Coega[13]	Terrestrial	T[B]	-	Recharge
New in TS	Knersvlakte[13]	Terrestrial	T[B]	-	Recharge
Dundee	Dundee[5]	Season/Temp	S/F[D]	Family	Recharge
(Fernwood)	Namib[11]	Terrestrial	T[B]	-	Recharge
New in TS	Witbank	Terrestrial	T	-	Recharge

Wetland Contextualisation Notes:

A. The Champagne soil form is accurately described as a permanent wetland zone soil as this soil occurs in peatlands and marches.

B. These soils do not have signs of hydromorphism and are therefore considered to be “terrestrial zone soils”.

C. Rensburg soil discussion – notes

D. From a wetland perspective a neocutanic B horizon is considered a terrestrial soil horizon as it does not contain mottles. The stratified alluvium horizon however is associated with recent deposition in alluvial environments and is therefore considered to be indicative of riparian zones (and therefore part of the seasonal / temporary part of wetlands). In the case of grey low chroma colours dominating the horizon a G horizon, or signs of wetness, would be identified and this would confirm its presence in wetland zones.

E. The presence of a soft carbonate B horizon under a melanic A horizon does not require differentiation at family level in terms of presence of absence of signs of wetness. Under orthic A horizons this differentiation is made and it has an implication for the categorisation of these as wetland or terrestrial soils. For the purpose of this discussion and for the sake of “erring on the side of caution” the Steendal is excluded from wetland zones. This aspect requires more in-depth field investigation and poses a challenge to the interpretation of the land type inventory.

F. Due to the presence of a soft plinthic B horizon immediately below an A horizon this soil is grouped as a temporary / seasonal wetland soil.

G. The presence of a G horizon under the orthic A horizon is considered to be indicative of a regional water table. This soil is therefore grouped under the permanent wetland zone group.

H. The presence of an E horizon over a saturated or plinthic horizon (soft and hard) is considered under the current wetland guideline to indicate signs of wetness and therefore these soils fall into the temporary / seasonal wetland zone. The hard plinthic material is not considered by this author to indicate wet conditions but it is included here as the wetland delineation guidelines stipulate it as being part of the wetland zone.

I. The presence of an E horizon over a high chroma subsoil indicates bleaching from the top due to surface driven wetness and short periods of wetness due to an increase in clay content to the B horizon (temporary perching as a result of decreasing infiltration rate with increasing depth). This type of bleaching is not indicative of a perched water table and this soil is therefore not considered to be part of the wetland zone.

J. A and E horizons on podzol subsoils have formed due to bleaching through the removal of sesquioxides in complexes of organic acids (humic and fulvic acids) produced in the A horizon. The bleaching is therefore not the result of redox processes and strictly speaking these A and/or E horizons are therefore not indicative of wet conditions. The opposite is the case for subsoils under the podzol B that have redoximorphic features and these soils are therefore considered to be indicative of wetland zones.

K. The presence of an E horizon over an illuvial horizon (neocutanic/prismacutanic/pedocutanic/lithocutanic) indicates bleaching from the top down due to surface driven wetness and/or illuviation processes (dispersive clay minerals) with short periods of wetness due to an increase in clay content to the B horizon (temporary perching as a result of decreasing infiltration rate with increasing depth). This type of bleaching is not indicative of a perched water table and this soil is therefore not considered to be part of the wetland zone.

L. In the case of the Fernwood the soil has changed to accommodate deep eluvial horizons. These are not necessarily indicative of wet conditions (such as dunes) but it is included in the wetland guidelines as being part of the temporary/seasonal zone.

M. The hard plinthic horizon is not necessarily indicative of wet conditions but it is included in the wetland guidelines as being part of the temporary/seasonal zone.

N. The presence of a redoximorphic horizon (soft plinthic B / gleycutanic / unspecified material with signs of wetness / unconsolidated material with signs of wetness / signs of wetness at family level in soft carbonate B, lithocutanic B or saprolite) under a high chroma B horizon (whether apedal or structured) is not necessarily indicative of a wetland zone as the mottling typically occurs lower than 50 cm deep in the profile. In cases where these occur shallower the soil would qualify as a wetland zone soil in the wetland guidelines.

O. The presence of a soft carbonate B horizon (with signs of wetness at family level) under a high chroma B horizon is not necessarily indicative of a wetland zone as the mottling typically occurs lower than 50 cm deep in the profile. In cases where these occur shallower the soil would qualify as a wetland zone soil in the wetland guidelines.

6.6 Hydromorphic Properties in the Classification Systems

In the TS (Soil Classification Working Group, 1991) hydromorphic properties are termed "signs of wetness" and these are described as "… grey, low chroma colours, sometimes with blue or green tints, with or without sesquioxide mottling. The latter, if present, may be yellowish brown, olive brown, red or black." These signs occur within 1.5 meters of the soil surface and the material and form in which it occurs may not qualify as any of the diagnostic horizons described for the soil forms listed in **Tables 6.1** to **6.4**. The diagnostic horizons with "signs of wetness" implicit in their definitions are:

1. Organic O horizon
2. G horizon
3. Soft plinthic B horizon
4. E horizon (with qualification)
5. Hard plinthic B horizon (with qualification)

6. Unspecified material with signs of wetness
7. Unconsolidated material with signs of wetness

The implication is therefore that a diagnostic horizon, as listed in tables in this document, with specific diagnostic character other than redox morphology, may contain redox morphological features due to the regular presence of water. The horizons/materials of which other diagnostic properties dominate and that may contain redox morphology at family level are:

1. Soft carbonate B horizon
2. Lithocutanic B horizon
3. Saprolite
4. Stratified Alluvium
5. Prismacutanic (in which case the redox morphology requirements are specified as “continuous black cutans on vertical ped faces”)
6. Materials occurring beneath a placic pan

Signs of wetness underneath apedal horizons and pedocutanic and podzol B horizons are accommodated in “unspecified material with signs of wetness” and “unconsolidated material with signs of wetness” respectively.

6.7 <u>Land Type Database Interrogation – National Scale</u>

The land type inventory of the ARC was interrogated regarding the percentage occurrence, spatially, of specific soil forms per land type. The categorisation of the data was conducted according to the matrix provided in **Table 6.5**. Here the categorisation is consistent with the categories provided in **Table 6.4** with the simplification and omission for soil forms not accommodated in the BS. The categories were extracted from the database by the ARC in the form of percentage per interrogation category per land type. The average and range of data for “wetland” zones in the consolidated broad land types are indicated in **Figures 6.1** to **6.4**.

Table 6.5 Criteria and categories for the interrogation of the land type memoir database (Binomial System)

Soil Form	Conservative	Liberal	Revised	Hydrology*
Arcadia	Terrestrial	T	T	Recharge
Avalon	Terrestrial	S/T	T	Interflow Soil/Rock
Bainsvlei	Terrestrial	T	T	Interflow Soil/Rock
Bonheim	Terrestrial	T	T	Recharge
Cartref	Terrestrial	T	T	Interflow A/B horizons
Champagne	Permanent	P	P	Responsive
Clovelly	Terrestrial	T	T	Recharge
Constantia	Terrestrial	T	T	Interflow A/B horizons
Dundee	Seasonal/temporary	S/T	S/T	Recharge
Dunes	Terrestrial	T	T	Recharge
Erosion	Terrestrial	T	T	Interflow Soil/Rock
Estcourt	Terrestrial	T	T	Interflow A/B horizons
Fernwood	Terrestrial	S/T	S/T	Interflow A/B horizons
Glencoe	Terrestrial	S/T	T	Interflow Soil/Rock
Glenrosa	Terrestrial	S/T	T	Recharge
Griffin	Terrestrial	T	T	Recharge
Houwhoek	Seasonal/temporary	S/T	T	Recharge
Hutton	Terrestrial	T	T	Recharge
Inanda	Terrestrial	T	T	Recharge
Inhoek	Terrestrial	S/T	T	Recharge
Katspruit	Seasonal/temporary	P	P	Responsive
Kranskop	Terrestrial	T	T	Recharge
Kroonstad	Seasonal/temporary	S/T	S/T	Interflow A/B horizons
Lamotte	Seasonal/temporary	S/T	S/T	Interflow Soil/Rock
Longlands	Seasonal/temporary	S/T	S/T	Interflow A/B horizons
Magwa	Terrestrial	T	T	Recharge
Mayo	Terrestrial	T	T	Recharge
Milkwood	Terrestrial	T	T	Recharge
Mispah	Terrestrial	S/T	T	Recharge
Nomanci	Terrestrial	T	T	Recharge
Oakleaf	Terrestrial	T	T	Recharge
Pinedene	Terrestrial	S/T	T	Interflow Soil/Rock
Rensburg	Seasonal/temporary	P	S/T	Responsive
Shepstone	Terrestrial	T	T	Interflow A/B horizons
Shortlands	Terrestrial	T	T	Recharge
Sterkspruit	Terrestrial	T	T	Recharge
Swartland	Terrestrial	T	T	Recharge
Tambankulu	Seasonal/temporary	S/T	S/T	Interflow Soil/Rock
Terraces	Terrestrial	T	T	Recharge
Valsrivier	Terrestrial	T	T	Recharge
Vilafontes	Terrestrial	T	T	Interflow A/B horizons
Wasbank	Terrestrial	S/T	T	Interflow A/B horizons
Westleigh	Seasonal/temporary	S/T	S/T	Interflow Soil/Rock
Willowbrook	Seasonal/temporary	P	S/T	Responsive
Pans	Pans	Pans	Pans	Responsive
Marshes	Permanent	P	P	Responsive
Soil Form	**Conservative**	**Liberal**	**Revised**	**Hydrology***
Stream beds	Stream beds	Stream beds	Stream beds	Responsive
Other	Terrestrial	T	T	Recharge
Rock	Terrestrial	T	T	Recharge

* Hydrology = Int A/B + Responsive; Hydrology+ = Int A/B + Int Soil Rock + Responsive

