REPORT

WETLAND ASSESSMENT, CONSERVATION, MANAGEMENT AND REHABILITATION IN MINING ENVIRONMENTS ON THE MPUMALANGA HIGHVELD

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WETLAND ASSESSMENT, CONSERVATION, MANAGEMENT AND REHABILITATION IN MINING ENVIRONMENTS ON THE MPUMALANGA HIGHVELD

1. INTRODUCTION

1.1 TERMS OF REFERENCE

I, Johan van der Waals, was appointed by Victor Munnik Consulting to generate a report on the various soil and wetland aspects that influence and determine the assessment, conservation, management and rehabilitation wetlands and their associated water and ecological related parameters in opencast (or shallow) mining environments on the Mpumalanga Highveld. The focus of the report is on the unpacking, elucidation and discussion of the biophysical determinants of wetland assessment and functionality in environments where landscape hydrology is compromised or altered through mining activities.

1.2 BACKGROUND

The conservation of wetlands within mining environments with the specific impacts poses several challenges. These challenges include 1) the correct assessment techniques for wetlands in opencast mining environments, 2) the correct assessment of hydrological drivers of the wetland systems, 3) integration of the hydrological data for the wetland with the surface and groundwater hydrological data and management objectives of the mine and catchment, and 4) implementation of the most desirable and economically viable rehabilitation approach taking into account the requirements of the regulator and commitments attainable in the EMP.

The biophysical context of most open cast coal mining operations is the Mpumalanga Highveld with its characteristic plinthic catena landscapes. The dominance of plinthic soils is a function of the specific geology, topography, climate and hydrology of the Highveld. The plinthic soils exhibit very specific morphology related to periodic wetness and hydrology and wetland delineation exercise are readily conducted with a large degree of accuracy in this landscape. The philosophical approach to wetland delineation and the management and mine planning approaches based on these philosophies are inherently flawed due to the broader lack of understanding regarding the hydrological linkages in the plinthic catena landscapes.

1.3 AIM OF THIS REPORT

The aim of this report is to provide a systematic breakdown of the different components required for adequate wetland assessment, focussing specifically on hydrologically based assessment processes. This entails the description and elucidation of hydrological functioning of landscapes in order to propose realistic landscape and wetland management and rehabilitation procedures.

2. AREA LOCALITY AND DESCRIPTION

2.1 DISCUSSION AREA BOUNDARY

The area of discussion in this document is the Mpumalanga Highveld or the Eastern Highveld of South Africa (**Figure1**). Due to the dominant geology this is the area that currently constitutes the dominant opencast mine coal production area.

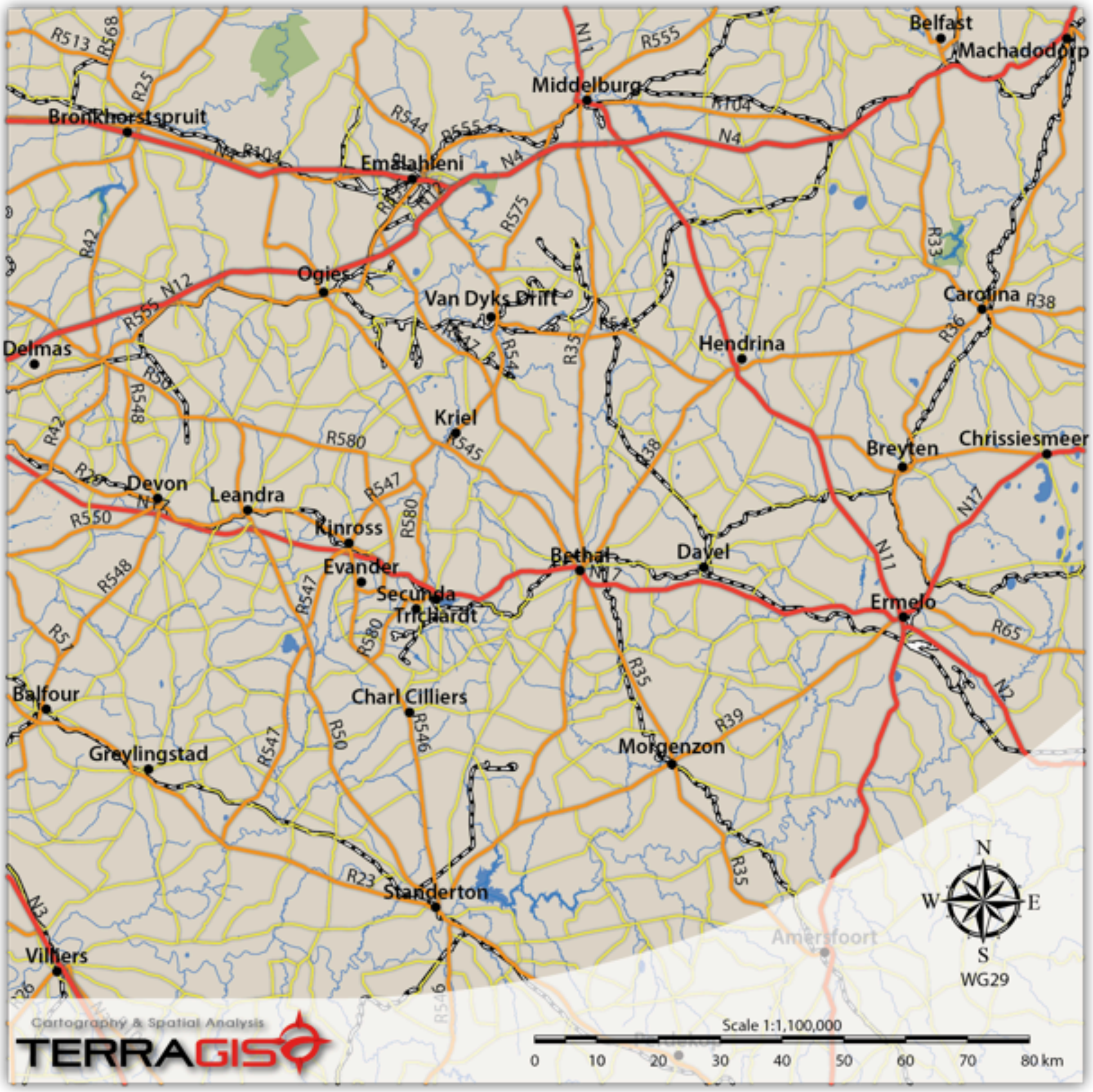

Figure 1 Locality of the discussion area

2.2 LAND TYPE DATA AND SOILS

Land type data for the area 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 land types associated with coal reserves and coalmines on the Mpumalanga Highveld are predominantly of the Ba and Bb land types (**Figure 2**).

A dedicated discussion of the Ba and Bb land types is provided in section 5 of this report.

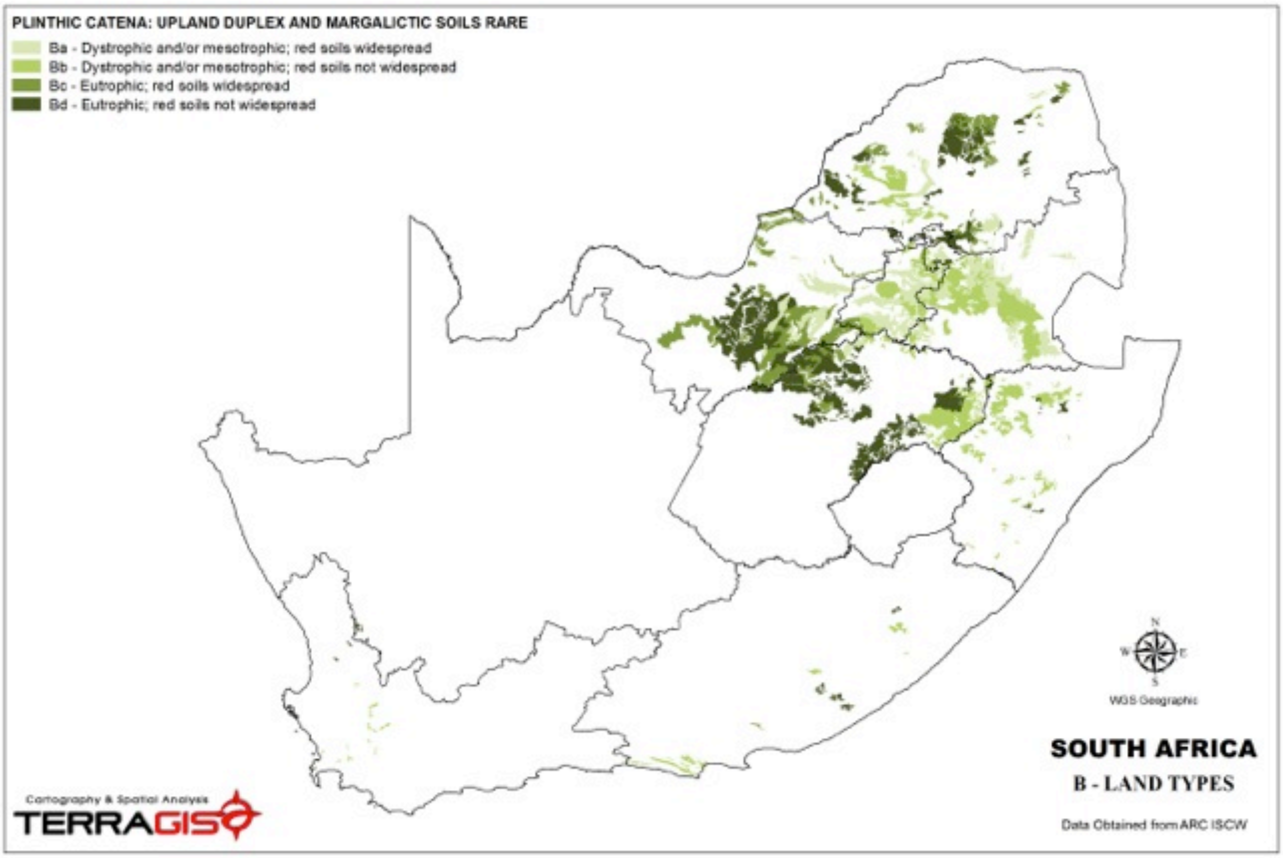

Figure 2 Plinthic land types in South Africa

Figure 3 provides a generalised soil associate map for the investigation area. The dominance of the plinthic landscapes is evident and is the main motivation for the focus of this investigation in the form of discussions on the impacts of opencast coal mining activities. Even though a large area of the Mpumalanga Highveld consists of structured soil landscapes these will not be discussed in detail as the coalmines in these areas are predominantly deeper and underground mines. The impacts of coal mining activities in structured and vertic soil environments warrants a separate discussion due to the distinct difference in landscape and soil hydrological drivers.

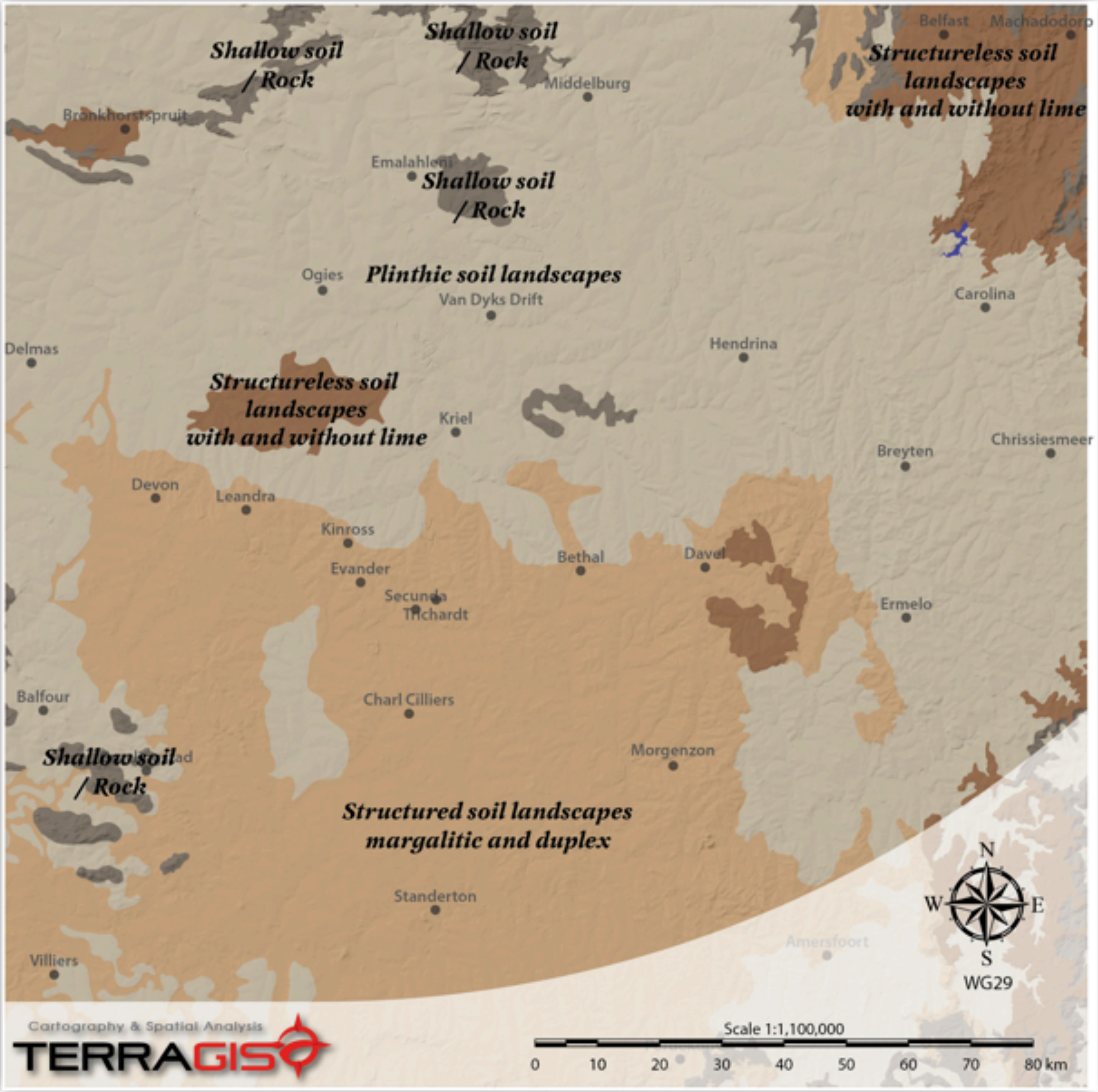

Figure 3 Generalised soil associate map of the investigation area

2.3 TOPOGRAPHY

The topography of the investigation area is undulating to hilly with very distinct drainage depressions and watercourses feeding some of the main rivers in South Africa (**Figure 4**). The eastern and southern sections are the highest with a decrease in altitude from east to west and towards the north.

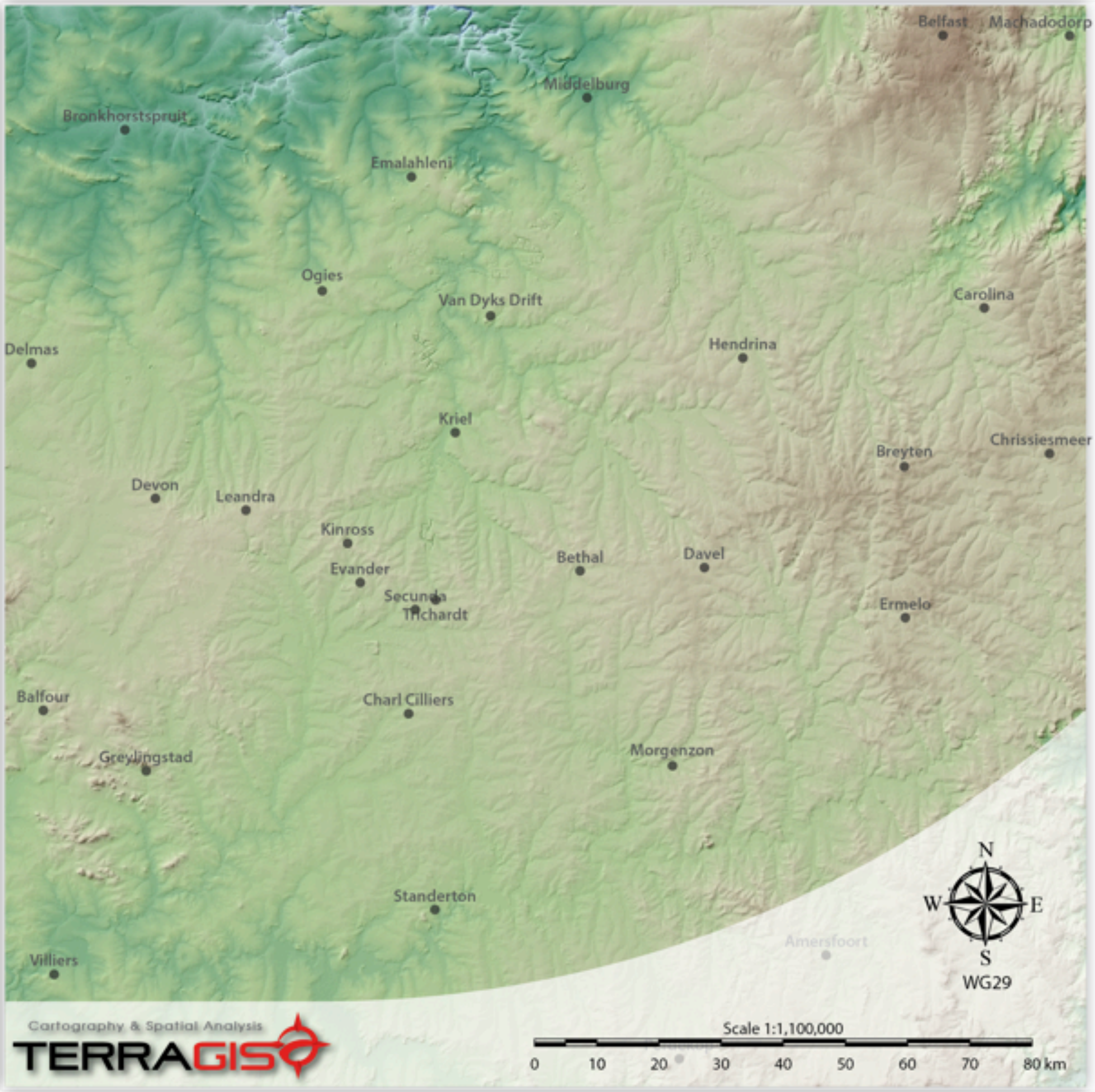

Figure 4 Topography of the investigation area

3. STATUTORY CONTEXT

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

Disclaimer: The following section represents a discussion that I use as standard in describing the statutory context of wetland delineation and assessment. This implies that the section is verbatim the same as in other reports provided to clients and the authorities. Copyright is strictly reserved.

3.1 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."

3.2 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;"

3.3 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.

3.4 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).

3.4.1 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."

3.4.2 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."

3.4.3 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."

3.4.4 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).

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, railway lines and other substrate disruptive activities, which reduces or changes wetland habitat directly or through changes in inundation patterns.		
Biota			
Terrestrial Encroachment	Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions.		
Indigenous Vegetation Removal	Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion.		
Invasive plant encroachment	Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading).		
Alien fauna	Presence of alien fauna affecting faunal community structure.		
Overutilisation of biota	Overgrazing, Over-fishing, etc		
TOTAL MEAN			

<u>Scoring guidelines per attribute:</u>
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.

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 should 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 should be elucidated and contextualised.

Biological Criteria

- "Terrestrial encroachment: Consequence of desiccation of wetland and encroachment of terrestrial plant species due to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions." Comment: Again this is a very relevant concept but 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 should be elucidated and contextualised.
- "Indigenous vegetation removal: Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion."
- "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

3.4.5 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

3.5 NATIONAL NORMS AND STANDARDS FOR THE REMEDIATION OF CONTAMINATED LAND (NSCLA) (GN R.331 OF 2014)

3.5.1 Background to the NSCLA

The assessment of contaminated land is conducted in accordance with the National Norms and Standards for the Remediation of Contaminated Land (NSCLA) (GN R.331 of 2014). The NSCLA is an outflow of Part 8 (Sections 35 to 41) of the National Environmental Management Waste Act (Act 59 of 2008) and it was implemented on the 2nd of May, 2014 (Papenfus, et al, 2015).

