Mobile: Sam - 072 437 1742
Mobile: Luke - 083 784 1997
Email: info@enviro-insight.co.za
Website: www.enviro-insight.co.za

Appendix F4:

Soils, Land Capability and Agricultural Potential

DRAFT REPORT

HIGH-LEVEL SOIL, LAND CAPABILITY, AGRICULTURAL POTENTIAL AND HYDROPEDOLOGY ASSESSMENT:

PROPOSED DUNBAR MINING PROJECT, MPUMALANGA PROVINCE

11 July, 2019

Compiled by:
J.H. van der Waals
(PhD Soil Science, Pr.Sci.Nat.)
Member of:
Soil Science Society of South Africa (SSSSA)

Accredited member of:
South African Soil Surveyors Organisation (SASSO)

Registered with:
The South African Council for Natural Scientific Professions
Registration number: 400106/08

Declaration

I, Johan Hilgard van der Waals, declare that:

- I act as the independent specialist in this application
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing
  - any decision to be taken with respect to the application by the competent authority; and
  - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- all the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of Section 24F of the Act.

J.H. VAN DER WAALS
TERRA SOIL SCIENCE

Executive Summary

The investigation site lies in the Bb4 land type on the Mpumlanga Highveld. The site conditions have been established through a dedicated investigation of with the data presented regarding the various phases. A dedicated discussion is provided regarding the statutory context of wetland assessment with a hydropedology application in opencast mining areas. A conceptual hydropedology functioning of the landscape has been established through the mapping of soils and interpretation of soil morphology. Detailed hydrological modelling cannot be conducted at this stage and will be possible with detailed soil assessment, analysis and modelling.

In order to provide a more detailed indication of water flow volumes and fluxes of water more detailed assessment is required with the integration of the data with geohydrological and surface hydrological modelling.

To summarise and emphasise:

The conceptual hydrological response for the site is derived from the soils that were identified and presented in **Figure 33**. The hydrological response is inferred from the soil properties and based on the concept discussed in section 5.6 and illustrated in **Figure 7**. The hydrological functioning of the areas that are provided in **Table 3** yield the following:

1. Recharge Zones: The dryland crop production areas function as recharge zones with lateral flow of water occurring at depth in the soils. Surface runoff occurs during high intensity rainfall events that exceed the infiltration capacity. A significant intercept occurs during the growing season with crop water use.
2. Deep Interflow Zones: Fractured rock and deep plinthic horizons represent interflow zones.
3. Shallow Interflow Zones: E horizons underlain by higher clay content soil horizons represent shallow interflow zones with intercept by wetland vegetation.
4. Responsive Soil Zones: Soil with high clay content in low lying landscape positions represent response areas where interflow water approaches the land surface or flows out onto the land surface at times. These zones are characterised by seasonal and permanent wetland vegetation depending on the duration of later flow contributions from the landscape.

The conceptual hydrological response for the site discussed above yields that the impacts of opencast mining, when viewed in the context of the discussion in section 5.12.1 (and illustrated in **Figure 16**) will be as follows:

1. Recharge Zones: If recharge zone soils are mined the implication will be a change in recharge characteristics of the landscape and severing of water flow paths feeding interflow (both shallow and deep) and responsive soil areas. The nett effect will be a removal of water from the system until the mine pit fills up and starts decanting. This will yield a variation in flow regime and a degradation of water quality due to acid mine drainage (AMD). The duration of the impact will depend on a range of factors that can only be modelled in the geohydrological investigation.

2. Deep Interflow Zones: The opencast mining of deep interflow zones will have a similar impact as discussed under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
3. Shallow Interflow Zones: The opencast mining of shallow interflow zones will have a similar effect to the discussion under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
4. Responsive Soil Zones: Responsive soil areas are often not mined as these occur within wetlands and watercourses with associated buffers and floodlines precluding mining developments. However, with the water feed for the response having been severed through mining of the recharge and interflow soils the responsive areas cease exhibiting the natural background condition response.

The practical implications of the above impacts are the following:

1. Arbitrary buffers on responsive areas soils (read “wetlands” and “watercourses”) do not have any effect on the protection of the water resource. This aspect renders the concept of a buffer moot since it has no practical application or benefit in opencast coal mining areas.
2. The protection of flow parameters in landscapes that undergo opencast coal mining is also a moot point as the flow is drastically altered through the severing of all the flow paths and recharge and storage characteristics of the landscape. The re-establishment of flow can only happen during the rehabilitation phase – if properly planned. However, during this phase the implementation of plans to deal with AMD and altered flow regimes and water quality is critical in order to regain some of the original flow and water dynamics in the landscape.

TABLE OF CONTENTS

HIGH-LEVEL SOIL, LAND CAPABILITY, AGRICULTURAL POTENTIAL AND HYDROPEDOLOGY ASSESSMENT REPORT: PROPOSED DUNBAR MINING PROJECT, MPUMALANGA PROVINCE

1. INTRODUCTION

1.1 TERMS OF REFERENCE

Terra Soil Science was appointed by **Enviro Insight** to conduct a high-level soil, land capability and agricultural potential assessment of the proposed Dunbar Coal Mining Project in the Mpumalanga Province. The focus of the investigation is to address aspects that include wetland distribution and functioning, landscape hydropedology and impacts of the mining activities and site development on the hydrological functioning of the wetlands and watercourses.

1.2 AIM OF THIS REPORT

The aim of this report is to provide a perspective on the interaction between landscape, soil and wetland / watercourse characteristics and its application in an agricultural setting earmarked for coal mining. This is to be done through the description and contextualisation of the hydropedology of the site, description of the historical and future hydrological impacts and to provide specific management recommendations regarding the management of the site during and after mining.

1.3 DISCLAIMER

This report was generated under the regulations of NEMA (National Environmental Management Act) that guides the appointment of specialists. The essence of the regulations are 1) independence, 2) specialisation and 3) duty to the regulator. The independent specialist has, in accordance with the regulations, a duty to the competent authority to disclose all matters related to the specific investigation should he be requested to do such (refer to declaration above).

It is accepted that this report can be submitted for peer review (as the regulations also allow for such). However, the intention of this report is not to function as one of several attempts by applicants or competent authorities to obtain favourable delineation outcomes. Rather, the report is aimed at addressing specific site conditions in the context of current legislation, guidelines and best practice with the ultimate aim of ensuring the conservation and adequate management of the water resource on the specific site.

Due to the specific legal liabilities wetland specialists face when conducting wetland delineations and assessments this author reserves the right to, in the event that this report becomes part of a delineation comparison exercise between specialists, submit the report to the competent authorities, without entering into protracted correspondence with the client, as an independent report.

1.4 METHODOLOGY

The report was generated through:

1. The collection and presentation of baseline land type and topographic data for the site;
2. The thorough consideration of the statutory context of wetlands assessment, the process of wetland delineation and land capability / agricultural potential assessment;
3. The identification of water related landscape parameters (conceptual and real) for the site;
4. Aerial photograph interpretation of the site;
5. Focused soil and site survey in terms of soil properties as well as drainage feature properties; and
6. Presentation of the findings of the various components of the investigation.

2. SITE LOCALITY AND DESCRIPTION

2.1 SURVEY AREA BOUNDARY

The site lies between 25° 54' 54" and 25° 59' 03" south and 29° 27' 06" and 29° 30' 53" east approximately 20 km west of the town of Hendrina in the Mpumalanga Province (**Figure 1**).

2.2 REGIONAL GEOLOGY

The regional geology, as inferred from the 1:250 000 geological map data of the area (Council for Geoscience), consists of fine to coarse-grained sandstone, shale and coal seams (Vryheid formation), with remnants of a network of dolerite sills, sheet and dykes, mainly intrusive into the Karoo Supergroup (Karoo Dolerites). To the south of the site massive porphyritic rhyolite and pyroclastic rocks (Rooiberg) occur.

2.3 LAND TYPE DATA

Land type data for the site was obtained from the Institute for Soil Climate and Water (ISCW) of the Agricultural Research Council (ARC). 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). The soil data was interpreted and re-classified according to the Taxonomic System (Soil Classification Working Group, 1991).

The site falls into the **Bb4** land type (Land Type Survey Staff, 1972 - 2006) with **Figure 2** providing the land type distribution around the site. A detailed description and explanation of the characteristics of the specific land types is provided in sections 5.6 and 5.7. Ba land types denote areas dominated by plinthic soils with dominantly red apedal horizons overlying the plinthic horizons and Bb land types denote areas similar to the above but dominated by yellow and bleached soils.

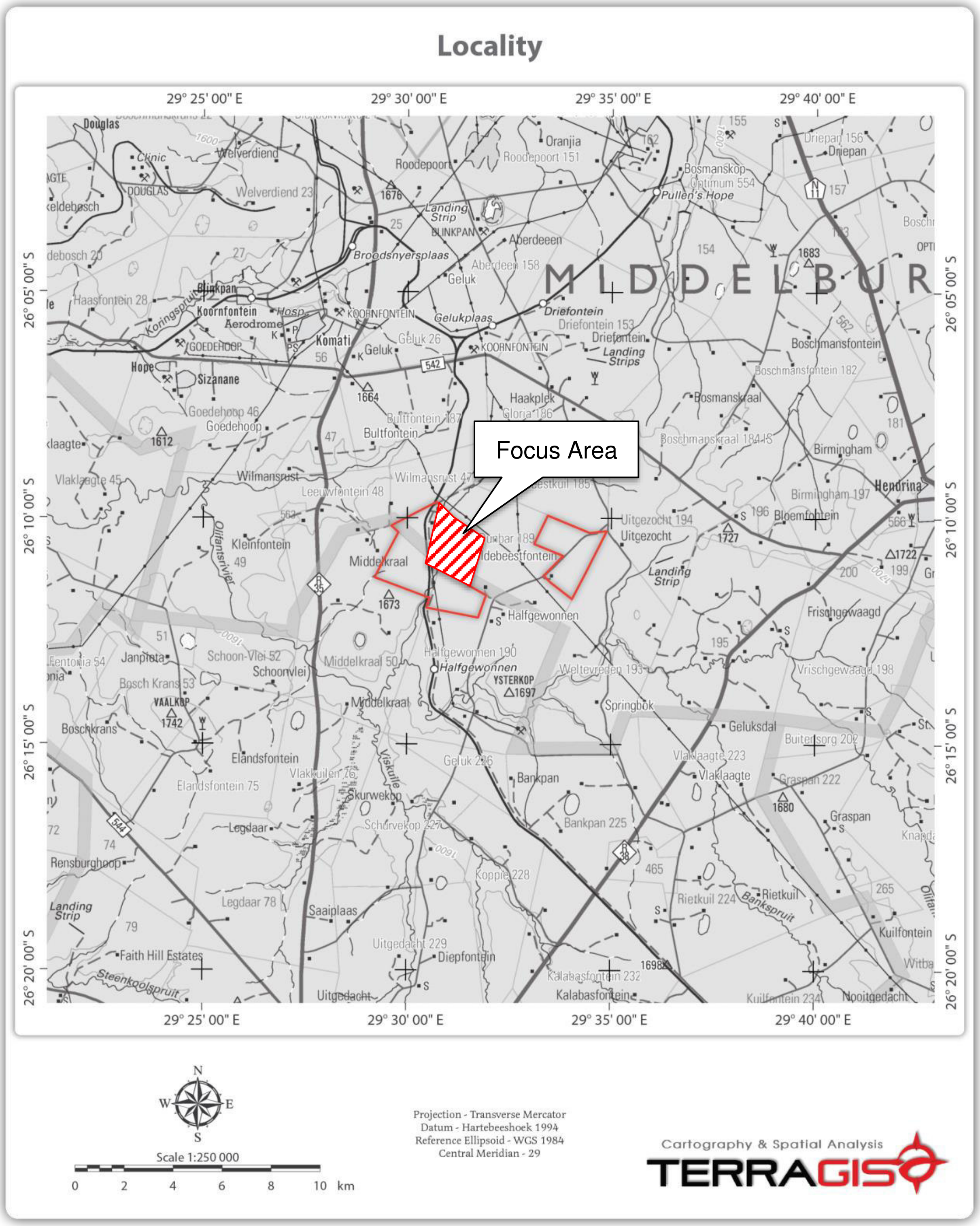

Figure 1 Locality of the survey site and focus area

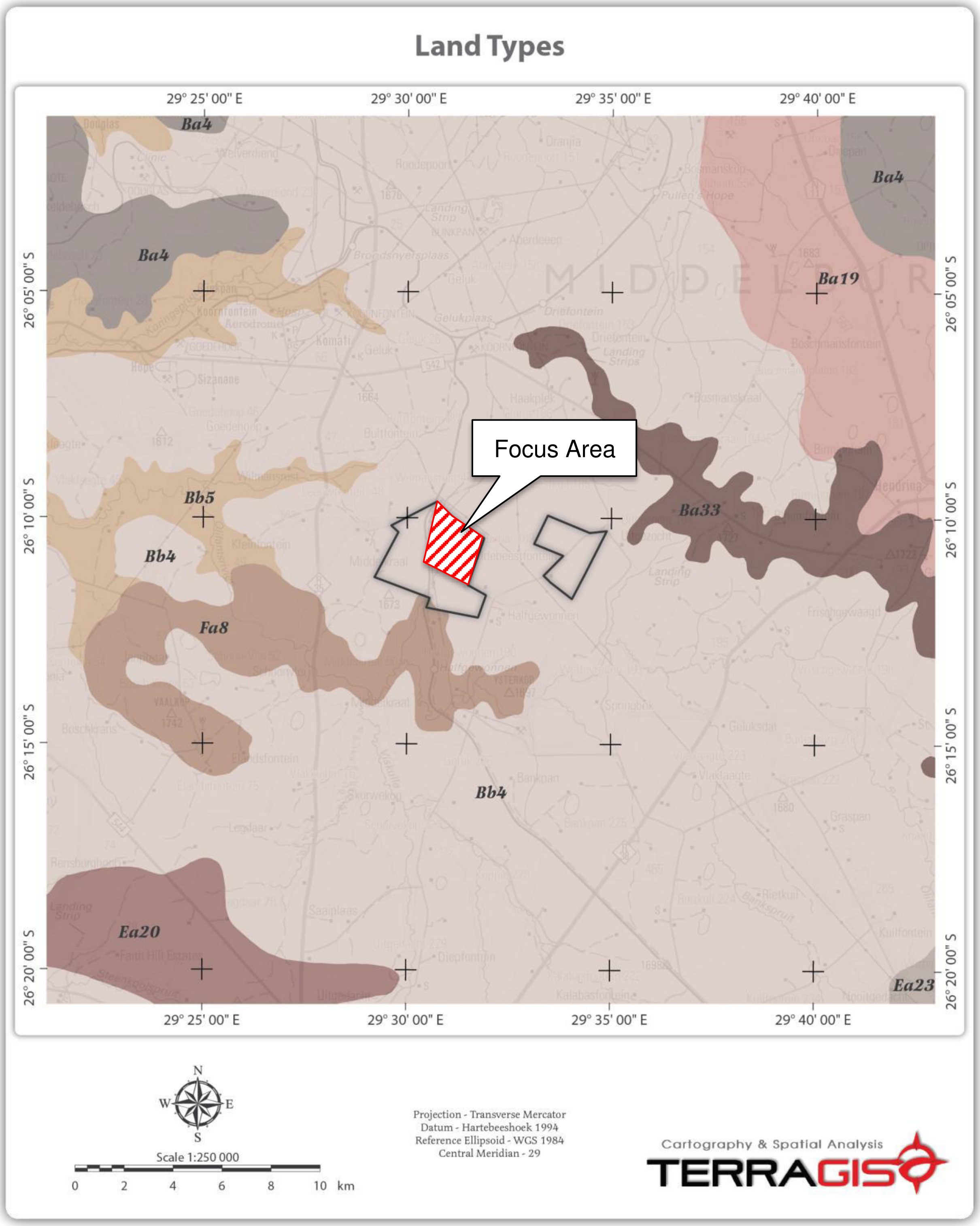

Figure 2 Land type map of the survey site and surrounding area

2.3 LAND USE

The current land use on the survey site consists of mix of dryland agriculture and grazing. The land use is evident from the satellite image in **Figure 3**.

Figure 3 Satellite image of the focus area survey site

2.4 TOPOGRAPHY

The topography of the site is predominantly flat undulating with a west-north-westerly aspect. A distinct watercourse and associated valley is evident in the western section. The contours for the site were interpreted to generate a digital elevation model (DEM) (**Figure 4**).