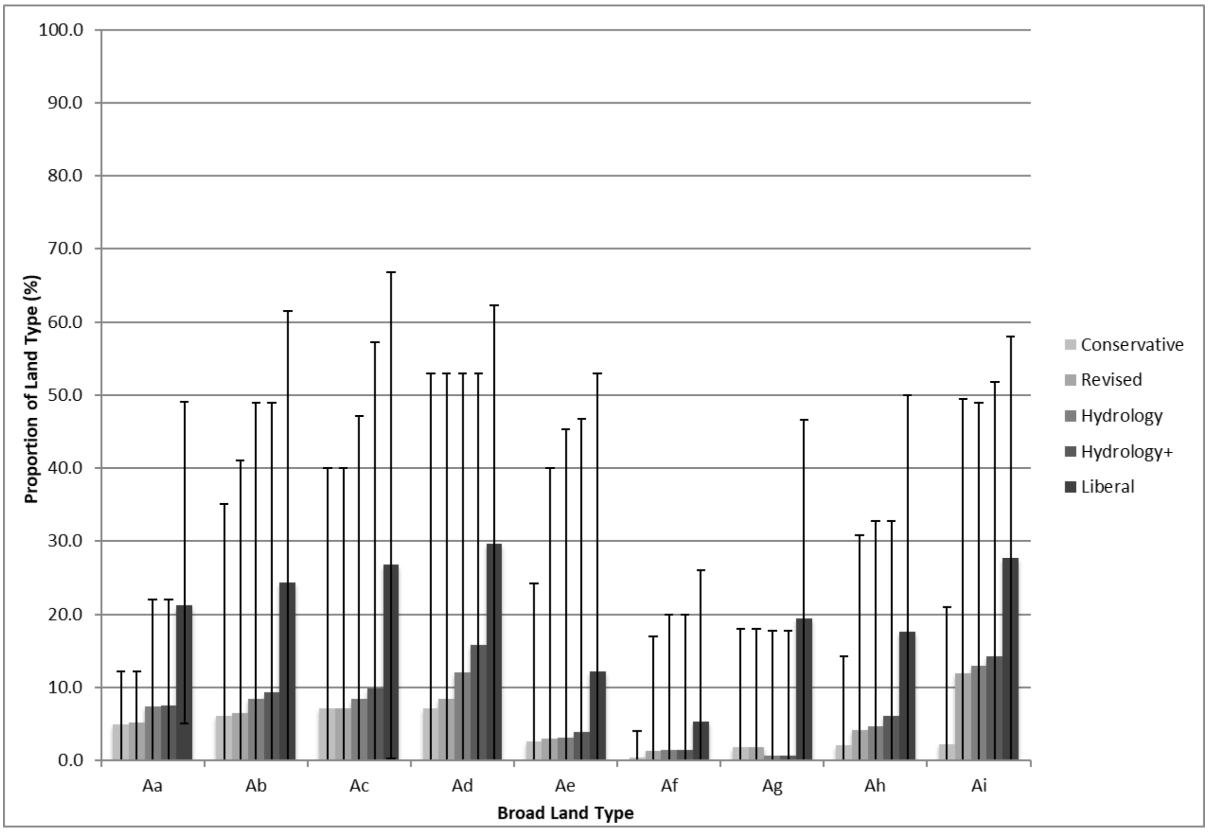

Figure 6.1 Average and range of data for the broad land types Aa to Ai

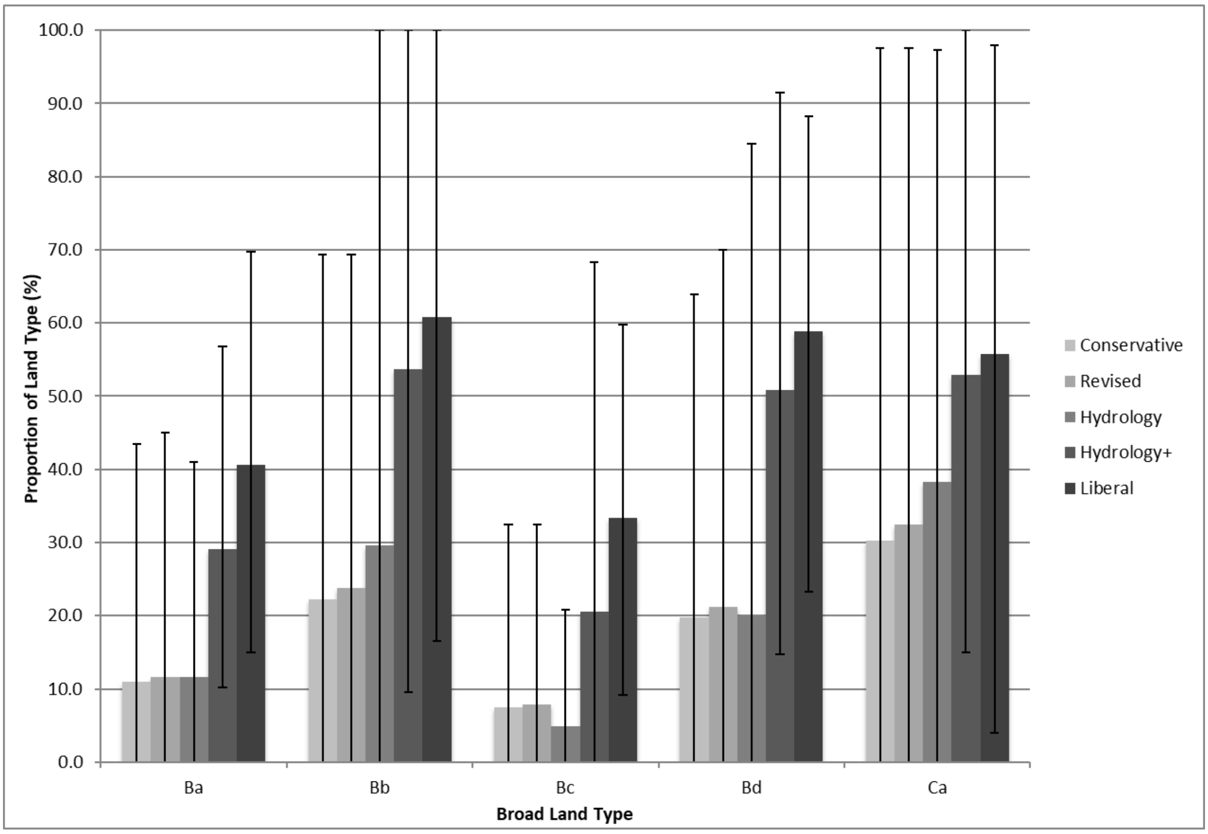

Figure 6.2 Average and range of data for the broad land types Ba to Ca

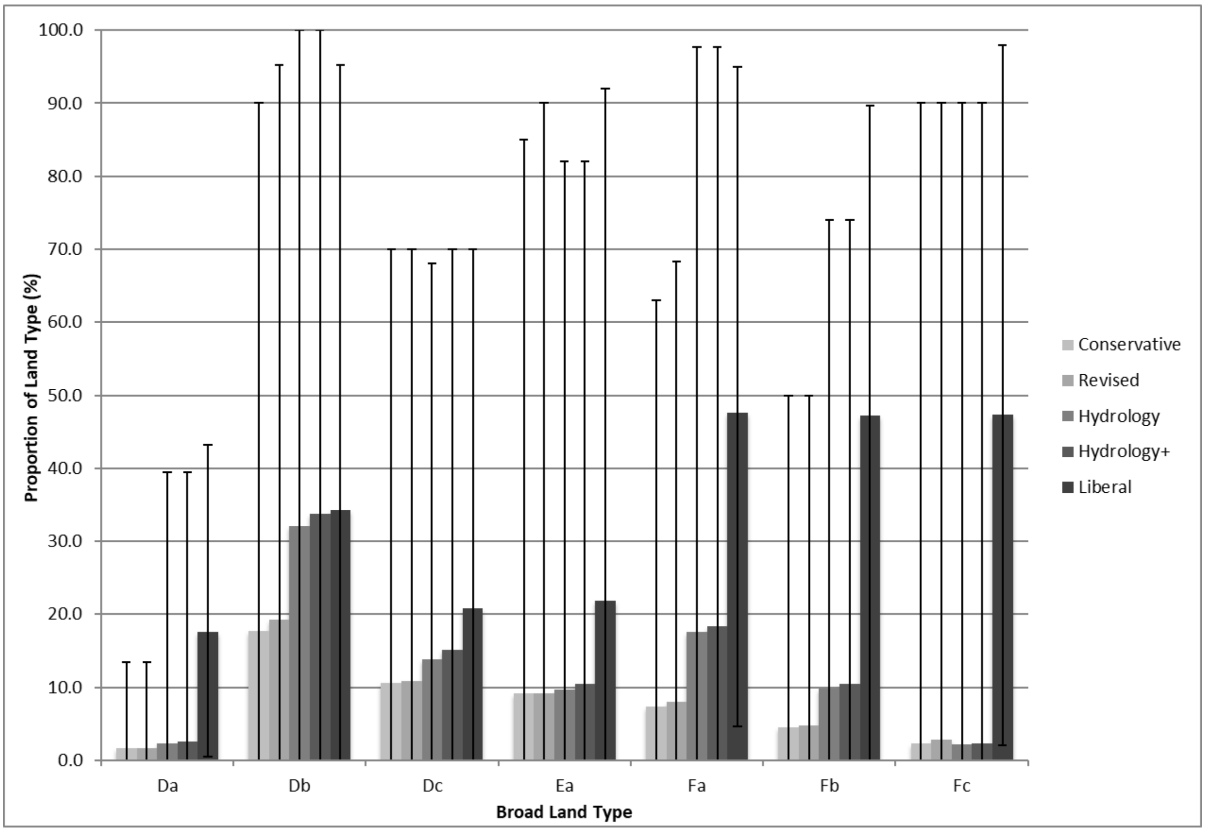

Figure 6.3 Average and range of data for the broad land types Da to Fc

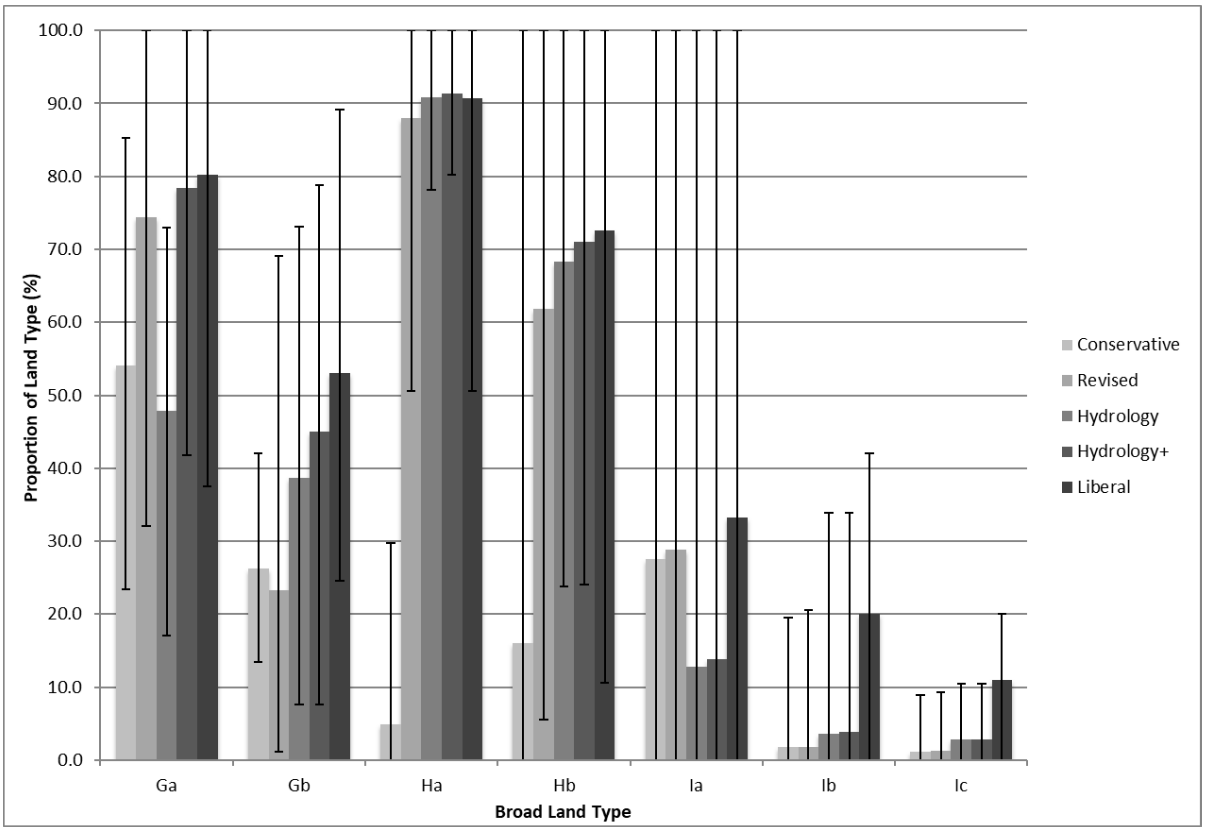

Figure 6.4 Average and range of data for the broad land types Ga to Ic

Note: For the interpretation of this data reference has to be made to the broad land type soil description in Chapter 5. The data interpretation is based on three main observation processes namely:

1. Comparison of broad land types in general regarding the extent of wetland soil distribution. Specifically note the average values (solid bars) and the range of the constituent data (line bars).
2. Interpretation of broad land types in the context of the general soil description provided in Chapter 5. Refer specifically to the water regime and anticipated redox expression trends for the various broad land types.
3. Comparison of the differences between the "Conservative", "Revised", "Hydrology", "Hydrology+" and "Liberal" soil wetland classification categories described earlier.

The data clearly indicates a number of trends namely:

1. <u>The A land types</u> **(Figure 6.1**), as defined in terms of a lack of a water table, indicate a very low proportion of wetland soils per land type if the liberal approach is excluded. These land types n general indicate a dominance of terrestrial soils as dictated by a lack of hydromorphic indicators due to the lack of water tables within the soil profiles. It therefore follows that wetland delineation exercises will identify on small proportions of these land types as qualifying as wetlands from a soil perspective.
2. <u>The B land types</u> (**Figure 6.2**), as defined in terms of the dominance of plinthic (and therefore "water-table" or interflow dominated) soils indicate a very high possible proportion of the landscape as consisting of soils with hydromorphic properties and therefore leads to the identification of large areas as "wetland" from a soil perspective. This is expected as these soils are, by definition, characterised by extensive lateral fluctuating water-tables. It is interesting to observe that the red dominated land types show a smaller proportion of wetland soils than the yellow and grey dominated land types. This is expected as the yellow and grey soils impose an interpretation bias towards wetland soils as the colours are closer to the generally accepted colours of hydromorphic conditions. It is also interesting to note that in many of the Bb and Bd land types up to 100 % of the landscape can be interpreted as "wetland" based on more liberal interpretation of wetland soil properties.
3. <u>The C land types</u> (**Figure 6.2**), indicate a combination of B, D and E land type characteristics. These will be discussed under the relevant other broad land types.
4. <u>The D land types</u> (**Figure 6.3**), indicate similar trends as the B land types in that the red soil dominated land types (Da) show a smaller proportion of wetland

soils that the non-red soil dominated land types (Db). Of interest is the fact that the ranges for all the levels of interpretation for the Db land types indicate occurrence of "wetland" soils of up to 100%. This also indicates that the difference in wetland soil categorisation criteria for the Db land types is small. The same applies to the Dc land types albeit with a smaller proportion and range.

5. The E land types (**Figure 6.3**), indicate a wide range of wetland soil occurrence across the land types but again, as in the case for the Db and Dc land types, there is little difference between the wetland soil categorisation criteria.
6. The F land types (**Figure 6.3**), indicate a wide range of wetland soil occurrence but little difference between the Fa to Fc categories. This is attributed to the wide ranging geology that make up these land types. Of interest is the large jump in wetland soil occurrence in the liberal interpretation of wetland soil properties.
7. The G land types (**Figure 6.4**), indicate a large occurrence of wetland soils throughout. This is considered an artefact and the result of the interpretation of E horizon and bleached soil properties as being indicative of wetland soil conditions. The slight difference between the Ga and Gb land types is attributed to the occurrence of materials with hydromorphic properties at depth in the Ga land type soils as opposed to their absence in the Gb land type soils.
8. The H land types (**Figure 6.4**), indicate a very large proportion of both broad land types to consist of wetland soils. The same limitation to the interpretation of wetland soil indicators in sandy soils, as discussed for the G land types, is applicable here. It therefore follows that an over-estimation of wetland soil occurrence is a distinct risk in the H land types.
9. The Ia land types (**Figure 6.4**), indicate through the large variation with a near 100 % occurrence of wetland soils in many land types, the correlation with alluvial environments. In this land type the signs of hydromorphism are less prominent when compared to signs of alluvial deposition.
10. The Ib and Ic land types (**Figure 6.3**), indicate a very small occurrence of wetland soils. This is ascribed to the general lack of well-expressed soils due to the dominance of rock and young soil landscapes.