3.5.2 Limitations of the NSCLA

Papenfus et al, (2015) discusses some of the challenges regarding the use of the NSCLA in various soils. These challenges pertain to the main assumptions that were made in the generation of the soil screening values (SSV) in that soil pH values were assumed to be 7 and set distribution coefficients (K_d values – indicative of the soil and water mobile fraction of a particular element/compound) were adopted. The thrust of the challenge is the fact that soils are much more variable and investigations conducted by Papenfus et al, (2015) confirm these concerns. The implication is that the NSCLA cannot be used with certainty as the variables in natural and polluted environments render the SSV values moot.

The NSCLA does not address acidified soils and the subsequent alteration of pollutant mobility. Although the NSCLA addresses sulphate as an anion salt it is clear that soil variation in terms of natural sulphate and gypsum contents has not been considered.

The NSCLA also omits elements that are of concern in mining environments such as uranium and does not indicate how to deal with highly acidified and salt impacted soils and materials present in current and old mining impact areas.

3.6 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?
6. What are the site and wetland remedial actions to be taken to assess and prevent pollutant mobilisation on the site and reduce the risk of future site development to workers and inhabitants / land users.

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 not 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.

4. GAPS IN EXISTING WETLAND ASSESSMENT TOOLS

4.1 PHILOSOPHICAL AND PRACTICAL CHALLENGES REGARDING THE FOUNDATION OF WETLAND ASSESSMENT

Leading up to and during the generation of the first rehabilitation report it became evident that there were several challenges regarding the assessment and delineation of wetlands. Most of these challenges are grounded in the philosophy underpinning wetland science and assessment. Although these aspects will be addressed in detail later in the report the essence of the problem includes:

1. Wetlands are often viewed as discrete entities with measurable properties and boundaries. Most wetlands, however, are in essence entities that are visible reflections/expressions of water in a landscape. It is the hidden component of wetlands, the water feeding mechanisms and processes in the larger landscape, which are often overlooked or merely addressed superficially. This implies that for a thorough wetland assessment all hydrological parameters have to be elucidated in as much detail (at least conceptual) as is practically achievable.
2. Wetland assessments are often biased towards ecological parameters. Although this is understood and supported to a degree the main relevance of wetland assessments stems from the inclusion of the definition in the National Water Act as well as its link with water courses. The fact that wetlands are protected in the National Water Act therefore implies a bias towards the water resource with the ecological parameters being dependent on the water – and not the other way round.
3. Due to the linked nature of wetlands and their supporting landscape it is evident that development or land use impacts that do not alter the landscape's hydrology have very little impact on the hydrological functioning of the wetland. The opposite is true for impacts that alter the landscape's hydrology in such a way that surface, subsurface and groundwater flow paths of water are severed or severely modified (examples include opencast mining operations and urban developments with extensive excavated foundations). It follows therefore that the delineation, ecological assessment and superficial hydrological assessment of a wetland cannot provide meaningful answers regarding the maintenance (through mitigation and adequate intervention) of water flow regimes – regimes that are responsible for the presence and functioning of the wetland in the first place.

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

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

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

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

4.2 WETLAND DELINEATION CHALLENGES

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

Although a major step forward in the approach to wetlands, these guidelines were published in 1999 and it was without considering detailed soil morphological and chemical parameters that influence the expression of wetness in soil. As the science has developed and expanded it has become apparent that the original approach is limited and scientifically flawed in some instances. This aspect has major ramifications in the event that prosecutions are based on such information. The detail regarding the proposed changes to the guidelines cannot be discussed here but will be elucidated in a set of documents currently in preparation for discussion by DWA and the broader scientific fraternity.

4.2.1 Detailed Disaggregation and Interpretation of the Definition of a Wetland

Wetlands are defined in the NWA as:

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

From a scientific, practical and legal perspective the interpretation of the definition poses a number of challenges. In order to address the challenges it is necessary to disaggregate the definition and discuss the challenges as follows:

1. "Land which is transitional between terrestrial and aquatic systems …": this implies areas with variable hydrological and ecological characteristics of which the variation can be described as the linear (assumed) transition from one pole (terrestrial/dry) to another (aquatic/wet).
2. "… where the water is usually at or near the surface …": Although the regular condition is implied there is no reference to any empirical interpretation. This aspect therefore introduces uncertainty and the potential for significantly variable interpretation.
3. "… or the land is periodically covered with shallow water …": This statement introduces and alternative to the above statement but, again there is no reference to any empirical interpretation and it therefore introduces uncertainty and the potential for significantly variable interpretation
4. "and which land in normal circumstances …": Normal circumstances are not defined with a subsequent introduction of uncertainty and variability in interpretation. According to Mernewecke and Kotze (1999) "normal circumstances" in the definition refers to "without human modifications".
5. "… supports or would support vegetation typically adapted …": Vegetation species and communities can be described and named and can provide distinctly measurable indicators of wetland conditions. This is therefore a clear indicator if the requisite scientific knowledge is available.
6. "… to life in saturated soil.": Soil saturation (degree, intensity and duration) can be measured empirically (although at significant financial and time cost) or deduced from the soil morphology to varying degrees of certainty. The soil morphological indictors (all functions of soil forming factors and processes) have been studied and described extensively in the soil science literature.

An evaluation of the disaggregation above yields that the only certain descriptors, from a scientific, practical and legal perspective, are vegetation and soil indicators. In this sense the then Department of Water Affairs and Forestry (DWAF) generated "Resource Directed Measures for the Protection of Water Resources" (DWAF, 1999). In Appendix W6 of the document guidelines for the delineation of wetlands are provided (Mernewecke and Kotze, 1999). In this document distinct emphasis is placed on the use of soil characteristics in conjunction with vegetation characteristics (if present) for the delineation of wetlands. The document also refers specifically to the fact that a certain degree of proficiency in terms of soil classification with the SA Taxonomic System (Soil Classification Working Group, 1991) is required for such surveys. In the event of challenging sites it advises that qualified soils scientists conduct the delineation exercises.

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

4.2.2 Auditable Process

The manual aims to provide a "… scientifically robust, simple to apply and … standardised, affordable and auditable method of spatially defining …" hydrologically sensitive areas.

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

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

4.2.3 Wetland Indicators

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

1. The topographic indicator is limited to wetlands that are associated with surface topographical variation and it is therefore limited to specific landscape positions. The topographic indicator does not make allowance for variation in physical properties below the soil surface. In this sense aspects such as return-flow zones and interflow zones (that

often occur in midslope or footslope positions) are not accommodated. In practice these areas prove the most problematic in terms of interpretation and delineation.

2. The vegetation indicator is limited predominantly by regional and local variation in edaphic and climatic conditions. The regionalization of vegetation guidelines should address this aspect satisfactorily.
3. The soil form indicator suffers from a number of limitations namely:
   a. Soil forms present in an area do not necessarily indicate wetlands. Soil forms have to be viewed in wider context as their classification is also not an auditable process. (Unfortunately pedologists often have significant variation in interpretation!) The presence of a specific soil form may indicate the presence of a wetland though but this aspect will have to be confirmed on the site through additional indicators.
   b. Certain soil forms are erroneously assigned to specific wetland conditions viz. the Rensburg that is assigned to permanent wetland areas but which is actually characterized by dominance of smectite clay minerals that can only form in seasonal wetland conditions. This discussion warrants a report in itself and will therefore not be further elucidated in this report.
   c. Improved elucidation of the presence of soil forms in landscapes is required. This is especially relevant as the roles of the soils in wetlands and wetland functioning is often poorly understood. On this topic there are current research projects underway that focus on the description of hillslope hydrology and the soil morphological indicators of such hydrology. Linked to this is the established concept of soil variation along a topographic sequence (catena concept) for specific environments or land types. This aspect links up to the concept of soil formation (pedogenesis) and hydropedology which is finding new and very relevant application in the elucidation of environmental processes.
4. The soil wetness indicator is in all probability the most problematic as there are numerous physical and chemical determinants. The main indicator of reduction is the very handy redox morphological variation of Fe – and this is the assumption that most wetland delineation exercises are based upon. (A dedicated discussion of this aspect is provided later in the report.) There is a distinct variability in expression of the quantity / intensity parameters of mottles in different soil environments. This variation is in most cases linear for simple parameters but soils always exhibit combinations of variable parameters that make linear interpretation highly suspect and problematic. A brief elucidation of the problem components include:
   a. The Fe content and reserve of soils and parent material vary significantly and impart varying expression of Fe redox morphology with consequent challenges in interpretation. This aspect induces variation between landscapes with homogenous parent materials (within the specific landscape) or within landscapes where variation in parent materials is found within the landscape.
   b. The Mn content of soils influence redox poise processes that in turn influence the expression of Fe redox morphology. Additional sources of variation include:
      i. Textural influences on expression of mottles;
      ii. Climatic / rainfall gradients; and

        iii. Variation in pH gradients linked to electron activity (Eh). The redox morphology changes linearly with these parameters with the distinct expression of mottles (intensity, colour, contrast) decreasing linearly with increasing pH (even if Eh remains constant).
    c. Soil colour varies significantly between different chemical and physical environments (even if pH and Eh remains relatively similar) and as such one set of wetness criteria cannot be applied universally.
    d. With the advancement of science concepts that were accepted to be true 30 years ago are now considered erroneous. A distinct example of this is references to “blue green colouration” in soils classification texts that indicate conditions of distinct saturation in those texts. This colouration has, with recent research, been proven to occur under very specific redox conditions that indicate only intermediate reduction, even though the soil may be saturated. The historically held conviction that “saturation equals reduction” has been proven to not apply religiously in all environments. It is therefore imperative that the application (wetland delineation) keeps up with the science.

4.2.4 Proposed Improvements

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

1. Updating of the current delineation guidelines (including the draft version from 2008) to serve as a national standard document indicating variability in SA (broadly) through:
    a. Improvement of the landscape indicator to include seepage (including interflow, seepage and return-flow wetlands)
    b. Improvement and correction of the soil form indicator description. Introduction of the concept of “driest soils on crests and wettest soils in depressions” as a method of determining the range of soil variation in specific landscapes.
    c. Improvement and correction of the soil wetness indicator description to reflect differing pH/Eh/parent material environments. Linking of soil wetness indicators to the concept of “driest soils on crests and wettest soils in depressions” as a method of determining range of soil variation in different landscapes.
    d. Introduction of measuring and inference tools for generation of empirical data on wetness.
    e. Introduction of regional and/or land type based detailed guidelines that will include:
        i. Localized topographic indicators and pointers / aids;
        ii. Localized soil form sequences (catena) and soil form variability. (Utilize method of soil form variation range in land type); and
        iii. Localized variation in terms of soil wetness indicators. (Utilize method of soil form variation range in land type).

2. Correction of scientific inaccuracies and inconsistencies in the current documents and improvement of the principles and guidelines to a proper standard through focused research, peer review and formal publication.

4.3 PES AND EIS

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

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

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

Although it is understood that DWA prescribes the PES and EIS values for broader planning purposes these parameters are near nonsensical in the context of Leliefontein. The main reason being that data does not exist to generate a rating for the pre-mining condition of the wetlands/watercourses. This is exacerbated by the fact that a number of water courses were mined out completely. The mined watercourses therefore do not exist anymore and can therefore not be rated. During the rehabilitation planning for the site new water courses will have to be constructed and these will differ substantially from the original ones.

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.

In order to discuss the procedures followed and the results of the wetland identification exercise it is necessary at the outset to provide some theoretical background on soil forming processes, soil wetness indicators, water movement in soils and topographical sequences of soil forms (catena).

5.1 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.

5.1.1 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.

5.1.2 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.

5.2 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.

5.3 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).

5.4 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 5** provides a simplified schematic representation of an idealised landscape (in “profile curvature”. The total precipitation (rainfall) on the landscape from the crest to the lowest part or valley bottom is taken as 100 %. Most geohydrologists agree that total recharge, the water that seeps into the underlying geological strata, is less than 4 % of total precipitation for most geological settings. Surface runoff varies considerably according to rainfall intensity and distribution, plant cover and soil characteristics but is taken as a realistic 6 % of total precipitation for our idealised landscape.

The total for surface runoff and recharge is therefore calculated as 10 % of total precipitation. If evapotranspiration (from plants as well as the soil surface) is taken as a very high 30 % of total precipitation it leaves 60 % of the total that has to move through the soil and/or geological strata from higher lying to lower lying areas. In the event of an average rainfall of 750 mm per year it results in 450 mm per year having to move laterally through the soil and geological strata. In a landscape there is an accumulation of water down the slope as water from higher lying areas flow to lower lying areas.

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

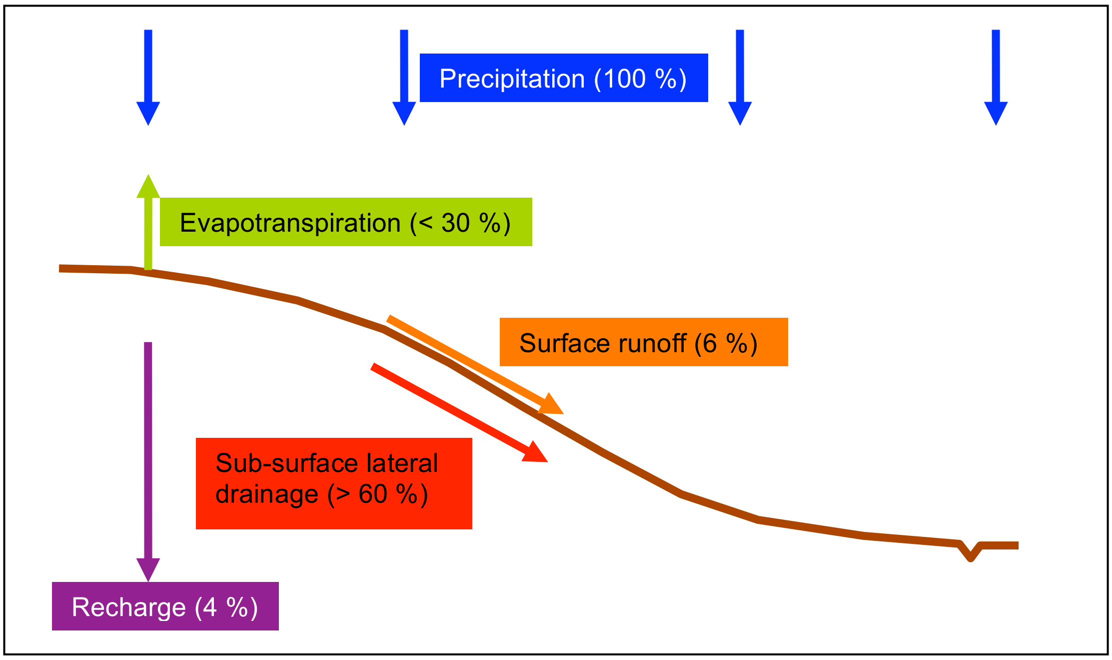

Figure 5 Idealised landscape with assumed quantities of water moving through the landscape expressed as a percentage of total precipitation (100 %).

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 6** provides a schematic representation of the different flow regimes that are usually encountered. 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 (referred to as response zone or soils); 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.

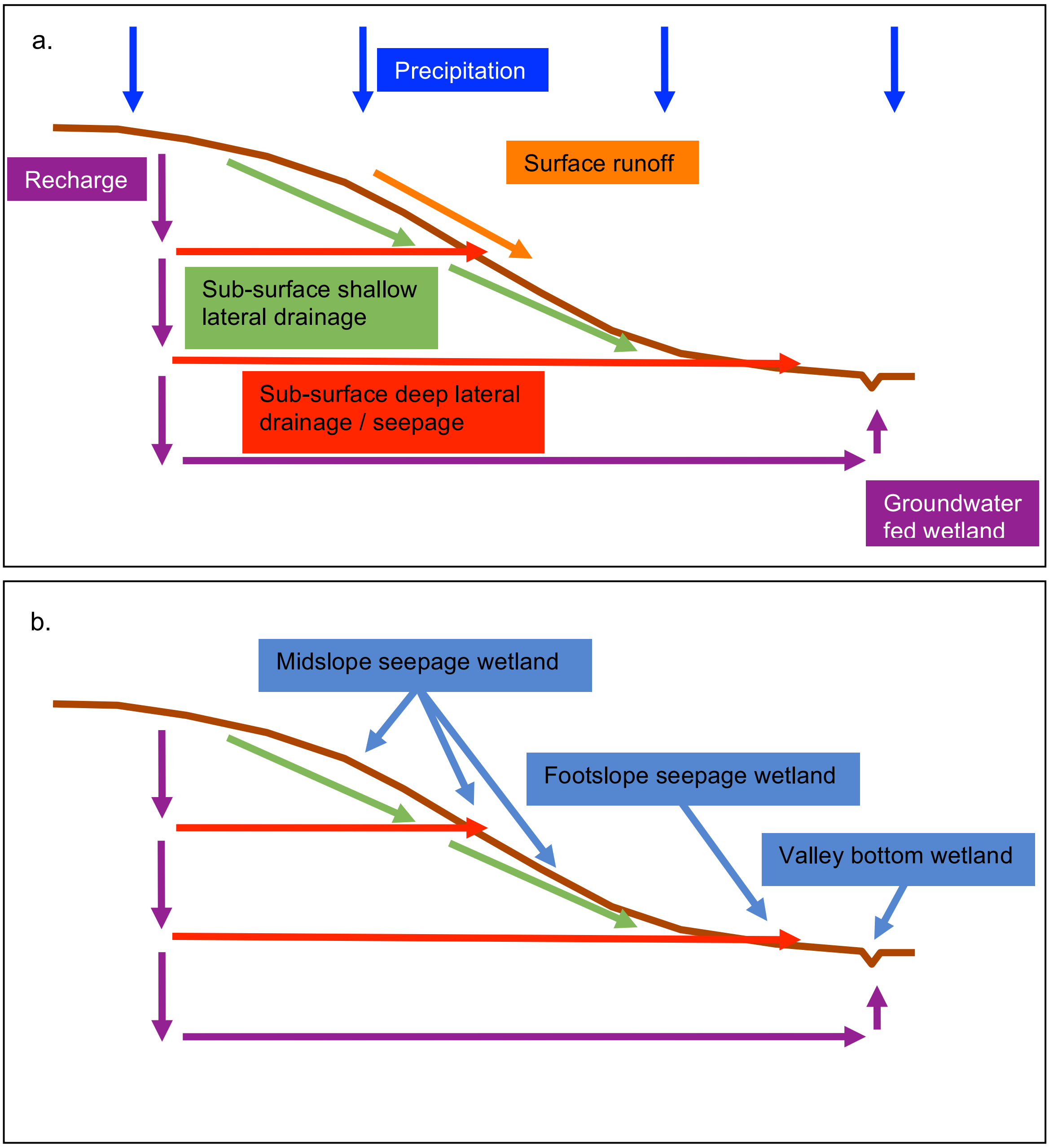

Figure 6 Different flow paths of water through a landscape (a) and typical wetland types associated with the water regime (b)

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 7** 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.