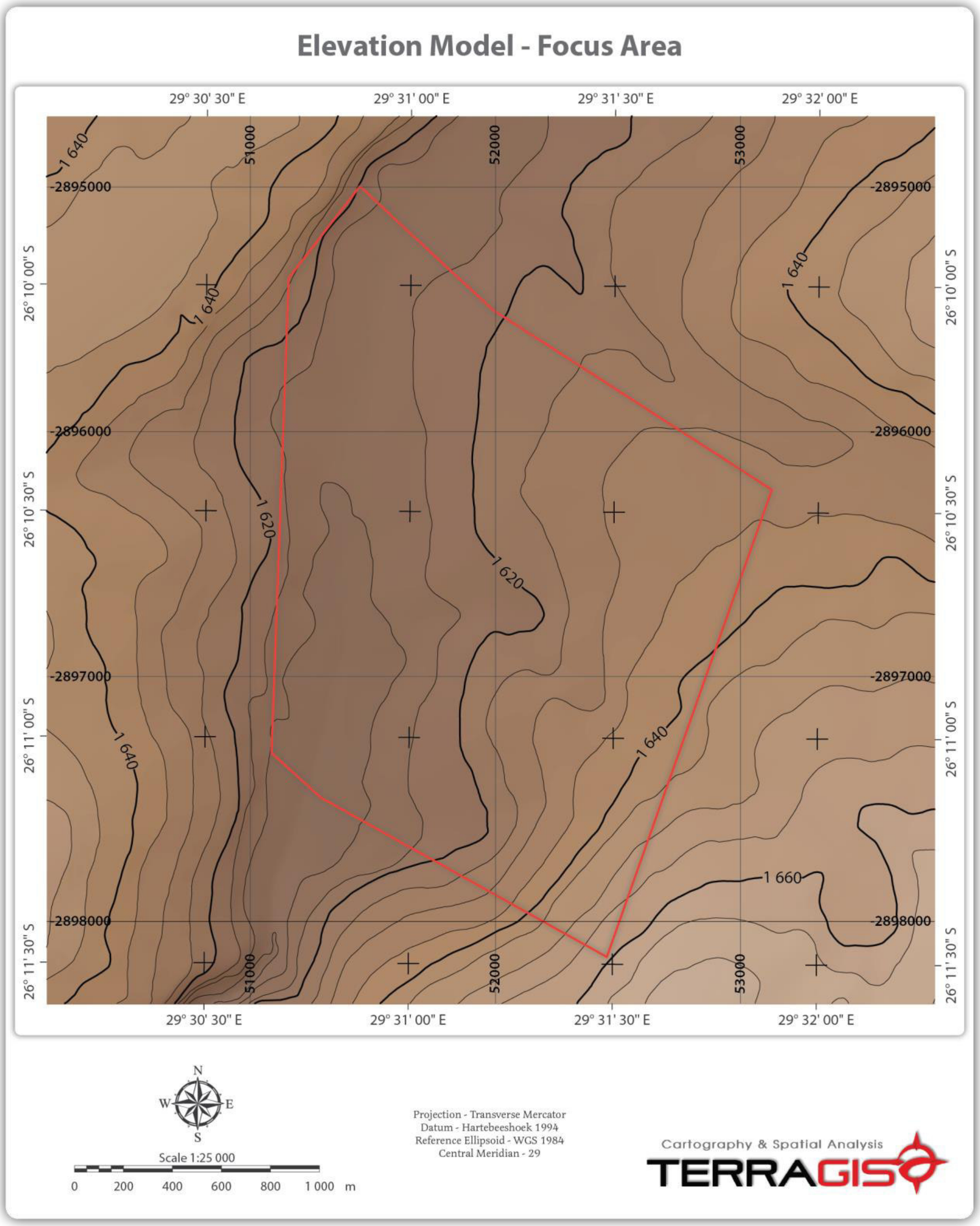

Figure 4 DEM of the survey site

3. PROBLEM STATEMENT

During applications for mining licenses many different specialist investigations are conducted. The Department of Water and Sanitation (DWS) has indicated that in many cases these various specialist studies do not necessarily integrate seamlessly when considered for the purposes of water use licence applications (WULA). During several dedicated and focussed workshops it has been postulated that an integration of the water related aspects of the various reports could be integrated within a "hydropedology" assessment where the focus is on the management of water for the purpose of maintaining wetland and surface water processes. This is a challenging exercise as many of the feeding mechanisms of wetlands or watercourses are hidden under the soil surface for large parts of many landscapes. The discussion below focuses on the statutory and biophysical context of this challenge linked to the assessment of agricultural potential and land capability parameters. The aim is therefore on the integration between the current wetland statutory context and related aspects of the NWA ito water quality and supply within an agricultural / land capability context.

4. STATUTORY CONTEXT

The following is a brief summary of the statutory and practical context of wetland delineation and assessment as well as agricultural potential assessment. Where necessary, additional comment is provided on problematic aspects or aspects that, according to this author, require specific emphasis.

4.1 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."

4.2 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;”

4.3 THE WETLAND DELINEATION GUIDELINES

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). 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 50cm 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 MacVicar et al., 1991) are listed as indicative of permanent, seasonal and temporary wetland zones.
- Soil Wetness Indicator. Certain soil colours and mottles are indicated as colours of wet soils. The guidelines stipulate that this is the primary indicator for wetland soils. (Refer to the guidelines for a detailed description of the colour indicators.) 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 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. The applicability of these guidelines in the context of the survey site will be discussed in further detail later in the report.

Due to numerous problems with the delineation of wetlands there are a plethora of courses being presented to teach wetland practitioners and laymen the required techniques. Most of the courses and practitioners focus on ecological or vegetation characteristics of landscapes and soil characteristics are often interpreted incorrectly due to a lacking soil science background of these practitioners. As such this author regularly presents, in conjunction with a colleague (Prof. Cornie van Huysteen) from the University of the Free Sate, a course on the aspects related to soil classification and wetland delineation.

4.4 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).

4.4.1 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."

4.4.2 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 unimpacted characteristics of a water resource. Reference conditions quantitatively describe the ecoregional type, specific to a particular water resource."

4.4.3 The Resource Directed Measures for Protection of Water Resources: Appendix W1 (Ecoregional Typing for Wetland Ecosystems)

Artificial modifiers are explained namely:

"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.“

4.4.4 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 present ecological state (PES) of the wetland was determined according to the method described in "APPENDIX W4: IER (FLOODPLAIN WETLANDS) PRESENT ECOLOGICAL STATUS (PES) METHOD" of the "Resource Directed Measures for Protection of Water Resources. Volume 4: Wetland Ecosystems" as published by DWAF (1999). However, the PES methodology already forms an adaptation from the methodology to assess palustrine wetlands. Hillslope seepage wetlands 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.

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

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, that lead to flow modifications. Important Note: 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. Important Note: 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.

Table 1 presents the scoresheet with criteria for the assessment of habitat integrity of palustrine wetlands (as provided in the RDM documentation).

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.

Important Note: The present ecological state (PES) determination is, as discussed earlier in the report, based on criteria originally generated for palustrine and floodplain wetlands. Seepage wetlands very rarely have the same degree of saturation or free water and consequently often do not have permanent wetland zones. These wetlands are therefore often characterised by seasonal or temporary properties and as such a standard PES approach is flawed. The existing criteria is provided below as is a comment on the applicability as well as proposed improvements.

Table 1 "Table W4-1: Scoresheet 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, railwaylines 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 speciesdue 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.		
Overutilisation 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." Comment: Although the description is wide it is very evident that seepage or hillslope wetlands do not become inundated but rather are fed by hillslope return flow processes. 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 hillslope 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 seepage water quality that can be natural but significantly different to exposed water bodies. The main reason for this being the highly complex nature of 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 hillslopes 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 on hillslopes 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 shoud be elucidated and contextualised.
- "Topographic Alteration: Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railwaylines 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 on hillslopes 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 shoud 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 on hillslopes 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 shoud 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."
- "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."
- "Overutilisation 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

4.4.5 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

4.5 WATER QUALITY MANAGEMENT

Sections 19 and 20 of the NWA deal with pollution and degradation aspects of water resources. Although these will not be discussed in further detail the essence is that pollution and degradation of resources should be prevented and the Act allows for the state to intervene and recover remediation costs if the land owner does not address the prevention and remediation.

4.6 AGRICULTURAL POTENTIAL BACKGROUND

The assessment of agricultural potential rests primarily on the identification of soils that are suited to crop production. In order to qualify as high potential soils they must have the following properties:

- Deep profile (more than 600 mm) for adequate root development,
- Deep profile and adequate clay content for the storing of sufficient water so that plants can weather short dry spells,
- Adequate structure (loose enough and not dense) that allows for good root development,
- Sufficient clay or organic matter to ensure retention and supply of plant nutrients,
- Limited quantities of rock in the matrix that would otherwise limit tilling options and water holding capacity,
- Adequate distribution of soils and size of high potential soil area to constitute a viable economic management unit, and
- Good enough internal and external (out of profile) drainage if irrigation practices are considered. Drainage is imperative for the removal (leaching) of salts that accumulate in profiles during irrigation and fertilization.

In addition to soil characteristics, climatic characteristics need to be assessed to determine the agricultural potential of a site. The rainfall characteristics are of primary importance and in order to provide an adequate baseline for the viable production of crops rainfall quantities and distribution need to be sufficient and optimal.

In the case where crop production is not possible due to soil or climatic constraints aspects such as grazing potential and carrying capacity is considered. Grazing capacity is mainly determined by vegetation characteristics of a site and would therefore have to be deduced from vegetation reports (that do address carrying capacity) or from dedicated discussions with farmers and land users. The combination of the above mentioned factors will be used to assess the agricultural potential of the soils on the site.

4.7 LAND CAPABILITY BACKGROUND AND CLASSIFICATION

4.7.1 Land Capability Classification – DAFF

Land capability refers to the specific land use and agronomic practices that a given piece of land is capable of in the context of the original land capability categories published in the USA in the 1960's. The land capability concept is a bit broader than the "land suitability" approach expounded by the FAO (Food and Agriculture Organisation of the UN) where the latter aims to pronounce on the suitability of a specific area of land for a specific "land utilization type" (LUT). In the more recent South African case for "land capability" the then Department of Agriculture, Forestry and Fisheries (DAFF) established a requirement for the classification of land based on the criteria provided in **Table 2**. These categories are not significantly different from the original concept but have been amended for the South African context.

Table 2 Land capability classes for assessment of land

Land Capability Class	Definition	Conservation Need	Use suitability
I	No or few limitations. Very high arable potential. Very low erosion hazard.	Good agronomic practice.	Annual cropping.
II	Slight limitations. High arable potential. Low erosion hazard.	Adequate run-off control.	Annual cropping with special tillage or ley (25%)
III	Moderate limitations. Some erosion hazards.	Special conservation practice and tillage methods.	Rotation of crops and ley (50 %).
IV	Severe limitations. Low arable potential. High erosion hazard.	Intensive conservation practice.	Long term leys (75 %)
V	Watercourse and land with wetness limitations.	Protection and control of water table.	Improved pastures or Wildlife
VI	Limitations preclude cultivation. Suitable for perennial vegetation.	Protection measures for establishment eg. Sod-seeding	Veld and/or afforestation
VII	Very severe limitations. Suitable only for natural vegetation.	Adequate management for natural vegetation.	Natural veld grazing and afforestation
VIII	Extremely severe limitations. Not suitable for grazing or afforestation.	Total protection from agriculture.	Wildlife

The assessment of land capability rests squarely on the assessment of soil properties for agricultural purposes as discussed in the previous section. These properties will therefore be used to determine the specific land capability class for the survey area.

4.7.2 Land Capability Classification – Chamber of Mines

The land capability classes above must not be confused with the classes required for the assessment of land for EIAs and mining licences by the Chamber of Mines. These classes are a simplification of the above namely 1) arable, 2) grazing, 3) wilderness and 4) wetland. It is critical to note here that the criteria for "wetland" in this classification are not specified as is the case for wetland delineation discussed earlier. In this regard it is often found that wetland delineation outcomes and land capability classifications of wetlands yield entirely different boundaries mainly due to the inclusion of large areas of grazing, arable and wilderness land in the definition of a wetland in the NWA.

4.8 SUMMARY AND PROPOSED APPROACH

When working in environments where the landscape and land use changes are significant (such as urban and mining environments) it is important to answer the following critical questions regarding the assessment and management planning for wetlands:

1. What is the reference condition?
2. What is the difference between the reference condition and the current condition and how big is this difference from a hydrological driver perspective?
3. What are the hydrological drivers (as a function of geology, topography, rainfall and soils) and what are the relative contributions of these drivers to the functioning of the wetland system?
4. What is the intended or planned land use in the wetland as well as terrestrial area and how will these developments impact on the hydrology of the landscape and wetlands?
5. How can the intended land use be plied to secure the best possible hydrological functioning of the landscape in terms of storm water attenuation, erosion mitigation and water quality?

The key to the generation of adequate information lies in the approach that is to be followed. In the next section an explanation about and motivation in favour of will be provided for a hydropedology assessment approach. Due to the detailed nature of the information that can be generated through such an approach it is motivated that all wetland assessments be conducted with the requirements of criminal law in mind. The main reason for this is the fact that many well-meaning administrative exercises often yield no tangible results due to the gap in terms of information that is required should there be a compliance process followed.

To Summarise:

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. 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.

5. CHALLENGES REGARDING WETLAND DELINEATION AND HYDROPEDOLOGY ASSESSMENTS IN PLINTHIC MINING ENVIRONMENTS FOR THE PURPOSE OF WETLAND REHABILITATION AND RE-ESTABLISHMENT

Disclaimer: The following section represents a discussion that I use as standard in describing the challenges regarding wetland delineation and management in plinthic mining environments. This implies that the section is verbatim the same as in other reports provided to clients and the authorities. Copyright is strictly reserved.

5.1 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 5**).

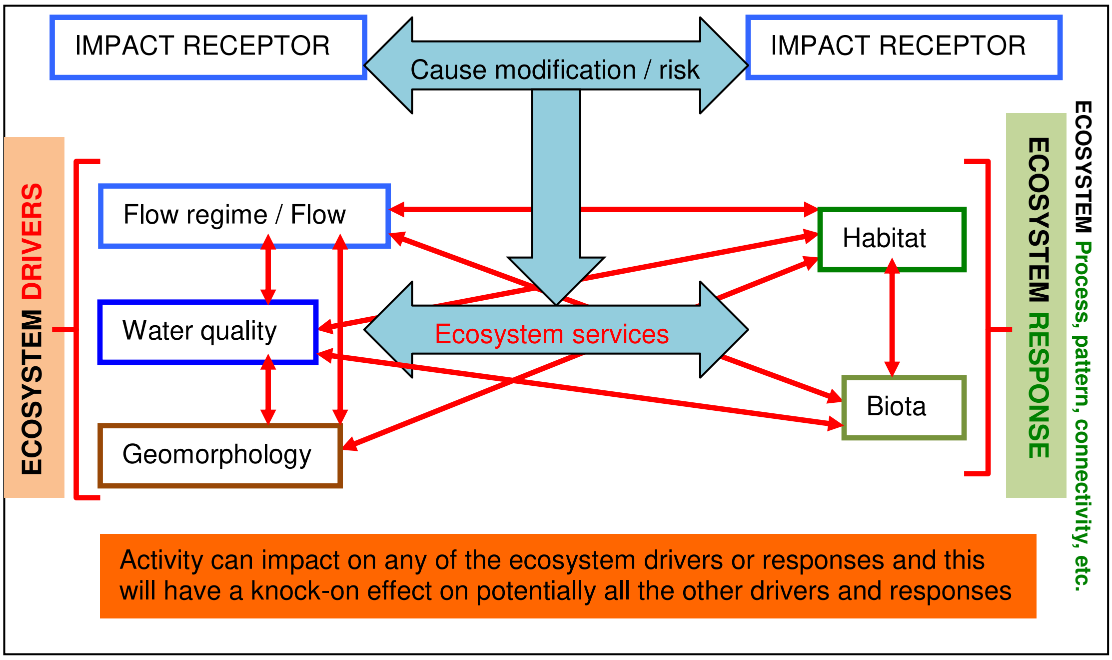

Figure 5 Ecosystem services drivers and responses (sourced from DWS)

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 5**). 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.

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.

5.2 SOIL AS A TOOL FOR LANDSCAPE CONTEXT AND HYDROLOGICAL DRIVER 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 subhumid 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.

5.3 RECOMMENDED ASSESSMENT APPROACH – HYDROPEDOLOGY INVESTIGATION

In order to discuss the procedures followed and the results of the hydropedology exercise it is necessary at the outset to provide some theoretical background on the discipline of hydropedology in the context of soil forming processes, soil wetness indicators, water movement in soils and topographical sequences of soil forms (catena). Plinthic environments are those where numerous lateral water flow mechanisms occur within a relatively shallow distance from the soil surface leading to the expression of mottles and fluctuating water tables within the soil profiles. The expression redox morphology in the soil profile is therefore the ideal/optimal indicator of hydropedological parameters in the landscape.

5.3.1 Hydropedology Background

The identification and delineation of wetlands rest on several parameters that include topographic, vegetation and soil indicators. Apart from the inherent flaws in the wetland delineation process, as discussed earlier in this report, the concept of wetland delineation implies an emphasis on the wetlands themselves and very little consideration of the processes driving the functioning and presence of the wetlands. One discipline that encompasses a number of tools to elucidate landscape hydrological 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.

Wetlands are merely those areas in a landscape where the morphological indicators point to prolonged or intensive saturation near the surface to influence the distribution of wetland vegetation. Wetlands therefore form part of a larger hydrological entity that they cannot be separated from.