6.8 Land Type Database Interrogation – Regional Application

The interrogation of the land type data can be conducted for regional situations as well. **Figure 6.5** provides digital elevation model for the City of Johannesburg area in Gauteng with the detailed land type distribution.

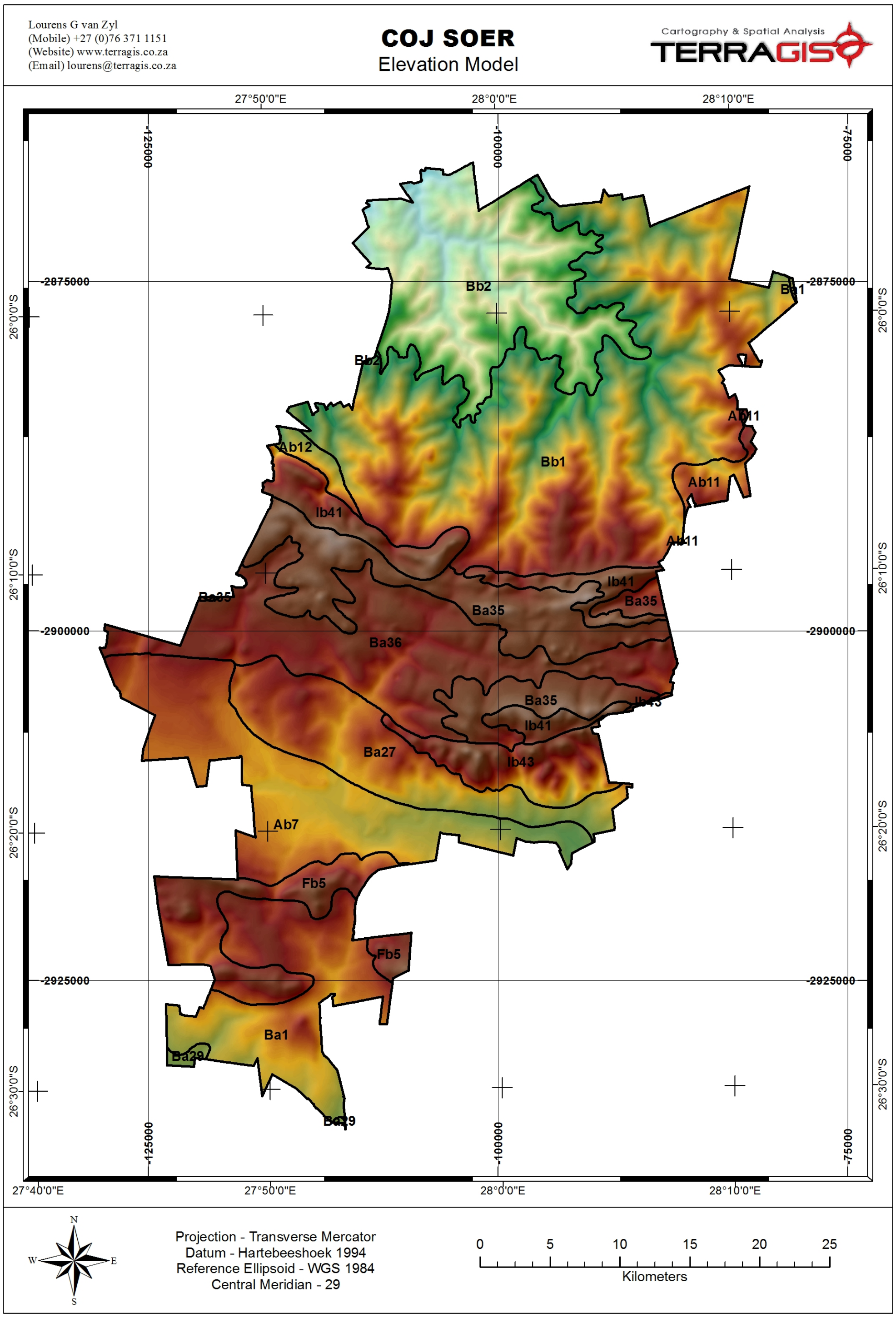

Figure 6.5 Digital elevation model of the City of Johannesburg area with superimposed land type boundaries

The interrogation of the land type data, according to the same methodology as discussed above but, with the extraction of the detailed land type data results yields some very interesting insights into the variability of landscapes. In **Figure 6.6** the data results are provided.

The data in **Figure 6.6** clearly indicates that there is a significant difference wetland soil occurrence between the various land types. As discussed earlier in this document the Ab, Ba and Bb land types yield significantly different proportions due to the dominant soils that occur in these. The Bb land types are characterised by bleached and sand fraction dominated soils derived from the Halfway House Granite Dome. In this regard liberal interpretation of the soil criteria yields wetland soils making up 77 % of the landscape. In contrast, the Ab7 land type, that is dominated by dolomite parent materials barely wetland soils making up less than 10 % of the land surface. The marked difference in wetland expression in these cases point to a distinct geology, hydrology and soil chemistry control over the expression of redox morphology that is used to delineate wetlands.

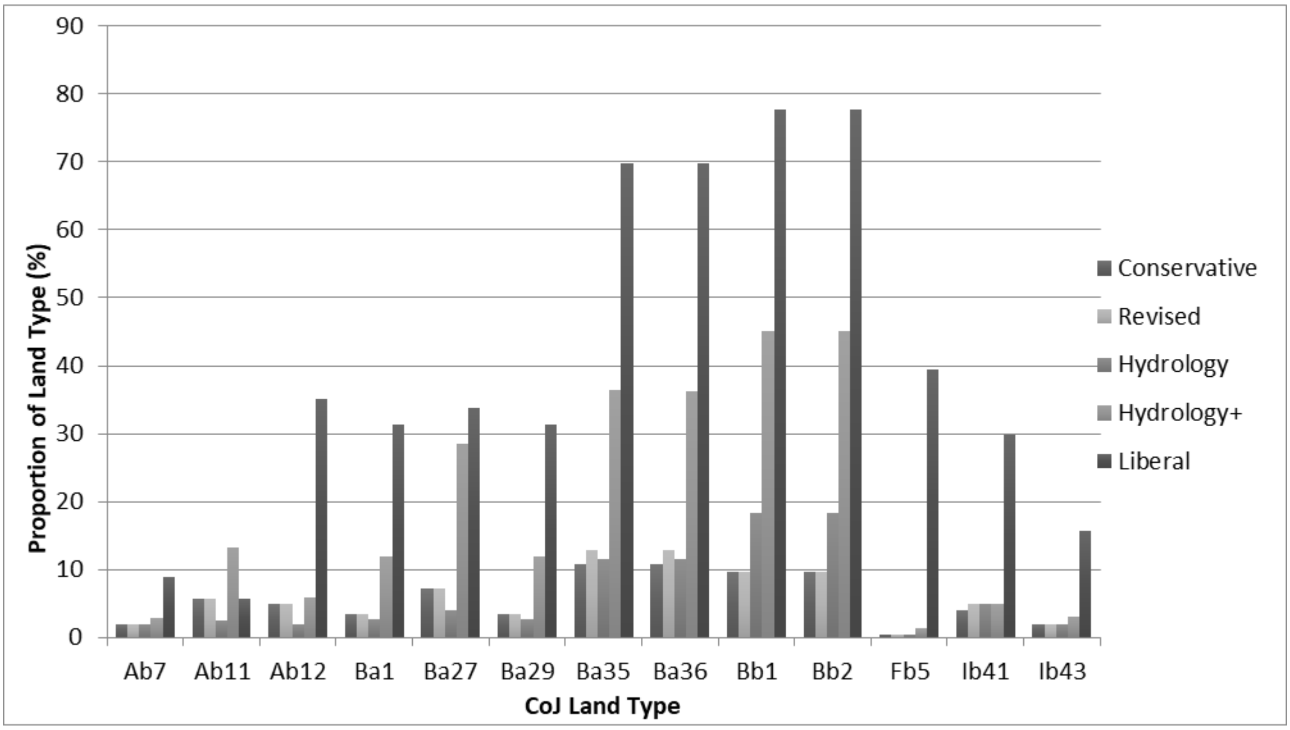

Figure 6.6 Land type interrogation data on wetland soil proportions for the City of Johannesburg

6.9 Summary and Conclusion

The unpacking of the land type data to provide context and detail for wetland assessments is an elaborate process. The first part entailed the correlation of the soil classification approach followed in the generation of the land type data with the current classification approach followed in South Africa. The second part entailed the interrogation of the land type data based on variable approaches to the understanding and categorisation of wetland soils. These ranged from conservative to liberal approaches with widely varying degrees of subjective wetland expression. This component also entailed the interrogation of the land type memoir data based on broad hydrological categories for South African soils. The implication of the variation in expression is the fact that wetland workers will report differences in findings due to varying approaches – a critical observation that will guide the quality and applicability of wetland assessment outcomes.

The third part was the application of the above processes to a real life scenario such as the challenges faced with wetland delineation and assessment within an area with high urbanisation pressures but where the underlying geology dictates differential wetland expression.

The outcomes of the exercise indicate that there is a clear case to be made for the generation of 1) regional wetland guidelines based on geological, climate and topographical determinants and 2) dedicated hydrological impact "realm" guidelines for development scenarios such as urban, opencast mining, forestry, agriculture, etc.

The basis for the regionalisation will have to be the land type data and geographical information data layers at a high level and more dedicated field contextualisation at a more detailed level. The chapters that follow are aimed at a systematically increased level of information unpacking for the purpose of generating realistic and accurate regional wetland delineation and assessment guidelines.

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CHAPTER 7 – PEDOLOGICAL CONTEXT OF WETLAND ASSESSMENT AND DELINEATION

7.1 Introduction

In the previous chapter a striking example was provided of geology, hydrology and soil chemistry based variation in the expression of redox morphology that is used to identify wetland soils. In this chapter the principles of hydrology and pedology, and its integration into the concept of "hydropedology" will be elucidated.

7.2 Hydropedology Context of Wetland Assessment

The biophysical context of a wetland is largely that of the soils of the landscape with the associated vegetation. The soil component includes the hydrology of the soils as well as the associated landscape hydrology (as briefly elucidated in Chapter 3). In order to place all these aspects in perspective it is necessary to provide adequate context and elucidation on the dominant pedological drivers of wetland expression. The section below provides a condensed explanation of the relevant parameters.

7.2.1 Introduction to the Concept of Hydropedology

One discipline that encompasses a number of tools to elucidate the interrelation of landscape hydrological processes with soil forming processes is "hydropedology" (Lin, 2012). The crux of the understanding of hydropedology lies in the fact that pedology is the description and classification of soil on the basis of morphology that is the result of soil and landscape hydrological, physical and chemical processes. But, the soils of which the morphology are described, also take part in and intimately influence the hydrology of the landscape. Soil is therefore both an indicator as well as a participator in the processes that require elucidation.

The subset of tools in soil science that can be used for the elucidation of hydropedology include:

- Soil physics – mathematical description of water flow regimes in soils. This includes the concept of soil hydrology that links up with the parameters discussed below.
- Soil chemistry – description and elucidation of chemical parameters determining morphological expression of wetness.

- Soil morphology – quantitative and qualitative description of visible features of soil as determined by soil physical, chemical, hydrological and biological characteristics.

7.2.2 Pedogenesis – Soil Forming Factors

Pedogenesis is the process of soil formation. Soil formation is a function of five (5) factors, namely:

- Parent material
- Climate
- Topography
- Living organisms
- Time

Due to the volume of material cannot provide detail and reader is referred to standard soil science texts for further information.

7.2.3 Pedogenesis – Soil-Forming Processes

These factors interact to lead to a range of different soil forming processes that ultimately determine the specific soil formed in a specific location. Central to all soil forming processes is water and all the reactions (physical and chemical) associated with it (**Figure 7.1**). The physical processes include water movement onto, into, through and out of a soil unit. The movement can be vertically downwards, lateral or vertically upwards through capillary forces and evapotranspiration. The chemical processes are numerous and include dissolution, precipitation (of salts or other elements) and alteration through pH and reduction and oxidation (redox) changes. In many cases the reactions are promoted through the presence of organic material that is broken down through aerobic or anaerobic respiration by microorganisms. Both these processes alter the redox conditions of the soil and influence the oxidation state of elements such as iron (Fe) and manganese (Mn). Under reducing conditions Fe and Mn are reduced and become more mobile in the soil environment. Oxidizing conditions, in turn, lead to the precipitation of Fe and Mn and therefore lead to their immobilization. The dynamics of Fe and Mn in soil, as well as their zones of depletion through mobilization and accumulation through precipitation, play an important role in the identification of the dominant water regime of a soil and could therefore be used to identify wetlands and wetland conditions.