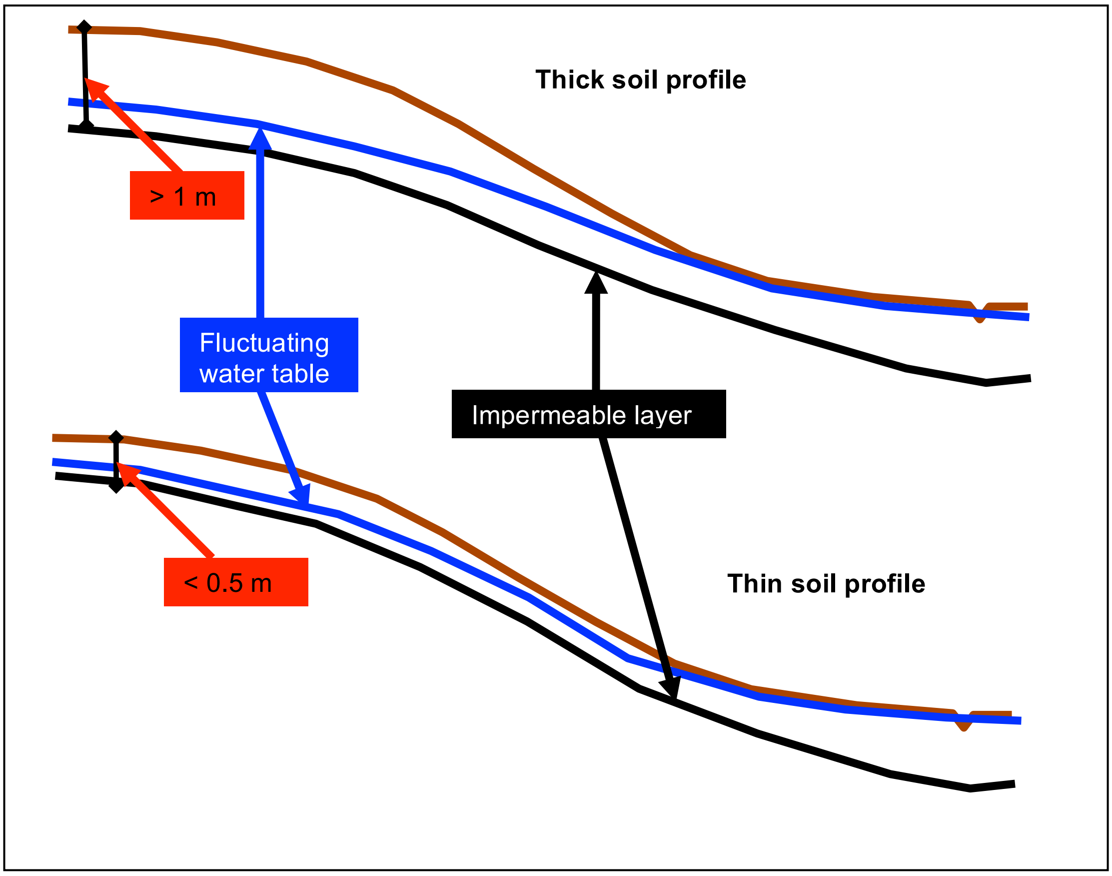

Figure 7 The difference in water flow between a dominantly thick and dominantly thin soil profile.

5.4 FREE DRAINING VERSUS INWARD FLOWING SYSTEMS

Free draining systems in this case refer to typical hillslopes where water drains towards the lowest point in the landscape and the flows out in a drainage feature or watercourse. Inward draining systems have no outflow (such as pans) and the dominant water removal is therefore through evaporation losses. **Figure 8** 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.

The dominant hydrological functioning of the landscapes can be assumed to be very similar if only the side slopes are considered. **Figure 9** provides and 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.

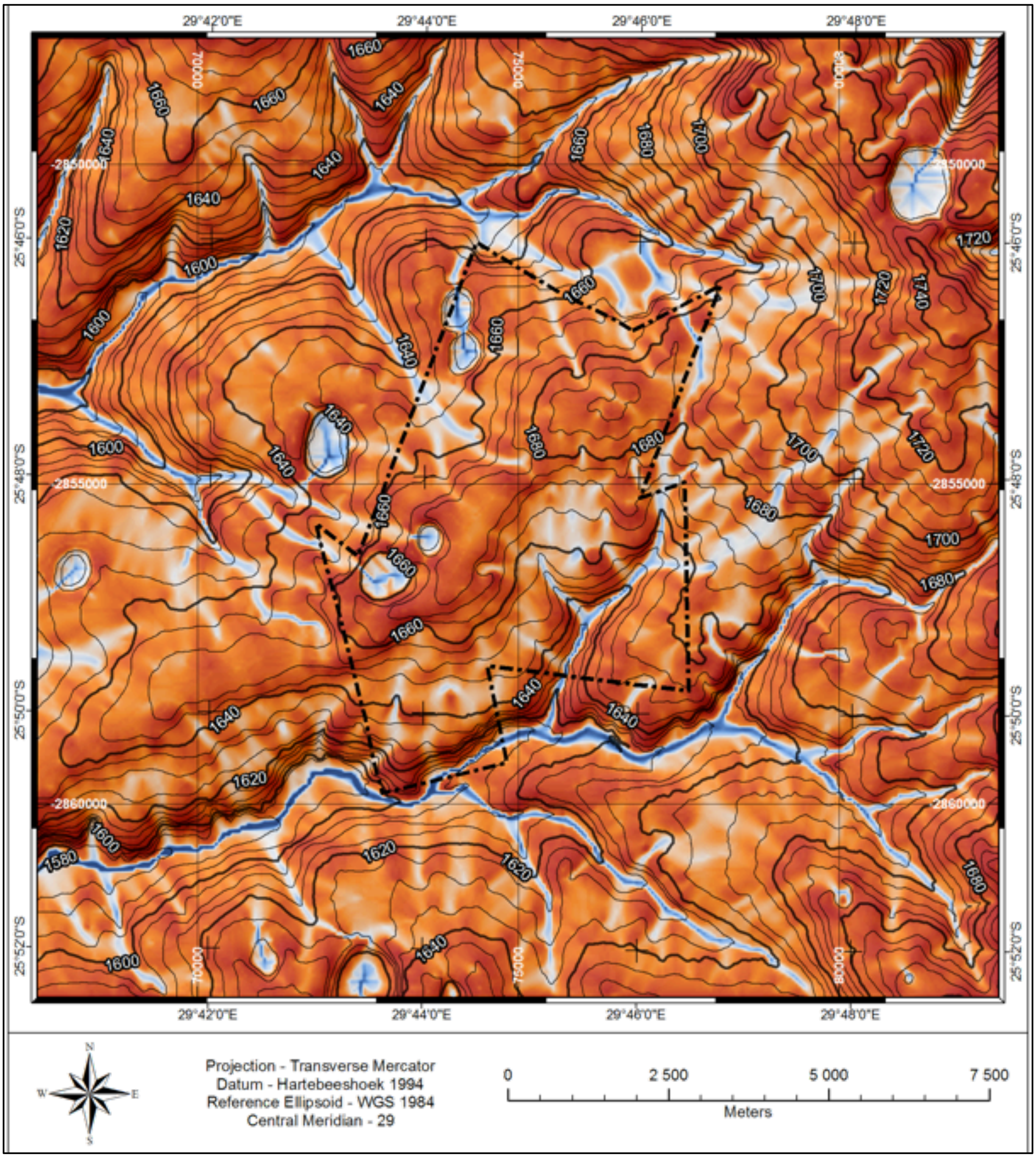

Figure 8 Topographic wetness index (TWI) of an area on the Mpumalanga Highveld indicating both free draining (linear) and inwardly draining (circular) features

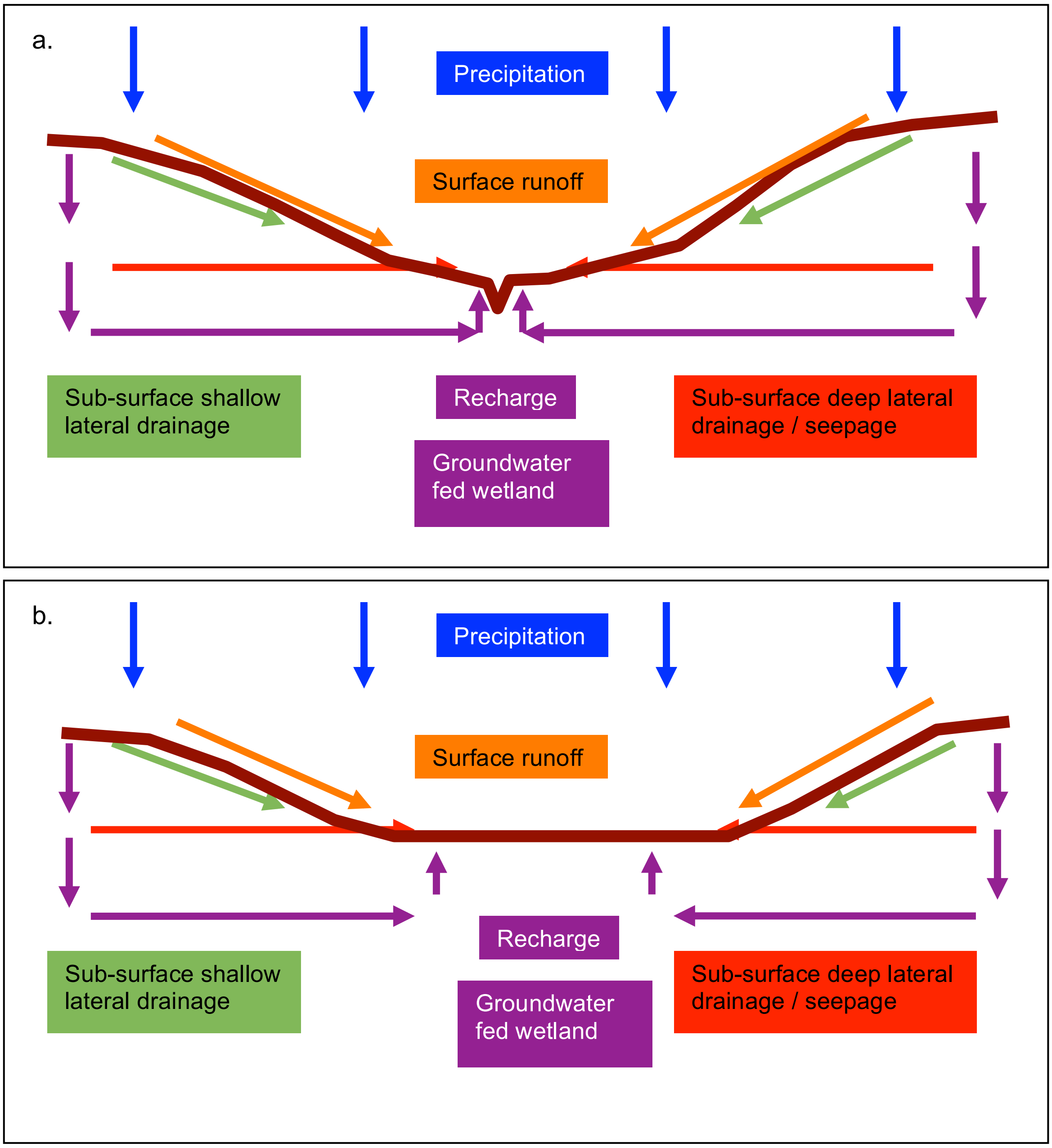

Figure 9 Similarity in flow paths for free draining (a) and inward draining (b) systems

5.5 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 10** 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.

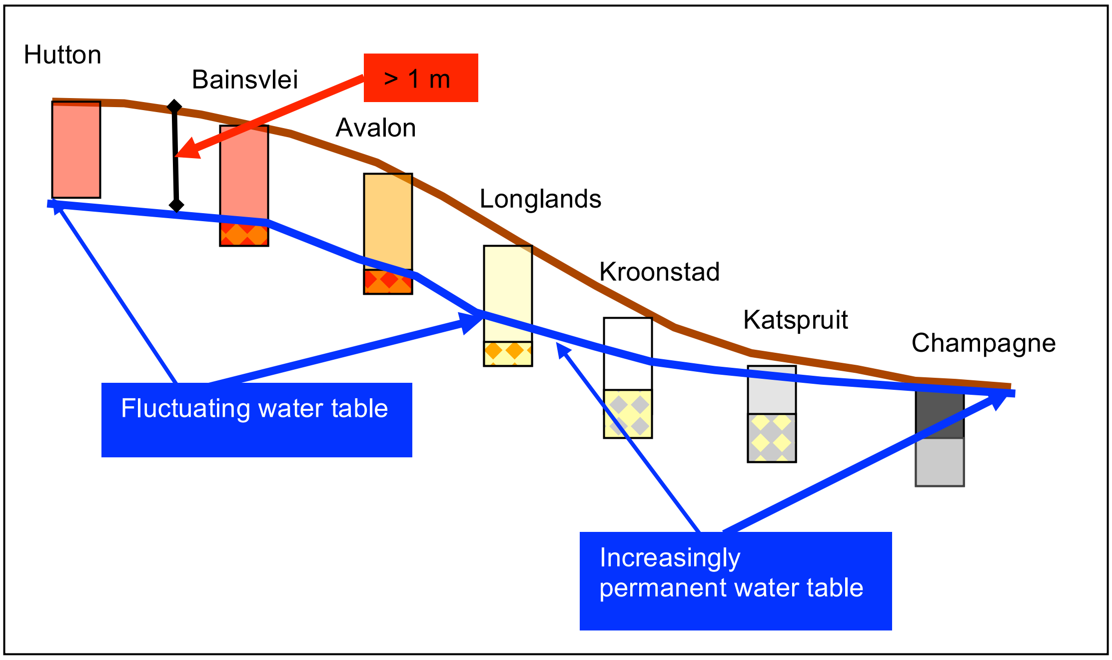

Figure 10 Idealised catena on a quartz rich parent material.

5.6 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 11** 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).

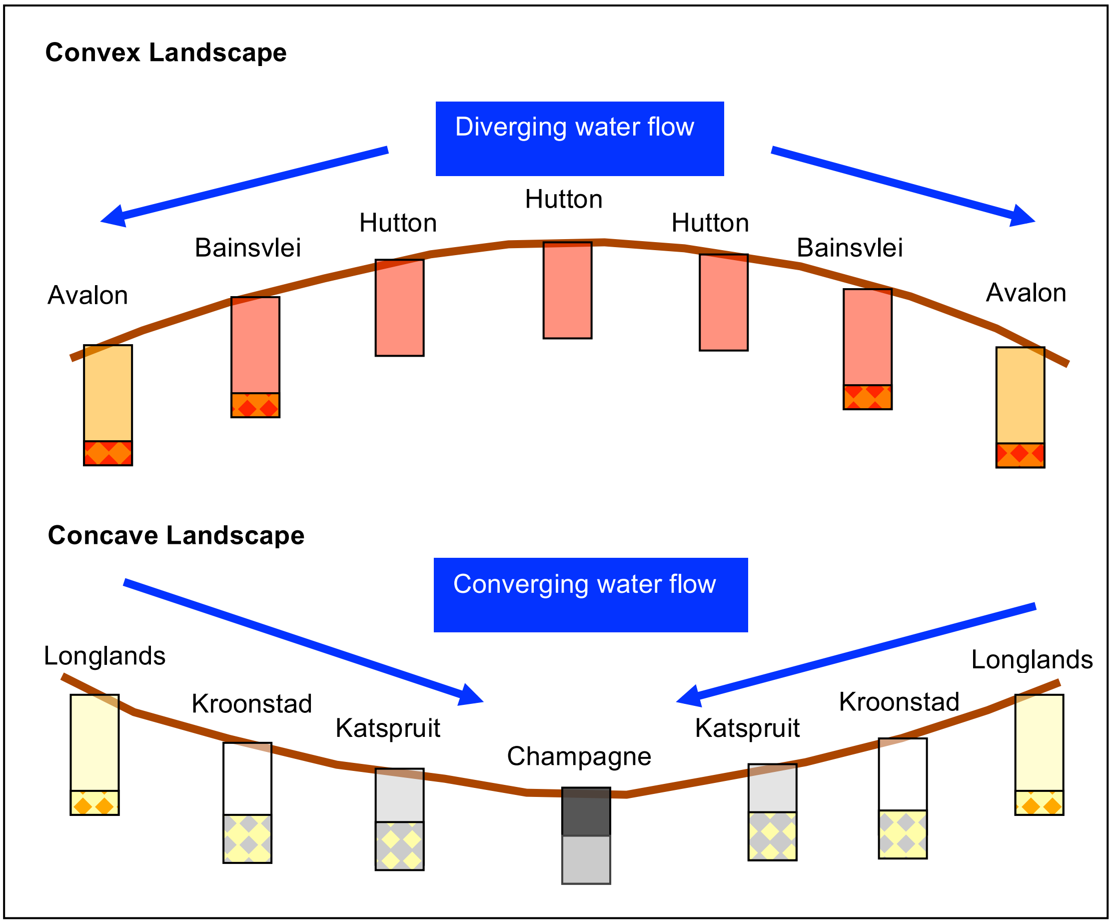

Figure 11 Schematic representation of the soils in convex and concave landscapes in an idealised catena

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

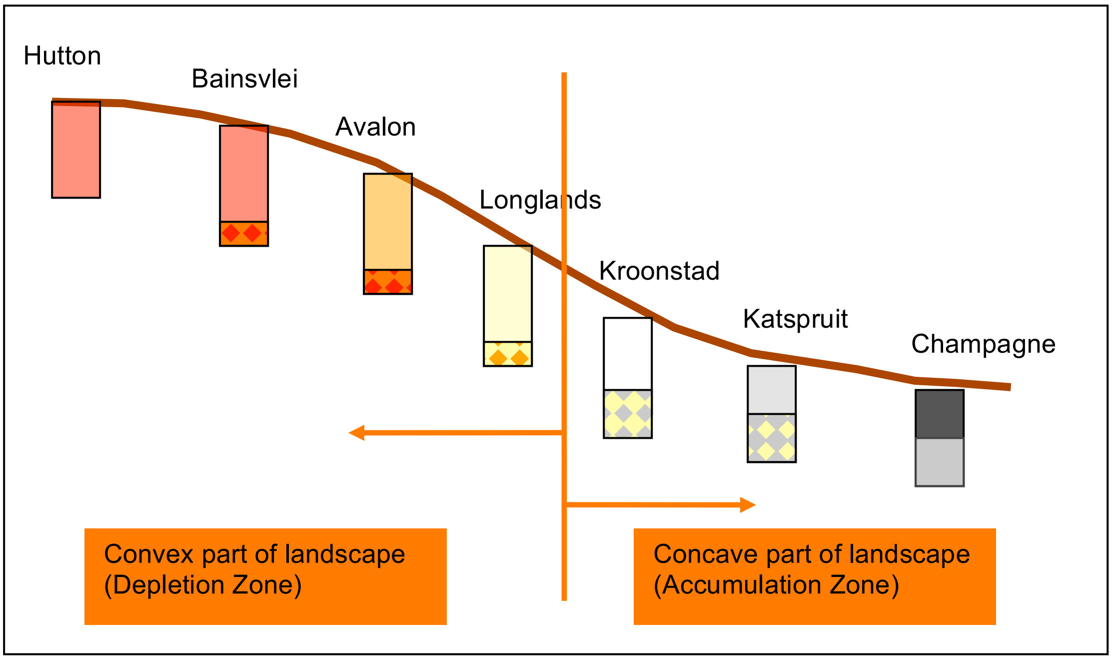

Figure 12 Schematic representation of the soils in a combined convex and concave landscape in an idealised catena

5.7 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 13**). 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.