The crux of a hydropedology assessment should be the accurate contextualisation of morphological properties of soils (used in describing and classification – pedology) as well as the physical properties that will determine the hydrological functioning of the soils.

5.3.2 Hydropedology – Proposed Approach

In order to provide detailed pedohydrological information both detailed soil surveys and hydrological investigations are needed. In practice these intensive surveys are expensive and very seldom conducted. However, with the understanding of soil morphology, pedology and basic soil physics parameters as well as the collection and interpretation of existing soil survey information, assessments at different levels of detail and confidence can be conducted. In this sense four levels of investigation are proposed namely:

1. Level 1 Assessment: This level includes the collection and generation of all applicable remote sensing, topographic and land type parameters to provide a “desktop” product. This level of investigation rests on adequate experience in conducting such information collection and interpretation exercises and will provide a broad overview of dominant hydropedological parameters of a site. Within this context the presence, distribution and functioning of wetlands will be better understood than without such information.
2. Level 2 Assessment: This level of assessment will make use of the data generated during the Level 1 assessment and will include a reconnaissance soil and site survey to verify the information as well as elucidate many of the unknowns identified during the Level 1 assessment.
3. Level 3 Assessment: This level of assessment will build on the Level 1 and 2 assessments and will consist of a detailed soil survey with sampling and analysis of representative soils. The parameters to be analysed include soil physical, chemical and mineralogical parameters that elucidate and confirm the morphological parameters identified during the field survey.
4. Level 4 Assessment: This level of assessment will make use of the data generated during the previous three levels and will include the installation of adequate monitoring equipment and measurement of soil and landscape hydrological parameters for an adequate time period. The data generated can be used for the building of detailed hydrological models (in conjunction with groundwater and surface hydrologists) for the detailed water management on specific sites.

For most wetland delineation exercises a Level 2 or Level 3 assessment should be adequate. For this investigation a Level 2 assessment was conducted.

Note: The dynamics of water movement in a soil profile and hillslope is too complex to address in detail here. However, the reader is referred to various investigation and publications provided below for further detail.

Publications list:

Bouwer, et al., (2015), Le Roux and du Preez (2006), Le Roux and du Preez (2008), Le Roux et al., (2015), Le Roux et al., (2011), Van Tol et al., (2013a), Van Tol et al., (2013b), Van Tol et al., (2010a), Van Tol et al., (2010b), Van Zijl et al., (2013), Van Zyl and Le Roux (2014), Van der Waals (2013), Van Huyssteen et al., (1997), Van Huyssteen et al., (2007), Van Huyssteen et al., (2009).

5.4 PEDOGENESIS

Pedogenesis is the process of soil formation. Soil formation is a function of five (5) factors namely (Jenny, 1941(:

- Parent material;
- Climate;
- Topography;
- Living Organisms; and
- Time.

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. 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 Fe and 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, 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.

5.5 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 where 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:

  $$\text{Gravitational potential} = \text{Gravity} \times \text{Height}$$

  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:

  $$I = Q/A.t$$

  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).

5.6 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 6** 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.

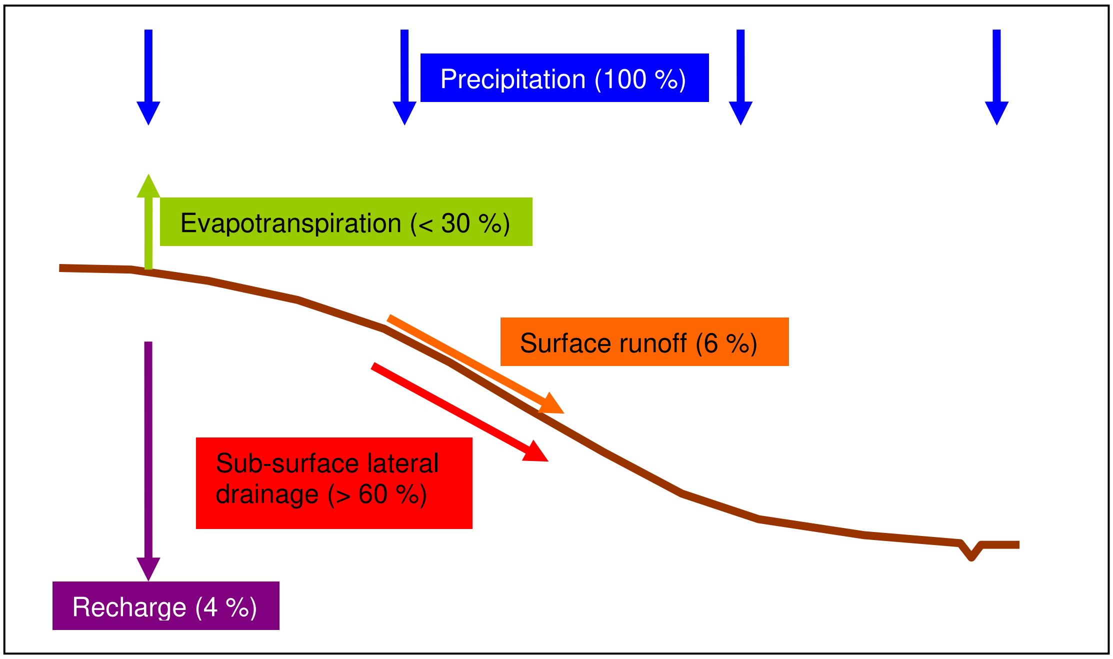

Figure 6 Idealised landscape with assumed quantities of water moving through the landscape expressed as a percentage of total precipitation (100 %).

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.

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 7** provides a schematic representation of the different flow regimes that are usually encountered.

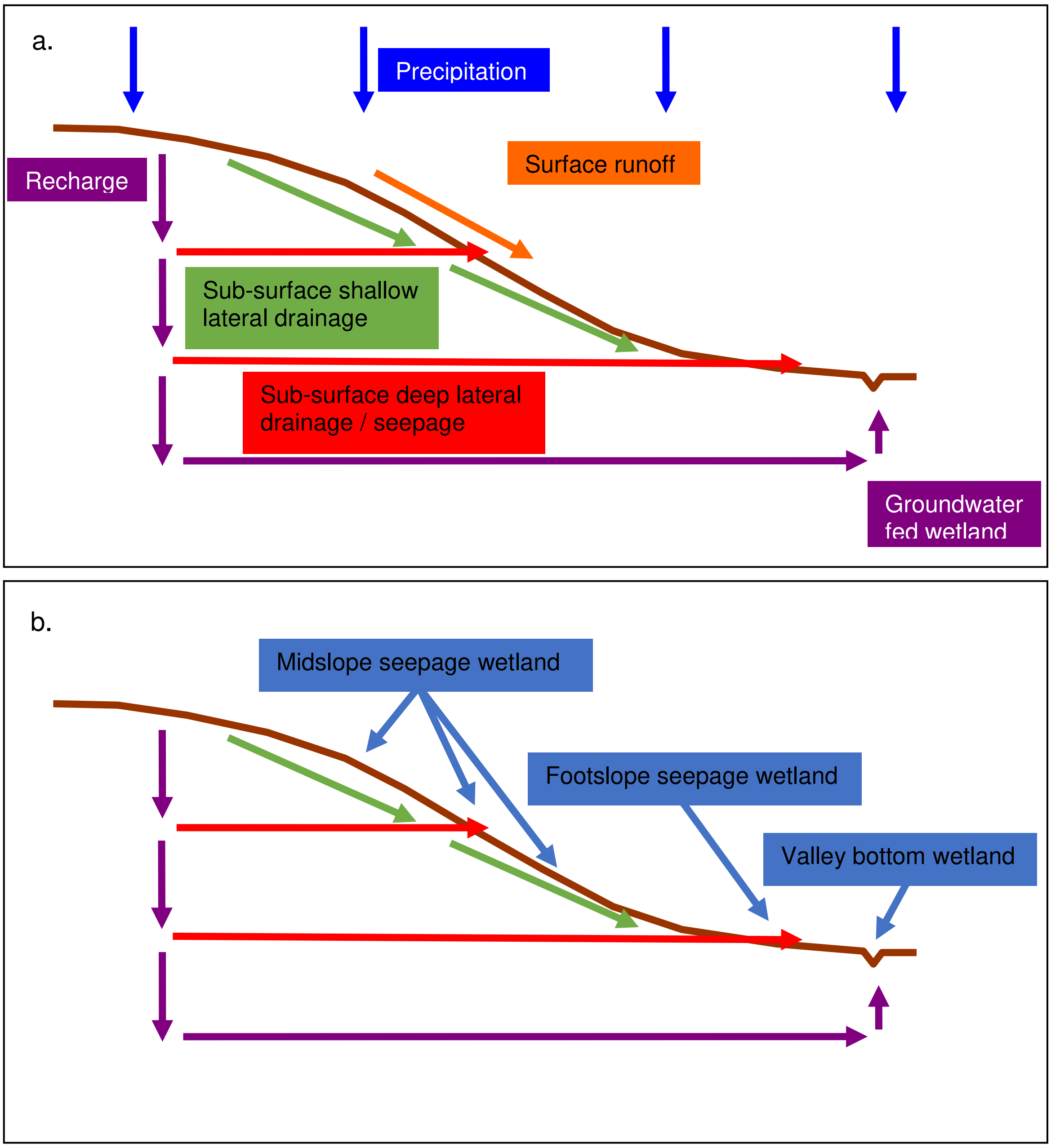

Figure 7 Different flow paths of water through a landscape (a) and typical wetland types associated with the water regime (b)

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.

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 8** 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.

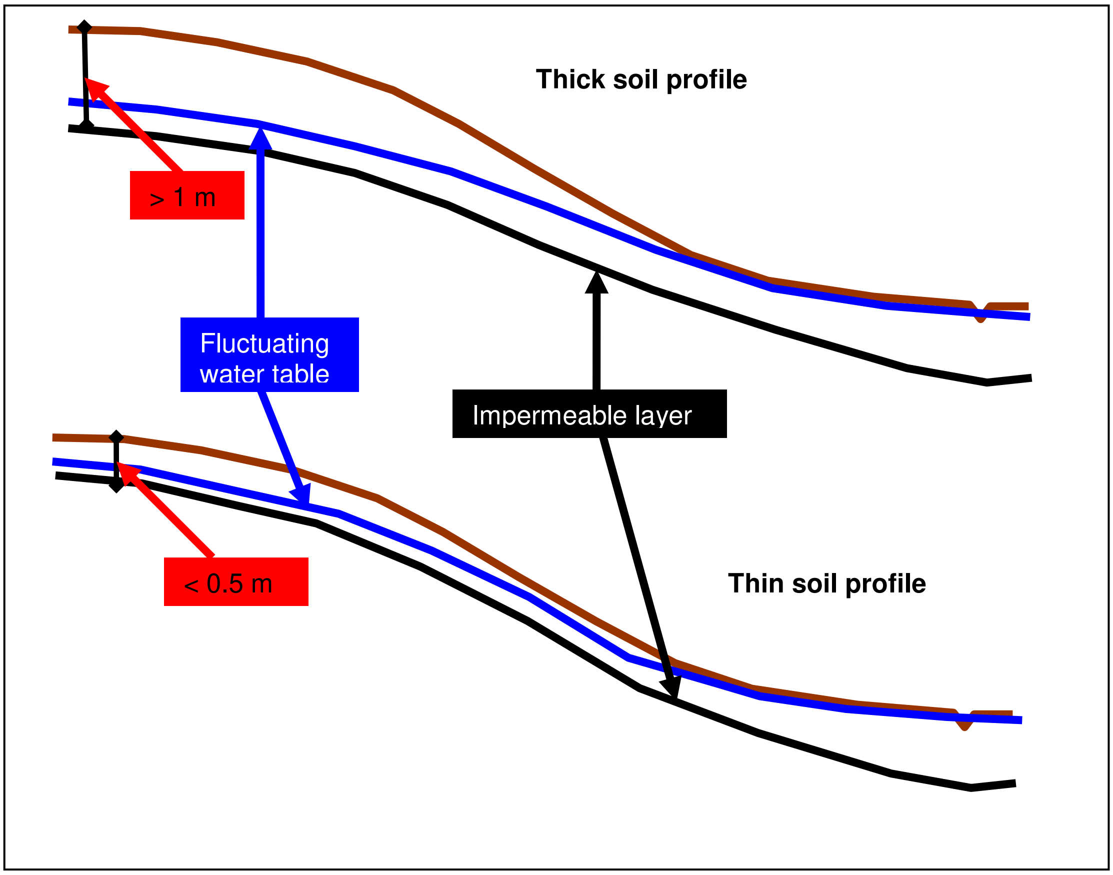

Figure 8 The difference in water flow between a dominantly thick and dominantly thin soil profile.

5.7 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 then 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. **Figure 9** provides a topographic wetness index (TWI) of a mining area in which free draining (linear features) and inwardly draining (circular features) are indicated. The blue lines indicate concentration of water flows. The implication of the two systems on rehabilitation planning will be discussed later in the report.

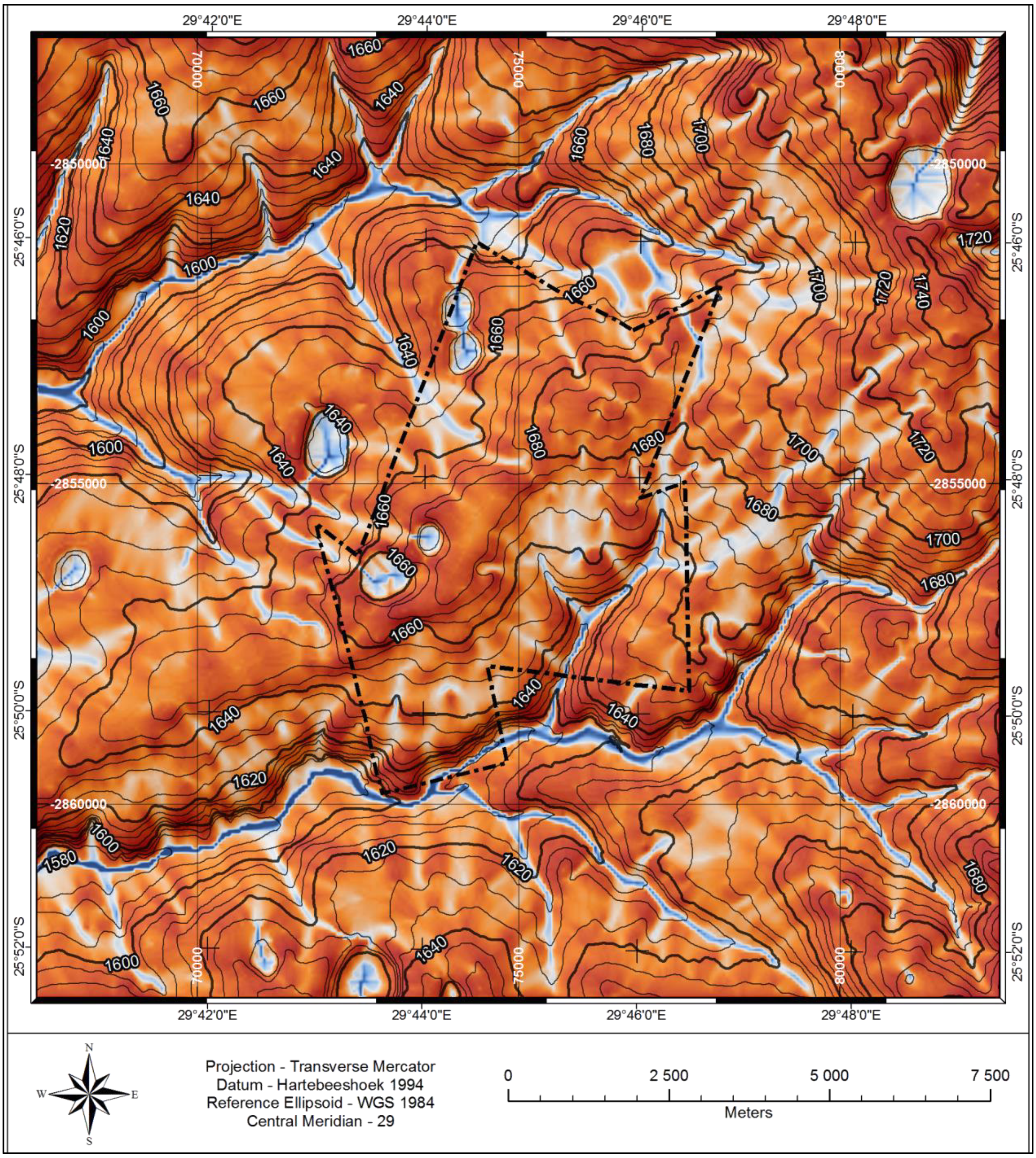

Figure 9 Topographic wetness index (TWI) of an area on the Mpumalanga Highveld indicating both free draining (linear) and inwardly draining (circular) features

The dominant hydrological functioning of the landscapes can be assumed to be very similar if only the side slopes are considered. **Figure 10** 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.