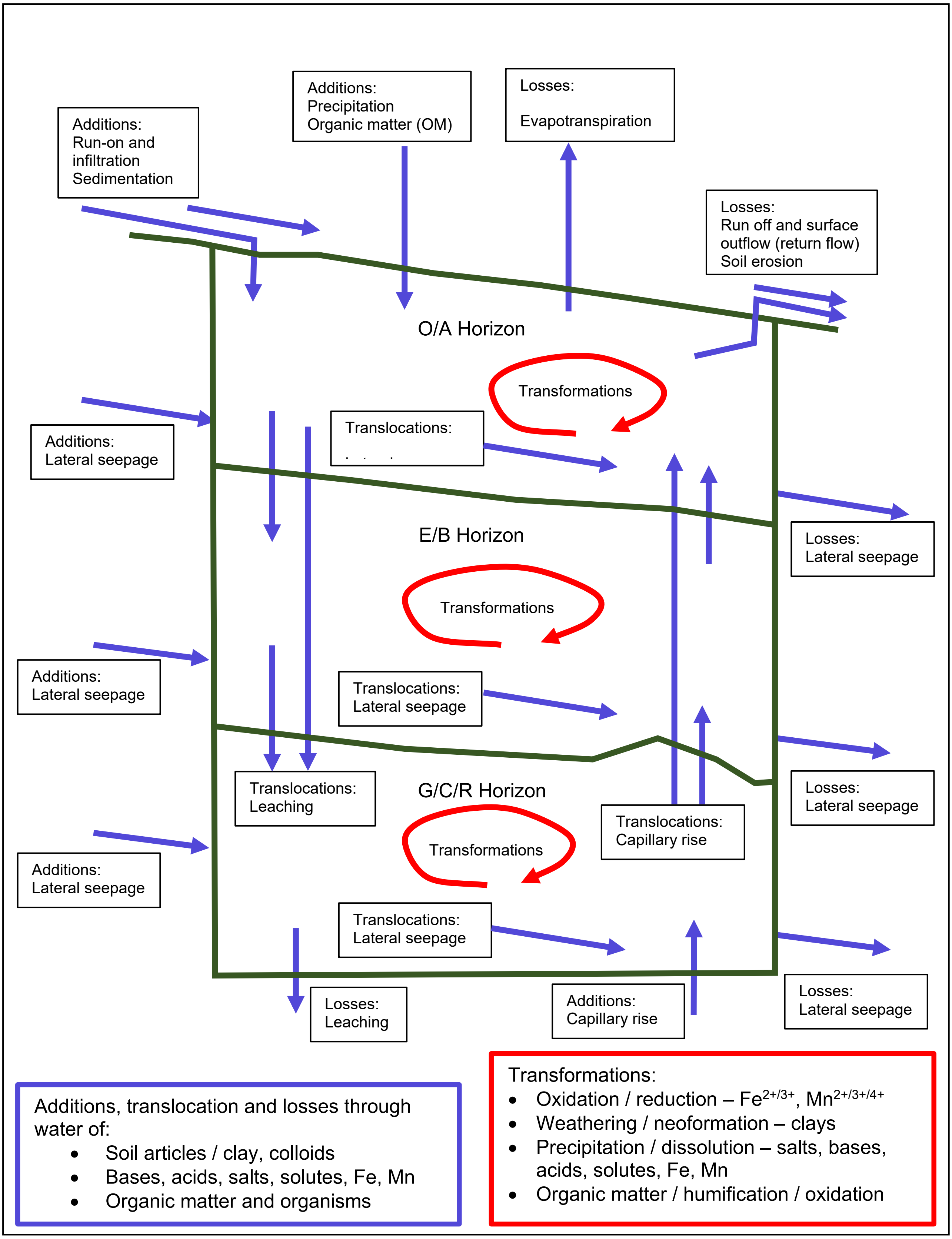

Figure 7.1 Summary of soil forming processes, as mediated by water dynamics, which play a role in redox morphology development and expression

The discussion provided above is a very brief synopsis of the processes that apply to the understanding of redox morphology drivers and determinants. For further elucidation the reader is referred to numerous soil science texts that discuss the processes in much more detail.

7.3 Redox Morphology Determinants

Due to the direct correlation between Fe (and Mn) dynamics in soils and the morphological expression of redox processes and conditions it follows that these parameters will have a direct bearing on the interpretation of wetness parameters. It must be emphasized here however that a number of factors influence the mineralogy and morphological expression of Fe (and Mn) in soils. Redox morphology therefore has to be considered in a broader context that includes the following:

1. Degree and duration of saturation;
2. Hydrological processes determining the degree of loss or addition of sesquioxides, clay, salts and organic carbon.
3. Soil pH and pH buffering capacity as determined by a range of soil minerals and conditions;
4. Soil texture and clay mineralogy;
5. Iron “reserve” or total amount of Fe in the soil that can undergo redox reactions;
6. Manganese content of the soil and its influence on redox poise (buffering) processes; and
7. Organic matter dynamics and the associated energy source for microbial activity that leads to reducing conditions.

7.3.1 Redox Morphology as determined by Degree and Duration of Saturation

The **degree of saturation** in a soil can be described as the extent to which the pores are filled with water. It therefore follows that the saturation can be expressed (amongst others) as the proportion (percentage) of the pore volume that is filled with water compared to the total available volume. There are several saturation indices used by soil physicists and the reader is referred to more specific soil physics texts for an elucidation. In this document the extent or proportion of the total possible saturation will be used as a concept.

The **duration of saturation** is described as the time span over which a soil is saturated to a specific (referenced or measured) extent. This parameter requires specific measurement in the field over a specific time period and for hydrological modelling parameters require elucidation over a few cycles / seasons of rainfall at least.

The degree and duration of saturation determines the extent to which a soil will become anoxic or anaerobic. **Figure 7.2** provides a schematic representation of the aspects of gas exchange and its associated energy dynamics based on degree and duration of saturation. In well-aerated soils an equilibrium exists between the atmosphere and the soil air in terms of composition.

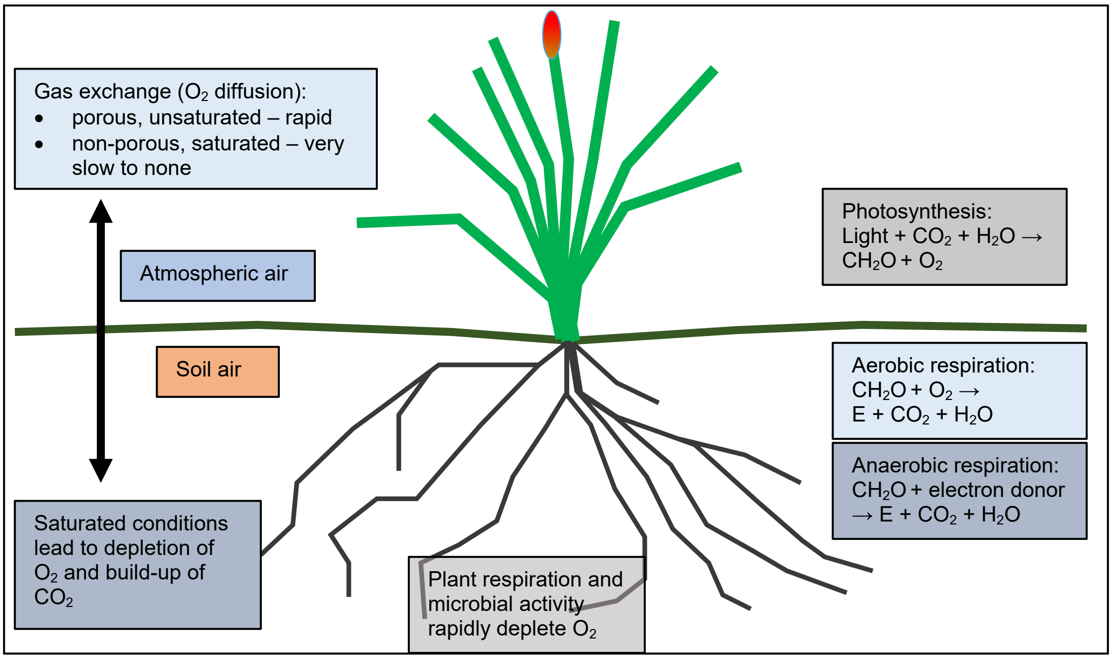

Figure 7.2 Gas exchange and soil energy dynamics as influenced by saturation

Once the surface of a soil is sealed (through water or mechanical means) or when the soil is saturated to a specific level the gas exchange slows down or ceases completely. The diffusion rate of oxygen in water is a factor of 10 000 times slower in water than in air and it follows that dissolution of oxygen into water will therefore also be slow. Whereas above ground plant structures take up CO_2 and release O_2 through the process of photosynthesis, the below ground structures (roots) require O_2 for respiration processes and release CO_2. Soil organisms also respire and therefore also release CO_2. In the event that the soil surface is sealed or the soil is saturated the CO_2 levels increase in the soil and the O_2 decrease. This process can lead to a complete depletion of O_2 and the soil is said to be “anaerobic”. Under these conditions all aerobic organisms start dying but anaerobic organisms then multiply and thrive as they can use other compounds as electron acceptors to complete their respiration (anaerobic) processes.

The chemistry of anaerobic soils is too wide a topic to address in this document and the reader is referred specialised text for further elucidation. Suffice to say that the main electron acceptors that we are interested in are Mn and Fe that yield the distinctive colours associated with the morphology of redox depletions (grey and low chroma colours) and redox accumulations (wide range of high chroma colours associated with Fe and Mn oxides and hydroxides, typically including red, yellow and black). In a hillslope context it can be expected that the degree and duration of saturation will increase down a slow as is indicated in **Figure 7.3** This concept will be elucidated in more detail in subsequent chapters.

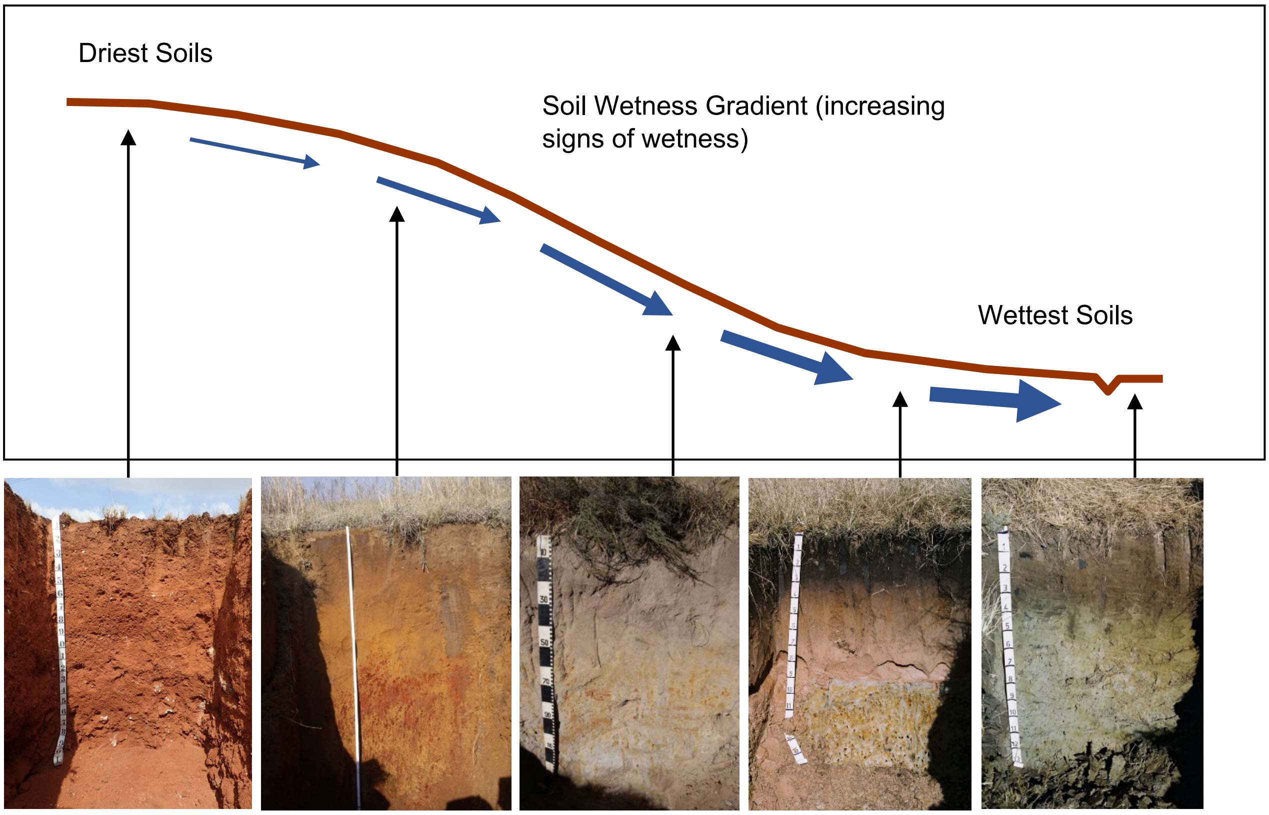

Figure 7.3 Conceptual indication of increased soil wetness along a hillslope with profiles (soil forms from left to right: Hutton – Avalon – Longlands – Kroonstad – Katspruit)

Various examples of a high degree and long duration of saturation are provided in **Figures 7.4** to **7.6**. These include saturated subsoils, saturated E horizons, saturated sandy profiles, saturated clay enriched horizons and peat materials formed due to saturation.