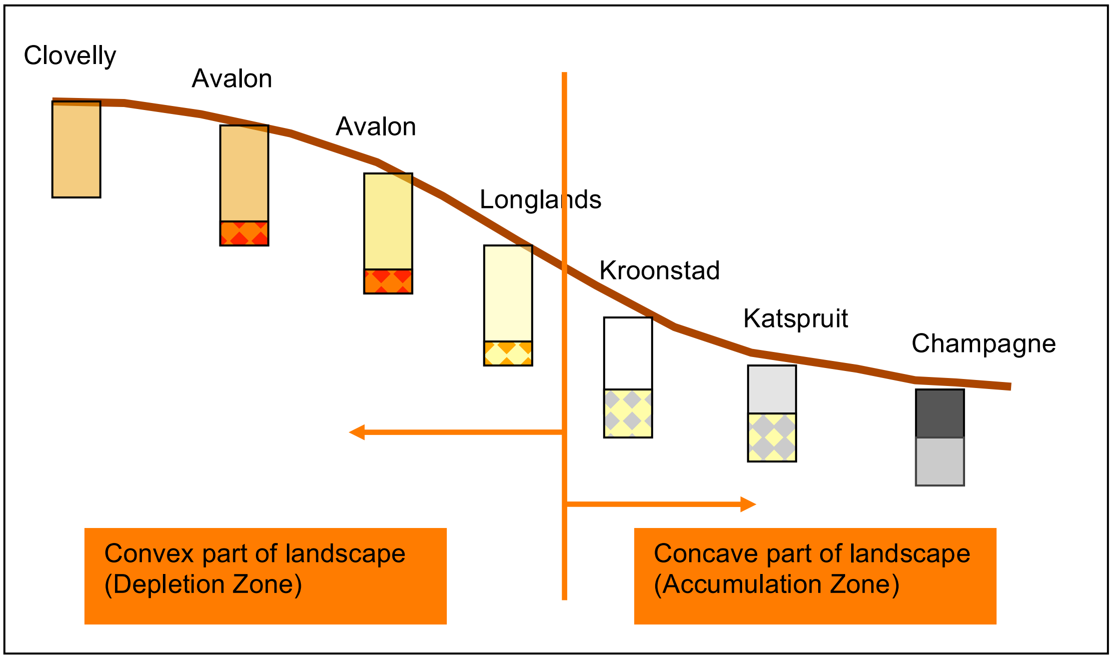

Figure 13 Schematic representation of the soils in a combined convex and concave landscape in an yellow and bleached soil dominated landscapes

5.8 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 14**). 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.
See figure 8 and explain agricultural potential and

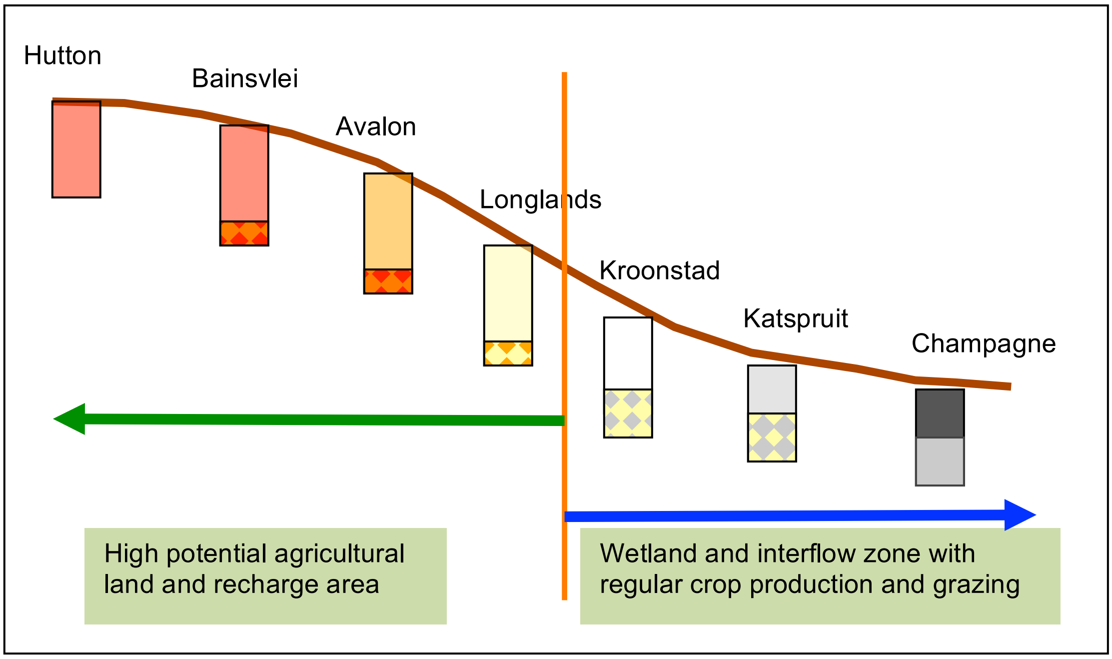

Figure 14 Schematic representation of the soils in a combined convex and concave landscape with an indication of land capability split along agricultural and wetland soils

5.9 IMPLICATIONS FOR WETLAND CONSERVATION IN OPENCAST MINING ENVIRONMENTS

5.9.1 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 15** provides a schematic representation (as contrasted with **Figure 6**) of water dynamics in an opencast mining environment in a free draining system. **Figures 16** to **23** indicate examples of the flow regimes on a specific mine indicated schematically in **Figure 15**.

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.

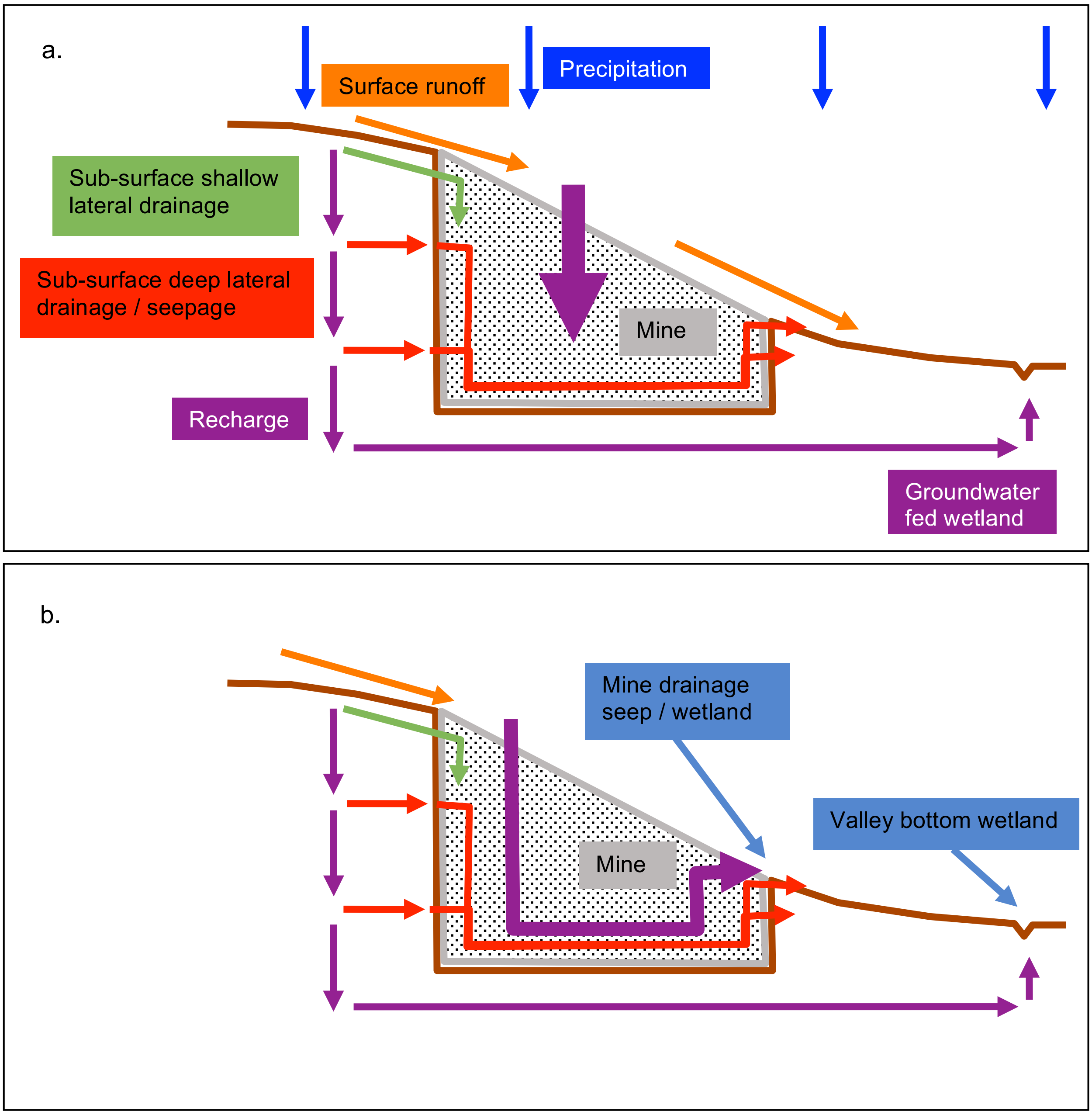

Figure 15 Different flow paths of water through a landscape with an opencast mine (a) and typical wetland types associated with the water regime (b)

Figure 16 Opencast mine profile indicating a thin bleached soil profile (arrow)

Figure 17 Opencast mine profile indicating 1) a thin bleached soil profile overlying 2) a hard plinthic layer and 3) weathered sandstone

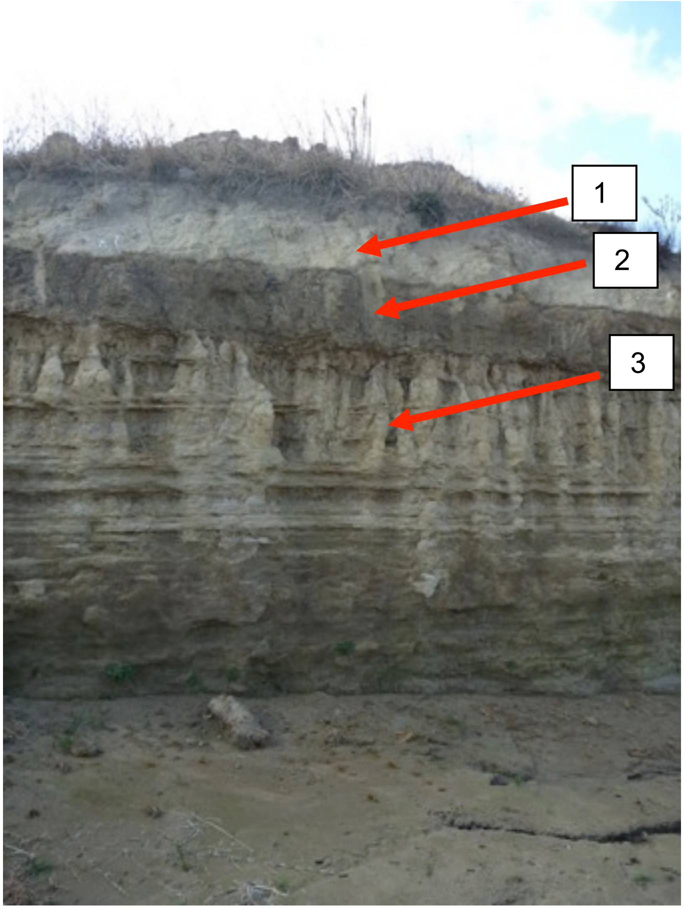

Figure 18 Opencast mine profile indicating 1) a thin bleached soil profile overlying 2) a hard plinthic layer and 3) weathered sandstone

Figure 19 Opencast mine profile indicating a distinct flow path (arrow) beneath the soil profile

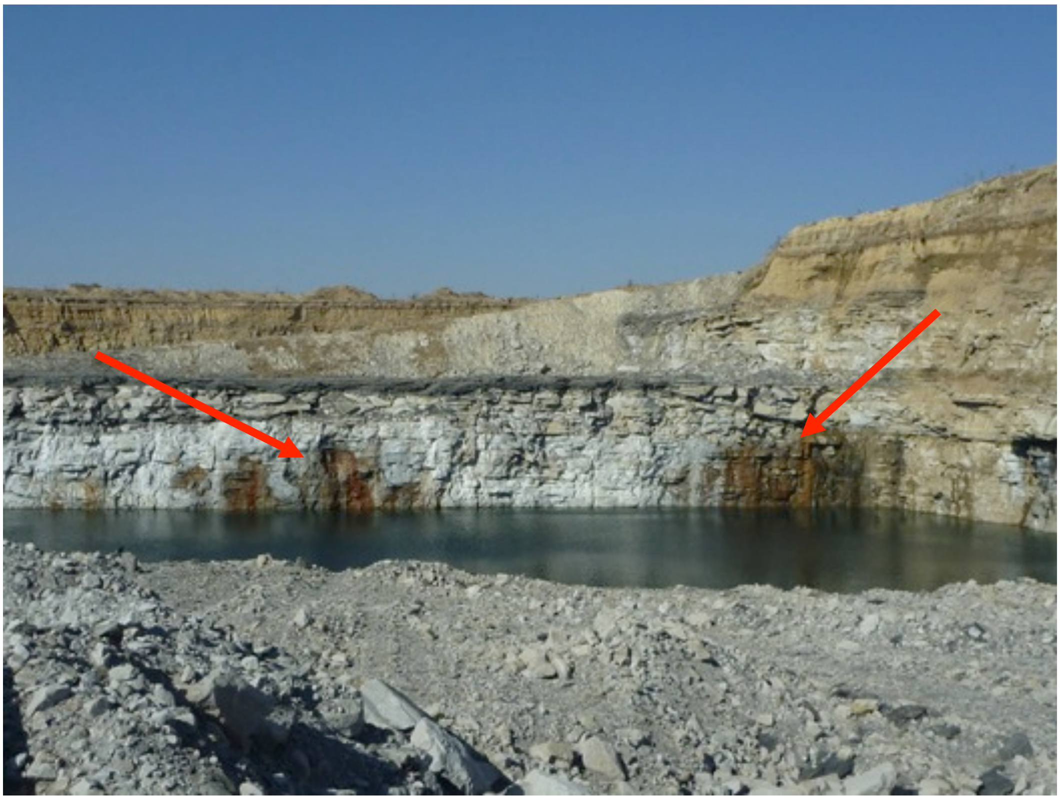

Figure 20 Opencast mine profile indicating a distinct flow path (arrows) in the bedrock

Figure 21 Opencast mine profile indicating numerous distinct flow paths (arrows) through the exposed profile (soil, weathered sandstone, carbonaceous shale, hard sandstone)

Figure 22 Road cutting with exposed flow (outside of a wetland area) at the end of July 2013

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

5.9.2 Inwardly Draining Systems

The same principles as above, but in this case for an inward draining system, are illustrated in **Figure 24**. 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 25** and **26** with the wetland area making up only a small section of the entire catchment. The drop in ground level surrounding the pan (**Figure 24b**) decreases water supply.

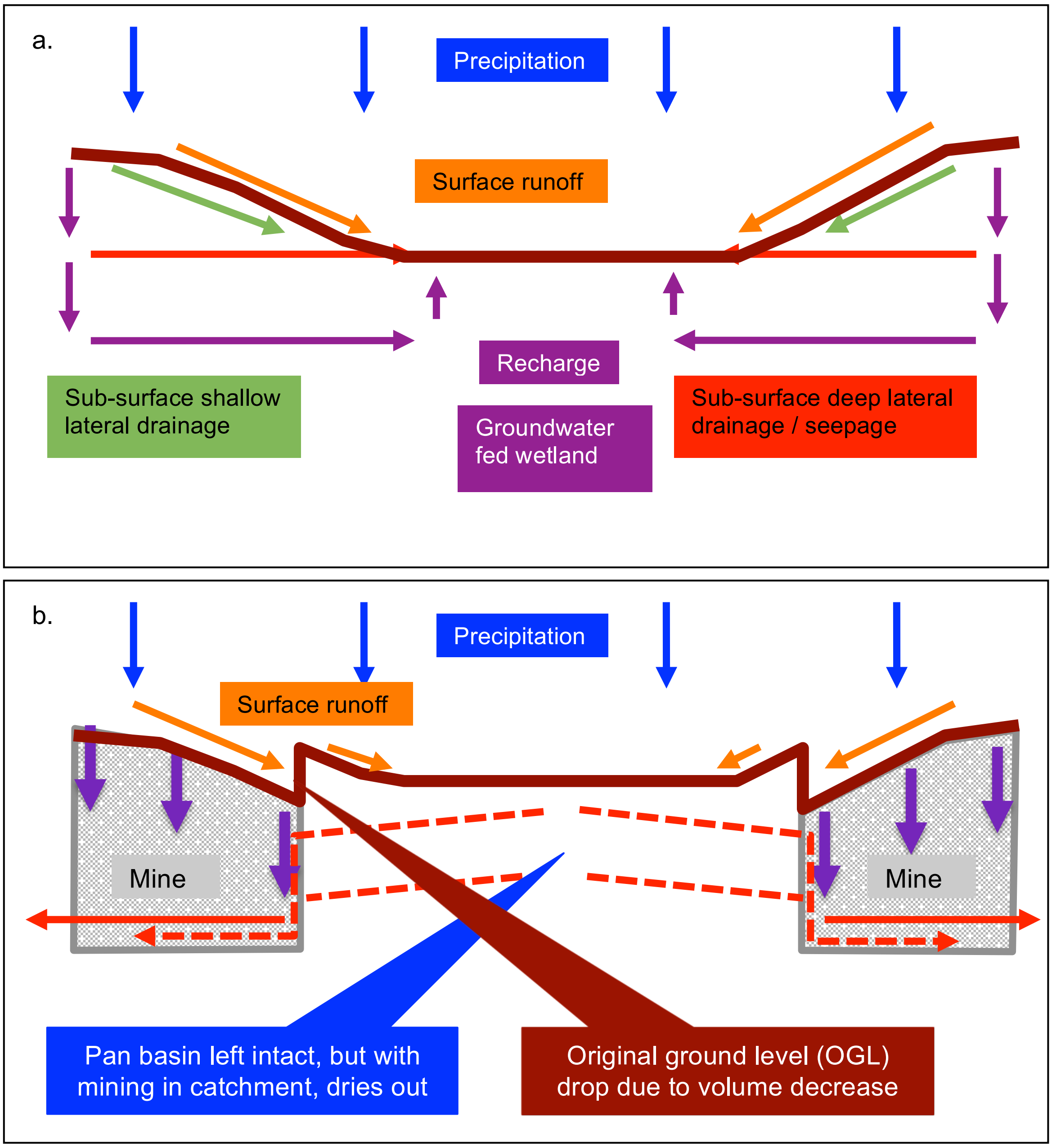

Figure 24 Water dynamics in an inwardly draining system under natural conditions (a) and under conditions where the area surrounding the depression has been mined (b)

Figure 25 Pan system with two pans that are not connected to drainage features on the surface

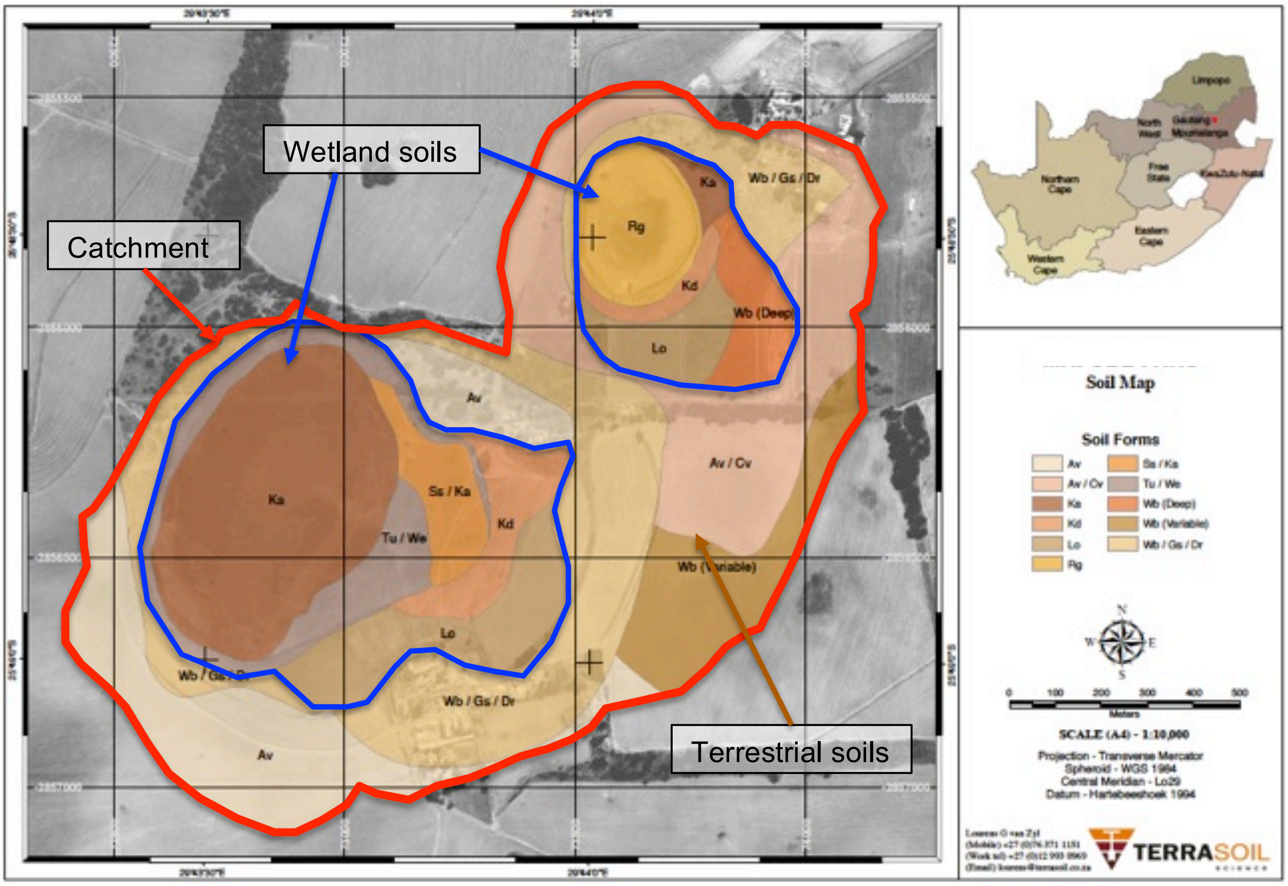

Figure 26 Soil map of the pan system indicating wetland and terrestrial soils and the catchment

5.9.3 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 19**.