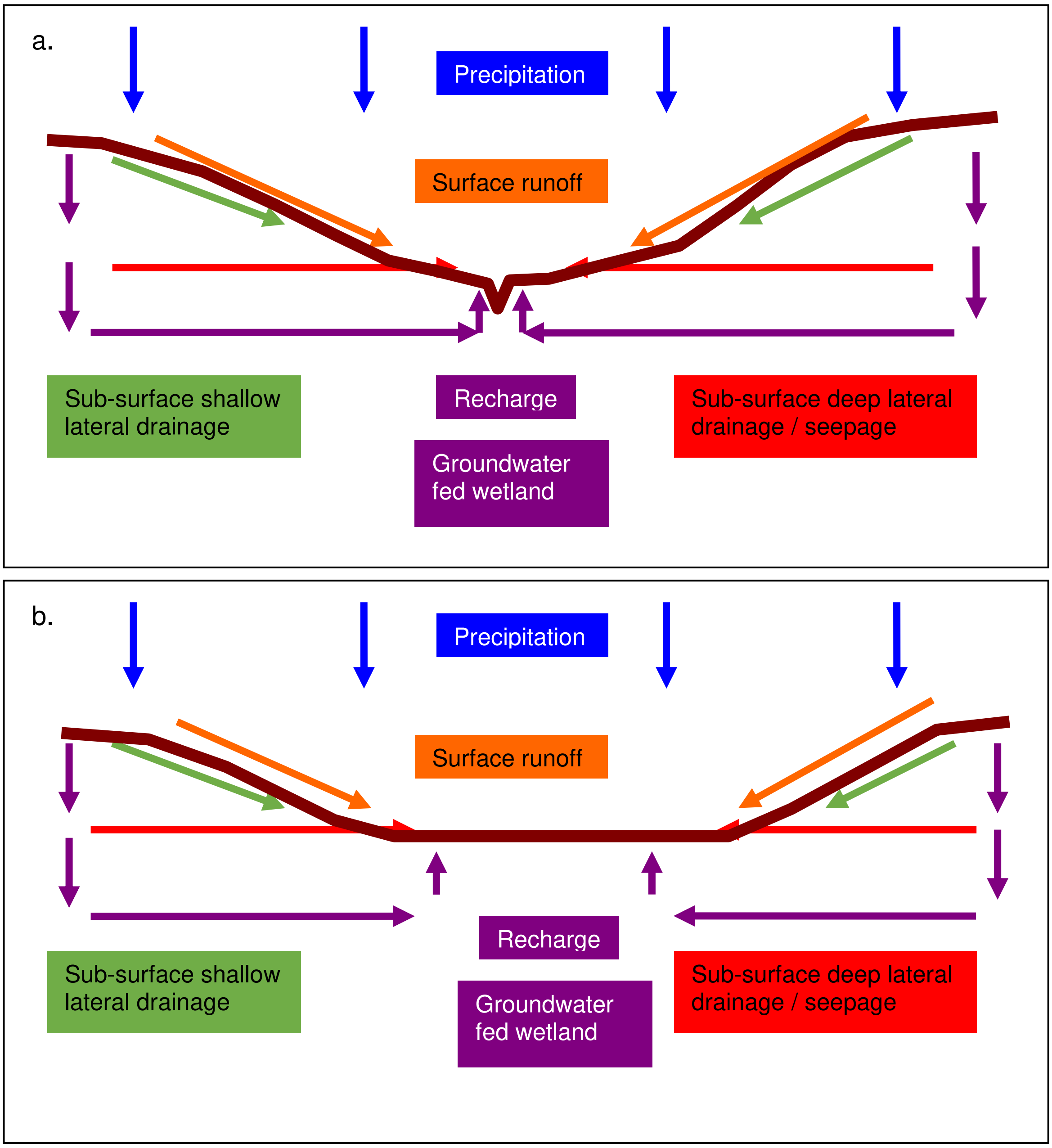

Figure 10 Similarity in flow paths for free draining (a) and inward draining (b) systems

5.8 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 11** 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. Extreme examples of such landscapes are discussed below.

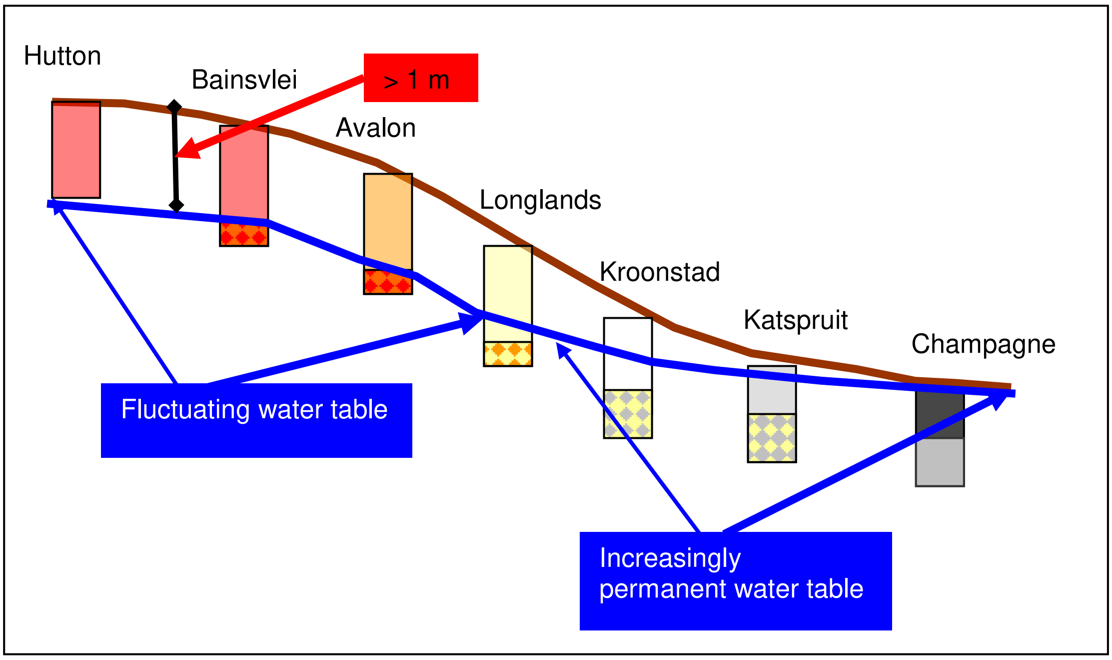

Figure 11 Idealised catena on a quartz rich parent material.

5.9 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 12** 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).

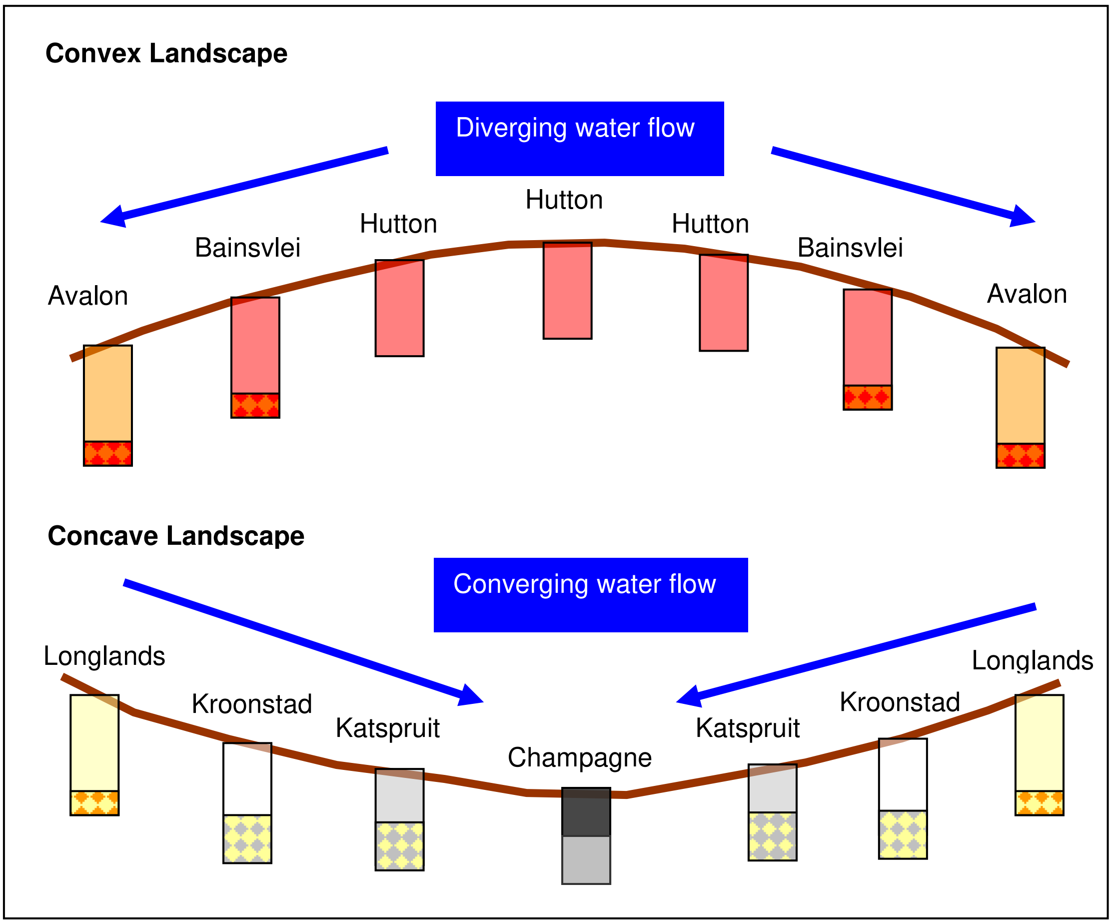

Figure 12 Schematic representation of the soils in convex and concave landscapes in an idealised catena

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 13**). The processes in this landscape are the same as those described for the convex and concave landscapes above.

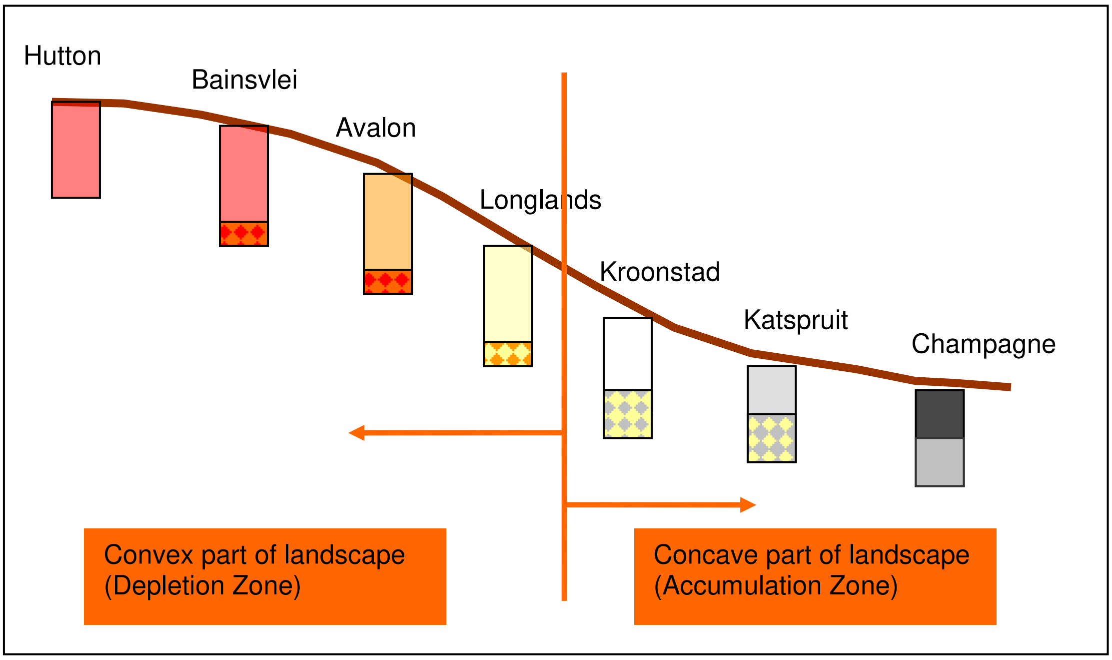

Figure 13 Schematic representation of the soils in a combined convex and concave landscape in an idealised catena

5.10 BA AND BB PLINTHIC CATENA

The plinthic catena specifically found on the Mpumalanga Highveld is dominated by Ba and Bb land types. The Ba land types denote areas where red soils dominate and are conceptually the same as the idealised catena described above. The Bb land types denote areas where yellow and bleached soils dominate (**Figure 14**). Additional variation is found in the form of soil depth as well as the extent of soft versus hard plinthic material occurrence.

Due to the emphasis placed on soil colour (and colours associated with wetness) in the wetland delineation guidelines (DWAF, 2005) the difference between the red and yellow/bleached soil dominated land types leads to a slight over representation of wetlands in the Bb land types as the bleached colours are used as wetland indicators. The difference is considered an artefact associated with a less intense influence of dolerite in certain landscapes. The subsequent exaggeration of wetland spatial extent in these landscapes is not considered to be significant in terms of the mining impacts discussed later in the report.

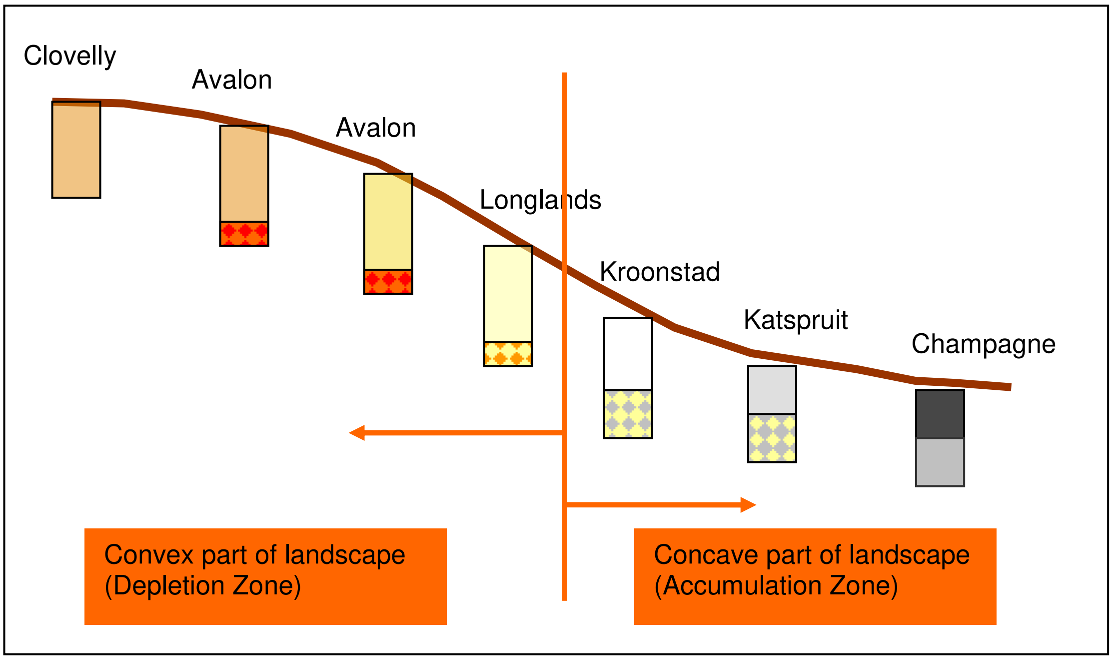

Figure 14 Schematic representation of the soils in a combined convex and concave landscape in an yellow and bleached soil dominated landscapes

5.11 WETLAND – TERRESTRIAL SOIL LINKAGES AND AGRICULTURAL POTENTIAL CONUNDRUM

The soils and landscape discussed in the previous sections can be divided into terrestrial and wetland soil areas (**Figure 15**). Although the main discussion in this document centres around wetlands and hydrological linkages it is important to note that the terrestrial area has 1) high agricultural potential and 2) functions as the recharge area for the wetlands. The conundrum in this discussion is evident when one considers the mining authorisation process often conducted by consultants / specialists and adjudicated by the specific competent authority. Due to the intense emphasis on wetlands it is found that wetland areas are 1) identified, 2) delineated, and 3) conserved with a buffer. The tragedy in the process lies in the fact that the terrestrial areas are often perceived to be the most impacted parts of the site (due to historical agricultural use, tillage and ecological alteration) and therefore easily sacrificed for opencast mining and therefore completely compromising the headwaters and feeding areas of the wetlands. It follows therefore that the exact process followed to protect the wetlands is so flawed that it leads to a drastic decrease in water supply and therefore a significant degradation in the functioning of the wetland.