Figure 7.4 From left to right: Sandy soil profile with free water in the profile – redox morphology in the form of vesicular zones of high chroma Fe accumulation (oxidation) and dark and grey zones of Fe depletion – reduction and Fe depletion along an active root and a vesicular zone of Fe accumulation next to it

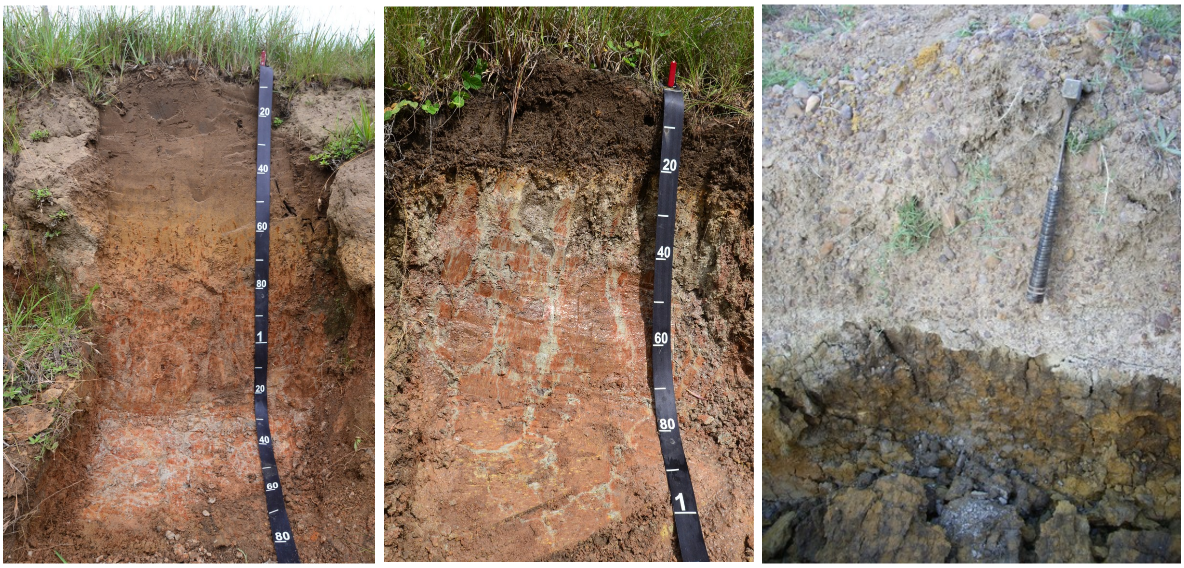

Figure 7.5 Profiles with expression of saturation (from left to right: profile with saturation at depth – saturation in the entire profile – saturation in an E horizon above an illuvial clay layer)

Figure 7.6 Various colours and materials that indicate pronounced and prolonged saturation (note the blueish grey as well as olive green tints that indicate the presence of double layered hydroxides)

7.3.2 Redox Morphology as determined by Losses or Additions

In **Figure 7.1** the concepts of losses and additions are described. The main drivers of redox morphology are:

1. Additions of water that will lead to higher degrees of saturation and longer periods of saturation;

2. The addition of organic matter that is decomposed by organisms and that yields the energy (specifically electrons) for the redox reaction processes;
3. Reduction and depletion of Fe and Mn through solubilisation and removal from the profile or localised areas (redox depletion);
4. Losses of water through drainage or evapotranspiration leading to decreased saturation and subsequent increased oxygen ingress and oxidation: and
5. Ingress of reduced Fe and Mn rich water that can undergo oxidation with subsequent precipitation and accumulation (redox accumulation).

In general these processes summarise the main dynamics in soil related to the formation of redox morphology. Examples are provided in **Figures 7.7** to **7.10**.

7.3.3 Redox Morphology in Alkaline Soils

The section above described the main drivers of redox morphology with emphasis on Fe and Mn oxides and hydroxides. Wetland delineation is a very challenging exercise in areas dominated by alkaline soils such as lime containing and/or vertic/melanic soils. This is mainly due to the almost complete absence of Fe-mottles in the soils that grade from the terrestrial to the wetland areas. There are a number of reasons that will be explained in more detail below.

In order to illustrate the stability and distribution of Fe minerals in soils the figure provided below (**Figure 7.11**) was copied from page 124 of a book entitled “Soil Chemistry” by Bohn *et al.,* (1990). The essence is that when reduction and oxidation reactions of Fe (in this case) are considered in soils both the electron activity (driver of reducing conditions) and pH have to be considered as they are intimately linked and dependent on each other. Suffice to say that for redox and mineral stability purposes they are indicated on the same graph. From Figure 4.6 (**Figure 7.11**) it is clear that as the Eh decreases (increasing reducing conditions) the dominant Fe species in solution changes from Fe^{3+} (insoluble and forming brightly coloured minerals) to Fe^{2+} (soluble and essentially colourless). Once pH is included in the observation it is clear that distinct Fe minerals come into play. Applying the decreasing Eh values to Fe minerals at high pH it is clear that the dominant Fe mineral under oxidizing conditions is FeOOH (Goethite – predominantly yellow). As the conditions become more reducing the equilibrium shifts to $FeCO_3$ (Siderite – white) and thereafter to FeS_2 (Pyrite). Whereas goethite has a distinct colour in soil, siderite and pyrite are less conspicuous in small quantities. It follows therefore that Fe minerals are much less visible in high pH reduced soils than in oxidised soils. In addition, vertic and melanic soils are dark-coloured and it is therefore also clear that this dark colour will mask the presence of the above-mentioned Fe minerals.

Figure 7.7 Examples of Fe depletions (losses – light coloured and bleached) and Fe accumulations (additions – bright coloured or high chroma) in a variety of matrices

Figure 7.8 Zones of Fe accumulation along root channels where ingress of oxygen rich air occurs

Figure 7.9 High chroma matrix with depleted preferential flow zones and indications of Fe accumulation upon oxidation in landscape seepage processes intercepted by a road

Figure 7.10 Accumulation of Fe oxides and hydroxides to form a hard plinthite layer as a third horizon in a Wasbank soil form

Another factor related to pH is the degree of reduction that is required to reduce Fe from its oxidised to its reduced state. From the graph it is clear that there is a steep decreasing gradient as the pH of the soil increases. This implies that much more intensive reducing conditions are required for the same degree of Fe reduction when high pH conditions (as those experienced in vertic and melanic soils) are compared to low pH conditions.

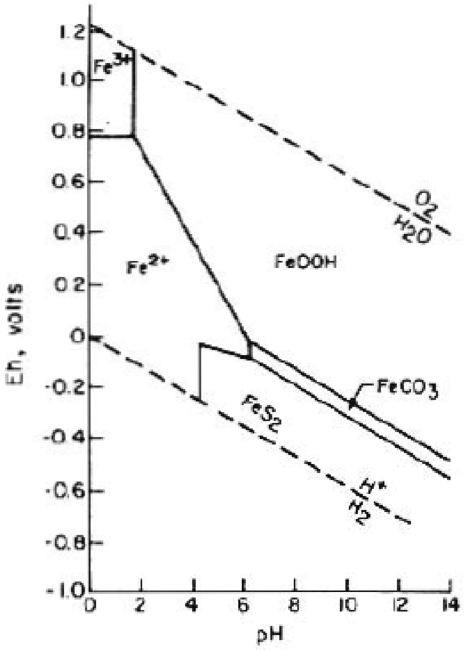

FIGURE 4.6. The *Eh*–pH diagram of various iron ions and compounds.

Figure 7.11 Eh pH diagram as sourced from Bohn *et al.,* (1990), p124.

The situation becomes even more complex as other intermediate Fe minerals (blue green rusts) come into play. The essence of the presence of blue-green rusts is that they are tints that occur extensively in poorly drained and poorly aerated soils such as G-horizons under vertic and/or melanic A-horizons. These minerals are not stable and often disappear within a few minutes of exposure to the atmosphere. They, in all probability, form some of the most important Fe phases in vertic soils but disappear rapidly. Before they disappear it is also evident that these minerals are visible against a grey matrix but poorly visible against a black or dark background.

In essence therefore, a number of factors, including degree of reduction, soil pH and dominant Fe minerals, conspire against the use of Fe indicators in vertic, melanic and lime containing soils for the delineation of wetlands. There is no quick solution to this problem and delineators should use as many other indicators of wetland conditions in such soils as they can.

Figures 7.12 to **7.14** provide an indication of the conditions experience in alkaline soils.

7.3.4 Redox Morphology in Manganese-Dominated Soils

Earlier it was indicated that the two metals of interest in redox morphology expression are Fe and Mn. Manganese is reduced before Fe and as such all the labile Mn has to be reduced before Fe will undergo reduction. Most soils have much lower Mn levels than Fe levels and this sequence is generally not an impediment to the development of redox morphology in periodically wet soils. However, some soils, such as those derived from dolomite in the central and eastern parts of South Africa, exhibit very high Mn levels and presence of visibly numerous Mn accumulations and nodules. An investigation by Mudaly (2015) indicated that the high Mn levels in these soils buffer (pause) reduction processes significantly with the result that Fe reduction does not occur readily. The dominance of red colours in Mn dominated soils is indicated in **Figures 7.15** and **7.16**.

Coupled with the more dominantly well-drained hydrology of dolomite landscapes, it follows that the soils in these landscapes very rarely exhibit any “classic” signs of redox morphology in the form of redox depletions and grey colours even though some seasonal wetland plant species may be present. A compounding factor is the fact that Mn can undergo solid state reduction and oxidation reactions and can therefore persist much longer in soil under conditions under which Fe would have been mobilised through reduction and removal of soluble fractions. This phenomenon is often confusing for wetland investigators and is addressed in further detail in later chapters with reference to specific case studies.

Figure 7.12 Redox morphology (Fe and Mn) as expressed in alkaline lime containing soils (note the absence of high chroma colours except for some diffuse black Mn concretions)

Figure 7.13 Black vertic soils (with Gilgai microrelief) with very diffuse Fe redox morphology in the upper horizon

Figure 7.14 Left: Augured soil material from a micro-low (left of tape) and micro-high (right of tape) indicating the colour difference between the two zones yet without Fe redox morphology; Right: oxidised root channels in a saturated vertic horizon indicating ingress of oxygen rich air and a subsequent localised lowering in pH to yield Fe hydroxide minerals

Figure 7.15 Examples of Mn redox morphology are 1) top and middle: Mn accumulations through precipitation as concretions or on the edge of rocks that undergo weathering and translocation of Mn from inside the rock, 2) bottom: red dominated soil profile with diffuse accumulations of Mn as slightly darker zones on ped surfaces

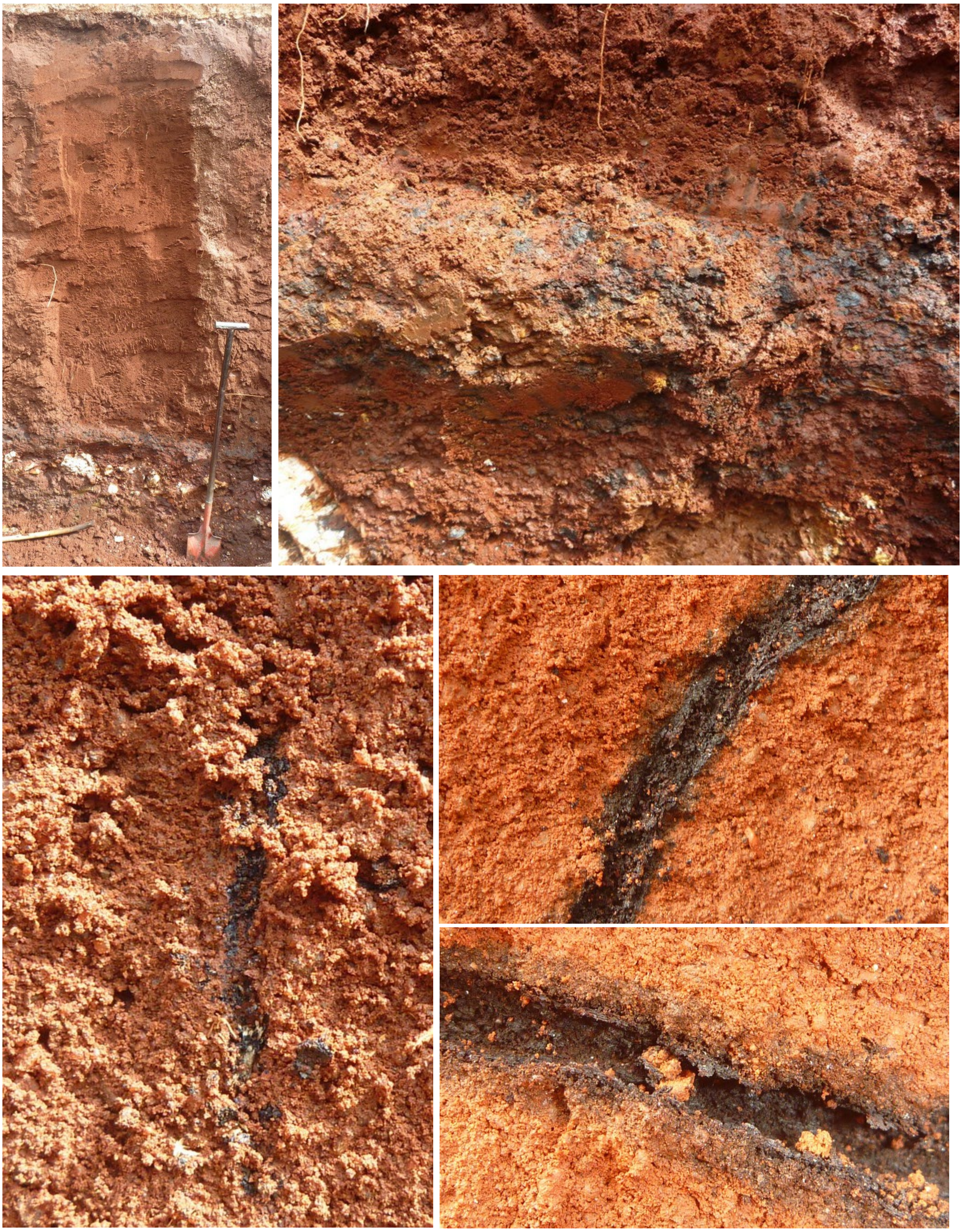

Figure 7.16 Examples of Mn redox morphology are 1) top: Mn accumulation as a distinct hardened horizon (manganocrete) at the bottom of the profile, 2) Mn translocation and precipitation in preferential flow channels along old root channels or animal burrows