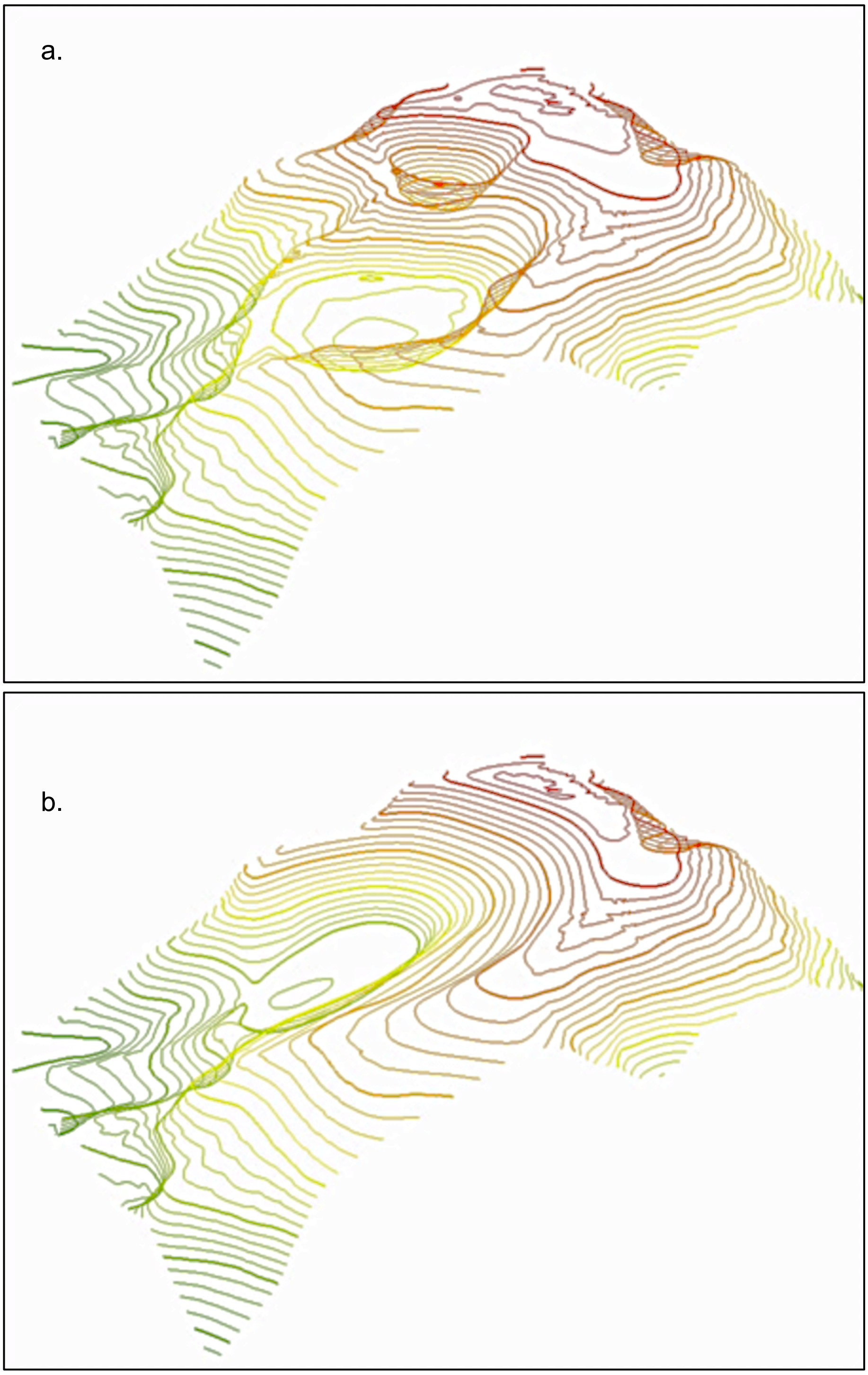

Figure 27 3D model of a pan system before mining (a) and a conceptual design for a post mining landscape reestablishment (b)

The pre-mining hydrology is inward draining and therefore saturated with water and with free water standing in the pan basin (**Figures 28** and **29**). 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 (**Figure 30**). 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. A distinct example of this phenomenon is the soil profiles in **Figure 30** that indicate a soil morphology similar to vertic properties but where the dominant clay mineral is kaolinite in the presence of very high Na levels. The swelling properties erroneously attributed to smectite clay dominance was afterwards correctly assigned to the effect of Na dispersion of kaolinitic clays. 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.

Figure 28 Free water standing in the pan basin

Figure 29 Saturated soil forming the pan basin floor

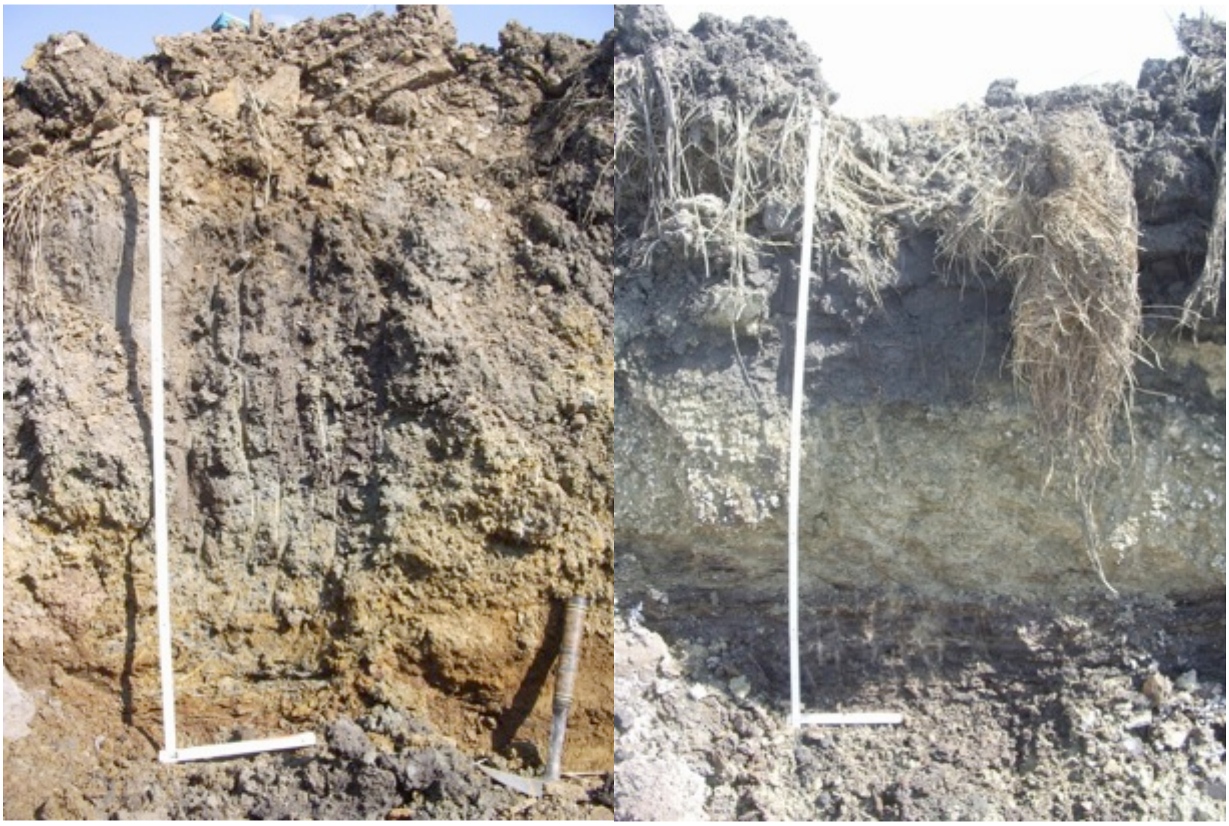

Figure 30 Saturated soil (Katspruit form), with swelling properties due to the effect of high Na levels, forming the pan basin floor

6. 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.

6.1 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.

6.2 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 15** and **24** 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 31**)

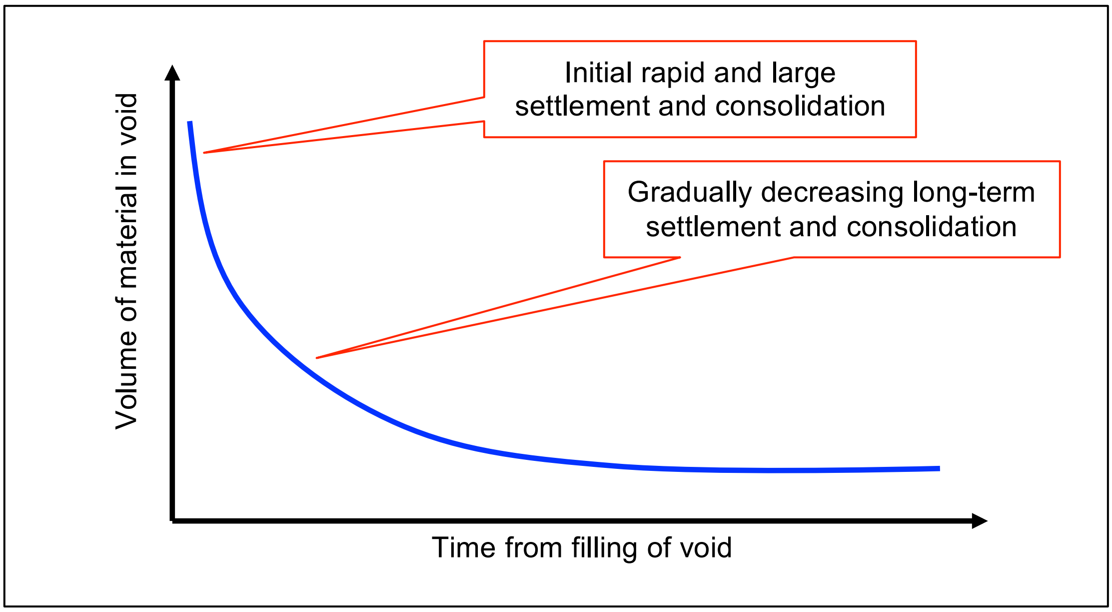

Figure 31 Change in settlement and consolidation intensity over time

6.3 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.

6.4 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.

6.5 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.

6.6 IMPLICATIONS FOR POST MINING WATER QUALITY MANAGEMENT

As indicated in **Figure 15** 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.

7. CASE STUDIES

A number of case studies are discussed below to illustrate the concepts discussed earlier in this report. Many of the cases will be dealt with as anonymous sites due to the sensitivity of the projects and client privilege and non-disclosure considerations. Some of the sites were physically assessed by the author and others were identified on Google Earth only as examples of the topics discussed above. The format used for the different case studies is not the same throughout as the information presented is either 1) similar to the information provided in reports to clients or 2) a brief summary of the conditions identifiable in Google Earth.

7.1 FREE DRAINING SYSTEM WITH WETLAND MINED: MINING ACTIVITIES IN UNNAMED TRIBUTARY OF THE HOLBANKSPRUIT AND ITS ASSOCIATED WETLAND (LELIEFONTEIN)

The impacts in the Holbankspruit from the Leliefontein mine activities are wider than the discussion provided here. However, the specific wetland / watercourse area that was mined provides a clear example and application of the conceptual aspects addressed earlier in the report.

7.1.1 Locality

The position of this impact is indicated in **Figure 32**. The yellow arrow indicates the direction in which an oblique aerial photograph was taken (image 2067; taken 23/01/2013; presented in **Figure 33**). The site lies in the Bb21 land type meaning that the entire landscape is dominated by yellow and bleached soils leading to a potential overestimation of wetland zones.

Figure 32 Position of the impacted wetland with direction of image 2067

7.1.2 Form of Wetland Identification

This wetland was identified by making use of the following:

1. <u>Aerial photographs / satellite images</u>: Google Earth images (satellite) as well as aerial photographs (Mowbray) were used to identify aspects (colour and texture on image) that are consistent the presence of wetland features in other parts of the same landscape. The darker green colour within this area is consistent with other non-impacted wetlands in the same landscape and indicates that an area with seasonal wetland characteristics was

present before mining. A distinct incised drainage channel, as is present upslope from this wetland, was absent – indicating that it was an un-channelled valley bottom wetland.

2. Topographic data: This data includes contours as well as a watercourse that is indicated on 1:50 000 and 1:10 000 scale topographic maps. From this data it is evident that the drainage feature conforms to the definition of a watercourse and that the levelled-out (or flared) area next to the Holbankspruit constitutes an area with regular presence of water following runoff from upslope.
3. Soil data: Soil data could not be generated for the site as the site had been mined. Peripheral soil data was generated.
4. Vegetation data: Due to the mining impacts vegetation data could not be generated for the site.

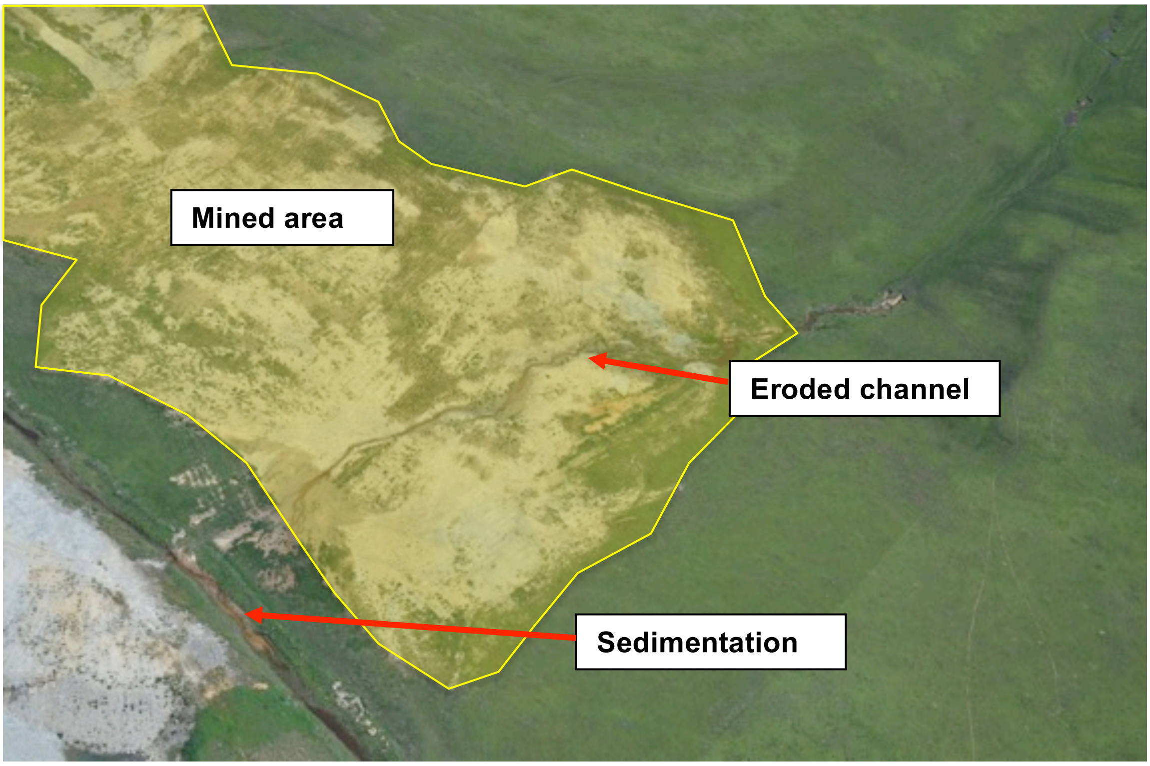

Figure 33 Image 2067 indicating bare soil in the mined area, significant erosion on site and sedimentation in the Holbankspruit

7.1.3 Description of Activity/Impact

The activities related to the impacted wetland and characteristics of the site entail the following:

1. The activity entails the recent historical mining of a watercourse and associated floodplain wetland area.
2. The area has been filled with spoil material (**Figures 34** and **35**). It is evident from field surveys that the spoil material contains large quantities of carbonaceous material (**Figure 36**) as well as pyritic sandstone (**Figures 37** to **39**). No contours or soil stabilization structures are evident.
3. At the time of the survey there has been no dedicated vegetation establishment on the site as part of the rehabilitation processes.

4. Significant erosion is evident on the site (**Figures 40** to **43**). The erosion is the result of an un-stabilized water course/channel that is forming due to water flowing from upland areas and the existing watercourse above the mining area as well as from overland flow from surrounding land.
5. Significant sedimentation, originating from the eroded areas of the unnamed tributary, is evident in the Holbankspruit river channel (**Figures 42** and **43**).

Figure 34 Wetland area filled-in with mine spoil and soil material

Figure 35 Wetland area filled-in with mine spoil material

Figure 36 Carbonaceous material in the mined wetland area

Figure 37 Pyritic sandstone rocks in the mined wetland area

Figure 38 Pyritic sandstone rocks in the mined wetland area

Figure 39 Sulfur salts on rock surfaces where pyritic materials have undergone oxidation

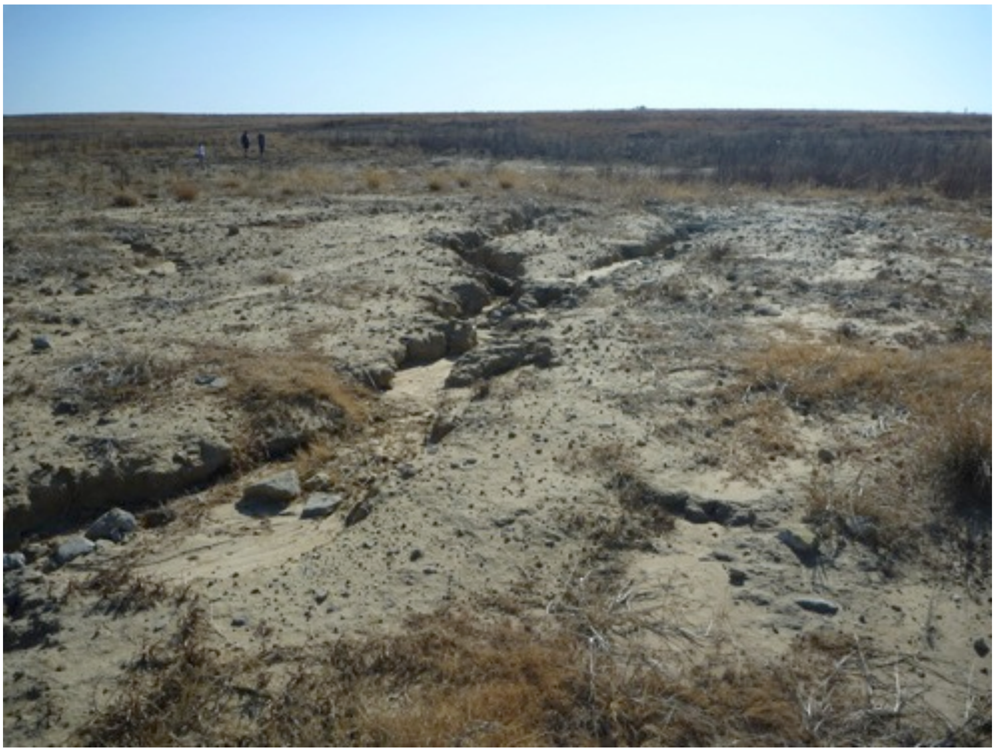

Figure 40 Eroded channel (sheet and gully erosion) on the in-filled wetland site

Figure 41 Eroded channel (gully erosion) of the unnamed tributary of the Holbankspruit on the in-filled wetland site

Figure 42 Eroded channel (gully erosion) of the unnamed tributary of the Holbankspruit on the in-filled wetland site with a sediment fan on the edge of the Holbankspruit

Figure 43 Sediment within the channel of the Holbankspruit

7.1.4 Conceptual Hydrology of Impacted Area

The hydrology of the impacted area will be elucidated during the detailed assessment of the site in terms of hydrogeology, vadose zone hydrology and surface hydrology. It is however possible to postulate (to an intermediate level of certainty) regarding the hydrology. These flow paths are the following (**Figure 44**):

1. Overland and channelled flow of water from upslope through the drainage feature.
2. Infiltration into the former void (or mined and backfilled area) that is approximately 10 m deep (anecdotal evidence – to be confirmed once detailed survey data has been obtained). The "recharge" into the backfilled material is postulated to be a factor of 10 to 50 higher than that of the original soil and geological material layers on the site.
3. Overland flow from areas surrounding upslope areas (**Figures 45** to **47**).
4. Hillslope subsurface flow process (interflow)
5. Ingress of water into the porous material with percolation down to the floor of the original void.
6. Filling of water in porous "void" with subsequent decant into the Holbankspruit.