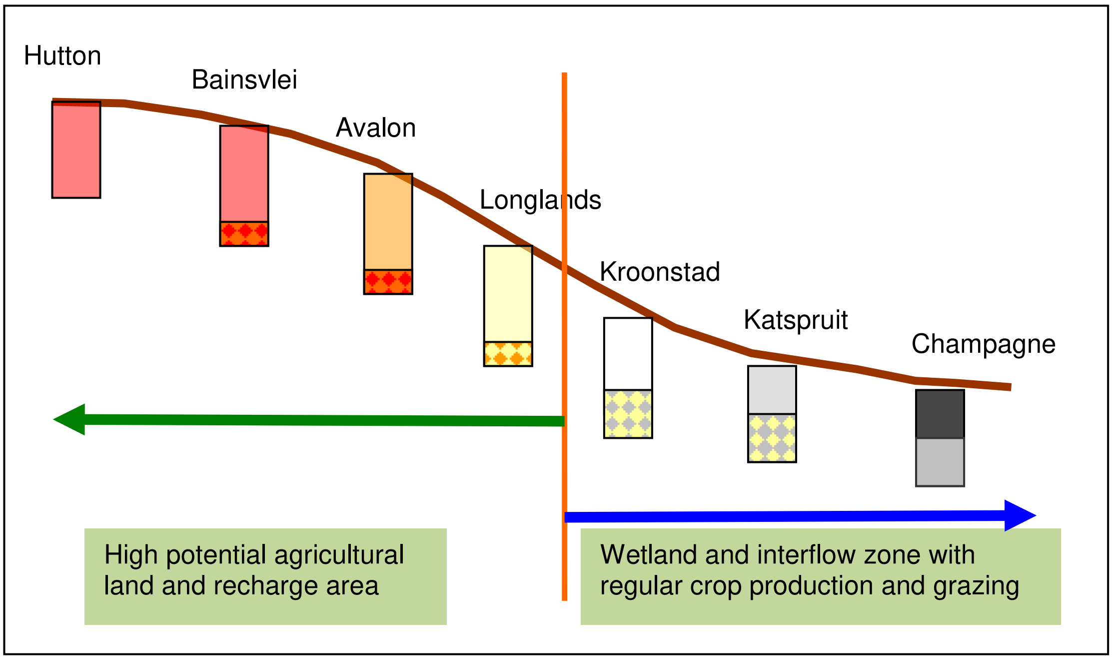

Figure 15 Schematic representation of the soils in a combined convex and concave landscape with an indication of land capability split along agricultural and wetland soils

5.12 IMPLICATIONS FOR WETLAND CONSERVATION IN OPENCAST MINING ENVIRONMENTS

5.12.1 Free Draining Systems

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. **Figure 16** provides a schematic representation (as contrasted with **Figure 7**) of water dynamics in an opencast mining environment in a free draining system. **Figures 17** to **24** indicate examples of the flow regimes on a specific mine indicated schematically in **Figure 16**.

With the typical opencast mining the “topsoil” and overburden rock is stripped to access the ore body 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 the landscape flows. 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. If there is an elevated pyrite content associated with 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.

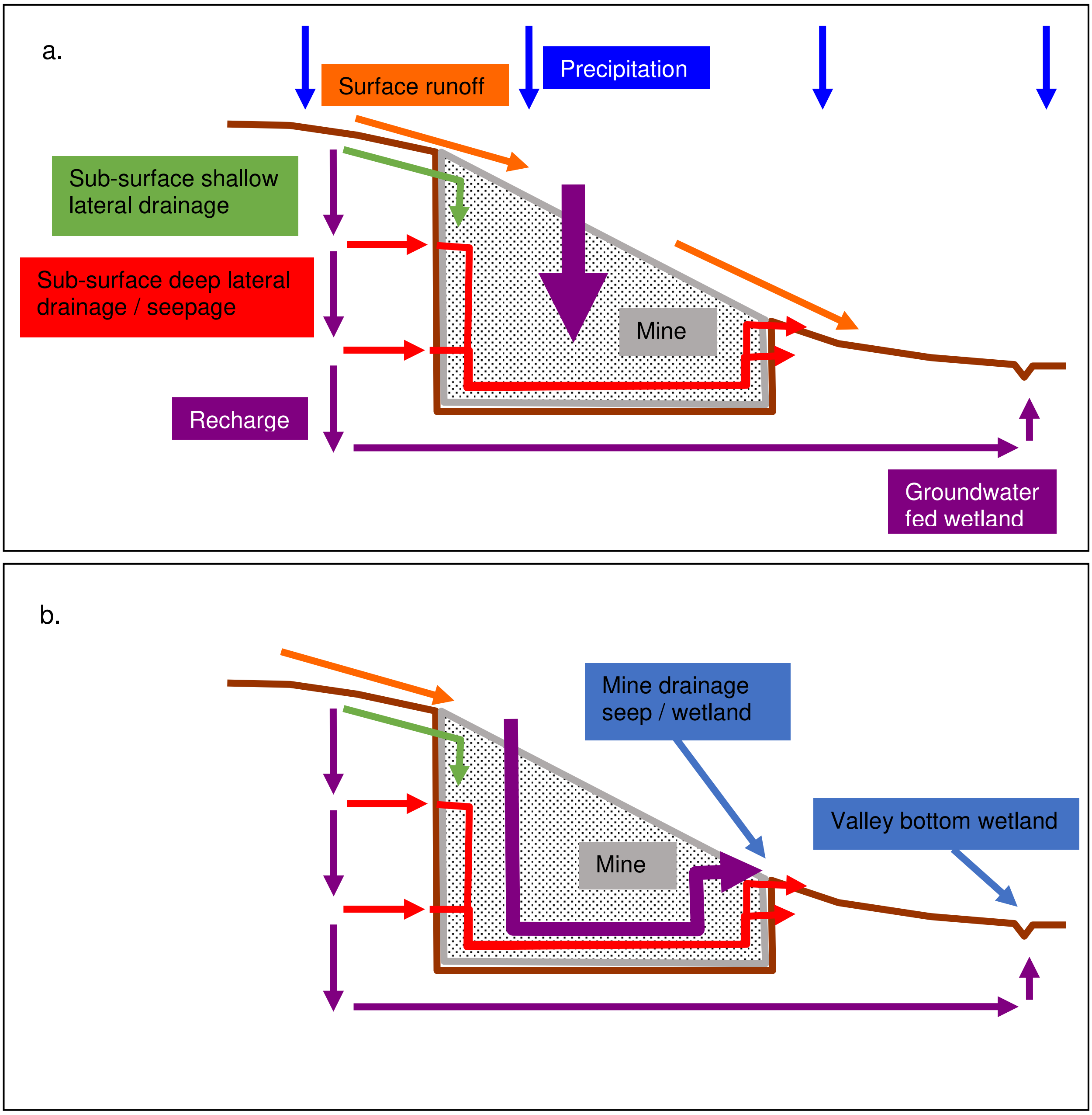

Figure 16 Different flow paths of water through a landscape with an opencast mine (a) and typical wetland types associated with the water regime (b)

Figure 17 Opencast mine profile indicating a thin bleached soil profile (arrow)

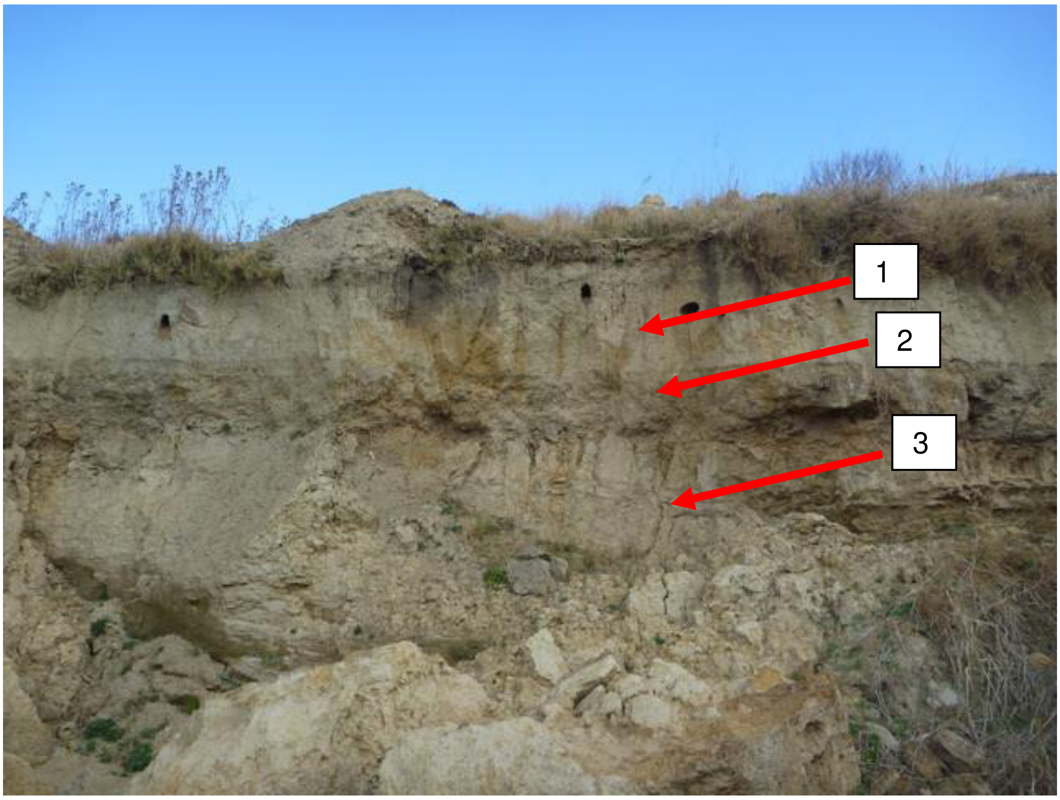

Figure 18 Opencast mine profile indicating 1) a thin bleached soil profile overlying 2) a hard plinthic layer and 3) weathered sandstone

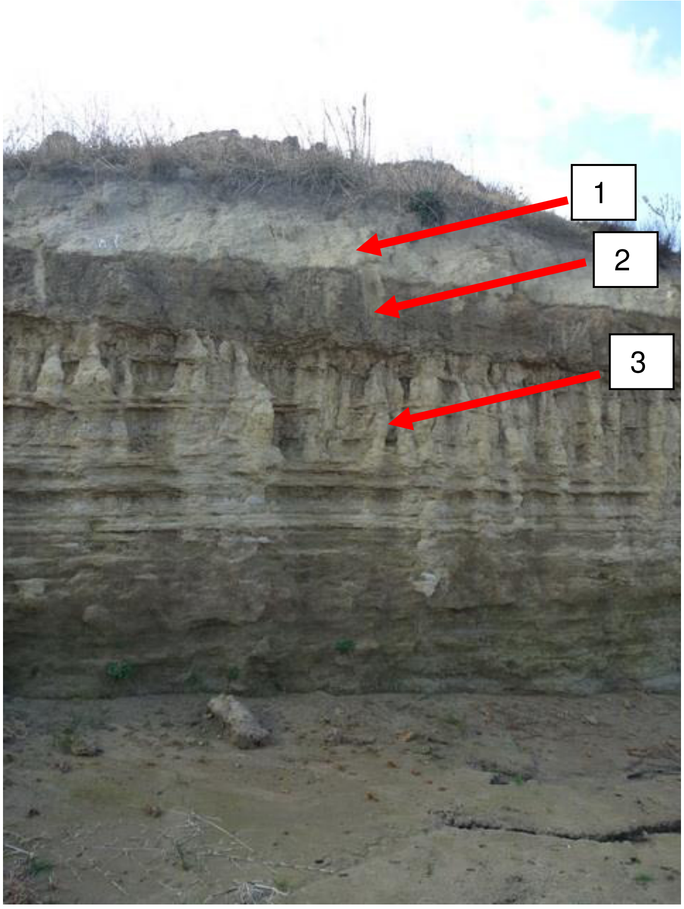

Figure 19 Opencast mine profile indicating 1) a thin bleached soil profile overlying 2) a hard plinthic layer and 3) weathered sandstone

Figure 20 Opencast mine profile indicating a distinct flow path (arrow) beneath the soil profile

Figure 21 Opencast mine profile indicating a distinct flow path (arrows) in the bedrock

Figure 22 Opencast mine profile indicating numerous distinct flow paths (arrows) through the exposed profile (soil, weathered sandstone, carbonaceous shale, hard sandstone)

Figure 23 Road cutting with exposed flow (outside of a wetland area) at the end of July 2013

Figure 24 Road cutting with exposed flow (outside of a wetland area) at the end of July 2013

5.12.2 Inwardly Draining Systems

The same principles as above, but in this case for an inward draining system, are illustrated in **Figure 25**. In the case where the landscape around the depression (pan) has been mined up to the "wetland buffer" (or often practically the 1:100 flood line) there is 1) a decrease in ground level due to a volume decrease through coal removal and 2) a raising of the depression above the surrounding landscape. The consequence is a depression (pan) system with a drastically decreased catchment that leads to a significant drying out of the system and concomitant change in ecological character over time. This aspect is illustrated by the pan system indicated in **Figures 26** and **27** with the wetland area making up only a small section of the entire catchment. The drop in ground level surrounding the pan (**Figure 25b**) decreases water supply.

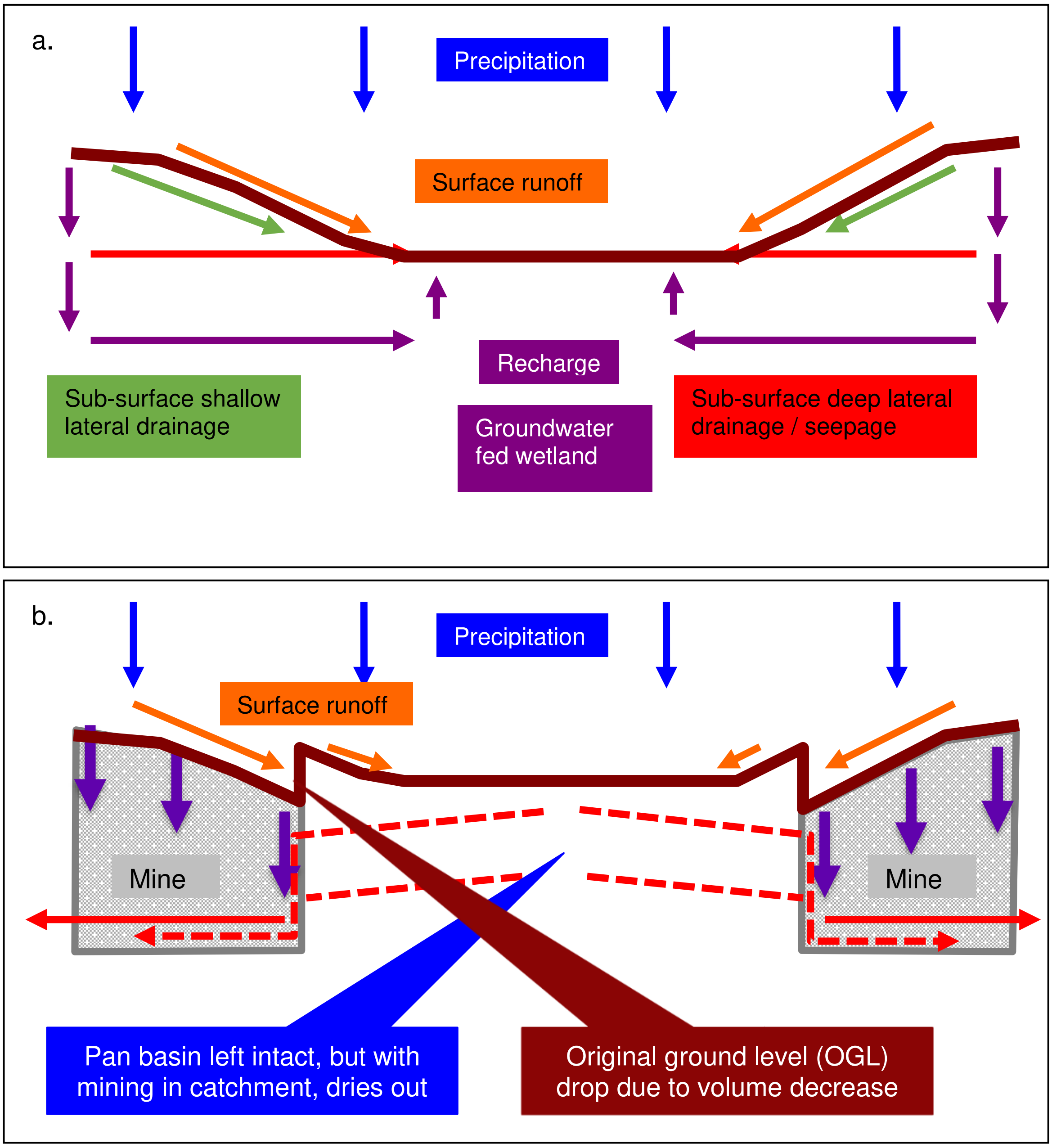

Figure 25 Water dynamics in an inwardly draining system under natural conditions (a) and under conditions where the area surrounding the depression has been mined (b)

Figure 26 Pan system with two pans that are not connected to drainage features on the surface