7.3.5 Redox Morphology as Influenced by Iron Reserve

The total Fe content of a soil can be referred to as its “Fe reserve”. Soils vary considerably in their total Fe content and as such a gradient of susceptibility to the formation of redox depletions upon Fe reduction can be found. Generally this gradient is directly proportional to the Fe content with lower Fe content soils exhibiting more rapid redox depletion pressures than soils with high Fe contents or the same degree / duration of saturation and energy input in the form of electrons. A trend that is often observed is that sandy soils undergo bleaching more rapidly than clayey soils, under the same redox pressures. This phenomenon is ascribed to Fe reserve. The variability in soil Fe reserve is indicated by the pictures in **Figures 7.17** and **7.18**.

Figure 7.17 Two profiles with materials with very low Fe reserves as expressed by the distinct bleaching and white/grey colours in a sandy matrix

7.3.6 Redox Morphology as Influenced by Clay Content

The clay content of a soil determines to a large degree the types and intensity of chemical reactions in a soil. This aspect is especially evident when soils of varying clay content, under similar conditions, are compared in terms of their buffering of chemical changes. The variation is too complex to address in detail in this section but the general trends regarding clay influences on redox morphology are:

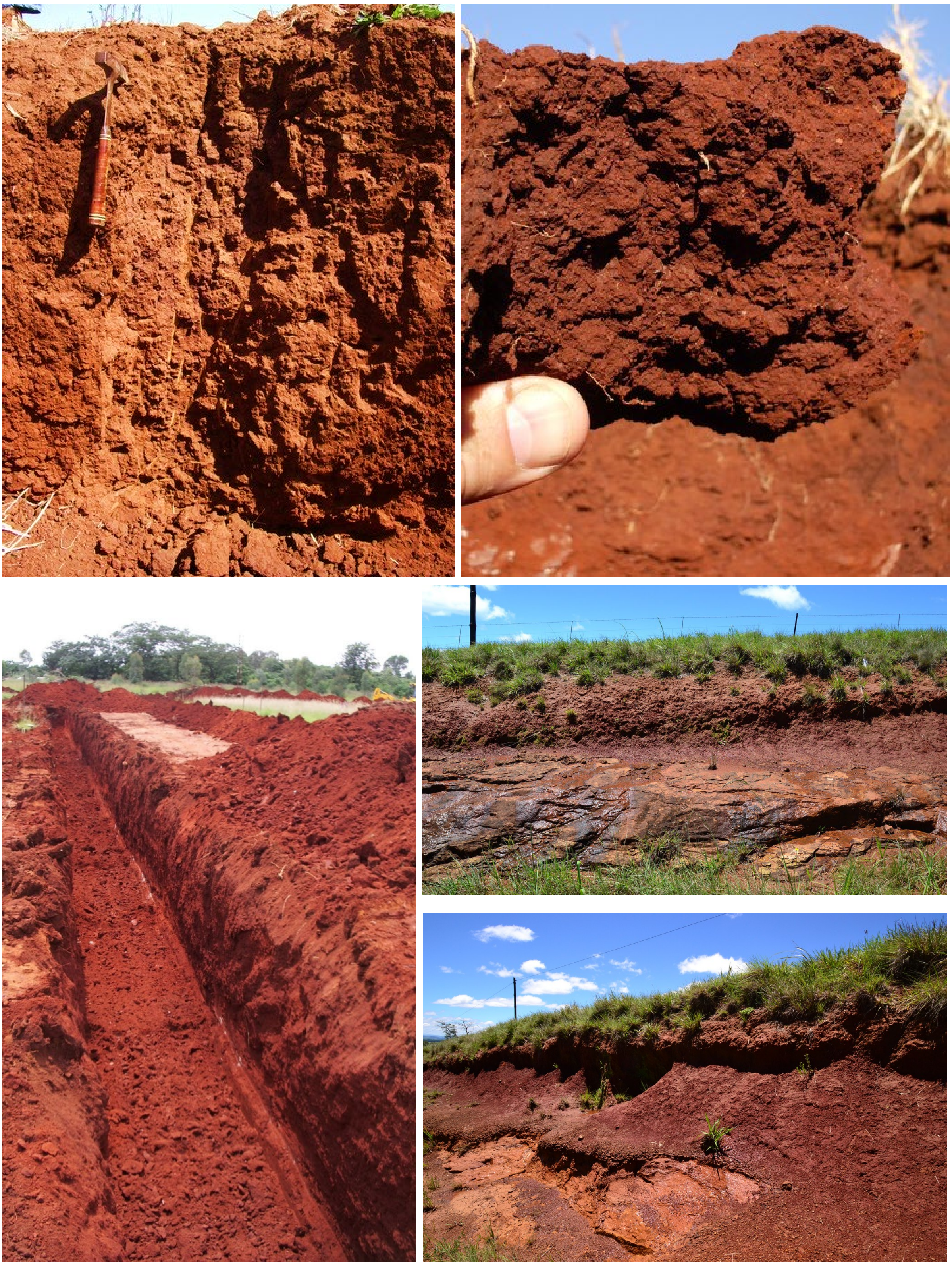

Figure 7.18 Soil materials with a high Fe reserve in a high clay content matrix (note the lateral seepage on the rock interface under the red soil materials in the images at the bottom right)

1. Soils with higher clay content will also exhibit higher Fe reserves than soils with lower clay contents if they are the same colour.
2. Iron precipitation occurs more readily on finer textured surfaces than on coarser textured surfaces under oxidising conditions due to a difference in Gibbs free energy in the stable state.
3. Water potential differences between sandy and clayey soils are significant at the same degree of saturation. Under these conditions, removal of Fe from clay surfaces will require more energy than removal from sand gain coatings for similar redox state conditions.
4. Clay materials hold water more strongly against drying pressures and the clays will therefore remain saturated and wet for longer. This aspect introduces a concept of rapid changes in coarse materials and slower changes in finer textured materials. The results is therefore a differential expression of colour and Fe mineral stability as mediated by the water regime of the soil.
5. The chemical activity of especially kaolinite, goethite/hematite and gibbsite clay fraction minerals is such that they exhibit pH dependent charge. As redox reactions also directly influence soil pH it follows that the surface charges of these minerals will alter during conditions of variable redox. In this regard the clay minerals act as electrostatic sinks for soluble Fe and Mn during reduced conditions thereby concentrating these elements on the clay mineral surface. During conditions of oxidation and lack of water the Fe and Mn oxidise and precipitate in situ on the clay minerals. In addition, the oxidising process leads to acid generation and a change of charge on the clay surface from negative to positive, thereby repelling the positively charged Fe/Mn ion. Without water to remove the newly “liberated” ion it precipitates on the clay surface as a new Fe/Mn mineral. In this way the “accretion” of Fe into mottles versus an often depleted matrix is mediated.

An observation that is often made in the field by soil surveyors is the lack of distinct mottling in sandy soils with clay contents below 8%. This is especially problematic in the delineation of wetlands in sand dominated environments if the main delineation approach is to search for and identify mottles. The low clay content of the sandy soils, coupled with other parameters discussed later in this chapter, preclude the formation of mottles under conditions of fluctuating moisture due to the lack of concentration mechanisms and precipitation surfaces for Fe (refer to point 5 above).

The range of conditions regarding clay content and redox morphology expression is provided in **Figure 7.19**.

Figure 7.19 Redox morphology expression as a function of clay content: sandy soils lack significant “concentration” and “accumulation” surfaces for Fe where as such surfaces occur readily in higher clay content soils and in clay “nodules” in sandy soils

7.3.7 Redox Morphology as Indicated by Organic Matter (Presence and Content)

Organic matter accumulation in a landscape is facilitated under conditions where microbial decomposition of the added materials is slower than the accumulation rate (deposition rate by plants and organisms). There are four main factors that inhibit microbial activity in this context, individually and in combination, and these are:

1. Low temperatures;
2. Saturated and anoxic conditions;
3. Extremes of pH; and
4. High osmotic pressures in conditions with high salt concentrations.

It is well-known that organic matter accumulates in marshes and swamps and that these produce swamp gasses as a result of the formation of methane (CH_4) and hydrogen sulphide (H_2S). The formation of these gasses indicates the one extreme of organic matter accumulation. On the other end of the scale is entirely terrestrial soils with low organic matter contents. Between these extremes there is a range of organic matter contents in soils as a function of wetness. This range often forms the basis for classification of organic matter enriched horizons with the organic O horizon being defined in the South African system as consisting of more than 10% organic carbon over a vertical distance of 200 mm. Lower organic carbon contents are accommodated in the orthic A horizon – if the result of wetness parameters. It has been proposed to improve the classification parameters o include more categories and to assimilate peat classification parameters.

The morphology of wet organic matter rich horizons is dominated by dark colours in the South African context. From unpublished data it is apparent that the Munsell colour value of sandy soils with more than 2% organic carbon falls below 3. The case for clayey soils varies a bit more, with organic C levels exceeding 3% yielding a Munsell colour value below 3. These values represent the lower ranges of what is considered a regularly wet soil in a return flow environment. This parameter provides a very handy indicator for the identification of wetter soils in landscapes where other redox morphology indicators are lacking (**Figures 7.20** and **7.21**).

Figure 7.20 Soils with distinct organic matter accumulation due to various degrees of wetness

Figure 7.21 Elevated organic carbon topsoils (due to regular wetness) overlying sandy and bleached subsoils

The preceding discussion does not apply to diagnostic humic A horizons though (**Figure 7.22**) Humic A horizons are defined as having an OC range from 1.8 to 10 (the cut-off for organic O horizons). Data for humic soils in KwaZulu-Natal indicate average OC values of 4% and above. The diagnostic humic A horizon is found in well-drained (recharge) soils and by definition have no signs of redox morphology immediately below the humic horizon. It is critical that the OC enriched horizon be contextualised through formal classification procedures and tools to determine whether it is diagnostic humic A (and well drained) as part of a terrestrial area or whether the OC enriched horizon is the result of saturation processes (in which case the reduced redox morphology context should be evident).

Figure 7.22 Red (Inanda form) and yellow (Magwa form) humic soils with elevated organic carbon in a well-drained profile due to climatic conditions

7.3.8 Redox Morphology as Influenced by Organic Matter Content

The influence of organic matter on the expression of redox morphology is intricate as organic matter has a higher cation exchange capacity (CEC) than active clay minerals. The functional groups of the organic molecules also undergo charge alteration based on pH and Eh fluctuations. These two characteristics lead to a very large capacity of the organic matter to sequester, through electrostatic attraction and adsorption as well as organic complex formation, charged ions from the soil solution. Elements such as Fe and Mn that become soluble under reducing conditions readily adsorb onto organic molecules as these also have increased negative charge under higher pH an Eh conditions. Similar to the clays as described earlier, upon drying and oxidation the organic molecule functional groups acidify and become positively charged, effectively repelling the metal ions. The concomitant oxidation of Fe and Mn yield insoluble amorphous minerals in the organic matter matrix. Through this mechanism organic matter acts as a sink for soluble redox sensitive elements under reduced conditions and effectively prevents these from forming other stable minerals that may be expressed as mottles through systematic accretion. Additionally, elevated organic matter levels yield a dark coloured soil and therefore effectively masks any amorphous or small-scale Fe minerals that may have formed in the matrix (**Figure 7.23**). This mechanism is postulated to be one of the main determinants of the lack of Fe redox morphology expression in sandy soils such as in Maputaland.

Figure 7.23 Organic carbon rich horizons act as a sink for cations (Fe, Mn and Al)

A distinct departure from the above conditions is the ingress of air into saturated, organic matter-rich horizons along preferential channels (decayed root and worm channels). Under these conditions the large pores are the first to drain upon gradual drying with a related ingress of O_2-rich air. Soluble Fe (and Mn) diffuse in the soil solution to the O_2-rich areas and precipitate as oxides and hydroxides yielding high chroma channel linings. In many landscapes the presence of oxidised root channels is indicative of a saturated soil environment (**Figure 7.24**).