The relative contribution of each component can only be quantified (relatively) once the hydrological assessments have been completed.

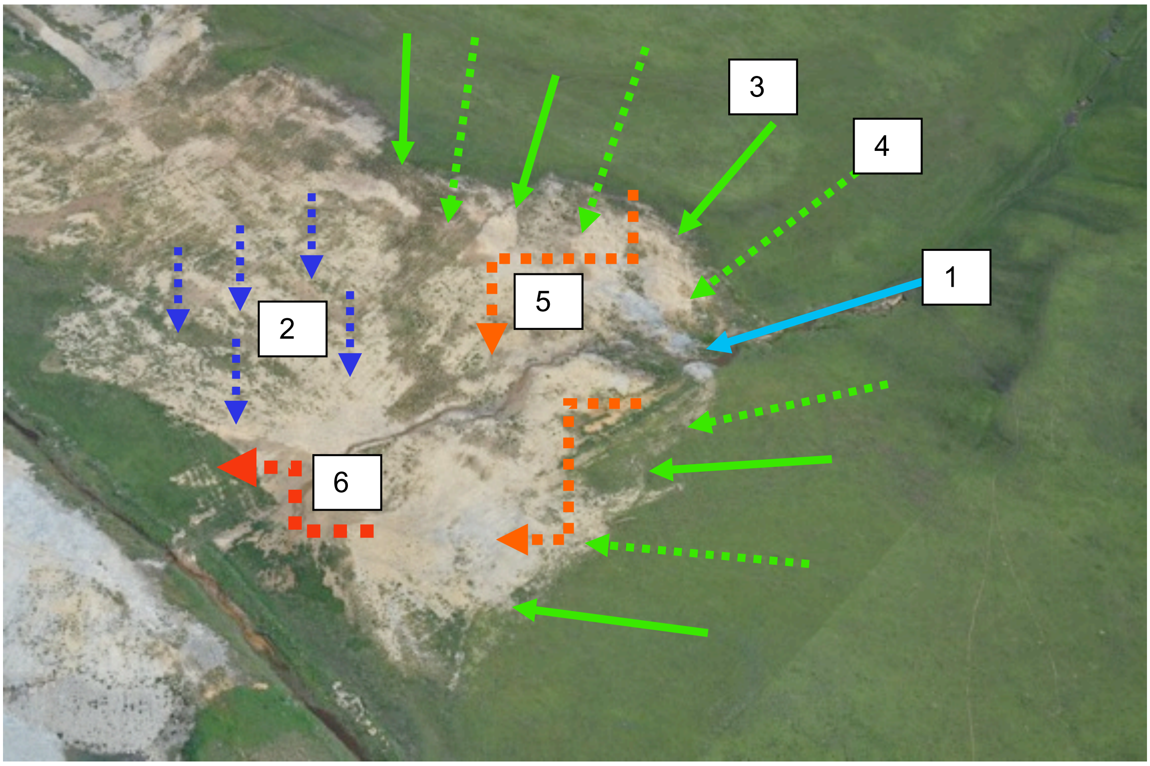

Figure 44 Flow dynamics of water on the impacted site

Figure 45 Daylighting of water from upslope areas of the mined wetland area (November 2011)

Figure 46 Daylighting of water on the upslope area of the mined wetland area (November 2011)

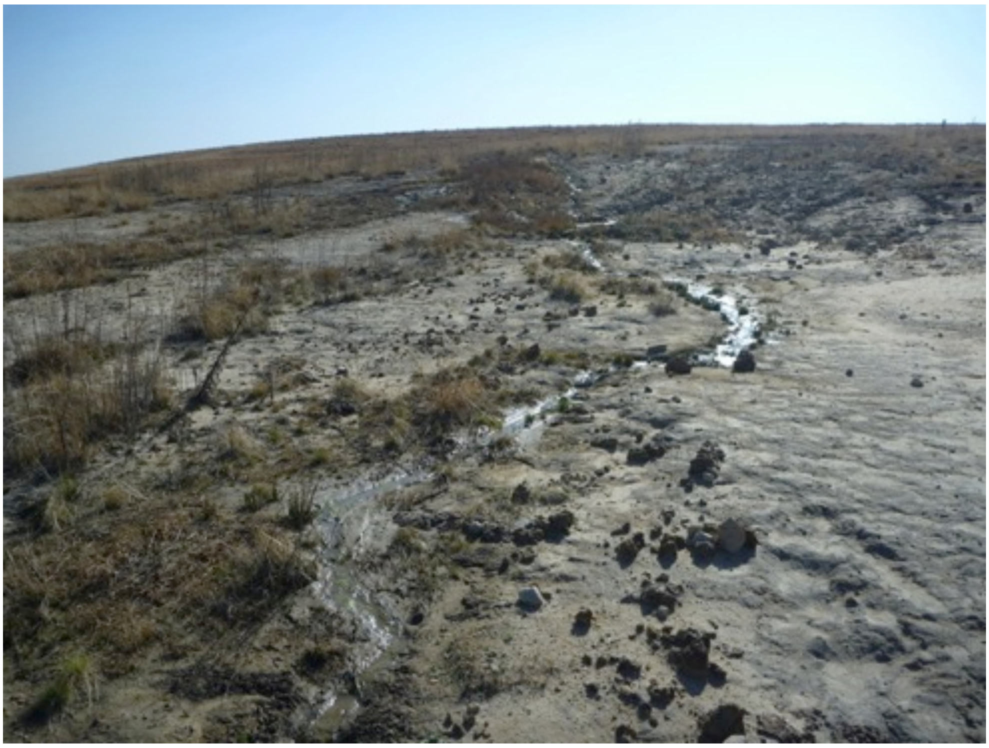

Figure 47 Daylighting of water from upslope areas of the mined wetland area (July 2013)

7.1.5 Required Rehabilitation Activities and Actions

The following rehabilitation activities and actions are required to rehabilitate the site:

1. Immediate intervention regarding stabilization of the channelled and eroded areas should be conducted to arrest erosion and sediment generation.
2. Detailed land survey to generate contours.
3. Clearing of surface (by hand or machine) of carbonaceous material and pyritic sandstone.
4. Topsoiling of site.
5. Design and construction of soil stabilization structures in the form of swales, berms and gabions to prevent erosion and sediment generation.
6. Installation of a lining within the channelled section of the site to prevent ingress of water into the porous backfilled material.
7. Assessment and prediction of soil wetness parameters that will result from the soft engineering interventions as well as hydrological modelling of the catchment area (in terms of water volumes and fluxes – hydrograph).
8. Generation of a re-vegetation strategy and plan to vegetate bare areas with plants adapted to the identified soil moisture regimes.
9. Medium to long-term assessment and monitoring of efficacy of rehabilitation measures.
10. Implementation of ad-hoc interventions as identified and required by the assessment and monitoring.

7.1.6 Practical Challenges Regarding the Application of Current Statutory Instruments and Guidelines

A number of practical challenges exist regarding the application of statutory instruments and guidelines driving the rehabilitation of the site. Below follows a dedicated discussion of each with specific practical reference to the site.

1. Application of PES/EIS assessment parameters. The PES assessment parameters cannot be applied to the mined-out areas even though it can be applied to the un-mined but impacted areas immediately upstream/upslope and downstream/downslope. The main reasons are:
    a. There is no correlation between the pre-mining hydrology and the post-mining hydrology within the mined area. With spoil and topsoil infilling processes there might be a visual correlation in terms of slopes and contours. However, the hydraulic conductivity (saturated and unsaturated) of the post-mining materials differs radically from that before mining.
    b. The generation of a PES rests primarily on the generation of anecdotal evidence on surface hydrology by a non-hydrology qualified person. With wetland feeding mechanisms being very varied and predominantly sub-surface it is clear that surface hydrological parameters do not provide an accurate indication of the dynamics of the water resource in the context of the landscape, with the original wetland being only the manifestation of the resource near the land surface.
    c. The PES parameter does not require significant input of water quality and feeding mechanisms. In order for a management tool such as this to be effective in opencast mining environments this glaring omission will have to be corrected as a matter of urgency.
    d. The determination of the PES would in all probability have yielded a value of and A or B before mining. Due to the mining impacts and alteration of hydrology (surface, vadose zone and groundwater) the only option is to class this area as an F. However, an F categorization does not accommodate the impacts on the site with the problem that significant input ito rehabilitation could yield a functioning wetland that can only qualify as an F after mining. The rehabilitated wetland would have to be assessed anew in terms of its hydrological drivers and a new category would have to be assigned. There will however be no correlation with the pre-mining wetland never mind the status of the post-mining wetland.
2. Legislation governing activities in wetlands/water courses. Due to the drastic alteration of the site and its associated hydrology there is no correlation with the area with any characteristics of a watercourse or wetland. It is therefore a debatable question as to whether the rehabilitated area constitutes a wetland/water course. If it does not qualify then no listed activities relating to wetlands/water courses are triggered through rehabilitation activities in this area. Under such conditions the only regulations/section of the act that could apply are:

    a. Section 19 of the NWA (Prevention of pollution) – in terms of downslope sedimentation or pollution effects.
    b. Rectification of unauthorized activities (Section 24 G NEMA) – in terms of the illegal mining of the original wetland.
    c. Duty of care (Section 28 NEMA) in terms of downslope impacts.
3. <u>Pragmatic decision on the wish list of the regulator</u>. Due to the difficulty in finding clarity on the above aspects it is imperative that the regulator make a decision on its post-mining wish list. The options include:
    a. Solely a "rehabilitated" surface to the spoil material;
    b. A water course (which would require stabilization ito erosion, design and construction); or
    c. A new wetland (which would require stabilization ito erosion, design, construction and wetland establishment).

   The option decided upon must tie in with the water management measures implemented for the rest of the site as it all forms part of one overall management plan and objective.

7.2 FREE DRAINING SYSTEM WITH CATCHMENT (AGRICULTURAL SOILS) MINED: MINING ACTIVITIES IN CATCHMENT OF STEENKOOLSPRUIT AND TRIBUTARIES (KRIEL)

The area that has been mined between the Steenkoolspruit and its tributary as well as the area west of the tributary is indicated in **Figure 48**. This large area falls into the Bb4 land type with the drainage depressions falling into the Ea20 land type (vertic soil dominated), and the post-mining topography approximates the pre-mining topography. The difference between the two lies in the presence of final voids that are depressions in the landscape.

The challenge with the mined areas between the streams includes several aspects regarding the land and water management. These challenges are:

1. The landscape is free draining with the exception of the final voids that hold a significant volume of water. The water in these voids/dams has elevated sulphate levels (approximately 800 ppm at near neutral pH) and cannot be released into the Steenkoolspruit without 1) treatment to remove sulphates or 2) a relaxation in the water quality standards as enforced by DWA. As long as the water level remains low enough there is no risk of release into the stream. However, as the water levels in the voids rise and the rainfall continues contributing to surface water volumes the risk of release into the stream increases. The process is similar to the discussion provided in section 5.9.
2. The now porous spoil material (as opposed to the original hard rock material) continues to contribute sulphates to the water in the pores between soil and rock particles. As this water migrates to the lowest point in the landscape the supply of sulphate to the water in the final voids, and ultimately the Steenkoolspruit, will continue.
3. The final voids on the site allow for an opportunity to test, treat and / or pump the water elsewhere. The general feeling with the regulator is that final voids are unacceptable in post-mining landscapes. This author however feels differently and sees the final voids as water treatment points and access points to gauge the water quality that is seeping

through the landscape. With the advent of passive treatment technologies and processes the final voids afford an opportunity to access the polluted water. In a landscape without final voids the only way to access the water is through boreholes or in decant and outflow areas. These are often close to wetlands and the space available for treatment is therefore limited.

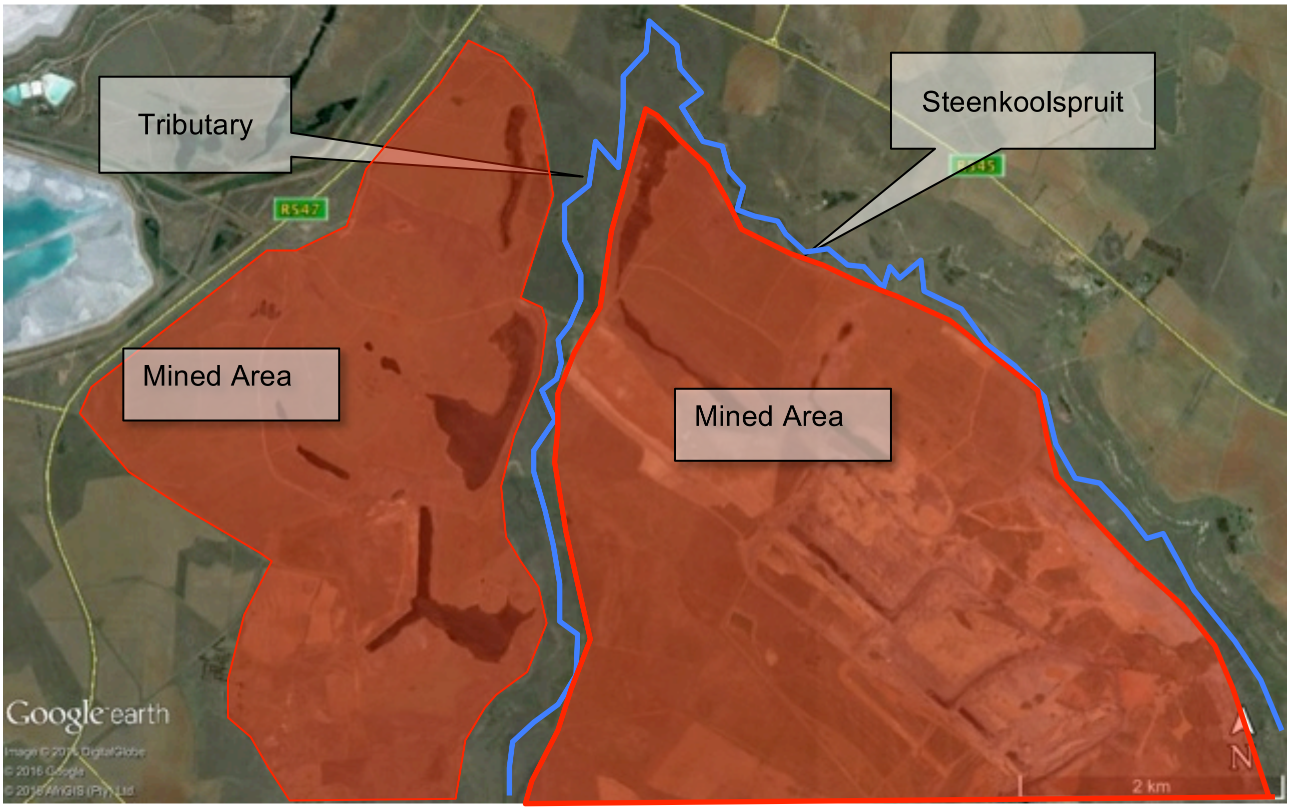

Figure 48 Mined area between and west of the Steenkoolspruit and its tributary near Kriel

7.3 FREE DRAINING SYSTEM WITH MINING IN CATCHMENT: JAGLUST

An example of a free draining system where the mine is situated within the headwaters (or recharge area) of the wetlands and streams is the Jaglust mine near Carolina. The site lies in the Bb15 land type. The pre- and during mining Google Earth images are provided in **Figure 49**. The hydrological setting is provided in **Figure 50** with **Figure 51** providing a more detailed indication of surface water flow paths on the site (with original contours superimposed on a recent satellite image with the mine footprint visible). From the maps it is evident that the mine is situated within the recharge zone of the streams and seepage wetlands as well as a pan that was situated on the crest.

A transect through the landscape perpendicular to the drainage lines (**Figure 52**) was generated and is provided in **Figure 53**.

Figure 49 Google Earth images (top: 2006/10/11; bottom: 2013/01/09) indicating the transition of the landscape and the mining impacts on the crest of the landscape with the disappearance of the pan

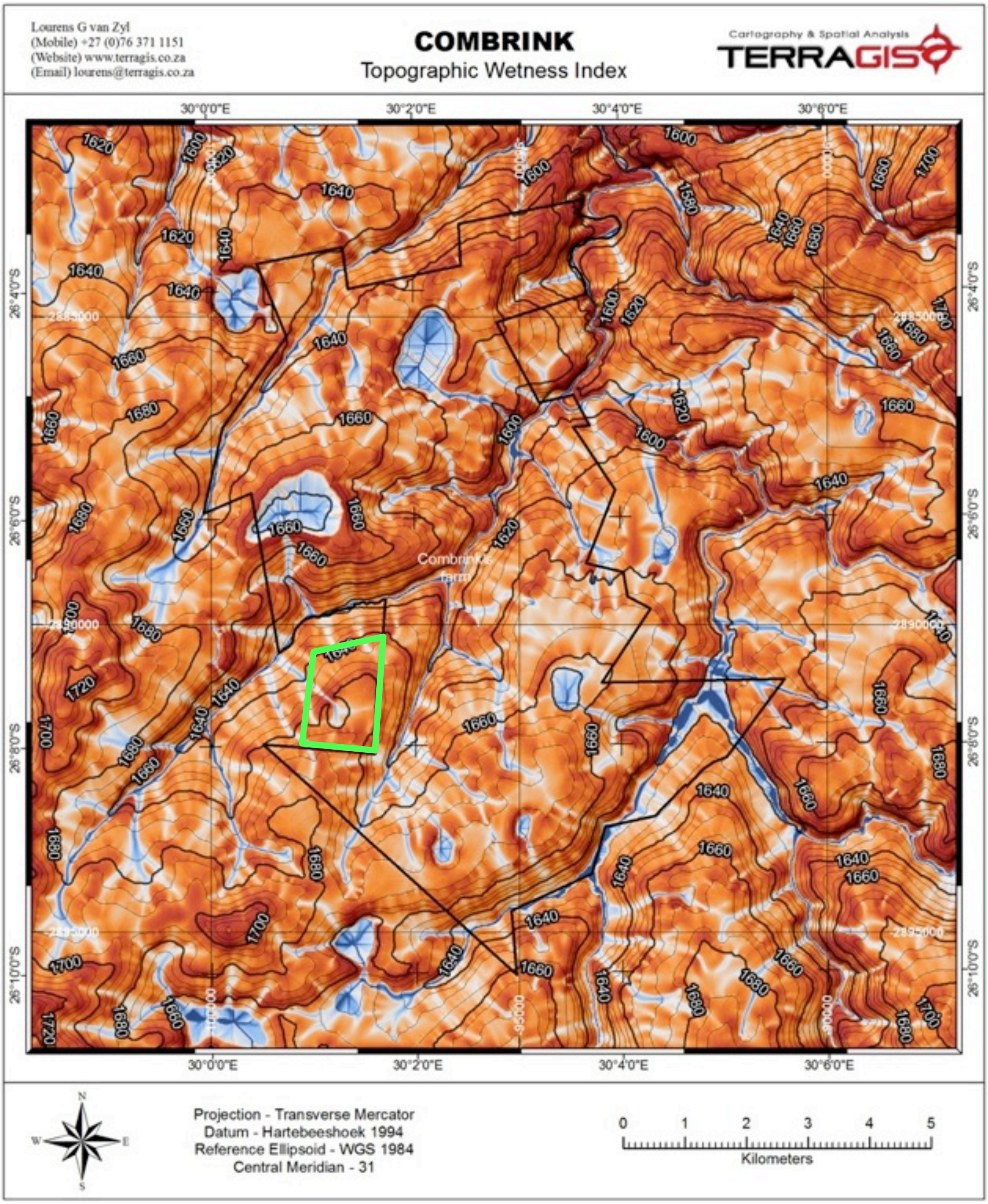

Figure 50 Position of the Jaglust mine (green polygon) relative to the farm area imposed on a TWI of the general area