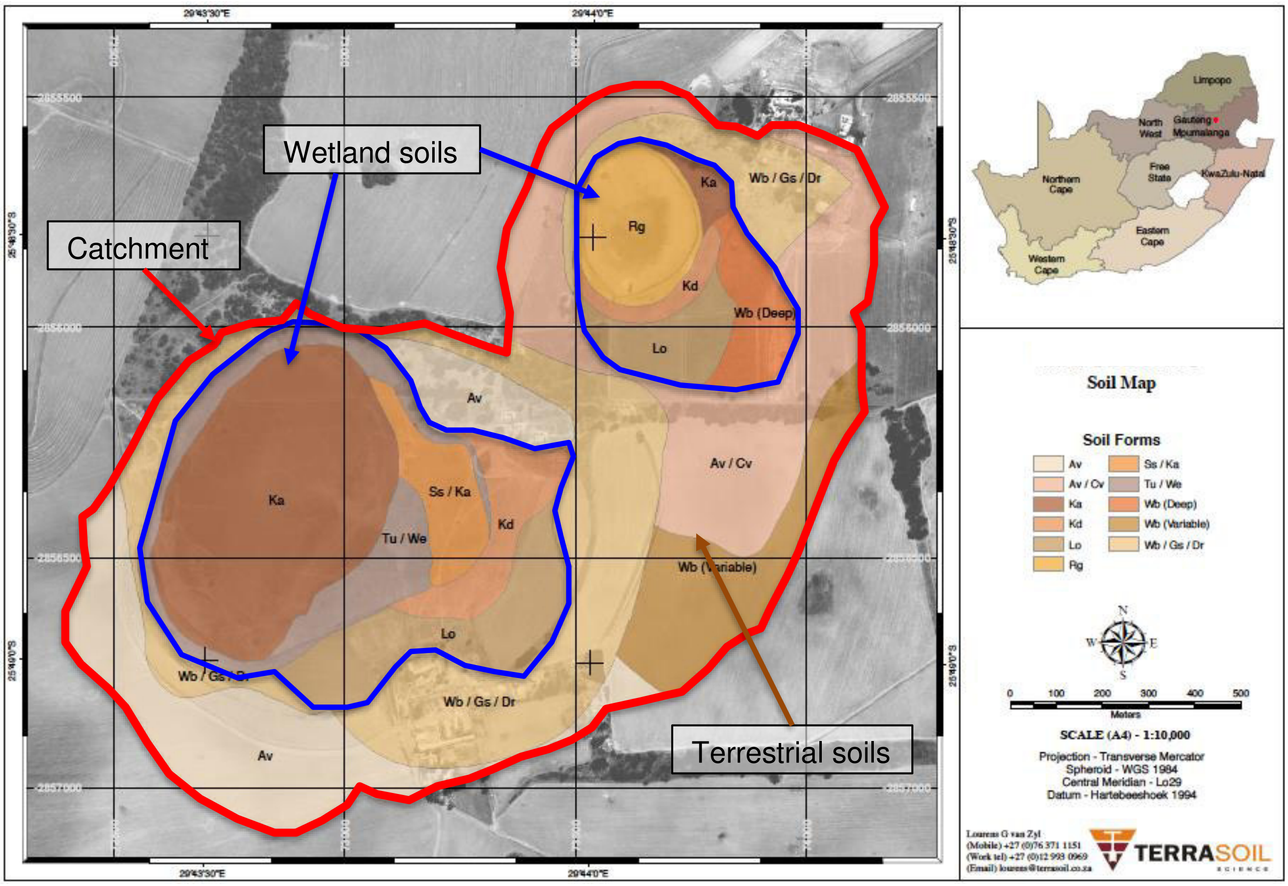

Figure 27 Soil map of the pan system indicating wetland and terrestrial soils and the catchment

5.12.3 Complete Mining of Terrestrial and Wetland Zones

In the case where the entire landscape is mined a complete destruction of the hydrological processes is experienced and the entire landscape is “rehabilitated”. The complete mining of a pan system requires a change in hydrology to a free draining system in order to minimise stability risks on the post-mining site. A 3D model of the pan system before mining and a conceptual reestablishment design is provided in **Figure 28**.

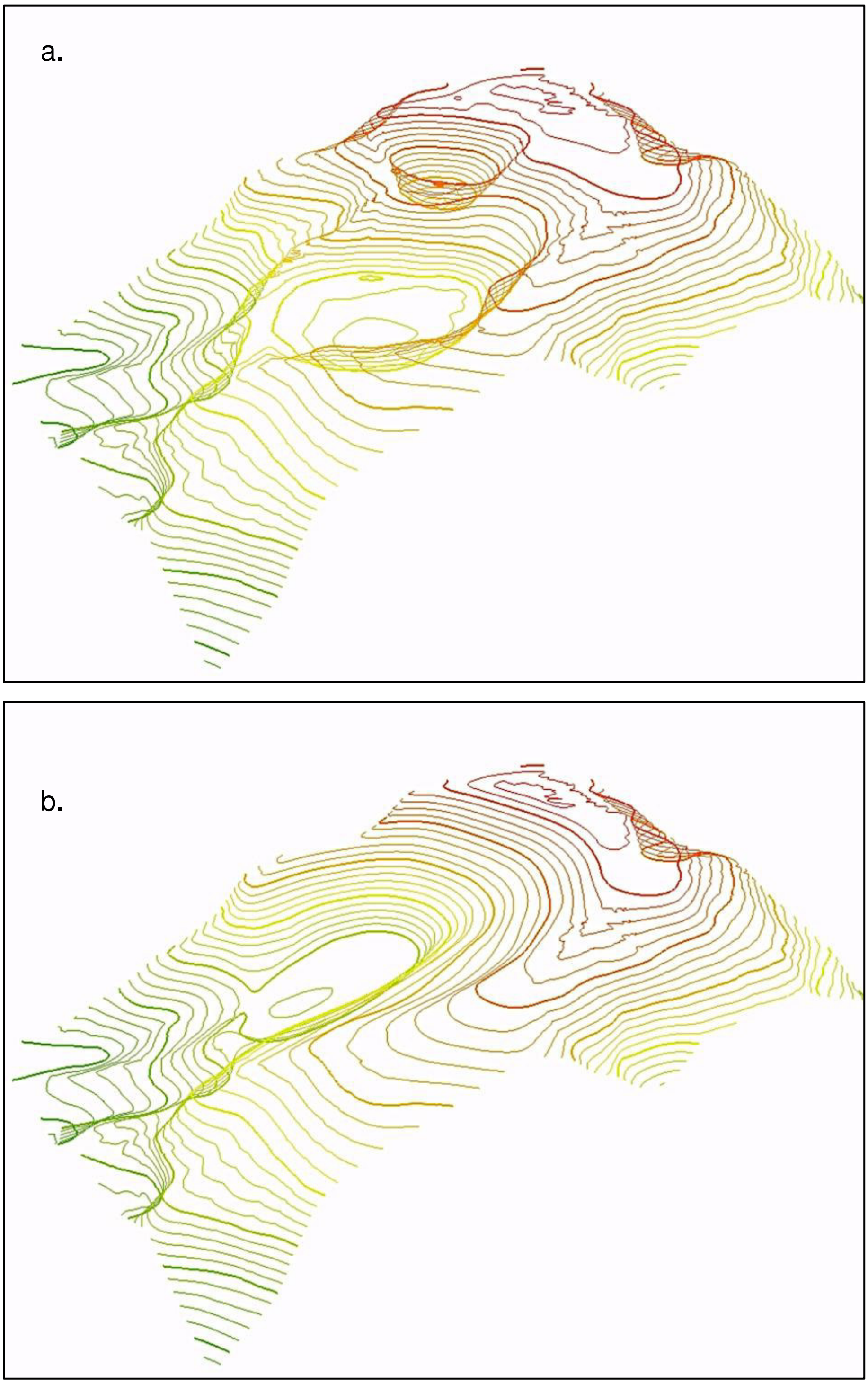

Figure 28 3D model of a pan system before mining (a) and a conceptual design for a post mining landscape reestablishment (b)

The pre-mining hydrology is inward draining and therefore saturated with water and with free water standing in the pan basin. The soil profiles indicate depression conditions with an accumulation of salts and weathering products – often in the form of specific clay minerals having formed in the accumulation environments over millennia. The chemistry of the pan basin floors (data not presented here) usually indicate and accumulation of Na to very high levels, which is indicative of poor or non-existent drainage in a landscape such as the Eastern Highveld that usually exhibits very low Na levels in free draining environments. The high Na levels impart dispersive properties to the clay minerals with a subsequent instability and distinct tendency for erosion should these soils be deposited on slopes.

5.13 GEOTECHNICAL, SOIL STABILITY AND HYDROLOGICAL FUNCTIONING CONSIDERATIONS IN WETLAND REHABILITATION AND RE-ESTABLISHMENT

The reestablishment of plinthite layers is also often proposed as a means to ensure the hydrological functioning of a post-mining landscape. At the outset it needs to be emphasised that the stripping of soils before mining is a process that is described in the "soil utilisation guide" provided with the EIA and EMP for mining applications. These guides are based on detailed soil surveys and provide stripping, stockpiling and soil placement guidelines. In practice these plans are practically difficult and financially restricting to execute and most, if not all, mining operations therefore do not execute the plans.

The establishment of plinthic layers poses another challenge in that the plinthic layers are the products of landscape hydrological processes rather than the cause of these hydrological processes. The same applies to extensive E horizon profiles that act as lateral conduits for water in most plinthic landscapes. It is therefore counter intuitive to promote the re-establishment of such layers in the post-mining landscape positions without being able to re-establish the hydrological functioning of the landscape as discussed in the previous section.

5.13.1 Soil and Material Handling Planning for Rehabilitation

In order to plan and execute a mine stripping, storage and placement plan for mined material the assessment of a proposed mining site should consist of the following parameters (ideal):

1. Conduct a detailed soil survey to identify, classify and map the soils of the site.
2. Conduct a detailed geological assessment of the coal bearing strata and overlying material to determine material characteristics (nature, acid generation capacity, etc.).
3. Generate a mine plan.
4. Generate a soil stripping, stockpile and placement plan in line with the mine plan.
5. Generate a rehabilitation plan in line with national guidelines and / or requirements of the competent authority.
6. Implement the rehabilitation plan and conduct monitoring with interventions where required.

Due to the cost associated with the above exercise most mines execute components of the above. In in many cases the soil stripping, stockpiling and placement guidelines are either very generic or very detailed – in which case they are too costly to execute. Detailed wetland rehabilitation requires a higher level of intensity than that described above and is therefore even more costly than generic rehabilitation processes.

5.13.2 Geotechnical Considerations

If the process set out above is followed in detail then the geotechnical stability of the materials come in to play with respect to the long-term integrity of rehabilitation efforts and its planning. A pre-mining landscape consists of a hard and temporally stable geological base with the weathered zone with soils and wetlands at the surface. The hydrological functioning of the landscape is a function of the hardness and permeability of the varying materials in the various layers. As indicated in **Figures 16** and **25** the mine voids are filled with unconsolidated materials with a permeability that is rather homogenous with variation in depth. The alteration in permeability is the main cause of the increase in recharge characteristics of the landscape. However, the unconsolidated materials are not stable and will undergo different degrees of settling and consolidation as a function of the dry and wet conditions of the material with the wetness changing over time due to the increased recharge. A decrease in material volume is therefore inevitable but difficult to predict as a result of several factors that introduce variability in the material characteristics, cohesion between particles and loading of overlying layers. Additionally, the settlements may be differ spatially and the total settlement and consolidation will continue for many years with a decrease in intensity over time (**Figure 29**)

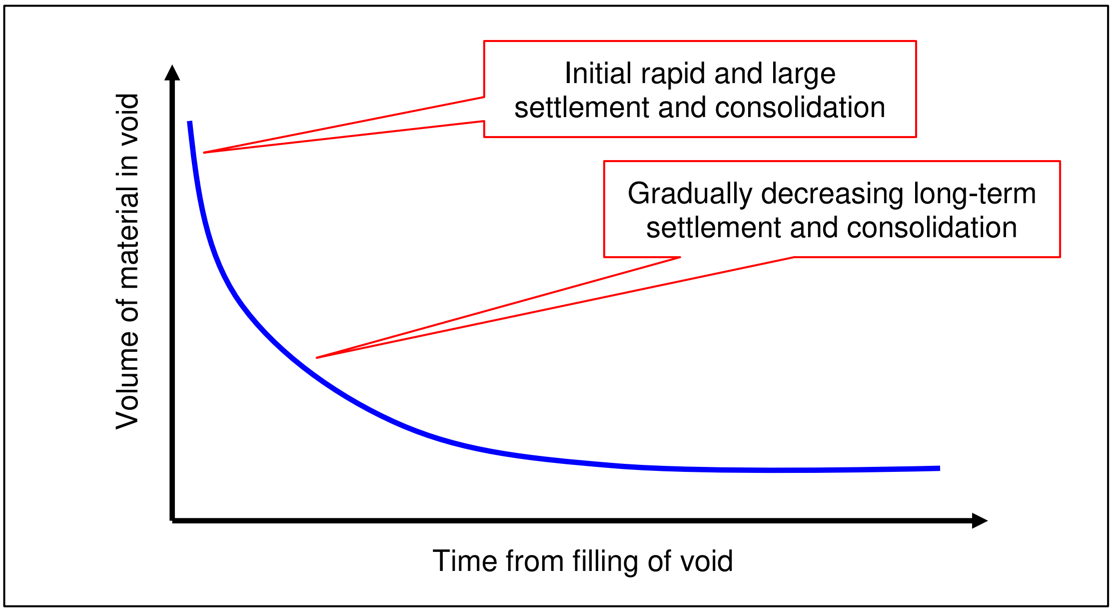

Figure 29 Change in settlement and consolidation intensity over time

5.13.3 Soil Stability and Hydrological Functioning Considerations

The post-mining landscape's hydrological functioning is therefore significantly different to the pre-mining landscape with a consequent drastic alteration in flow regimes and wetland feeding processes. Interested and affected parties, as well as the regulator, often indicate that the pre-mining landscape's hydrology should be mimicked with the rehabilitation design. This requirement is near impossible to meet as the re-establishment of pre-mining hydrological processes would require the construction or installation of impermeable liners to counteract and arrest the high permeability of the newly placed unconsolidated materials. These liners however have to remain intact in order to maintain functionality. The significant settling and consolidation, and the spatial variability of such processes, preclude the successful long-term functioning of such liners. The only way to increase the probability of success and maintenance of integrity of the liners is to significantly increase the compaction and shaping of the underlying spoil layers. The cost of such intensive exercises often exceeds the value of the coal in the mine in the first place and these approaches are therefore never implemented.

A compounding factor in the above consideration is the fact that the post-mining landscapes have to be free draining to prevent accelerated consolidation, failure of containment structures due to compromised integrity upon settling differentially, adverse human safety and environmental impacts and processes such as sediment generation. Whereas the planning and rehabilitation of wetlands require minimal professional certification, the design and construction of stable structures requires the sign-off of a professional engineer. In practice engineers are very loathe to sign-off on structures of which the integrity and stability poses uncertainties.

Additionally, the placement of pan basin soils on slopes is risky due to the dispersive nature of the clay soils that have elevated Na levels. The elevated Na levels in comparison to Ca levels lead to a distinct instability of the clays due to dispersion induced by the Na. On slopes these soils therefore have no cohesion when wet and they will readily erode and "flow" downslope.

5.13.4 Re-establishment of Plinthic Layers

An argument that is often put forward is that if plinthic layers can be re-established that the hydrological functioning of the post-mining landscape can mimic that of the pre-mining landscape. The argument rests on a number of exaggerated expectations however. The following aspects are of critical relevance to the above argument.

1. It is important to understand that the occurrence of plinthic layers is not a function of the soil itself but rather of the underlying weathered and hard rock materials. The plinthic layers originate predominantly due to return flow of water out of the landscape where the lateral flow paths in fractured or stratified rock layers intercept the topography. It therefore follows that these flow paths have to be established first in the filled-in spoil before the plinthic layers will function in a similar way as in the pre-mining landscape.
2. The establishment of lateral flow paths in unconsolidated spoil material is not feasible due to the design, placement, compaction and sealing efforts required to attain such.

These lateral flow paths pose significant geotechnical stability challenges that are to costly and risky to address.

3. The consolidation and settlement characteristics of the spoil material lead to a constantly changing material environment from a physical strength and void characteristic perspective. It is inevitable that deliberately constructed seals and flow paths will be severed or compromised through shifts in layers and material.
4. The lateral movement of water within a plinthic landscape is often characterised by slow, almost horizontal, seepage through sandy E-horizons. These soils are stable in-situ as they are in equilibrium with the hydrological processes that dominate the landscape. The construction of such seepage zones with similar flow rates and stability is not readily performed and these lateral seepage areas will require significant maintenance and stabilisation (in contrast to the natural conditions.

Taking into account the above challenges regarding the establishment of plinthite type lateral flow paths leads to the preferred option of keeping water flows on the surface in post-mining landscapes. On the surface the water is visible, treatable and the erosion and stability impacts can be managed more efficiently that if these flow paths were buried.

5.13.5 Implications for Post Mining Land Capability

In the EMP process for a standard opencast mine there is a distinct irony. Whereas these mines are often licensed to mine in "terrestrial" areas that comprise high potential agricultural land the relevant authorities (DAFF) require the land to be rehabilitated to as close to the original land capability as possible. In order for crops to grow the infiltration of the soil must be at a maximum to ensure enough water in the soil profile. On the other hand, DWS would require that the water infiltrating into the porous material should be a minimum in order to minimise acid and sulphate generation in the porous spoil material – the aim therefore being to minimise acid mine drainage decants. The above description indicates that there is a distinct conflict in what is advised and required for mines during the EIA/EMP process. What is more disconcerting is that this issue is not adequately addressed at regulator level and the mines are often provided with conflicting guidelines.