Figure 7.24 Wet profiles with elevated organic carbon A horizons mask redox morphology in the surface horizons due to a large cation exchange capacity in these horizons but exhibit oxides root channels due to ingress of oxygen-rich air at times that the water table drops

7.3.9 *Redox Morphology as Determined by Aridity*

From the preceding discussions it is apparent that the presence of water in high concentrations and for long periods yield distinct redox morphology indicators. However, with decreasing precipitation and increasing aridity these conditions become less pronounced and last for shorter periods with decreased expression of reducing and fluctuating conditions. At a point the expression of Fe redox morphology ceases. In many cases these more arid soils have elevated levels of carbonates and associated alkaline pH. So, where a transition area may still exhibit grey colours of redox depletions, the dominant Fe mineral is siderite that is white in colour. Section 7.3.3 deals with the characteristics of alkaline soils in terms of redox accumulations. It therefore follows that the Fe is masked by the presence of lime as it has the same colour as siderite.

In even dryer conditions the precipitation of carbonates and sulphates start to dominate and redox morphology as described earlier is essentially absent. The flow path of water is readily indicated by the expression of secondary carbonates and gypsum precipitates. In the absence of distinct redox morphology indicators the interpretation of lime and gypsum redistribution can yield an accurate description of soil water regime. These indicators however do not qualify per se as redox morphology and will currently not withstand scrutiny as a correlation to the saturation requirements of wetland soils as stated in the definition of a wetland in the NWA.

The main aspect determining the degree and intensity of redox morphology expression is rather obvious namely climate and amount of moisture / water. In Chapter 5 the soils of South Africa were discussed with a distinct reference to the rainfall distribution. It is evident that the expression of wetness, and satisfaction of the degree and period of saturation requirements implied in the definition of a wetland in the NWA, will increase roughly on a west to east gradient. In the western parts many soils associated with low lying positions, and therefore satisfying the description of a watercourse, or occurring in a position associated with wetland conditions will not exhibit redox morphology due to a lack of water. In these cases other indicators can be used and these include:

- Presence and accumulation processes of salts in the form of halite, gypsum and lime; and
- Differential concentrations of salts that can indicate zones of depletion and zones of accumulation.

The trend is that the more arid the environment becomes the more difficult it is to identify hydrologically important soils and processes through the use of redox morphology indicators. In this regard it is critically important that the wetland guidelines be expanded to include specific reference to landscapes where the “normal” wetland indicators do not apply. The section that follows provides a discussion on the contextualisation of redox morphology indicators with reference to the arid area challenges. **Figures 7.25** to **7.29** provide an indication of the wide range of conditions that are determined by aridity.

Figure 7.25 Lime accumulation under arid conditions

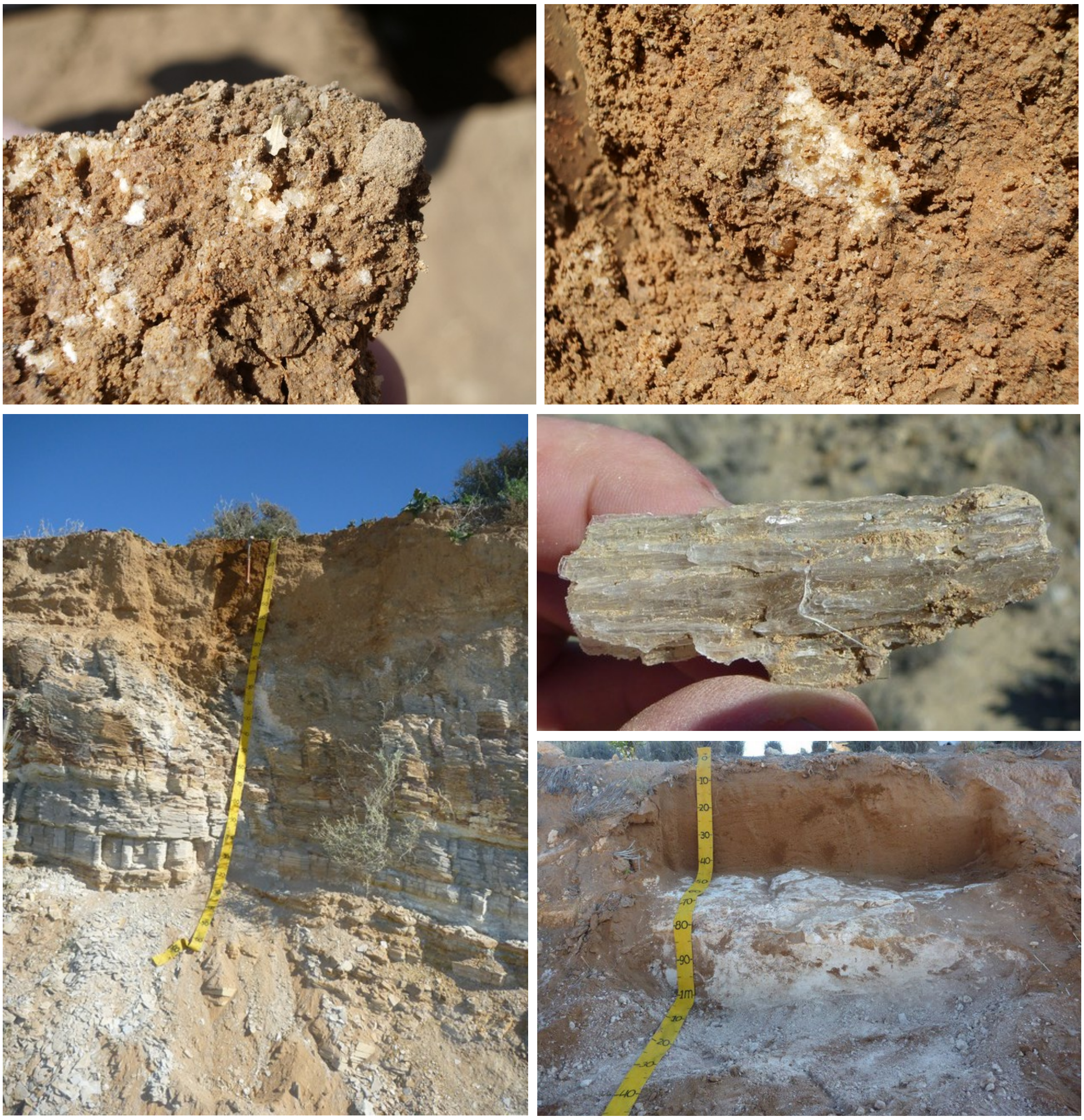

Figure 7.26 Gypsum accumulation under arid conditions

Figure 7.27 Desert pavement surfaces in arid conditions

Figure 7.28 Salt accumulation under arid conditions

Figure 7.29 Vertic soil properties in a low rainfall area as formed from dolerite (compare the images in Figures 7.13 and 7.14 as an indication of the same parent material in higher rainfall settings)

7.3.10 Redox Morphology as Determined by Rock Weathering Processes

The weathering of rock materials leads to transformation of Fe (and Mn) minerals through the weathering of primary minerals, with Fe (and Mn) incorporated in the mineral with varying degrees of colour expression, to the reductive mobilisation of Fe (and Mn) from the weathering rock zones into soil zones with a subsequent oxidative precipitation as high chroma secondary minerals (**Figures 7.30** and **7.31**). In these situations the outer edges of the rocks often yield the most concentrated zones of oxidised minerals (refer also to **Figure 7.15** for Mn translocation in weathering rock). However, due to the large inherent variability, the Fe and Mn accumulation may also occur within planes of weathering within the rock matrix.

Weathering rock profiles are often associated with bleached soil materials as overlying layers or as tongues of weathering into the underlying rock (**Figures 7.31** and **7.32**).

Figure 7.30 Weathering rock examples with Fe translocation within the rock and soil matrix

Figure 7.31 Weathering profiles in granite in the form of tongues of bleached material and zones of distinct translocation and accumulation of Fe

Figure 7.32 Weathering profiles in shale with bleaching and Fe removal due to soil formation within the upper zones and the inherent parent material colour in the lower zones

Variation in geological materials, such as dolerite intrusions into shale or sandstone material, yield conditions of variable Fe content, redox buffering, weathering rates and redox morphology expression. Very distinct examples of these are provided in **Figure 7.33** where the soil colour and redox morphology differs drastically between the original sandstone / shale parent materials and the more recently intruded, but more readily weathered, dolerite material.

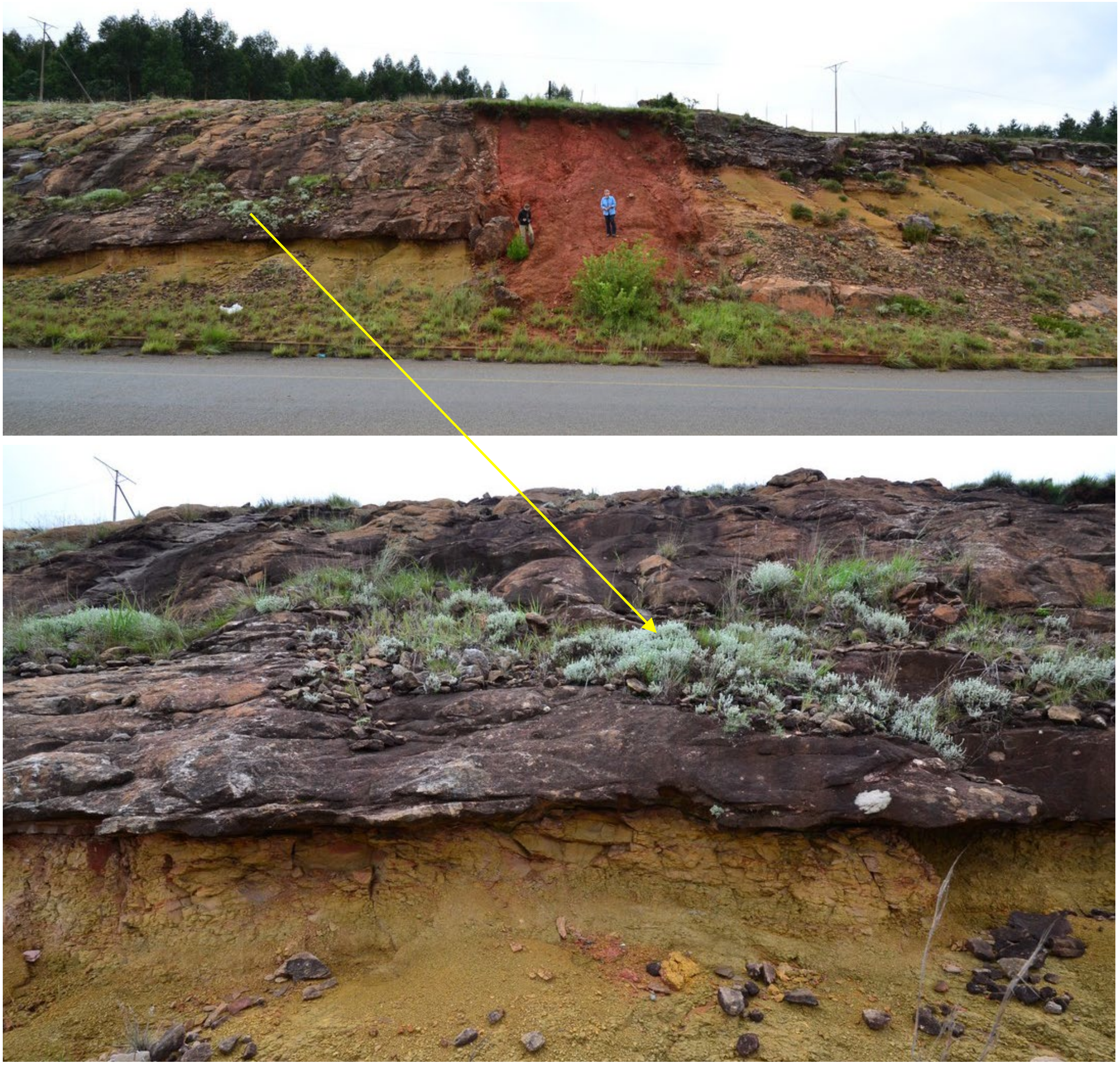

Figure 7.33 In-situ sandstone (resistant upper layer) and shale (weathered lower layer) materials with a distinct dolerite pipe intrusion (weathered to red soil) in the centre of the top image (note the dip of the left-hand side layers compared to the layers on the right-hand side of the intrusion)

7.3.11 Redox Morphology as Determined by Landscape Age and Historic Climate Change

The South African landscape is very old and has undergone a number of climatic changes in the past number of millions of years. For a detailed discussion on these aspects refer to Partridge and Maud (1987), Partridge (1998) and Partridge, Botha and Haddon (2006). It is therefore important to note that the landscape and its associated soils exhibit evidence of the historic wetter climatic conditions. There is debate in the scientific community about the expression of redox morphology and whether these expressions are in phase with the current climate with Le Roux and du Preez (2006) indicating that there is a correlation. Whereas there is little debate surrounding morphology that can alter (such as mottles and bleaching) the debate is not clear regarding the persistence of cemented materials such as hard plinthite and extensive occurrence of concretions. The presence of the latter cannot be assigned only to current climatic conditions as the resistance to weathering of these materials leads to persistence in the landscape after climate change – especially if the recent changes are towards more arid conditions. A distinct example of such persistence is the presence of hard plinthite material under red apedal B horizons – an aspect that was considered to be improbable based soil forming principles by several workers. It is important to note however that the presence of such materials, albeit not caused by the current climate, still play a distinct role in the physical and chemical functioning of the soils and as such have to be classified and assessed according to standard protocols. However, whereas these materials may exhibit redox morphology of wetter historical climates it is critical that their role and genesis be assessed for the purpose of determining whether an area is a wetland (as contemplated in the NWA) or not.