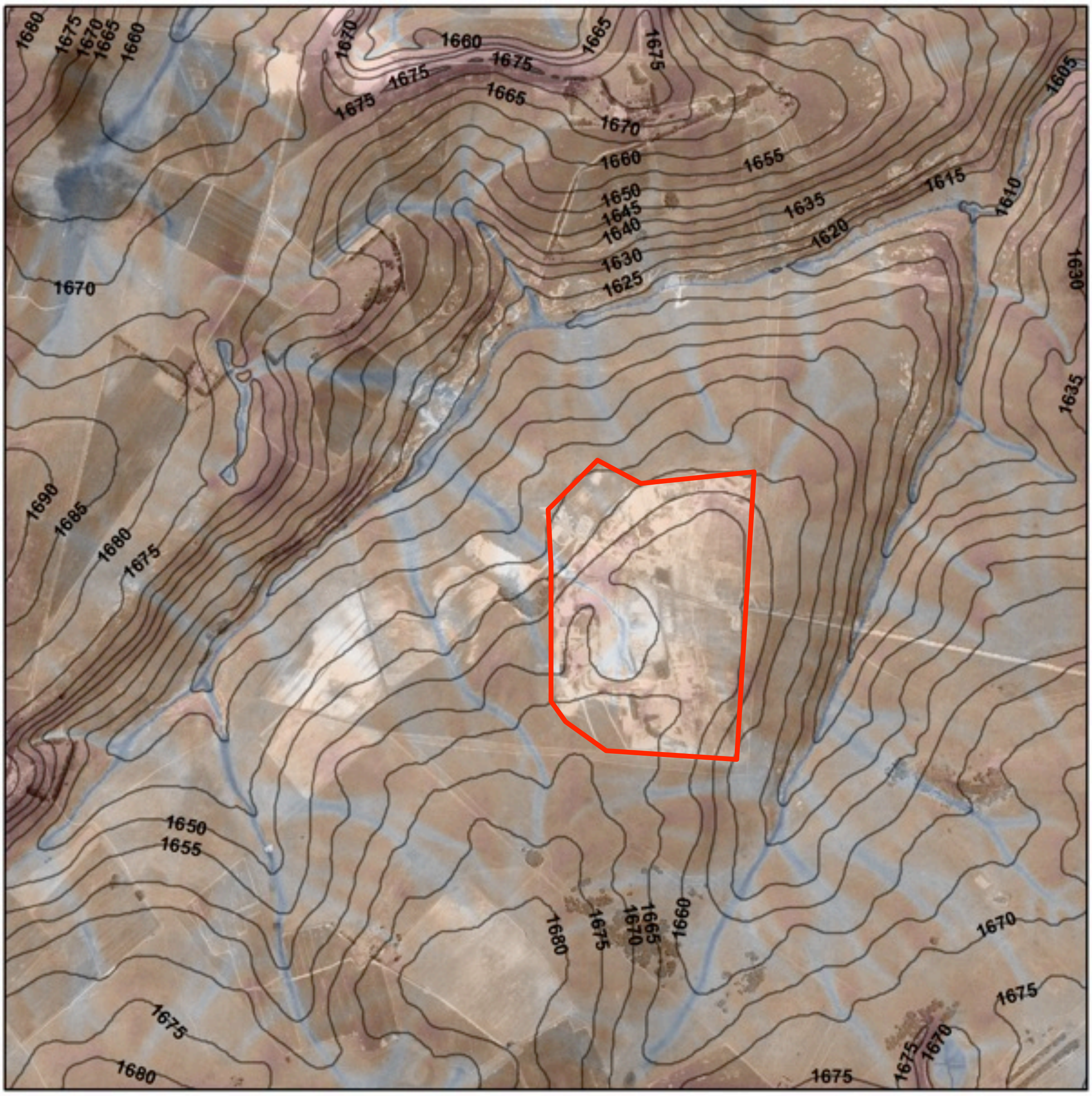

Figure 51 Position of the Jaglust mine (red polygon) relative to the two drainage features on the western and eastern side as well as the drainage depressions from the crest

The impacts that are expected in terms of hydrological functioning are similar to those discussed in section 5.9. The water quality parameters are not known for the site but the EMP of the mine should provide an indication of the acid-base accounting for the materials and the expected water quality that will flow out of the mine void over time. It is expected with a large degree of confidence that the mine will lead to an increase in sulphate levels in the streams surrounding the mine. The impact on acidy cannot be predicted without the data regarding the acid-base accounting. The challenges regarding the water yield and quality management of this site will depend entirely on the commitments made by the mine in the EMP and the successful execution of the commitments into the long-term future.

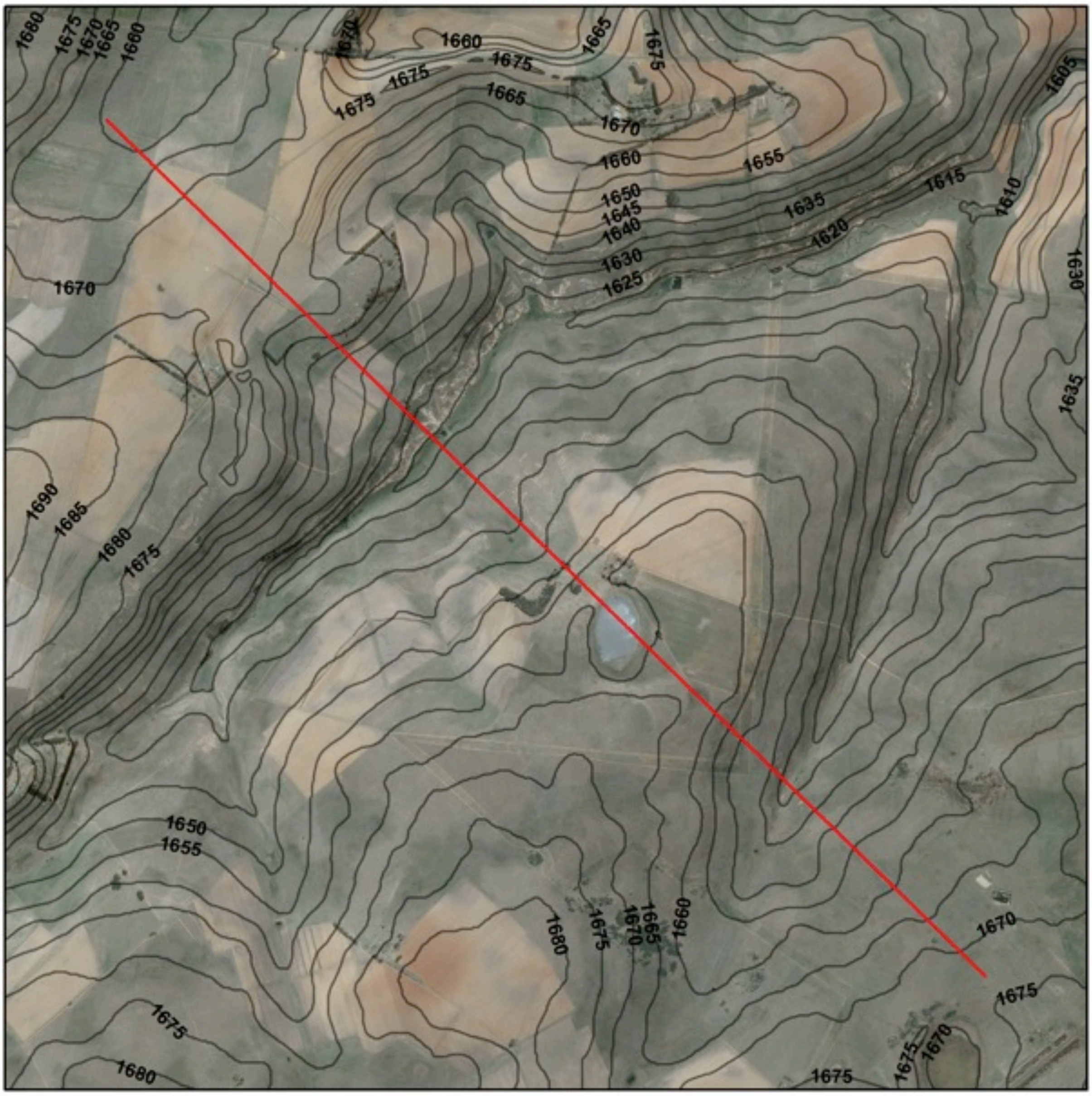

Figure 52 Transect along which a profile was generated

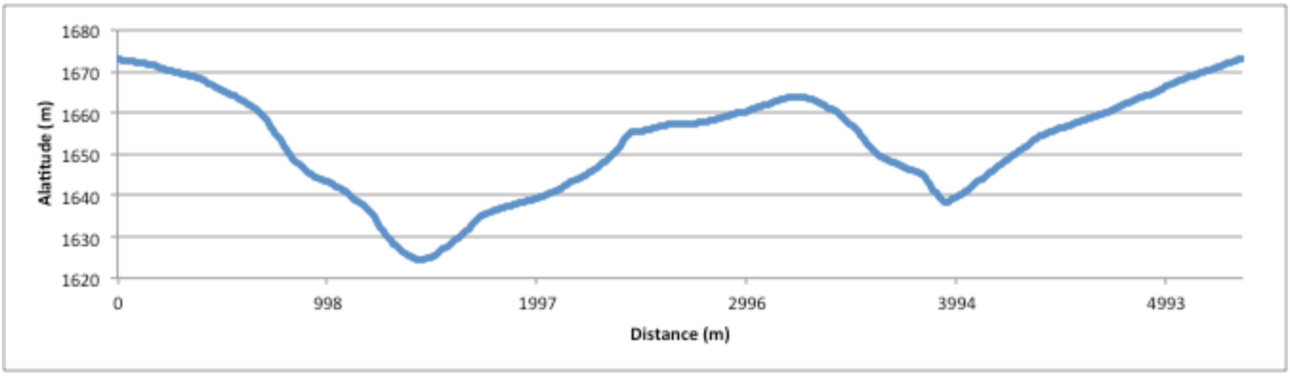

Figure 53 Transect through the Jaglust mining area site indicating the proximity of two drainage depressions

7.4 FREE DRAINING SYSTEM WITH MINING IN CATCHMENT: SEVERAL MINES IN ONE CATCHMENT - ELANDSPRUIT

An example of a situation where several mines occur in the same catchment is found in the case of the farm Elandspruit near Middelburg (Ba37 and Ba4 land types). The digital elevation model of the site is provided in **Figure 54**. The satellite image of the site with the catchment is provided in **Figure 55** and the TWI is provided in **Figure 56**.

It is important to note that the impacted watercourse has a catchment that is situated to the east. This catchment consists of the recharge zone for the subsoil lateral flow paths of water until these daylight close to the start of the watercourse.

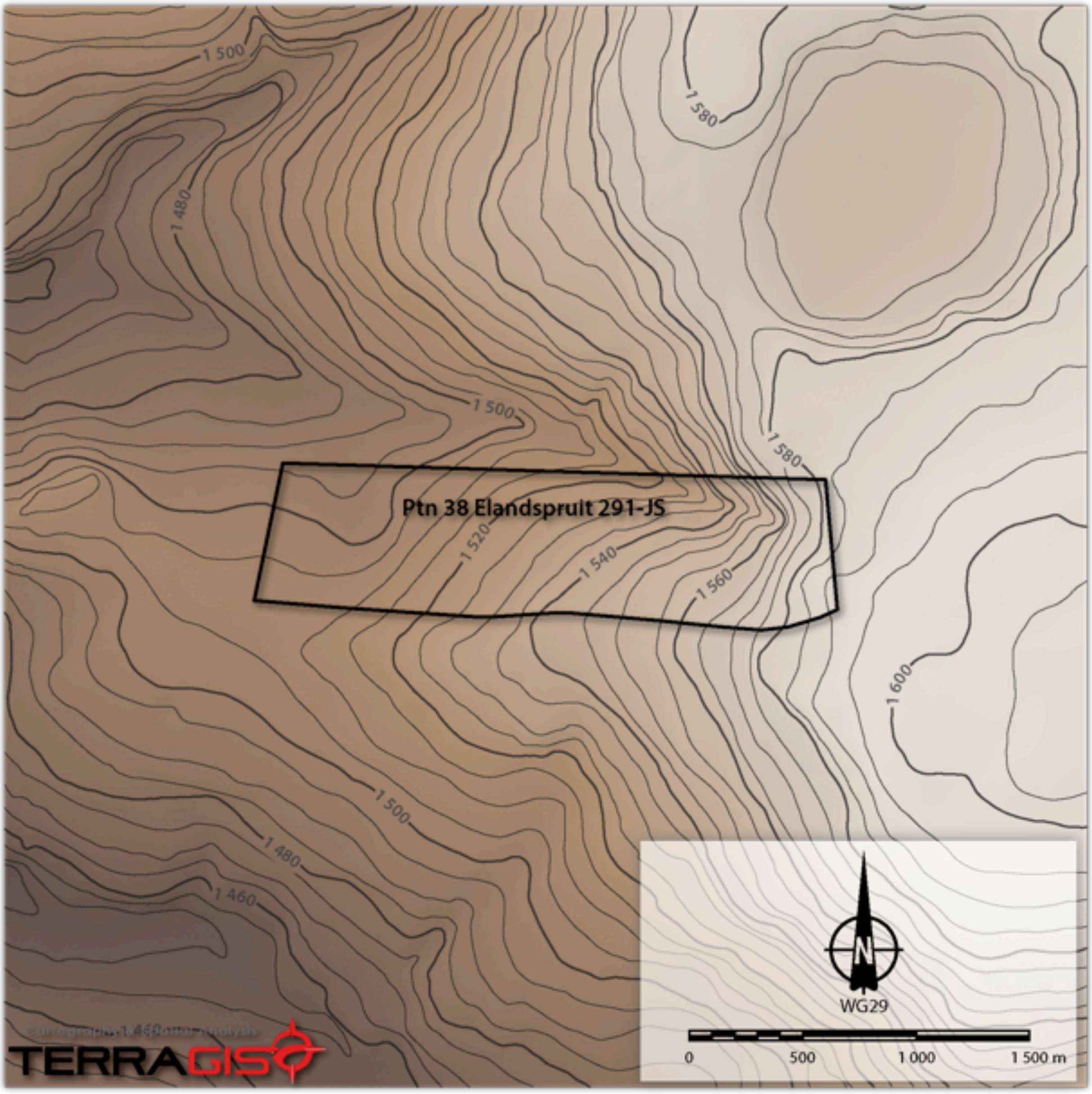

Figure 54 Digital elevation model (DEM) of the Elandspruit farm mining site and its drainage feature

Figure 55 Satellite image of the Elandspruit farm mining site and its drainage feature with the surface water catchment of the watercourse.

The catchment indicated in Figure 53 does not necessarily correspond with the "headwaters" of the wetland as the recharge zone for the watercourse may be larger or smaller due to the variability in the geological layers underlying the soils.

The challenges regarding this site are found in the following:

1. The fact that several small mines are situated within the catchment is a challenge. These mines are, as far as this author's knowledge stretches, not required to generate an integrated water management plan This responsibility lies primarily with the mine closest to the watercourse – an aspect that does not make sense since the subsoil flow paths of water do not follow mine boundaries. In this case the best approach to the management of the water quality and quantity that will eventually flow into the

watercourse will be to generate an integrated and combined water management and treatment plan for all the mines.

2. The permitted distance from the mine to the watercourse is often determined on the basis of a wetland delineation exercise. It is very obvious in this case that the wetland boundary has no correlation with the extent of the recharge area and catchment. The imposition of a buffer is therefore an exercise in futility as the water impacts will be significant irrespective of the distance of the mine from the wetland.

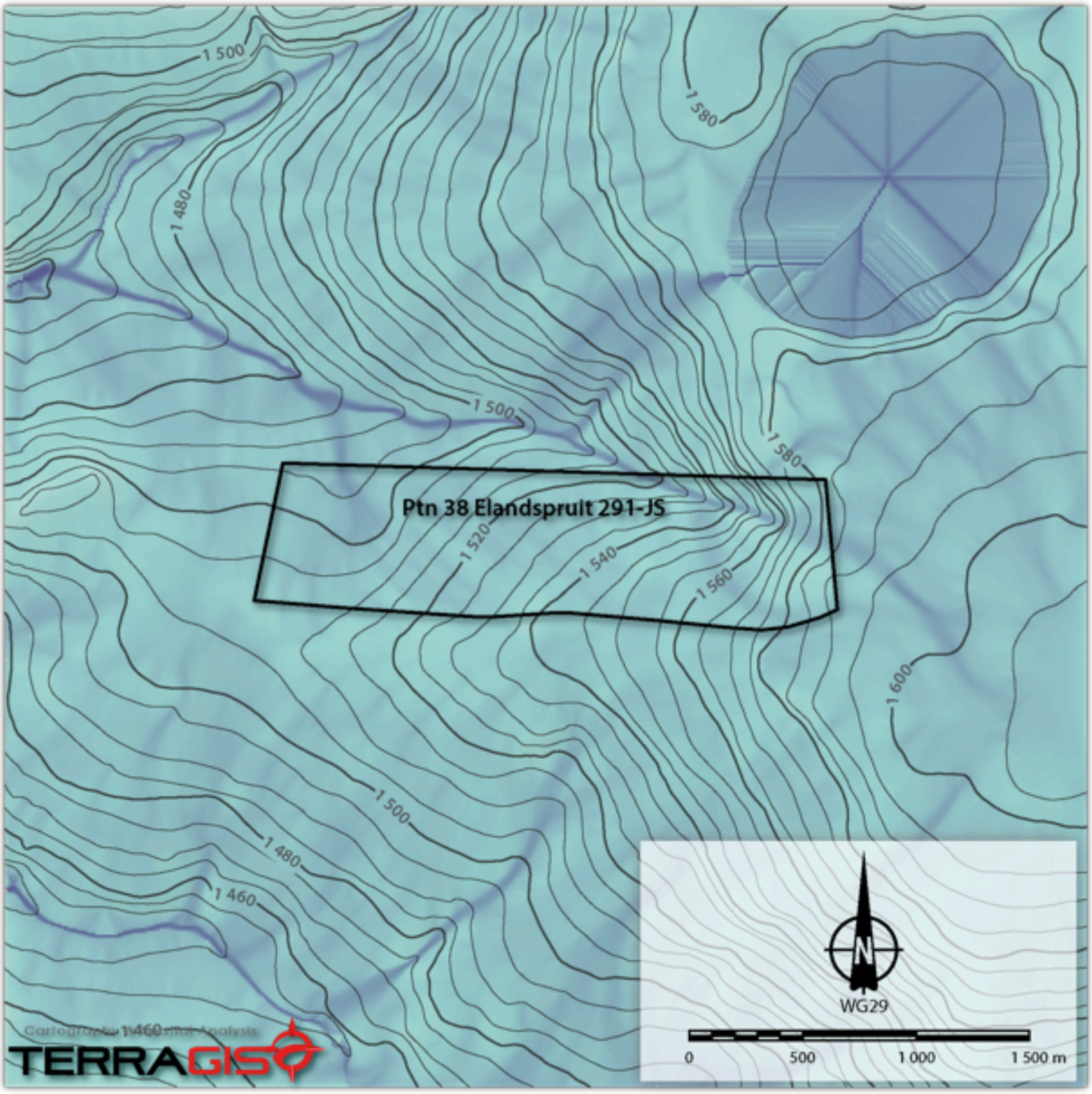

Figure 56 Satellite image of the Elandspruit farm mining site and its drainage feature with the surface water catchment of the watercourse.