5.13.6 Implications for Post Mining Water Quality Management

As indicated in **Figure 16** the seepage of mine impacted water from spoil deposits is a distinct risk in mining environments. The implication is that 1) new wetlands can occur in mining environments as water drains out on toe seep areas or 2) wetlands that are established can experience ingress of poorer quality water in terms of acidity, metals and sulphates. The change in water quality has an adverse effect on the ecological characteristics of the wetland systems into which the water flows. The extent of the effect is determined by the difference in pH and salt load of the polluted water compared to the natural wetland water.

6. METHOD OF INVESTIGATION

The process of the soil and hydropedology assessment entails the aspects listed in the methodology description below.

6.1 AERIAL PHOTOGRAPH INTERPRETATION, LAND USE AND SOIL INVESTIGATION UNITS

An aerial photograph interpretation exercise was conducted through the use of Google Earth images and historical aerial photographs of the site. Due to the position of the site, the plinthic catena and the availability of multiple google earth images it as possible to conduct a high-level soil surface colour interpretation of the site. The surface soil colour corresponds to the subsoil horizons in the manner as explained in Van der Waals (2013), and could therefore be used as a first approximation of the soil distribution on the site. The land use characteristics were used to determine, in conjunction with the soil survey information, the land capability and agricultural potential parameters of the site.

6.2 TERRAIN UNIT INDICATOR

Contours of the site (5 m intervals) were used to provide an indication of drainage depressions and drainage lines. From this data the terrain unit indicator was deduced through the use of a topographic wetness index (TWI) determination. The TWI also provides an indication of curvature characteristics (concave vs convex) of the landscape and was used in the generation of the soil map.

6.3 SOIL SURVEY

The reconnaissance soil survey was conducted on several days in July 2019 before the start of the rainy season. Due to the extent of the site and the distinct surface soil colour patterns a smart sampling approach was followed for the soil survey. This survey focussed on the interpretation of surface soil colour characteristic correlation with subsurface soil characteristics as reported on by Van der Waals (2013). The survey sites were therefore chosen as being representative of the various soil surface colours or as sites along transects to capture maximal soil form variation.

6.4 SOIL ANALYSIS

Soil analysis was not conducted.

6.5 LAND CAPABILITY AND AGRICULTURAL POTENTIAL

The land capability assessment was conducted using the soil survey results through assigning of specific soil form groups and soil depth criteria to the four classes “arable”, “grazing”, “wilderness” and “wetland”. The agricultural potential of the site to a degree mimics the land capability categories described above and was interpreted according to the same soil form and soil depth criteria.

6.6 SITE HYDROPEDOLOGY CONTEXT DETERMINATION

For the purposes of the hydropedology assessment the context of the specific site was determined. This was done through the thorough consideration of the geological, topographical, climatic, soil, hydropedological and catchment context of the site. The elements of context are described in more detail below in the various sections.

7. SITE SURVEY RESULTS AND DISCUSSION

7.1 AERIAL PHOTOGRAPH INTERPRETATION, LAND USE AND SOIL INVESTIGATION UNITS

The aerial photography interpretation yielded that the surface soil colour in the ploughed areas provides a clear soil mapping tool through the interpretation of surface soil colour variation as described by Van der Waals (2013) (**Figure 30**). The land use of the site consists predominantly of dryland agriculture and grazing with depressions dominated by wetland conditions (**Figure 31**).

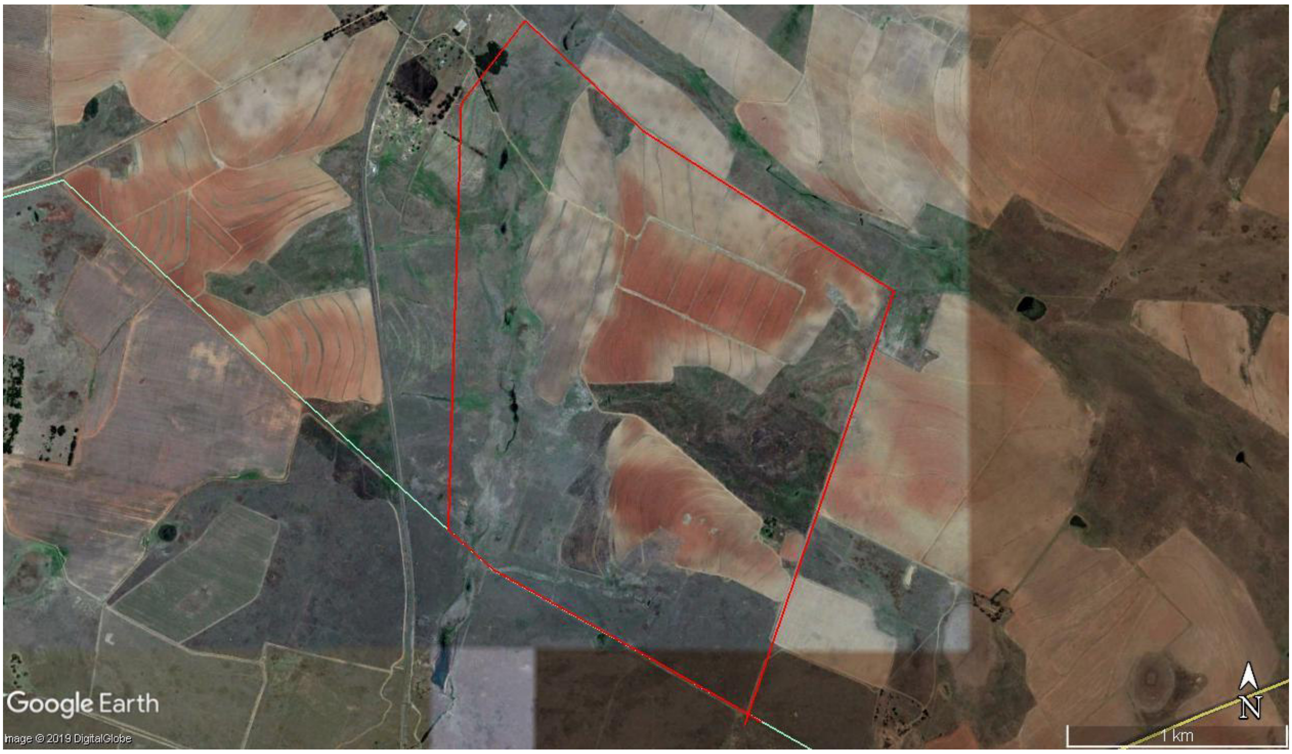

Figure 30 Google Earth image indicating land use and soil colour patterns

7.2 TERRAIN UNIT INDICATOR

The contour data for the site as well as the surrounding area was used to generate a topographic wetness index (TWI) (**Figure 32**). From extensive experience on the field of hydropedology it is evident that the TWI provides a very accurate indication of water flow paths and areas of water accumulation that are often correlated with wetlands – if soil and topographic conditions are conducive to the formation of redoximorphic features in the soils. This is a function of the topography of the site and ties in with the dominant water flow regime in the soils and the landscape (refer to previous sections where the concept of these flows was elucidated). Areas in blue indicate concentration of water in flow paths with lighter shades of blue indicating areas of regular water flows in the soils and on the surface of the wetland / terrestrial zone interface.

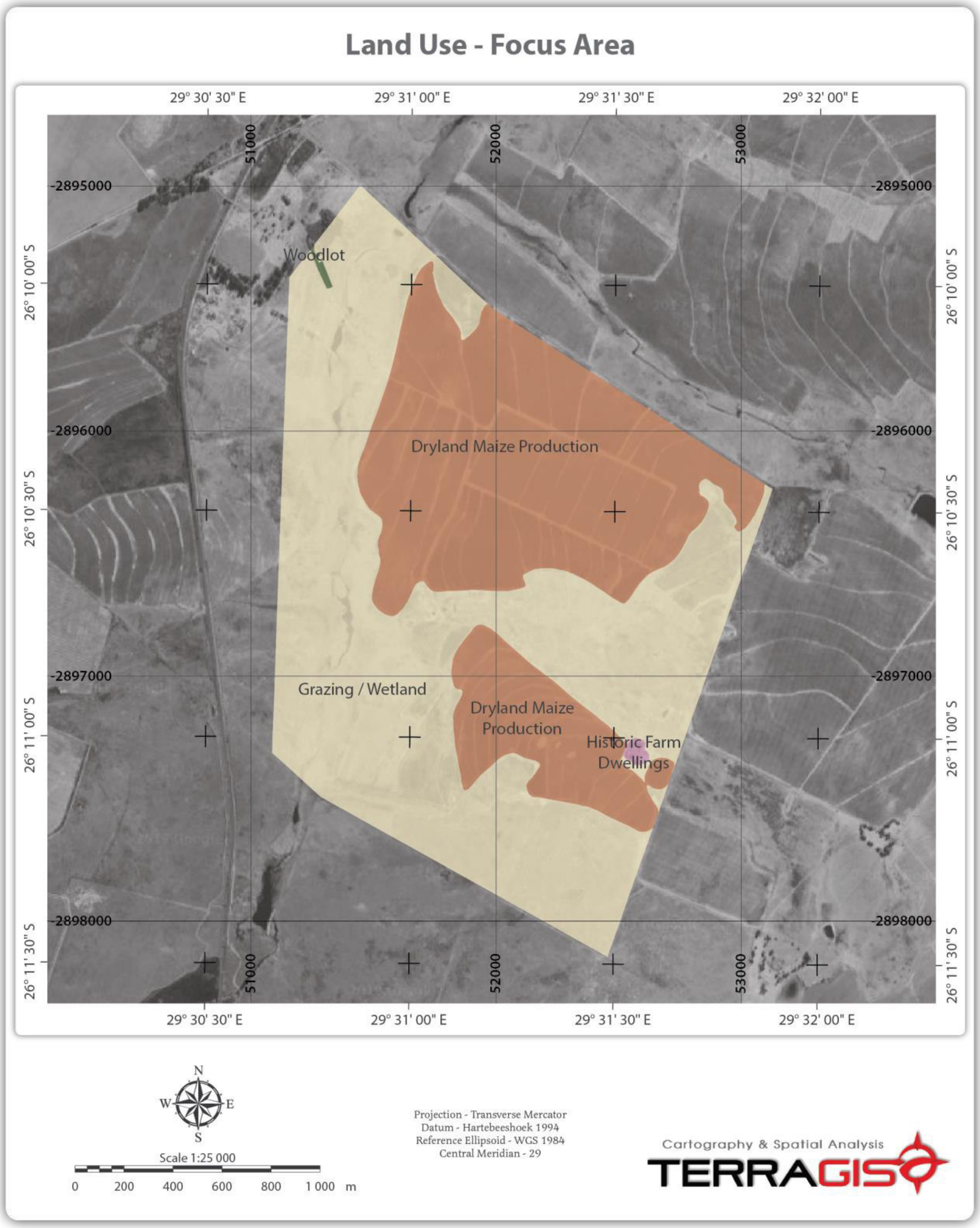

Figure 30 Land use map of the investigation site

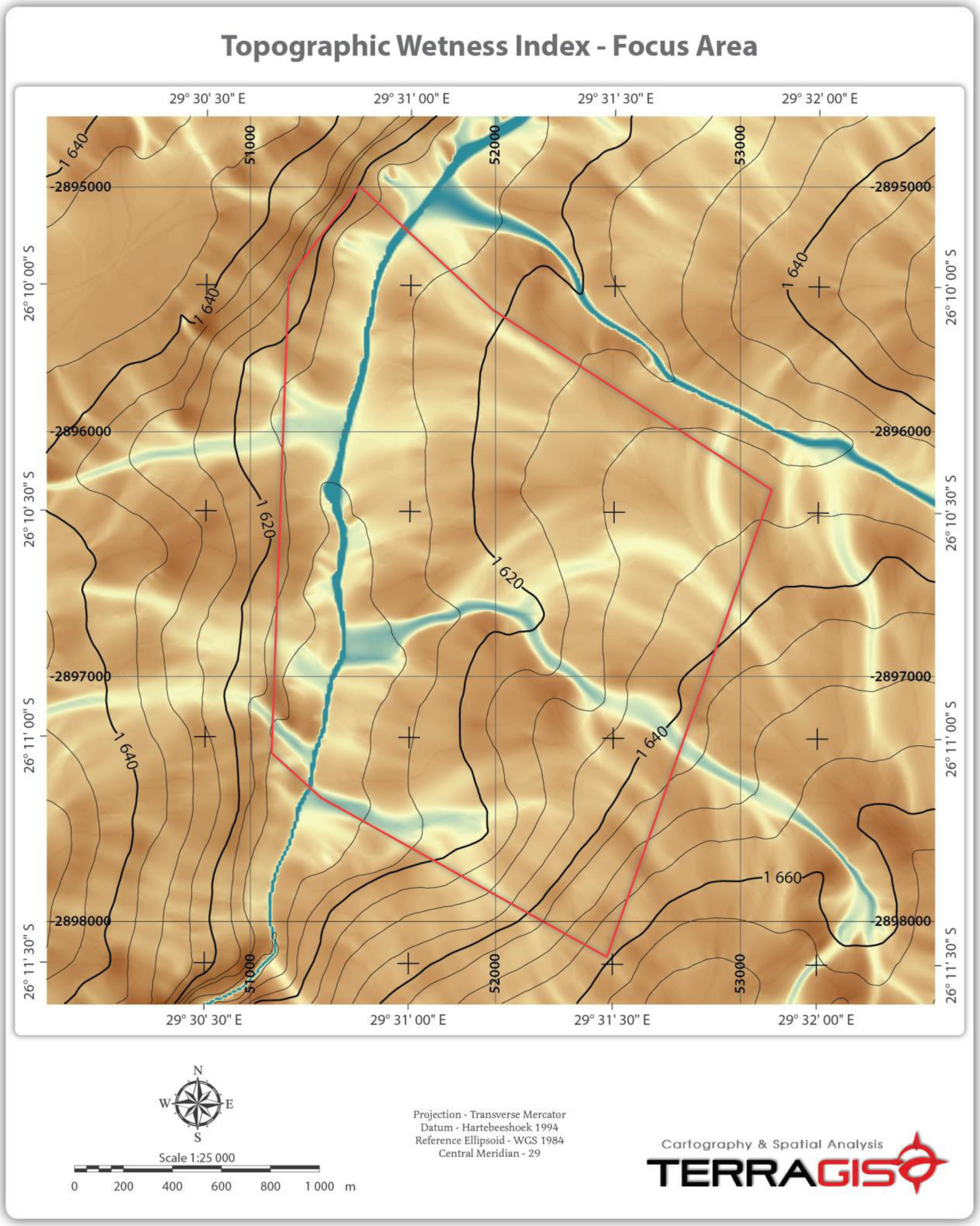

Figure 32 Topographic wetness index (TWI) of the survey site

The terrain unit indicator provides a good correlation in terms of the surface water accumulation paths and the wetlands and grey soils on the site as identified in the aerial photograph interpretation section.

7.3 SOIL SURVEY

The reconnaissance soil survey yielded a generalised soil map for the site (**Figure 34**).