A distinct example of such a conundrum is located north of Pretoria in the Moeka area. A separate detailed case study of this site is available from the author. In summary, the site is characterised by vertic soils with widespread G horizon subsoils. The soils are of the Rensburg form and as such the wetland guidelines (DWAF, 2005) indicate that these are "permanent wetland soils". The vegetation however is dry bushveld originally but now exhibiting wetland vegetation due to the additional water (**Figures 7.34** and **7.35**). With subsequent changes and increases in the water dynamics of the Soshanguve urban area, water has been released on a regular basis onto the soils on the specific site with a wetland signature developing over the past ten years to the detriment of the original land owners that used the land for agricultural activities. The presence of the wetland leads to a "compliance conundrum" in terms of what the remedy may be for the land owners who have been deprived of their land use rights through the development of the wetland. In this case the assessment of the wetland conditions have to take into account the soils that have formed during wetter periods in the geological past but that have not exhibited such conditions during the recent human settlement history of the area.

Figure 7.34 Dry bushveld vegetation on structured soils making way for wetland vegetation due to urban water runoff

Figure 7.35 Historical aerial photograph (left: 1972) indicating agricultural holdings as contrasted with a Google Earth image (right: 2015) indicating a very large wetland vegetation signature across the agricultural holding area

7.4 LANDSCAPE APPLICATIONS – THE IDEALISED CATENA

7.4.1 The Catena Concept

Here it is important to take note of the "catena" concept. This concept is one of a topographic sequence of soils in a homogenous geological setting where the water movement and presence in the soils determine the specific characteristics of the soils from the top to the bottom of the topography. **Figure 7.36** illustrates an idealised topographical sequence of soils in a catena for a quartz-rich parent material. Soils at the top of the topographical sequence are typically red in colour (Hutton and Bainsvlei soil forms) and systematically grade to yellow further down the slope (Avalon soil form). As the volume of water that moves through the soil increases, typically in midslope areas, periodic saturated conditions are experienced and consequently Fe is reduced and removed in the laterally flowing water.

In the event that the soils in the midslope positions are relatively sandy, the resultant soil colour will be bleached or white due to the colour dominance of the sand quartz particles. The soils in these positions are typically of the Longlands and Kroonstad forms. Further down the slope there is an accumulation of clays and leaching products from higher lying soils and this leads to typical illuvial and clay rich horizons. Due to the regular presence of water the dominant conditions are anaerobic and reducing and the soils exhibit grey colours often with bright yellow and grey mottles (Katspruit soil form). In the event that there is a large depositional environment with prolonged saturation soils of the Champagne form may develop (typical peat land). Variations on this sequence (as is often found on the Mpumalanga Highveld) may include the presence of hard plinthic materials instead of soft plinthite with a consequent increase in the occurrence of bleached soil profiles. This sequence of soils and soil colours is considered a textbook example of the juxtaposition of soil colours as indicative redox and redox morphology gradients.

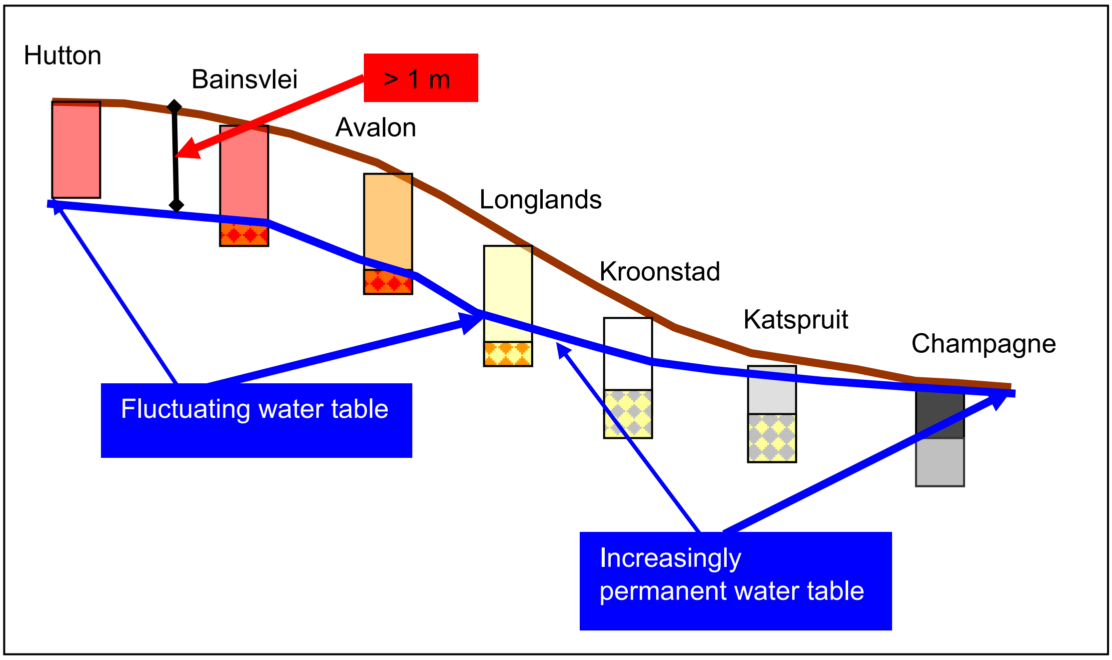

Figure 7.36 Idealised catena on a quartz rich parent material

7.4.2 Convex Versus Concave Landscapes in an Idealised Catena

An additional factor of variation in all landscapes is the shape of the landscape along contours (referred to a "plan curvature"). Landscapes can be either concave or convex, or flat. The main difference between these landscapes lies in the fact that a convex landscape is essentially a watershed with water flowing in diverging directions with a subsequent occurrence of "dryer" soil conditions. In a concave landscape water flows in converging directions and soils often exhibit the wetter conditions of "signs of wetness" such as grey colours, organic matter and subsurface clay accumulation. **Figure 7.37** presents the difference between these landscapes in terms of typical soil forms encountered in an idealised catena. In the convex landscape the subsurface flow of water removes clays and other weathering products (including Fe) in such a way that the midslope position soils exhibit an increasing degree of bleaching and relative accumulation of quartz (E horizons).

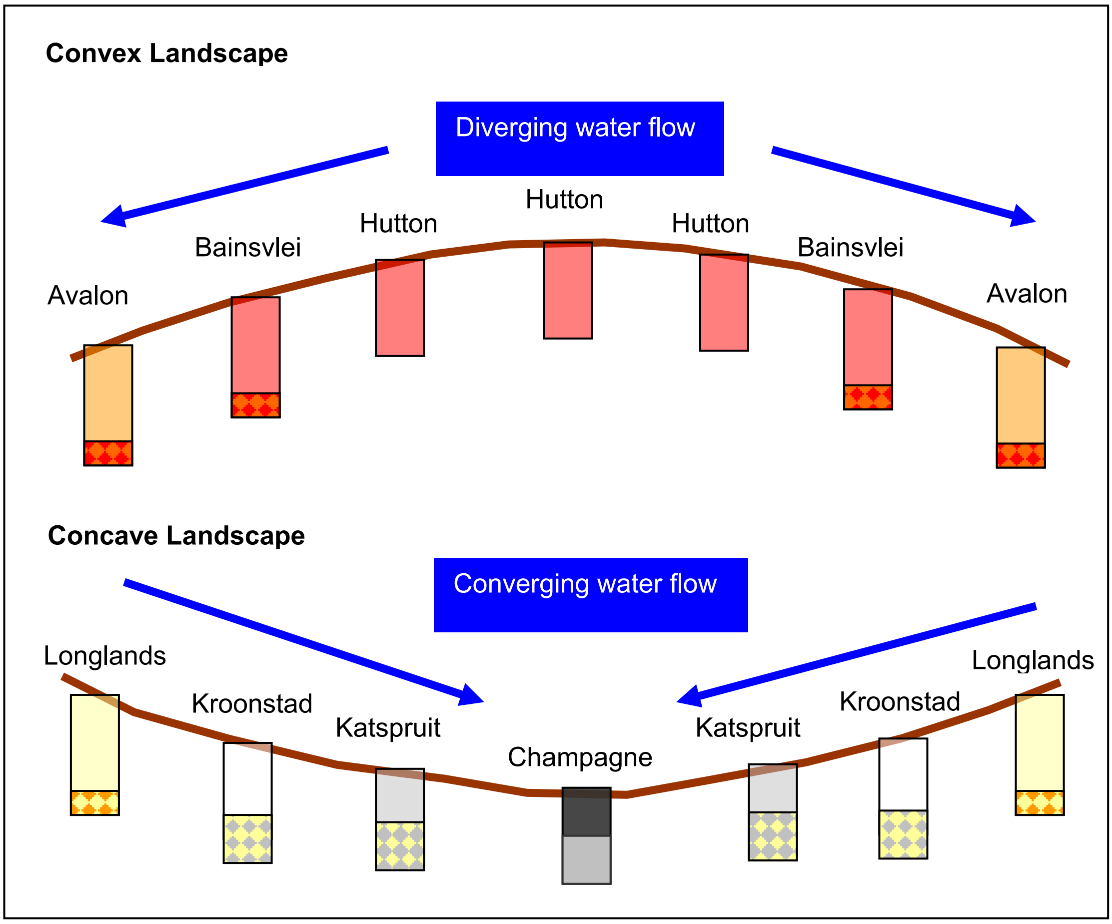

Figure 7.37 Schematic representation of the soils in convex and concave landscapes in an idealised catena

In the concave landscapes, clays and weathering products are transported through the soils into a zone of accumulation where soils start exhibiting properties of clay and Fe accumulation. In addition, coarse sandy soils in convex environments tend to be thinner due to the removal of sand particles through erosion and soils in concave environments tend to be thicker due to colluvial accumulation of material transported from upslope positions. Similar patterns are observed for other geological areas with the variation being consistent with the soil variation in the catena.

Often these concave and convex topographical environments occur in close proximity or in one topographical sequence of soils. This is often found where a convex upslope area changes into a concave environment as a drainage depression is reached (**Figure 7.38**). The processes in this landscape are the same as those described for the convex and concave landscapes above.

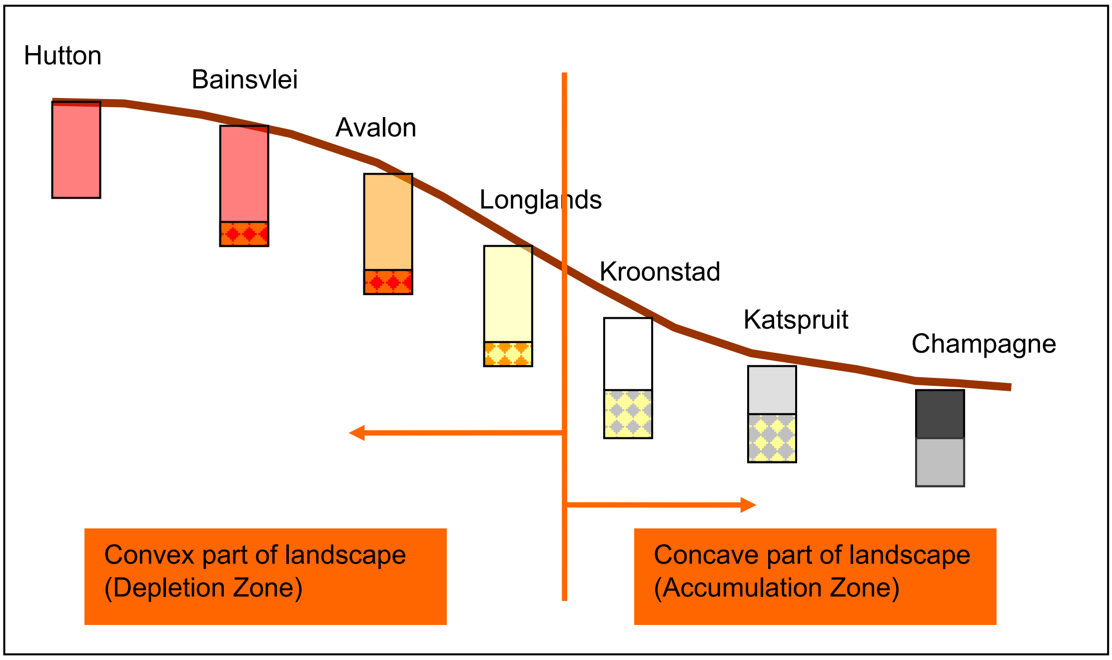

Figure 7.38 Schematic representation of the soils in a combined convex and concave landscape in an idealised catena

7.5 SUMMARY AND CONCLUSION

In the preceding sections, the wide range of redox morphology expression was discussed and elucidated in brief. A typical landscape catena, where the redox morphology expression follows an "ideal" wetland context, was elucidated.

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