7.5 INWARD DRAINING SYSTEM MINED COMPLETELY: MAFUBE

Several examples exist regarding the mining of the complete catchment and wetland on inward draining systems. A distinct example is the pans of Mafube (Ba 19 land type) as discussed in 5.9. The essence of mine planning process in the case of Mafube was to design a completely new landscape with the following characteristics:

1. Alteration of the pre-mining topography, that was inward draining, to a free draining system that would link up with a watercourse to the west and that is situated significantly higher that the decant point for the water that would fill up the voids underground. This was planned specifically for a stability safety purpose.
2. Establishment of a number of depressions on the rehabilitated area that will act as water reservoirs to mimic pan wetland systems. The water flow into and out of these systems is designed to be on the surface as subsoil flow zones would pose stability challenges in the consolidating material. Additionally, the maximum free water level allowed in the "pan" systems was set at 40 cm to prevent large increases in mass on the rehabilitated material. Excess water in the pans would be released through free draining surface structures.
3. The dispersive soils mined from the original pan basins would be used as the bulk of the soil win the new pan systems. Due to the dispersivity of the soils they would 1) yield adequate natural liner material if placed in the depressions and 2) would pose significant stability challenges if used on slopes. The underlying liners had to be engineered to stringent specifications to prevent settlement that could cause breaches in the liner with a subsequent leaking through of dispersive soil material from the basins once they contain water.
4. The ecological parameters of the new "pan" systems would differ significantly from the pre-mining environment due to the drastic change in hydrological functioning. The only parameter that would be relatively easy to manipulate would be the hydro-period of the pan system that could be managed to approximate the hydro-period of the pre-mining system.

7.6 INWARD DRAINING SYSTEM CATCHMENT MINED: SEVERAL

Several examples exist of inward draining systems that have been mined partially or in which the catchment of the systems have been mined within the Ba4 land type. **Figure 57** indicates a pan of which one half has been mined and **Figure 58** indicates a pan of which a large section of the catchment has been mined. In the case of **Figure 57** it is not clear whether a retaining structure has been constructed on the edge of the mine. This structure would be required to ensure that no leaking would take place from the pan into the mine spoil in the void. In the case of both pans the catchments are significantly impacted and smaller than the pre-mining condition. This implies that both these systems will be drier in the future and therefore impacting on the hydrological functioning of the systems. With an impact on the hydrological functioning it is to be expected that the ecological parameters will also change significantly. An open question is what the EMP commitments of these mines are within the context of the wetland assessments and impact determination that have been conducted during the EIA/EMP process.

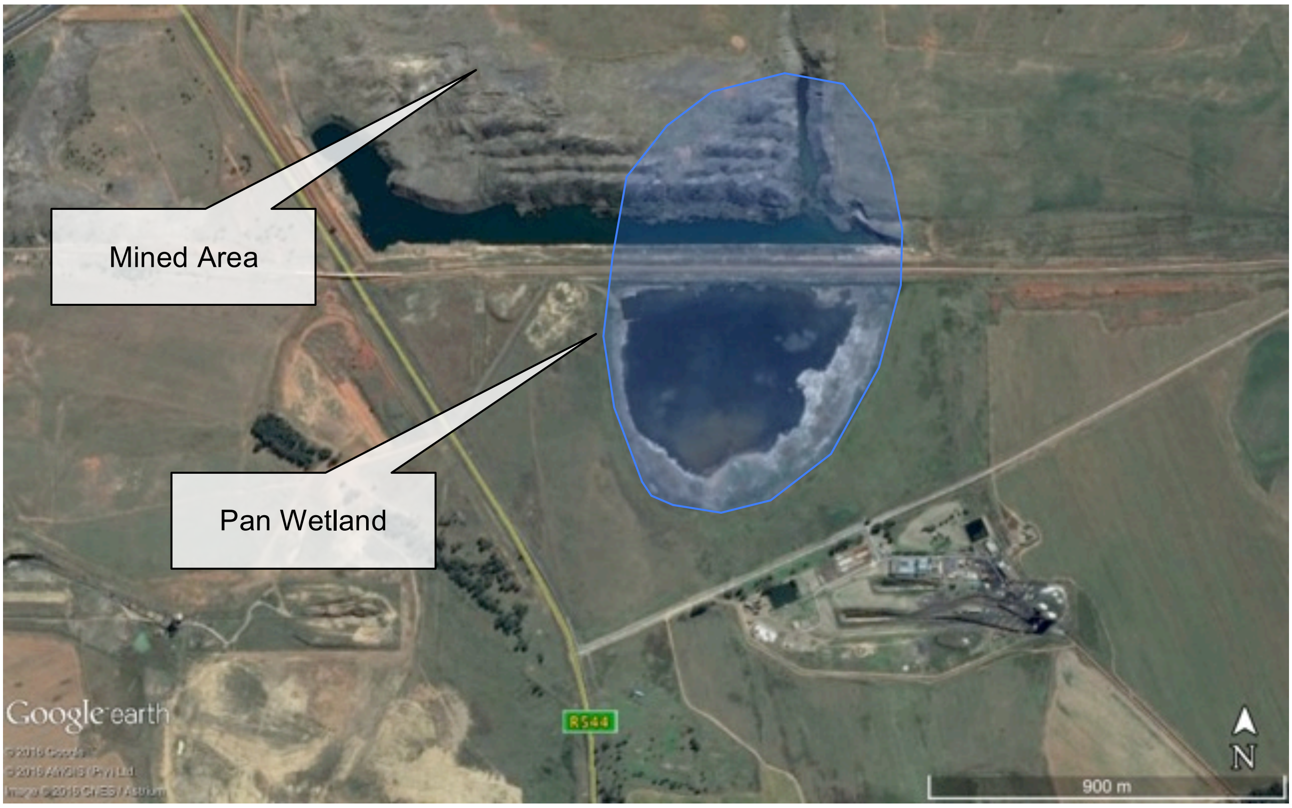

Figure 57 Inward draining pan system that has been cut in half

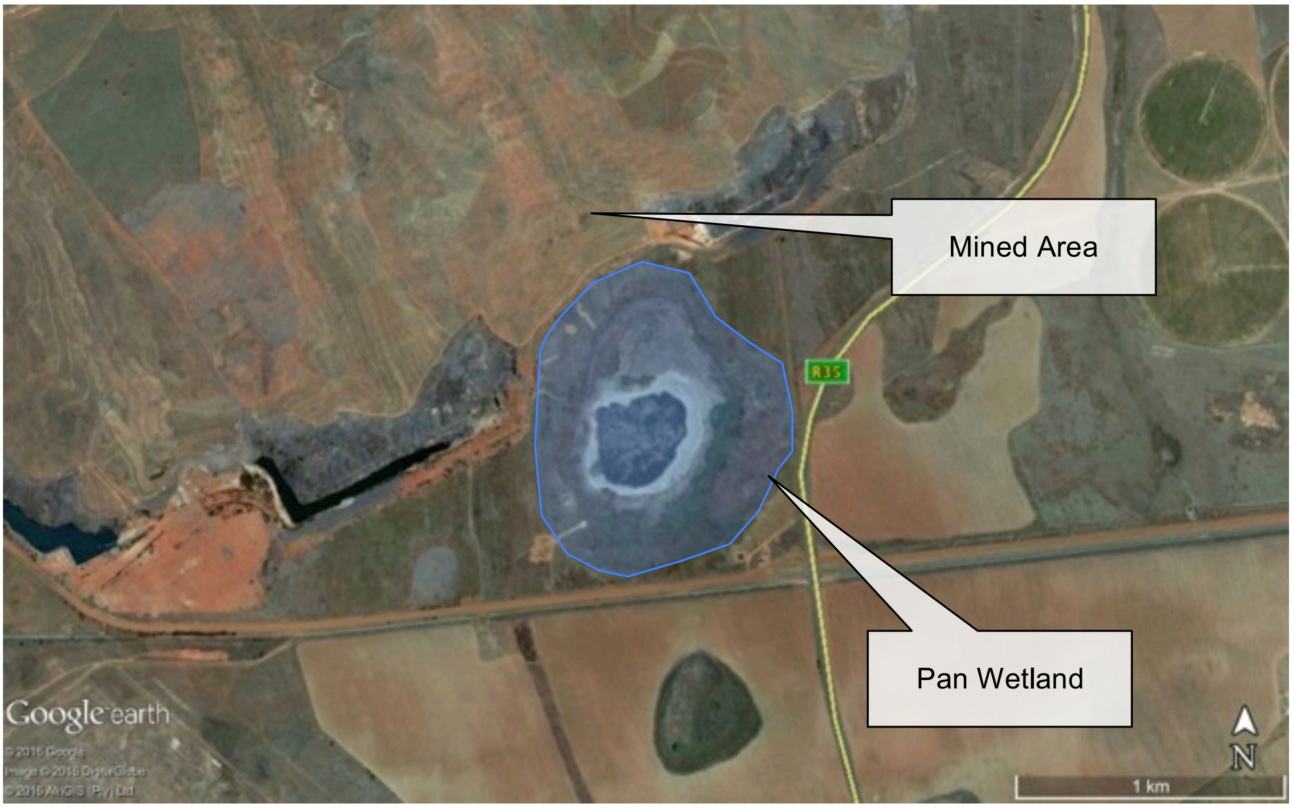

Figure 58 Inward draining pan system of which the catchment has been significantly reduced

7.7 FREE DRAINING SYSTEM WITH MINING IN CATCHMENT AND SIGNIFICANT WATER QUALITY IMPACTS: ELANDSFONTEIN

An example of a mine with significant water generation and quality impacts is Elandsfontein that lies in the Ba5 land type. The overall mine site is indicated in **Figure 59** and this includes:

1. Historical open pit mining area backfilled with carbonaceous spoils the now generate AMD.
2. Coal material handling area and wash plant.
3. Recent open pit mining on the edge of a watercourse.
4. Historical coal stockpile generating AMD effluent.
5. Underground disposal of coal fines generating AMD.

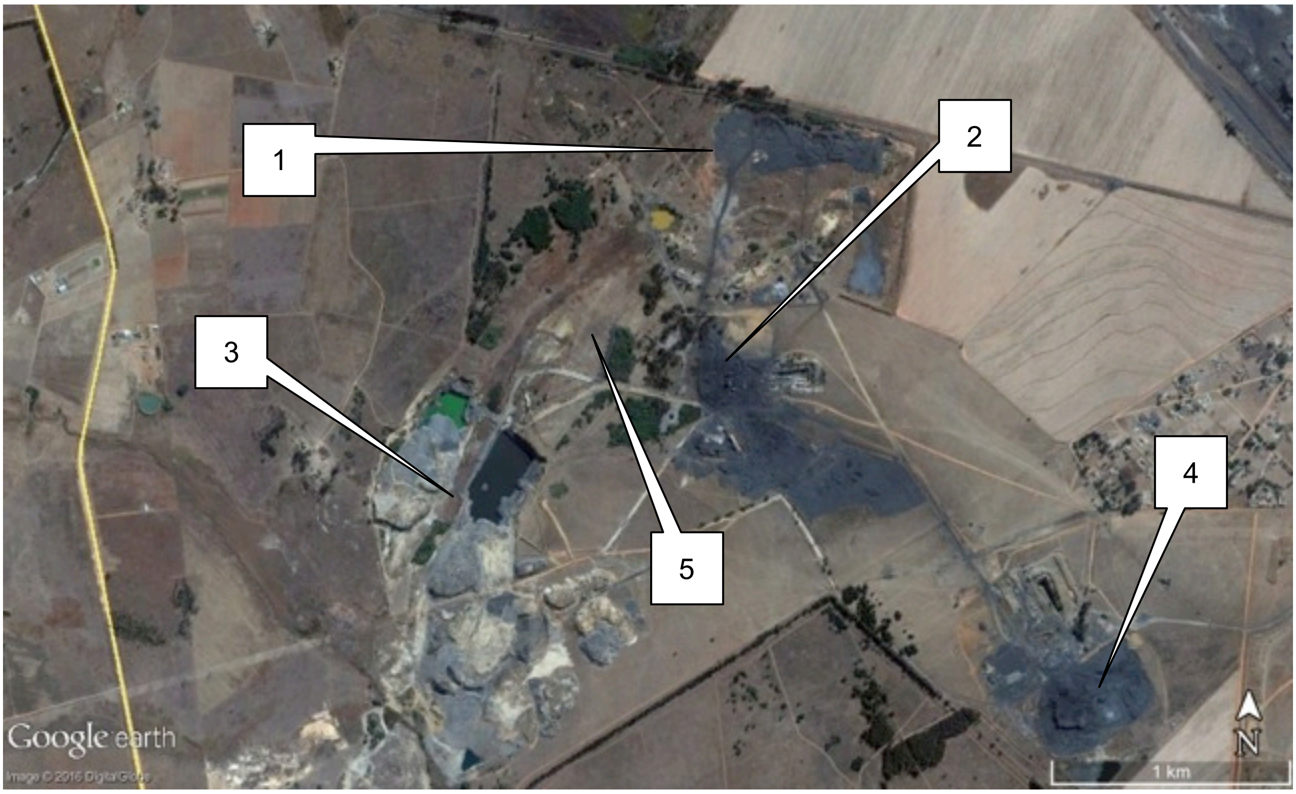

Figure 59 Elandsfontein mine site with various impacts

The main acid mine drainage effluent problems are 1) associated with AMD generated underground in old mine workings filled with coal fines from the wash plant and 2) AMD generated through the oxidation of pyrites in an old coal stockpile. The underground disposal facility is filled with water and the water is flowing out of two boreholes that “punctured” the underground source. (**Figure 60**). The effluent pH is below 3 and the resultant acid water plume is distinctly visible in the image. From the coal stockpile indicated in **Figure 61** AMD runoff accumulates in two unlined containment dams from which the water percolates and leaches underground to daylight in a seep on a different property near surface water bodies (watercourse, wetland and dam). The connectivity of the seepage zone is a function of the landscape’s geology and it follows similar patterns to natural seepage areas and wetlands encountered on the Mpumalanga Highveld. The implication of the seep and acid water outflow is that the poor quality water is affecting the water quality and land management options of other landowners and water management authorities.

Figure 60 Acid water outflow zone (with visible plume) through boreholes (red arrows) that "punctured" an underground disposal facility

Figure 61 Coal stockpile (yellow arrow) with containment dam (red arrow) that leaks and leads to acid water seeps downslope (green arrows)

7.8 INWARD DRAINING SYSTEM MINE WATER IMPACTED: LANDAU

An example of water quality impacts in an inward draining system is observed in a pan within the Bb5 and Bb13 land types. **Figure 62** indicates the pan system before impact and after the disposal of sulphate rich water into the pan.

Figure 62 Pan system before mine water impact (top) and after disposal of sulphate rich mine water (bottom)

7.9 REHABILITATION SOIL PROFILES AND SPOIL INTERFACE: MAFUBE

The soil and soil cover characteristics of a rehabilitated landscape is provided in soil profiles from Mafube (**Figures 63** and **64**). The soil profiles vary in thickness and overlie spoil material with a high infiltration/percolation potential due to the lack of significant compaction and sealing. Whereas the soil profiles can hold a significant amount of water (dependent on profile thickness, texture and bulk density parameters) it is inevitable that water will percolate through to the underlying spoil. In this case the water contributes to the mine water management requirements, and depending on the acid/base chemistry of the spoil, with a sulphate and/or rich decant water.

Several investigations are focussing on the water management of the soil capping to minimise water impacts. One such investigation currently under way is assessing the irrigation potential of rehabilitated mine landscapes with neutralised acid mine water. There is currently no coherent and sustainable water management strategy for rehabilitated landscapes and research into this aspect is critical as increasing large areas are being altered into these “new” landscapes.

Figure set 63 Soils of the Witbank form with 170 cm and 60 cm soil depths to spoil respectively

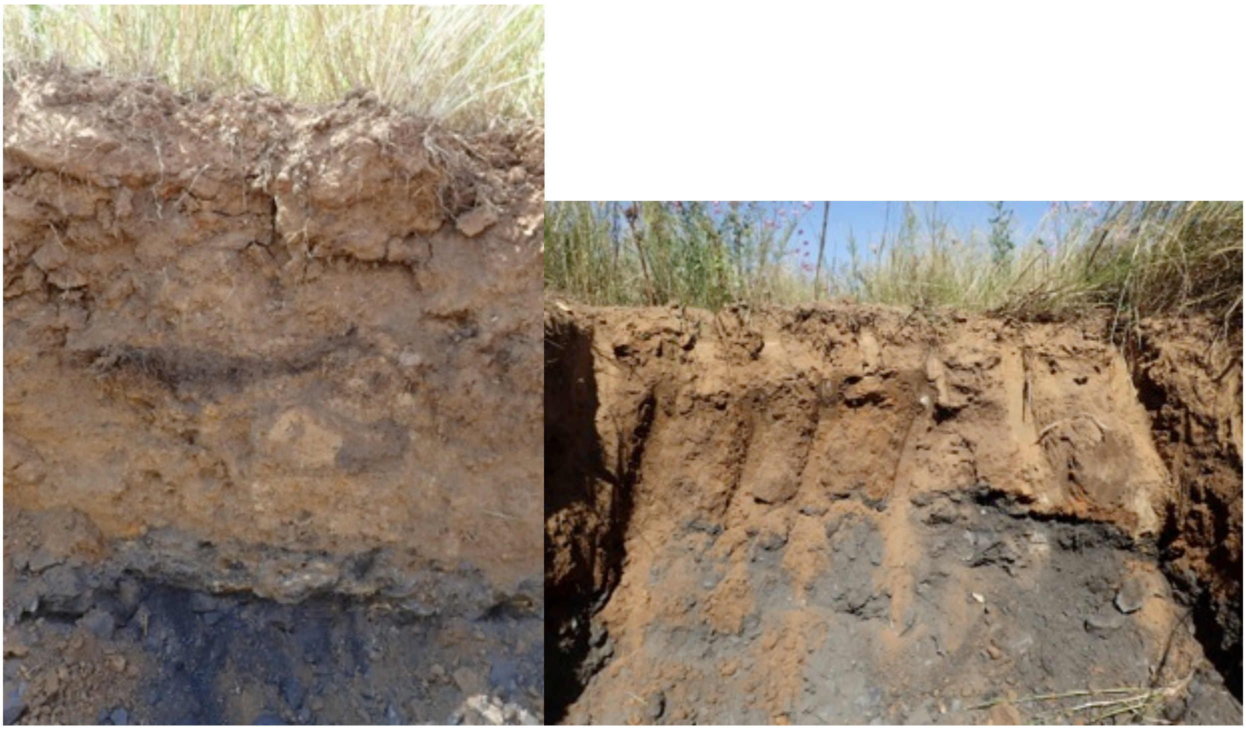

Figure set 63 Soils of the Witbank form with 60 cm and 40 cm soil depths to spoil respectively

8. CONCLUSIONS AND RECOMMENDATIONS

The plinthic landscapes of the Mpumalanga Highveld are characterised by very specific geology, soils and hydrological processes. These processes are the result of the predominantly horizontal orientation of sandstone and coal bearing layers as well as the old and stable landscape in which the soils have formed. Due to the age of the landscape the soils are considered to be very good indicators of landscape hydrology and as such the “hydropedology” is a very useful tool in the understanding, elucidation and conceptual description of water related dynamics and impacts. In this regard the impacts of mining activities on water quality and quantity can be elucidated conceptually through the consideration of the specific mining and landscape context.

Mining impacts have been disaggregated in this manuscript to include most of the various examples that this author has encountered. The impacts are predominantly associated with 1) the alteration of landscape hydrology and 2) the alteration of material properties to increase permeability and specific surface of oxidation sensitive minerals such as pyrite.

Due to the variable nature of the landscape topography and coal bearing layers the impacts very from mine to mine. However, the mines are all situated near to or within hydrologically sensitive areas that also exhibit distinct and extensive wetland distribution. The assessment of these wetlands often rests on the ecological response to the water in the landscape but rarely accommodate the hydrological drivers due to the complexity of elucidating the drivers and flow paths. For an integrated wetland and mining water management solution the only option is to generate suitable information and data to be able to conceptualise meaningful and sustainable water management approaches.

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