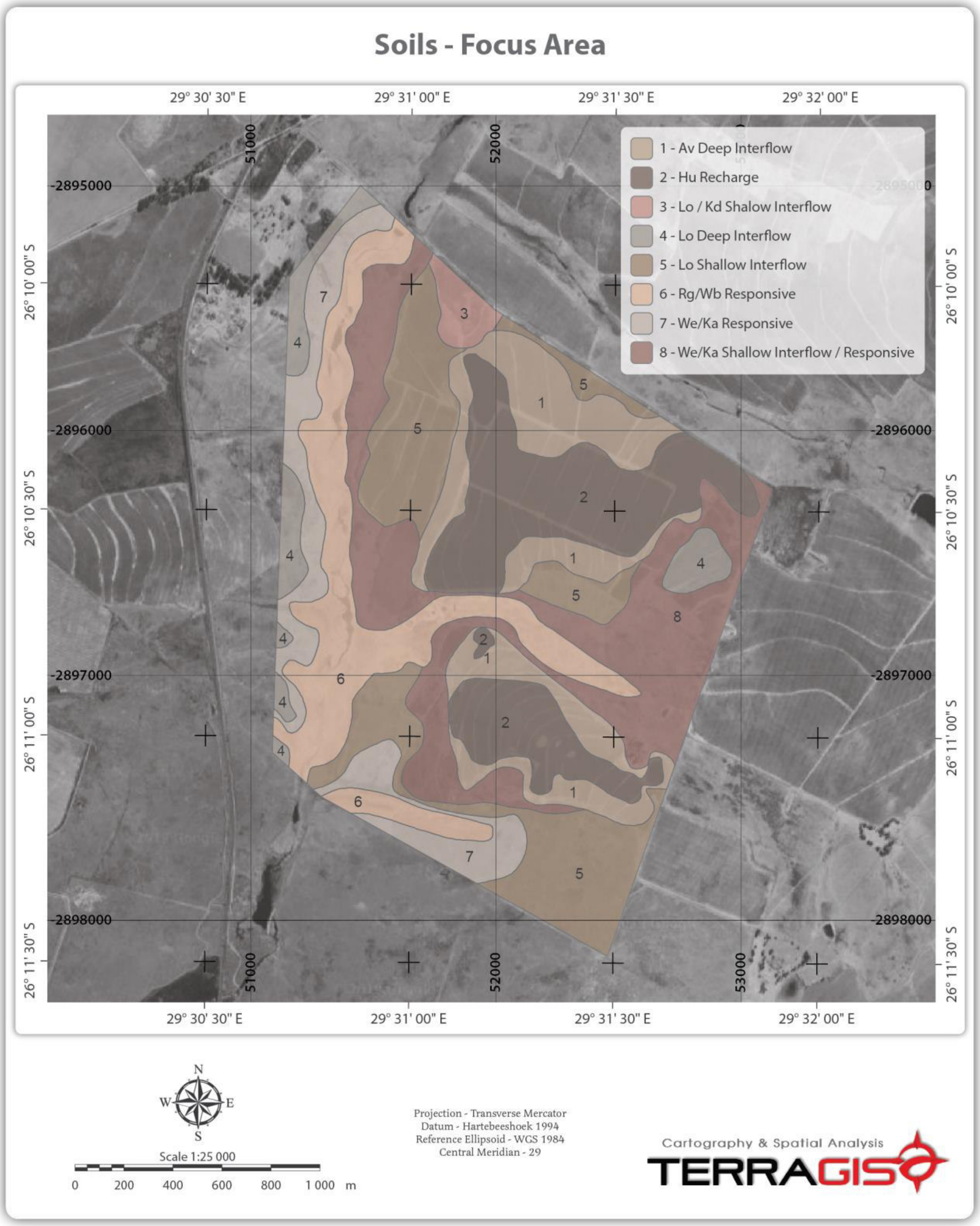

Figure 33 Generalised soil map for the investigation site

The soils on the site have been divided into hydrological units as provided in **Table 3**.

Table 3 Soils and hydrological functioning

Soil Unit	Soil Form	Diagnostic Horizons	Hydrological functioning (soil profile depth)
Av	Avalon	Orthic A / Yellow-brown Apedal B / Soft Plinthic	Recharge into deep interflow between soil profile and fractured rock interface
Hu	Hutton	Orthic A / Red Apedal B / Unspecified – usually fractured / weathering rock	Recharge into deeper fractured rock interface
Lo	Longlands	Orthic A / E / Soft Plinthic	Shallow interflow in E horizon on and to a lesser extent soft plinthic horizon
Kd	Kroonstad	Orthic A / E / G	Shallow interflow in E horizon on clay rich G
Rg	Rensburg	Vertic A / G	Responsive soil – return flow
Wb	Willowbrook	Melanic / G	Responsive soil – return flow
We	Westleigh	Orthic A / Soft Plinthic	Shallow interflow / return flow in zones with vegetation signature
Ka	Katspruit	Orthic A / G	Responsive soil – return flow

7.4 LAND CAPABILITY AND AGRICULTURAL POTENTIAL

The land capability and agricultural potential map of the site are provided in **Figure 34**.

8. CONCEPTUAL HYDROLOGICAL RESPONSE

The conceptual hydrological response for the site is derived from the soils that were identified and presented in **Figure 33**. The hydrological response is inferred from the soil properties and based on the concept discussed in section 5.6 and illustrated in **Figure 7**. The hydrological functioning of the areas that are provided in **Table 3** yield the following:

1. Recharge Zones: The dryland crop production areas function as recharge zones with lateral flow of water occurring at depth in the soils. Surface runoff occurs during high intensity rainfall events that exceed the infiltration capacity. A significant intercept occurs during the growing season with crop water use.
2. Deep Interflow Zones: Fractured rock and deep plinthic horizons represent interflow zones.
3. Shallow Interflow Zones: E horizons underlain by higher clay content soil horizons represent shallow interflow zones with intercept by wetland vegetation.
4. Responsive Soil Zones: Soil with high clay content in low lying landscape positions represent response areas where interflow water approaches the land surface or flows out onto the land surface at times. These zones are characterised by seasonal and permanent wetland vegetation depending on the duration of later flow contributions from the landscape.

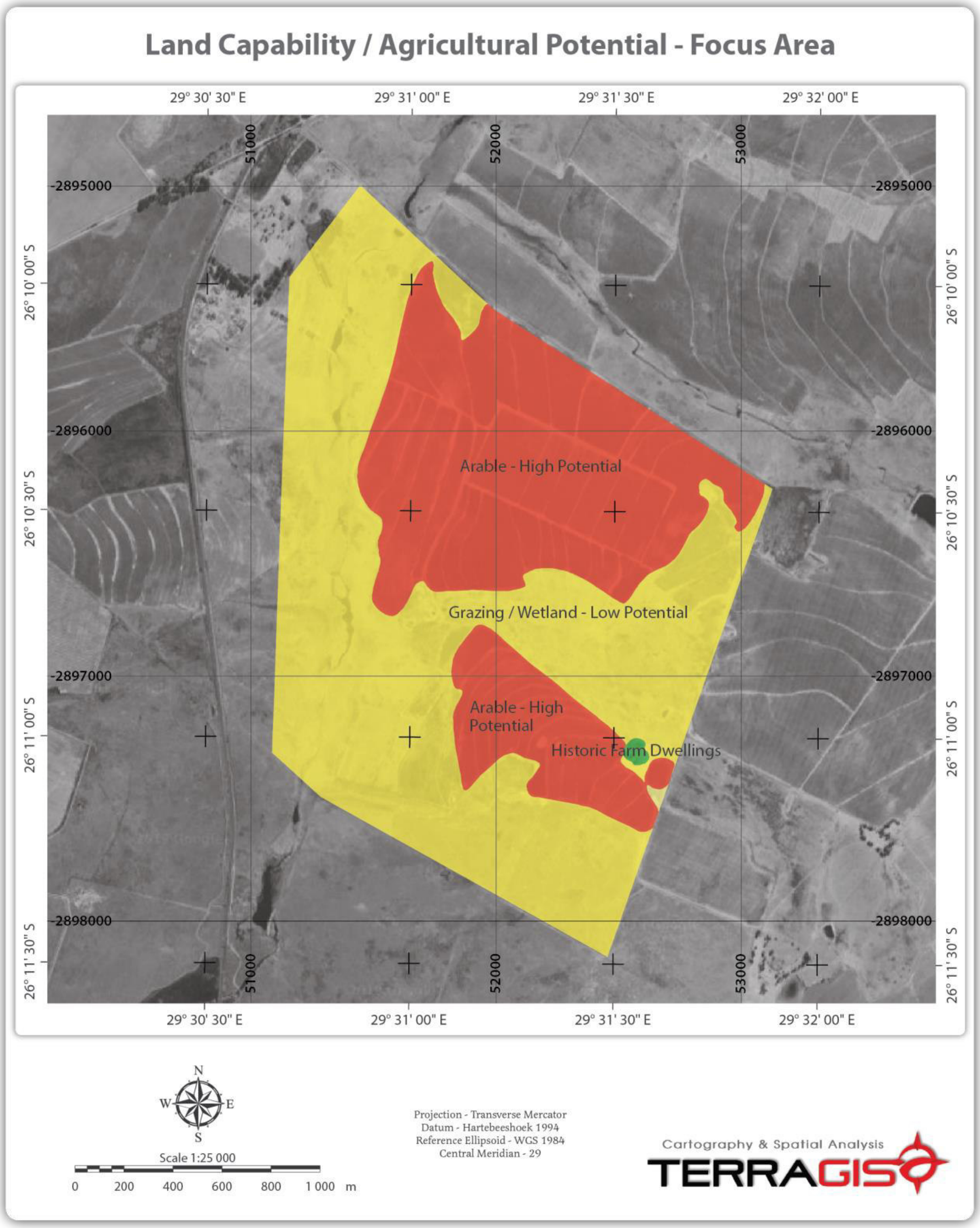

Figure 34 Land capability map of the investigation site

9. CONCEPTUAL HYDROLOGICAL RESPONSE – IMPLICATIONS FOR OPENCAST MINING

The conceptual hydrological response for the site discussed above yields that the impacts of opencast mining, when viewed in the context of the discussion in section 5.12.1 (and illustrated in **Figure 16**) will be as follows:

1. Recharge Zones: If recharge zone soils are mined the implication will be a change in recharge characteristics of the landscape and severing of water flow paths feeding interflow (both shallow and deep) and responsive soil areas. The nett effect will be a removal of water from the system until the mine pit fills up and starts decanting. This will yield a variation in flow regime and a degradation of water quality due to acid mine drainage (AMD). The duration of the impact will depend on a range of factors that can only be modelled in the geohydrological investigation.
2. Deep Interflow Zones: The opencast mining of deep interflow zones will have a similar impact as discussed under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
3. Shallow Interflow Zones: The opencast mining of shallow interflow zones will have a similar effect to the discussion under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
4. Responsive Soil Zones: Responsive soil areas are often not mined as these occur within wetlands and watercourses with associated buffers and floodlines precluding mining developments. However, with the water feed for the response having been severed through mining of the recharge and interflow soils the responsive areas cease exhibiting the natural background condition response.

The practical implications of the above impacts are the following:

1. Arbitrary buffers on responsive areas soils (read “wetlands” and “watercourses”) do not have any effect on the protection of the water resource. This aspect renders the concept of a buffer moot since it has no practical application or benefit in opencast coal mining areas.
2. The protection of flow parameters in landscapes that undergo opencast coal mining is also a moot point as the flow is drastically altered through the severing of all the flow paths and recharge and storage characteristics of the landscape. The re-establishment of flow can only happen during the rehabilitation phase – if properly planned. However, during this phase the implementation of plans to deal with AMD and altered flow regimes and water quality is critical in order to regain some of the original flow and water dynamics in the landscape.

10. CONCLUSIONS AND RECOMMENDATIONS

A conceptual hydropedology functioning of the landscape has been established through the mapping of soils and interpretation of soil morphology. Detailed hydrological modelling cannot be conducted at this stage and will be possible with detailed soil assessment, analysis and modelling.

In order to provide a more detailed indication of water flow volumes and fluxes of water more detailed assessment is required with the integration of the data with geohydrological and surface hydrological modelling.

To summarise and emphasise:

The conceptual hydrological response for the site is derived from the soils that were identified and presented in **Figure 33**. The hydrological response is inferred from the soil properties and based on the concept discussed in section 5.6 and illustrated in **Figure 7**. The hydrological functioning of the areas that are provided in **Table 3** yield the following:

5. Recharge Zones: The dryland crop production areas function as recharge zones with lateral flow of water occurring at depth in the soils. Surface runoff occurs during high intensity rainfall events that exceed the infiltration capacity. A significant intercept occurs during the growing season with crop water use.
6. Deep Interflow Zones: Fractured rock and deep plinthic horizons represent interflow zones.
7. Shallow Interflow Zones: E horizons underlain by higher clay content soil horizons represent shallow interflow zones with intercept by wetland vegetation.
8. Responsive Soil Zones: Soil with high clay content in low lying landscape positions represent response areas where interflow water approaches the land surface or flows out onto the land surface at times. These zones are characterised by seasonal and permanent wetland vegetation depending on the duration of later flow contributions from the landscape.

The conceptual hydrological response for the site discussed above yields that the impacts of opencast mining, when viewed in the context of the discussion in section 5.12.1 (and illustrated in **Figure 16**) will be as follows:

5. Recharge Zones: If recharge zone soils are mined the implication will be a change in recharge characteristics of the landscape and severing of water flow paths feeding interflow (both shallow and deep) and responsive soil areas. The nett effect will be a removal of water from the system until the mine pit fills up and starts decanting. This will yield a variation in flow regime and a degradation of water quality due to acid mine drainage (AMD). The duration of the impact will depend on a range of factors that can only be modelled in the geohydrological investigation.
6. Deep Interflow Zones: The opencast mining of deep interflow zones will have a similar impact as discussed under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
7. Shallow Interflow Zones: The opencast mining of shallow interflow zones will have a similar effect to the discussion under point 1 above. Mining of these areas implies that the recharge areas are also mined and it is therefore seen as a cumulative impact.
8. Responsive Soil Zones: Responsive soil areas are often not mined as these occur within wetlands and watercourses with associated buffers and floodlines precluding mining developments. However, with the water feed for the response having been severed through mining of the recharge and interflow soils the responsive areas cease exhibiting the natural background condition response.

The practical implications of the above impacts are the following:

3. Arbitrary buffers on responsive areas soils (read “wetlands” and “watercourses”) do not have any effect on the protection of the water resource. This aspect renders the concept of a buffer moot since it has no practical application or benefit in opencast coal mining areas.
4. The protection of flow parameters in landscapes that undergo opencast coal mining is also a moot point as the flow is drastically altered through the severing of all the flow paths and recharge and storage characteristics of the landscape. The re-establishment of flow can only happen during the rehabilitation phase – if properly planned. However, during this phase the implementation of plans to deal with AMD and altered flow regimes and water quality is critical in order to regain some of the original flow and water dynamics in the landscape.

REFERENCES

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

Brady, N.C. and Weil, R.P. 1999. *The Nature and Properties of Soils*. Twelfth edition. Upper Saddle River, New Jersey: Prentice Hall.

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

Hillel, D. 1982. Introduction to soil physics. Academic Press, INC. Harcourt Brace Javonovich, Publishers.

Jenny, H. 1941. Factors of soil formation. New York, NY, USA: McGraw-Hill Book Company, p 281

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.

Land Type Survey Staff. (1972 – 2006). *Land Types of South Africa: Digital map (1:250 000 scale) and soil inventory databases*. ARC-Institute for Soil, Climate and Water, Pretoria.

Le Roux, P.A.L. and du Preez, C.C. 2006. Nature and distribution of South African plinthic soils: Conditions for occurrence of soft and hard plinthic soils. *South African Journal of Plant and Soil* Volume 23 (2), pp120-125

Le Roux, P.A.L. and du Preez, C.C. 2008. Micromorphological evidence of redox activity in the soft plinthic B horizon of a soil of the Bainsvlei form in an arid bioclimate. *South African Journal of Plant and Soil*, 25 (2), pp 84-91

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

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

Lin, H. 2012. Hydropedology: addressing fundamentals and building bridges to understand complex pedologic and hydrologic interactions. *In* (Ed.) Lin, H. Hydropedology: synergistic integration of soil science and hydrology. Academic Press (Elsevier), Oxford, pp. 3-39.

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.

Van der Waals, J.H. 2013. Soil colour variation between topsoil and subsoil horizons in a plinthic catena on the Mpumalanga Highveld, South Africa. *South African Journal of Plant and Soil* **30**(1): 47–51

Van Tol, J.J., Le Roux, P.A.L., Lorentz, S.A., and Hensley, M. 2013a. Hydropedological Classification of South African Hillslopes. *Vadose Zone Journal*, 12 (4) (electronic web copy).

Van Tol, J.J., Hensley, M., and Le Roux, P.A.L. 2013b. Pedological criteria for estimating the importance of subsurface lateral flow in E horizons in South Africa soils. *Water SA*, 39 (1), pp 47-56.

Van Tol, J.J., Le Roux, P.A.L., Hensley, M., and Lorentz, S.A. 2010a. Soil as indicator of hillslope hydrological behaviour in the Weatherley Catchment, Eastern Cape, South Africa. *Water SA*, 36 (5), pp 513-520.

Van Tol, J.J., Le Roux, P.A.L., and Hensley, M. 2010b. Soil indicators of hillslope hydrology in the Bedford catchments, South Africa. *South African Journal of Plant and Soil*, 27 (3), pp 242-251.

Van Tol, J.J., van Zijl, G.M., Riddell, E.S., and Fundisi, D. 2015. Application of hydropedological insights in hydrological modelling of the Stevenson Hamilton Research Supersite, Kruger National Park, South Africa. *Water SA,* 41 (4), pp 525-533.

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

Van Zijl, G.M., and Le Roux, P.A.L. 2014. Creating a conceptual hydrological soil response map for the Stevenson Hamilton Research Supersite, Kruger National Park, South Africa. *Water SA*, 40 (2), pp 331-336.

Van Huyssteen C.W., Ellis, F., and Lambrechts, J.J.N. 1997. The relationship between subsoil colour and degree of wetness in a suite of soils in the Gabrouw district, western Cape II. Predicting duration of water saturation and evaluation of colour definitions for colour-defined horizons. *South African Journal of Plant and Soil* 14 (4), 154– 157.

Van Huyssteen, CV Hensley M and le Roux PAL, 2009. Refining the interpretation of orthic horizons in South Africa. *Eurasian Soil Science*, 42 (13), pp 1443-1447.

Van Huyssteen, C.W., le Roux, P.A.L., Hensley, M., and Zere, T.B. 2007. Duration of water saturation in selected soils of Weatherley, South Africa . *South African Journal of Plant and Soil,* 24 (3), pp 152-160.